Tennessee Valley Authority
Division of Water Control Planning
Engineering Laboratory

PREDICTION AND CONTROL OF WATER TEMPERATURES IN WHEELER RESERVOIR DURING OPERATION OF THE BROWNS FERRY NUCLEAR PLANT

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Browns Ferry Nuclear Plant

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PREDICTION AND CONTROL OF WATER TEMPERATURES IN WHEELER RESERVOIR DURING OPERATION OF THE BROWNS FERRY NUCLEAR PLANT

INTRODUCTION

The facilities for disposing of wasted heat from the Browns Ferry Nuclear Plant are being planned and constructed to protect the waters of Wheeler Reservoir for the following uses: public water supply, swimming and other whole body water-contact sports, fish and wildlife, and agricultural and industrial water supply. Of these uses the propagation of warm water fish and other aquatic life is judged to be the one requiring the highest degree of protection from thermal effects. Insofar as is possible, the Browns Ferry power plant operation and the flows in Wheeler Reservoir will be regulated by TVA in a manner which will prevent adverse thermal effects. This report describes the studies which have been made to determine the temperature and flow distribution patterns which will be induced in Wheeler Reservoir by the operation of Browns Ferry. This program has been in progress at the TVA Engineering Laboratory in Norris, Tennessee, since 1966 and has utilized a variety of methodologies including field measurements, model studies, and analytical predictions.

The report first discusses the present hydro-thermal regime in Wheeler Reservoir, drawing upon previous field measurements. Then the condenser cooling water system of the Browns Ferry Plant is described. Next the studies involving the design and performance of the discharge facilities are presented. These include basic testing of the diffuser pipe configuration, two-dimensional model studies of the mixing zone, a three-dimensional thermal model study of Wheeler Reservoir in the vicinity of the plant, and an analytical model of downstream temperature regimes. The temperature and flow distributions predicted by these studies are given for one-, two-, and three-unit open cycle operation. Finally, the operation of the cooling system in a helper mode is briefly discussed along with plans for future laboratory and field studies.

PRESENT HYDRO-THERMAL REGIME IN WHEELER RESERVOIR

The Browns Ferry Nuclear Plant is located on Wheeler Reservoir about 20 miles upstream from Wheeler Dam. The topography of the reservoir at the site, Figure 1, consists of a main navigation channel about 1800 feet wide and 30 feet deep bordered by shallow overbank areas which vary from 2 to 10 feet in depth and 2000 to 6000 feet in width. In the vicinity of the plant there are several embayments formed where small creeks enter Wheeler Reservoir.

The hydraulic regime in the reservoir is controlled by the operation of Guntersville (upstream) and Wheeler (downstream) Dams. These projects are operated primarily for hydro power production and navigation and at some periods of the year for flood control. Under present operating rules the water level in Wheeler Reservoir does not vary more than six feet during the year. The instantaneous reservoir flow at the Browns Ferry site presently may vary from greater than 100,000 cfs in a downstream direction to about 20,000 cfs in the upstream direction, depending upon the nature of the peaking operations at the two hydro-electric plants. The mean annual flow in the Tennessee River at Browns Ferry is about 45,000 cfs. The creeks entering Wheeler Reservoir near Browns Ferry do not contribute a significant amount of flow.

Water temperatures in Wheeler Reservoir have been monitored by permanent recording stations since the fall of 1968. The temperatures range from about 40° F. in the winter to a maximum (at the surface) of 85°-90° F. in the summer. The maximum top to bottom vertical temperature difference is about 5°-8° F. Additional measurements made by boat and airborne infrared surveys indicate that diurnal fluctuations and solar heating in local shallow areas may result in horizontal temperature differences of several degrees especially between the main channel and the shallow areas.

The relatively weak thermal structure in Wheeler Reservoir prevents the formation of significant density currents. Therefore, the water passing into the Wheeler intake is withdrawn from the entire depth of the reservoir at the Dam. Thus the temperature of the water just downstream from Wheeler Dam is the average of the temperature of the water reaching the dam.

HEAT DISPERSAL FACILITIES

In an open cycle operation, heat rejected by the Browns Ferry Nuclear Plant will be wasted to the adjacent reservoir waters from which it will then be transferred to the atmosphere.

Each unit will have an intake with pumps capable of producing a maximum total flow of 1450 cubic feet per second, (see Figure 2.). As presently constructed, all units use a short, common intake channel located on the right bank (plant side), 1200 feet upstream from the diffuser pipes. The pump house structure consists of 18 bays each having a traveling screen. Each intake is designed such that water is withdrawn from the reservoir over the full depth. For full three-unit operation, the maximum average velocity at the entrance to the intake channel, during the period April-September, when biotic entrainment is of interest will be about 0.7 foot per second. The flow will accelerate to an average velocity of about 1.3 feet per second midway between the entrance and the structure. The intake structure consists of 18 bays that have net openings of 8 feet 8 inches by 20 feet; thus the average velocity will be about 1.4 feet per second during three-unit operation and is independent of the reservoir elevation. The maximum average velocity through the traveling screens which have net openings 3/8" x 3/8" will be about 1.8 feet per second during the April-September period. Intake channel velocities will be reduced to one-third for one-unit operation and to two-thirds for two-unit operation. Bay and screen velocities will remain the same regardless of the number of units operating. The intake is being modified for use with auxiliary cooling; the new design will result in essentially the same intake velocities as those discussed above. In-plant velocities are typically about 7 fps.

The condenser water flow and temperature rise will depend upon the mode of operation. In an <u>open mode</u> the heated water will pass directly from the condensers into Wheeler Reservoir through the submerged diffuser pipes. The condenser flow will be 1450 cfs per diffuser pipe and the temperature rise will be 25° F. Travel time through the plant will be 7 to 11 minutes total, depending upon the unit, with approximately 5-9 minutes of that time after passage through the condenser. In a <u>helper mode</u> the temperature of the heated water after leaving the condensers will be reduced by passing it through the cooling tower system before it is discharged through the diffuser. In this mode the condenser flow and temperature rise will be 1223 cfs and 31.7° F. for each unit; however, the temperature of the water leaving the towers will depend upon the wet bulb temperature, which is highly variable, and the tower design, which has not been completed. In any case the temperature will be such that the final mixed flow temperature in the river will not exceed the applicable temperature standard. Travel times will also depend upon the details of the tower system, but they will be significantly longer than those in an open mode. In a closed mode the cooling water will pass through the cooling towers and return directly to the intake without having any contact with the reservoir. A makeup flow of about 72 cfs per unit will be withdrawn from Wheeler Reservoir through the intake gate to replace 36 cfs of evaporative losses and 36 cfs of blowdown flow per unit. The blowdown flow will be at the tower discharge temperature which will be extremely variable, ranging from below the river temperature to 30-40° F. above the river temperature depending upon the wet bulb temperature and the tower design. At present it is planned to discharge the blowdown through one or more of the large diffuser pipes. If further testing indicates that this procedure will not result in sufficient mixing to meet the standards applicable to the discharge, a separate diffuser system will be constructed for discharge of the blowdown.

The perforated, corrugated, galvanized steel diffuser pipes shown diagramatically in Figure 2 are laid side-by-side across the bottom of the 1800-foot wide channel. The pipes are 17 feet, 19 feet and 20 feet 6 inches in diameter and of different lengths. Each has the last 600 feet perforated on the downstream side with more than 7,000 holes two inches in diameter spaced six inches on centers in both directions. These pipes will distribute the cooling water evenly near the bottom of the river channel along the full length of the diffuser portion of each pipe, and mix it with the overflowing cooler water. The diffuser for Unit 1 occupies the central portion of the main river channel while Unit 2 occupies the lefthand (far) third, and Unit 3 the righthand third.

BASIC STUDIES OF THE HEAT DISPERSAL FACILITIES

Hydraulic Design of the Diffusers

The manifold-type, multiport, pipe-system adapted for diffusion of the heated condenser water is similar to those used in marine outfalls. The discharged water will issue from the diffuser ports at a relatively high velocity and the turbulence created by these jets will cause mixing of the heated discharge with the cooler reservoir water.

The diffuser system was designed to meet the following requirements:

1. Each pipe must handle a flow of 1,450 cfs
2. The total discharge from all three pipes must be uniformly distributed across the 1800-foot wide main channel.
3. The jet velocity must be sufficiently high to create complete mixing of the condenser discharge with the reservoir flow available to the diffusers.
4. The total head at the entrance to the pipes should not exceed 4.5 feet of water.

In preliminary design studies, consideration was given to concrete pipes with about 10-inch diameter holes on about 4-foot centers. Because of the low design head of 4.5 feet of water, these holes would have had to be equipped with smooth entrance nozzles. However, cost studies indicated that standard corrugated, galvanized, structural steel plate pipes could be manufactured and installed at appreciably less cost.

The attachment of nozzles to corrugated pipe is, however, both difficult and expensive. To overcome this problem, the idea was advanced to use holes with diameters of the order of one to two inches and to put these holes in the valley of each corrugation, thereby making use of the corrugation geometry to create a two-dimensional quasi-bellmouth. Since the discharge coefficient for such hole configurations was not known, laboratory investigations to find the value of this discharge coefficient were necessary before design calculations could be undertaken. A model study was performed at the TVA Engineering Laboratory in 1967 to determine the hydraulic characteristics of the jets issuing from the diffuser holes. The tests were performed at a scale of 1:2 thus providing realistically high model turbulence levels for the range of pipe diameters and hole sizes expected in prototype. The study showed that the flow will issue from the diffusers ports at nearly a 90° angle and with a discharge coefficient which is a function primarily of the ratio of velocity head to total energy in the pipe.

The design of the diffuser involved selection of a main pipe diameter and discharge port size which, for the design discharge flow, will produce a discharge distribution, jet velocity, and total entrance head as specified above in items 1 to 4. This procedure utilized the discharge coefficients determined by the model study and corrugated pipe friction factors measured at the U.S. Army Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi (Reference 1). These data were inputs to an analytical model of the diffuser's hydraulic performance which calculated the distribution of the discharge and the energy grade line along the diffuser pipes. The final diffuser design shown in Figure 3 was selected on the basis of these calculations.

Two-Dimensional Model Testing of the Jet Mixing Region

Based on the available state-of-the-art knowledge of submerged jets, it was expected that the design discharge velocity of about 9 fps would result in efficient mixing of the discharge flow with the ambient flow passing over the diffuser. Since no diffuser of the multiport, corrugated pipe configuration had ever been tested, a two-dimensional model study was undertaken to examine the characteristics of the mixing induced by the diffuser discharge and to determine the angle of discharge with the horizontal which would minimize bed scour downstream from the diffuser. These tests were performed at the MIT R. M. Parsons Lab for Water Resources and Hydrodynamics

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Reference 1: Grace, J. L., Jr., "Resistance Coefficient for Structural Plate Corrugated Pipe," Technical Report No. 2-715. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, February 1966.

during 1967 and 1968. The model scales were 1:15 horizontally and vertically providing the undistorted model required for jet mixing zone studies. The principal results of the investigations were:

1. Mixing of the jets with that portion of the flow passing over the diffusers will occur rapidly. This is illustrated by Figure 4 which shows the temperature distribution obtained from model tests in the immediate vicinity of the diffusers for a simulated steady reservoir flow of 20,000 cubic feet per second. Within a matter of a few feet from the diffuser, the temperature was reduced to about 11° F. above ambient. The maximum temperature at the reservoir bottom was about 6-7° F. above ambient over an area extending a distance of about 30 feet from the diffuser. At distances greater than about 50 feet, the observed temperature agreed well with the theoretical fully mixed rise of 5.5° F. Figure 5 shows additional temperature distributions for flows of 6,500, 13,000 and 26,000 cubic feet per second and illustrates that an upstream wedge will form at lower reservoir flows.

On the basis of the MIT tests, it is expected that the mixing will result in uniform temperature over the full depth within a distance of about 100-200 feet horizontally from the diffuser pipe. The zone of jet mixing will extend no more than 200 feet from the diffuser horizontally and no more than 5-10 feet above the top of the diffuser pipe.

2. Outside of the mixing zone the temperatures will be no greater than the mixed temperature Tm which may be calculated as:

$$Tm = Tr + \frac{\Delta Tc}{\frac{Qm}{Qc} + 1 - R} \qquad (1)$$

where
Tr = ambient river temperature
ΔTc = condenser temperature rise
Qc = condenser cooling water flow
Qm = that portion of the total river flow Qr which mixes with the diffuser discharge.
R = the fraction of the intake flow which is at temperature Tm, i.e., the amount being recirculated. The remaining fraction, (1 - R), will be at the ambient temperature Tr.

It is clear from Equation (1) that for large dilutions ($Q_m >> Q_c$), the amount of recirculation (the value of R) has only a small effect upon the mixed temperature. It is emphasized that Equation (1) predicts steady state temperatures that are approached asymptotically after any change in the river flow rate, often over a period of hours. The significance of this is that Equation (1) will predict a temperature rise that is too high for a certain length of time after a decrease in river flow and too low after an increase. The determination of Q_m and the unsteady behavior of the mixing are a part of the three-dimensional thermal model results described in a later section.

