WR96-1-45-145

A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR SEQUOYAH NUCLEAR PLANT, CHICKAMAUGA RESERVOIR, TENNESSEE

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NORRIS, TENNESSEE

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Report No. WR96-1-45-145

Norris, Tennessee
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EXECUTIVE SUMMARY

Section 316(a) of the Federal Water Pollution Control Act Amendments of 1972 provides a method by which alternative thermal limits can be obtained for point source discharges. In 1989, the Tennessee Valley Authority (TVA) successfully completed a 316(a) demonstration for Sequoyah Nuclear Plant (SQN) to increase the thermal limit for the river temperature rise from upstream to downstream of the plant from 3.0 C° (5.4 F°) to 5.0 C° (9.0 F°) for months November through March. This modification was requested primarily to avoid damage by ice during wintertime operation of the cooling towers. The investigation presented herein is given as a supplement to the original 316(a) study to examine additional changes in the thermal limit criteria. These changes are sought due to issues that have arisen since 1989 concerning the operation of both SQN and the TVA reservoir system.

In general, to protect the aquatic habitat from waste heat in industrial operations, the water quality criteria for Tennessee gives upper limits for three thermal-related parameters: the river temperature rise from upstream to downstream of the plant (**ΔT**), the river temperature downstream of the plant (**T_d**), and the rate of change of river temperature downstream of the plant (**dT_d/dt**). For SQN, permit requirements specify that these parameters are to be monitored using running 1-hour average values for **T_d**, **ΔT**, and **dT_d/dt**, all derived from data collected every 15 minutes. In this supplement, the following changes are requested collectively in the permit requirements:

- Monitor **ΔT** and **T_d** based, in part, on a running 24-hour average,
- Include April and May in the period of wintertime operation (i.e., for April and May, increase the limit for **ΔT** from 3.0 C° to 5.0 C°, as currently exists for months November through March), and
- Increase the limit for **dT_d/dt** from 2.0 C°/hour (3.6 F°/hour) to 5.0 C°/hour (9.0 F°/hour).

Twenty-four hour averaging is needed to distinguish thermal events that *do provide* timely relief for the aquatic habitat from those that *do not provide* relief. At SQN, the limits for **T_d** or **ΔT** often are encountered only for part of the day. Since the lift pumps cannot be cycled on and off in short periods, cooling towers currently are used around-the-clock to maintain compliance in these events. However, in such cases, tower operation is considered unnecessary because thermal relief usually occurs within a short time by evening cooling and/or high river flows from peaking operations. In contrast, when the limits for **T_d** or **ΔT** are encountered for as long as 24 hours, timely relief is not available and action must be taken to protect the aquatic habitat. Based on the EPA Quality Criteria for Water, 24-hour averaging is considered compatible with the minimum frequency of temperature monitoring believed to be biologically significant. Also, from an operational standpoint, twenty-four hour averaging is more "synchronous" with the time needed to implement such action (i.e., startup of cooling towers, alteration of river flows, or curtailment of SQN generation).

The request to increase the limit for **ΔT** in April and May is due, in part, to the Lake Improvement Plan (LIP), a program initiated in 1991 to improve water quality in the TVA reservoir system and enhance related socioeconomic activity. Under the LIP, river flows are curtailed in the early spring to aggressively fill reservoirs. At reduced flow, however, dilution and mixing of the thermal plume from SQN is restricted, which increases the plant **ΔT**. To keep temperatures below the 3.0 C° limit, a high river flow is needed, which is in direct conflict with the desire to fill reservoirs. April and May also is a period of low demand in hydro operations. As such, this period usually is set aside to perform maintenance at the dams. However, tasks that require the hydroturbines to be shut down, such as work on trashracks, are difficult to perform because of the potential impact on the **ΔT** limit at SQN. Increasing the limit for **ΔT** in April and May will allow TVA to better fulfill goals in the LIP without excessively constraining operations at SQN and nearby hydropower projects.

An increase in the limit for $\mathbf{dT_d/dt}$ is sought for several reasons. First, it can be shown that $\mathbf{dT_d/dt}$ is influenced primarily by unsteady flow in Chickamauga Reservoir, not changes in SQN operations. Second, when the November through March limit for **ΔT** was increased from 2.0 C° to 5.0 C° by the 316(a) demonstration of 1989, no corresponding change was made in the limit for $\mathbf{dT_d/dt}$. However, for unsteady conditions, $\mathbf{dT_d/dt}$ and **ΔT** are related in a manner such that a larger **ΔT** is accompanied by a larger $\mathbf{dT_d/dt}$. Subsequently, it has been found that the higher limit for **ΔT** cannot be fully utilized without exceeding the current limit for $\mathbf{dT_d/dt}$. Third, when water temperatures are cool, maintenance of $\mathbf{dT_d/dt}$ below 2.0 C°/hour requires near-steady flow in the river, which destroys TVA's ability to perform peaking operations at Watts Bar and Chickamauga Dams. In March and April it also can impede LIP reservoir filling. Fourth, the cooling towers at SQN can be used to keep $\mathbf{dT_d/dt}$ below the current 2.0 C°/hour limit; however, as before, this will cause extensive ice damage during wintertime operation.

To justify the changes given above, evidence provided in this report demonstrates that the current limits are more stringent than those necessary to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife. According to EPA protocol, such a demonstration is best accomplished by protecting the most temperature-sensitive fish species judged important, desirable, or both. In general, thermal criteria are included in water quality standards to protect the reproduction, growth, and survival of the temperature-sensitive species. In this study, therefore, the impact of the proposed alternate thermal criteria were evaluated in terms of these sustenance factors for aquatic life. The Tennessee Wildlife Resources Agency (TWRA) originally identified sauger, white crappie, and threadfin shad, and later blue and channel catfish, as representative important species in Chickamauga Reservoir. TWRA also expressed concern as to whether a freshwater mussel community exists in the vicinity of the SQN diffuser and, if present, how the thermal variances will impact that community.

In establishing power plant operational limits, use of 24-hour rather than 1-hour averaging of water temperature data is considered responsive to the requirements of resident fish communities. Fish are known to make short-term forays (2 to 3 hours) into water heated up to 3.0 C° above their upper lethal temperature without undo stress. Except in extreme instances (e.g., rapid changes of water temperature in excess of 10.0 C°), thermal impacts to resident fish species are minimized if timely relief from the condition is available. Short-term exposure (i.e., less than 24-hour duration) to a **ΔT** of 5.0 C° as a result of operation of SQN, in all except for the hot summer months, is not considered detrimental to the maintenance of a balanced fish or mussel community either in Chickamauga Reservoir or in the immediate vicinity of the diffuser. During months with high ambient temperature (i.e., July and August), however, short-term exposure to a **ΔT** of 3.0 C° or more can have significant negative impacts on the growth and survival of some species (i.e., sauger and white crappie). Hence, despite the implications of the EPA Quality

Criteria for Water, the conservative protection offered by 1-hour limits is still advocated to control extreme temperature events. The limits recommended herein are:

- The 1-hour average $\mathbf{T_d}$ shall not exceed 33.9°C (93.0°F) without consent of the permitting authority.

- The 1-hour average $\mathbf{T_d}$ shall not exceed 32.0°C (89.6°F) more than 6 hours in a 24-hour period.

The inclusion of April and May in the current $\mathbf{\Delta T}$ variance of 5.0 C° for November through March will have no substantive impact on sensitive fish communities. Movement of sauger past the diffuser to the spawning area will not be impaired by an increase in $\mathbf{\Delta T}$ during April and May since the fish will be several miles upstream at the spawning site or returning downstream after the spawn. From the literature, it is found that sauger larvae potentially drifting past the plant can tolerate a $\mathbf{\Delta T}$ of 5.0 C° without adverse impacts. White crappie spawn mainly in overbank areas out of the influence of the SQN discharge. Any crappie larvae or juveniles that cross the diffuser area can withstand a $\mathbf{\Delta T}$ of higher than 5.0 C° without adversely impacting survival or growth. Peak spawning of threadfin shad occurs between 22°C and 27°C. Based on historical data, and assuming SQN operation at full capacity, only two 1-hour $\mathbf{\Delta T}$ events a year are expected to result in water temperatures downstream of the plant greater than 27°C in April and May. With this small frequency of occurrence, an increase in the $\mathbf{\Delta T}$ limit to 5.0 C° during these months will not adversely impact threadfin shad reproduction.

Concerns over blue and channel catfish focus on the attraction of these species, and subsequently sport and commercial fishermen, to the diffuser area. This combination could result in the overharvest of one or both of these species, especially by commercial fishermen. While attraction of blue catfish and sport fishermen to the diffuser area has been observed, no commercial fishing is done in the area due to the diverse current patterns created by the underwater dam upstream of the diffusers. Field surveys have found that the numbers harvested by sport fishermen is insignificant compared to the overall reservoir population of these species.

The increase in the rate of change in river temperature, $\mathbf{dT_d/dt}$, from 2.0 C°/hour to 5.0 C°/hour will not have adverse impacts under most ambient water temperatures for any of the selected fish species. In general, fish can survive instantaneous water temperature changes from 5.0 C° to 10.0 C° without adverse impacts. However, as ambient temperatures approach the upper lethal limit for a particular species, a rapid rate of change can lower the upper lethal limit. Based on historical data, and assuming SQN operation at full capacity, June and July are the only months where the monthly average ambient water temperature exceeds 25°C and contains $\mathbf{dT_d/dt}$ events above the current 2.0 C°/hour limit (about 3 events per year). Optimum growth of even cool-water species such as sauger can be maintained at sustained water temperatures of 22°C to 25°C. In no cases within the period of record has the monthly average ambient temperature at SQN exceeded 30°C, near the upper lethal water temperature for sauger. It is apparent that a $\mathbf{dT_d/dt}$ limit of 5.0 C°/hour is sufficient to prevent adverse impact to important resident indigenous fish species.

Mussel communities in the vicinity of the SQN diffusers are relatively sparse and include individuals representing species which are widespread and relatively abundant elsewhere in the

Tennessee River. The only suitable habitat downstream of the diffusers is located within 100 meters along the right descending side of the channel (i.e., looking downstream). The wide range of sizes occurring in this area is indicative of a reproducing population indicating that the existing SQN diffuser discharge is not detrimental to the survival or recruitment of these mussel species. It is not anticipated that any of the requested thermal variances will adversely impact the existing mussel community below the SQN diffusers.

As can be identified from earlier discussions, TVA currently has three basic methods to regulate water temperatures at SQN - altering hydro operations at upstream and downstream dams, operating the cooling towers, and curtailing plant generation. In general, the use of each method incurs an operational cost that can be estimated for the changes in thermal criteria examined herein. Based on historical data, the cost of 1-hour averaging vs. 24-hour averaging for $\mathbf{\Delta T}$ and $\mathbf{T_d}$ is about \$69,000/year, the cost for maintaining the April/May $\mathbf{\Delta T}$ limit of 3.0 C° rather than 5.0 C° is about \$47,000/year, and the cost of maintaining the current $\mathbf{dT_d/dt}$ limit of 2.0 C°/hour is about \$12,000/year (all 1996 dollars). The latter cost assumes $\mathbf{dT_d/dt}$ is controlled by altering hydro operations. If circumstances require the use of cooling towers to control $\mathbf{dT_d/dt}$, then ice damage may potentially occur. In this case, the economic evaluation given in the SQN 316(a) of 1989, states "\$16-20 million would be needed to modify the cooling towers to increase their resistance to ice damage; or yearly repair of ice damage would be needed which, based on experience with previous events, would cost \$0.5-1.5 million" (1989 dollars). These costs include only TVA operational expenses. In cases involving altering the river flow, other social costs may be incurred (e.g., income by recreational industries). At this time, no reliable data are available for these costs.

In terms of the detailed requirements of the NPDES permit, the following table gives a succinct comparison of the current and proposed alternate thermal limit criteria summarized above. Taken in unison, these changes will not threaten the protection and propagation of a balanced, indigenous population of fish and wildlife in Chickamauga Reservoir. This is borne out by hydrothermal computations based on twenty years of field data and numerous biological studies conducted by TVA and other investigators. Ongoing programs to monitor the behavior of the SQN thermal plume and fish and shellfish populations in Chickamauga Reservoir will be used to track and verify these conclusions. Any new information that contradicts these results will immediately be brought to the attention of the permitting authority for examination and appropriate action.

NPDES Permit Requirements for Sequoyah Nuclear Plant
Summary of Current and Proposed Alternate Thermal Limit Criteria

Current Thermal Criteria		Proposed Alternate Thermal Criteria
Maximum River Temperature Downstream of Plant T_d		
• Compute T_u and T_d by averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging).	→	• Compute T_u and T_d by two methods: (1) averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging), and (2) averaging the current 15-minute value with the previous ninety-six 15-minute values (24-hour averaging).
• The 1-hour average T_d shall not exceed 30.5°C (86.9°F). • If the 1-hour average T_u approaches or exceeds 30.5°C (86.9°F) and the cooling towers are in operation with the plant in helper mode (3 lift pumps and one cooling tower per operating unit), the 1-hour average T_d can be higher, but shall not exceed 33.9°C (93.0°F) without consent of the permitting authority.	→	• The 1-hour average T_d shall not exceed 33.9°C (93.0°F) without consent of the permitting authority. • The 1-hour average T_d shall not exceed 32.0°C (89.6°F) more than 6 hours in a 24-hour period. • The 24-hour average T_d shall not exceed 30.5°C (86.9°F). • If the 24-hour average T_u approaches or exceeds 30.5°C (86.9°F) and the cooling towers are in operation with the plant in helper mode (3 lift pumps and one cooling tower per operating unit), the 24-hour average T_d can be higher, but shall not exceed 32.0°C (89.6°F).
Maximum Rise in River Temperature from Upstream to Downstream of Plant ΔT		
• Compute ΔT by averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging).	→	• Compute ΔT by averaging the current 15-minute value with the previous ninety-six 15-minute values (24-hour averaging).
• The 1-hour average ΔT shall not exceed: 5.0 C° (9.0 F°) for November through March, 3.0 C° (5.4 F°) for April through October.	→	• The 24-hour average ΔT shall not exceed: 5.0 C° (9.0 F°) for November through May, 3.0 C° (5.4 F°) for June through October.
Maximum Rate of Change of River Temperature Downstream of Plant dT_d/dt		
• Compute dT_d/dt by averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging).	→	• No change in computation of dT_d/dt.
• The 1-hour average dT_d/dt, shall not exceed 2.0 C°/hour (3.6 F°/hour).	→	• The 1-hour average dT_d/dt, shall not exceed 5.0 C°/hour (9.0 F°/hour).

Notes:
1. T_u is the ambient river temperature upstream of plant, computed at the 1.5-meter (5-foot) depth by averaging intake measurements at the 1.0-meter, 1.5-meter, and 2.0-meter depths.
2. T_d is the river temperature downstream of plant, computed at the 1.5-meter (5-foot) depth by means of a numerical model that solves the thermohydrodynamic equations governing the flow and thermal conditions in Chickamauga Reservoir.
3. $\Delta T = T_d - T_u$ is the rise in river temperature from upstream to downstream of the plant.
4. dT_d/dt is the rate of change of river temperature downstream of plant, computed based on values of T_d as given above. $dT_d/dt = [(T_d)_t - (T_d)_{t-\Delta t}]/\Delta t$, where subscript t refers to the current value of T_d, subscript t-Δt refers to the previous value of T_d, and $\Delta t = 0.25$ hours.

ACKNOWLEDGMENTS

This supplemental 316(a) demonstration was performed by a team of individuals possessing a diverse range of expertise in helping to obtain the changes in the thermal limit criteria for SQN as summarized herein. The work of each team member is recognized as valuable and important to the successful completion of this study. Specific acknowledgments include the following:

- Debby Bodine of TVA Sequoyah Nuclear Plant for overall guidance and communication of environmental issues and data related to the operation of the plant.

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- Gary Hickman, Johnny Buchanan, and Neil Woomer of TVA Water Management Environmental Compliance for evaluation of the biological aspects of the proposed thermal limit variations. An in-depth literature review for biological aspects also was performed by Jeff Hennie, a TVA summer intern.

- Walter Harper and Ming Shiao of the TVA Engineering Laboratory for evaluation of the hydrothermal aspects of the proposed thermal limit variations.

- Terry Parkman and Randy Kerr of TVA Water Management Reservoir System Operations for communication of issues and data related to the operation of the reservoir system.

- Charles Feagans and Janis Dintsch of TVA Electric Systems Operations for performing economic evaluations of the proposed thermal limit variations.

Contributions by the above persons were assembled in this report by Paul Hopping of the TVA Engineering Laboratory. Tasks for editing and compiling the final report were performed by Cindy Webb and Catherine Patty, also of the TVA Engineering Laboratory.

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1.0 INTRODUCTION

This study is provided as a supplement to the original 316(a) demonstration for Sequoyah Nuclear Plant (SQN) presented by Wrenn et al., in August 1989. The original demonstration sought to increase the limit for the river temperature rise at the plant from 3.0 C° (5.4 F°) to 5.0 C° (9.0 F°) for the "winter" months November through March, due primarily to problems encountered with ice damage in the cooling towers. Since the results of the present study are strongly connected to the original demonstration, the report by Wrenn et al. (1989) is included herein as Appendix A.

In this supplement TVA is requesting changes in the thermal criteria at SQN for: (1) the period of averaging for river temperature data, (2) the duration of the winter operation limit for the river temperature rise from upstream to downstream of the plant, and (3) the limit for the rate of river temperature change downstream of the plant. In the first case, a change is requested to include 24-hour averaging of temperature data. In the second case, a change is requested to include April and May in the period of winter operation. In the third case, a variance is requested to increase the limit for the rate of temperature change. These alternative criteria are sought collectively due to operational issues that have arisen for both SQN and TVA Reservoir System Operations (RSO) since presentation of the original 316(a) demonstration. Those for the plant are related to use of cooling towers to control short-term, temperature-limit events. For RSO, operational issues are related to procedures for filling and maintaining reservoir water levels in TVA's Lake Improvement Plan (see TVA, 1990).

As in the original demonstration, evaluations for requesting a change in the thermal criteria follow the guidelines of Section 316(a) of the Federal Water Pollution Control Act Amendments of 1972. To obtain approval for alternate limits, the owner of the point source must demonstrate that the criteria intended to control the thermal discharge are more stringent than those necessary to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife. Assessments of this kind traditionally are made by protecting the most temperature-sensitive species in the receiving water body judged to be important, desirable, or both. Species identified in the original study by Wrenn et al. (1989) include sauger (*Stizostedion canadense*), white crappie (*Pomoxis annularis*), and threadfin shad (*Dorosoma petenense*). Blue and channel catfish (*Ictalurus furcatus* and *Ictalurus punctatus*--both of which are important commercial species), native mussels, and SQN use of biocides were all recently identified as concerns by the Tennessee Wildlife Resources Agency (TWRA), and hence also are examined in this supplemental demonstration.

The discussions presented herein summarize the results of studies to evaluate the potential effects of the proposed alternate thermal criteria at SQN. The history of the temperature limits at SQN and hydrothermal aspects of Chickamauga Reservoir are briefly updated to include new information that has emerged since the original 316(a) demonstration. The effects of changes in the thermal discharge criteria are evaluated in terms of the number and magnitude of extreme temperature events. These results are based on twenty years of actual river temperature and flow data collected at SQN and the maximum discharge of waste heat from the plant. The biological determination is presented by examining the effects of the extreme temperature events on the aquatic species previously identified. The techniques for compliance verification and the economic impact of the proposed new criteria are provided.

2.0 HISTORY OF TEMPERATURE CRITERIA FOR SEQUOYAH NUCLEAR PLANT

A detailed history of the temperature criteria for SQN is given in the original 316(a) demonstration by Wrenn et al. (Appendix A). Records of the late 60s and early 70s show a wide range of professional opinion regarding water temperature criteria for the Tennessee Valley region. This uncertainty was due largely to the lack of data for the effects of water temperature on fish and wildlife in the Southeast. Today, questions still remain. However, experience gained via ongoing biological investigations at TVA and elsewhere has substantially increased confidence in assessing the impact on fish and wildlife of changes such as those summarized in this supplement.

The first milestone for the current thermal limits at SQN was established on December 14, 1971, when the Tennessee Water Quality Board adopted state temperature criteria for industrial water supply. EPA subsequently approved the criteria on June 9, 1972. The limits established by these criteria include a maximum water temperature of 30.5°C (86.9°F), a maximum increase in water temperature from ambient of 3.0 C° (5.4 F°), and a maximum rate of change of water temperature of 2.0 C°/hour (3.6 F°/hour).

In the original 316(a) demonstration of 1989, the maximum rise in water temperature from ambient was requested to be changed from 3.0 C° (5.4 F°) to 5.0 C° (9.0 F°) for the winter months November through March. This increase was accepted by the EPA on December 19, 1989, with the provision that confirmative field studies be added as part of the permit modification. Under these conditions, NPDES Permit TN0026450, effective October 1, 1993 to September 30, 1998, includes as the current thermal limit criteria for SQN (see Appendix B):

Maximum River Temperature Downstream of Plant (**T_d**)
T_d shall not exceed 30.5°C (86.9°F). However, if the river temperature upstream of the plant, **T_u**, approaches or exceeds 30.5°C and the cooling towers are in operation (3 pumps and one cooling tower per operating unit), **T_d** can be higher, but shall not exceed 33.9°C (93.0°F) without consent of the permitting authority.

Maximum Rise in River Temperature from Upstream to Downstream of Plant (**ΔT**)
$\Delta T = |T_d - T_u|$ shall not exceed 5.0 C° (9.0 F°) for months November through March and 3.0 C° (5.4 F°) for months April through October.

Maximum Rate of Change of River Temperature Downstream of Plant (**dT_d/dt**)
dT_d/dt, shall not exceed 2.0 C°/hour (3.6 F°/hour).

The permit also specifies that:

- Compliance with $\mathbf{T_d}$, $\mathbf{\Delta T}$, and $\mathbf{dT_d/dt}$ shall be applicable at the edge of a mixing zone not exceeding 750 feet wide, 1500 feet downstream of the diffusers, and 275 feet upstream of the diffusers.

- $\mathbf{T_u}$ (i.e., ambient temperature) shall be computed at the 1.5-meter (5.0-foot) depth upstream of the plant by averaging measurements taken at the 1.0-meter, 1.5-meter, and 2.0-meter depths.

- $\mathbf{T_d}$ and $\mathbf{dT_d/dt}$ shall be computed at the 1.5-meter (5.0-foot) depth downstream of the plant by means of a numerical model that solves the thermohydrodynamic equations governing the flow and thermal conditions of Chickamauga Reservoir.

- Temperature measurements and computations shall be collected every 15 minutes.

- $\mathbf{T_d}$, $\mathbf{\Delta T}$, and $\mathbf{dT_d/dt}$ shall be determined once per hour by averaging the current readings with the previous four 15-minute readings.

The last requirement is known as 1-hour averaging.

3.0 HEAT DISSIPATION SYSTEM FOR SEQUOYAH NUCLEAR PLANT

Pertinent information for the design and operation of the heat dissipation system for SQN is given in Appendix A.

4.0 PRECURSORY HYDROTHERMAL INFORMATION

A summary of the hydrothermal aspects of Chickamauga Reservoir is given in Appendix A. Included is information about the characteristics of the river flow, temperature patterns in the main channel and shallow regions, and daily and seasonal variations in temperature. In the 316(a) demonstration of 1989, discussions were given of potential changes in the TVA procedures for operating the reservoir system. These changes came to fruition in 1991 as the TVA Lake Improvement Plan (LIP). Under the LIP, the river system is now operated to aggressively fill the tributary lakes in the spring and delay unrestricted drawdown of these reservoirs until after July 31. Compared to historical operation, this action is expected to reduce flows in Chickamauga Reservoir from mid-March to July 31, and increase flows in the drawdown period after July 31. This is demonstrated in Figure 1, which shows the computed monthly average flow at Chickamauga Dam with and without the LIP changes. These computations were performed using the TVA Weekly Scheduling Model and are based on actual inflow data from 1903 to 1992. The comparison shows that on the average the LIP will reduce the flow in

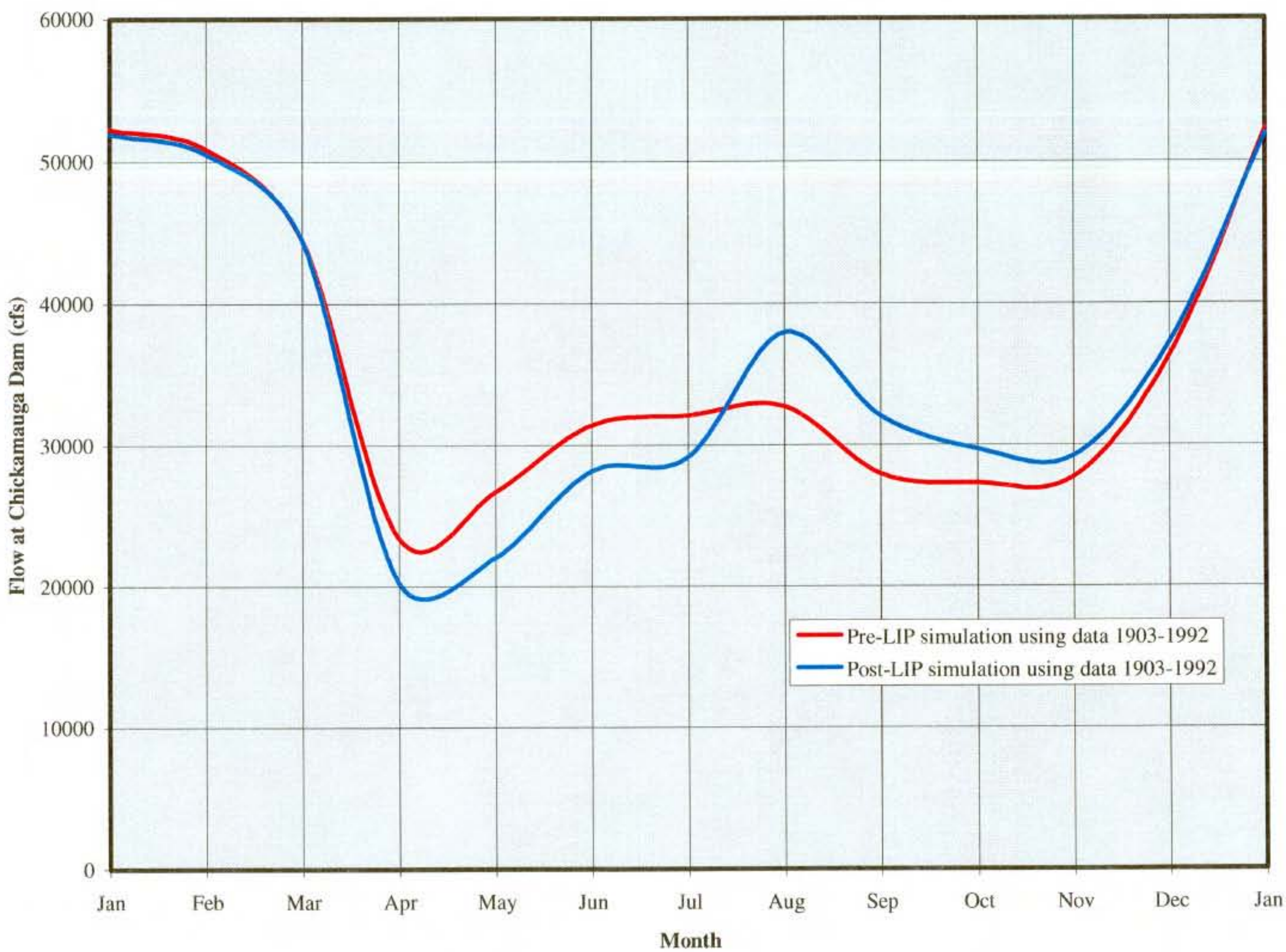

Figure 1. Computed Monthly Average River Flow at SQN

Chickamauga Reservoir by about 3,000 cfs in months April through June and increase the flow by as much as 5,000 cfs beginning in August.

As for thermal impacts, reduced flow in April will promote an earlier onset of reservoir stratification. After July 31, higher flow will increase mixing and tend to destratify the reservoir sooner than in the past. An indication of the potential change of water temperature resulting from the LIP can be obtained by examining data from SQN, available beginning in 1976. Given in Figure 2 is the monthly average river temperature at the five-foot depth upstream of the plant (i.e., $\mathbf{T_u}$). Two curves are shown, one for years 1976-1990 (pre-LIP) and one for years 1991-1995 (post-LIP). As shown, the post-LIP temperature is warmer than the pre-LIP temperature in months April through July, at most by about 0.7 C°. This occurs even though, on the average, the post-LIP years were cooler than the pre-LIP years for months May through July, based on the measured air temperature at SQN. During reservoir drawdown (i.e., after July), the water temperatures are essentially the same.

It needs to be emphasized that the results in Figure 2 are biased, thus diminishing the likelihood that the changes shown are a full result of the LIP. Most important is the fact that the pre- and post-LIP trends are based on different years of information. Other meteorologic and/or hydrologic conditions in these periods may contribute to the observed temperature differences. To fully assess the impact of the LIP, operational changes in the reservoir system need to be examined using a single period of record (e.g., Figure 1). Other factors affecting water temperature also need to be examined, such as solar radiation, wind, dew point, and cloud cover (i.e., not just flow and air temperature). With all these factors, no reliable procedure currently is available to adjust historical water temperature data for changes under the LIP. Since the anticipated effect on the water temperature is small (e.g., less than 1 C°), hydrothermal analyses for the SQN thermal limits given in this study use the full period of available temperature data, 1976-1995, and neglect potential differences between the pre-LIP and post-LIP years.

5.0 PRECURSORY BIOLOGICAL INFORMATION

Wrenn et. al. (1989) projected no adverse impacts on resident fish communities in Chickamauga Reservoir from a change in the allowable temperature rise $\Delta\mathbf{T}$ from 3.0 C° to 5.0 C° in the winter months November through March, as a result of SQN operation. After the plant had been operating under this variance for two years, Kay and Buchanan (1995) were unable to document any negative influences on resident fish populations or fishing use in the vicinity of the SQN diffusers. The objective of this supplement is to determine if the same is expected for the potential biological effects of the new thermal limits proposed herein. The process begins by first presenting available data on current aquatic communities and important fish species. Included are the results of a survey conducted in the vicinity of the diffusers which show the presence, abundance, and distribution of the resident freshwater mussel community.

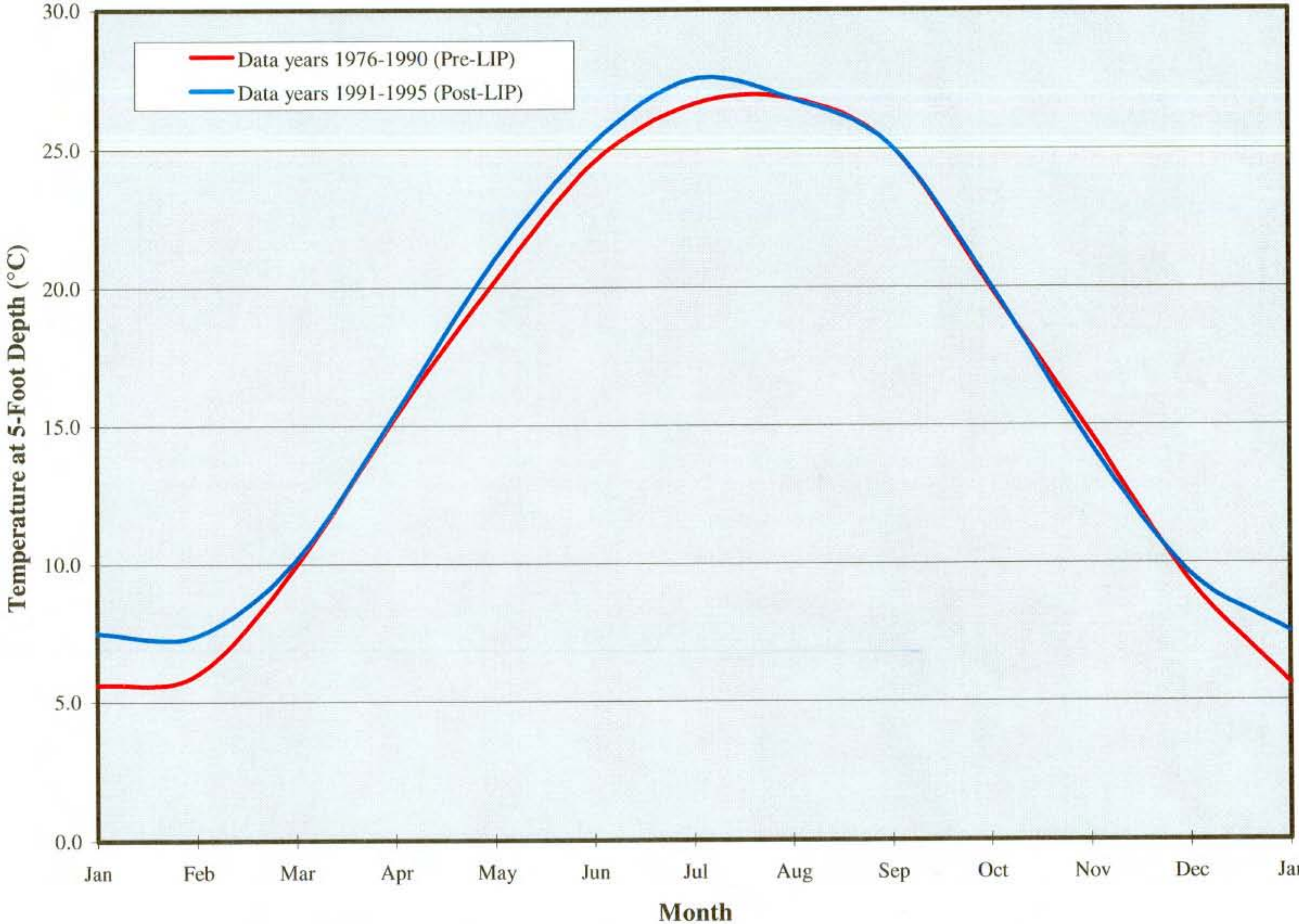

Figure 2. Measured Monthly Average Upstream River Temperature at SQN

5.1 Fish Community and Sport/Commercial Fishery

Reservoir Fish Assemblage Index (RFAI) sampling in Chickamauga Reservoir shows no decline in fish community status since that program was initiated in 1991 (Scott, 1992 and Dycus, 1995). RFAI uses multiple sampling gears to improve sampling efficiency for fish in both shoreline (electrofishing) and deeper water (experimental gill netting) areas. All mainstream sections (i.e., inflow, transition, and forebay zones) and major embayments of each TVA reservoir are sampled on an annual or biennial basis to assist in determining environmental quality. Sampling results for Chickamauga Reservoir can be broken into SQN operational periods under pre-variance and post-variance regimes. The number of species collected during these periods indicates no reduction in diversity after the thermal variance for the winter ΔT became effective in 1993 (see Table 1).

Comparison of RFAI scores from 1991 to 1995 above SQN at Tennessee River Mile (TRM) 490 and below SQN at TRM 473 reveals no significant differences between the quality of resident fish communities at the two sites (see Table 2). Annual variations within each site are minimal. The RFAI scores ranged from 41 to 51 throughout the 5-year period and compare favorably with average scores from similar areas in other mainstream Tennessee River reservoirs (e.g., 42 and 41 for forebay and transition zones, respectively). These results indicate no effect of SQN operation on the resident fish community. RFAI scores for the forebay zone of Chickamauga Dam, located downstream of the SQN diffuser (TRM 473), remained high after the winter ΔT variance became effective in 1993, indicating no adverse impacts from the new thermal regime (Table 2).

Wrenn et al. (1989) reported 73 species of fish collected from Chickamauga Reservoir cove rotenone samples between 1970 and 1989. Comparisons of the number of fish species collected prior to operation of SQN (1970-1980) with collections after SQN became operational (1981-1992), and after the current winter ΔT variance went into effect (1993-1995), suggest a decline in diversity of fish throughout the period (Table 1). However, while pre-SQN operation data covers 10 years and post-SQN operational data covers 11 years, the post-thermal variance period includes only 2 years of data collection (1993 and 1995, no rotenone sampling in 1994). It is known that species rarely collected using the cove rotenone sampling technique (i.e., those normally not inhabiting the shallow portions of coves off the main channel) are documented only when numerous years of data are available. Similar biases also occur through periodic collection of several species immigrating from small streams into the back of coves that are not permanent reservoir residents.

Reservoir-wide creel surveys have been conducted periodically on Chickamauga Reservoir by TWRA prior to and after SQN became operational. After the winter ΔT variance became effective in 1993, black basses (*Micropterus* sp.) have been the most sought after sport fish in Chickamauga Reservoir, accounting for 34 percent of the overall fishing effort during 1994 and 1995 (O'Bara, 1995; 1996). Crappie (*Pomoxis* sp.) drew 14 to 17 percent of the fishing effort during these years and sauger made up 6 percent.

Heated effluent areas can concentrate fishing effort on a reservoir, especially during winter months (McNurney and Dreier, 1981). Based on reservoir-wide sport fish creel surveys for Chickamauga Reservoir during pre-SQN and post-SQN operation, Wrenn et al. (1989) found no negative influences of diffuser operation on fishermen effort or success. Comparison of creel results after the winter ΔT variance became effective in 1993 show that the crappie catch rate

Table 1. Species of Fish Collected from Chickamauga Reservoir Cove Rotenone and Electrofishing/Gill Netting Samples Prior to SQN Operation (1970-1981), After SQN Operation (1981-1992), and After the Original 316(a) Variance Became Effective (1993-1995)

Scientific Name	Common Name	Electrofishing and Gill Netting		Cove Rotenone		
		Post SQN	Post Variance	Pre SQN	Post SQN	Post Variance
Icythyomyzon casteneus *	Chestnut lamprey		X	X	X	X
Polyodon spathula *	Paddlefish			X		
Lepisosteus oculatus	Spotted gar		X	X	X	X
Lepisosteus osseus	Longnose gar	X	X	X	X	X
Alosa chrysochloris	Skipjack herring	X	X	X	X	X
Dorosoma cepedianum	Gizzard shad	X	X	X	X	X
Dorosoma petenense	Threadfin shad	X	X	X	X	X
Hiodon tergisus	Mooneye	X	X	X		
Campostoma anomalum	Central stoneroller		X	X	X	X
Carassius auratus	Goldfish			X		
Ctenopharyngodon idella	Grass carp		X			
Cyprinella galactura	Whitetail shiner			X		
Cyprinella spiloptera	Spotfin shiner	X	X	X	X	X
Cyprinella whipplei	Steelcolor shiner		X	X	X	X
Cyprinus carpio	Common carp	X	X	X	X	X
Hypopsis storeriana *	Silver chub			X		
Notemigonus crysoleucas	Golden shiner	X	X	X	X	X
Notropis atherinoides	Emerald shiner	X	X	X	X	X
Notropis buchanani	Ghost shiner			X	X	X
Notropis chrysocephalus *	Striped shiner		X	X	X	
Notropis volucellus	Mimic shiner			X	X	X
Opsopoeodus emiliae *	Pugnose minnow			X	X	
Pimephales notatus	Bluntnose minnow	X	X	X	X	X
Pimephales vigilax	Bullhead minnow		X	X	X	X
Pimephales promelas	Fathead minnow			X		
Carpiodes carpio	River carpsucker		X	X	X	
Carpiodes cyprinus	Quillback	X	X	X	X	
Catostomus commersoni *	White sucker			X		
Hypentelium nigricans	Northern hog sucker	X	X	X	X	X
Ictiobus bubalus	Smallmouth buffalo	X	X	X	X	X
Ictiobus cyprinellus	Bigmouth buffalo			X		
Ictiobus niger	Black buffalo			X	X	
Minytrema melanops	Spotted sucker	X	X	X	X	X
Moxostoma anisurum	Silver redhorse		X			
Moxostoma carinatum	River redhorse			X		
Moxostoma duquesnei	Black redhorse	X	X	X	X	
Moxostoma erythrurum	Golden redhorse		X	X	X	X
Moxostoma macrolepidotum	Shorthead redhorse	X		X		
Ictalurus furcatus	Blue catfish	X	X	X	X	
Ictalurus melas	Black bullhead			X	X	X
Ictalurus natalis	Yellow bullhead			X	X	X
Ictalurus nebulosus	Brown bullhead				X	X
Ictalurus punctatus	Channel catfish	X	X	X	X	X
Pylodictis olivaris	Flathead catfish	X	X	X	X	X
Fundulus notatus	Blackstripe topminnow			X		
Fundulus olivaceus	Blackspotted topminnow			X	X	X
Gambusia affinis	Western mosquitofish			X	X	X

Table 1 Continued.

Scientific Name	Common Name	Electrofishing and Gill Netting		Cove Rotenone		
		Post SQN	Post Variance	Pre SQN	Post SQN	Post Variance
Labidesthes sicculus	Brook silverside	X	X	X	X	X
Morone chrysops	White bass	X	X	X	X	X
Morone mississippiensis	Yellow bass	X	X	X	X	X
Morone saxatilis	Striped bass	X	X		X	
Ambloplites rupestris	Rock bass			X		
Lepomis auritus	Redbreast sunfish	X	X	X	X	X
Lepomis cyanellus	Green sunfish	X	X	X	X	X
Lepomis gulosus	Warmouth	X	X	X	X	X
Lepomis macrochirus	Bluegill	X	X	X	X	X
Lepomis megalotis	Longear sunfish	X	X	X	X	X
Lepomis microlophus	Redear sunfish	X	X	X	X	X
Micropterus dolomieui	Smallmouth bass	X	X	X	X	X
Micropterus punctulatus	Spotted bass	X	X	X	X	X
Micropterus salmoides	Largemouth bass	X	X	X	X	X
Pomoxis annularis	White crappie	X	X	X	X	X
Pomoxis nigromaculatus	Black crappie	X	X	X	X	X
Etheostoma caeruleum *	Rainbow darter			X	X	X
Etheostoma kennicotti *	Stripetail darter			X	X	
Perca flavescens	Yellow perch	X	X	X	X	X
Percina caprodes	Logperch	X	X	X	X	X
Stizostedion canadense	Sauger	X	X	X	X	X
Stizostedion vitreum	Walleye	X	X			
Aplodinotus grunniens	Freshwater drum	X	X	X	X	X
	TOTAL	39	48	65	55	46

* Species either not full-time residents of reservoirs or usually not captured with these gear types.

Table 2. Reservoir Fish Assemblage Index Scores from Above (TRM 490) and Below (TRM 473) the SQN Diffuser Outlet (TRM 483.8)

Year	TRM 490	TRM 473
1991	45	44
1992	41	46
1993	51	45
1994	41	41
1995	50	47
Mainstem Reservoir Averages (1991-1995)	42 (transitions zones)	41 (dam forebay zones)

increased from between 0.68 and 0.86 fish per hour in 1991-1993 to between 1.02 and 1.23 fish per hour in 1994-1995. Sauger catch rates ranged from 0.47 to 0.70 fish per hour prior to the variance and from 0.98 to 1.05 fish per hour after the variance, indicating no adverse impacts on fishermen success rates.

Kay and Buchanan (1995) reported no significant attraction of fishermen or important sport fish to the diffuser area before, or after, the winter ΔT variance for SQN. Blue catfish, a species often sought by both commercial and sport fishermen, did show some attraction to the diffuser area, comprising 42 percent of the total catch of winter gill netting samples in the vicinity of SQN. Only 36 boats were observed in the diffuser area during thrice weekly pressure counts from November 1993 through March 1994 and November 1994 through March 1995. Anglers caught 67 fish (46 blue catfish) in 65 hours of fishing for a catch rate of 1 fish/hour.

In 1993 and 1994, an average of only five or six commercial fishermen were working Chickamauga Reservoir during any quarter of a year (Todd; 1994, 1995). These fishermen harvested an estimated 402,814 pounds of fish in 1993 (8.5 percent of the Tennessee statewide harvest) and 137,306 pounds of fish in 1994 (3.7 percent of the Tennessee statewide harvest). Freshwater drum (*Aplodinotus grunniens*) made up 42 percent of the catch in 1993, followed by common carp (*Cyprinus carpio*) at 23 percent, buffalo (*Ictiobus* sp.) at 14 percent, channel catfish at 12 percent, blue catfish at 8 percent, and other at 1 percent. In 1994, channel catfish accounted for 51 percent of the commercial catch, followed by buffalo at 22 percent, common carp at 15 percent, blue catfish at 7 percent, and flathead catfish (*Pylodictis olivaris*) at 3 percent.

5.2 Freshwater Mussel Community

A series of TVA random search dive surveys conducted within and above the discharge mixing zone at SQN indicate that native mussels are uncommon at all four sites (see Table 3). The 211 minutes of total dive time yielded only 35 live mussels (0.17 mussels per dive minute). These animals represented eight species, all of which are widespread and relatively abundant elsewhere in the mainstem Tennessee River. The right (descending) side of the channel closest to the diffuser contained the most live mussels (22); however, even there a live mussel was found only once in every two or three minutes of dive time. Only two live mussels were found at the mid-channel site in the center of the mixing zone and only one live mussel was found at the left-side site upstream from the discharge diffuser. Live and dead Asiatic clam shells also were common along the sides of the channel in addition to sometimes dense populations of a *Viviparus* snail species (probably *V. subpurpureus,* olive mysterysnail). While they are not native mussel species, zebra mussels (*Dreissena polymorpha*) were found at both the mid-channel site in the center of the mixing zone and along the right side just downstream from the discharge diffuser.

Nearly all of the live native mussels encountered during this survey were measured before being returned to the river. Lengths of these animals indicate that most of the species were represented by a variety of size classes (see Table 4). While no attempt was made to estimate ages (sometimes possible by counting external growth rest "lines"), the variety of sizes almost certainly indicates that these animals represent a variety of age classes. The relatively small individuals of the washboard (*Megalonaias nervosa*), pink heelsplitter (*Potamilus alatus*), elephant-ear (*Elliptio crassidens*), and especially fragile papershell (*Leptodea fragilis*) suggest that all of these species have reproduced successfully in this part of the Tennessee River in recent years.

Table 3. Results from TVA Random Dives in the Tennessee River Near SQN Diffuser on September 5, 1996

Dive Station	**1**	**2**	**4**	**3**	
Description	Center of channel, under downstream power line.	Center of channel, upstream from power lines.	Right edge of channel, upstream from power lines and station 2.	Left edge of channel, upstream from diffuser.	
Typical Depth (feet)	59	53	53	39 - 45	
Dive Time (minutes)	65	39	52	55	
Substrate Description (materials listed in order of relative abundance)	Bedrock with lenses of silt and sand.	Bedrock with patches of cobbles.	Snails with sand, silt, and Corbicula shells.	Gravel and cobbles with lots of Corbicula shells.	
Freshwater Mussels					Total
Megalonaias nervosa	5		4		9
Potamilus alatus	1		7		8
Obliquaria reflexa	1	1	4		6
Elliptio crassidens	2	1			3
Leptodea fragilis			3		3
Tritogonia verrucosa			3		3
Anodonta grandis	1		1		2
Amblema plicata				1	1
Total Count	10	2	22	1	35
Species Included	5	2	6	1	8
Other Bivalves					
Corbicula manilensis	X	X	X	X	
Dreissena polymorpha		5	5		10

X = Live specimens observed but not counted.

Table 4. Shell Lengths of Bivalve Mollusks Encountered by TVA Divers in the Tennessee River Near SQN on September 5, 1996

Bivalve Species	Count	Mean	Individual Lengths								
Native Mussels											
Megalonaias nervosa	9	112.1	72.5	81.4	113.2	115.3	129.6	140.1	149.6	159.6	160.8
Potamilus alatus	8	141.2	115.8	127.3	128.5	128.9	135.3	161.4	162.5	170.0	
Obliquaria reflexa *	5	47.8	41.0	46.6	48.9	50.1	52.2				
Elliptio crassidens	3	110.2	91.3	96.4	142.8						
Leptodea fragilis	3	51.5	19.9	22.8	111.9						
Tritogonia verrucosa	3	104.1	95.6	98.5	118.3						
Anodonta grandis	2	147.0	146.3	147.6							
Amblema plicata	1	127.3	127.3								
Zebra Mussels											
*Dreissena polymorpha**	6	16.1	15.1	15.3	15.5	16.5	16.6	17.8			

* - one of the *O. reflexa* specimens was not measured and several zebra mussels were lost or crushed before they could be measured.

There is relatively little suitable habitat for native mussels in the center of the original channel in the vicinity of the SQN diffuser, but a slightly higher percentage of stable sand, gravel, and cobble habitat occurs along its sides. The numbers of small and large native mussels (and the other aquatic mollusks) along the right side and in the center of the SQN diffuser mixing zone suggest that the current discharge does not have any detrimental effect on the survival or recruitment of these mollusks. It is also apparent that current thermal characteristics of the SQN discharge do not have any negative impacts on the sparse resident mollusk community. More mussels were found within the mixing zone than at the single site examined just upstream from the diffuser.

5.3 Important Fish Species

To address the potential impact of the proposed new thermal limit criteria, species originally identified by Wrenn et al. (1989) as sensitive or important in Chickamauga Reservoir are again used in this study. These are sauger, white crappie, and threadfin shad. Recent discussions with TWRA have identified blue and channel catfish as species of concern, hence these are also included. Sauger is an important cool-water sport fish species with a relatively low maximum thermal tolerance (See Table 5). Threadfin shad is a major forage species in the reservoir that experiences severe stress below 10°C and near total mortality below 4°C (Griffith, 1978; Lewis and Heidinger, 1979; Irwin and Bettoli, 1995). White crappie is an important warm-water sport fish having the lowest tolerance for high water temperatures of any of the popular Centrarchid (sunfish) species inhabiting the reservoir (Mathur and McCreight, 1980). Blue and channel catfish are important commercial fish species. Blue catfish have shown some tendency to congregate in the vicinity of the SQN diffuser (Kay and Buchanan, 1995).

Table 5. Upper or Lower Incipient Lethal Temperatures (Where 50% Mortality Occurs) With Associated Acclimation Temperatures, Maximum Growth Temperatures, and Applicable Lifestage for Four Key Species in Chickamauga Reservoir.

Species	Incipient Lethal Temperature (Acclimation Temperature)			Maximum Growth Temperature		Life-stage
	U/L	(°C)	Reference	(°C)	Reference	
Sauger	U	30.4 (23.9)	Koenst & Smith 1976	22.0	Koenst & Smith 1976	Juvenile
White Crappie	U	32.8 (25.6)	Peterson et al. 1974	27-28.5	Gammon 1973	Adult
Threadfin Shad[3]	L	4-5 (17)	Griffith 1978			Juvenile
Channel Catfish	U	36.6 (26)	Allen & Strawn 1968	32	Kilambi et al. 1970	Juvenile

Notes: 1. U = upper incipient lethal temperature.
2. L = lower incipient lethal temperature.
3. Lower incipient lethal temperature used for threadfin shad due to their sensitivity to cold.

Biological aspects of concern based on operation of SQN under the requested thermal variance include impacts on mortality, reproduction, growth, concentration in the thermal plume, and fishermen harvest. The applicability of these aspects vary with individual species and are addressed accordingly. In the original 316(a) demonstration, Wrenn et al., (1989) also addressed potential impacts of the **ΔT** variance on impingement and disease. Their discussion of these impacts remains sufficient to cover present proposals and will not be repeated in this document (see Appendix A).

5.3.1 Sauger

Sauger in Tennessee River reservoirs historically have experienced considerable fluctuations in population density (Hackney and Holbrook, 1978). The extreme sauger population decline in Chickamauga Reservoir during the mid to late-1980s was thoroughly documented by Hevel (1988), Hickman et al. (1989), Hickman et al. (1990), and Hevel and Hickman (1991). Yeager (1990), St. John (1990), Brown (1990), and Pegg et al. (1996) also noted the decline of sauger in other Tennessee River reservoirs and searched for causes. Water velocities and water temperatures during the April spawning period are generally cited as important factors in sauger spawning success and ultimately year-class strength (Yeager, 1990; Yeager and Shiao, 1992; Hickman and Buchanan, 1996). Brooks (1993) also reported that optimal water temperatures during spawning (7-10°C) and incubation, coupled with high water levels, promoted fry and fingerling survival in the Illinois River.

5.3.2 Crappie

Mooneyhan (1989) and McDonough and Buchanan (1991) discussed the decline in the Watts Bar and Chickamauga Reservoir crappie populations from 1970 through 1989 and addressed possible causes. Cove rotenone results from Chickamauga Reservoir (Jenkins, 1996) also indicated low crappie densities during this time period. Prior to 1988, white crappie dominated the *Pomoxis* population in Chickamauga Reservoir (over 90 percent). However, after a prolonged drought from 1985-1988, black crappie juveniles made up over 80 percent of the crappies collected (McDonough and Buchanan, 1991). Expanding aquatic vegetation and resultant changes in fish and invertebrate community structures were suggested as the most important factors affecting young white crappie survival in both reservoirs.

5.3.3 Threadfin Shad

Numbers of juvenile threadfin shad in Chickamauga Reservoir cove rotenone samples have fluctuated considerably between 1970 and 1995 (Jenkins, 1996). Peak mean density of 22,913 young-of-the-year (YOY) threadfin per hectare was found in 1985, with the lowest mean density, 53 fish per hectare, occurring in 1978. Threadfin shad are very sensitive to cold water temperatures (severe stress below 10°C and near total mortality below 4°C) and severity of winters often is the determining factor in reproductive success the following year (Griffith, 1978; Lewis and Heidinger, 1979). Adult densities often are reduced to a point where significant recruitment is not possible. Low density estimates of YOY threadfin in Chickamauga Reservoir were preceded by especially cold winters (Jenkins, 1996).

5.3.4 Blue and Channel Catfish

Chickamauga Reservoir has consistently been one of the top five producers of commercially harvested blue and channel catfish in the state of Tennessee. In 1993, Chickamauga led the state with 31,351 pounds of blue catfish harvested (Todd, 1994). Considering sport fishing, only four percent of the effort on Chickamauga Reservoir in 1995 was expended for catfish (O'Bara, 1996). Channel catfish comprised 83 percent of the catfish sport harvest and blue catfish 17 percent.

6.0 PROPOSED ALTERNATE THERMAL DISCHARGE LIMITS

6.1 24-Hour Averaging

It is proposed herein to monitor $\mathbf{T_d}$ and $\mathbf{\Delta T}$ based, in part, on a running 24-hour average. This modification will involve averaging the current readings for $\mathbf{T_d}$ and $\mathbf{\Delta T}$ with the previous ninety-six 15-minute readings. The present 1-hour method averages the current readings with only the previous four 15-minute readings. In a manner similar to that in the existing NPDES permit, the following condition will be needed to account for the case when the upstream ambient temperature exceeds the downstream limit:

- If the 24-hour average $\mathbf{T_u}$ approaches or exceeds 30.5°C (86.9°F) and the cooling towers are in operation with the plant in helper mode (3 lift pumps and one cooling tower per operating unit), the 24-hour average $\mathbf{T_d}$ can be higher, but shall not exceed 32.0°C (89.6°F).

For 24-hour averaging, the 1-hour temperature can still be much higher than the 24-hour limit. Since the aquatic habitat can yet be damaged by short-term exposure at extreme temperatures (e.g., biological aspects provided later), support still exists for the conservative protection offered by 1-hour limits for $\mathbf{T_d}$. Based on TVA experience at the Browns Ferry Nuclear Plant (BFN), where 24-hour averaging has been implemented without adverse biological impacts (see TVA, 1983), the following requirements are recommended:

- The 1-hour average $\mathbf{T_d}$ shall not exceed 33.9°C (93.0°F) without consent of the permitting authority.

- The 1-hour average $\mathbf{T_d}$ shall not exceed 32.0°C (89.6°F) more than 6 hours in a 24-hour period.

6.1.1 Operational Aspects

Twenty-four hour averaging is needed to distinguish water temperature events that *do provide* timely relief for aquatic habitat from those that *do not provide* timely relief. Depending on meteorology, hydrology, and other operational goals of the river system (e.g., reservoir filling, minimum flows, mosquito control, peaking operations), water temperatures that reach the limits for T_d or ΔT often encounter these extremes only for a short part of the day. These temperatures can be controlled, in part, by SQN cooling tower operation. However, the cooling tower lift pumps are not designed to be cycled on and off for only a few hours. As a result, the cooling towers often are operated around-the-clock to control events that occur for only a short time. When river temperatures are such that the limits for T_d or ΔT occur in this manner, the aquatic habitat typically obtains relief from the event within several hours by natural mechanisms of heat dissipation (e.g., evening cooling for T_d and daytime peak/high river flows for ΔT). When temperatures reach the limits for T_d or ΔT for periods as long as 24 hours, timely relief is not available and action is needed to mitigate the excess water temperature. In general, 24-hour averaging is more "synchronous" with the response time needed to implement methods to control temperatures, that is, operation of cooling towers, alteration of river flows, or curtailment of SQN generation.

A good example of this problem is given in Figure 3, which shows the downstream river temperature T_d for simulations of SQN operation with two units at full load in August 1988. The simulations are performed for 1-hour and 24-hour averaging and use the same numerical model for diffuser-induced mixing as that in the 316(a) demonstration of 1989. The temperature spikes shown for 1-hour averaging are caused by afternoon solar heating in the surface layer of the river. Not having the ability to forecast these spikes, cooling towers probably would have been operated continuously from August 1-27, a total of 648 hours. In this period, the 1-hour T_d met or exceeded the 30.5°C limit only about 105 hours, occurring in 19 temperature spikes of average duration 5½ hours. For 24-hour averaging, the cooling towers probably would have been operated to control T_d on two occasions, August 2-3 and August 15-23, a total of 264 hours. In this process, 24-hour averaging averts overuse of the cooling towers (i.e., from 648 to 264 hours) and better aligns operation with periods where relief is needed from long-term, excess water temperatures. Further, it should be emphasized that 24-hour average river temperatures can be predicted with much higher confidence than 1-hour average temperatures. This, in turn, improves TVA's ability to plan and prepare for tower operation. Also, from an air quality standpoint, reduced use of the cooling towers will decrease the amount of particulate material released to the atmosphere.

6.1.2 Hydrothermal Aspects

The effect of changing the averaging period from 1 to 24 hours again can be evaluated using the numerical model for diffuser-induced mixing. Based on historical data for meteorology and hydrology, the model simulates the combined operation of Chickamauga Reservoir and SQN to obtain expected values of T_d and ΔT. The results given here are for data from 1976-1995 and assume SQN operation of two units at full load.

T_d: For 1-hour and 24-hour averaging, respectively, Tables 6 and 7 show for each month the average annual number of times T_d is expected to meet or exceed the indicated temperature. For 1-hour averaging T_d never exceeds 32.0°C, whereas for 24-hour averaging T_d never exceeds 31.5°C. In general, events causing a high T_d will occur in the warm summer months. For temperatures at and above the current compliance limit (i.e., 30.5°C), events for 1-hour averaging occur in months June through August, whereas for 24-hour averaging they occur only for July and August (see also Figure 4). The total number of events for each temperature range is given at the bottom of Tables 6 and 7.

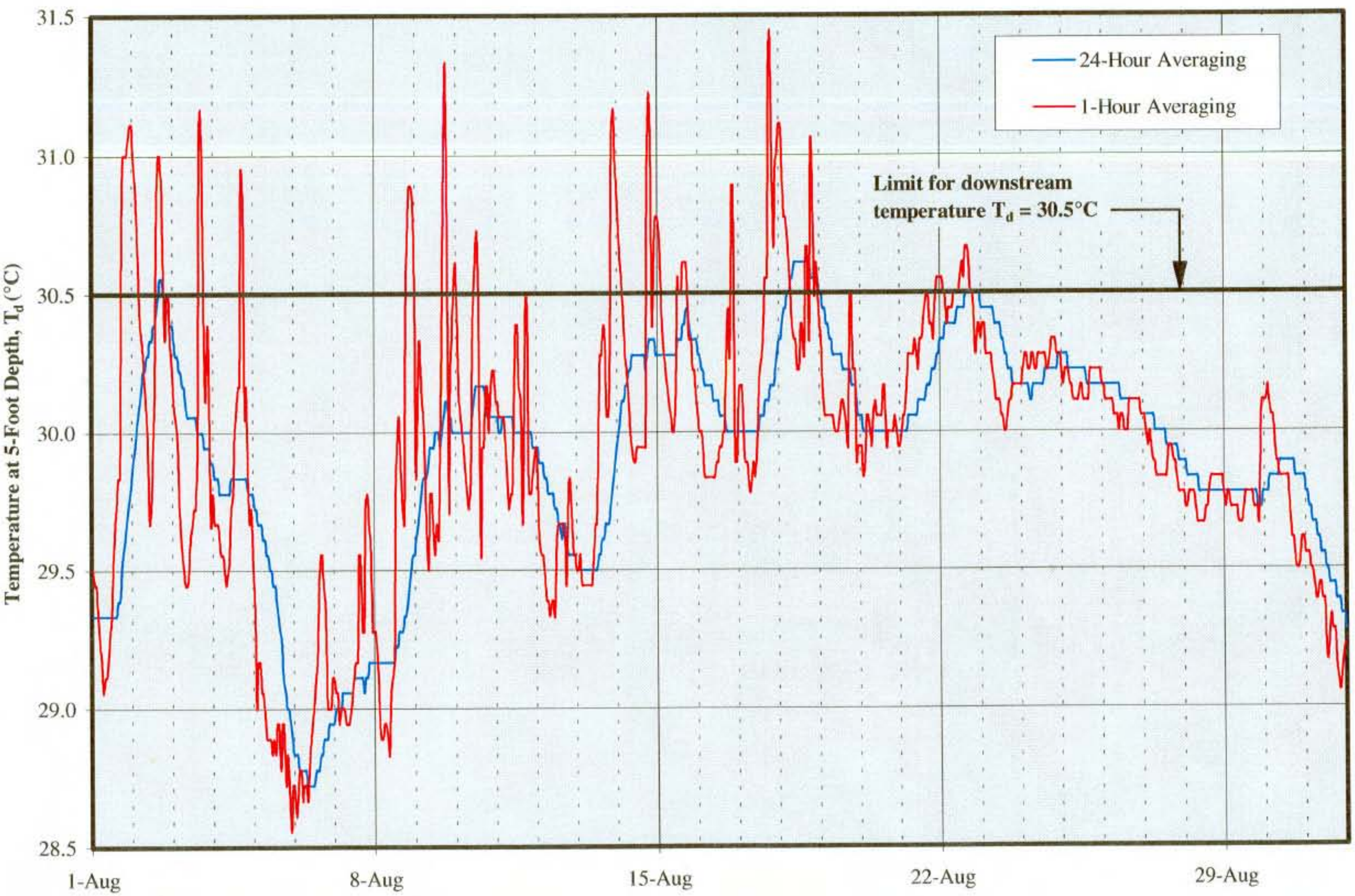

Figure 3. Downstream River Temperature $\mathbf{T_d}$ for Simulation of SQN with Two Units at Full Load in August 1988

Table 6. Average Annual Number of Times T_d is Greater Than or Equal to the Indicated Temperature for **1-Hour Averaging**

Month	$T_d \geq 26.5$°C	$T_d \geq 27.0$°C	$T_d \geq 27.5$°C	$T_d \geq 28.0$°C	$T_d \geq 28.5$°C	$T_d \geq 29.0$°C	$T_d \geq 29.5$°C	$T_d \geq 30.0$°C	$T_d \geq 30.5$°C	$T_d \geq 31.0$°C	$T_d \geq 31.5$°C	$T_d \geq 32.0$°C
Jan	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0	0	0	0	0
May	5	2	1	1	0	0	0	0	0	0	0	0
Jun	275	215	131	64	28	5	2	1	1	0	0	0
Jul	603	561	511	445	328	207	115	61	24	8	1	0
Aug	660	591	496	402	308	217	129	66	13	2	0	0
Sep	422	361	264	160	95	47	16	3	0	0	0	0
Oct	15	12	8	6	2	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,980	1,742	1,411	1,078	761	476	262	131	38	10	1	0

Notes: • Results based on SQN operation with two units at full load from 1976 to 1995. • Current limit for 1-hour T_d is 30.5°C (dark shading).

Table 7. Average Annual Number of Times T_d is Greater Than or Equal to the Indicated Temperature for **24-Hour Averaging**

Month	$T_d \geq 26.5$°C	$T_d \geq 27.0$°C	$T_d \geq 27.5$°C	$T_d \geq 28.0$°C	$T_d \geq 28.5$°C	$T_d \geq 29.0$°C	$T_d \geq 29.5$°C	$T_d \geq 30.0$°C	$T_d \geq 30.5$°C	$T_d \geq 31.0$°C	$T_d \geq 31.5$°C	$T_d \geq 32.0$°C
Jan	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0	0	0	0	0
May	2	0	0	0	0	0	0	0	0	0	0	0
Jun	256	207	116	53	19	3	1	0	0	0	0	0
Jul	595	560	513	446	308	169	95	53	20	6	0	0
Aug	664	592	508	394	286	191	111	62	8	1	0	0
Sep	423	357	258	151	84	35	10	1	0	0	0	0
Oct	16	12	9	5	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,956	1,728	1,404	1,049	697	398	217	116	28	7	0	0

Notes: • Results based on SQN operation with two units at full load from 1976 to 1995. • Proposed limit for 24-hour T_d is 30.5°C (dark shading).

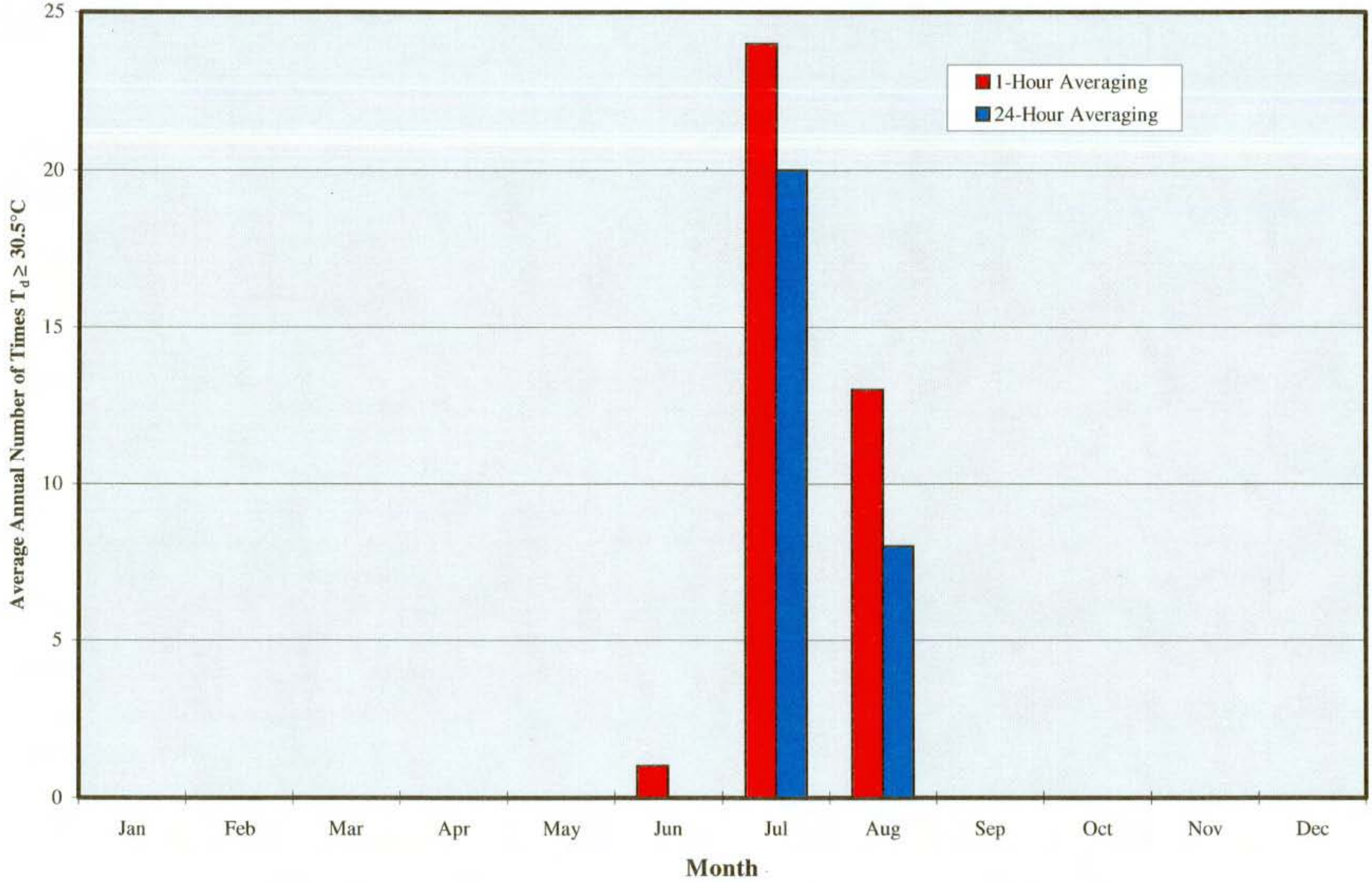

Figure 4. Average Annual Number of Times $\mathbf{T_d}$ is Greater Than or Equal to 30.5°C

Within a given range, 24-hour averaging reduces slightly the total number of events. For the current 30.5°C limit, 24-hour averaging is expected to reduce the average annual number of times action is needed to mitigate $\mathbf{T_d}$ from about 38 to 28. This reduction, ten events per year, represents the cases under the current method of 1-hour averaging where cooling towers are needed to mitigate short-term temperature spikes.

ΔT: For 1-hour and 24-hour averaging, respectively, Tables 8 and 9 show for each month the average annual number of times **ΔT** is expected to meet or exceed the indicated temperature change. In general, events causing a high **ΔT** occur in the months where cool water temperatures and periodic low flows curtail mixing of the SQN thermal plume. The current **ΔT** limits for 1-hour averaging are 5.0 C° in months November through March and 3.0 C° in months April through October. For November through March, both the 1-hour and 24-hour average **ΔT** never exceed the 5.0 C° limit. Hence, attention is needed only for the 3.0 C° limit for April through October. Plotted in Figure 5 are the results for $\mathbf{\Delta T} \geq 3.0$ C°. For months April through October it can be seen that the 1-hour average **ΔT** exceeds 3.0 C° in April, May, and October, whereas the 24-hour average **ΔT** exceeds 3.0 C° only in April. In the former case the total average annual number of $\mathbf{\Delta T} \geq 3.0$ C° events is 41 (i.e., 37 in April, 3 in May, and 1 in October), whereas in the latter it is 14. That is, under the current compliance limits, 24-hour averaging is expected to reduce the average annual number of times action is needed to mitigate excess **ΔT** from about 41 to 14. This reduction, 27 events per year, again represents the cases under the current method of 1-hour averaging that demands short-term cooling tower operation. Excessive **ΔT**'s also can be controlled by increasing the river flow. As discussed later, however, increasing the river flow is undesirable during reservoir filling in April and May (see Section 6.2.3).

6.1.3 Biological Aspects

The Quality Criteria for Water given by the EPA (1976) recommends conditions to protect fish growth, reproduction, and winter survival using the maximum weekly average temperature and conditions to prevent a potentially lethal environment using a short-term (daily) temperature maximum. Based on this, Wrenn et al. (1989) emphasized that the required minimum frequency of temperature measurement considered biologically significant is daily, and noted that the existing hourly interval is extremely conservative relative to protecting fish reproduction and winter survival.

In general, only at temperatures near the upper lethal limit for a particular species will a limited short-term exposure to a higher temperatures have adverse biological impacts. As summarized earlier, maximum water temperatures at SQN will occur in the period June through August (e.g., Figure 2). During these months, and assuming SQN operation with two units at full load, historical data indicates that the 1-hour $\mathbf{T_d}$ is not expected to exceed 32.0°C *at all*, and will exceed the current 30.5°C limit on the average only 38 times per year (Table 6). As emphasized in Figure 3, these events will occur as brief short-term spikes. Note that $\mathbf{T_d}$ includes **ΔT** (i.e., $\mathbf{T_d} = \mathbf{T_u} + \mathbf{\Delta T}$), and that during these same months **ΔT** is not expected to exceed 3.0 °C (Table 8). Exposure to these temperatures for such a few interspersed hours per year will not effect the growth or survival of the species considered in this study. Also recall that these temperatures

Table 8. Average Annual Number of Times **ΔT** is Greater Than or Equal to the Indicated Temperature Rise for **1-Hour Averaging**

Month	ΔT ≥1.0 C°	ΔT ≥2.0 C°	ΔT ≥3.0 C°	ΔT ≥4.0 C°	ΔT ≥5.0 C°
Jan	250	127	89	1	0
Feb	285	162	99	2	0
Mar	349	229	104	1	0
Apr	511	320	37	0	0
May	461	166	3	0	0
Jun	350	69	0	0	0
Jul	387	109	0	0	0
Aug	501	198	0	0	0
Sep	607	330	0	0	0
Oct	628	376	1	0	0
Nov	475	268	63	0	0
Dec	300	188	107	0	0
Total	5,104	2,542	503	4	0

Notes:
- Results based on SQN operation with two units at full load from 1976 to 1995.
- Current limit for 1-hour $\mathbf{T_d}$ is 5.0 C° Nov-Mar and 3.0 C° Apr-Oct (dark shading).

Table 9. Average Annual Number of Times **ΔT** is Greater Than or Equal to the Indicated Temperature Rise for **24-Hour Averaging**

Month	ΔT ≥1.0 C°	ΔT ≥2.0 C°	ΔT ≥3.0 C°	ΔT ≥4.0 C°	ΔT ≥5.0 C°
Jan	253	122	46	0	0
Feb	314	145	38	0	0
Mar	401	203	36	0	0
Apr	525	289	14	0	0
May	459	120	0	0	0
Jun	326	17	0	0	0
Jul	379	35	0	0	0
Aug	565	96	0	0	0
Sep	666	197	0	0	0
Oct	670	360	0	0	0
Nov	519	213	14	0	0
Dec	340	165	41	0	0
Total	5,417	1,962	189	0	0

Notes:
- Results based on SQN operation with two units at full load from 1976 to 1995.
- Proposed limit for 24-hour **ΔT** is 5.0 C° Nov-May and 3.0 C° Jun-Oct (dark shading).