3. Minimum scour was observed with an elevated jet angle of 24°. (See Figure 3.)

The Three-Dimensional Thermal Model

The thermal regime induced in Wheeler Reservoir by the operation of Browns Ferry in either the open or helper modes will depend upon a complex interaction between the intake and discharge flows and the regulated flows in the reservoir. The purpose of the three-dimensional thermal model study has been to assess the performance of the discharge configuration and to determine the relationship between the reservoir flow and the temperature distribution.

The model encompasses a five-mile reach of Wheeler Reservoir with the Browns Ferry intake and diffuser situated near the center of this reach. The model (see Figure 6) is distorted, having a vertical scale ratio of 1:50 and a horizontal scale ratio of 1:250. Values of various parameters are given for model and prototype in Table I.

TABLE I

Parameter	Prototype	Model
Length of modeled section	27,000 ft	108 ft
Reservoir width (approx.)	6,000 ft	24 ft
Reservoir depth: river channel	30 ft	.6 ft
shallow area	10 ft	.2 ft
Mean annual reservoir flow	40,000 cfs	200 gpm
Condenser cooling flow/unit	1,450 cfs	7.4 gpm
Condenser temperature rise	25° F	25° F
Diffuser length/unit	600 ft	2.4 ft

The prototype reservoir geometry, which is highly irregular and three-dimensional, is reproduced to scale in the model. The reservoir flows in the prototype are primarily controlled by hydro power peaking operations at the Wheeler and Guntersville plants, resulting in large discharge and stream velocity fluctuations. The model is provided with a flow supply system capable of producing time varying reservoir flows in either direction. The basic data taken from the model consists of temperatures measured by an array of 400 thermistor probes. Sampling of temperatures, reservoir flow valve adjustments, and other minor functions such as reading water levels are under the control of a digital computer. All data reduction is also handled by computer. Such automatic control is necessary to model the unsteady discharge hydrographs which are common in the prototype.

The three-dimensional thermal model is designed to give information about the intermediate region between the jet mixing area, immediately adjacent to the diffusers, and the far field upstream and downstream regions. This region is of great importance in evaluating thermal effects becuase the highest temperatures outside of the mixing zone will occur here. In addition, the dynamics of the flow in the intermediate region may affect the magnitude of the mixing flow, Qm. Finally, the observed behavior of the heated layer provides the required starting boundary condition for downstream heat loss calculations.

The dominant physical phenomena in the intermediate region are the convection of mass and heat, the formation of stratified conditions, and to a lesser extent the loss of heat through the water surface. The scales of the three-dimensional thermal model were chosen to ensure correct similitude of the convection, stratification, and surface heat loss. Field studies in the prototype have been conducted and are continuing with the purpose of determining the pattern of reservoir currents and the surface heat loss characteristics in the vicinity of the plant. In the model the distribution of the upstream reservoir flow may be adjusted to replicate prototype current conditions. A study of the surface heat exchange in the model has been made to facilitate the evaluation of surface heat loss upon model temperature data. Careful sensitivity testing is continuing to determine whether or not the upstream distribution of flow, surface heat loss, boundary roughness, and distorted diffuser configuration have any significant effects upon the observed flow and temperature structure. To date, it appears that the first three are not of major significance and probably the diffuser configuration is not either.

A series of steady reservoir flow tests have determined the three-dimensional flow and temperature distributions in the modeled area for one-, two- and three-unit operation. These tests indicate the following pattern of behavior:

1. The intake flow will be withdrawn from the full depth and will consist of water which flows downstream from the shallow area on the plant side and from the righthand side of the main channel. This flow distribution will tend to minimize recirculation of heated water.

2. Recirculation will occur only in the low flow situations when all of the upstream flow is being drawn into the mixing zone. In these cases, it can be shown on theoretical grounds that the mixed temperature rise will be virtually independent of the degree of recirculation [see Equation (3)]. The model data confirm this conclusion.

3. For reservoir flows of large magnitude, i.e., greater than 50,000-70,000 cfs, the natural flow distribution in the reservoir will not be significantly altered by the mixing action of the diffusers. Velocities will be in the downstream direction over the full depth and over the entire width of the reservoir, see Figure 7. No heated water will move upstream from the diffusers, thus, preventing any recirculation ($R = 0$). The mixed flow, at temperature T_m, leaving the jet mixing region will form a heated

surface layer downstream above a lower layer consisting of that portion of the ambient flow which does not pass through the mixing region. The mixing flow Qm will be determined by the amount of flow which passes over the diffuser naturally. Field measurements of currents in Wheeler Reservoir indicate that about 22 percent of the total reservoir flow passes over each of the three diffuser sections, making a total of about 65 percent in the deep river channel. The mixing flow Qm will depend upon how the flow downstream from the intake is redistributed across the channel during operation of the plant. However, the resulting mixed temperature is relatively insensitive to this factor and is given approximately by

$$Tm = Tr + \frac{167{,}000}{Qr} \tag{2}$$

where Qr is the total reservoir flow. The value of Tm given by Equation (2) is for one, two or three units and is shown in Figure 10.

4. For reservoir flows less than about 7-10 times the diffuser flow all of the reservoir flow will be drawn into the jet mixing zone. The flow pattern in these cases is shown schematically in Figure 8. A large eddy will occur over the total depth in the wide lefthand shallow area adjacent to the diffusers as a result of the diversion of the river flow. Since no ambient water will pass by the diffusers without mixing, the entire downstream region will be at the mixed temperature over the full depth. A surface layer of water at the mixed temperature may extend upstream from the diffusers either because of the eddy currents or because of gravitational spreading.

For this case the mixing flow Qm is equal to the total reservoir flow Qr less the intake flow Qc(1 - R) and the mixed temperature is given by:

$$Tm = Tr + \frac{25Qc}{Qr} \tag{3}$$

which is independent of the amount of recirculation. A plot of Equation (3) is also shown on Figure 10.

5. For reservoir flows greater than 7-10 times the diffuser flow but less than 50,000-70,000 cfs, the sum of the intake flow and the mixing flow, Qm, demanded and diverted by the diffusers will be equal to about 7-10 times the condenser flow. The remainder of the river flow Qr will pass by

the side of the diffusers unmixed. The flow pattern in these cases is shown in Figure 9. No eddy will be present in the subsurface flow as the portion of the ambient water, which passes the diffusers without mixing, will be an underflow over the shallow lefthand area. Downstream from the diffusers the ambient flow which did not mix will form a cooler bottom layer beneath an eddying surface layer of water at the mixed temperature. The surface layer will spread laterally across the shallow area and depending upon the magnitude of the river flow may even spread upstream from the diffusers. No recirculation occurs for these cases, making R = 0 in Equation (1).

$$Tm = Tr + \frac{25}{P} \qquad (4)$$

where P is about 7-10 as shown in Figure 10. The resulting temperature rise is about 2.5-3.5° F.

6. <u>The upstream movement of a heated surface layer</u> is a highly three-dimensional phenomena which is only qualitatively similar to the upstream wedge in a two-dimensional channel. In the cases where the surface layer reaches the upstream boundary of the model, with our present understanding, it is not possible to predict how much further the warm water will extend in the prototype. However, it is expected that the vertical thickness of the layer will decrease in the upstream direction.

7. <u>The downstream flow of mixed water</u> at temperature Tm will initially be limited to the deep river channel just below the diffusers, but within a few miles of the diffusers it will spread over the full width of the reservoir. As previously discussed, the degree of vertical stratification will be dependent upon the magnitude of the reservoir flow. However, the downstream surface layer will lose heat to the atmosphere at a rate independent of the depth of the heated layer. This will be discussed in the next section.

<u>Downstream Water Surface Temperature Predictions</u>

The changes in the downstream reservoir temperature resulting from the operation of Browns Ferry were determined by routing the initial increase in temperature using the following one-dimensional, steady-state equation:

$$\Delta Tx = \Delta To \exp\left[\frac{-K}{\rho c} \frac{XB}{Qm + Qc}\right] \qquad (5)$$

where ΔTx = the increase in surface temperature at the end of a routing reach

ΔTo = the increase in surface temperature at the beginning of a routing reach

X = length of routing reach

B = effective width of the reach

K = environmental heat exchange coefficient

Qm = the portion of the total river flow that mixes with the diffuser discharge

Qc = the diffuser discharge

ρ = density of water

c = specific heat of water

For computational purposes, the reservoir was divided into six reaches varying in length from 2.1 to 4.2 miles. Equation (5) was applied successively to each reach by using the temperature rise at the beginning of the reach, ΔTo, to obtain the temperature at the end of the reach, ΔTx, which then became the initial temperature rise for the following reach.

The effective width of the heated water for each reach was based upon observations of the three-dimensional model which showed that the main body of heated water flows downstream spreading laterally across the reservoir and that the full width of the reservoir will be covered at a distance of about 3 miles from the diffusers. Within the first three miles, the effective width for heat dissipation will be about one-half of the average reservoir width. The formation of an eddy in the shallow area opposite the plant at low flows was previously described. It was assumed, for the purpose of the temperature predictions, that no heat will be transported from the main body of flow by the eddy. The effect of this assumption is that the downstream temperature predictions are slightly high when such an eddy exists.

The environmental heat exchange coefficient affects the rate at which the temperature decreases. An increase in the coefficient causes a more rapid die-off. This coefficient is a function of meteorological conditions; hence, it varies seasonally and from year to year. To account for the meteorological variations, temperature routings were made for each month of the 12-year period 1960 through 1971 based upon coefficients determined for the average meteorological conditions that existed during the middle week of the month. From these routings, the mean and 95 percent confidence limits of the routed temperatures were computed.

The discharge Qm + Qc represents that portion of the reservoir flow that will be heated above ambient. As previously discussed, Qm + Qc may be equal to or less than the total reservoir flow depending upon the magnitude of the total reservoir flow. Qm + Qc affects the rate of temperature die-off and the initial temperature rise in the near field. As Qm + Qc increases, the die-off rate and the initial temperature rise decreases.

Predictions were made for one-, two-, and three-unit operation assuming initial temperature rises of 10, 5 and 3.5° F. The results of these predictions are shown in Plates 11 through 46.

THE STEADY HYDRO-THERMAL REGIME IN WHEELER RESERVOIR DURING OPEN CYCLE OPERATION

Based upon the data in the previous section, the following sections will discuss quantitatively the predicted steady flow and temperature distributions during operation of Browns Ferry Plant as an open cycle system. One-unit operation is treated first followed by discussions of the two- and three-unit ones.

One-Unit Operation

The single unit condenser flow of 1450 cfs will result in maximum intake channel velocities of 0.4 ft/sec. Heated water will be discharged through the diffuser section of the active unit and will mix with the reservoir flow in the manner described in the previous sections. The jet mixing zone will be just downstream from the active diffuser section and will be approximately 20 feet high, 200 feet long and 600 feet wide, thus occupying about 12,000 square feet (or 9 percent) of the total reservoir cross section and about 2,400,000 cuft of volume. The water leaving the mixing zone will be at the mixed temperature Tm which is dependent upon the reservoir flow Qr as shown in Figure 10. For reservoir flows less than about 10,000 to 14,500 cfs, the entire reservoir flow will be drawn into the jet mixing zone, either from behind the diffusers or from along the sides of the mixing region.

Predictions of the downstream temperature increase above ambient are shown on Plates 11 through 22 for the middle week of each month. Predictions were made for the following cases:

1. A reservoir flow of 3600 cfs and its associated temperature rise of 10° F.
2. A reservoir flow of 7200 cfs and its associated temperature rise of 5° F.
3. A reservoir flow greater than 10,200 cfs but less than about 50,000 cfs which gives a temperature rise of 3.5° F.

The relationship between reservoir flow and temperature was taken from Plate 10. Complete mixing of the reservoir flow and the condenser flow occurs for the first two cases. For case 3, only 10,200 cfs of the reservoir flow mixes with the condenser flow and the remainder flows as a cooler underflow.

Two-Unit Operation

The two-unit condenser flow of 2900 cfs will result in maximum intake velocities of 0.9 ft/sec. The location of the mixing zones will depend upon which two units are operating. The total mixing zone will be about 1200 feet wide and occupy 18 percent of the total reservoir cross sectional area and a volume of 4,800,000 cuft. The mixed temperature rises in the intermediate zone are shown in Figure 10 as a function of the reservoir flow. Complete mixing of the reservoir flow with the discharge will occur for flows of less than 20,000-29,000 cfs.

Predictions of the downstream temperature increase above ambient are shown on Plates 23 through 34 for the middle week of each month. Predictions were made for the following cases:

1. A reservoir flow of 7200 cfs and its associated temperature rise of 10° F.

2. A reservoir flow of 14,500 cfs and its associated temperature rise of 5° F.

3. A reservoir flow greater than 20,300 cfs but less than about 50,000 cfs which gives a temperature rise of 3.5° F.

The relationship between reservoir flow and temperature was taken from Plate 10. Complete mixing of the reservoir flow and the condenser flow occurs for the first two cases. For case 3, only 20,300 cfs of the reservoir flow mixes with the condenser flow and the remainder flows as a cooler underflow.

Three-Unit Operation

The condenser flow will be 4350 cfs and the maximum intake velocity 1.3 ft/sec. The discharge will occur over the full 1800-foot diffuser structure resulting in a mixing zone which will occupy 27 percent of the reservoir cross sectional area and a volume of 7,200,000 cuft. The mixed temperature rise is shown in Figure 10. Complete mixing of the reservoir flow with the discharge will occur for reservoir flows less than 30,000 to 43,500 cfs.

Predictions of the downstream temperature increase above ambient are shown on Plates 35 through 46 for the middle week of each month. Predictions were made for the following cases:

1. A reservoir flow of 10,900 cfs and its associated temperature rise of 10° F.

2. A reservoir flow of 21,800 cfs and its associated temperature rise of 5° F.

3. A reservoir flow greater than 30,500 cfs but less than about 50,000 cfs which gives a temperature rise of 3.5° F.

The relationship between reservoir flow and temperature was taken from Plate 10. Complete mixing of the reservoir flow and the condenser flow occurs for the first two cases. For case 3, only 30,500 cfs of the reservoir flow mixes with the condenser flow and the remainder flows as a cooler underflow.

HELPER MODE OPERATION

The construction of cooling towers at Browns Ferry will make possible the operation of the condenser cooling system in a helper mode where a portion of the heat will be removed from the condenser water by the towers before it is discharged into the river. Although the details of the design are not final, it will involve a somewhat lower condenser water flow (1223 cfs) for each unit, a higher condenser rise (31.7° F.), and a lower temperature rise in the discharged water than in an open cycle operation. In addition the flow from a single unit, if it is shown to provide more desirable mixing characteristics, may be discharged through all three diffuser sections. These differences from open cycle operation will result in a different relationship between the reservoir flow magnitude and the temperature rises in the reservoir but operations in general should result in similar flow and temperature patterns as described for the open mode of operation.

FUTURE PROGRAMS

This report has described the present state of knowledge about the hydrothermal regime which will occur in Wheeler Reservoir at the Browns Ferry Nuclear Plant site. The treatment has been limited to steady conditions during operation of the plant as an open cycle system and has been based primarily upon model data. The following sections discuss the differences expected when unsteady reservoir flows or helper mode operation is considered. The continuing investigation of these modes is outlined, including plans for obtaining post-operational field data to verify and supplement model results.

Unsteady Reservoir Flows

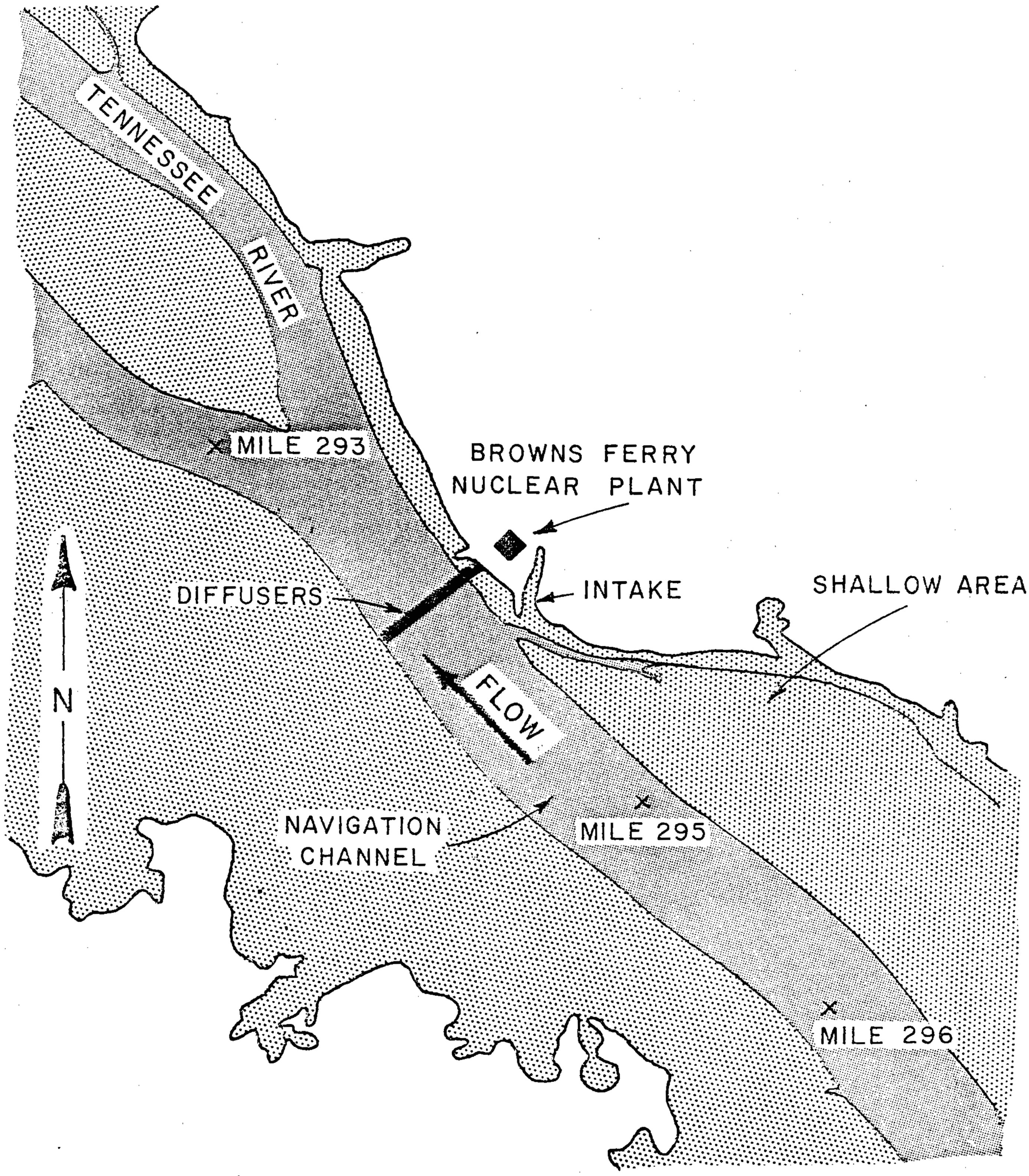
The temperature rises described in the preceeding sections are steady-state values reached asymptotically after a change in flow conditions. If the reservoir flow is constantly changing, the temperature and flow distribution may never be in a steady state condition. It is clear that if the reservoir flow remains greater than a certain magnitude, the mixed temperature rise in the reservoir will never exceed the steady state value corresponding to that minimum flow. If the reservoir flow fluctuates below the minimum value for some short length of time, the temperature rise may not increase significantly. A continuing program of testing in the three-dimentional thermal model has as its objective the determination of what unsteady flow regulation policies will be required to keep the induced temperature rises in Wheeler Reservoir below the desired value.

Helper Mode Operation

As the designs are firmed up, model tests will be used to predict the three-dimensional flow and temperature distributions for helper mode operation as they were predicted for open cycle operation and to determine the most expedient operating method for achieving the desired temperature standards. These studies will finally be firmed up by field investigations after the units are in operation.

Field Measurements

The operation of Browns Ferry Nuclear Plant and the regulation of Wheeler Reservoir flows will be determined by the readings from a system of continuously recording fixed temperature monitors (see Figure 47). There will also be intensive surveys by boat and airborne techniques to measure the details of the temperature distribution in the vicinity of the plant. This information will begin to be available as soon as the plant commences one-unit operation. The field data will be compared with model results to verify and refine the predictions presented in this report and to develop the final required operating procedures.