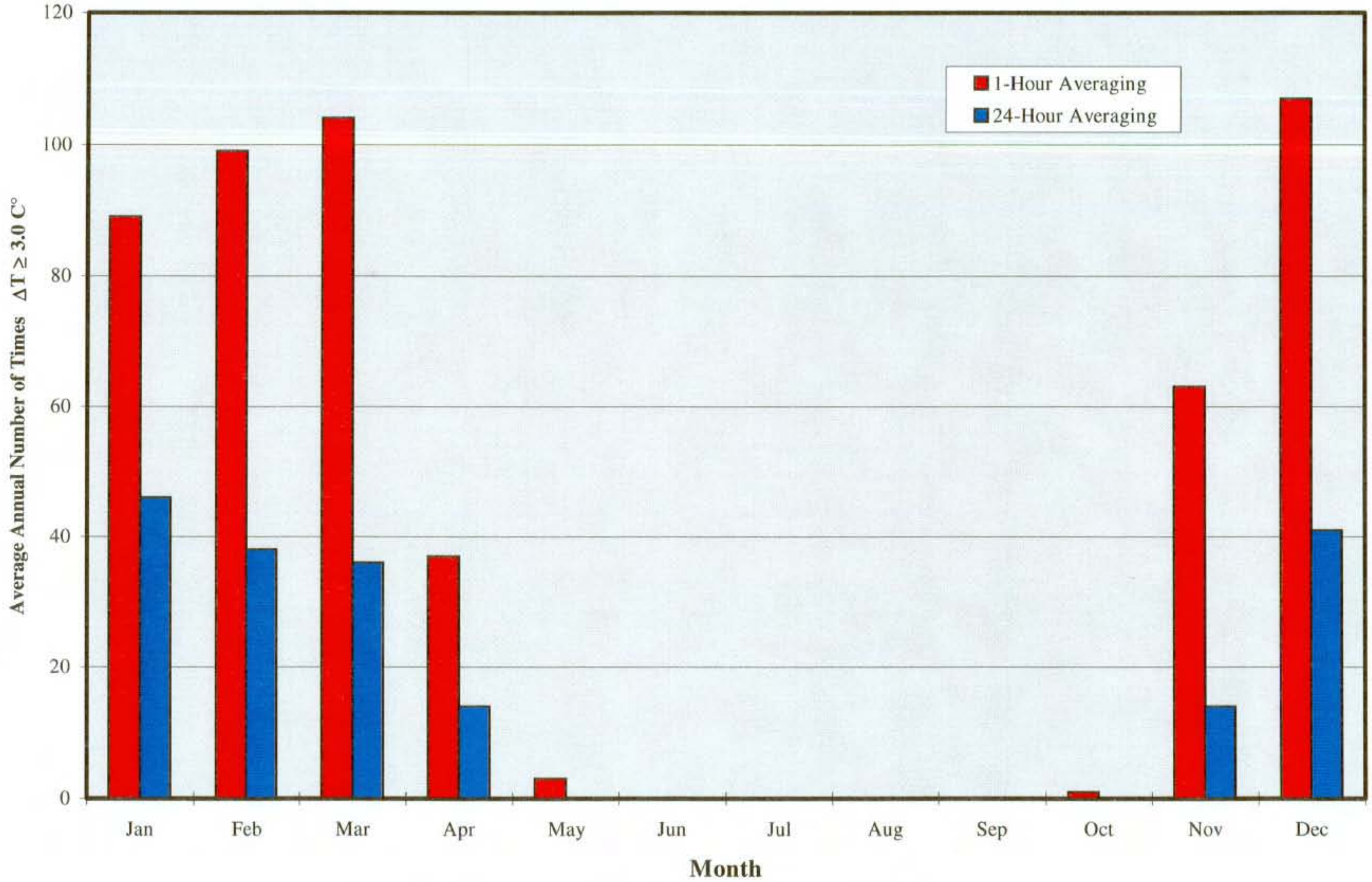

Figure 5. Average Annual Number of Times ΔT is Greater Than or Equal to 3.0 C°

occur in the surface layer of the reservoir (5-foot depth). Away from the mixing zone, the temperature of the bottom water in the main channel of the reservoir historically has always remained below 30.0°C.

Use of the current 1-hour averaging of water temperature to set power plant operational requirements suggests that short-term exposure to a $\Delta\mathbf{T}$ of 3.0 C° to 5.0 C° is detrimental to the maintenance of a balanced community of the important indigenous fish species. Tranquilli et al. (1981) found that movement of fish between heated and unheated areas had no effect on average growth in length or weight on Lake Sangchris, Illinois. Neill and Magnuson (1974) reported that yellow perch (*Perca flavescens*), a cool-water relative to sauger, make short-term feeding forays (2 to 3 hours) into water heated up to 3.0 C° above their upper lethal temperature. Except in extreme instances (e.g., rapid changes in water temperature greater than 10.0 C°), thermal impacts to resident fish species are minimized if timely relief from the condition is available.

Under the above conditions, the use of a running 24-hour average water temperature is considered responsive to thermal requirements of resident fish communities. When prolonged exposure (24 hours or more) to a $\Delta\mathbf{T}$ greater than or equal to the summertime limit of 3.0 C° or the wintertime limit of 5.0 C° occurs, operation of cooling towers, alteration of river flows, or curtailment of plant generation will still be required to mitigate excess water temperature. However, even though ambient temperatures leading to damaging values of $\mathbf{T_d}$ are not expected from a historical standpoint, this does not preclude such events from occurring in the future, especially with changes potentially resulting from TVA's Lake Improvement Plan. During months with high ambient water temperature, short-term $\Delta\mathbf{T}$ events yielding $\mathbf{T_d}$ values of 33.0 C° and higher can have significant negative growth and survival impacts for species sensitive to extreme temperatures (i.e., sauger and white crappie). Therefore, to protect these species, and despite the implications of the EPA Quality Criteria for Water, 1-hour $\mathbf{T_d}$ limits are still advocated to control extreme temperature events. The limits proposed herein are based on similar requirements used at TVA's Browns Ferry Nuclear Plant (TVA, 1983). The limits, introduced earlier, are:

- The 1-hour average $\mathbf{T_d}$ shall not exceed 33.9°C (93.0°F) without consent of the permitting authority.
- The 1-hour average $\mathbf{T_d}$ shall not exceed 32.0°C (89.6°F) more than 6 hours in a 24-hour period.

6.2 Increase Duration of Winter Temperature Rise Limit

For the river temperature rise from upstream to downstream of SQN, it is proposed herein to include the months April and May in the period of wintertime operation. With this change, the NPDES permit would specify that:

> $\Delta\mathbf{T} = |\mathbf{T_d} - \mathbf{T_u}|$ shall not exceed 5.0 C° (9.0 F°) for months November through May and 3.0 C° (5.4 F°) for months June through October.

As in the current permit, $\mathbf{T_u}$ would be determined at the 5-foot depth upstream of the plant and $\mathbf{T_d}$ would be determined at the 5-foot depth downstream of the plant. This change is sought in addition to the 24-hour averaging discussed earlier.

6.2.1 Operational Aspects

During the months of April and May, the hydrothermal condition of Chickamauga Reservoir is characterized by a water column with temperatures typically less than 20°C (68°F), and little or no stratification. As part of its goal to be environmentally responsible, and in accord with the Lake Improvement Plan, TVA currently curtails river flows during this period to aggressively fill the reservoirs. At low flows, however, dilution and mixing of the thermal plume from SQN is reduced. In combination with a cool, uniformly-mixed water column, this increases the plant $\mathbf{\Delta T}$. To maintain the 3.0 C° compliance limit, high river flow and/or extensive use of the cooling towers are required. In this manner, the demand for high flow is in direct conflict with the desire to fill the reservoirs.

From the standpoint of power supply, April and May also are periods of low demand for TVA hydro operations. As a result, it is desirable during this time to perform maintenance at the dams. However, tasks that require the hydroturbines to be shut down, such as work on trashracks, is difficult to perform because of the potential impact on the $\mathbf{\Delta T}$ limit at SQN. Altogether, therefore, increasing the duration of the wintertime $\mathbf{\Delta T}$ limit to include the months April and May will permit TVA to better fulfill the goals of the Lake Improvement Plan without excessively constraining operations at SQN and/or the neighboring hydropower facilities.

6.2.2 Hydrothermal Aspects

The effect of adding months April and May to the period of wintertime operation can be evaluated based on information previously given in Table 9. Assuming SQN operation with two units at full load, and 24-hour averaging, $\mathbf{\Delta T}$ is expected to exceed the current 3.0 C° an average of roughly 14 times per year (i.e., see April and May in Table 9). If the limit for $\mathbf{\Delta T}$ is changed for these months to the wintertime limit, 5.0 C°, the expected number of events drops to zero, giving TVA the flexibility needed to efficiently fill the reservoir system.

6.2.3 Biological Aspects

The inclusion of months April and May in the current $\mathbf{\Delta T}$ variance of 5.0 C° for November through March will be discussed on a species basis due to variations in the potential concerns.

Sauger--Sauger in Chickamauga Reservoir spawn during April nearly 40 river miles upstream of SQN. The potential for the requested variance to impact sauger spawning is limited to interruption of the normal migration of adults to the spawning area and mortality of larvae drifting past the plant after hatching. As for the impact on migration, studies by Schneider et al. (1977) at TVA's Bull Run Fossil Plant on the Clinch River found that the sauger spawning migration past the plant is not hindered by the thermal discharge. Neill and Magnuson (1974) found that yellow perch, a cool-water species closely related to sauger, avoided the area of a power plant outfall in the summer when water temperatures exceed 29°C. At SQN, however, the maximum 1-hour average water temperature in April and May is not expected to exceed 28.5°C (see Table 6). Moss et al. (1978) found that the thermal discharge from a steam plant on the Coosa River, Alabama, adjusted movement patterns for largemouth bass, flathead catfish, and channel catfish, but did not prevent movement of individuals past the plant. Their work, although, was again limited to summer observations. At SQN, Hevel and Hickman (1991) and Kay and Buchanan (1995) report no significant concentration of sauger in the vicinity of the diffusers during the fall/winter period when sauger migrate past the plant, indicating no alteration of the natural migration pattern. Perhaps above all else, an increase in the temperature rise in the vicinity of SQN during April and May will not change adult sauger spawning migration patterns since the fish will be either on the upstream spawning shoals or returning downstream after the spawn.

McCauley and Read (1973), McCauley and Huggins (1979), and Peterson (1993) found percid YOY are more tolerant of high temperature than adults. Assuming SQN operation of two units at full load, sauger larvae drifting past the SQN diffuser during April and May will be subjected to a maximum **ΔT** of 3.0 to 4.0 C° (i.e., based on the last 20 years of historical data and 1-hour averaging - see Table 8). The monthly mean ambient water temperature during this period ranges from 17.2°C to 22.5°C with a mean of about 19.7°C (see Figure 2). Koenst and Smith (1976) found sauger larvae acclimated to 19.9°C to have an upper incipient lethal temperature (temperature at which 50 percent mortality occurs) of 29.5°C, representing a **ΔT** of 9.6 C°. Hokanson (1977) determined that walleye, a close relative of sauger, acclimated to a temperature of 25.8°C, which in Chickamauga Reservoir is more likely to occur in June or July, had an upper incipient lethal temperature of 31.6°C, representing an instantaneous **ΔT** of 5.8 C°. These data suggest an increase in the allowable **ΔT** to 5.0 C° during April and May will not have an adverse impact on sauger larvae passing the SQN diffusers.

Crappie--The potential effects of the SQN heated discharge on crappie populations include the impact on reproductive success due to alteration in spawning times, thermally induced mortality of juvenile white crappie, and adverse impact on growth and incidence of disease of both juveniles and adults. Even downstream of the plant diffusers, the majority of crappie spawning occurs outside the main channel (i.e., the primary area of thermal impact) in overbank areas (Wrenn et al., 1989). For the Peach Bottom Atomic Power Station on Conowingo Pond, Mathur and McCreight (1980) found no evidence of early spawning of white crappie in the thermal plume compared to that in ambient areas. Kay and Buchanan (1995) found no attraction to the SQN discharge area or advancement of spawning time of either crappie species in Chickamauga Reservoir.

White crappie juveniles acclimated to a water temperature of 25.6°C (near the anticipated temperature at hatching) had an upper incipient lethal temperature of 32.8°C (Peterson et al., 1974; Eaton et al., 1995). This represents a **ΔT** of 7.2 C°, which is well above the 5.0 C° maximum proposed in this demonstration. Baker and Heidinger (1996) reported that black crappie juveniles acclimated to a water temperature of 24°C had an instantaneous upper lethal limit of from 31.5 to 35.1°C, depending on size. Therefore, no adverse impacts on survival would be anticipated for the small portion of the white or black crappie population in Chickamauga Reservoir that might cross the SQN diffuser area in a given year.

Barwick and Lorenzen (1984) found no measurable effect of elevated water temperature on growth of black crappie due to nuclear plant operation on the Keowee Reservoir in South Carolina. Gammon (1973) and Magnuson et al. (1990) report that maximum growth potential for white crappie occur from 27-28.5°C. Gruninger et al. (1977) found no differences in the incidence of parasitism between nine species of fish (including white crappie) from heated waters and fish of the same species taken outside the influence of thermal loading. As emphasized earlier, based on operation of SQN at full capacity, the water temperature downstream of the plant in April and May is not expected to exceed 28.5°C. Under these conditions, no reduction in growth or increase in disease of white crappie is anticipated due to SQN operation under the proposed **ΔT** variance.

Threadfin Shad--Lewis and Heidinger (1979) reported that threadfin shad were attracted to the heated effluent of a power plant during winter. A potential exists for the creation of a winter thermal refuge for threadfin shad in the vicinity of SQN diffusers during plant operational periods that could increase over-winter survival of adult threadfin shad. This artificial enhancement could provide a suitable number of spawners the following spring enhancing the potential for a large threadfin shad year class. However, if long non-operational periods occur during the winter at SQN, water temperatures would decline, potentially resulting in large mortality of attracted threadfin shad. It must be kept in mind that these fish would have died due to ambient conditions unless they were in the vicinity of a natural refuge such as a spring outlet. It is virtually impossible for a majority of the reservoir's population of threadfin shad to congregate near the diffusers and neglect all other natural refuges. A thermal gradient is necessary for fish to follow to the warmer area. This is not available for fish located above or several miles downstream of the plant, or in the major tributaries. Kay and Buchanan (1995) found no threadfin shad in the vicinity of the SQN diffusers using experimental gill nets during the November-March periods of 1993 through 1995, indicating no significant attraction to the diffuser area during winter months.

Peak threadfin shad spawning in the southeast has been observed at water temperatures between 22 and 27°C (Irwin and Bettoli, 1995). Based on historical data and assuming SQN operation at full capacity, only two **ΔT** events a year are expected to result in water temperatures downstream of the plant greater than 27°C in April and May (see Table 6). With this small frequency of occurrence, a rise in the allowable **ΔT** to 5.0 C° during these months will not adversely impact threadfin shad reproductive success.

Blue and Channel Catfish--In a supplemental creel census from April 1982 through June 1984, restricted to the general vicinity of the SQN diffusers, Wrenn et al. (1989) and Peck and Buchanan (1995) found blue and channel catfish to be the primary species caught by sport fishermen during summer and, to a lesser extent, winter. Between 1993-1995, Kay and Buchanan (1995) conducted a three day a week creel survey in the SQN diffuser area from November through March, and found blue catfish (46 individuals) made up 69 percent of the fishermen catch and channel catfish (14 individuals) 21 percent. A total of 51 percent of the anglers interviewed were fishing for catfish.

Blue catfish were the most numerous species captured in gill nets (42 percent of the total catch) during the same time frame (Kay and Buchanan, 1995). However, numbers were highest in nets set one-half mile upstream of the diffuser area. Channel catfish made up only 6 percent of the overall catch. Hevel and Hickman (1992) and Dycus (1995) reported similar gill net catch rates of blue catfish from areas throughout Chickamauga Reservoir. Even though blue catfish appear to be numerous in the area, and to be a primary target of fishermen, the number harvested is insignificant considering the overall reservoir population. No evidence of commercial fishing in the diffuser area has been observed. A change in the allowable **ΔT** from 3.0 C° to 5.0 C° at SQN during April and May is not expected to further increase concentrations of blue or channel catfish in the vicinity of the SQN diffusers. As a result, no significant changes in fishermen use or fish harvest in the area are expected. The new thermal criteria for **ΔT**, subsequently, will have no adverse impacts for blue and channel catfish populations in Chickamauga Reservoir.

6.3 Increase Limit for Rate of Temperature Change

It is proposed herein to increase the limit for the rate of change of river temperature downstream of the plant, $\mathbf{dT_d/dt}$, from 2.0 C°/hour (3.6 F°/hour) to 5.0 C°/hour (9.0 F°/hour). Under this revision, the computation of $\mathbf{dT_d/dt}$ would be performed using 1-hour averaging as in the present NPDES permit requirements (i.e., average the current value of $\mathbf{dT_d/dt}$ with the previous four readings). This change is sought in addition to 24-hour averaging and increased duration of winter temperature rise limit discussed earlier.

6.3.1 Operational Aspects

Events for the rate of temperature change can be caused by unsteady operation of SQN and/or unsteady operation of Chickamauga Reservoir. Since SQN generation normally is steady, almost all observed $\mathbf{dT_d/dt}$ events are caused by the latter (i.e., in conjunction with the heat discharged by SQN). Typical conditions creating these events can be described using the data shown in Figure 6. Unsteady flows are initiated at Watts Bar and Chickamauga Dams. The hydroturbines at these sites are routinely shut down during periods of low power demand, reducing the flow at SQN (Plot A). Under these conditions, the heated discharge from the plant collects in a thermal "pancake" in the mixing zone, increasing the downstream temperature $\mathbf{T_d}$ (Plot B) and causing a positive $\mathbf{dT_d/dt}$ event (Plot C). When peaking operations resume at Watts Bar and Chickamauga Dams, flow in the river quickly accelerates and flushes the SQN thermal "pancake" downstream, promptly decreasing $\mathbf{T_d}$ and causing a negative $\mathbf{dT_d/dt}$ event (Plot C).

The only occasions where SQN contributes significantly to a $\mathbf{dT_d/dt}$ event, with either steady or unsteady river flows, is during plant startup or shutdown. By comparison, however, the magnitude of $\mathbf{dT_d/dt}$ caused by plant startup and plant shutdown is small compared to that by reservoir operations. So small, in fact, that it is almost impossible to reach the current limit for the rate of temperature change. During SQN startup, ascension of plant generation, and the subsequent discharge of heat to the river, are carried out gradually, typically over a period of at least one day (e.g., compared to flow changes of 40,000 cfs that occur within a few hours - see Figure 6). In an emergency situation SQN plant shutdown can be rapid; however, any sudden changes in flow and/or water temperature from the plant are attenuated by the 32-acre diffuser pond at the plant outlet, which has a retention time of at least six hours (see Appendix A, Figure 1).

Another factor in seeking a change in the limit for $\mathbf{dT_d/dt}$ is related to the variance obtained in the original 316(a) demonstration of 1989. When the NPDES limit for **ΔT** was increased from 2.0 C° to 5.0 C° for months November through March, greater wintertime flexibility was obtained for operating SQN and Chickamauga Reservoir. This presumably was to eliminate the need for cold weather operation of the SQN cooling towers. Such operation causes extensive ice damage in the tower fill, costing millions of dollars to repair. In general, however, the rate of river temperature change $\mathbf{dT_d/dt}$ is naturally connected to **ΔT**. For unsteady conditions, a higher **ΔT** will be accompanied by a higher $\mathbf{dT_d/dt}$. When the NPDES limit for **ΔT**

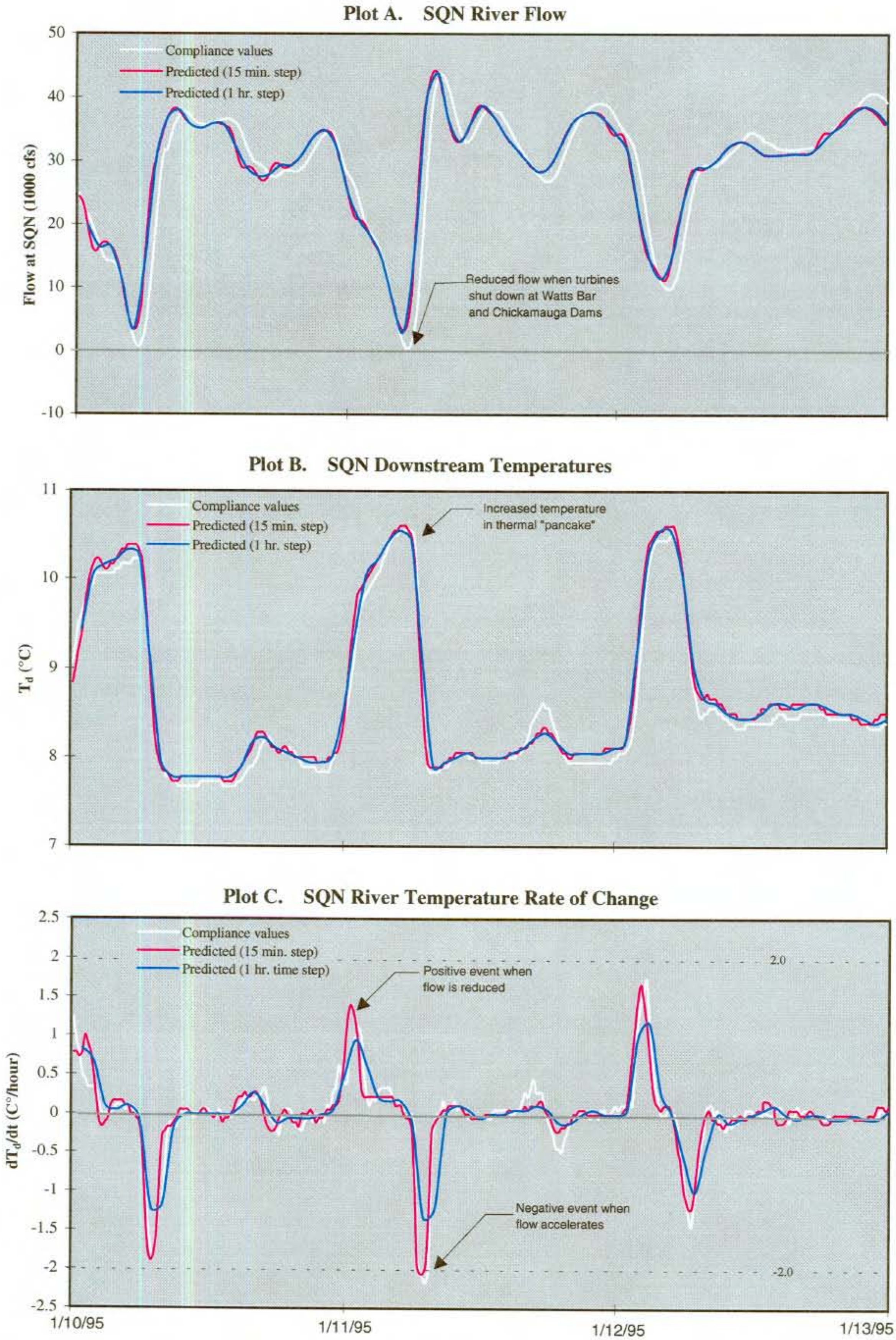

Figure 6. Typical Conditions Creating $\mathbf{dT_d/dt}$ Events at SQN, January 10-12, 1995

was increased from 2.0 C° to 5.0 C°, no corresponding change was made in the limit for $\mathbf{dT_d/dt}$. Subsequently, it has been discovered that the higher wintertime limit $\mathbf{\Delta T}$ = 5.0 C° cannot be fully utilized without exceeding the current limit $\mathbf{dT_d/dt}$ = 2.0 C°/hour. When water temperatures are cool, maintenance of $\mathbf{dT_d/dt}$ below 2.0 C°/hour requires near-steady flow in the river, which destroys TVA's ability to perform peaking operations at both the Watts Bar and Chickamauga Dams. In March and April it also can adversely impact filling operations under the LIP. Cooling tower operation at SQN can be used to keep $\mathbf{dT_d/dt}$ below the 2.0 C°/hour limit; however, as before, extensive ice damage will be incurred during wintertime operation.

Yet another issue is the method of analysis for $\mathbf{dT_d/dt}$ used in the 316(a) demonstration by Wrenn et al. (1989). In the original work, the interpretation of results for $\mathbf{dT_d/dt}$ was performed with a time step incompatible with the frequency of data collection. Specifically, $\mathbf{dT_d/dt}$ was examined with a 1-hour time step whereas the data for $\mathbf{T_d}$ are collected at a 15-minute time step. The effect of this oversight was to reduce the expected magnitude of $\mathbf{dT_d/dt}$. As such, the current problem with the existing $\mathbf{dT_d/dt}$ limit was not detected in the original demonstration. The effect of time step in the $\mathbf{dT_d/dt}$ computation is shown in Figure 6, Plot C. As shown, the magnitude of the peak compliance values of $\mathbf{dT_d/dt}$ are underpredicted by computations with a 1-hour time step, whereas computations with a 15-minute time step provide good agreement with the actual peak $\mathbf{dT_d/dt}$ compliance values.

As a final comment, it is emphasized that other states in the Tennessee River watershed do not carry $\mathbf{dT_d/dt}$ limits for industrial water supply (see TVA, 1973).

6.3.2 Hydrothermal Aspects

In general, the impact of a rate of temperature change event travels down the reservoir simultaneously with waves generated by a sudden acceleration or deceleration of the river flow. In this travel, the magnitude of $\mathbf{dT_d/dt}$ is attenuated by mechanisms that spread and dissipate the heat from the thermal discharge, both in the reservoir and to the atmosphere.

To determine the region of impact for the rate of temperature change, numerical simulations were performed using a one-dimensional, hydrothermal model for Chickamauga Reservoir. The model was calibrated using data from field measurements of a $\mathbf{dT_d/dt}$ event in March 1995. After calibration, simulations were performed using the meteorology and river flow for the event producing one of the largest historically observed occurrences of $\mathbf{dT_d/dt}$. As before, SQN operation was assumed to include two units at full load. Results for this "worst case" scenario are shown in Figure 7, which gives a plot of the computed peak $\mathbf{dT_d/dt}$ as a function of river mile. Based on the current limit of 2.0 C°/hour, the model indicates that the river region affected by $\mathbf{dT_d/dt}$ includes a reach extending downstream a distance of about 5.5 miles from the plant diffusers. This volume is considered conservative (i.e., larger than actual) in that the one-dimensional model does not fully include all the mechanisms that spread and dissipate heat from the thermal discharge. It also is emphasized that results from the one-dimensional model apply only to the main channel of the reservoir. Natural attenuation of flow in the overbank and embayment regions will substantially reduce the propagation of $\mathbf{dT_d/dt}$ waves in these areas.

The expected frequency of $\mathbf{dT_d/dt}$ events again can be evaluated using the numerical model for diffuser-induced mixing previously mentioned. Based on historical river flows and temperatures from 1976-1995, and SQN operation of two units at full load, Table 10 gives for each month the average annual number of times $\mathbf{dT_d/dt}$ is expected to meet or exceed the indicated rate of river temperature change. Figure 8 shows the events in categories $\mathbf{dT_d/dt} \geq 2.0$

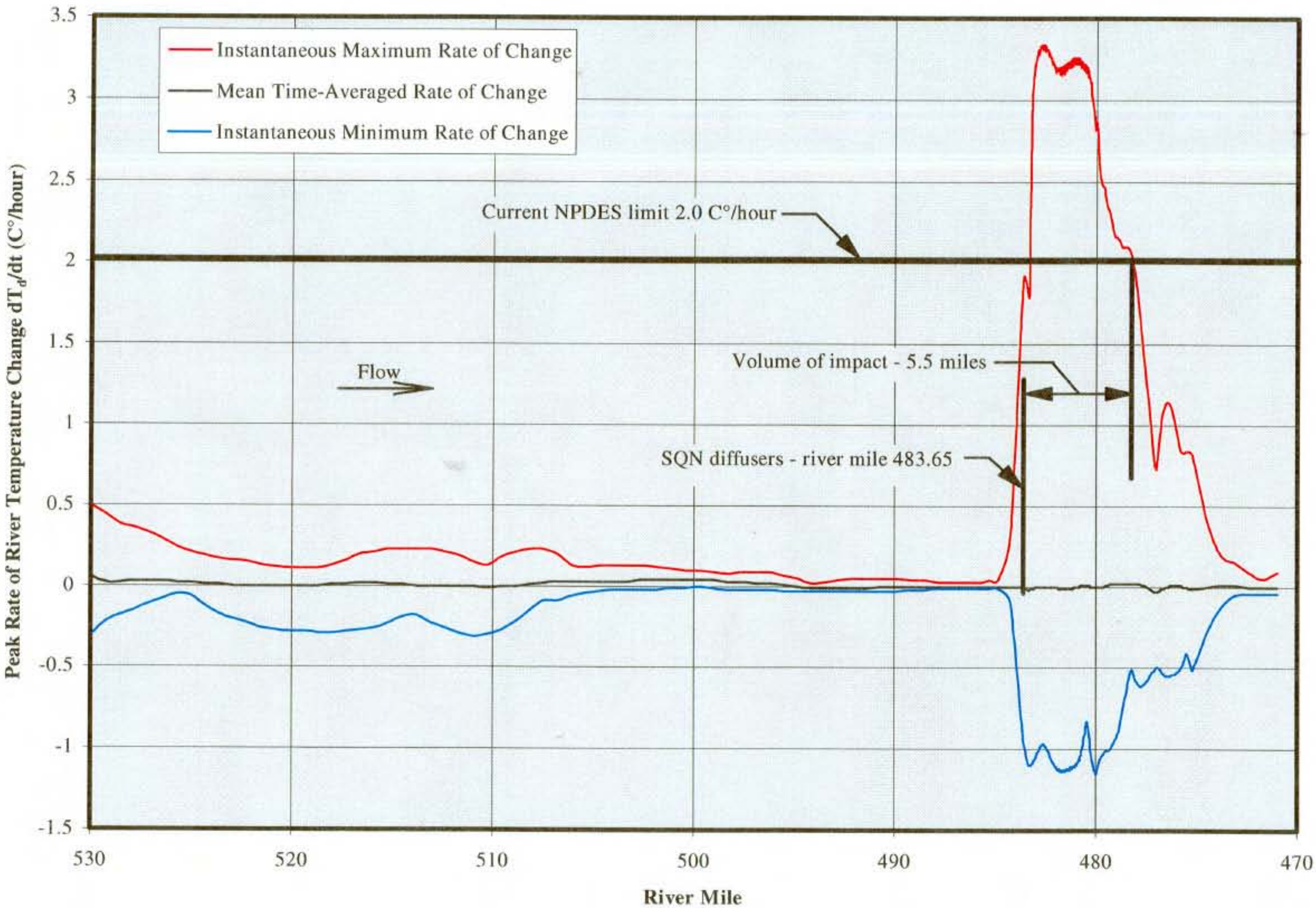

Figure 7. Region of Impact for Extreme $\mathbf{dT_d/dt}$ Events

Table 10. Average Annual Number of Times **dT_d/dt** is Greater Than or Equal to the Indicated Rate of Change for **1-Hour Averaging**

Month	$dT_d/dt \geq 2.0$ C°/hr	$dT_d/dt \geq 2.2$ C°/hr	$dT_d/dt \geq 2.4$ C°/hr	$dT_d/dt \geq 2.6$ C°/hr	$dT_d/dt \geq 2.8$ C°/hr	$dT_d/dt \geq 3.0$ C°/hr	$dT_d/dt \geq 3.2$ C°/hr	$dT_d/dt \geq 3.4$ C°/hr	$dT_d/dt \geq 3.6$ C°/hr	$dT_d/dt \geq 3.8$ C°/hr
Jan	7	3	2	2	1	1	1	1	1	0
Feb	8	4	4	3	3	2	1	1	1	0
Mar	4	2	2	1	1	1	0	0	0	0
Apr	1	1	1	0	0	0	0	0	0	0
May	1	1	1	0	0	0	0	0	0	0
Jun	2	1	1	1	1	0	0	0	0	0
Jul	1	1	1	1	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0
Oct	1	1	1	1	0	0	0	0	0	0
Nov	3	2	1	1	0	0	0	0	0	0
Dec	4	2	1	1	1	1	1	0	0	0
Total	32	18	15	11	7	5	3	2	2	0

Notes: • Results based on SQN operation with two units at full load from 1976 to 1995.

• Current limit for 1-hour **dT_d/dt** is 2.0 C°/hour (dark shading).

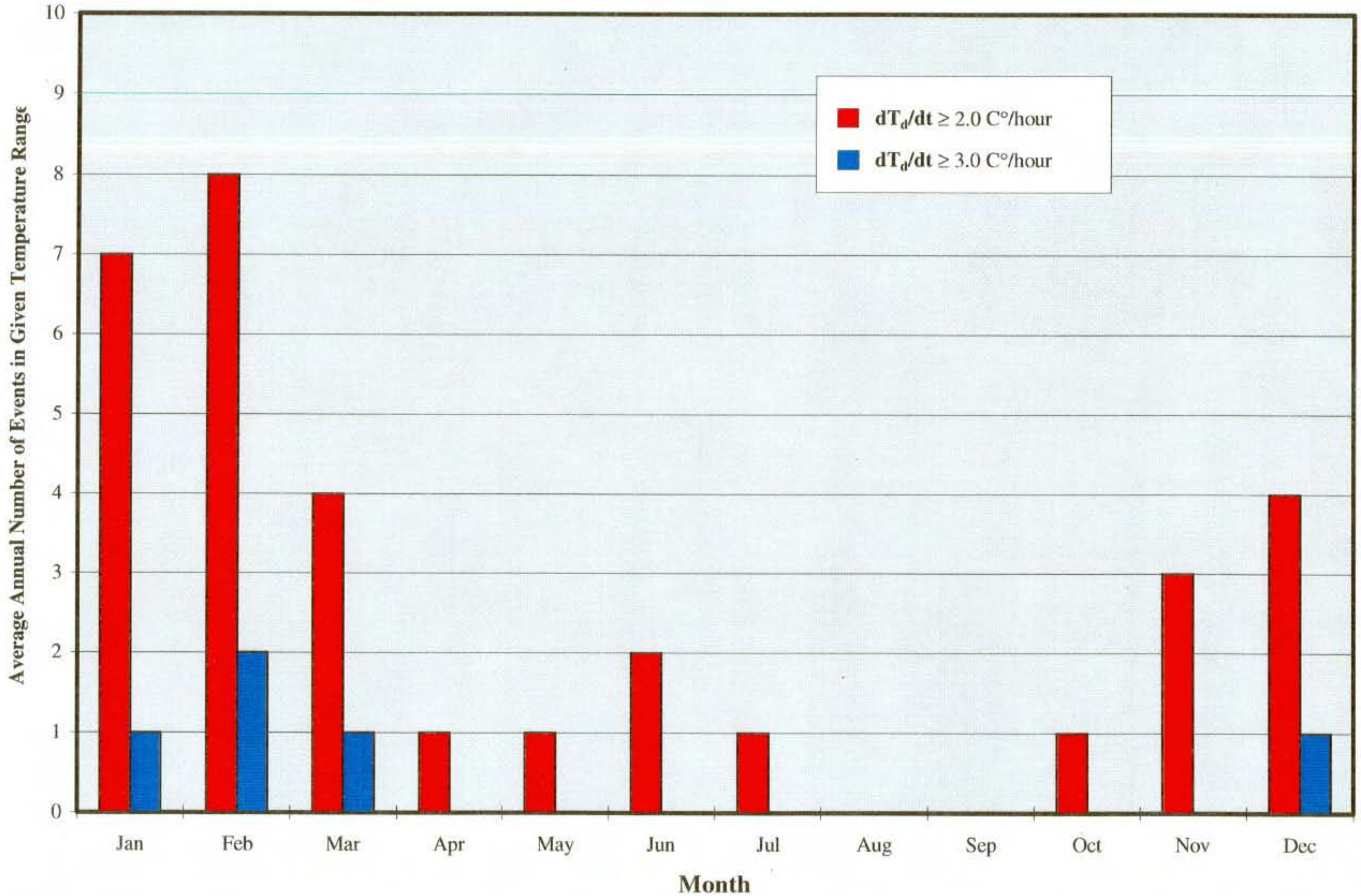

Figure 8. Average Annual Number of Times $\mathbf{dT_d/dt}$ is Greater Than or Equal to the Indicated Rate of Change for **1-Hour Averaging**

and $\mathbf{dT_d/dt} \geq 3.0$ C°/hour. For the current limit, 2.0 C°/hour, events occur in all months but August and September. In general, the number of occurrences is larger in the cool months of November through March. In part, this is due to the same reasons given for observed higher values of $\mathbf{\Delta T}$ (i.e., inhibited mixing by cold water and low flows - see Section 6.1.2). Since the simulations were performed with steady generation at SQN, the $\mathbf{dT_d/dt}$ events shown in Table 10 and Figure 8 are nearly all caused by unsteady river flow initiated by peaking operations at the upstream and downstream dams. For the entire year, the average annual number of times $\mathbf{dT_d/dt}$ is expected to meet or exceed the current 2.0 C°/hour limit is 32 (Table 10). The maximum observed occurrence of $\mathbf{dT_d/dt}$ is 3.6 C°/hour. Hence, by increasing the limit to 5.0 C°/hour, which yet provides protection for the aquatic habitat (e.g., biological aspects given below), the average annual number of times special operations is needed to control $\mathbf{dT_d/dt}$ is expected to drop to zero. This gives TVA the flexibility needed to perform peaking operations, fill the reservoir system, and eliminate potential ice damage in the SQN cooling towers.

6.3.3 Biological Aspects

Under most ambient water temperatures, all species considered herein as indicators can survive instantaneous water temperature changes of from 5-10 C° with no adverse effects (Koenst and Smith, 1976; Peterson et al., 1974; and Eaton et al., 1995). Therefore, it would be apparent that a $\mathbf{dT_d/dt}$ limit of 5.0 C°/hour is sufficient to prevent adverse impact to important resident indigenous species. However, as ambient or acclimation temperatures approach the upper lethal limit for a particular species, a rapid rate of change can, in effect, lower the upper lethal limit below that attainable with a more gradual temperature increase (Hokanson and Koenst, 1986; Peterson, 1993). Over the 20-year period of record, June and July are the only months where the 1-hour average ambient water temperature is expected to exceed 25°C and contain $\mathbf{dT_d/dt}$ events above the current 2.0 C°/hour limit (3 events total per year - see again Table 10). Optimum growth of even cool-water species such as sauger can be maintained at sustained water temperatures of 22 to 25°C (Koenst and Smith, 1976; EPA, 1976). In no case did the 1-hour average maximum ambient water temperature exceed 30°C, near the upper lethal water temperature for sauger (Koenst and Smith, 1976; Eaton et al., 1995). Due to avoidance of the diffuser area by cool-water species as upper lethal temperatures are approached in summer (Neill and Magnuson, 1974), it is not anticipated that the requested increase in allowable rate of temperature change to 5.0 C°/hour will adversely influence individual or population viability or growth.

7.0 SEQUOYAH NUCLEAR PLANT BIOCIDE TREATMENT

Cooling towers are used for cooling of the condenser cooling water (CCW) at Sequoyah. Biocide presently is not added to the CCW. Any future treatment of CCW with biocide would be for the protection of piping inside the plant. No biocide is added for protection of the cooling towers. Therefore, changes to the thermal criteria as proposed herein will have no impact on the use of biocide at SQN.

8.0 THERMAL LIMIT VERIFICATION TECHNIQUES

8.1 Hydrothermal Aspects

The present method of thermal limit verification is described in the 316(a) demonstration of 1989 (Appendix A). Briefly, the compliance values for $\mathbf{T_d}$, $\mathbf{\Delta T}$, and $\mathbf{dT_d/dt}$ are determined based on a combination of measurement and numerical modeling techniques. The measurements and calculations are performed every 15 minutes to generate real-time values for $\mathbf{T_d}$, $\mathbf{\Delta T}$, and $\mathbf{dT_d/dt}$. These are then combined with previous 15-minute values to generate hourly averages as specified in the NPDES permit. If the alternate criteria proposed herein are approved, the present method of thermal limit verification will be updated to compute the required 24-hour averages and monitor the new temperature limits. A detailed summary of these modifications is given in Table 11. It should be emphasized that for these alternate criteria, the location, number, and frequency of temperature and flow measurements remain unchanged.

TVA currently provides verification of the behavior of the SQN thermal plume by a program given by Ostrowski and Shiao (1987). The program defines field surveys that are to be performed for different meteorological and hydrological conditions throughout the year. This verification will continue under the alternate thermal criteria proposed herein.

8.2 Biological Aspects

Monitoring of major changes in fish populations in Chickamauga Reservoir currently is provided by TVA's Clean Water Initiative (CWI). This program includes general sampling of fish and benthic invertebrate communities every-other-year and contains sampling stations both upstream and downstream of SQN. If significant, any biological impacts of the alternate thermal limit criteria proposed herein should be discernible by CWI evaluations.

9.0 ECONOMIC EVALUATION OF ALTERNATIVE THERMAL LIMITS

The procedures currently used by TVA to maintain compliance with the present SQN thermal limits can each be assigned an operational cost. To run the cooling towers, costs are incurred for energy to use the lift pumps and other support equipment, as well as for labor to startup, shutdown, and maintain tower machinery. Energy used in tower operation must be replaced by using the next higher cost resources available, usually the less efficient coal-fired plants, and on occasion, high-cost gas or oil-fired combustion turbines, or off-system purchases. If the cooling towers are required in the winter, costs also may be incurred to repair damage caused by ice. If thermal compliance requires altering the river flow, costs will be incurred in shifting hydro generation at the dams from peak to offpeak, and at times, replacing power system capacity. Maintaining thermal limits by reducing SQN generation will incur replacement costs for power system energy. In this process, other costs are incurred in performing extra work associated with ramping load at the nuclear plant.

Table 11. Summary of Current Proposed Alternate Thermal Limit Criteria for SQN

Current Thermal Criteria		Proposed Alternate Thermal Criteria
Maximum River Temperature Downstream of Plant T_d		
• Compute T_u and T_d by averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging).	→	• Compute T_u and T_d by two methods: (1) averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging), and (2) averaging the current 15-minute value with the previous ninety-six 15-minute values (24-hour averaging).
• The 1-hour average T_d shall not exceed 30.5°C (86.9°F). • If the 1-hour average T_u approaches or exceeds 30.5°C (86.9°F) and the cooling towers are in operation with the plant in helper mode (3 lift pumps and one cooling tower per operating unit), the 1-hour average T_d can be higher, but shall not exceed 33.9°C (93.0°F) without consent of the permitting authority.	→	• The 1-hour average T_d shall not exceed 33.9°C (93.0°F) without consent of the permitting authority. • The 1-hour average T_d shall not exceed 32.0°C (89.6°F) more than 6 hours in a 24-hour period. • The 24-hour average T_d shall not exceed 30.5°C (86.9°F). • If the 24-hour average T_u approaches or exceeds 30.5°C (86.9°F) and the cooling towers are in operation with the plant in helper mode (3 lift pumps and one cooling tower per operating unit), the 24-hour average T_d can be higher, but shall not exceed 32.0°C (89.6°F).
Maximum Rise in River Temperature from Upstream to Downstream of Plant ΔT		
• Compute ΔT by averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging).	→	• Compute ΔT by averaging the current 15-minute value with the previous ninety-six 15-minute values (24-hour averaging).
• The 1-hour average ΔT shall not exceed: 5.0 C° (9.0 F°) for November through March. 3.0 C° (5.4 F°) for April through October.	→	• The 24-hour average ΔT shall not exceed: 5.0 C° (9.0 F°) for November through May. 3.0 C° (5.4 F°) for June through October.
Maximum Rate of Change of River Temperature Downstream of Plant dT_d/dt		
• Compute dT_d/dt by averaging the current 15-minute value with the previous four 15-minute values (1-hour averaging).	→	• No change in computation of dT_d/dt.
• The 1-hour average dT_d/dt, shall not exceed 2.0 C°/hour (3.6 F°/hour).	→	• The 1-hour average dT_d/dt, shall not exceed 5.0 C°/hour (9.0 F°/hour).

The following evaluations include estimates of the average annual costs associated with changing the thermal limits as proposed in this demonstration. The costs are based on simulations of SQN and Chickamauga Reservoir using the same historical data as that used in the hydrothermal aspects presented earlier (e.g., see Section 6.1.2). These estimates include only the types of costs mentioned above. In cases involving altering the river flow, however, it is emphasized that other "social" costs may be incurred. For example, if requirements for SQN thermal compliance prevent filling and maintenance of reservoir levels as given in the TVA Lake Improvement Plan, income generated by recreational industries will suffer (e.g., fishing and boating). Since no reliable data are yet available for these industries, such costs are not included in this economic evaluation.

9.1 24-Hour Averaging

Twenty-four-hour averaging is proposed to monitor, in part, $\mathbf{T_d}$ and $\mathbf{\Delta T}$. As such, costs have been examined for each of these compliance parameters.

Operational Strategy to Control Violations - $\mathbf{T_d}$--Based on historical data, water temperatures reaching the limit for $\mathbf{T_d}$ are expected to occur only in the summer (e.g., June through August - see Tables 6 and 7). In these cases, the hydrothermal structure of Chickamauga Reservoir typically creates a situation where $\mathbf{T_d}$ cannot be attenuated by adjusting flow in the river. Under these conditions the operational sequence to prevent a $\mathbf{T_d}$ violation would be to first use the cooling towers, and if needed, then reduce SQN generation.

Cost - $\mathbf{T_d}$--With the above strategy, Table 12 gives the estimated average annual cost of maintaining compliance for $\mathbf{T_d}$. As shown, the only cost incurred is that due to cooling tower operation, no reductions in SQN generation are expected. Overall, the average cost of 1-hour vs. 24-hour averaging to control $\mathbf{T_d}$ is about $34,000/year for tower usage.

Table 12. Average Annual Cost of Maintaining Compliance for $\mathbf{T_d}$ (1996 Dollars)

Averaging Period	Alter Hydro Operations to Spread River Flow	SQN Cooling Tower Operation	SQN Load Reductions
1-hour	NA	$60,000	$0
24-hour	NA	$26,000	$0
1 vs. 24-hour	NA	$34,000	$0

NA - Spreading river flows not applicable for maintaining $\mathbf{T_d}$ compliance.

Operational Strategy to Control Violations - $\mathbf{\Delta T}$--Based on historical data, water temperatures reaching the current limits for $\mathbf{\Delta T}$ are expected to occur only in April, May and October (e.g., see Tables 8 and 9). For the purpose of estimating the cost, the operational strategy to control $\mathbf{\Delta T}$ violations is assumed to include the following steps:

1. To reduce periods of low flow/high $\mathbf{\Delta T}$, alter hydro operations at Watts Bar and Chickamauga Dams by curtailing peaking operations and spreading the discharge uniformly throughout the day.

2. If $\mathbf{\Delta T}$ is still is too high, use SQN cooling towers throughout the day.

3. If $\mathbf{\Delta T}$ is still is too high, use SQN load reductions to meet the limit.

Cost - $\mathbf{\Delta T}$--With the above strategy, Table 13 gives the estimated average annual cost of maintaining compliance for $\mathbf{\Delta T}$. As shown, costs are incurred only for hydro operations and cooling tower usage, no reductions in SQN generation are expected. Overall, the average cost of 1-hour vs. 24-hour averaging to control $\mathbf{\Delta T}$ is about $9,000/year for hydro operations and $26,000/year for tower usage.

Table 13. Average Annual Cost of Maintaining Compliance for ΔT (1996 Dollars)

Averaging Period	Alter Hydro Operations to Spread River Flow	SQN Cooling Tower Operation	SQN Load Reductions
1-hour	$10,000	$37,000	$0
24-hour	$1,000	$11,000	$0
1- vs. 24-hour	$9,000	$26,000	$0

Cost - T_d & ΔT--Combining efforts to control both T_d and ΔT, the average cost of 1-hour vs. 24-hour averaging is about $9,000/year for hydro operations and $60,000/year for tower usage, or $69,000/year total for all operational conditions.

9.2 Increase Duration of Winter Temperature Rise Limit

Operational Strategy to Control Violations - The assumed operational strategy to control ΔT violations is the same as that given above.

Cost - To increase the duration of the winter temperature rise limit, the maximum ΔT for April and May would be changed from 3.0 C° to 5.0 C°, as currently exists for months November through March. Based on historical data, the average annual number of times ΔT would be expected to exceed the new limit in these months is zero (e.g., see Table 8). Hence, the cost for maintaining compliance with the current ΔT limit in April and May is essentially the same as that shown in Table 13 for 1-hour averaging (i.e., neglecting the one event per year expected in October - again see Table 8). Overall, therefore, the average cost of meeting the existing 3.0 C° limit for April and May is about $47,000/year total for hydro operations and SQN cooling tower usage.

9.3 Increase Limit for Rate of Temperature Change

Operational Strategy to Control Violations - Extreme events for dT_d/dt are caused primarily by unsteady flows with cold ambient water temperatures. Under these conditions, the operational strategy to control dT_d/dt is assumed to include the following steps:

1. To limit unsteady flows, alter hydro operations at Watts Bar and Chickamauga Dams by ramping the discharge no more than one generating unit per hour.
2. If water temperatures are too cold and natural conditions will not allow steady flow to be maintained by hydro operations (e.g., a large storm event or low river flow with water temperature below about 4°C/39°F), use SQN cooling towers throughout the day.
3. If dT_d/dt is still too high, use SQN load reductions to meet the limit.

Cost - As proposed in this demonstration, the limit for dT_d/dt would be increased from 2.0 C°/hour to 5.0 C°/hour. With this new limit, the average annual number of dT_d/dt events needing control would drop from about 32 to zero (e.g., see Table 10). Events for $\mathbf{dT_d/dt}$ usually occur in pairs, such as when river flows are accelerated and decelerated via a normal cycle of daily releases at Watts Bar and Chickamauga Dams. Hence, the cost of the current $\mathbf{dT_d/dt}$ limit is equivalent to altering hydro operations for about 16 days per year, primarily in months November through March. The estimated average cost for this action is about $12,000/year.

Simulations using historical data indicate that $\mathbf{dT_d/dt}$ events requiring the use of cooling towers are not likely to occur. Such events require the simultaneous occurrence of two hydrothermal characteristics—natural, unsteady river flow and a water temperature below about 4°C (39°F). Although they have never been observed together, these characteristics have been observed individually. As such, $\mathbf{dT_d/dt}$ events that require cooling towers must be considered as a possible operational scenario. Since cold water is a factor, such events would probably take place during periods with freezing air temperatures. To prepare for these events, the economic evaluation given in the SQN 316(a) demonstration by Wrenn et al., 1989, states "$16-20 million would be needed to modify the cooling towers to increase their resistance to ice damage; or yearly repair of ice damage would be needed which, based on experience with previous events, would cost $0.5-1.5 million" (1989 dollars).

9.4 Total Operational Cost

Summarizing the above evaluations, the operational cost of the current thermal limit criteria compared to all changes proposed herein is given in Table 14. As shown, the total estimated cost is about $93,000/year.

Table 14. Summary of Average Annual Cost for Current SQN Thermal Limit Criteria

Temperature Parameter	Cost To Meet Current Thermal Criteria	Cost To Meet Proposed Alternate Thermal Criteria	Cost of Current vs. Proposed Alternate Thermal Criteria
$\mathbf{T_d}$	$60,000	$26,000	$34,000
$\mathbf{\Delta T}$	$47,000	$0	$47,000
$\mathbf{dT_d/dt}$	$12,000	$0	$12,000
Totals	$119,000	$26,000	$93,000

Notes: 1. Current thermal criteria includes:
- 1-hour averaging.
- Max $\mathbf{\Delta T}$ = 3.0 C° in April and May.
- Max $\mathbf{dT_d/dt}$ = 2.0 C°/hr.

2. Proposed alternate thermal criteria includes:
- 24-hour averaging.
- Max $\mathbf{\Delta T}$ = 5.0 C° in April and May.
- Max $\mathbf{dT_d/dt}$ = 5.0 C°/hr.

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APPENDICES

APPENDIX A

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TENNESSEE VALLEY AUTHORITY

Resource Development

Nuclear Power

A PREDICTIVE SECTION 316(a) DEMONSTRATION FOR AN ALTERNATIVE WINTER THERMAL DISCHARGE LIMIT FOR SEQUOYAH NUCLEAR PLANT, CHICKAMAUGA RESERVOIR, TENNESSEE

TVA/WR/AB--89/11

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EXECUTIVE SUMMARY

Section 316(a) of the Federal Water Pollution Control Act Amendments of 1972 provides for alternative point source thermal limits. The owner of a point source must demonstrate that the effluent limits intended for control of a thermal discharge are more stringent than necessary to assure protection and propagation of a balanced, indigenous population of fish and wildlife. If the appropriate regulatory agency agrees with the demonstration, alternate limits that will assure protection of such populations may be granted.

The present thermal limits for the discharge of cooling water from the Tennessee Valley Authority (TVA) Sequoyah Nuclear Plant (SQN) into Chickamauga Reservoir include a maximum temperature rise of 3 C° (5.4 F°), applicable throughout the year. Occasionally, from November through March, the weather becomes sufficiently cold that the only feasible way to meet this limit (short of derating the plant) is to operate the cooling towers. Operation of the cooling towers under these extreme cold weather conditions can cause severe ice damage to the internal structure of the towers that must be repaired each spring to meet potential requirements for summer operation.

The purpose of this document is to demonstrate to the state of Tennessee that the existing temperature rise limit is more stringent than necessary to protect the balanced, indigenous population of fish and wildlife in Chickamauga Reservoir; and that an alternate rise limit of 5 C° (9 F°), applicable only from November through March, will provide the required protection.

The present thermal standards for Tennessee were imposed by the Environmental Protection Agency (EPA) at a time when the environmental effects of thermal discharges had not been fully studied and were not well known. As a result, the thermal criteria reflect conservative safety factors that subsequent research has often shown overcompensated for that lack of background data. The success of the 316(a) demonstration for alternative thermal criteria at Browns Ferry Nuclear

Plant, which relied heavily on recent research, demonstrates the EPA thermal criteria initially imposed can be adjusted based on our current understanding of thermal effects.

According to EPA, protection of balanced communities of aquatic organisms is best accomplished by protecting the most temperature-sensitive fish species judged important, desirable, or both. The thermal rise criterion is included in the standards to protect the reproduction and winter survival of these important temperature-sensitive species. Tennessee has identified sauger, threadfin shad, and white crappie as representative important species in Chickamauga Reservoir. Therefore, reproduction and winter survival were evaluated for these species in the demonstration. Tennessee has further identified other concerns relating to concentrations of fish in a heated discharge: impingement, fishing pressure and predation, disease, and sampling methods. Therefore, these concerns were also evaluated.

A general concern in setting thermal rise criterion for winter survival is potential cold shock. Nuclear plant shutdown results in a relatively slow decrease in discharge temperature. Fish mortality resulting from cold shock has never been reported following shutdown of any TVA power plant, nuclear or otherwise. Where such fish kills have occurred at non-TVA facilities, the temperature decline was three to four times greater than the 5 C° (9 F°) temperature rise being considered in this demonstration.

TVA's monitoring during operation of SQN has shown that there is minimal winter attraction of sauger to the SQN thermal plume, and little or no impingement or increased fishing pressure in the vicinity of SQN. It has also been shown that no sauger spawning occurs near SQN and that the only significant sauger spawning area in Chickamauga Reservoir is more than 35 miles upstream from SQN.

Threadfin shad are sensitive to cold and may be attracted to thermal discharge areas by thermoregulatory behavior. Even though such attraction undoubtedly occurs at SQN, it is unlikely that this attraction would result in increased impingement, because the intake is well upstream from the heated discharge. The heated discharge could, however, have a positive effect on shad survival during very cold winters when massive shad die-offs commonly occur after ambient temperatures drop to 4 to 5°C (39 to 41°F). Attraction to the thermal plume could result in increased susceptibility to predation; however, the absence of a concentrated sport fishery indicates a lack of large numbers of predator fish in the vicinity. Most threadfin shad spawning occurs throughout the reservoir in April and May, a time when the ambient reservoir temperature is higher than the temperature in the warmest part of the thermal plume in late March. This indicates that any advanced spawning caused by the proposed thermal rise limit would be minimal.

White crappie are widely distributed throughout the reservoir and show little attraction to the SQN discharge or to thermal discharges in general. Spawning occurs almost exclusively in protected coves and embayments; very little spawning occurs in or along the main river channel. Advanced spawning has not occurred under the present rise limit; and because the proposed additional rise would not alter the thermal plume to include primary spawning areas, no advanced spawning would be expected to occur. Increased fishing pressure would not be expected to occur, because crappie are not attracted to the thermal discharge and therefore do not become concentrated in the thermal plume. A decline in numbers of adult crappie (and sauger) in Chickamauga Reservoir, documented by TVA in special targeted studies from 1986 through 1988, occurred during a time when no thermal discharges were occurring at SQN.

According to studies reported at two national symposia on thermal ecology, discharges of condenser cooling water from power plants, regardless of the temperature rise, have not caused significant fish disease problems. There is no evidence that such problems have occurred or will occur at SQN.

Low dissolved oxygen levels in the reservoir at SQN originate upstream and are restricted to summer months when the reservoir is thermally stratified. Because the reservoir is fully mixed from November through March and average dissolved oxygen levels are high throughout the water column, the proposed increase in temperature rise limit would have little effect on winter levels of dissolved oxygen downstream from the plant. In any case, under average flow conditions, the water in Chickamauga Reservoir downstream from SQN is displaced in about two days. Thus, any effect of SQN operation in March would pass out of the reservoir well before thermal stratification occurred.

Hydroacoustic sampling has indicated some degree of fish attraction to both thermal and nonthermal (structural) factors in the vicinity of the diffuser discharge. However, observations to date indicate that exceptionally large concentrations of game and prey species of any kind have not occurred there in winter.

Computer simulations of worst-case plant operation show that under the proposed temperature rise limit the present 3 C° (5.4 F°) limit would have been exceeded an average of 27 percent of the time (on an hourly basis) between November and March during the last 13 years. Temperature rises larger than 4 C° (7 F°) would have occurred about 4 percent of the time. Although TVA is not requesting that the existing hourly compliance interval be changed at this time, it is important to note that EPA's current recommendations for applying temperature criteria to protect fish growth, reproduction, and winter survival are based on maximum weekly average temperature conditions. Consequently, hourly temperature measurements are extremely conservative, and hourly excursions above the present 3 C° (5.4 F°) limit, or the proposed 5 C° (9 F°) limit, are not biologically significant. For example, considering only 24-hour average temperatures for the period of record, the temperature rise downstream of SQN would only infrequently have exceeded 4 C° (7 F°).

The present temperature rise limit at SQN can impose significant costs to TVA. To meet the existing limit, TVA balances changes in hydro operations, the use of cooling towers, and plant load reductions. Present operational schemes and a historical 12-year meteorological and river temperature data base were used to determine the economics of the present temperature rise limit. An average of 1990 and 1995 SQN operation costs and future power costs resulted in average yearly costs of $635,000 to meet the present limit. In addition to these operating costs, $16-20 million would be needed to modify the cooling towers to increase their resistance to ice damage; or yearly repair of ice damage would be needed which, based on experience with previous events, would cost $0.5-1.5 million.

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A PREDICTIVE SECTION 316(a) DEMONSTRATION FOR AN ALTERNATIVE WINTER THERMAL DISCHARGE LIMIT FOR SEQUOYAH NUCLEAR PLANT, CHICKAMAUGA RESERVOIR, TENNESSEE

INTRODUCTION

Section 316(a) of the Federal Water Pollution Control Act Amendments of 1972 provides for alternative point source thermal limits. The owner of a point source must demonstrate that the effluent limits intended for control of a thermal discharge are more stringent than necessary to assure protection and propagation of a balanced, indigenous population of fish and wildlife. If the appropriate regulatory agency agrees with the demonstration, alternate limits that will assure protection of such populations may be granted.

The purpose of a thermal discharge limit is for the protection and propagation of balanced, indigenous populations of shellfish, fish, and wildlife in the receiving water body. According to protocol established by the Environmental Protection Agency (EPA), this is best accomplished by protecting the most temperature-sensitive fish species judged important, desirable, or both. Sauger, threadfin shad, and white crappie were identified by Tennessee Wildlife Resources Agency (TWRA) and Tennessee Division of Water Pollution Control (TDWPC) as representative important species in Chickamauga Reservoir. Therefore, these species are emphasized in this demonstration for a winter (November-March) temperature rise limit of 5 C° (9 F°), as opposed to the present 3 C° (5.4 F°) limit, for the thermal discharge from TVA's Sequoyah Nuclear Plant (SQN).

This assessment is based on present EPA guidelines for applying water quality criteria for temperature, other 316(a) studies by the Tennessee Valley Authority (TVA), results of the biological monitoring program for SQN, EPA-TVA cooperative research on development of temperature criteria, and the hydrothermal conditions of the SQN heated discharge into Chickamauga Reservoir.

Water quality temperature criteria related to fish and aquatic life in trout and nontrout waters in Tennessee were established in the early 1970s. For nontrout waters, such as Chickamauga Reservoir, the main components of thermal discharge limits are: maximum temperature, 30.5°C (86.9°F); temperature change (rise), 3 C° (5.4 F°), relative to an upstream control point; and maximum rate of change, not to exceed 2 C°/hour (3.6 F°/hour). It is important to recognize that the temperature maximum and temperature rise are not functionally independent. Previously, an independent relationship could have been inferred because guidelines for setting a temperature rise limit were not clearly defined in EPA's preliminary recommendations in 1971.

The purpose of the temperature maximum and temperature rise was later clarified in EPA's published recommendations for applying numerical temperature criteria for protection of freshwater fish (EPA, 1976; Brungs and Jones, 1977). However, requirements for a temperature rise limit, as now applied at SQN, were not included because other methods were thought to be more appropriate. 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, 24-hour, exposure 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 is not specified. These recommendations further emphasize that temperature criteria should be applied with adequate understanding of the normal seasonal distribution of the important species.

Because elevated temperatures resulting from a thermal discharge are obviously a function of the temperature rise, seasonal temperatures for growth, reproduction, or winter survival can be controlled by a temperature rise limit, especially during winter and spring. A temperature rise limit also could be used to control the maximum temperature during summer; however, in the case of SQN, the summer maximum is usually limited by the summer ambient temperature regime.

According to the most recent EPA recommendations, the 3 C° (5.4 F°) temperature rise limit was originally included to set, indirectly, seasonal maximum limits for reproduction and winter survival, whereas the 30.5°C (86.9°F) maximum limit was applied as the maximum summer temperature for growth. However, the 30.5°C (86.9°F) maximum temperature limit frequently has been incorrectly interpreted as the upper limit for survival. There are no provisions in the present Tennessee thermal criteria for a short-term maximum temperature limit for survival. If there were such a limit, it would obviously have to be higher than 30.5°C (86.9°F) in the summer because fish survive higher water temperatures that occur frequently under natural conditions when there is no thermal discharge.

This 316(a) demonstration for SQN addresses only the temperature rise (change) limit, which is presently 3 C° (5.4 F°). It evaluates potential effects of a proposed 5 C° (9 F°) temperature rise limit relative to seasonal requirements for reproduction and winter survival of the representative important species. It also evaluates other concerns identified by the TDWPC and TWRA related to concentration of fish in a heated discharge, including impingement, fishing pressure and predation, disease, and sampling methods.

HISTORY OF THE DEVELOPMENT OF TEMPERATURE CRITERIA FOR SEQUOYAH NUCLEAR PLANT AND HEAT DISSIPATION SYSTEM ISSUES

The TVA Board of Directors authorized construction of SQN in August 1968. Construction started in mid-1970. Unit 1 began commercial operation July 1, 1981, and unit 2 began commercial operation June 1, 1982. Both units operated more or less continuously until August 1985, when both units were shut down because of safety concerns. Unit 2 was restarted in May 1988, and unit 1 was restarted in January 1989.

An important consideration in the initial planning of the plant was the design of a heat dissipation system that would allow efficient plant operation and at the same time protect the aquatic resources of Chickamauga Reservoir. However, during the design and construction period, resolution of that issue was difficult because of a changing and uncertain basis for the development of temperature criteria. As a result, when numerical criteria were eventually established, the heat dissipation system required substantial retrofitting. Simultaneously, further research was initiated to evaluate the appropriateness of the numerical criteria.

SQN is located at approximately mile 484 of the Tennessee River (TRM 484) on Chickamauga Reservoir. This segment of the Tennessee River is classified by the state of Tennessee for the following uses: municipal, industrial and agricultural water supply; propagation of warmwater fish and other aquatic life; water-contact recreation; navigation; and the final disposal of treated municipal and industrial wastewater. To protect the quality of water for these uses, Tennessee has adopted various water quality criteria, including temperature criteria.

Development of Tennessee Temperature Criteria

The Federal Water Pollution Control Act, as amended by the Water Quality Act of 1965, required each state to adopt water quality criteria for interstate waters and submit them to the Federal Water Pollution Control Administration (FWPCA) for approval. At the time of the initial planning for SQN, Tennessee had submitted proposed temperature criteria to the FWPCA that called for a maximum temperature of 33.9°C (93°F) and a maximum temperature rise of 5.6 C° (10 F°). These criteria were similar to those being proposed to the FWPCA by other states in the Southeast, and some states had already received approval. However, questions continued to arise about the adequacy of the temperature criteria, and the FWPCA rejected the Tennessee proposals.

In April 1971, FWPCA's successor agency, EPA, conducted a Water Quality Standards Setting Conference in connection with its announced intention to promulgate standards for Alabama. A review of that conference is relevant here because the discussion of issues influenced the outcome of temperature criteria debates in all states in the Tennessee Valley region, and because the debate illustrates the diversity of professional opinion and the fragile technical basis upon which rests the present temperature criteria for these states.

Temperature Criteria Issues

The 1971 Water Quality Standards Setting Conference offered an opportunity for interested parties to present their points of view on Alabama's standards and, by extension, on regional water quality standards in general. The opinions expressed by the participants clearly indicated recognition of the potential impacts of the discharges of heated effluents to surface waters. Numerous such impacts were cited, including mortality, reproductive impairment, increased toxicity of certain pollutants, reduced assimilative capacity, and shift of phytoplankton populations toward undesirable species. Although all participants agreed that temperature criteria were necessary for protecting aquatic life, the degree of protection necessary was disputed.

The state of Alabama, Alabama Power Company, and TVA each supported the criteria of 33.9°C (93°F) maximum temperature and 5.6 C° (10 F°) temperature rise favored by most of the regional states, including Tennessee. They contended that natural stream temperatures frequently exceeded EPA's proposed 30°C (86°F) maximum without causing observable impact. TVA cited experience with numerous heated discharges where both the 30°C (86°F) maximum and the 2.8 C° (5 F°) rise were exceeded without causing adverse impact. In addition, these groups cited the difficulties and high costs associated with the more stringent criteria. They strongly urged EPA to carefully consider and balance all the water uses in developing criteria.

At that time, two states adjoining Alabama (Georgia and Florida) had received EPA approval for temperature criteria less stringent than those that had been proposed by Alabama and rejected by EPA. The remaining states adjoining Alabama had proposed temperature criteria comparable to those proposed by Alabama. Because Federal guidelines required that state standards be consistent and comparable with those of downstream or adjacent states, and because EPA rejected similar criteria proposed by the remaining states, EPA eventually withdrew its approval of the Georgia criteria and required the adoption of more stringent temperature criteria.

TVA suggested that, in view of the many uncertainties regarding temperature impacts on aquatic life, the adoption of final temperature criteria should await completion of research in progress at TVA's Browns Ferry Biothermal Research Station. This research had been proposed by TVA in 1967 as a means of obtaining an adequate data base for the development of temperature criteria. EPA (and its predecessor) agreed to the need for such research, as evidenced by EPA's active participation in project planning and, beginning 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 TVA agreed to conduct a cooperative research program to investigate the effects of heat on aquatic life.

The preceding review illustrates the uncertainty and divergence of professional opinion during development of temperature criteria for the Southeast and the Tennessee Valley region. Today, many years after the adoption of these criteria, unresolved questions remain. These include questions about the temperature maximum and temperature rise criteria actually necessary to protect aquatic life, and about the proper methods of applying such criteria. The research completed at Browns Ferry showed that the basis for many of the prior decisions made during the development of temperature criteria were questionable. The results from this joint EPA-TVA research will be a fundamental basis for the present demonstration for SQN.

In 1983, TVA submitted to Alabama and EPA a demonstration for alternative temperature criteria for its Browns Ferry Nuclear Plant (BFN) on Wheeler Reservoir in north Alabama. The BFN demonstration relied extensively on results of the joint EPA-TVA biothermal research. As a result of the demonstration, the temperature criteria for BFN were revised from the 30°C (86°F) maximum temperature and 2.8 C° (5 F°) temperature rise criteria established following the 1971 EPA conference to a 32.2°C (90°F) maximum 24-hour average temperature, a 5.6 C° (10 F°) 24-hour average temperature rise, a 33.9°C (93°F) maximum instantaneous temperature, and a 33.4°C (92°F) maximum temperature for any 6-hour period during a 24-hour period. These alternative criteria for BFN apply throughout the year. Both Alabama and EPA determined that these revised criteria would provide sufficient safeguards to protect the aquatic resources of the Tennessee River in north Alabama. The economic effect of these alternative temperature criteria, which still provide adequate protection for the aquatic resources of the Tennessee River, is an average annual savings of more than $4 million (1983 dollars) when the plant is operating.

Sequoyah Nuclear Plant Heat Dissipation System

The initial design of the heat dissipation system for SQN and subsequent modifications to it were discussed in detail in the final environmental impact statement (issued February 13, 1974). Certain aspects of the history are summarized here to provide continuity with events subsequent to the release of the final environmental impact statement.

Design Criteria

The heat dissipation system for SQN was originally designed and constructed to meet criteria permitting a maximum temperature of 33.9°C (93°F), a maximum rate of temperature change of 1.7 C° (3 F°) per hour, and a maximum temperature rise of 5.6 C° (10 F°). These criteria were identical to those that had at the time been proposed to EPA by Tennessee as adequate to protect aquatic life and all other beneficial uses. In applying these criteria, however, TVA recognized in the early stages of plant design that the condenser water should not be discharged directly into the surface stratum of water in Chickamauga Reservoir. Instead, TVA decided to discharge the heated water through a submerged diffuser system to speed initial mixing of the heated water with the river water and restrict the mixing zone to a relatively small area.

On December 14, 1971, the Tennessee Water Quality Board adopted, and EPA subsequently approved, the presently applicable temperature criteria. TVA then determined that the diffuser system alone would not be adequate to assure acceptable compliance with these revised criteria. After evaluating a number of alternatives, TVA decided that the best long-term solution to meet the more stringent standards was to supplement the diffuser system with two natural-draft cooling towers.

Diffuser System

At SQN, heated water is discharged either from the condensers or from the cooling towers directly into a 32-acre pond, from which it can either be recirculated to the intake canal or discharged to the reservoir through two diffusers. Each diffuser line extends across a 600-foot wide overbank area into the 900-foot wide navigation channel and terminates in a 350-foot long diffuser section (Figure 1). The downstream diffuser pipe is 16 feet in diameter and extends 350 feet into the main channel; the upstream diffuser pipe is 17 feet in diameter and extends 700 feet into the channel. This leaves a 200-foot zone of passage in the side of the channel away from the plant. The diffuser pipes collectively contain about 12,000 2-inch ports, through which water is discharged for mixing with the reservoir water.

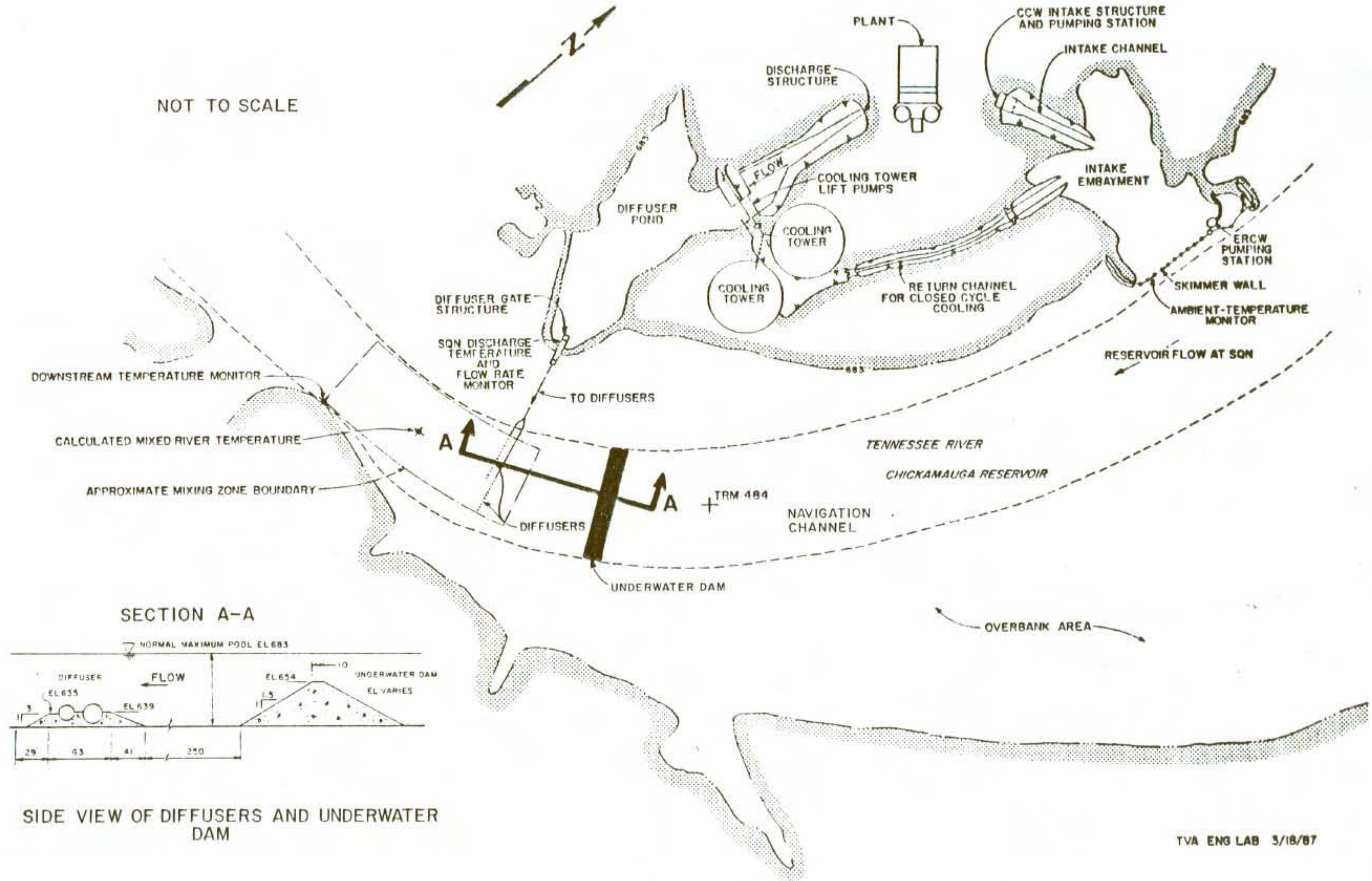


Figure 1. Sequoyah Nuclear Plant Thermal Discharge Features.

Flow through the diffuser pipes is controlled by the difference in elevation (i.e., driving head) between the diffuser pond and the reservoir. At maximum pump capacity (three condenser cooling water (CCW) pumps per unit), the two diffusers discharge a total of about 3,000 cubic feet per second (cfs) with a driving head up to 6.0 feet. During fall, winter, and spring when upstream temperatures are less than 13°C (55°F), better plant performance and protection of the low-pressure turbines warrants using two CCW pumps per unit to maintain suitable condenser turbine backpressure. Maximum diffuser discharge for two CCW pumps per unit is a total of 2,000 cfs. An underwater dam constructed of quarry rock is located about 250 feet upstream from the diffusers. The crest of this dam is at elevation 654 feet above mean sea level (msl). This dam retards upstream movement of the warm water layer formed during low reservoir flows and impounds cooler water in the lower layer of the reservoir to make it available at the plant intake.