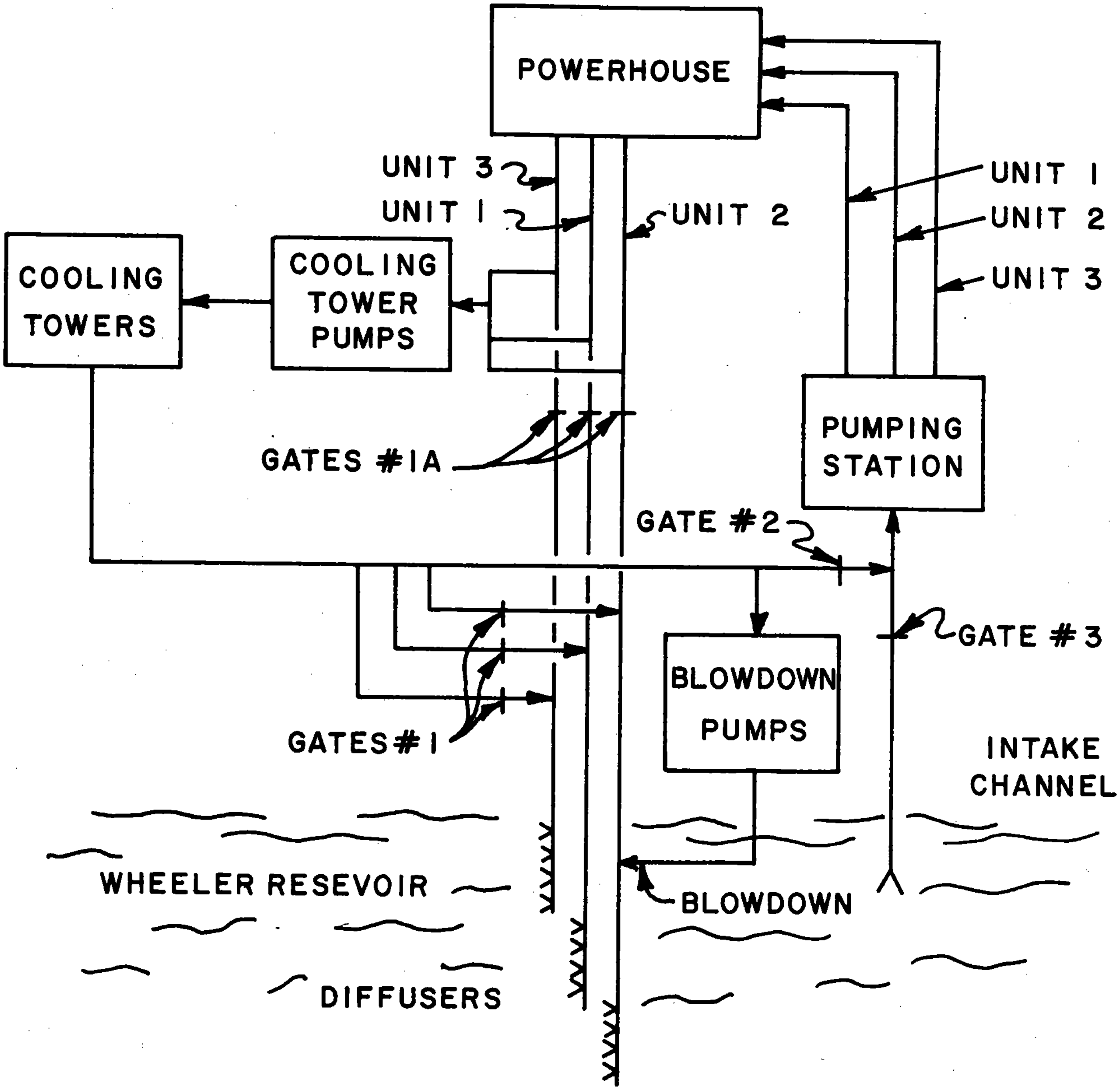
DRAWN JMC	ENGINEER KDS
CHECKED	APPROVED

TEMPERATURE PREDICTIONS

SITE LOCATION

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920-A-108



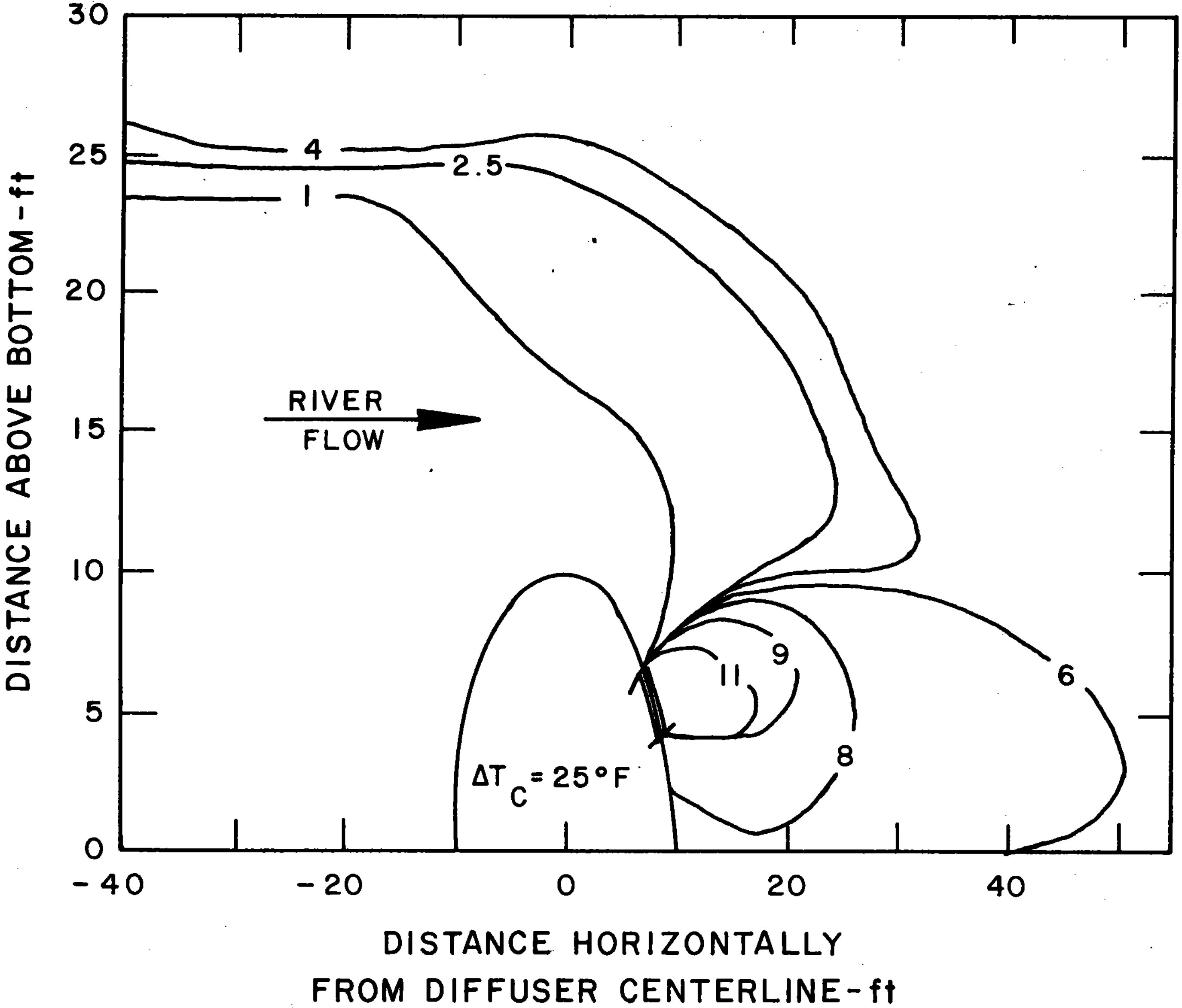
TEMPERATURE PREDICTIONS

COOLING WATER SYSTEM

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920	A-109

DRAWN | ENGINEER | CHECKED | APPROVED



Q_R = 20,000 cfs

Q_C = 4,350 cfs

$\Delta T_{theor.}$ = 5.5°F

NOTE: ISOTHERM VALUES ARE TEMPERATURE INCREASES OVER AMBIENT RIVER TEMPERATURE

DRAWN	ENGINEER
CHECKED	APPROVED

TEMPERATURE PREDICTIONS

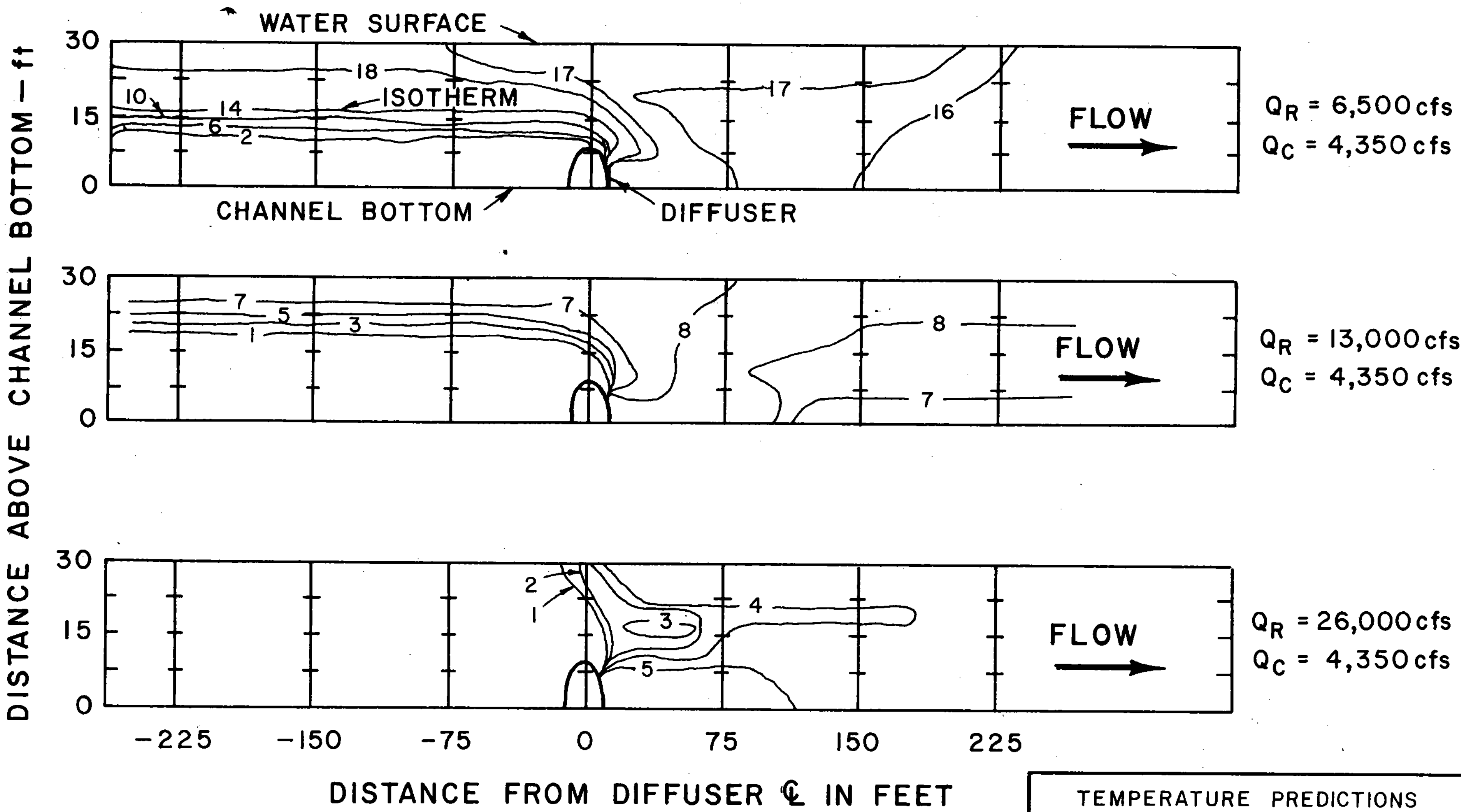
STRUCTURE OF THE JET MIXING REGION

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920	A-111

PLATE 4

N0670-2116-0-40-30-11



NOTE: ISOTHERM VALUES ARE TEMPERATURE INCREASES OVER AMBIENT RIVER TEMPERATURE

DRAWN	ENGINEER
JMC	KDS
CHECKED	APPROVED
KDS	

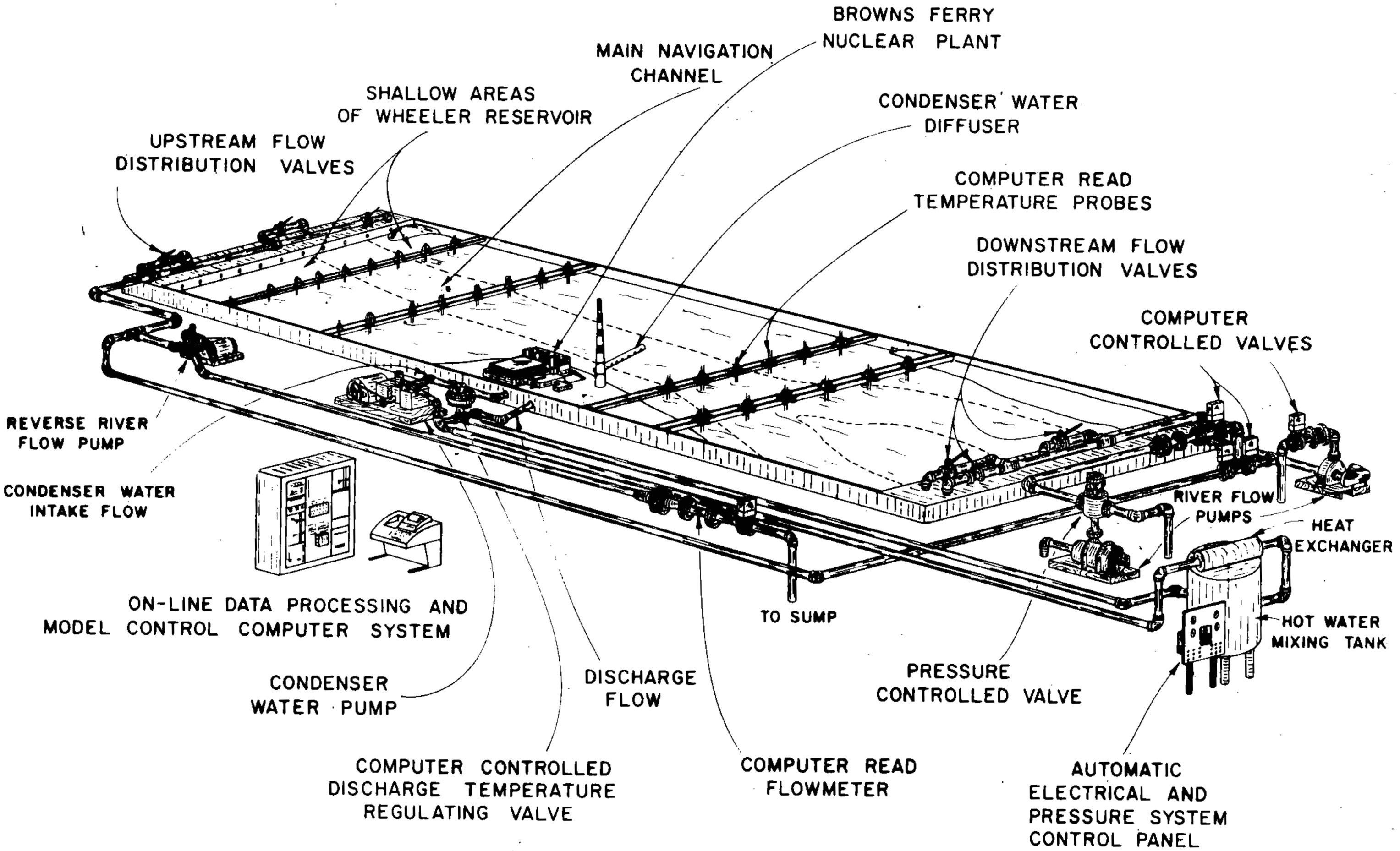
TEMPERATURE PREDICTIONS

TEMPERATURE RISE IN THE JET MIXING REGION

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920 A-112