Cooling Towers

The condenser cooling water drawn from Chickamauga Reservoir can be routed back to the reservoir in one of three ways: (1) directly to the diffuser pond and out the diffusers (open mode); (2) through the cooling towers and then to the diffuser pond and out the diffusers (helper mode); or (3) through the cooling towers and back to the intake canal (closed mode). The cooling towers are used in the latter two modes when conditions are such that temperature criteria cannot be met by open mode operation. Such conditions may occur during hot weather when tower operation may be required to meet the maximum temperature limit or during cold weather when the towers may be needed to meet the temperature rise limit. However, because of plant design, closed mode operation during the summer is not feasible.

The two CCW cooling towers at SQN are hyperbolic natural-draft design with external, cross-flow heat exchangers. The towers are constructed of a combination of precast, prestressed, and poured-in-place, reinforced concrete. The 41 heat exchanger sections in each tower have concrete louver blades, polyvinyl chloride (PVC) fill, and PVC drift eliminators, with asbestos cement divider walls between the sections.

During cooling tower operations, hot circulating water is pumped to the hot water flumes that circle the top of the heat exchanger. The hot water is supplied to the towers by a common pumping station. The hot water in the flumes is distributed by spray nozzles over the fill material for cooling by evaporation.

Heat Dissipation System Operation Issues

The cooling towers must be operated to meet the current temperature rise criterion during extreme cold weather. This can lead to icing, which in turn can cause serious structural damage to the cooling towers.

Wintertime Operation

The present temperature rise criterion of 3 C° (5.4 F°) cannot always be met by open mode operation during low river flow and cold weather. TVA has three possible alternatives during those times: reduce plant load, augment river flow, or operate the cooling towers. Reduction of plant load is obviously an undesirable alternative at any time, especially when demand is high during cold weather. It is not always possible to achieve compliance by augmenting reservoir flow, because the required amount of water may not be available in the reservoir system. The third alternative, operating the cooling towers, is the least undesirable choice under the present circumstances. However, operation of the cooling towers may cause ice damage to the towers, which must be repaired each year so that the towers can be operated at maximum efficiency to help meet the temperature limits.

The crossflow design of the cooling towers can cause localized ice formation when air temperatures are below freezing. During cold weather in 1984 and 1985, cooling tower operations resulted in ice buildup that caused substantial damage to the PVC fill and concrete louvers of the towers. No damage has yet occurred to the external supporting structure of the towers as a result of icing.

If the present 3 C° (5.4 F°) temperature rise limit remains in effect, TVA must either (1) repair the present damage and modify the towers to be more resistant to ice damage or (2) repair the present tower damage, be ready to run SQN in closed mode if icing conditions are forecast, and repair the damage each spring as needed to meet summer operation requirements.

Therefore, TVA is seeking to demonstrate that an increase in the temperature rise criterion from 3 C° (5.4 F°) to 5 C° (9 F°) for November through March will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in the receiving water, and thereby avoid or minimize the need for operating the cooling towers during this period.

BIOLOGICAL DETERMINATION

Fish Species Composition, Relative Abundance, and Sportfish Harvest

Since starting monitoring studies on Chickamauga Reservoir in 1970, 73 fish species have been collected by various methods (Table 1). Total standing stock estimates (number and biomass), derived from cove rotenone samples, have ranged from about 36,000/ha with a biomass of 187 kg/ha in 1980 to 46,000/ha and 528 kg/ha in 1985 (Table 2; TVA, 1986). Typically, cove population samples have been dominated by a few species. Through 1985, four species have exceeded 10 percent of the total number of fish caught: bluegill, 44 percent; gizzard shad, 13 percent; threadfin shad, 13 percent; and redear sunfish, 12 percent. Biomass has been dominated by gizzard shad, 43 percent; bluegill, 9 percent; freshwater drum, 8 percent; and common carp, 8 percent. Mean percentage biomass of the representative important species in rotenone samples since 1970 has been threadfin shad, 4 percent; white crappie, 0.73 percent; and sauger, 0.07 percent.

In gill net samples, 14 species qualified as important (dominant) on the basis of the species occurring in 50 percent or more of samples and comprising at least 1 percent (number) of the catch. Again, only three species (gizzard shad, skipjack herring, and mooneye) ever comprised more than 10 percent of the catch (TVA, 1985b). In contrast to their relatively low occurrence in rotenone samples, the following species were common in gill net samples: skipjack herring, blue catfish, channel catfish, white bass, spotted bass, white crappie, and sauger.

A reservoirwide creel survey, planned jointly by TWRA and TVA, has been conducted periodically before and during operation of SQN. Also, from April 1982 through June 1985, TVA collected angler harvest data in the vicinity of the plant, TRM 482-485.6 (the SQN diffuser discharge pipes are located at TRM 483.6). In the 1983 creel-year (July 1983-June 1984), an estimated 263,000 fish with a total biomass of 102,000 kg were harvested from Chickamauga Reservoir by sport fishing (TVA, 1986). Estimated biomass harvested in 1984 declined to about 61,000 kg. However, mean annual biomass harvested during the 5-year

Table I. Common and Scientific Names[a] of Fish Collected from Chickamauga Reservoir Before and During Operation of Sequoyah Nuclear Plant, 1970 to 1985.

Species	Common name	Group[b]	Rotenone	Gill net	Creel census	Meter netting
Icthyomyzon castaneus	Chestnut lamprey	C	X			
Polyodon spathula	Paddlefish	C	X			X
Lepisosteus oculatus	Spotted gar	C	X	X		
Lepisosteus osseus	Longnose gar	C	X	X		
Lepisosteus platostomus	Shortnose gar	C	X	X		
Alosa chrysochloris	Skipjack herring	C	X	X		X
Dorosoma cepedianum	Gizzard shad	P	X	X		X
Dorosoma petenense	Threadfin shad	P	X			X
Hiodon tergisus	Mooneye	C	X	X		X
Campostoma anomalum	Stoneroller	P	X			
Carassius auratus	Goldfish	P	X	X		
Cyprinus carpio	Carp	C	X	X	X	X
Hybopsis storeriana	Silver chub	P	X			X
Notemigonus crysoleucas	Golden shiner	P	X	X		X
Notropis atherinoides	Emerald shiner	P	X			X
Notropis buchanani	Ghost shiner	P	X			X
Notropis chrysocephalus	Striped shiner	P	X			
Notropis cornutus	Common shiner	P	X			
Notropis emiliae	Pugnose minnow	P	X			
Notropis galacturus	Whitetail shiner	P	X			
Notropis spilopterus	Spotfin shiner	P	X			
Notropis volucellus	Mimic shiner	P	X			
Notropis whipplei	Steelcolor shiner	P	X			
Pimephales notatus	Bluntnose minnow	P	X			X
Pimephales vigilax	Bullhead minnow	P	X			X
Pimephales promelas	Fathead minnow	P	X			
Carpiodes carpio	River carpsucker	C	X			X[c]
Carpiodes cyprinus	Quillback carpsucker	C	X			
Catostomus commersoni	White sucker	C	X	X		
Hypentelium nigricans	Northern hogsucker	C	X	X		
Ictiobus bubalus	Smallmouth buffalo	C	X	X		X[c]
Ictiobus cyprinellus	Bigmouth buffalo	C	X			
Ictiobus niger	Black buffalo	C	X			
Minytrema melanops	Spotted sucker	C	X	X		
Moxostoma carinatum	River redhorse	C	X	X		
Moxostoma duquesnei	Black redhorse	C	X			
Moxostoma erythrurum	Golden redhorse	C	X	X		
Moxostoma macrolepidotum	Shorthead redhorse	C	X			
Ictalurus furcatus	Blue catfish	C	X	X	X	X
Ictalurus melas	Black bullhead	C	X	X		
Ictalurus natalis	Yellow bullhead	C	X	X		
Ictalurus nebulosus	Brown bullhead	C	X	X		
Ictalurus punctatus	Channel catfish	C	X	X	X	X

Table I (Continued)

Species	Common name	Group[b]	Rotenone	Gill net	Creel census	Meter netting
Pylodictis olivaris	Flathead catfish	C	X	X	X	X
Fundulus notatus	Blackstripe topminnow	P	X			
Fundulus olivaceus	Blackspotted topminnow	P	X			
Gambusia affinis	Mosquitofish	P	X			
Labidesthes sicculus	Brook silverside	P	X			X
Morone chrysops	White bass	G	X	X	X	X
Morone mississippiensis	Yellow bass	G	X	X	X	X
Ambloplites rupestris	Rock bass	G	X	X	X	
Lepomis auritus	Redbreast sunfish	G	X	X		
Lepomis cyanellus	Green sunfish	G	X			
Lepomis gulosus	Warmouth	G	X	X		
Lepomis humilis	Orangespotted sunfish	P	X			
Lepomis macrochirus	Bluegill	G	X	X	X	X
Lepomis megalotis	Longear sunfish	G	X	X		
Lepomis microlophus	Redear sunfish	G	X	X	X	X
Micropterus dolomieui	Smallmouth bass	G	X		X	
Micropterus punctulatus	Spotted bass	G	X	X	X	
Micropterus salmoides	Largemouth bass	G	X	X	X	X[c]
Pomoxis annularis	White crappie	G	X	X	X	X
Pomoxis nigromaculatus	Black crappie	G	X	X	X	
Etheostoma asprigene	Mud darter	P	X			X[c]
Etheostoma caeruleum	Rainbow darter	P	X			
Etheostoma kennicotti	Stripetail darter	P	X			
Etheostoma spectabile	Orangethroat darter	P	X			
Perca flavescens	Yellow perch	G	X	X	X	X
Percina caprodes	Logperch	P	X			
Stizostedion canadense	Sauger	G	X	X	X	X
Aplodinotus grunniens	Freshwater drum	C	X	X	X	X
Stizostedion vitreum	Walleye	G		X	X	
Morone saxatilis	Striped Bass	G		X	X	

[a] Taken from Common and Scientific Names of Fishes, American Fisheries Society Special Publication No. 12, Fourth Edition, 1980.

[b] P = prey, C = commercial, G = game.

[c] Unidentified specimens within family or genus.

Table 2. Number of Samples and Mean Annual Standing Stock of all Young, Intermediate, and Harvestable Fish Collected in Cove Rotenone Samples from Chickamauga Reservoir, 1970 Through 1988.

Year	No. Samples	Young		Intermediate		Harvestable		Total	
		No./ha	kg/ha	No./ha	kg/ha	No./ha	kg/ha	No./ha	kg/ha
1970	12	7,353	12.61	534	24.80	931	182.49	8,819	219.91
1971	4	7,018	17.27	724	97.95	863	168.04	8,604	283.26
1972	4	12,872	63.06	932	30.96	1,394	271.21	15,199	365.23
1973	4	13,092	72.52	955	36.44	1,572	290.20	15,619	399.16
1974	4	9,737	34.23	673	21.98	1,263	194.91	11,673	251.13
1975	4	12,684	37.18	443	14.94	1,364	187.09	14,491	239.21
1976	5	14,662	37.20	1,179	26.39	1,400	272.84	17,241	336.43
1977	5	33,121	96.18	1,164	26.41	1,441	223.97	35,981	346.56
1978	5	19,883	31.70	960	19.98	2,584	184.51	23,427	236.19
1979	5	17,973	22.91	1,375	27.41	2,872	209.04	22,220	259.36
1980	5	34,424	44.71	537	10.08	1,020	132.58	35,981	187.37
1981	5	53,515	66.21	1,590	34.14	2,278	327.68	57,383	428.03
1982	5	33,655	56.23	977	24.37	1,919	209.92	36,551	209.52
1983	5	46,500	70.74	1,209	26.60	2,513	344.07	50,223	441.41
1984	5	24,814	43.58	937	22.47	3,545	383.25	29,296	449.30
1985	5	43,064	143.49	986	26.88	2,361	357.54	46,411	527.91
1986	5	33,393	63.82	962	30.37	1,832	251.51	36,188	345.70
1987	5	43,547	89.91	1,420	26.96	1,677	233.85	46,644	350.72
1988	5	55,086	109.33	1,214	23.59	1,350	204.04	57,650	336.96

monitoring period after SQN began operating was 93,000 kg, compared to a mean biomass of 68,000 kg during the 6-year monitoring period before it began operating. The four dominant species (biomass) in 1983 and 1984 were largemouth bass, channel catfish, blue catfish, and white crappie (Table 3). Largemouth bass comprised 28 percent of the total biomass harvested in both years. Overall, white crappie has dominated the harvest, but numbers and biomass harvested have been cyclic. Harvest estimates for some species since 1984 are not directly comparable because TWRA changed the reporting period to the calendar year and made some programming changes. These changes have resulted in some apparent omissions and changes in the database, which are being evaluated by TWRA and TVA.

Fishing pressure on Chickamauga Reservoir has increased significantly since 1972, but yearly variations have been substantial. Since 1976, annual fishing pressure has ranged from 273,882 hours in 1977 to 523,780 hours in 1983. For the 6-year period before operation of SQN, mean annual pressure was about 337,000 hours; for the 5-year period during operation of SQN, it was 479,000 hours. Generally, the increase in fishing pressure has been reflected in lower harvest rates (number of fish per hour of effort) but higher total harvest (TVA, 1985b; 1986).

Temperature Requirements and Life History Aspects of Representative Important Species

The fish community in Chickamauga Reservoir is dominated by warmwater species. With the exception of the percids (e.g., sauger, walleye, and yellow perch) and striped bass, all important game and commercial species are in this category. Percids are generally recognized as coolwater species that occur in conjunction with both warmwater and coldwater species (Hokanson, 1977; Kendall, 1978). According to a temperature classification of temperate-climate freshwater fish (Hokanson, 1977), some of the distinguishing requirements that separate the three categories are as follows:

Table 3. Estimated Biomass Harvested by Anglers on Chickamauga Reservoir, Tennessee, January 1972 Through December 1987.

Species	Biomass, kg															
	1972[a]	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985[a]	1986[a]	1987[a]
White crappie	23,764	33,145	11,441	13,265	16,933	23,886	19,080	16,423	36,765	28,874	14,533	10,304	11,543	8,073.69	13,235.45	21,965.64
Bluegill	8,913	5,980	9,994	6,942	7,010	4,591	4,839	2,450	2,817	3,129	4,627	5,447	3,166	4,725.65	15,267.48	10,015.14
White bass	10,470	3,857	4,340	2,571	4,483	6,537	22,151	8,569	7,299	9,452	26,659	5,719	638	-	-	16,612.95
Channel catfish	9,501	10,541	6,805	7,546	19,023	11,773	11,481	9,404	16,891	6,255	20,680	19,609	8,118	17,750.82	14,699.14	30,532.64
Freshwater drum	6,311	1,479	1,292	127	4,35	5,495	1,300	1,316	862	471	3,019	4,056	1,161	-	-	4,906.06
Largemouth bass	8,425	5,286	5,684	9,076	4,289	3,609	10,207	10,902	10,780	17,326	22,711	28,288	17,035	13,296.18	11,818.48	28,597.28
Blue catfish	2,432	24,947	1,147	753	5,037	1,707	2,090	3,064	6,656	6,352	24,666	10,895	7,495	10,236.08	8,361.69	17,885.14
Redear sunfish	1,007	610	1,630	1,348	1,763	350	245	117	480	56	121	71	41	203.26	-	-
Spotted bass	1,845	1,427	1,554	1,526	780	469	488	721	175	310	708	262	-	90.34	85.64	372.18
Smallmouth bass	1,827	42	91	101	448	693	196	415	107	1,123	755	929	-	180.67	397.06	270.68
Black crappie	440	474	948	1,072	1,908	517	892	974	669	1,271	1,729	997	1,217	649.28	1,409.18	5,210.58
Sauger	981	1,374	1,651	887	5,858	4,766	10,972	8,501	3,320	1,635	2,109	2,117	786	4,194.93	9,708.59	7,842.94
Other sunfish[b]	53	123	21	33	403	53	-	929	108	1,751	1,124	6,166	38	67.75	5,410.96	1,881.22
Yellow perch	73	179	111	-	-	153	118	275	402	352	1,753	651	906	-	-	4,682.76
Yellow bass	70	79	98	84	362	178	433	130	10	130	509	796	12	-	-	798.50
Flathead catfish	364	216	14	955	780	740	58	6,491	2,073	543	666	-	216	2,275.31	-	-
Rock bass	138	103	-	-	26	23	10	-	-	25	53	46	245	197.61	116.78	0.00
Carp	704	185	57	-	971	1,470	-	558	-	405	-	-	-	-	-	629.33
Walleye	124	-	188	-	565	-	193	57	310	-	94	-	-	-	70.07	60.90
Striped bass	16	1,243	62	-	-	1,193	1,787	7,651	2,815	2,694	4,582	6,000	4,203	1,236.46	1,681.68	5,724.87
Totals	77,458	91,290	47,128	46,286	75,487	68,203	86,540	78,947	92,539	82,170	131,098	102,353	60,797	63,178.03	82,262.20	157,988.81

[a] Calendar year versus creel year, July–June, for other years.

[b] Sunfish other than bluegill and redear.

Classification	Spawning °C	Spawning °F	Upper Lethal °C	Upper Lethal °F
Warmwater (eurytherm)	15-32	59-90	>34	>93
Coolwater (mesotherm)	3-23	37.4-73	28-34	82-93
Coldwater (stenotherm)	<15	<59	<26	<79

Although temperature requirements for sauger and walleye are similar, sauger is the dominant of the two species in Chickamauga Reservoir. Both species exhibit negative phototaxis (light sensitivity), sauger more than walleye. The dominance of sauger in mainstream reservoirs of the Tennessee River system is attributed to the relatively high turbidity of these waters (Schlick, 1978). Sauger prefer areas of moderate current over rock, gravel, or mixed rubble substrates. Although they may be found throughout the reservoir from late spring through summer, they apparently spend little time in areas of mud or silt substrate. Sauger are highly migratory, and by November or early December they usually concentrate below Watts Bar Dam. Also, they are known to frequent thermal discharge basins in the TVA system during autumn to spring (Wrenn, 1975). However, creel surveys and gill net samples indicate attraction to the SQN discharge area during winter has been minimal. Principal spawning areas in Chickamauga Reservoir, as in other TVA mainstream reservoirs (TVA, 1983; 1985b), are in the upper reaches.

In contrast to most warmwater species, which survive temperatures near freezing (less than 4°C, 39°F), threadfin shad are stressed at temperatures below 10°C (50°F), and temperatures below 4°C (39°F) are usually lethal (Griffith, 1978). This schooling, planktivorous species is a desirable forage fish found throughout Chickamauga Reservoir. Intolerance of cold temperature, which frequently causes mass mortalities, coupled with a high fecundity rate, results in dramatic population fluctuations for this species. This phenomenon is demonstrated in cove rotenone samples in Chickamauga Reservoir, where biomass estimates for this species have ranged from less than 1 kg/ha from 1978 through 1980, to 92 kg/ha in 1985 (Table 4). However, some of the lower estimates may have been influenced by dense aquatic vegetation

Table 4. Numbers and Biomass of Each Size Group of Threadfin Shad in Cove Rotenone Samples, Chickamauga Reservoir, 1970-1988.

	Young of Year		Intermediate[a]		Adult		Total	
	No./ha	kg/ha	No./ha	kg/ha	No./ha	kg/ha	No./ha	kg/ha
1970	2,732.68	2.94	-	-	0.31	0.01	2,732.99	2.95
1971	3,351.72	7.19	-	-	0.00	0.00	3,351.72	7.19
1972	8,094.18	41.72	-	-	52.33	1.46	8,146.51	43.18
1973	7,248.00	50.51	-	-	6.21	0.20	7,254.21	50.72
1974	6,916.67	28.02	-	-	3.10	0.13	6,919.78	28.16
1975	3,906.97	23.05	-	-	122.96	4.07	4,029.94	27.12
1976	3,401.95	11.75	-	-	0.00	0.00	3,401.95	11.75
1977	1,566.42	17.31	-	-	0.00	0.00	1,566.42	17.31
1978	53.10	0.34	-	-	0.00	0.00	53.10	0.34
1979	363.60	0.80	-	-	0.47	0.01	364.06	0.81
1980	448.09	0.79	-	-	0.00	0.00	448.09	0.79
1981	3,294.25	8.29	-	-	0.00	0.00	3,294.25	8.29
1982	368.97	1.00	-	-	1.43	0.03	370.40	1.03
1983	8,838.26	23.67	-	-	0.00	0.00	8,838.26	23.67
1984	866.60	2.13	-	-	0.00	0.00	866.60	2.13
1985	22,913.04	92.19	-	-	0.48	0.02	22,913.52	92.21
1986	4,912.88	8.64	-	-	0.00	0.00	4,912.88	8.64
1987	12,454.17	18.07	-	-	0.00	0.00	12,454.17	18.07
1988	21,816.41	43.31	-	-	0.00	0.00	21,816.41	43.31

[a] No intermediate size class considered.

in coves. In the absence of aquatic vegetation, Houser and Bryant (1967) reported that cove standing crops were equal to open-water standing crops in Beaver and Bull Shoals Reservoirs in Arkansas. Threadfin shad apparently spawn throughout Chickamauga Reservoir, but spawning usually occurs at the surface in floating debris or near the shoreline (Lambou, 1965).

Although temperature requirements for white crappie are similar to those for other centrarchids, Mathur et al., (1981) noted that white crappie preferred lower temperatures than five other centrarchids for a given acclimation temperature in laboratory tests for temperature preference. Under field conditions during the summer, a temperature preference of 22 to 27°C (72 to 81°F) was reported for white crappie and 27.8 to 29.8°C (82 to 86°F) for black crappie (Coutant, 1975). White crappie are distributed throughout Chickamauga Reservoir, but in late winter they usually concentrate in the larger creek embayments. Spawning occurs in protected bays and coves and in shallow areas around islands. Nest depths for white crappie are related to water clarity and are reported to range from 0.02 to 6 m. White crappie prefer to spawn among stumps, roots, and along overhanging banks (Carlander, 1977; Vasey, 1972).

Winter Survival

Seasonal maximum temperature criteria for growth, reproduction, and winter survival normally apply to temperature conditions in most of the receiving water body (outside the approved mixing zone). Because fish may concentrate in a mixing zone, winter maximum temperatures within the mixing zone should be considered. Fish congregating in thermal discharges of power plants can acclimate to elevated temperatures. If the temperature of the discharge declines rapidly, these fish could be suddenly exposed to ambient temperature. Responses of fish to this situation depend on the extent and duration of the temperature reduction and physiological condition of the fish. At the extreme, cold shock (a condition characterized by disorientation, loss of equilibrium, or death) can occur. Fish are most susceptible to cold shock when the temperature decline is too rapid to allow acclimation to the lower temperatures and when the fish are confined (for example, in discharge channels or confined basins) so that they cannot escape to areas with warmer temperatures. If the temperature decline is small, even immediate cooling can be tolerated unless lower lethal limits are exceeded.

In laboratory studies used to establish tolerance levels for low temperatures, fish typically are exposed to reduced temperatures almost instantaneously. In contrast, nuclear power plants usually continue to discharge heated water for hours or days following shutdown, resulting in a gradual temperature decline. Therefore, such laboratory studies do not accurately simulate the conditions of power plant shutdowns and cannot be used to predict occurrence of cold shock. Such laboratory studies should be viewed as "worst case" situations. From various laboratory studies conducted to establish the relationship between acclimation temperature and tolerance for low temperature, Brungs and Jones (1977) concluded that the temperature rise should not exceed 10 to 13 C° (18 to 23 F°) during winter. Although specific laboratory studies have not been conducted for sauger and white crappie, tolerance levels reported for closely related species indicate that both sauger and white crappie can tolerate a temperature decline of 10 C° (18 F°) or more. Smith and Koenst (1975) reported that walleye mortality did not occur until the temperature dropped 17.6 C° (31 F°). Both smallmouth bass (Horning and Pearson, 1973) and largemouth bass (Hart, 1952) tolerated a temperature decline of 13 C° (23 F°). During a series of long-term temperature experiments conducted by TVA in large, outdoor channels at Browns Ferry Nuclear Plant (EPA-TVA joint research project), sudden temperature declines of 5 to 8 C° (9 to 14 F°) in winter were tolerated by bluegill, fathead minnows, smallmouth bass, and white crappie (Wrenn, 1980, 1984; and Heuer, 1983).

In Chickamauga Reservoir essentially all fish species except threadfin shad normally tolerate an annual temperature decline of 20 C° (36 F°) or more. Unquestionably, threadfin shad would be the species most vulnerable to cold shock associated with a temperature decline in the SQN thermal discharge. However, the situation for threadfin shad is more complex.

According to Griffith (1978), the most important factor influencing equilibrium loss (equated to mortality) for threadfin shad is the final low temperature, not the magnitude of the decrease. He reported that, in laboratory tests, this species was stressed at temperatures below 10°C (50°F) but displayed no loss of equilibrium in test temperatures above 6°C (43°F); 50 percent of the threadfin shad died after the temperature remained at 5°C (41°F) for one day, and none survived exposure of 4°C (39°F) for three days.

Similar lower lethal limits have been observed under field conditions. McLean et al., (1979) reported mass mortalities of threadfin shad in Watts Bar Reservoir when the temperature dropped below 4°C (39°F), but they noted that some threadfin shad survived in coves with groundwater seepage (9°C, 48°F) and in the Kingston Fossil Plant thermal discharge. Griffith and Tomljanovich (1976) indicated that threadfin shad in TVA reservoirs could be exposed to temperatures that approached stress levels by late November, but that they apparently were able to tolerate these sustained low temperatures for several weeks or were able to follow gradients to areas with warmer temperature.

Historically, no fish mortalities have been reported following shutdown of any TVA coal-fired or nuclear generating plant. Therefore, data from various fishkills known to have occurred as a result of shutdowns of other thermal discharges at non-TVA facilities were reviewed. These data indicate that freshwater fishkills occurred only when the temperature decline was extreme, 18 C° (32 F°) or more. This suggests that the EPA nomograph (Brungs and Jones, 1977) may be conservative when applied to freshwater fish.

Under the proposed maximum river temperature rise limit of 5 C° (9 F°) for November through March at SQN, cold shock would be unlikely for any fish species except threadfin shad. Threadfin shad in most of Chickamauga Reservoir will be susceptible to naturally occurring cold shock regardless of the SQN thermal discharge limit. In relation to the much greater effect of the periodic occurrence of adverse winter temperatures on this species throughout much of the reservoir, the possibility of cold shock from shutdown of SQN thermal discharge does not represent a significant additional impact on this species. Over the long term, raising the SQN thermal discharge limit would be expected to improve winter survival for threadfin shad because of the higher temperature in the thermal plume.

Reproduction

Temperature is important for initiation and completion of fish spawning, and the potential for adverse impacts resulting from power plant thermal discharges has been recognized. Because the influence of temperature on spawning depends on the thermal history of adults before the spawning period as well as on the temperature in the spawning area, thermal discharges that are restricted to zones outside of suitable spawning habitat would be expected to have little influence on fish reproduction. Therefore, the chief remaining concerns are that higher temperatures might induce advanced (early) spawning or, at the other extreme, might remain sufficiently high throughout the year that they might inhibit or preclude spawning. As long as the seasonal temperature cycle is not disrupted in waters that receive a thermal discharge, indigenous fish populations would be more likely to spawn early than not to spawn at all.

Operation of SQN under the proposed 5 C° (9 F°) temperature rise limit would not disrupt the normal seasonal temperature cycle in Chickamauga Reservoir and would not sustain temperatures at a level high enough to be likely to repress gonad development or inhibit or preclude spawning. Therefore, the most likely impact of the proposed limit is the possibility of early spawning and the related potential impacts. It is these impacts that are emphasized in this assessment.

Advanced spawning by white crappie, bluegill, and smallmouth bass in elevated thermal regimes has been documented under temperature-controlled conditions in large, outdoor channels (Wrenn and Grannemann, 1980; Heuer et al., 1983; and Wrenn, 1984). In thermal regimes 3 to 6 C° (5 to 11 F°) above ambient--encompassing the proposed discharge limit for SQN--spawning was advanced two to three weeks but occurred within the normal spawning temperature ranges reported for these species. A general, undocumented concern regarding early spawning has been that newly hatched fry may not survive because an adequate food supply might not yet be available or because the fry might be exposed to greater extremes of low or high temperatures. However, results of these experiments with bluegill and smallmouth bass showed that, although spawning can be advanced, similar changes occur simultaneously in the rest of the biological community (including spawning of other fish species). Therefore, the supply of food organisms was not limiting for growth and survival of newly hatched fry.

Mathur and McCreight (1980) evaluated the effects of the heated discharge (temperature rise of 5.6 to 11.1 C°, 10 to 20 F°) from the Peach Bottom Nuclear Station on white crappie reproduction in Conowingo Pond (lower Susquehanna River) in Pennsylvania. They found no evidence of earlier spawning in the thermal plume than in the ambient areas or during operation than before operation of the plant, as determined from gonosomatic ratios and larval fish catches. Also, they noted that white crappie did not reside permanently in the thermal plume and that a discrete population was not acclimated to warmer water for extended periods. Likewise, white crappie showed little attraction to the Cumberland Fossil Plant thermal discharge during winter and spring and appeared to avoid the discharge during summer (TVA, 1977).

Although the larval fish sampling phase for monitoring SQN was not designed specifically to assess early spawning, results of that monitoring before and during operation of SQN indicate that white crappie have not spawned early under a 3 C° (5.4 F°) temperature rise limit. Considering that a 2 C° (3.6 F°) increase in this limit would alter only a zone of the reservoir that is not a primary spawning area for white crappie, advanced spawning by this species would not be expected with a 5 C° (9 F°) limit from November through March. The earliest date that crappie larvae were collected before the plant began operation (1971-80) was April 23. During monitoring after the plant began operation, the earliest collection of crappie larvae was April 13, 1981. From 1982 through 1985, larvae were not present until the first week in May. Overall the relative abundance of crappie larvae in samples from the vicinity of SQN is low, 0.4 percent of all larvae collected.

A supplemental study of white crappie reproduction in the vicinity of SQN was conducted in 1986. The low numbers of crappie larvae in samples collected in the vicinity of the plant, as well as the concentration of adults usually observed in the larger embayments each spring, suggested that only limited spawning occurs in or along the main river channel. For this study, larval fish sampling transects were established in the main channel near the SQN diffusers (TRM 482.6) and downstream in the Dallas Bay area (TRM 480.8). Embayment sampling stations were located downstream from SQN in Wolftever Creek. Sixty-four samples were collected from April 29 to May 20. Although crappie larvae were present at all three locations on all sampling dates, progressively higher densities and smaller mean lengths clearly demonstrated that the embayment was the primary spawning area (Tables 5 and 6). On May 20, when peak densities occurred, numbers of crappie larvae ranged from 32/1000 m^3 at the diffuser transect to 414/1000 m^3 in Wolftever Creek embayment.

Laboratory and site-specific observations on the effect of elevated temperature regimes on sauger reproduction are not available. However, because of the spawning temperatures and time of spawning for this species over its geographical range and because it is a spring-spawner that requires a rising temperature regime for successful reproduction, advanced spawning by sauger would be possible in a thermal regime 5 C° (9 F°) above ambient. Reported spawning temperatures and times of spawning vary from 15°C (59°F) in late March (southern latitudes) to 5°C (41°F) in early June (northern latitudes), with the lowest reported spawning temperature from North Dakota (Hokanson, 1977). As indicated by the occurrence of larvae in ichthyoplankton samples, sauger in the Tennessee River system generally spawn from late March through mid-April at temperatures ranging from 12 to 15°C (54 to 59°F). At these temperatures, corresponding periods for egg incubation would be about 12 to 8 days, respectively (Smith and Koenst, 1975).

Table 5. Densities and Mean Lengths[a] of Crappie Larvae Collected at Three Transects in Chickamauga Reservoir, Spring 1986.

Transect	4/29/86 No./1,000 m^3	4/29/86 ML (mm)	5/6/86 No./1,000 m^3	5/6/86 ML (mm)	5/13/86 No./1,000 m^3	5/13/86 ML (mm)	5/20/86 No./1,000 m^3	5/20/86 ML (mm)
Diffuser	16.6	6.5	15.2	5.5	19.9	5.5	32.1	6.5
Dallas Bay	13.4	7.4	30.9	5.6	48.3	5.4	56.1	5.8
Wolftever Embayment	64.0	6.2	126.5	5.3	153.2	5.7	414.2	5.5

[a] Mean length = ML

Table 6. Estimated Fish Impingement at Sequoyah Nuclear Plant.

Common Name	1981	1982	1983	1984	1985[a]
Paddlefish	0	7	0	0	0
Lamprey	0	0	37	0	0
Chestnut lamprey	29	0	0	0	7
Shad, herring	0	0	183	0	0
Skipjack herring	73	149	270	1,221	1,089
Unidentified shad	0	0	0	70	0
Gizzard shad	453	9,967	2,365	1,502	1,499
Threadfin shad	56,582	15,829	4,687	29,221	14,862
Rainbow trout	0	0	0	7	0
Mooneye	37	60	15	14	15
Minnow, carp	0	7	0	0	0
Carp	0	0	7	0	0
Silver chub	102	30	0	0	0
River chub	7	0	0	0	0
Golden shiner	153	15	15	7	0
Emerald shiner	22	7	22	7	7
Common shiner	0	0	0	0	15
Spotfin shiner	0	0	0	14	0
Mimic shiner	0	0	15	35	0
Bluntnose minnow	22	238	37	126	0
Bullhead minnow	110	350	241	288	636
Spotted sucker	7	0	0	0	0
Golden redhorse	0	0	7	0	0
Blue catfish	102	127	146	175	102
Black bullhead	0	7	0	0	0
Yellow bullhead	7	7	7	0	0
Brown bullhead	0	0	0	0	7
Channel catfish	387	179	387	358	212
Flathead catfish	58	97	22	84	22
Mosquitofish	7	0	0	0	0
Unidentified temperate bass	0	0	0	0	7
White bass	51	782	95	267	44
Yellow bass	212	1,862	350	821	1,214
Striped bass	0	0	0	7	0
Rock bass	0	0	0	0	7
Unidentified sunfish	0	37	0	0	7
Warmouth	153	45	37	56	37
Redbreast sunfish	51	97	7	84	22
Green sunfish	2,759	74	22	35	37
Bluegill	4,672	3,553	2,613	2,365	1,426
Longear sunfish	110	0	7	21	7
Redear sunfish	256	216	73	161	66
Spotted bass	117	670	22	49	15
Largemouth bass	44	67	29	21	44

Table 6 (Continued)

Common Name	1981	1982	1983	1984	1985[a]
White crappie	190	97	139	35	22
Yellow perch	445	387	190	140	66
Logperch	22	268	15	84	0
Sauger	22	7	7	0	0
Freshwater drum	2,759	5,706	2,891	3,482	1,287
Banded sculpin	0	0	0	7	0
Mixed unidentified minnows	0	0	0	21	0
Total	70,022	40,947	14,958	40,789	22,779

[a] Based on 212 days of impingement as compared to 365 days for previous years.

The general lack of gravel substrate and the excessive water depths in the vicinity of SQN would preclude this zone as a prime spawning area for sauger, regardless of the thermal regime. The concentrations of adults that occur in the tailwater zone of Watts Bar Dam from December through April of each year, just before the spawning period, and the low numbers of sauger larvae collected in the vicinity of SQN (in 1984, for example, only one sauger larva was collected) indicate that primary spawning areas are well upstream from SQN. Gill net sampling since 1985, conducted as part of the revised aquatic monitoring program, has indicated that the Hunter Shoals area (TRM 521), 35 miles upstream from SQN, is the primary sauger spawning location in Chickamauga Reservoir. Extensive searching has failed to locate any other spawning areas in Chickamauga Reservoir.

Another potential impact of thermal discharges on percid reproduction has been postulated in relation to a chill-period requirement for gamete maturation in yellow perch. Under laboratory conditions, Jones et al. (1977) reported that egg maturation of yellow perch was depressed severely if exposure to temperatures of 4 to 6°C (39 to 43°F) was less than 120 days. Results from a laboratory study (Barans and Tubb, 1973) showed preferred winter temperatures to be 12 to 16°C (54 to 61°F) for this species. Therefore, it could be concluded from these laboratory results that yellow perch would be attracted to a thermal discharge, which would limit or preclude exposure to the required chill period and adversely affect reproduction.

However, there are questions about the ecological relevance of a chill period at the level and duration reported from the laboratory study of yellow perch reproduction. Although temperature requirements for sauger, walleye, and yellow perch are similar, no similar requirement of a chill period for gamete maturation has been reported for sauger or walleye. Chickamauga Reservoir has an expanding yellow perch population; however, its ambient temperature cycle shows that temperatures below 6°C (43°F) are not likely to persist more than 80 days. The same is true in other southern reservoirs that have yellow perch populations. Clugston et al. (1978) reported that winter temperatures in Keowee Reservoir, South Carolina, seldom dropped below 8°C (46°F); nevertheless, yellow perch spawned successfully (at 10°C, 50°F, the same as for northern populations) and maturity indices for females were essentially the same as for those in northern states. Spawning did occur about two months earlier in South Carolina than in northern waters.

Creel surveys and gill net samples show that neither yellow perch nor sauger have congregated in the SQN thermal discharge during winter. Results of telemetry studies in Minnesota showed that the mean winter temperature selected by yellow perch in the vicinity of a thermal discharge (temperature rise 15 C°, 27 F°) was 6.3°C (43°F) (Ross and Siniff, 1982). Response to temperature varied greatly among individual fish, and they selected significantly lower temperatures in the field than those reported in laboratory experiments. The researchers concluded that factors other than, or in addition to, temperature substantially influenced yellow perch spatial distribution in the field.

Because of the wide distribution of threadfin shad in areas of Chickamauga Reservoir with acceptable spawning habitat, the thermal discharge from SQN would not be expected to have an adverse impact on reproduction of this species. Although threadfin shad undergo rapid ovarian development and have been observed spawning at temperatures as low as 15°C (59°F) (Lambou, 1965), peak spawning normally occurs at 20 to 24°C (68 to 75°F) (Swingle, 1969). The ambient temperature of Chickamauga Reservoir is usually about 10 to 14°C (50 to 57°F) at the end of March (Figure 2); therefore, the proposed 5 C° (9 F°) temperature rise limit for November through March would provide only marginal spawning conditions for this species even in the warmest zone of the thermal plume. Although it is not possible to separate gizzard and threadfin shad larvae in the early stages (less than 20-mm long), shad larvae of either species have not been collected in the vicinity of SQN until late May.

Fish Concentration in the Thermal Plume

Within the context of the general concern expressed by TDWPC and TWRA regarding fish concentrating in the SQN thermal discharge, the

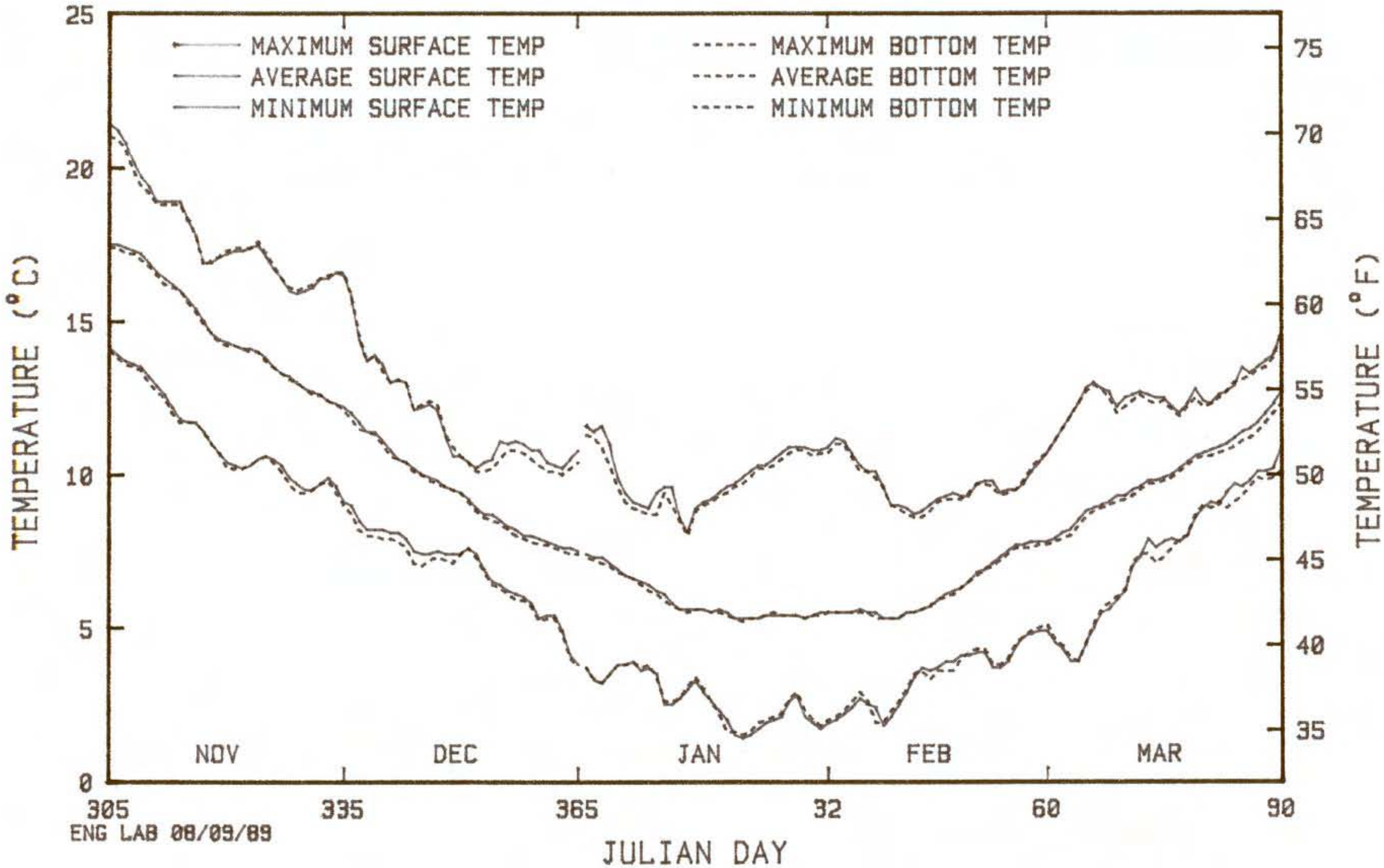


Figure 2. Ambient Daily Average River Temperatures Upstream From Sequoyah Nuclear Plant.

following points of particular concern will be addressed, with emphasis on the representative important species: impingement, fishing pressure and predation, disease, and fish sampling methods. By definition, the SQN thermal discharge plume includes the approved mixing zone as well as any additional areas of the reservoir outside of the mixing zone (normally downstream) in which temperatures are altered by the SQN discharge. As explained in the hydrothermal section of this report, under worst-case conditions hourly temperature rises within the mixing zone would exceed the present 3 C° (5.4 F°) limit 27 percent of the time. Natural mixing caused by changes in river flow that occur over a day would limit temperature rises downstream from the mixing zone to about 4 C° (7 F°). Because of the depth (15 meters, 50 feet) of water in which the discharge diffusers are located, vertical temperature gradients occur within the mixing zone, such that a 5 C° (9 F°) temperature rise at the surface usually would not be realized throughout the mixing zone. Therefore, we believe that under the increased temperature rise limit proposed for November through March, the actual frequency and duration of a 5 C° (9 F°) temperature rise would be limited, and the volume and area of the reservoir affected by such a temperature rise would also be limited.

Impingement

The propensity of threadfin shad to concentrate in large numbers in thermal discharges during winter (Dryer and Benson, 1956; Adair and Demont, 1971; Barkley and Perrin, 1971; and Wrenn, 1975) and to comprise the majority of fish impinged on power plant intake screens has been well documented (Griffith, 1978). However, neither the literature nor TVA's monitoring at various fossil and nuclear power plants provides evidence to link concentrations of threadfin shad (or any other fish species) in the thermal discharge with impingement. Although both phenomena are related to water temperature, the temperature and physiological relationships responsible for concentration are opposite of those responsible for impingement. Higher impingement rates for threadfin shad during late winter, usually January and February at most power plants in the Southeast, have been associated with cumulative low-temperature stress that may begin in late November. Concentration in the thermal discharge plume results from the ability of this species to locate and migrate into this zone, via thermoregulatory behavior, before its swimming ability is impaired at temperatures below 9°C (48°F) (Griffith and Tomljanovich, 1976; Griffith, 1978). Therefore, because of the absence of an upstream thermal gradient, higher impingement levels in January or February would not likely be caused by large numbers of threadfin shad moving downstream in an attempt to locate the SQN thermal discharge. Also, for fish that are acclimated to the thermal discharge, there is no physiological basis for them to move upstream through colder temperatures and concentrate near the SQN intake where they could be susceptible to impingement.

Although at SQN, impingement of all fish species is quite low throughout the year, the impingement that does take place occurs mostly during January. No sauger were collected from the intake screens during the last two years of sampling, 1984 and 1985. Previously, the combined total estimated impingement of sauger from 1981 through 1983 was 36 fish (Table 6). Impingement estimates for white crappie were similar; 5 were sampled in 1984, yielding a total annual estimate of 35 impinged. Annual impingement of threadfin shad since plant operation began has ranged from about 4,000 (1983) to 57,000 (1981). This is in contrast to 240,000 impinged at Kingston Fossil Plant (Watts Bar Reservoir) from November through April (McLean et al., 1979) and one million per day at Arkansas Nuclear One (Texas Instruments, Inc., 1976). McLean et al., estimated that the 240,000 threadfin shad impinged at Kingston Fossil Plant represented about 2 percent of the Watts Bar Reservoir population, and they could determine no adverse ecological impact. They concluded that the majority of threadfin shad, had they not been impinged, would have died from cold stress, because the ambient temperature was below 4°C (39°F).

TVA assumes that some threadfin shad are seasonally attracted to the SQN thermal discharge, and TVA has recently attempted to estimate the numbers that may be present. As indicated by the open-water location of the mixing zone, the relatively low temperature rise (usually less than 3 C°, 5.4 F°), and the general lack of a concentrated winter sport fishery in this area, numbers of threadfin shad in the SQN thermal discharge probably have not approached the concentrations observed at other TVA thermal discharges that are confined in basins or canals where the temperature rise is greater than 5 C° (9 F°). Regardless of the number of threadfin shad that may be present in the SQN thermal discharge or attracted to it, in light of the fact that no attractive thermal gradient exists in the intake channel increasing the temperature rise limit to 5 C° (9 F°) would not likely cause an increase in numbers of threadfin shad impinged upstream at the cooling water intake.

Fishing Pressure and Predation

This demonstration considers the potential adverse effects of fishing pressure primarily in relation to the game species, sauger and white crappie, and considers the effects of predation primarily in relation to threadfin shad.

Historically, fish have commonly concentrated in thermal discharge canals or basins of TVA power plants, especially fossil-fueled plants. Initial studies at these locations were limited to intermittent surveys, but they indicated a seasonal concentration of various species, intensive seasonal fishing pressure, and no mass mortalities from the effects of temperature differences (Dryer and Benson, 1956; TVA, 1969 and 1973). Later studies were more comprehensive, especially the 316(a) demonstrations conducted at fossil plants for permitting under the National Pollutant Discharge Elimination System (NPDES); overall, however, the conclusions of these studies were similar to those of previous studies. No adverse impacts to reservoir fish populations were evident. Winter concentrations of both gizzard and threadfin shad were common.

Dryer and Benson (1956) reported that the abundance of sauger and skipjack herring in the heated discharge from Johnsonville Fossil Plant (temperature rise more than 5 C°, 9 F°) on Kentucky Reservoir was directly related to numbers of threadfin shad during winter months.

During a 2-year investigation of the Colbert Fossil Plant discharge basin and channel on Pickwick Reservoir, sauger, walleye, and skipjack herring also occurred in conjunction with gizzard and threadfin shad concentrations in winter (Wrenn, 1975). Sauger and walleye were absent from the Colbert discharge channel in summer but reappeared there in November in phase with their usual appearance in tailwater areas below TVA dams. Moderate to heavy fishing pressure has occurred at both of these plants, but it has been practically impossible to evaluate the effect of harvest on the total reservoir populations of sauger or walleye. There has been no attempt to determine the effect of predation on threadfin shad at these locations relative to the total population dynamics of this species in the reservoir.

As noted previously, no concentration of fish or concentrated fishing pressure has been observed in the SQN thermal plume during winter. The absence of a concentration of predatory game fish may be associated with the absence of a concentration of prey fish such as threadfin shad. The supplemental creel survey conducted since 1982 in the vicinity of SQN (TRM 482.0-TRM 485.6; SQN mixing zone, TRM 483.4-TRM 483.6), although not designed to test the effect of fishing pressure within or outside of the mixing zone, has shown: (1) blue and channel catfish are the primary species caught within the mixing zone or nearest the discharge diffusers during summer and to a lesser extent during winter, (2) most crappie are caught upstream from SQN near Skull Island, (3) bass fishermen generally are scattered within the whole area, and (4) there are reports of a few sauger having been caught in the area but none have actually been observed in the creel survey.

The impact of fishing pressure, or more appropriately fish harvest, on the populations of various species in Chickamauga Reservoir is a complex issue that will require additional consideration in the future by TWRA and TVA. Because of the temperature and habitat conditions at SQN, however, and as a result of previous observations at existing thermal discharges where the temperature rise is greater than 5 C° (9 F°), no adverse impact relative to fishing pressure on sauger, white crappie, or other species would be expected under the proposed 5 C°

(9 F°) winter discharge limit. Even if fish and fishing pressure were concentrated in the thermal discharge, it would seem contradictory to single out fishing pressure at a thermal discharge as an adverse impact in view of the fact that the concentration of fish and fishermen in tailwater areas is generally recognized as desirable and in view of the fact that both TVA and TWRA promote and endorse various fish attractor projects.

Disease

Fish disease includes all health conditions caused by pathogens (parasites, bacteria, and viruses) and adverse water quality conditions (such as chlorine, dissolved gas supersaturation, and pesticides). Although pathogenic organisms are present in all water bodies, pathogenic disease is infrequently detected in wild fish and rarely causes mass mortalities (Strange, 1983). Therefore, water quality is usually the most important factor relative to health of wild fish.

Condenser cooling water discharges from power plants, regardless of the temperature rise, have not caused significant problems of fish disease, as shown by studies reported in the two national symposia on thermal ecology. An incidental occurrence of gas-bubble disease from supersaturation of dissolved gas (primarily nitrogen) in the discharge canal of Marshall Steam Station (temperature rise, 9.8 to 12 C°, 17.6 to 21.6 F°) was reported by Adair and Hains (1974). However, Otto (1976) reported that gas-bubble disease did not occur at the Zion Station (temperature rise, 8 C°, 14 F°) on Lake Michigan. Eure and Esch (1974) noted a higher loading of helminth parasites in largemouth bass in the heated zone of Par Pond (temperature rise greater than 10 C°, 18 F°), and one species of trematode was higher in mosquitofish in this waterbody (Aho et al., 1976). Neither of these studies indicated that differences in parasite levels caused significant adverse effects to the fish populations. Evaluation of thermal effluent from Connecticut Yankee Plant (27 months monitoring before operation and 21 months during operation) showed no adverse effects on water quality or microbiology in the thermal plume (temperature rise in warmest zone of plume, 11 C°, 20 F°) (Rankins et al., 1974).

The proposed increases in the temperature rise limit would have little effect on winter DO levels and might improve conditions near the bottom during the summer. There are no reports of heated discharges from power plants causing significant reductions in dissolved oxygen (DO) levels in effluents. As noted in this discussion, gas supersaturation is more likely to be an issue. Although low DO has occurred at SQN, this problem originates in upstream reservoirs and is associated with summertime thermal stratification rather than discharges of heated water. Because of the fully mixed or isothermal conditions that prevail from November through March in Chickamauga Reservoir, as well as the high rate of water exchange in this system (as discussed in the hydrothermodynamic section), low DO has not occurred during that period under the present 3 C° (5.4 F°) temperature rise limit. The proposed increase in that limit to 5 C° (9 F°) would result in a loss of less than 0.4 mg/L DO under average winter conditions, when DO averages about 9.3 mg/L.

Outbreaks of fish disease have not been observed in conjunction with operation of SQN under a 3 C° (5.4 F°) temperature rise limit, and none would be expected under the proposed 5 C° (9 F°) limit. TVA monitored fish disease in thermal discharges in conjunction with 316(a) demonstrations for fossil-fueled plants and determined no adverse effects to fish frequenting these discharges. Also, during the series of tests conducted in outdoor channels (temperature rise 3 to 9 C°, 5.4 to 16 F°) at TVA's Aquatic Research Laboratory (formerly the Browns Ferry Biothermal Research Station), no adverse effects of temperature on disease or water quality were observed.

Sampling Methods

During preliminary discussions concerning this demonstration, TWRA and TDWPC expressed questions or concerns about whether the fish sampling methods used in the NPDES monitoring program for SQN were adequate to address the issues of fish concentration in the thermal plume and assessment of reservoirwide populations. These issues are related; therefore, they are addressed concurrently.

The use of gill net sampling and cove rotenone sampling for estimating reservoir fish stocks was questioned in relation to impingement assessment and to differentiating adverse impacts of SQN from other point or nonpoint sources. As noted in the NPDES biomonitoring reports, selectivity of fish capture (by size, species, etc.) by both sampling methods places obvious limitations on the application of the data for precise population estimates. Both methods essentially provide a measure of relative abundance. However, the purpose for including each of these methods in the monitoring program was different. Gill net sampling (one station 0.3 to 0.4 km downstream from the approved mixing zone, and control stations upstream and well downstream) was used to monitor near-field effects or changes from the thermal discharge. Cove rotenone sampling and the reservoirwide creel surveys were used to monitor far-field conditions relative to the potential combined effects of plant operation (thermal, entrainment, impingement, and water quality). Because of the high natural variability in size (by number or biomass) of reservoir fish stocks as well as the limitations imposed by sampling methods, TVA generally recognized that only major changes or impacts could be detected. As concluded in the last two broad-coverage monitoring reports (TVA, 1985b; 1986), monitoring results (10 years before operation and 5 years during operation) have not identified significant adverse changes in fish stocks in Chickamauga Reservoir related to operation of SQN. However, it may be assumed that, had major adverse changes occurred, it may have been difficult to identify the source without followup investigations. Targeted monitoring studies have been initiated to evaluate the population status of individual, important fish species.

Other types of fish sampling gear and other sampling plans could be used to monitor fish populations in Chickamauga Reservoir. Generally, each type of gear has some inherent selectivity as to the size or species of fish captured. Although one type of gear may yield a larger sample of one or more species compared to another type, both can provide a measure of relative abundance that can be used to assess the population of those species. For example, large Wisconsin-type trap nets as well as gill nets were used in monitoring before operation of SQN (TVA, 1978). Although trap nets yielded a larger number of white crappie than gill nets, both types of gear provided a relative abundance value. Both trap net and gill net catches indicated a declining trend for this species from 1973 through 1978. However, due in part to the variability in the total number of trap net lifts per quarter and in the interval of time between lifts, trap nets provided an inconsistent assessment of seasonal distribution for white crappie. Therefore, gill net sampling, which had a consistent unit of effort and a greater number of observations within any given quarter, was selected as the most appropriate technique for evaluating seasonal distribution of white crappie and other species relative to operation of SQN.

In conjunction with the concern about unknown impacts of concentrating large numbers of fish in the SQN thermal plume or mixing zone, specific questions were asked about the use of hydroacoustic sampling. Although hydroacoustic fish sampling is not a new technique, its capabilities have greatly expanded by recent innovations in equipment design and computer development. This sampling technique is especially useful for quantifying numbers or biomass of pelagic species in deep waters. However, because this technique identifies fish only by length, conventional methods of fish capture are required to verify species composition and to establish length and weight relationships for use in estimating biomass. Another limitation of this sampling technique is its inability to detect fish near the surface and bottom areas. Typically, optimum sampling conditions require transducer placement 1 meter below the surface, and there is also a bottom window (which blanks out returning signals) of 1 meter. Fish cannot be detected in these two critical areas.

TVA began reservoirwide hydroacoustic sampling on Chickamauga Reservoir in August 1987, and subsequent surveys were made in March and August 1988 and in February 1989.

A special survey was conducted in the vicinity of SQN on January 12, 1989, when both units were operating near peak load (2,089 MWe). One unit (1,192 MWe) was generating during the February

1989 survey. An additional variable during the January and February 1989 surveys was riverflow. Floodgates were opened during the January survey, and the flow past SQN was about 60,000 cfs, compared to a flow of 10,200 cfs through Chickamauga Dam during the March 1988 survey. Although concurrent trawl sampling was not conducted for verification, results of the January and February surveys indicated higher target densities in the transects downstream from the underwater dam and the SQN diffusers compared to target densities immediately upstream, especially during January (Table 7). In this case, fish may have been attracted to both thermal and nonthermal conditions in this area. Target densities in the February 1989 survey (full operation of one unit at SQN), as a whole, were similar to those observed during March 1988 when the plant was not online.

Although hydroacoustic sampling may eventually provide a better quantitative estimate of fish concentration in the SQN thermal discharge than present methods, observations to date indicate that large concentrations of game and prey fish species have not occurred in winter. On the other hand, known winter concentrations of fish at power plants within and outside the TVA system have seldom caused adverse impacts. Winter concentration of fish in thermal discharges has been a common phenomenon, but definitive studies at various locations since the mid-1970s (including use of hydroacoustic surveys and radio telemetry) have shown that discrete populations of fish, especially predatory game species, do not reside continually in these areas and that temperatures selected by fish in these areas are usually intermediate between ambient conditions and the maximum temperature available (Neill and Magnuson, 1974; Minns et al., 1978; Ross and Winter, 1981; Ross and Siniff, 1982; and Spigarelli et al., 1982).

Status of Important Species

Having met the necessary NPDES permit requirements in 1985, as approved by EPA, TVA terminated several aspects of the broad coverage monitoring program that was originally designed to identify adverse

Table 7. Number of Targets Detected Per Cubic Meter By Transect During Hydroacoustic Surveys Conducted on Chickamauga Reservoir Near Sequoyah Nuclear Plant, January 12 and February 7, 1989.

Survey Transect Number	Transect Location (TRM)	Temperature (°C)	Target Density (No./m^3)	95 Percent Confidence Interval
		January 1989		
1	482.4	8.6	45.7	22.6
1A	482.9	-	11.4	6.6
1B	483.3	8.9	32.6	10.5
2	483.4	-	19.4	10.2
3[a]	483.6	9.0	39.4	15.4
4[b]	483.8	7.8	36.0	16.2
4A	484.3	-	27.4	5.6
5	484.9	7.8	12.3	7.2
6	485.4	7.8	10.7	10.6
		February 1989		
1	482.4	9.5	10.1	4.2
2	483.4	10.5	13.2	13.9
3[a]	483.6	-	21.7	11.0
4[b]	483.8	-	6.2	4.6
5	484.9	8.5	7.7	2.8
6	485.4	8.5	3.3	2.0

[a] Transect located immediately downstream from the diffuser area.
[b] Transect located immediately downstream from the underwater dam.

changes, both spatial and temporal, in water quality and biological communities from the operation of SQN (TVA, 1986). Although few changes were identified, a revised monitoring program has been continued since 1986 to address those changes that could potentially be attributable to SQN, as well as other issues of special concern that apply to Chickamauga Reservoir as a whole. Under this revised program, TVA initiated targeted investigations of population status and dynamics of sauger and white crappie that included additional sampling and data collection as well as further analyses of the existing database. Annual internal progress reports have been prepared. The following sections summarize the results through 1988.

White Crappie

Since 1972, white crappie dominated the creel overall on Chickamauga Reservoir, but largemouth bass or channel catfish harvest (biomass) has been higher since 1982. Wide fluctuations in estimates of annual white crappie harvest have been common, and from 1982 through 1985 a declining trend was apparent, ranging from about 14,000 kg in 1982 to 8,000 kg in 1985. Catch rates also declined. During this period and through 1987, trend analysis of the rotenone data showed declining trends in numbers and biomass of both intermediates and adults but not for young-of-year white crappie.

Results of TVA's investigations since 1986 indicate that the declining trend for adult white crappie in Chickamauga Reservoir is not a result of unsuccessful spawning, because annual mean densities of larval crappie and numbers and biomass of young-of-year crappie in cove rotenone samples have increased through time. Three factors have been identified as directly or indirectly affecting the white crappie population: increased submerged aquatic macrophytes (sevenfold increase in acreage since 1974), competition with sunfish (lepomis) for food and habitat, and high mortality of crappie during their first winter from failure to attain sufficient size to switch successfully to a piscivorous diet. Also, increased numbers and biomass of black crappie in creel and rotenone samples indicate that a total shift in dominance may be occurring between these two species. If this occurs, increased numbers and harvest of black crappie may compensate for declining numbers of white crappie. However, such declines may be only temporary: the estimated white crappie harvest exceeded 20,000 kg in 1987 (Table 3). TVA judges the potential for adverse impacts to white crappie from operation of SQN to be minimal.

Sauger

Although sauger occur occasionally in rotenone samples, only gill netting and creel surveys are effective sampling techniques for this species because of habitat preference and seasonal distribution. Although no distinct trends in relative population abundance of this species could be discerned by gill net sampling before 1986, an obvious decline in harvest estimates from creel surveys in 1979 through 1984 (Table 3) was of special concern to TWRA. Harvest estimates (biomass) increased during 1985 and 1986 and slightly declined in 1987. However, a new method of calculating harvest estimates, initiated by TWRA in 1984, resulted in much higher estimated harvest, even though the actual numbers of sauger creeled were similar in both study periods.

In cooperation with TWRA, TVA initiated an intensive program in 1986 that included gill net sampling and tagging (mark and recapture) to evaluate further the sauger population in Chickamauga Reservoir. Results of these investigations have provided important information on population density, distribution and movement, and timing and location of spawning.

Before spawning, sauger congregate below Watts Bar Dam from early February until late March. As water temperature approaches 11°C (52°F), most adult-male sauger move downstream 7 miles to the Hunter Shoals spawning area and remain there until early May. Females wait until imminently ready to spawn, move onto the spawning area, spawn, and leave the area within a few hours. Spawning activity is highest at the end of March and continues about two weeks into April, depending on water temperature. After spawning ceases, sauger generally disperse both upstream and downstream. Annually, 15 to 20 percent of the adult sauger move between Chickamauga and adjacent reservoirs. Considering this level of integration of reservoir sauger populations, it is evident key spawning areas in one reservoir may supply or supplement sauger year classes in other reservoirs.

Estimated numbers of adult sauger migrating to upper Chickamauga Reservoir declined from about 18,000 fish in 1986 to less than 1,300 fish in 1988. Total harvest rates remained stable over the 1986-88 period (5 to 8 percent), indicating that fishing pressure is not a significant cause of decreasing sauger abundance. The main reasons for declining abundance from 1986 through 1988 were the weakness of the 1985 and 1986 year classes and the normal high mortality of older age classes.

Water temperature, especially a gradual rise, was the only condition correlated with progression of spawning maturity and time of spawning. The operation schedule of Watts Bar Dam is an important influencing factor on water temperatures in the sauger spawning area of upper Chickamauga Reservoir. Consistent releases from the dam result in less variation in downstream water temperatures. Fluctuations in releases and downstream ambient water temperature during the 1986 sauger spawning period delayed both sauger maturation and spawning activity to the extent that water temperatures may have reduced gamete viability and egg survival. Gradual warming during the 1987 spawning season produced more sustained spawning activity at lower temperatures. Because yearling sauger are generally not collected during winter and spring sampling in reservoir headwaters, however, the first definitive information on success of the 1987 sauger spawn will be provided by sampling in 1989 and 1990.

Reduced turbidity is considered unfavorable for reproductive success of sauger and may be the most important factor affecting the apparent decline in the sauger population in Chickamauga Reservoir. However, the effect of high turbidity could not be evaluated as a factor influencing spawning success because the severe drought during the three years of study resulted in consistently low turbidity. Also, other TVA studies indicate that the drought in the 1980s affected sauger densities or reproductive success in other locations, especially in the Clinch River arm of Watts Bar Reservoir and in Fort Loudoun and Wheeler Reservoirs.

Although the most recent harvest estimates based on creel surveys are not consistent with the mark-and-recapture population estimates for adult sauger, results of the revised monitoring program definitely indicate that the sauger population is well below historical levels. Winter thermal discharge from SQN is not considered to be a factor in this decline.

HYDROTHERMAL ASPECTS OF CHICKAMAUGA RESERVOIR

The natural hydrothermal conditions of Chickamauga Reservoir from November through March are characterized by descriptions of reservoir geometry, river flow, and water temperature. The potential effects of an alternative wintertime thermal rise limit were evaluated by use of simulation models and historical monitoring data for river flow and temperature.

Natural Hydrothermodynamics of Chickamauga Reservoir

Chickamauga Reservoir Geometry

Reservoir Elevations--From November through March, reservoir levels are normally at winter or low pool elevations, near 675 feet msl. Figure 3 shows the operating guide curve for Chickamauga Reservoir. During November, the reservoir is drawn down for flood control, in anticipation of winter runoff. By mid-November the reservoir elevation is in the usual winter fluctuation range, with 675 feet msl targeted from January 1 through April 1.

Longitudinal Geometry--Chickamauga Reservoir extends 58.9 miles (94.8 km) from Chickamauga Dam (TRM 471.0) to Watts Bar Dam (TRM 529.9). The SQN intake is located at TRM 484.5 (right bank). The depth of the main channel shown in profile in Figure 4A increases between Watts Bar Dam and SQN, where the maximum channel depth is approximately 50 feet at low pool. From SQN, the main channel depth at low pool increases to a maximum of 65 feet at Chickamauga Dam.

Reservoir width follows a similar pattern of downstream increase. The reservoir is narrow and riverine with occasional embayments from Watts Bar Dam to the vicinity of Hiwassee River embayment (TRM 500). The reservoir width and cross-sectional area increase between the Hiwassee River embayment and Chickamauga Dam. In this reach, the reservoir includes shallow overbank areas with depths of 5 to 8 feet.

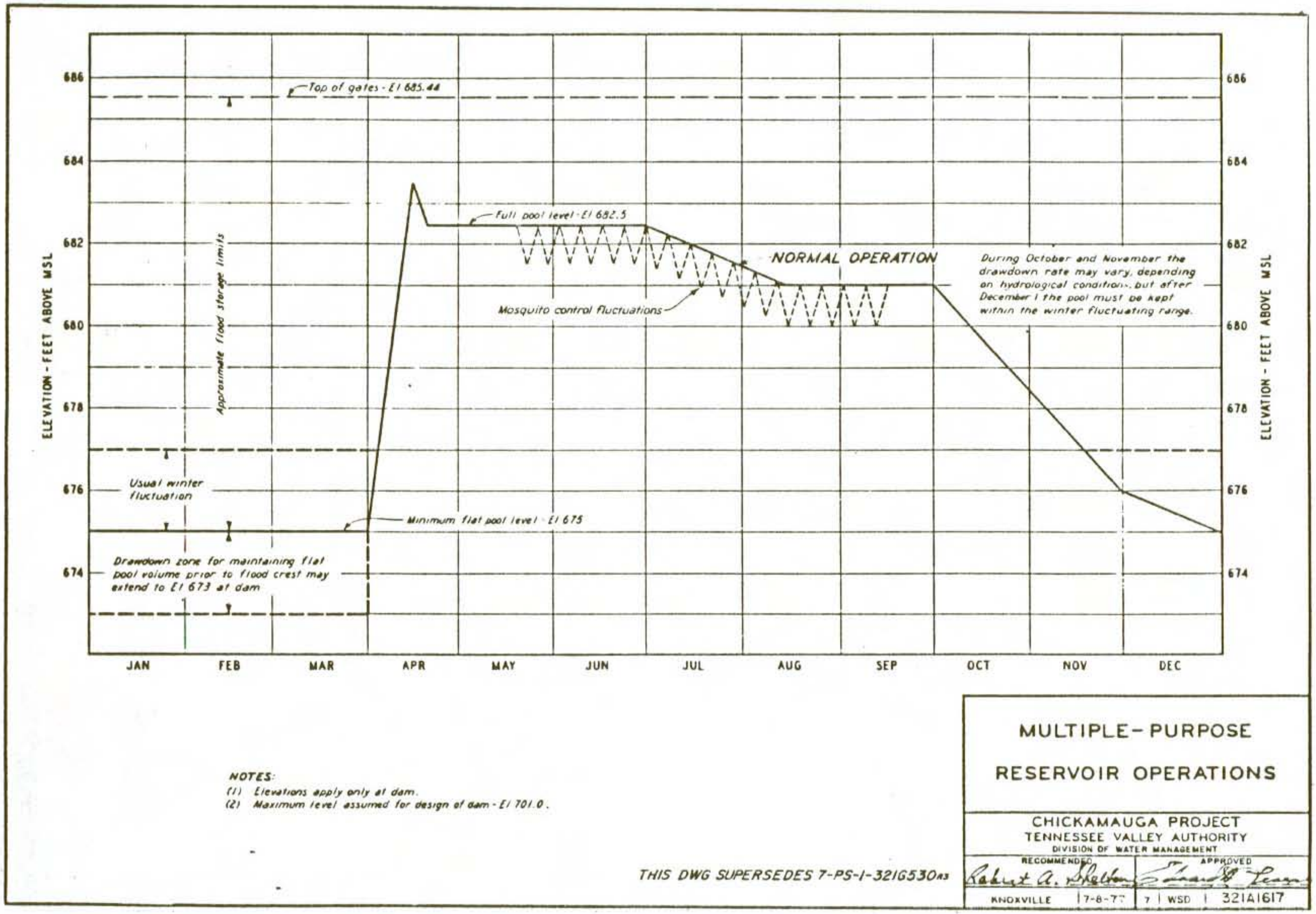
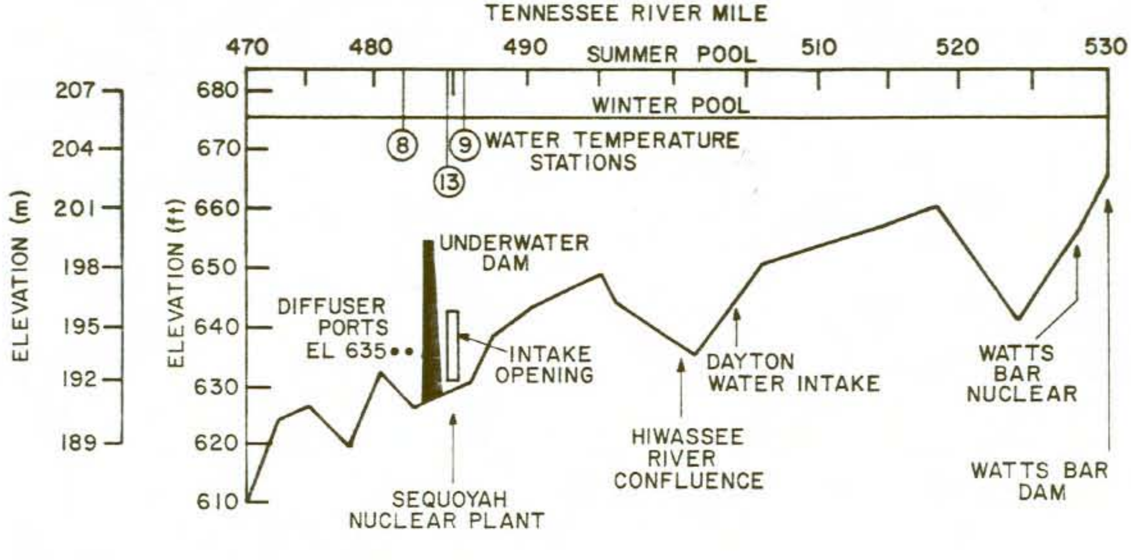


Figure 3. Reservoir Operating Guide Curve for Chickamauga Reservoir.

A. Chickamauga Reservoir Profile



B. Longitudinal Volume Distribution From Watts Bar Dam

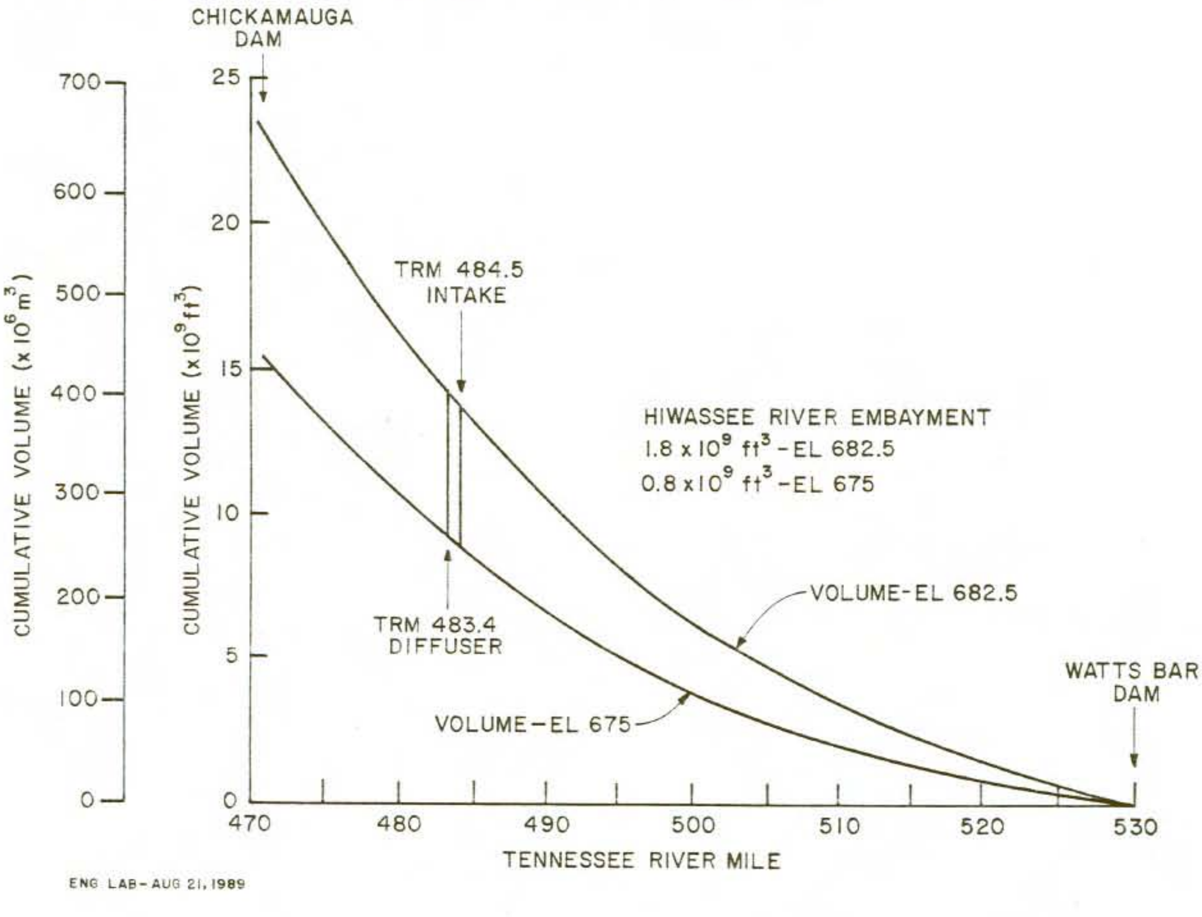


Figure 4. Chickamauga Reservoir Depth Profile and Longitudinal Volume Distribution.