PLATE 5



TEMPERATURE PREDICTION

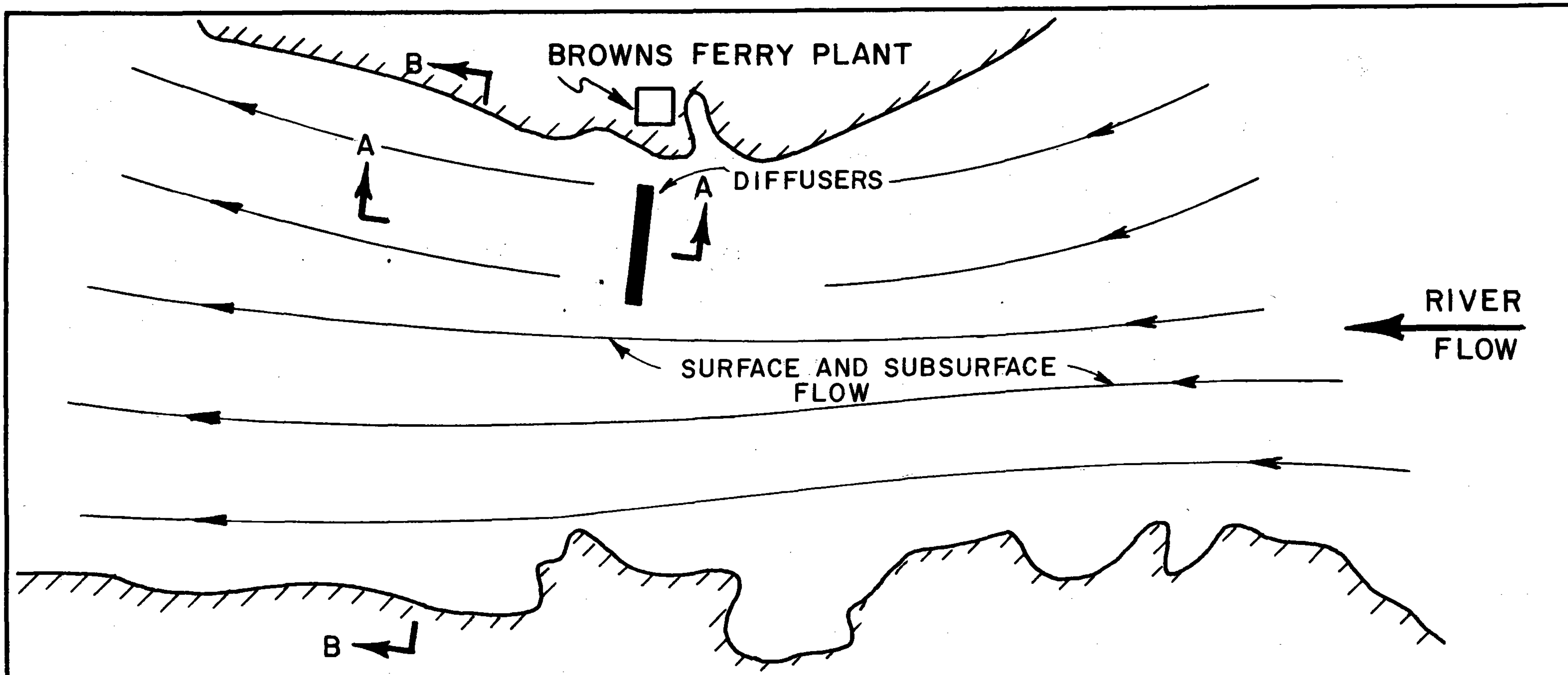
THREE DIMENSIONAL THERMAL MODEL

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

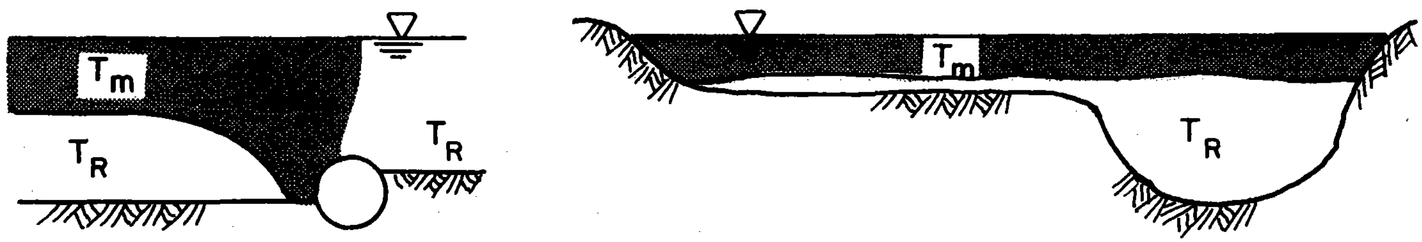
NORRIS	4-20-72	67	EL	920	A-113

DRAWN JWC | ENGINEER KDS | CHECKED KDS | APPROVED

PLATE 6



FLOW DISTRIBUTION



SECTION A-A

SECTION B-B

TEMPERATURE DISTRIBUTION

TEMPERATURE PREDICTIONS

HIGH RIVER DISCHARGE

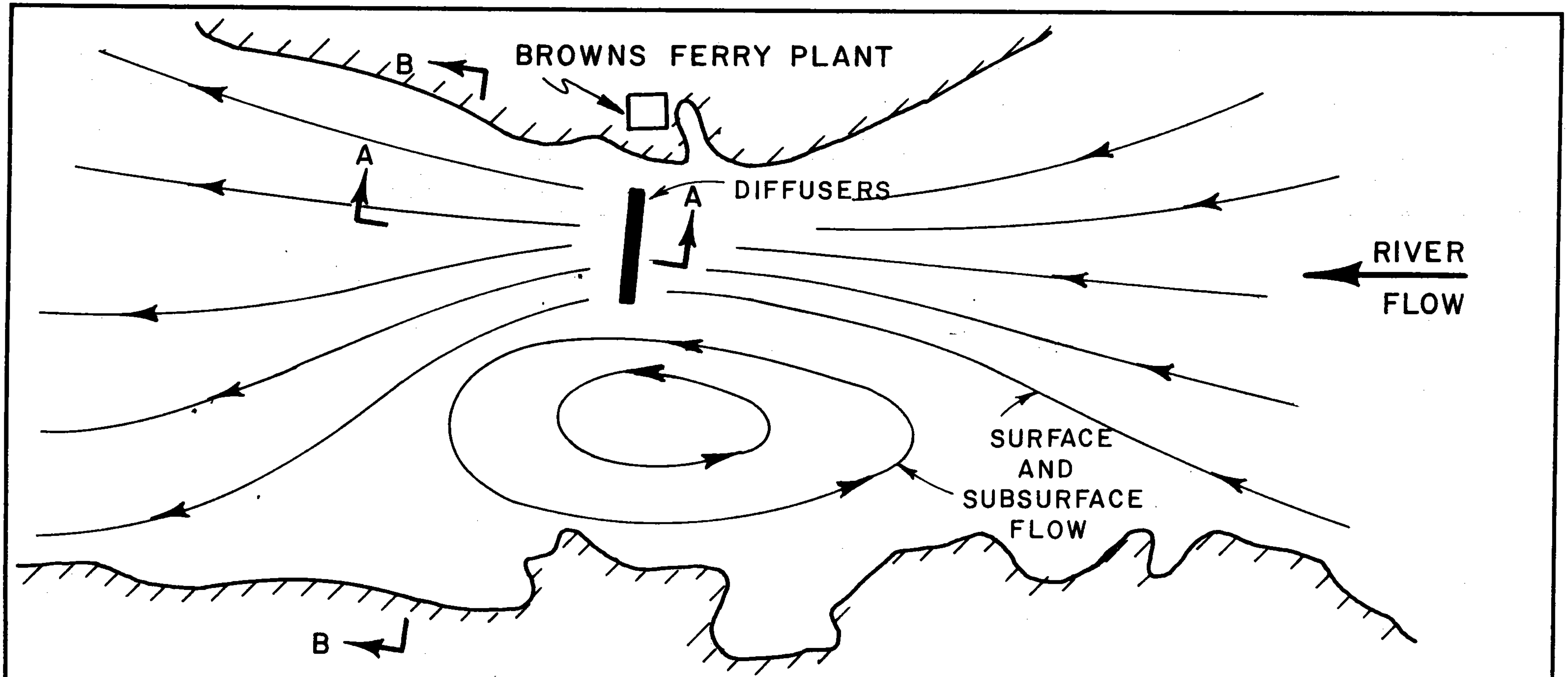
BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920	A-114

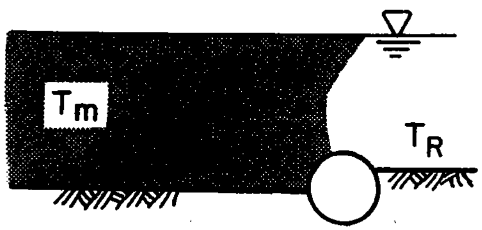
DRAWN JMC | ENGINEER KDS | CHECKED KDS | APPROVED

PLATE 7

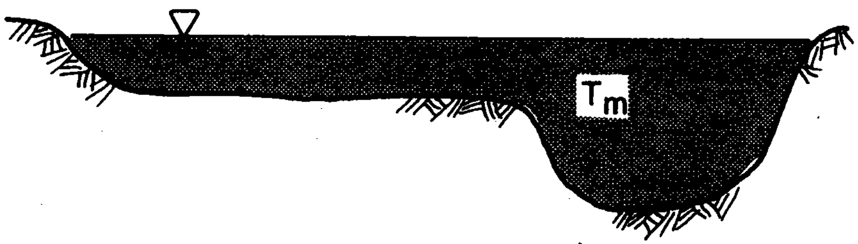
N0870-5616-0-40-30-11



FLOW DISTRIBUTION



SECTION A-A



SECTION B-B

TEMPERATURE DISTRIBUTION

DRAWN	ENGINEER
JMC	KDS
CHECKED	APPROVED
KDS	

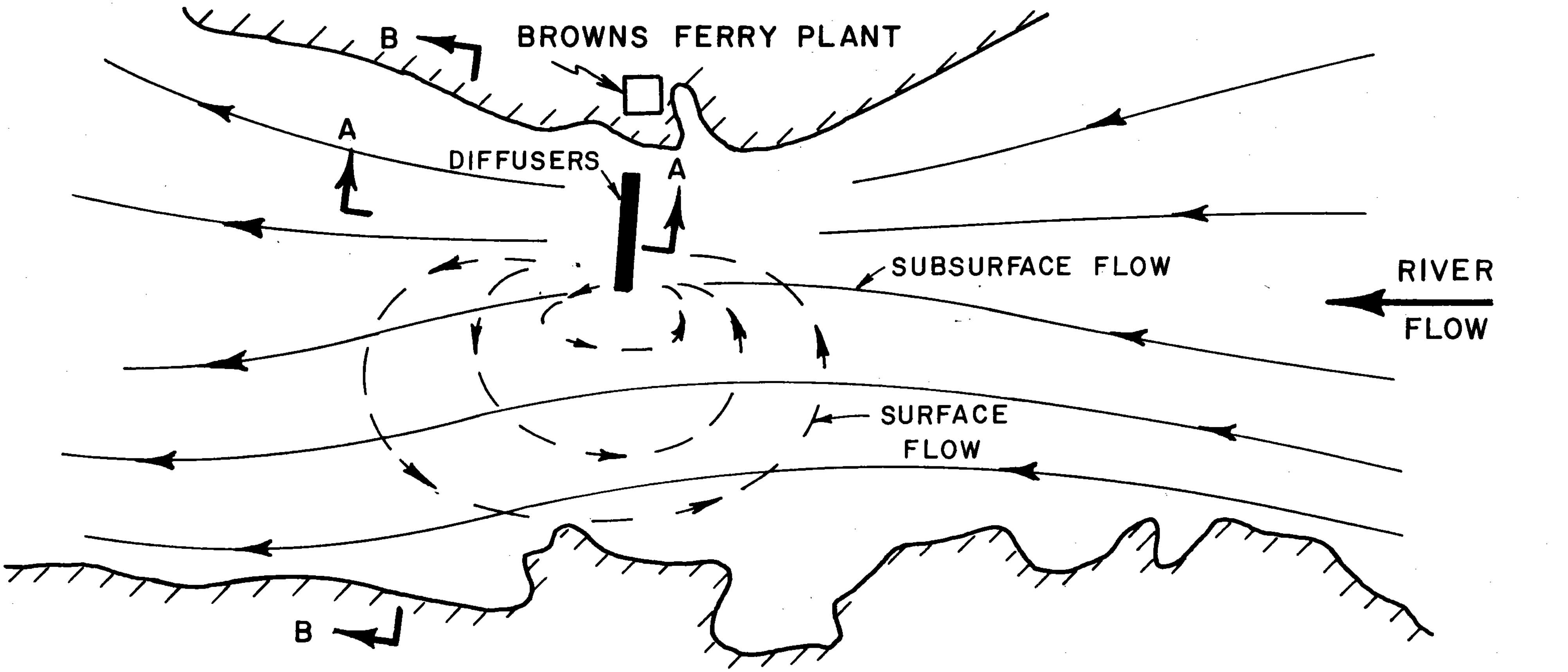
TEMPERATURE PREDICTIONS

LOW RESERVOIR DISCHARGE

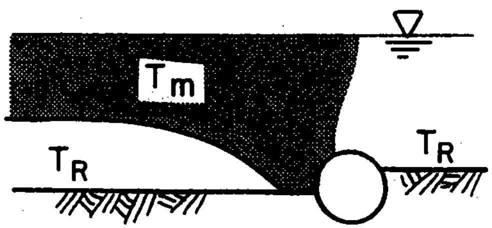
BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920	A-115