SQN is located within the segment of reservoir having both a deep main channel and shallow overbank areas. The downstream portion of Chickamauga Reservoir is deep and relatively wide with significant overbank areas.

The cross-sectional area above the Hiwassee River embayment is comparatively small, gradually increasing downstream towards SQN and further increasing towards Chickamauga Dam (Figure 4B). The different cross-sectional areas affect flow velocities and patterns at these reservoir locations. The upstream portion of the reservoir has higher velocities, which provide a great deal of turbulence and usually result in full mixing. Velocities in the downstream portion of Chickamauga Reservoir are lower because the cross-sectional area is greater. Turbulent mixing decreases as velocity decreases. However, slightly higher reservoir velocities in the winter, caused by low pool elevation, higher average flows, and normal cooling conditions, promote full mixing from November through March.

Shallow Regions--The shallow portions of Chickamauga Reservoir can be divided into embayment areas partially isolated from the main reservoir, shallow areas near shore along the main channel in the riverine reaches, and overbank areas along the main channel.

Embayments are often quite shallow, with mean depths of 3 to 6 feet, and are relatively isolated from the main channel flow. When fully mixed, embayments can cool rapidly in response to changing weather because of their large surface area relative to their volume (low mean depth). Embayments downstream from SQN may also contain slightly cooler water from runoff that has not been affected by the thermal discharge.

The shallow areas near the main channel in the riverine reaches are directly influenced by the main channel flows and temperatures.

Overbank areas, such as those between the Hiwassee River embayment and Chickamauga Dam (both upstream and downstream of SQN) 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.

When the reservoir is fully mixed from November through March, temperatures in shallow areas are very similar to those in the main channel, although the shallower areas may respond more quickly to changing weather.

River Flow and Residence Times

Historical Reservoir Operations--Instantaneous river flows in the vicinity of SQN depend upon previous discharges from Watts Bar Dam (TRM 529.9), 45.4 miles upstream, and from Chickamauga Dam (TRM 471), 12.5 miles downstream. The dams are normally operated for peaking power, and releases are reduced during the early morning hours when power demand is low. The 1976-88 annual average release at Chickamauga Dam was 29,787 cfs. Reservoir inflows from the Hiwassee River are of secondary importance, because the mean annual flow was 4,719 cfs for 32 years of record.

Because flows through Chickamauga Reservoir affect the mixing and travel time through various reservoir segments, flow conditions must be considered in evaluations of temperature patterns in the vicinity of SQN. A 1-dimensional, unsteady state, numerical flow-routing model (Ferrick and Waldrop, 1977) was used to determine hourly flows at SQN on the basis of hourly discharges from Watts Bar and Chickamauga Dams for 1976-88 (Table 8).

Table 8. Monthly River Flows at Sequoyah Nuclear Plant, 1976-88.

	Average Monthly Flow					
	Cumulative		Minimum		Maximum	
Month	Flow (cfs)	Years	Flow (cfs)	Year	Flow (cfs)	Year
Nov	25,100	1976-88	15,400	1978	55,800	1979
Dec	32,700	1976-88	12,800	1987	69,700	1977
Jan	36,000	1976-88	15,900	1981	63,900	1979
Feb	34,000	1976-88	22,300	1977	73,200	1982
Mar	30,700	1976-88	11,900	1988	72,200	1979

Residence times from SQN to Chickamauga Dam were estimated by displacing the cumulative volume of water contained in the reservoir at low winter pool elevation. This volume was divided by the historical flows to provide residence times in days (Table 9).

Table 9. Monthly Average Travel Times in Chickamauga Reservoir From Sequoyah Nuclear Plant to Chickamauga Dam.

	Monthly Average Residence Time, Days		
Month	Cumulative	Maximum	Minimum
Nov	3	5	1
Dec	2	6	1
Jan	2	5	1
Feb	2	3	1
Mar	2	6	1

Under average flow conditions, water in Chickamauga Reservoir downstream from SQN is displaced in about two days. At the lowest monthly flows in the historical record, residence time varied from three to six days. Any effect of SQN operations from November through March passes out of Chickamauga Reservoir well before the summer.

River flows near SQN vary significantly during the course of a day as a result of peaking operations at the upstream and downstream dams. Figures 5A and 5B show typical flows at SQN during months of low and average river flow. Hydro operation on a given day consists of zero release from the dams during the night. When the demand for electricity picks up, releases from the dams are used to meet peak demand periods. The dams release in increments of about 8,000 to 10,000 cfs in the normal range of efficient operation; therefore, flows during the day can range from 8,000 cfs to about 40,000 cfs at full hydro output. Spilling conditions during extremely wet years can cause higher flows. The daily fluctuations in dam releases can also cause reverse flows (sloshing) at SQN when releases are stopped at night. Appendix A shows a breakdown of hourly flows from November 1976 to March 1989. The minimum daily average flow at SQN for November through March has been between 5,100 and 6,300 cfs for 1976-89, based on the present minimum average daily flow constraint of 6,000 cfs from Chickamauga Dam.

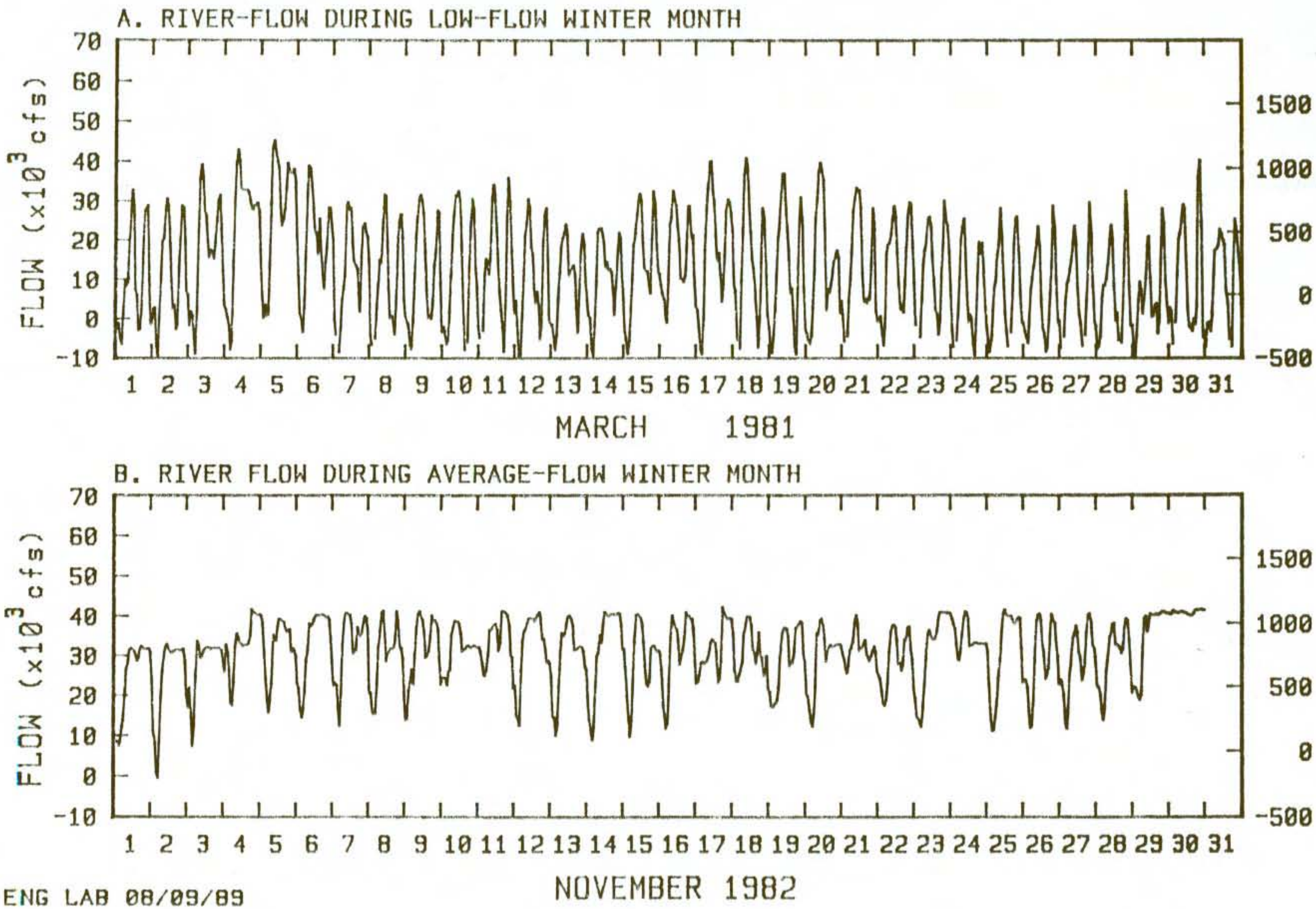


Figure 5. Typical River Flows at Sequoyah Nuclear Plant During Low and Average Flow Months.

Potential Changes in Reservoir Operations--TVA is conducting a Tennessee River and Reservoir System Operation and Planning Review, primarily to determine whether and what changes could or should be made to reservoir operations. Greater minimum tributary dam release flows and higher tributary lake levels are being considered as well as changes to releases from mainstream dams. Changes in reservoir operations could affect the November through March period and the historical flow data used in the evaluation (Miller and Parsly, 1989).

Potential minimum release flows would probably not affect releases at Watts Bar and Chickamauga Dams from November through March. A review of the modeling data from reservoir operation simulations showed essentially no effect of minimum release scenarios compared to the present (base case) operation. Most of the minimum flows were modeled at weekly intervals. Variations within the week may be similar to those that now occur.

Keeping tributary reservoirs at higher pool levels into the summer would affect flows at SQN from November through March. In general, dam releases would be slightly higher in November and December, about the same in January and February, and slightly less in March. Figure 6 shows a flow duration curve for March at Chickamauga Dam for modeling simulations that compared present operation (BASE5) with the JULY29 lake level case. The JULY29 simulation case targeted lake levels to a selected value until July 29. Lower flow occurrences increased by up to 7 percent during March when aggressive reservoir filling occurred. Potential changes in reservoir operation policy (TVA, 1989) will be made available for public review and more study before adoption. The effect of potential reservoir operation changes on the thermal conditions at SQN is discussed in a later section of the report. These potential changes, should they occur, would not be expected to alter the conclusions of this 316(a) demonstration.

Observed Natural Water Temperature Patterns

The temperature patterns observed in Chickamauga Reservoir are constantly changing in response to varying flow and meteorological

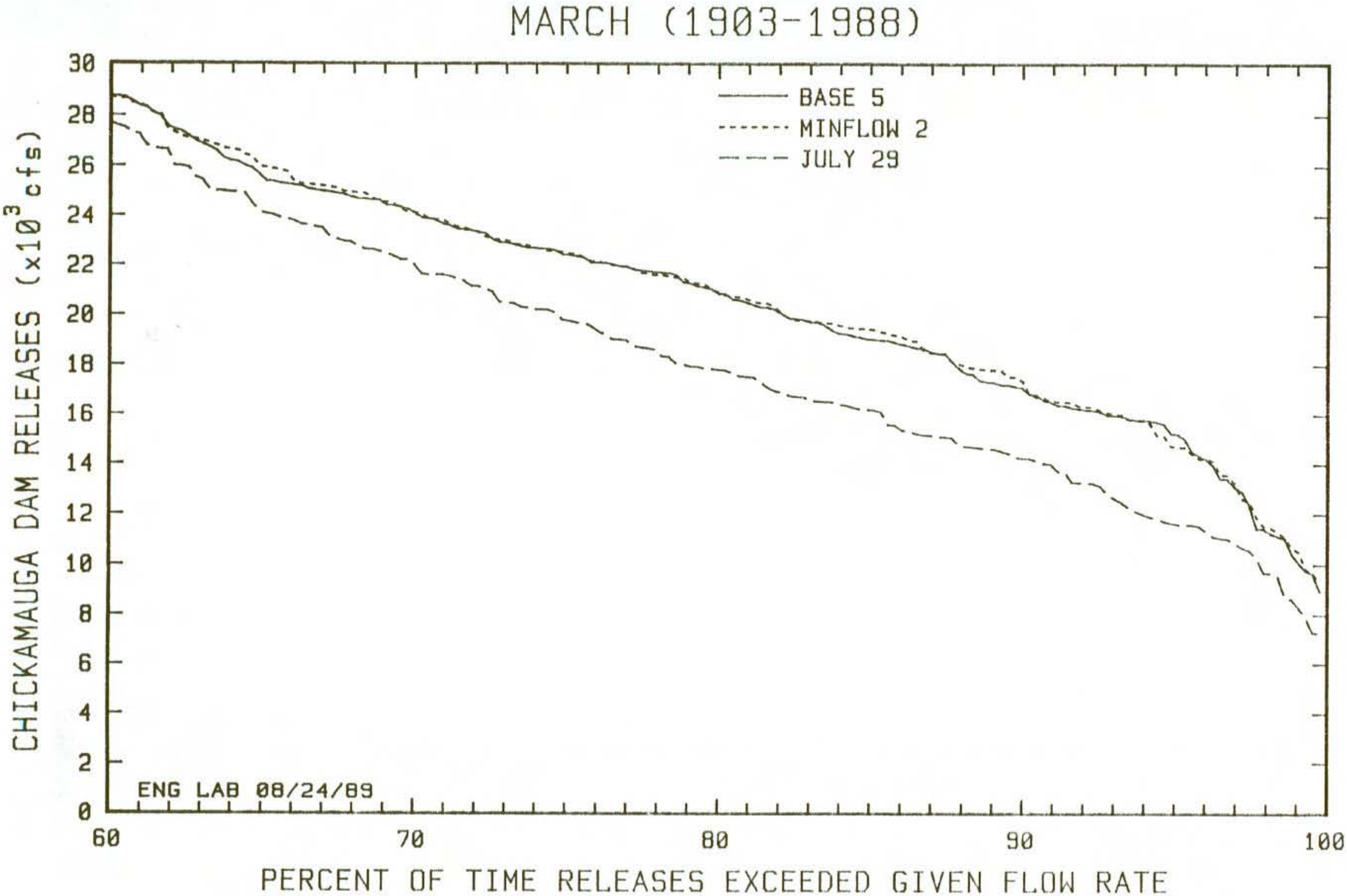


Figure 6. Flow Duration Curves for Releases From Chickamauga Dam During March, Based on Reservoir Operation Planning and Review Simulations.

conditions. Records of winter water temperature patterns are based on data from the SQN thermal monitoring network.

Time Scales and Magnitudes of Variation--Chickamauga Reservoir undergoes the annual cycle of temperature change typical of controlled reservoirs of medium depth. Figure 7 shows a typical annual cycle of water temperatures (for 1984) at the SQN intake. The overall magnitude of the seasonal variation is remarkably constant, with winter temperatures typically between 1 and 8°C (34 and 46°F), and summer temperatures approaching 29 to 31°C (84 to 88°F). Thus, water temperatures vary seasonally about 30 C° (54 F°).

From November through March, water temperatures range from 1 to 21°C (34 to 70°F), as shown in Figure 2. 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 fluctuations, but water temperatures in the entire reservoir commonly change by 3 C° (5 F°) in 10 days. These transient fluctuations are generally larger in spring. Any changes that affect water temperatures from November through March would not impact the annual cycle of water temperatures in other months because of the short residence time in the reservoir.

Daily variations in water temperatures upstream from SQN are small because the reservoir is fully mixed from November through March. Figure 8 shows hourly data upstream at the 5-foot depth. Extreme meteorological conditions of heating or cooling can sometimes change temperatures as much as 2 C° (4 F°) within a day; however, these extreme conditions are rare. Most daily variations are less than 1 C° (2 F°).

Temperature Patterns in the Main Channel--The main channel in the upstream, riverine portion of Chickamauga Reservoir is fully mixed during fall, winter, and early spring; therefore, diurnal fluctuations are relatively small. However, rapid changes in meteorological conditions can cause significant fluctuations in water temperature. In the downstream portion of the reservoir, near Chickamauga Dam, water

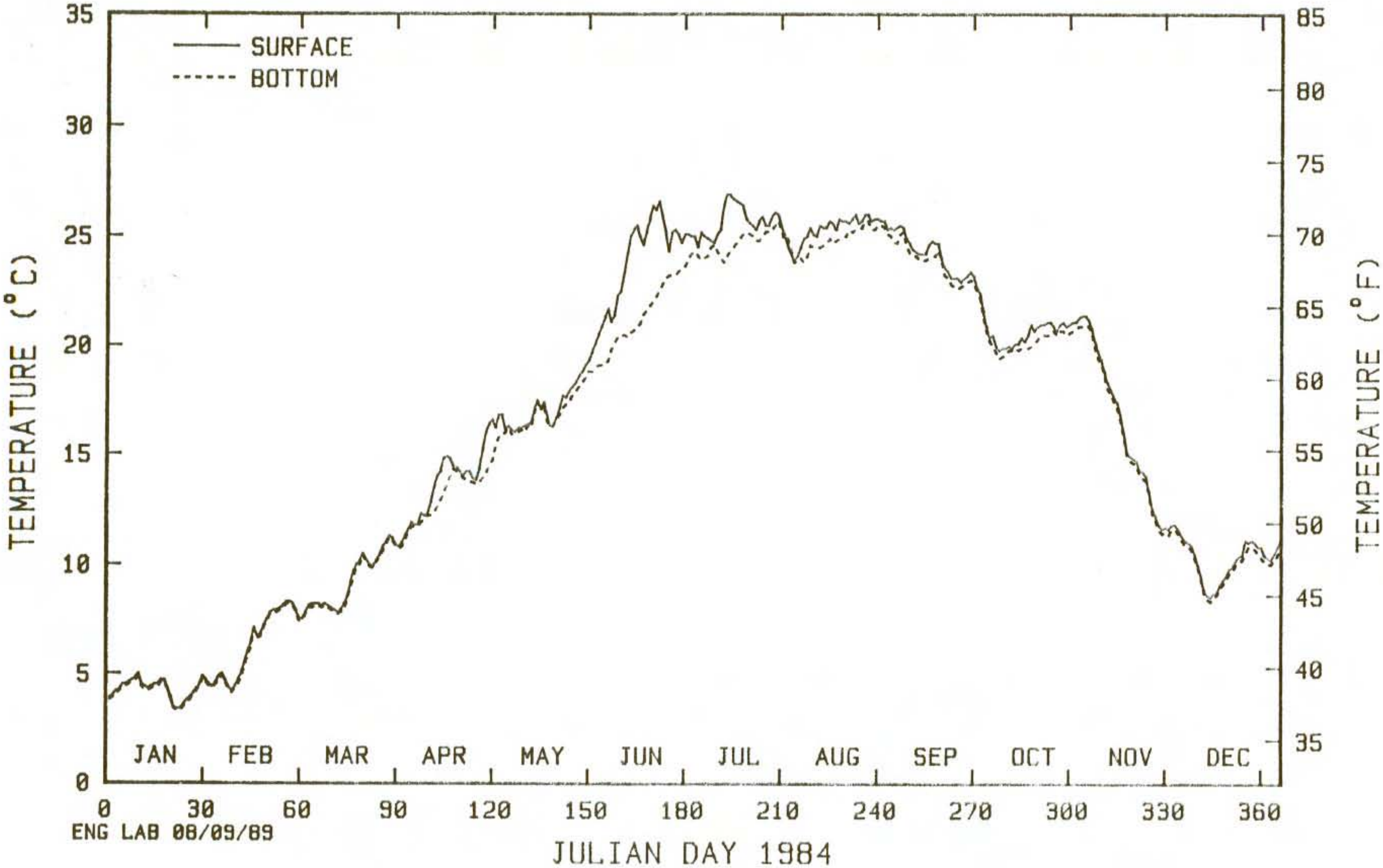


Figure 7. Annual Water Temperatures at Sequoyah Nuclear Plant Intake, 1984.

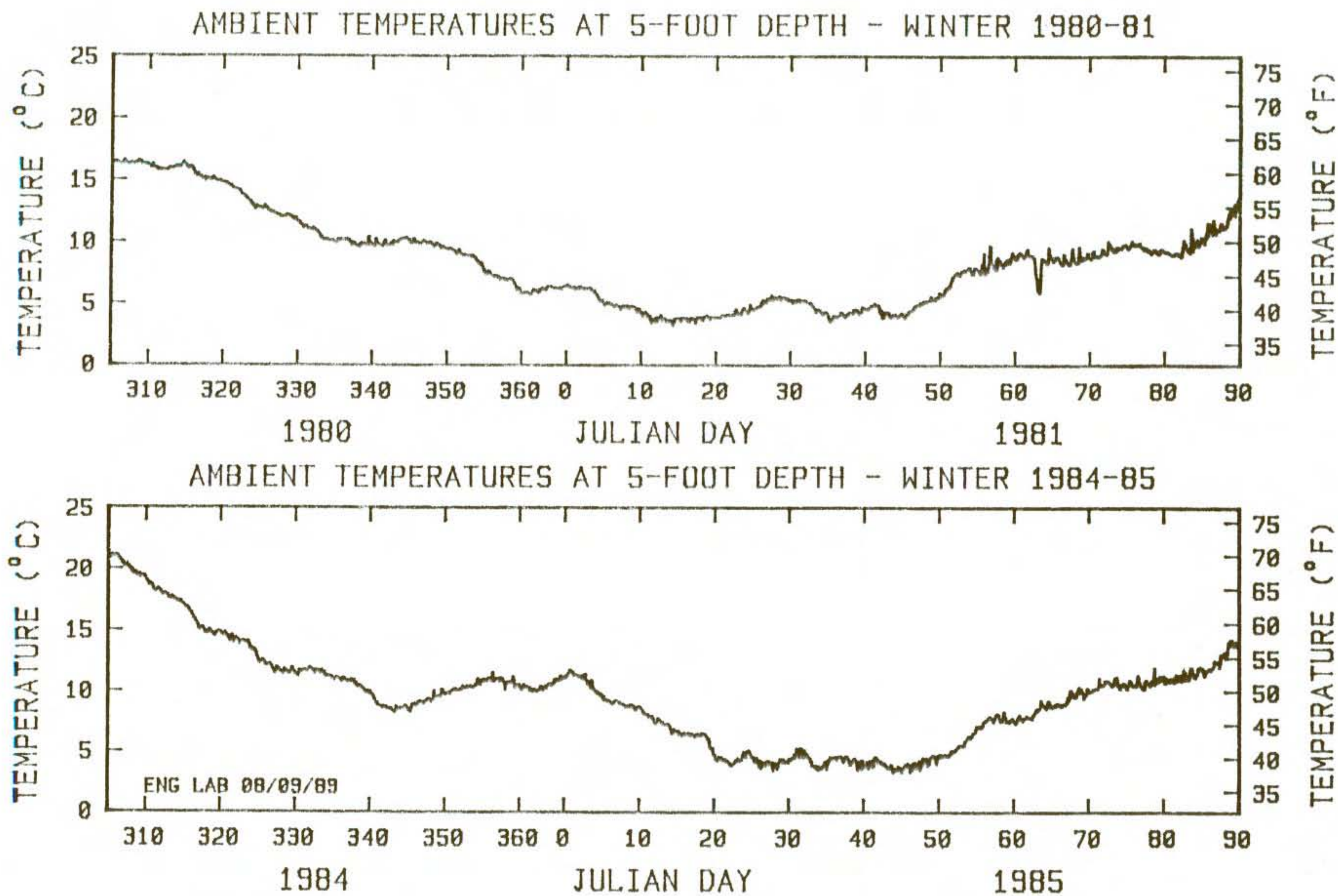


Figure 8. Daily Variation of River Temperatures Upstream From Sequoyah Nuclear Plant.

depths at low pool are near 65 feet, and the large cross-sectional areas result in low velocities and limited turbulent mixing. Because of low air and water temperatures and high flows, however, this downstream portion of the reservoir experiences little or no thermal stratification in winter.

Temperature Patterns in Shallow Regions--The temperature patterns are quite similar in the overbank and main channel areas, despite differences in depth and flow-induced mixing. Any differences are largely confined to the near-surface layer and to periods of rapid warming or cooling. Cooling is more rapid in the overbank areas, 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.

Fully Mixed Conditions at SQN--Daily average reservoir temperatures at the SQN intake, presented in Figure 2, are used to characterize the variation of surface and bottom temperatures. During November and December, convection cooling occurs because air temperatures are lower than water temperatures. During January, temperatures are usually fairly stable. In February and March, warmer air temperatures and solar radiation begin heating the reservoir. High flows and low pool elevations in the reservoir during the winter and early spring usually mean full mixing and uniform temperatures throughout the entire depth of the reservoir. Figure 2 shows that only near the end of March do surface temperatures begin to be slightly warmer than bottom temperatures.

Changes in Temperature Patterns Resulting From Potential Changes in Reservoir Operations--The minimum dam release and higher lake level alternatives are not expected to significantly alter temperature patterns in Chickamauga Reservoir in November through March. Because minimum release alternatives do not significantly affect flows in November through March, temperature patterns are not expected to change. Higher lake level alternatives would mainly affect temperatures in the mainstem reservoirs in the summer period, but there may be a tendency toward cooler November temperatures. Any potential delay in reservoir turnover would occur before November. Lower flows in February and March may cause a slight increase in stratification during surface heating periods (Hauser et al., 1989).

Hydrothermodynamics of Chickamauga Reservoir Under Proposed Winter Temperature Rise Limit

The effect of the proposed winter thermal limit for the SQN discharge into Chickamauga Reservoir was studied by use of simulation models and available historical data. Thirteen years of historic river flows and ambient temperatures were used. This period of record contains both normal and extreme temperature and flow conditions and should be representative. For a conservative evaluation, SQN was assumed to operate at maximum 2-unit loads for the entire study period, with no consideration given for refueling or maintenance outages. A computer model was used to simulate the effects of diffuser mixing of the heated discharge in the mixing zone for November through March from 1976 through 1989. The computer model used in this study is now used for demonstrating compliance with thermal discharge limits at SQN and includes upgrades made as a result of operational experience. Further information concerning the model can be found in McIntosh et al., 1983. An analytical model of the surface heat exchange was used to determine heat loss from the thermal plume downstream from the mixing zone.

Description of Model for Diffuser Mixing

The computer model simulates the diffuser-induced mixing downstream from SQN near the 5-foot compliance depth. The plant-induced temperature rise is defined as the difference between the diffuser-induced mixed river temperature downstream from the thermal discharge and the ambient temperature measured at the upstream intake. Initial diffuser-induced mixing occurs rapidly in the mixing zone; model-predicted temperatures occur within 500 feet downstream from the diffuser. The defined mixing zone for SQN extends 1,500 feet downstream from the diffusers. Natural mixing and surface heat loss downstream from this point will be discussed in a later section. The computer model of diffuser mixing requires four inputs: diffuser discharge temperature, diffuser discharge flowrate, ambient river temperature, and ambient river flowrate.

Discharge temperatures were based on a maximum net plant production of 2,560 MW of electric power with an associated waste heat output of 16.4×10^9 Btu/hr. Anticipated worst-case maximum plant operation from November through March, with four CCW pumps in operation, would result in a plant discharge flowrate of about 2,000 cfs. The resulting condenser temperature rise at maximum heat output is 20 C° (36 F°). The condenser temperature rise was added to the ambient upstream temperature at the intake depth to obtain a discharge temperature for thermal plume modeling. The simulation model evaluates the plant-induced temperature rise with the assumption that the plant is operated entirely on river cooling. Reduction of thermal discharge from use of cooling towers was, therefore, not considered.

Ambient river temperatures were obtained from monitors at Station 9 for the winters of 1976-77 through 1979-80 and at Station 13 for the winters of 1980-81 through 1988-89 (Figure 9). Station 9, the ambient monitor used until 1980, was located at TRM 485.2. Station 13, the present ambient monitoring station, is located on the intake skimmer wall at TRM 484.5.

River flowrates primarily depend on dam releases at Watts Bar and Chickamauga hydroelectric plants. Data for hourly dam releases for the 13 winter periods studied were used to run a finite-difference, unsteady flow model to evaluate the instantaneous river flows at SQN. The hourly flows at SQN are shown in Appendix A.

Results of the Diffuser Mixing Model

Results of the simulation model are summarized on a monthly basis. Examples of average and low river flow during winter months are shown in Figures 10 and 11. Graph A on these figures shows the upstream

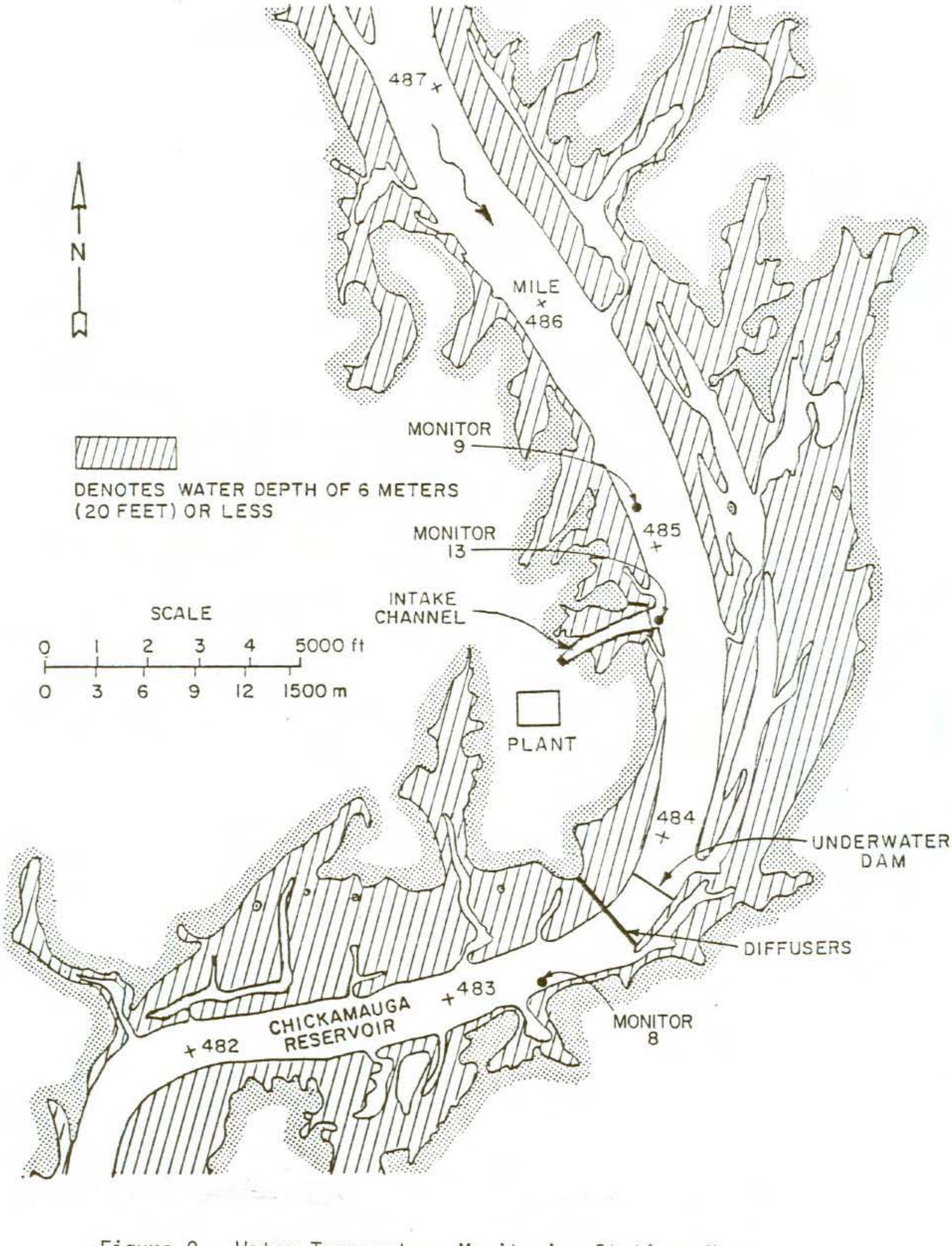


Figure 9. Water Temperature Monitoring Stations Near Sequoyah Nuclear Plant.

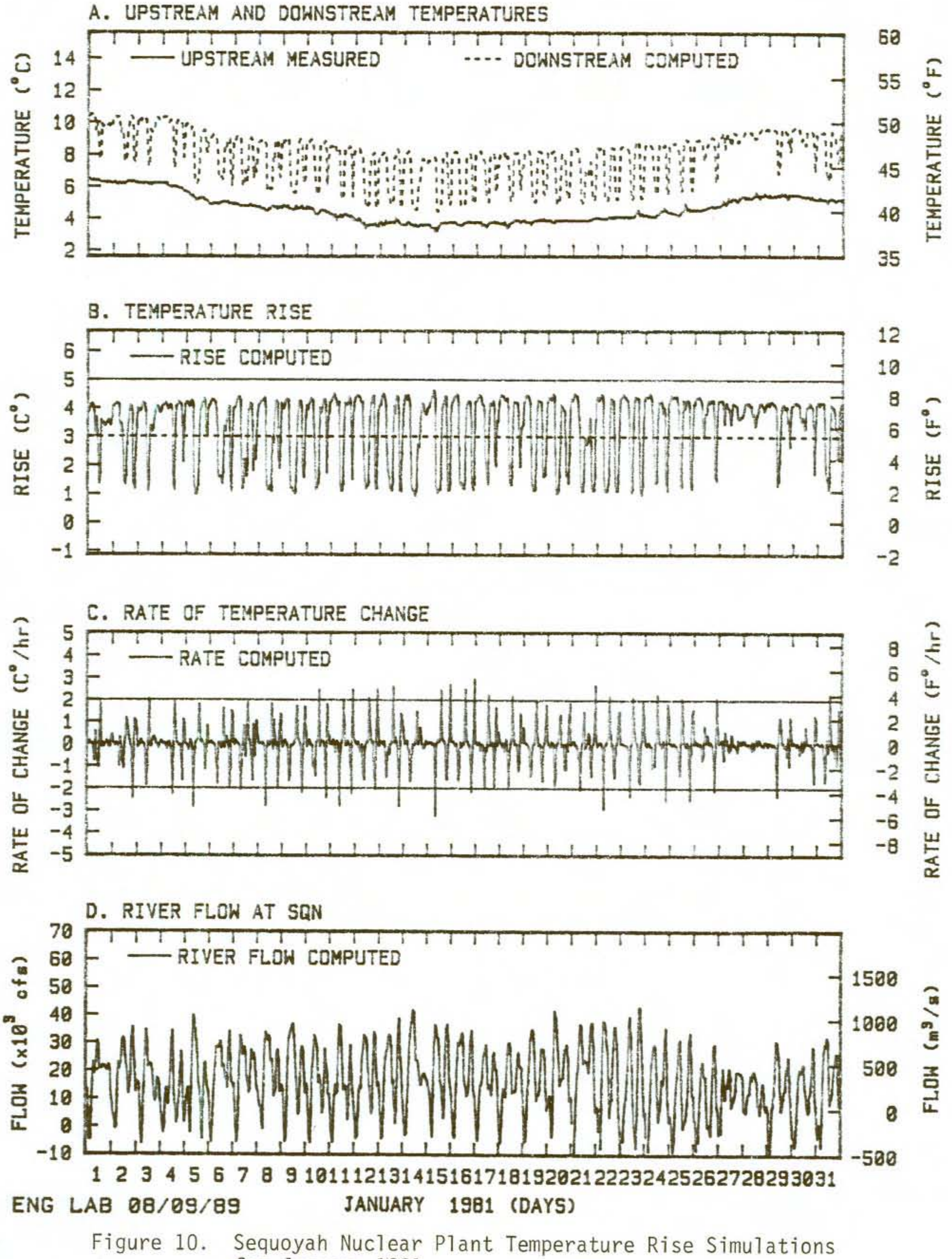


Figure 10. Sequoyah Nuclear Plant Temperature Rise Simulations for January 1981.