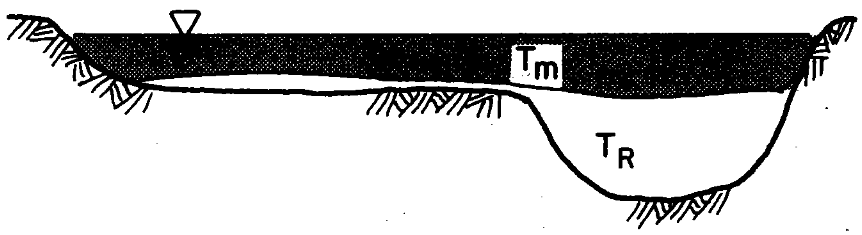
PLATE 8



FLOW DISTRIBUTION



SECTION A-A



SECTION B-B

TEMPERATURE DISTRIBUTION

DRAWN JMC	ENGINEER KDS
CHECKED KDS	APPROVED RJE

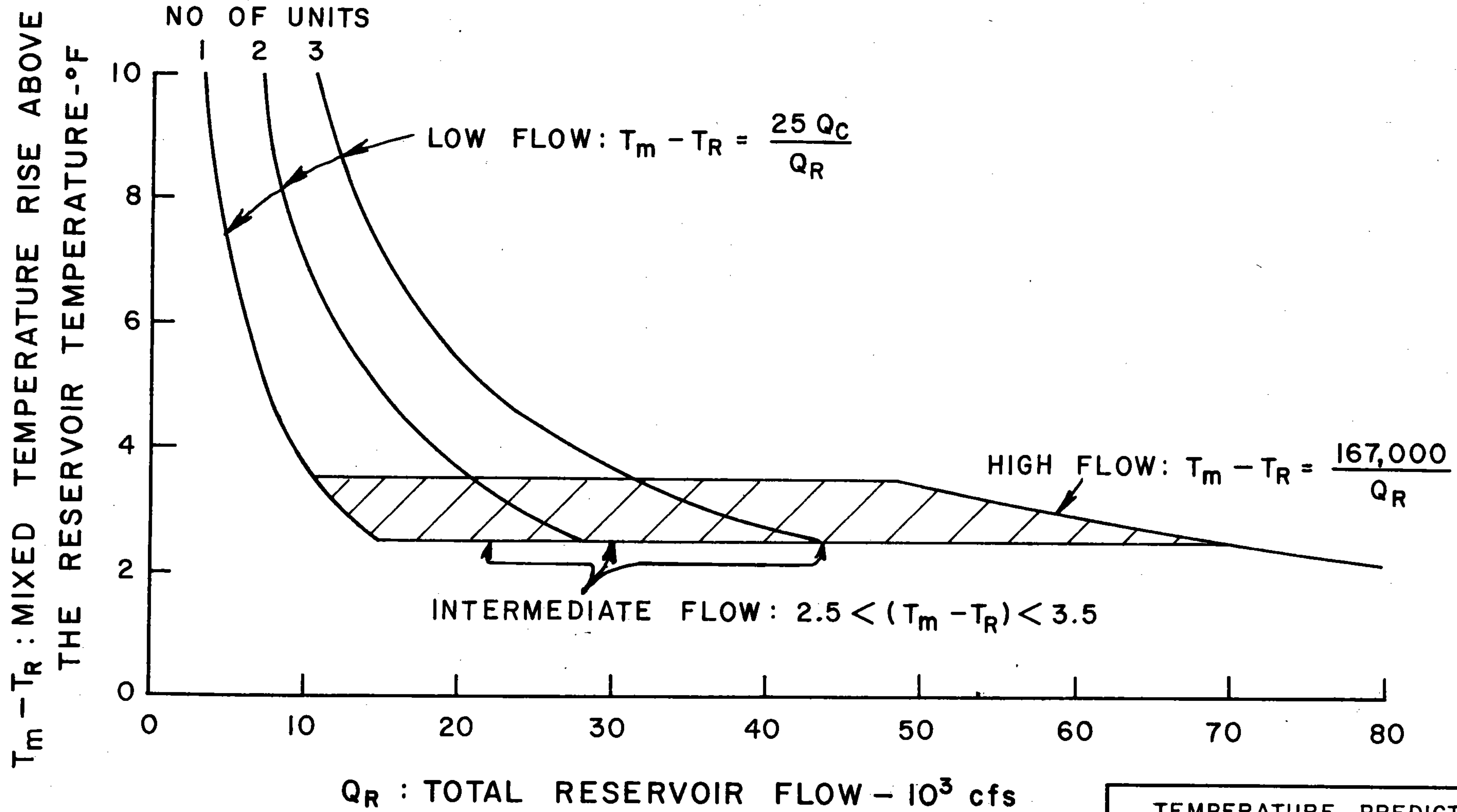
TEMPERATURE PREDICTIONS

INTERMEDIATE RIVER DISCHARGE

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920 A-116

PLATE 9



TEMPERATURE PREDICTIONS

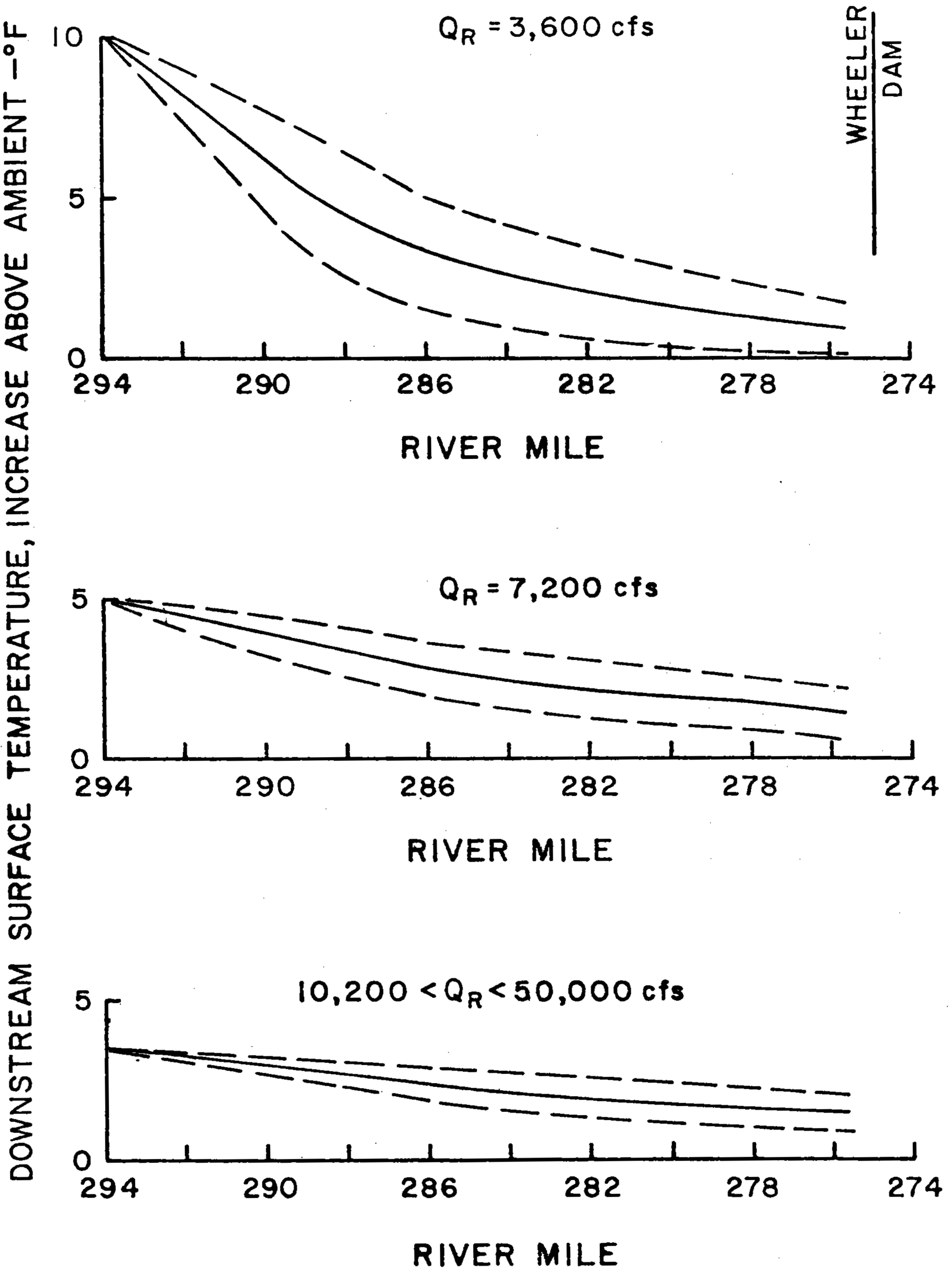
TEMPERATURE RISE OUTSIDE OF THE JET MIXING REGION

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-72	67	EL	920 A-117

DRAWN JMC	ENGINEER KDS
CHECKED KDS	APPROVED

PLATE 1



——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS
EFFECT OF PLANT ON DOWNSTREAM TEMP. JANUARY, 1 UNIT
BROWNS FERRY NUCLEAR PLANT TENNESSEE VALLEY AUTHORITY DIVISION OF WATER CONTROL PLANNING ENGINEERING LABORATORY
NORRIS 4-20-72 67 EL 920 A-118

DRAWN WRK ENGINEERED [signature] CHECKED [signature] APPROVED [signature]

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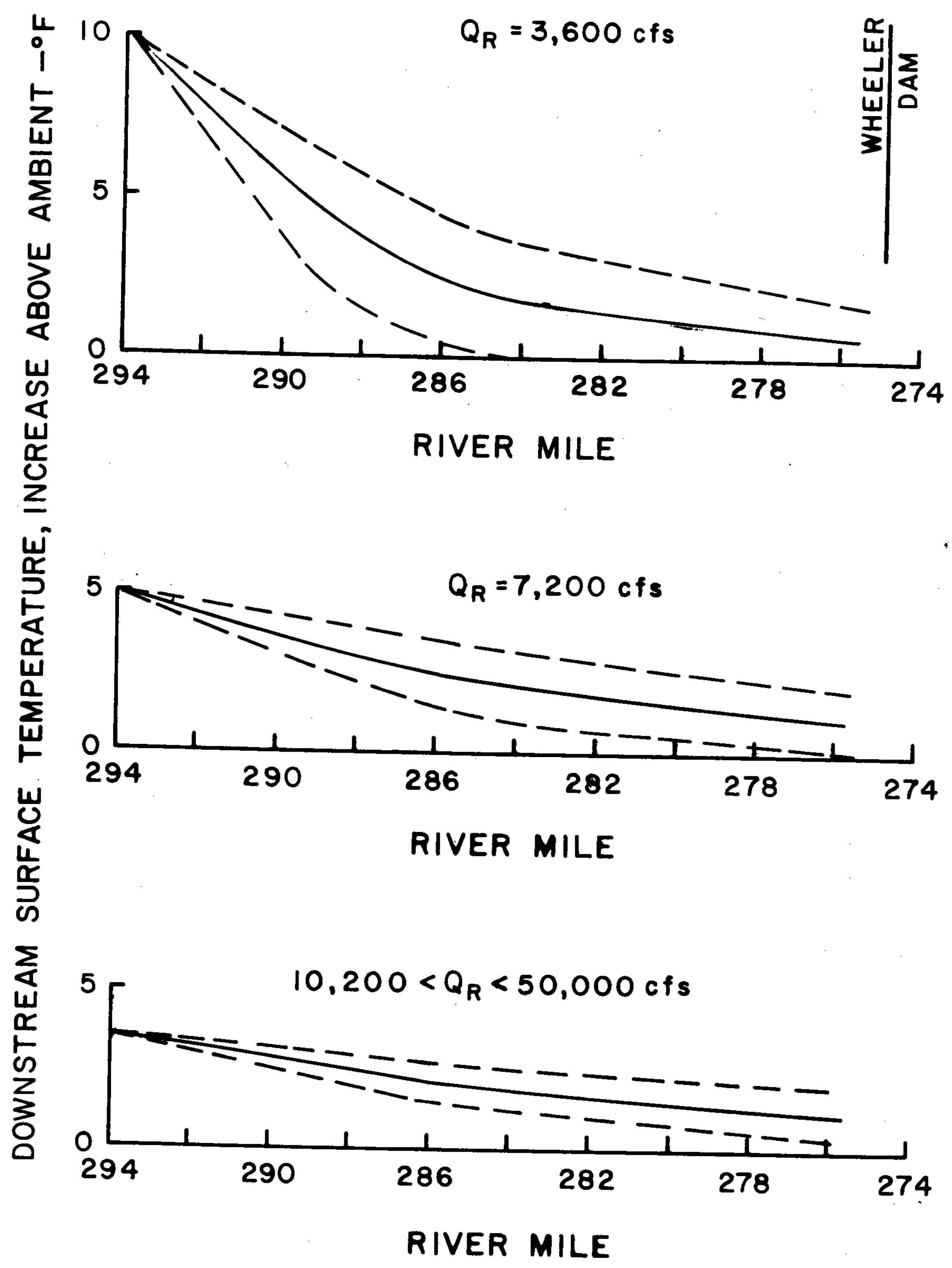


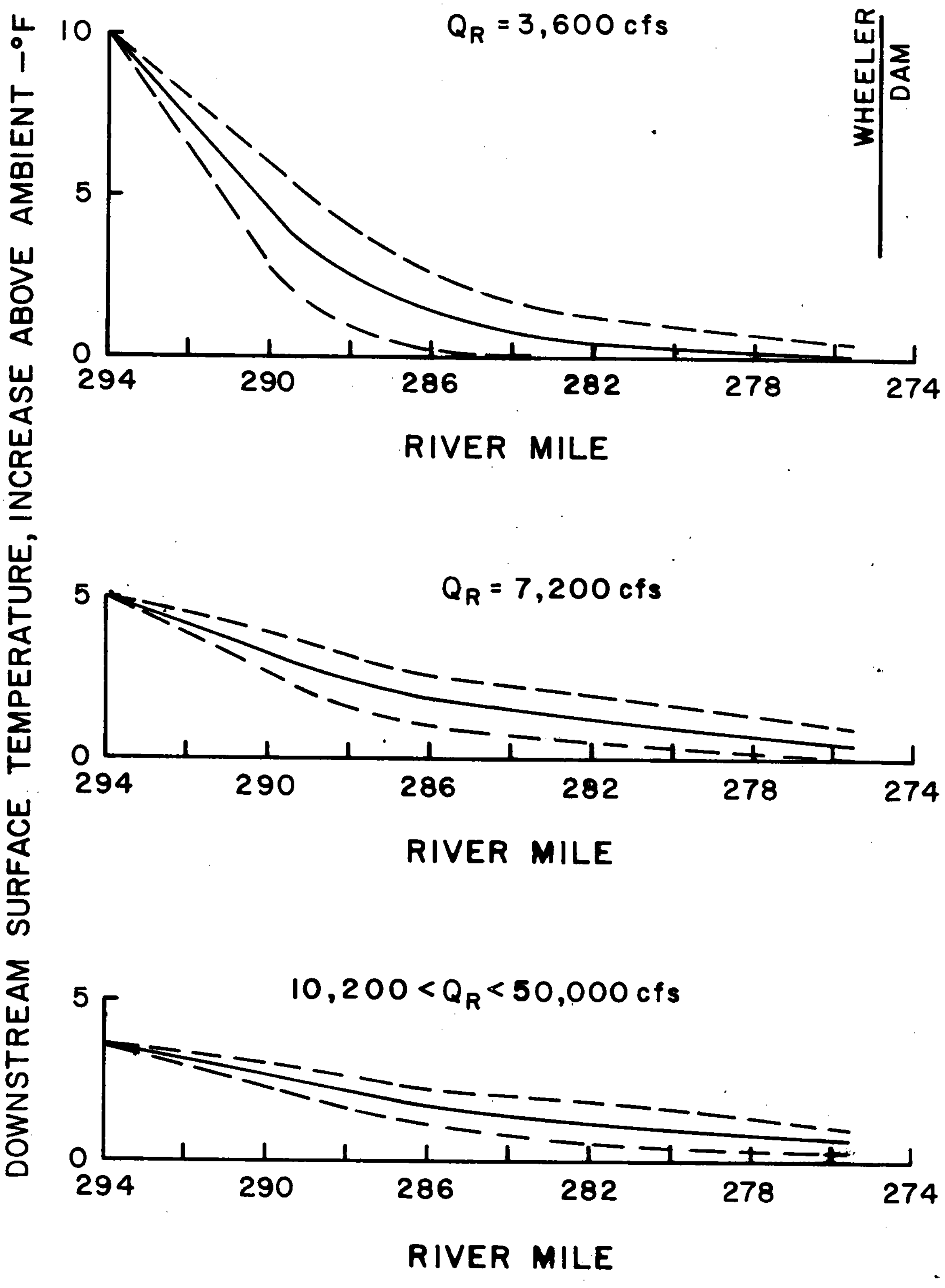
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. FEBRUARY, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-121

DRAWN / CHECKED / ENGINEER / APPROVED



——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

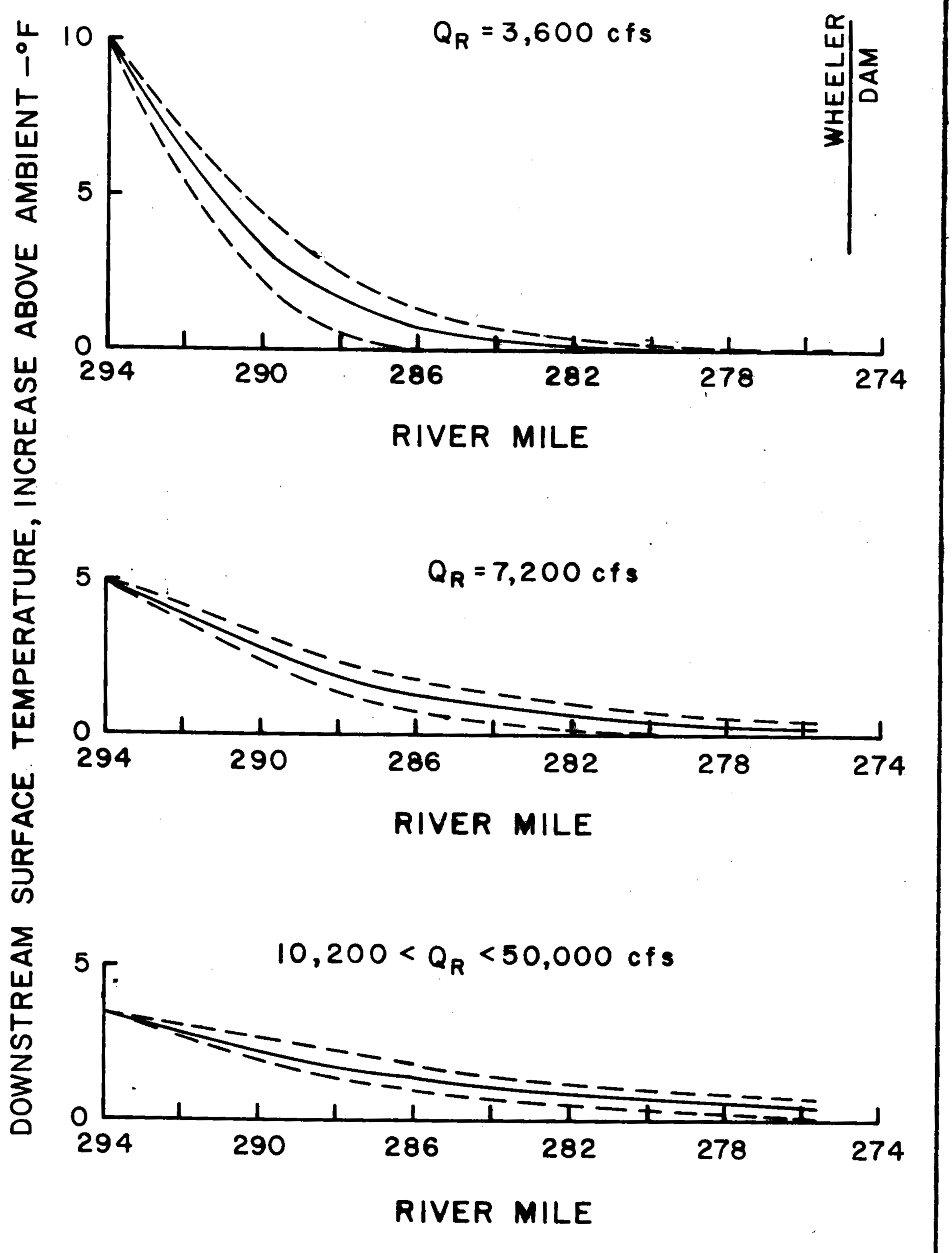
EFFECT OF PLANT ON DOWNSTREAM TEMP. MARCH, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN WKH	ENGINEER EEA
CHECKED LWH	APPROVED RE

NORRIS	4-20-72	67	EL	920	A-124

N0670-5616-0-40-30-11



——— MEAN

- - - - 95% CONFIDENCE LIMITS

DRAWN VMC	ENGINEER EED	CHECKED LWH	APPROVED RxE	

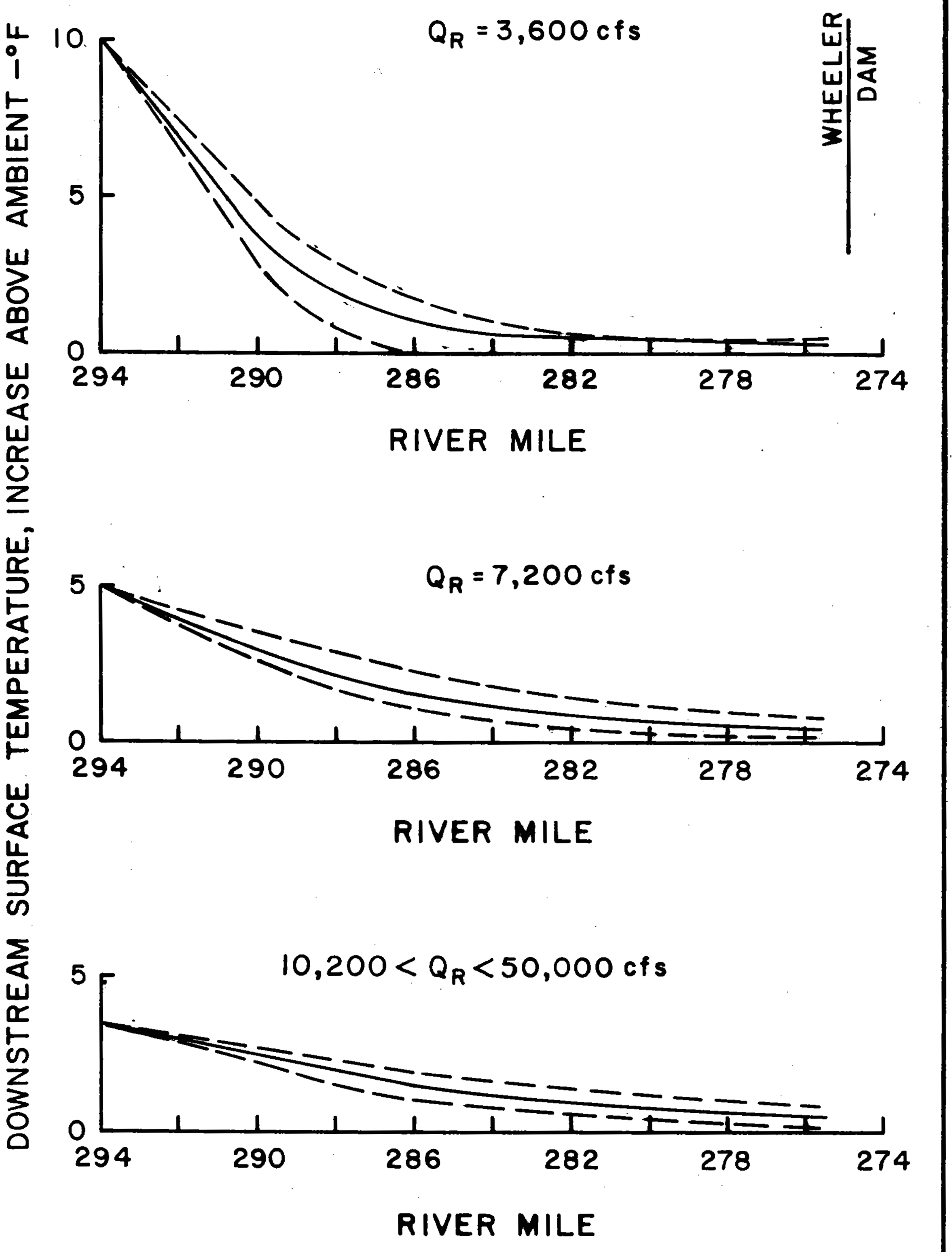
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. APRIL, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-127

N0670-5616-0-40-20-11



——— MEAN

– – – – 95% CONFIDENCE LIMITS

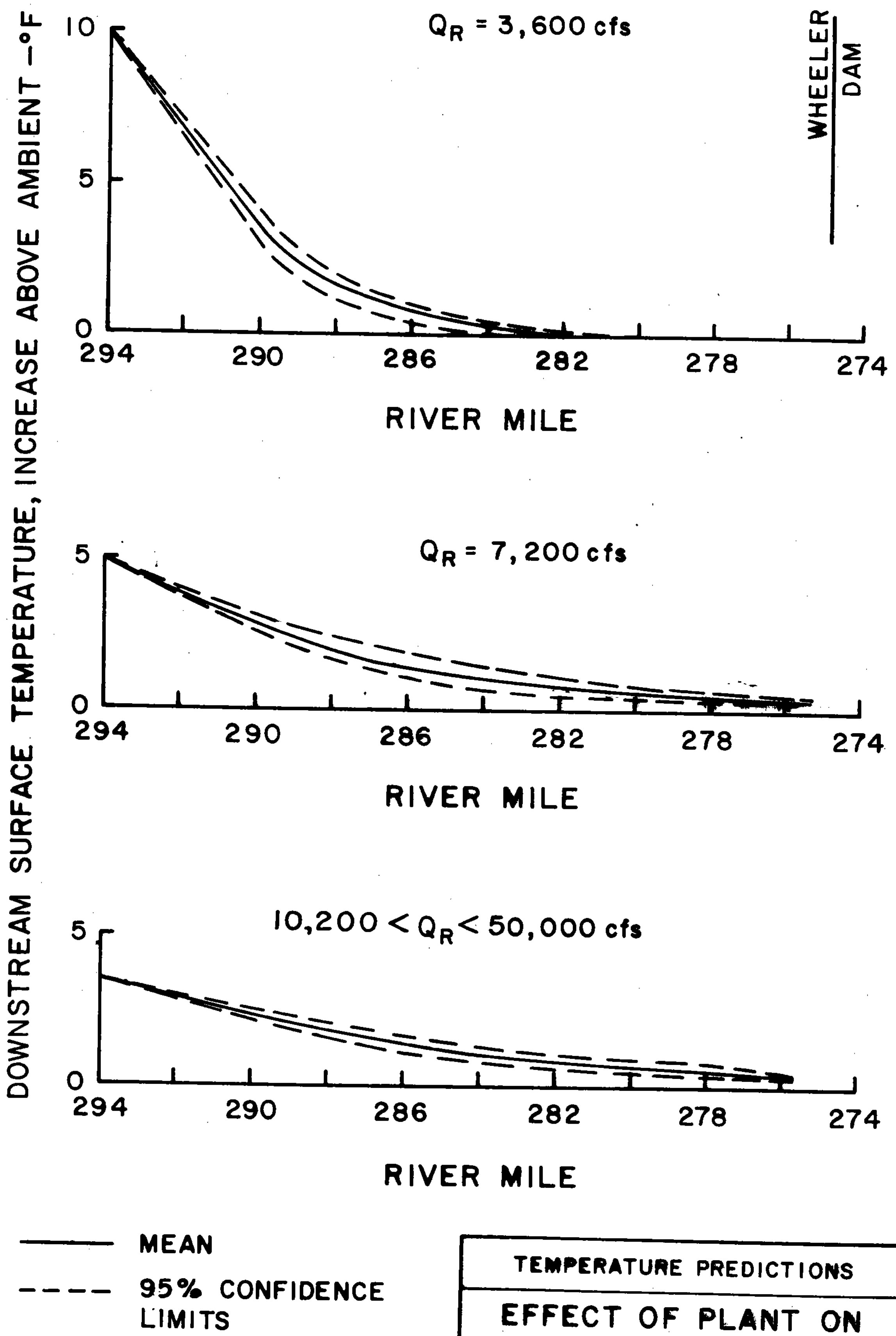
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. MAY, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER	CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-130