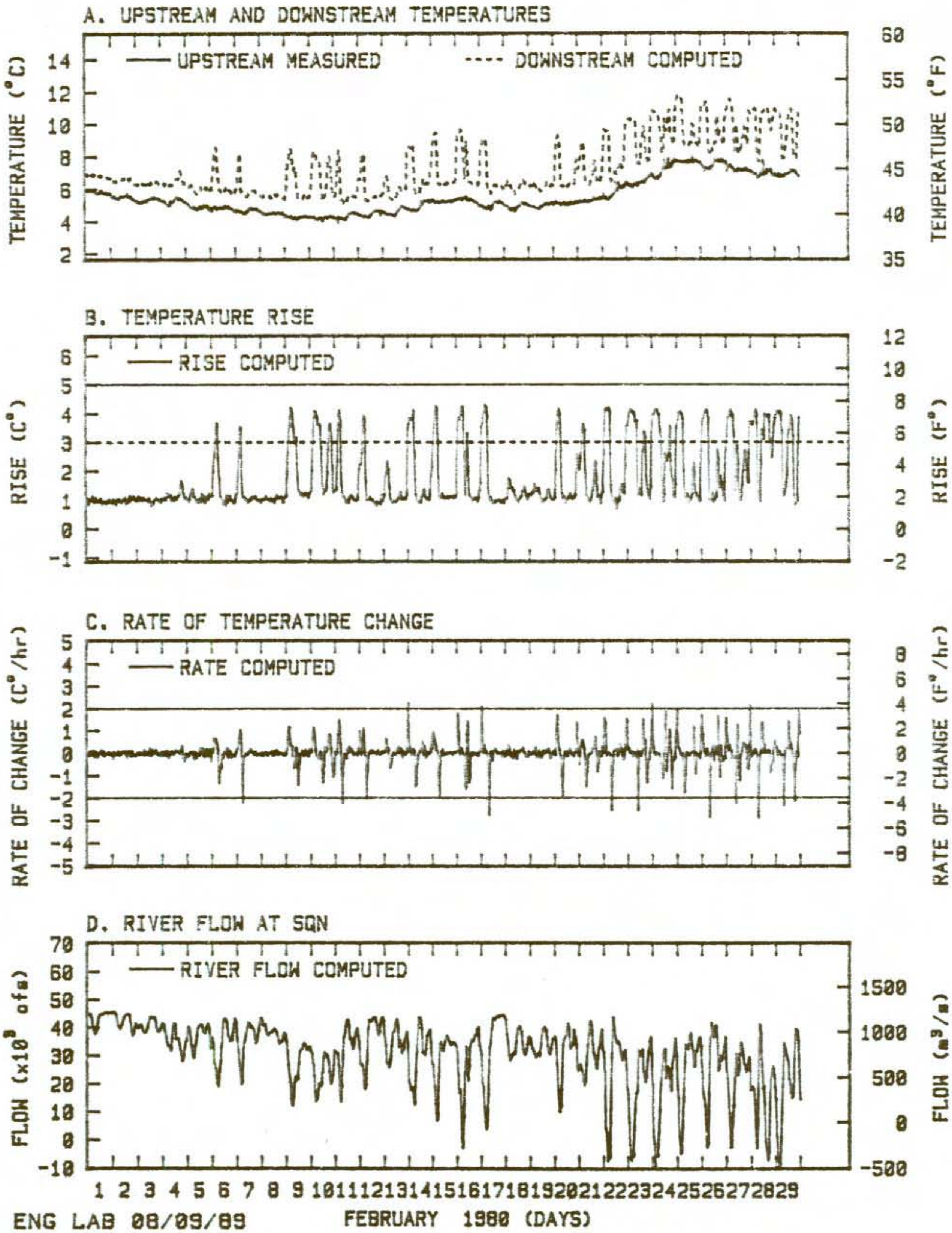


Figure 11. Sequoyah Nuclear Plant Temperature Rise Simulations for February 1980.

temperature measured at the 5-foot depth and downstream temperature modeled at the 5-foot depth. Graph B shows the modeled temperature rise, Graph C shows the modeled rate of temperature change, and Graph D shows river flows at SQN simulated by the routing model. The computed downstream temperature, temperature rise, and rate of temperature change are determined for the point where the diffuser-induced mixing ends, normally within 500 feet of the diffuser. On a daily basis, river flows vary from short periods of reverse flow (less than 10,000 cfs) during the night to 20,000 to 40,000 cfs during the day. Higher temperature rises occur when river flows drop below 26,000 cfs. Computed rates of temperature change are sometimes outside the defined 2 C° (3.6 F°) limit. These occurrences are based on instantaneous readings and are not indicative of real-time results. Compliance with the present rate of temperature change is based on an average of instantaneous readings taken every 15 minutes. These readings are then averaged over an hour to determine a more realistic measure of compliance with the rate of change limit.

Appendix B summarizes each of the 13 winters studied. Maximum SQN operation would exceed the present temperature rise limit an average of 27 percent of the time on an hourly basis. The majority of the higher temperature rises would be less than 4 C° (7 F°). Temperature rises higher than 4 C° (7 F°) would occur about 4 percent of the time. The most extreme winter was in 1980-81, when temperature rises would have exceeded 3 C° (5.4 F°) 63.6 percent of the time. Nearly all the temperature rises in 1980-81 were below 4.5 C° (8 F°).

Most, if not all, of the higher hourly temperature rises occur during periods of low releases from the upstream and downstream dams. On a daily basis, higher flow releases usually cause the daily average downstream temperature to be much lower. Reservoir temperature rises downstream from SQN will be an average of temperature rises in the mixing zone as river flows vary over the day and produce natural mixing. From a biological standpoint, the best way to consider the effects downstream from SQN is to look at 24-hour averages of the temperature rise. Appendix C shows 24-hour average temperature rises simulated by the diffuser-mixing model. When averaged over the day, the higher hourly temperature rises discussed previously bring downstream temperature rises to less than 4 C° (7 F°). Temperature rises based on 24-hour averages would be above the present 3 C° (5.4 F°) limit about 20 percent of the time. Based on EPA recommendations for applying temperature criteria, which are based on maximum weekly average temperature, even the 24-hour average temperature rise is a conservative approach relative to evaluating possible effects on fish reproduction or winter survival.

The effect of potential changes in reservoir system operation policy could affect river flows past SQN from November through March. As indicated earlier, reservoir system modeling simulations have shown that lower flow occurrences (between 25,000 and 10,000 cfs) increased mainly in March. Worst-case SQN two-unit operation can exceed the present temperature rise limit whenever river flows past SQN fall below about 26,000 cfs. Therefore, the frequency of temperature rises above the present limit would not increase significantly. The magnitude of the temperature rises would be higher, with no increase larger than about 1 C° (2 F°). Potential changes in reservoir system operation would not cause temperature rises higher than 5 C° (9 F°).

The modeled temperature rises represent conditions at the 5-foot compliance depth within the mixing zone. The vertical profile of temperatures depends on river flow conditions and ambient water temperatures. At higher river flows, the thermal plume approaches full mixing by the end of the mixing zone. At lower flows, less mixing causes higher temperature rises. The vertical profile of the plume under low flow conditions concentrates the higher temperatures in approximately the top one-third of the reservoir depth (Roberts, 1979a and 1979b). Conditions closer to the ambient temperature can be found at lower depths. Therefore, compensating effects occur. At higher flows, the temperature rise affects more of the reservoir depth but at a lower temperature; and at low flows, higher temperatures result but only occupy the upper layer of the reservoir.

Effects of the Proposed Winter Temperature Rise Limit on Chickamauga Reservoir Downstream from the Mixing Zone

Two mechanisms will affect water temperatures as the thermal discharge moves downstream. As discussed above, natural mixing in the reservoir, which occurs over a day as river flows vary as a result of hydro peaking operations, causes downstream temperature rises better represented by 24-hour averages. Surface heat exchange will also cool or heat the surface layer.

Surface cooling and heating of a water body is determined by meteorological conditions and water surface temperatures. The theoretical equilibrium temperature can be used to estimate surface heat exchange. This is the temperature to which a body of water would eventually stabilize if exposed to constant meteorological conditions. A body of water not at the equilibrium temperature will approach that temperature at a rate proportional to the difference between the actual surface water temperature and the equilibrium temperature, and to a rate constant, the heat transfer coefficient (a function of meteorological conditions).

Monthly average equilibrium temperatures were obtained for each month of the year from available weather data taken at the National Weather Service Station in Chattanooga, Tennessee. The values for ambient water temperature and equilibrium temperature used in this evaluation are given in Table 10.

Table 10. Surface Heat Transfer Data for the Effect of Sequoyah Nuclear Plant on Chickamauga Reservoir.

Month	Ambient Water Temperature		Equilibrium Temperature	
	(°C)	(°F)	(°C)	(°F)
November	15.0	59.0	12.0	53.6
December	9.5	49.1	5.8	42.4
January	5.4	41.7	2.6	36.7
February	5.6	42.1	7.3	45.1
March	9.7	49.5	13.6	56.5

During an average November and December, the equilibrium temperature is below the ambient water temperature, and meteorological conditions cause significant cooling of the water. This cooling continues to a lesser extent in January. In February, the equilibrium temperature is slightly higher than the ambient temperature, indicating that heating has begun. In March, the equilibrium temperature is significantly higher than ambient water temperature, indicating that normal spring heating has intensified.

An exponentially decaying heat transfer equation at steady-state rates of heat and water flow (Eddinger and Geyer, 1965; Fischer et al., 1979) was used to estimate the downstream distance required for the surface layer of the thermal plume to return to the present temperature rise limit of 3 C° (5.4 F°). The initial plume temperature (temperature when the thermal plume reaches the water surface or when the vertical momentum of the plume is exhausted) was determined for ambient reservoir flow and temperature by the diffuser-mixing model described above. The spatial temperature variation of the thermal plume was determined for various reservoir flowrates, based on full SQN operating conditions and average upstream ambient reservoir temperature. With constant reservoir flow rates up to 20,000 cfs, the distance that the thermal plume travels until its temperature cools 3 C° (5.4 F°) is less than 4.4 miles for the cooling months of November, December, and January. When meteorological conditions in February start heating the reservoir surface, the influence of the thermal plume can extend as far as Chickamauga Dam. In March, significant natural surface heating causes surface temperatures to increase.

THERMAL LIMIT COMPLIANCE VERIFICATION TECHNIQUES

The present method of verifying compliance with the temperature rise limit is based on a combination of measurements and modeling techniques. Measurements and modeling calculations are completed every 15 minutes for a quasi-continuous, real-time verification. Five 15-minute values are used to determine hourly average downstream mixed temperature and temperature rise. Currently, the hourly average temperature is compared with the NPDES temperature rise limit. The same method of verifying and reporting compliance based on the thermal computed compliance system is recommended for the alternative temperature rise limit.

The existing hourly interval for temperature reporting and compliance was established when EPA approved TVA's recommended temperature monitoring plan. At the time this plan was submitted, there were no EPA recommendations on the frequency of temperature measurement. EPA's subsequent temperature criteria recommendations (1976-77), that were directed to seasonal conditions to protect fish growth, reproduction, and winter survival, were based on maximum weekly average temperatures and a short-term (24-hour) temperature maximum to prevent potentially lethal conditions. Thus, the required minimum frequency of temperature measurement that would be biologically significant is daily. Although TVA is not requesting that the existing hourly compliance interval be changed at this time, it should be noted that this interval is extremely conservative relative to protecting fish reproduction and winter survival. As discussed previously, the existing temperature rise limit in the Tennessee temperature criteria (standards) was established to set seasonal limits, except for the summer period; and therefore, it should not be applied as an instantaneous maximum.

A continuing program for verifying the SQN thermal computed compliance system (Ostrowski and Shiao, 1987) was sent to Tennessee in 1987. Upon approval by Tennessee, this program will be used to document the modeling evaluations presented in this report. Field surveys at various river flows during fall, winter, and spring will be conducted to verify the modeled results.

ECONOMIC EVALUATION OF ALTERNATIVE THERMAL LIMIT

The present temperature rise limit on SQN can impose significant operational costs. The following is an evaluation of the cost associated with operating the plant under the current temperature limits vs the cost that will be incurred with a higher temperature rise limit during the winter operation from November 1 through March 31. The evaluation addresses the cost of repairing the existing cooling tower ice damage; subsequent maintenance costs; and the cost of changing hydro operations, using cooling towers, and reducing plant load to meet the limit.

Cooling Tower Operation and Repair Costs

If the current 3 C° (5.4 F°) temperature limit remains in effect, TVA must either modify the cooling towers to be more resistant to ice damage; or repair the current tower damage, be ready to run the plant in closed mode if potential icing conditions are forecasted, and repair the resulting damage each spring to meet summer operation requirements. The cost to modify the towers will be $16-20 million. The cost to repair the towers will vary considerably depending on the extent of the damage incurred. The 1984 ice damage cost approximately $0.5 million to repair and the 1985 damage will cost nearly $1.5 million to repair. Such cost would be incurred on an annual basis.

Economics of Meeting the Temperature Rise Limit Based on Available Historical Record

The historical data set used to determine the effects of the thermal discharge on Chickamauga Reservoir was used to determine the economic cost of meeting the temperature rise limit. Additional air temperature data was obtained from the National Weather Service Station in Chattanooga for determining potential freezing conditions. Simulations were made based on assumed full plant operation for the entire period.

Operational decisions for running the plant and reservoir system were based on knowing the actual conditions for the next day. Based on known forecast, TVA would use the following order to determine alternatives for meeting the thermal limit. If it appeared that SQN would violate the thermal limit the following sequence of actions would be taken.

1. Peaking operations at the upstream and downstream dams would be curtailed and releases would be distributed (or daily averaged) over the day.

2. If the limit was not met, cooling towers would be used if the air temperature was above 0°C (32°F) for the entire day.

3. If the air temperature was forecast to be less than 0°C at any time, load reductions would be used to meet the limit.

The costs associated with using this stepwise approach of curtailed hydro operations, use of cooling towers, and reduced plant load were calculated for the period from November 1976 through March 1988 (Table 11).

Table 11. Average Annual Costs of Meeting Current Temperature Rise Limit Based on Available Historical Record.

Hydro Operations	Cooling Tower	Load Reductions
\$101,000	\$94,000	\$440,000

This period of time was selected because it provided actual meteorological and river temperature data that could be applied to the operation of SQN. Under those environmental conditions a determination was made as to when modified hydro operations, cooling tower use, and plant load reductions would be needed to meet the temperature rise limit. Using that information, future power costs were used to calculate costs for meeting the limit. The need for each level of action was determined and costs for each level were calculated. A worst case scenario would involve a stepwise progression of the actions and the costs would be cumulative. <u>Using 1990 future power costs and \$7/MWH for SQN costs and 1995 future costs and \$8/MWH for SQN costs an average</u>

yearly cost of $635,000 for meeting the current temperature rise limit was derived.

Economics of Meeting the Proposed Temperature Rise Limit

Under the proposed temperature rise limit TVA would be able to meet the limit without the use of cooling towers or plant load reductions and the costs of those actions would be avoided. This would represent an average annual savings of $534,000 during the period from 1990 through 1995. In addition, the need to upgrade the cooling towers to improve their ability to resist ice damage would be eliminated as would the incremental costs for the annual ice damage repairs.

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Appendix A

Frequency of Hourly River Flow at Sequoyah Nuclear Plant for the Winters 1976-1989

Flowrate (x 10^3)

	<0	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	≥90
NOV 1976	3	25	91	234	356	11	0	0	0	0	0
DEC 1976	0	4	20	81	235	404	0	0	0	0	0
JAN 1977	2	2	12	87	242	301	98	0	0	0	0
FEB 1977	36	87	139	196	185	29	0	0	0	0	0
MAR 1977	17	61	105	210	255	96	0	0	0	0	0
Subtotal	58	179	367	808	1273	841	98	0	0	0	0
Sub %	1.6	4.9	10.1	22.3	35.1	23.2	2.7	0.0	0.0	0.0	0.0
NOV 1977	2	18	24	45	87	27	209	109	161	38	0
DEC 1977	0	0	0	0	0	0	58	325	311	50	0
JAN 1978	0	0	0	3	30	47	426	33	74	43	88
FEB 1978	0	0	4	35	202	228	116	36	38	13	0
MAR 1978	11	15	47	187	294	190	0	0	0	0	0
Subtotal	13	33	75	270	613	492	809	503	584	144	88
Sub %	.4	.9	2.1	7.5	16.9	13.6	22.3	13.9	16.1	4.0	2.4
NOV 1978	131	151	133	154	139	12	0	0	0	0	0
DEC 1978	18	51	67	120	288	200	0	0	0	0	0
JAN 1979	0	0	0	3	28	148	182	85	179	73	46
FEB 1979	0	3	16	77	194	239	46	39	23	5	30
MAR 1979	0	0	2	10	166	171	17	4	47	26	301
Subtotal	149	205	218	364	815	770	245	128	249	104	377
Sub %	4.1	5.7	6.0	10.0	22.5	21.2	6.8	3.5	6.9	2.9	10.4
NOV 1979	0	0	0	2	8	115	356	239	0	0	0
DEC 1979	0	0	13	27	202	252	250	0	0	0	0
JAN 1980	0	0	0	19	131	306	102	134	52	0	0
FEB 1980	27	23	72	130	314	130	0	0	0	0	0
MAR 1980	7	12	37	100	186	98	40	2	44	132	86
Subtotal	34	35	122	278	841	901	748	375	96	132	86
Sub %	.9	1.0	3.3	7.6	23.1	24.7	20.5	10.3	2.6	3.6	2.4
NOV 1980	67	105	164	238	144	2	0	0	0	0	0
DEC 1980	52	109	249	267	67	0	0	0	0	0	0
JAN 1981	78	150	234	184	93	5	0	0	0	0	0
FEB 1981	65	75	117	162	202	51	0	0	0	0	0
MAR 1981	175	175	160	158	66	10	0	0	0	0	0
Subtotal	437	614	924	1009	572	68	0	0	0	0	0
Sub %	12.1	16.9	25.5	27.8	15.8	1.9	0.0	0.0	0.0	0.0	0.0

Appendix A (Continued)

Flowrate (x 10^3)

	<0	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	$\geq$90
NOV 1981	70	136	240	173	100	1	0	0	0	0	0
DEC 1981	36	72	150	216	243	27	0	0	0	0	0
JAN 1982	0	1	3	4	70	145	45	331	142	3	0
FEB 1982	0	0	0	0	0	37	110	48	184	276	17
MAR 1982	3	11	23	41	119	223	302	22	0	0	0
Subtotal	109	220	416	434	532	433	457	401	326	279	17
Sub %	3.0	6.1	11.5	12.0	14.7	11.9	12.6	11.1	9.0	7.7	.5
NOV 1982	1	11	75	166	355	112	0	0	0	0	0
DEC 1982	0	0	0	0	0	41	205	279	219	0	0
JAN 1983	0	0	1	40	266	361	76	0	0	0	0
FEB 1983	0	0	9	44	123	355	141	0	0	0	0
MAR 1983	0	131	252	265	96	0	0	0	0	0	0
Subtotal	1	142	337	515	840	869	422	279	219	0	0
Sub %	.0	3.9	9.3	14.2	23.2	24.0	11.6	7.7	6.0	0.0	0.0
NOV 1983	1	73	155	236	252	3	0	0	0	0	0
DEC 1983	0	0	0	5	93	376	221	49	0	0	0
JAN 1984	0	9	65	175	284	193	18	0	0	0	0
FEB 1984	0	0	131	130	178	186	71	0	0	0	0
MAR 1984	0	0	49	138	229	167	161	0	0	0	0
Subtotal	1	82	400	684	1036	925	471	49	0	0	0
Sub %	.0	2.2	11.0	18.8	28.4	25.4	12.9	1.3	0.0	0.0	0.0
NOV 1984	29	63	123	168	330	7	0	0	0	0	0
DEC 1984	43	53	117	217	235	79	0	0	0	0	0
JAN 1985	32	84	126	190	199	113	0	0	0	0	0
FEB 1985	11	20	33	58	256	195	32	67	0	0	0
MAR 1985	1	253	177	160	121	32	0	0	0	0	0
Subtotal	116	473	576	793	1141	426	32	67	0	0	0
Sub %	3.2	13.1	15.9	21.9	31.5	11.8	.9	1.8	0.0	0.0	0.0
NOV 1985	64	85	130	317	124	0	0	0	0	0	0
DEC 1985	29	55	108	189	266	96	1	0	0	0	0
JAN 1986	88	153	195	195	85	28	0	0	0	0	0
FEB 1986	48	76	152	152	158	86	0	0	0	0	0
MAR 1986	90	109	163	228	147	7	0	0	0	0	0
Subtotal	319	478	748	1081	780	217	1	0	0	0	0
Sub %	8.8	13.2	20.6	29.8	21.5	6.0	.0	0.0	0.0	0.0	0.0

Appendix A (Continued)

Flowrate (x 10^3)

	<0	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	≥90
NOV 1986	38	31	117	215	273	46	0	0	0	0	0
DEC 1986	0	0	3	49	322	370	0	0	0	0	0
JAN 1987	13	26	57	151	248	249	0	0	0	0	0
FEB 1987	10	14	29	85	211	260	23	2	1	13	24
MAR 1987	27	24	70	108	130	106	165	86	15	13	0
Subtotal	88	95	276	608	1184	1031	188	88	16	26	24
Sub %	2.4	2.6	7.6	16.8	32.7	28.4	5.2	2.4	.4	.7	.7
NOV 1987	108	126	169	206	95	16	0	0	0	0	0
DEC 1987	143	171	191	174	62	3	0	0	0	0	0
JAN 1988	78	82	102	161	211	66	44	0	0	0	0
FEB 1988	48	69	129	220	200	30	0	0	0	0	0
MAR 1988	152	229	170	89	60	44	0	0	0	0	0
Subtotal	529	677	761	850	628	159	44	0	0	0	0
Sub %	14.5	18.6	20.9	23.3	17.2	4.4	1.2	0.0	0.0	0.0	0.0
NOV 1988	79	82	123	259	176	1	0	0	0	0	0
DEC 1988	75	124	159	172	138	55	0	0	0	0	0
JAN 1989	0	18	65	68	230	172	20	23	148	0	0
FEB 1989	1	31	51	56	126	206	200	1	0	0	0
MAR 1989	21	18	37	100	214	123	111	55	65	0	0
Subtotal	176	273	435	655	884	557	331	79	213	0	0
Sub %	4.9	7.6	12.1	18.2	24.5	15.5	9.2	2.2	5.9	0.0	0.0

FOR ALL YEARS FROM 1976 THROUGH 1989

Total Hrs.	2030	3506	5655	8349	11139	7689	3846	1969	1703	685	592
Avg %	4.3	7.4	12.0	17.7	23.6	16.3	8.2	4.2	3.6	1.5	1.3

Appendix B

Frequency of Hourly Temperature Rise at Sequoyah Nuclear Plant for the Winters 1976-1989.

	Temperature Rise (C°)					
	<3.0	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	≥5
	Hours					
NOV 1976	535	127	57	0	0	0
DEC 1976	697	18	25	4	0	0
JAN 1977	722	7	3	8	4	0
FEB 1977	377	51	82	126	36	0
MAR 1977	523	94	123	4	0	0
Subtotal	2854	297	290	142	40	0
Sub %	78.8	8.2	8.0	3.9	1.1	0.0
NOV 1977	664	55	0	0	0	0
DEC 1977	744	0	0	0	0	0
JAN 1978	744	0	0	0	0	0
FEB 1978	661	6	3	2	0	0
MAR 1978	618	69	50	7	0	0
Subtotal	3431	130	53	9	0	0
Sub %	94.7	3.6	1.5	.2	0.0	0.0
NOV 1978	321	372	26	0	0	0
DEC 1978	573	87	83	1	0	0
JAN 1979	744	0	0	0	0	0
FEB 1979	641	14	10	7	0	0
MAR 1979	740	4	0	0	0	0
Subtotal	3019	477	119	8	0	0
Sub %	83.3	13.2	3.3	.2	0.0	0.0
NOV 1979	719	0	0	0	0	0
DEC 1979	727	4	13	0	0	0
JAN 1980	740	4	0	0	0	0
FEB 1980	547	26	70	53	0	0
MAR 1980	664	30	37	13	0	0
Subtotal	3397	64	120	66	0	0
Sub %	93.1	1.8	3.3	1.8	0.0	0.0

Appendix B (Continued)

	Temperature Rise (C°) <3.0	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	≥5
	Hours					
NOV 1980	286	265	168	0	0	0
DEC 1980	225	114	319	86	0	0
JAN 1981	217	52	105	365	5	0
FEB 1981	381	42	105	143	1	0
MAR 1981	211	159	347	27	0	0
Subtotal	1320	632	1044	621	6	0
Sub %	36.4	17.4	28.8	17.1	.2	0.0
NOV 1981	248	385	86	0	0	0
DEC 1981	427	90	204	23	0	0
JAN 1982	740	0	1	3	0	0
FEB 1982	672	0	0	0	0	0
MAR 1982	693	31	20	0	0	0
Subtotal	2780	506	311	26	0	0
Sub %	76.7	14.0	8.6	.7	0.0	0.0
NOV 1982	571	143	5	0	0	0
DEC 1982	744	0	0	0	0	0
JAN 1983	741	0	3	0	0	0
FEB 1983	653	15	4	0	0	0
MAR 1983	344	165	235	0	0	0
Subtotal	3053	323	247	0	0	0
Sub %	84.3	8.9	6.8	0.0	0.0	0.0
NOV 1983	411	286	22	0	0	0
DEC 1983	744	0	0	0	0	0
JAN 1984	623	44	50	27	0	0
FEB 1984	531	70	95	0	0	0
MAR 1984	656	75	13	0	0	0
Subtotal	2965	475	180	27	0	0
Sub %	81.3	13.0	4.9	.7	0.0	0.0
NOV 1984	455	215	49	0	0	0
DEC 1984	463	88	192	1	0	0
JAN 1985	440	56	114	131	3	0
FEB 1985	597	13	49	13	0	0
MAR 1985	274	221	248	1	0	0
Subtotal	2229	593	652	146	3	0
Sub %	61.5	16.4	18.0	4.0	.1	0.0

Appendix B (Continued)

	Temperature Rise (C°)					
	<3.0	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	≥5
	Hours					
NOV 1985	416	303	0	0	0	0
DEC 1985	506	101	102	35	0	0
JAN 1986	246	82	258	158	0	0
FEB 1986	360	66	191	55	0	0
MAR 1986	437	161	146	0	0	0
Subtotal	1965	713	697	248	0	0
Sub %	54.2	19.7	19.2	6.8	0.0	0.0
NOV 1986	598	121	0	0	0	0
DEC 1986	736	8	0	0	0	0
JAN 1987	634	44	66	0	0	0
FEB 1987	612	27	33	0	0	0
MAR 1987	663	81	0	0	0	0
Subtotal	3243	281	99	0	0	0
Sub %	89.5	7.8	2.7	0.0	0.0	0.0
NOV 1987	580	46	93	0	0	0
DEC 1987	164	109	471	0	0	0
JAN 1988	439	40	136	129	0	0
FEB 1988	390	58	148	100	0	0
MAR 1988	184	256	300	4	0	0
Subtotal	1757	509	1148	233	0	0
Sub %	48.2	14.0	31.5	6.4	0.0	0.0
NOV 1988	362	329	29	0	0	0
DEC 1988	300	79	307	37	0	0
JAN 1989	633	34	66	11	0	0
FEB 1989	578	19	75	0	0	0
MAR 1989	647	56	41	0	0	0
Subtotal	2520	517	518	48	0	0
Sub %	69.9	14.3	14.4	1.3	0.0	0.0
FOR ALL YEARS FROM 1976 THROUGH 1989						
Avg total	34533	5517	5478	1574	49	0
Avg %	73.2	11.7	11.6	3.3	.1	0.0

Appendix C

Frequency of 24-Hour Average Temperature Rises at Sequoyah Nuclear Plant for the Winters 1976-1989.

	Temperature Rise (C°)					
	<3.0	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	≥5
			Hours			
NOV 1976	641	78	0	0	0	0
DEC 1976	744	0	0	0	0	0
JAN 1977	744	0	0	0	0	0
FEB 1977	538	134	0	0	0	0
MAR 1977	674	48	22	0	0	0
Subtotal	3341	260	22	0	0	0
Sub %	92.2	7.2	.6	0.0	0.0	0.0
NOV 1977	675	44	0	0	0	0
DEC 1977	744	0	0	0	0	0
JAN 1978	744	0	0	0	0	0
FEB 1978	672	0	0	0	0	0
MAR 1978	720	24	0	0	0	0
Subtotal	3555	68	0	0	0	0
Sub %	98.1	1.9	0.0	0.0	0.0	0.0
NOV 1978	565	154	0	0	0	0
DEC 1978	718	26	0	0	0	0
JAN 1979	744	0	0	0	0	0
FEB 1979	672	0	0	0	0	0
MAR 1979	744	0	0	0	0	0
Subtotal	3443	180	0	0	0	0
Sub %	95.0	5.0	0.0	0.0	0.0	0.0
NOV 1979	719	0	0	0	0	0
DEC 1979	744	0	0	0	0	0
JAN 1980	744	0	0	0	0	0
FEB 1980	669	27	0	0	0	0
MAR 1980	727	17	0	0	0	0
Subtotal	3603	44	0	0	0	0
Sub %	98.8	1.2	0.0	0.0	0.0	0.0

Appendix C (Continued)

	Temperature Rise (C°) <3.0	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	≥5
	Hours					
NOV 1980	335	356	28	0	0	0
DEC 1980	174	460	110	0	0	0
JAN 1981	58	419	257	10	0	0
FEB 1981	514	94	61	3	0	0
MAR 1981	118	533	93	0	0	0
Subtotal	1199	1862	549	13	0	0
Sub %	33.1	51.4	15.2	.4	0.0	0.0
NOV 1981	291	428	0	0	0	0
DEC 1981	577	159	8	0	0	0
JAN 1982	744	0	0	0	0	0
FEB 1982	672	0	0	0	0	0
MAR 1982	744	0	0	0	0	0
Subtotal	3028	587	8	0	0	0
Sub %	83.6	16.2	.2	0.0	0.0	0.0
NOV 1982	719	0	0	0	0	0
DEC 1982	744	0	0	0	0	0
JAN 1983	744	0	0	0	0	0
FEB 1983	672	0	0	0	0	0
MAR 1983	369	187	188	0	0	0
Subtotal	3248	187	188	0	0	0
Sub %	89.6	5.2	5.2	0.0	0.0	0.0
NOV 1983	538	181	0	0	0	0
DEC 1983	744	0	0	0	0	0
JAN 1984	725	13	6	0	0	0
FEB 1984	579	35	82	0	0	0
MAR 1984	744	0	0	0	0	0
Subtotal	3330	229	88	0	0	0
Sub %	91.3	6.3	2.4	0.0	0.0	0.0
NOV 1984	590	129	0	0	0	0
DEC 1984	575	160	9	0	0	0
JAN 1985	522	140	60	22	0	0
FEB 1985	659	13	0	0	0	0
MAR 1985	388	290	66	0	0	0
Subtotal	2734	732	135	22	0	0
Sub %	75.5	20.2	3.7	.6	0.0	0.0

Appendix C (Continued)

	Temperature Rise (C°) <3.0	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	≥5
			Hours			
NOV 1985	546	173	0	0	0	0
DEC 1985	596	127	21	0	0	0
JAN 1986	266	291	187	0	0	0
FEB 1986	399	103	170	0	0	0
MAR 1986	535	182	27	0	0	0
Subtotal	2342	876	405	0	0	0
Sub %	64.6	24.2	11.2	0.0	0.0	0.0
NOV 1986	719	0	0	0	0	0
DEC 1986	744	0	0	0	0	0
JAN 1987	727	17	0	0	0	0
FEB 1987	654	18	0	0	0	0
MAR 1987	744	0	0	0	0	0
Subtotal	3588	35	0	0	0	0
Sub %	99.0	1.0	0.0	0.0	0.0	0.0
NOV 1987	592	64	63	0	0	0
DEC 1987	170	223	351	0	0	0
JAN 1988	492	116	136	0	0	0
FEB 1988	490	141	65	0	0	0
MAR 1988	162	364	218	0	0	0
Subtotal	1906	908	833	0	0	0
Sub %	52.3	24.9	22.8	0.0	0.0	0.0
NOV 1988	414	306	0	0	0	0
DEC 1988	379	138	206	0	0	0
JAN 1989	674	27	43	0	0	0
FEB 1989	607	40	25	0	0	0
MAR 1989	725	19	0	0	0	0
Subtotal	2799	530	274	0	0	0
Sub %	77.7	14.7	7.6	0.0	0.0	0.0

FOR ALL YEARS FROM 1976 THROUGH 1989

Subtotal	38116	6498	2502	35	0	0
Sub %	80.8	13.8	5.3	.1	0.0	0.0

APPENDIX B

Sequoyah Nuclear Plant NPDES Permit TN0026450, Part IA., Outfall 101.

PART I

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

Tennessee Valley Authority is authorized to discharge process wastewater associated with the generation of electric power by thermonuclear fission and other associated operations, condenser cooling water, sanitary wastewater, dredge pond wastewater, strainer backwash, and storm water runoff from Outfalls 101, 103, 107, 110, 112, and 116 thru 118 to the Tennessee River, the Intake Forebay, and the Chickamauga Reservoir, as applicable.

These discharges shall be limited and monitored by the permittee as specified herein:

PERMIT LIMITS

OUTFALL 101

Condenser Cooling Water, Essential Raw Cooling Water, Cooling Tower Blowdown, Raw Cooling Water, Low Volume Wastes, Metal Cleaning Waste, Sanitary Wastewater, Miscellaneous Low Volume Wastes including Various Facilities Drains and Sumps, A/C Condensate, Steam Generator Blowdown, Regeneration Wastes From Condensate Demineralizer, and Storm Water Runoff

	EFFLUENT LIMITATIONS				MONITORING REQUIREMENTS	
	MONTHLY		DAILY			
EFFLUENT CHARACTERISTIC	AVG. CONC. (mg/l)	AVG. AMNT. (lb/day)	MAX. CONC. (mg/l)	MAX. AMNT. (lb/day)	MSRMNT. FRQNCY.	SAMPLE TYPE
FLOW	--		Report (MGD)		Continuous	Recorder
AMBIENT TEMP.	--		Report (Deg.C)		1/	1/
RIVER TEMP.	--		30.5 Deg.C		1/,2/,3/,4/	Modeled
CHLORINE (Ttl.Res.)	--	--	0.058 *	--	5/7	Calculate 5/
PCB's 7/	NO DISCHARGE		NO DISCHARGE		1/90	Grab
pH	Range 6.0 – 9.0		Range 6.0 – 9.0		1/7	Grab
OIL AND GREASE	15	--	20	--	1/7	Grab
TSS	30	--	100	--	1/7	Grab
96HR LC50 6/	--		Survival in 100% Effl.		1/180	Grab
NOEC 6/	Surv,Grwth,Repro. 48.98% Effl.		--		1/180	Grab

There shall be no distinct discharge of floating scum, solids, oil sheen, visible foam, and other floating matter in other than trace amounts in discharges from the Diffuser Pond.

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): Diffuser Gate prior to entry into the Tennessee River, except (1) Ambient Temperature shall be monitored at the river side of the plant intake skimmer wall, (2) River Temperature, Temperature Rise, and Rate of Temperature Change shall be determined at the downstream temperature recorder, and (3) Total Residual Chlorine as specified in Footnote (5).

* Chlorine, Total Residual, is to be measured as an "Instantaneous Maximum" concentration.

1/ Measurements shall be made every 15 minutes at the 1–meter, 1.5–meter, and 2–meter depths and the data transmitted to the plant. Temperatures at the three depths shall be averaged every 15 minutes to give a temperature at the 1.5–meter (approximately 5–foot) depth. The Ambient Temperature and River Temperature shall be computed once per hour by averaging the current depth–averaged temperature and the previous four 15–minute depth–averaged observations.

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Compliance with the river limitations (river temperature, temperature rise, and rate of temperature change) shall be monitored by means of a numerical model that solves the thermohydrodynamic equations governing the flow and thermal conditions in the reservoir. This numerical model will utilize measured values of the upstream temperature profile, flow through the diffuser pipes, temperature of the diffuser discharge, releases at Watts Bar and Chickamauga Dams, and the diffuser performance characteristics. The river temperature, temperature rise, and rate of temperature change shall be computed once per hour by averaging the current modeled value with the previous four 15–minute model results. In the event that the modeling system described here is out of service, an alternate method will be employed to measure water temperatures at least one time per day. Depth average measurements can be taken at a downstream backup temperature monitor (left bank Tennessee River mile 483.4) or by grab sampling from boats. Boat sampling will include average 5–foot depth measurements (average of 3, 5, and 7–foot depths) outside the skimmer wall and at quarter points and mid–channel at downstream Tennessee river mile 483.4 will be used to verify compliance with temperature rise and maximum river temperature limits. The downstream reported value will be a depth and lateral average of instream measurements. Monitoring in the alternative mode shall not be applicable when unsafe boating conditions occur.

2/ The maximum River Temperature of 30.5 Deg.C may be exceeded when the Ambient Temperature approaches or exceeds 30.5 Deg.C and the plant is operated in helper mode (full operation of one cooling tower, at least three lift pumps, per operating unit). In no case shall the plant discharge cause the downstream river temperature to exceed the lethal temperature of 33.9 Deg.C without the consent of the permitting authority.

3/ Compliance with River Temperature, Temperature Rise, and Rate of Temperature Change limitations shall be applicable at the edge of a mixing zone which shall not exceed the following dimensions: (1) a maximum length of 1500 feet downstream of the diffusers, (2) a maximum width of 750 feet, and (3) a maximum length of 275 feet upstream of the diffusers. The depth of the mixing zone measured from the surface varies linearly from the surface 275 feet upstream of the diffusers to the top of the diffuser pipes and extends to the bottom downstream of the diffusers. The thermal mixing zone also includes the entire Intake Forebay (during closed mode).

4/ The Temperature Rise shall be limited to 3.0 Deg.C during the months of April through October. The Temperature Rise shall be limited to 5.0 Deg.C during winter operation months of November through March. The Rate of Temperature Change shall be limited to 2.0 Deg.C per hour.

5/ The Total Residual Chlorine will be collected downstream of the ERCW heat exchangers prior to mixing with the cooling tower blowdown and the residual chlorine shall be calculated for the diffuser discharge based upon this analysis and the proportional flows of the CCW and ERCW systems. If the CCW system is chlorinated or neither unit is discharging flow from the CCW system, grab samples shall be collected at the Diffuser Gate and analyses performed not less than three days per week with four grab samples collected during one shift each day. Field tests for residual chlorine samples collected at the Diffuser Gate have a working detection level of about 0.1 mg/l, therefore, the Daily Maximum Concentration limit for residual chlorine, measured at the Diffuser Gate in such instances, shall be 0.1 mg/l. Under no circumstances, other than that listed above, shall the results of field tests be reported in lieu of the results of residual chlorine calculated based on measurements downstream of the heat exchangers prior to mixing with the cooling tower blowdown. If continuous application of a biocide other than Chlorine is to be utilized (longer than 2–hours per day), the permittee will submit to the Division a plan describing the biocide, material feed rate, and actions proposed to ensure compliance with established effluent limitations during biocide application.

6/ See Part III for the monitoring requirements and measurement frequencies of the LC50 and NOEC tests.

7/ Once the permittee has demonstrated compliance with the quarterly monitoring limits for PCB's for a period of one year, the monitoring frequency for PCB's may be reduced to once per year.