TEMPERATURE PREDICTIONS

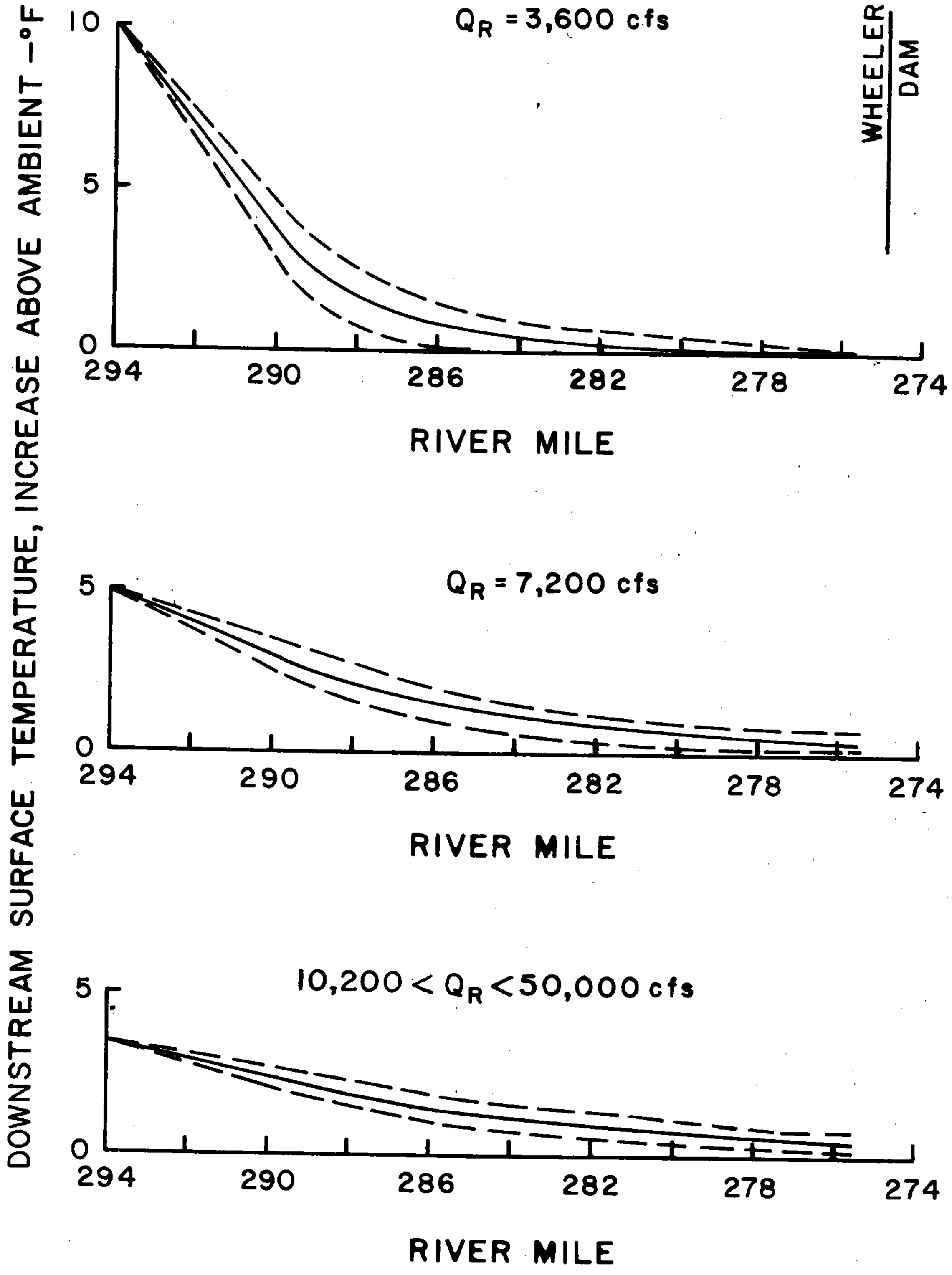
EFFECT OF PLANT ON DOWNSTREAM TEMP. JUNE, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER
CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-133

N0670-5616-0-40-30-11



——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

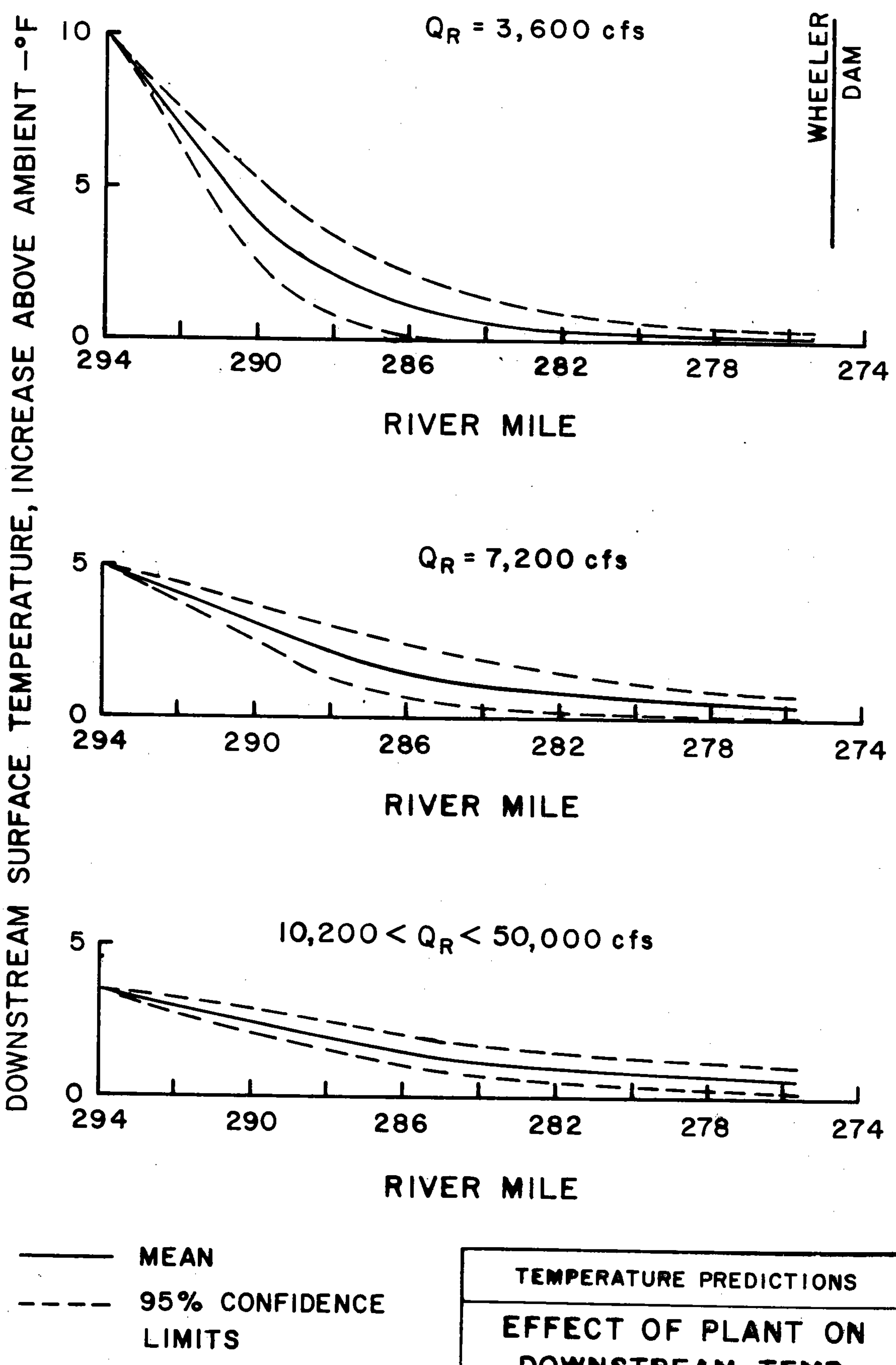
EFFECT OF PLANT ON DOWNSTREAM TEMP. JULY, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER
WLH	[signature]
CHECKED	APPROVED
[signature]	[signature]

NORRIS	4-20-72	67	EL	920	A-136

NO270-5616-0-40-30



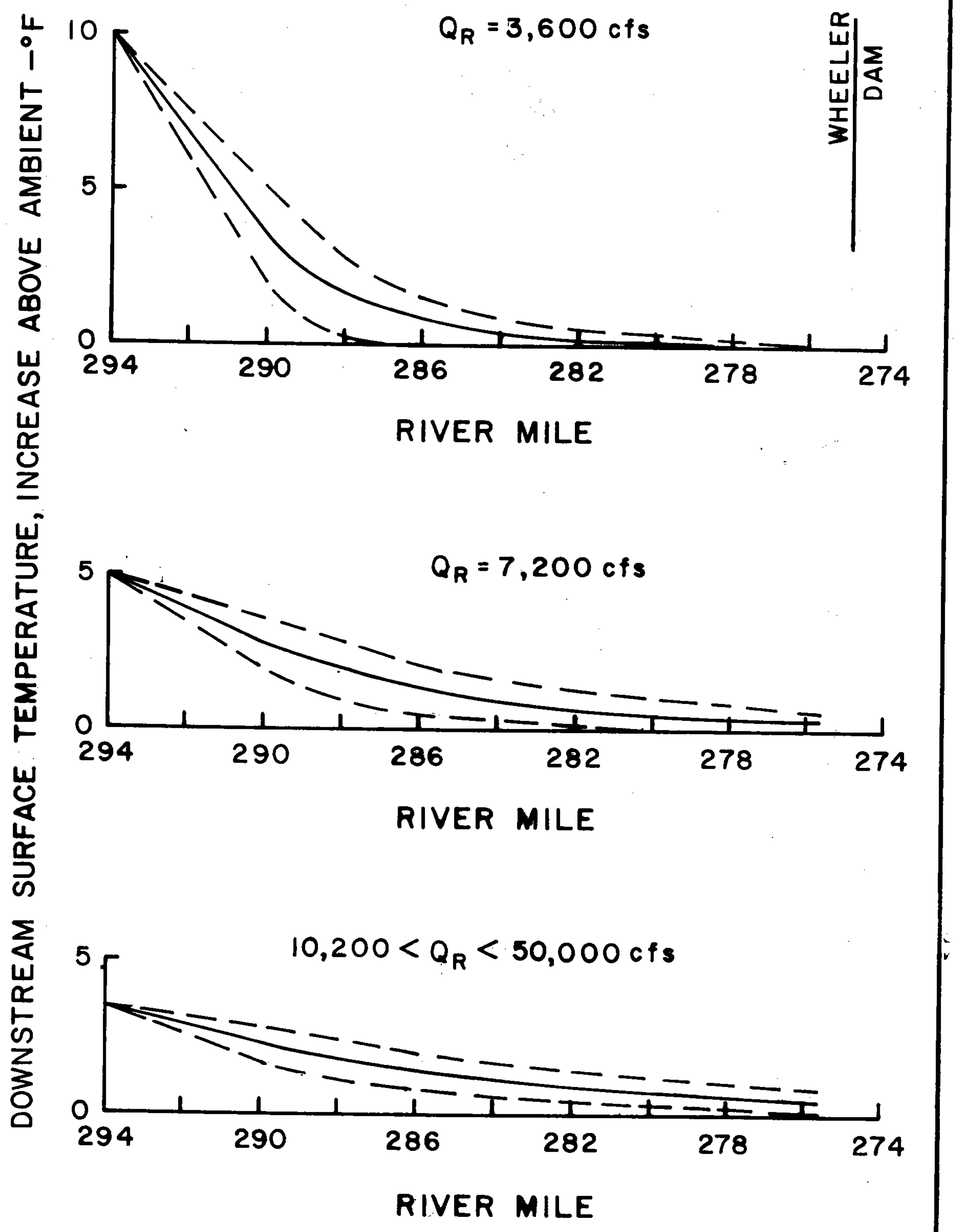
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. AUGUST, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-139

DRAWN	ENGINEER
JMC	
CHECKED	APPROVED



——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

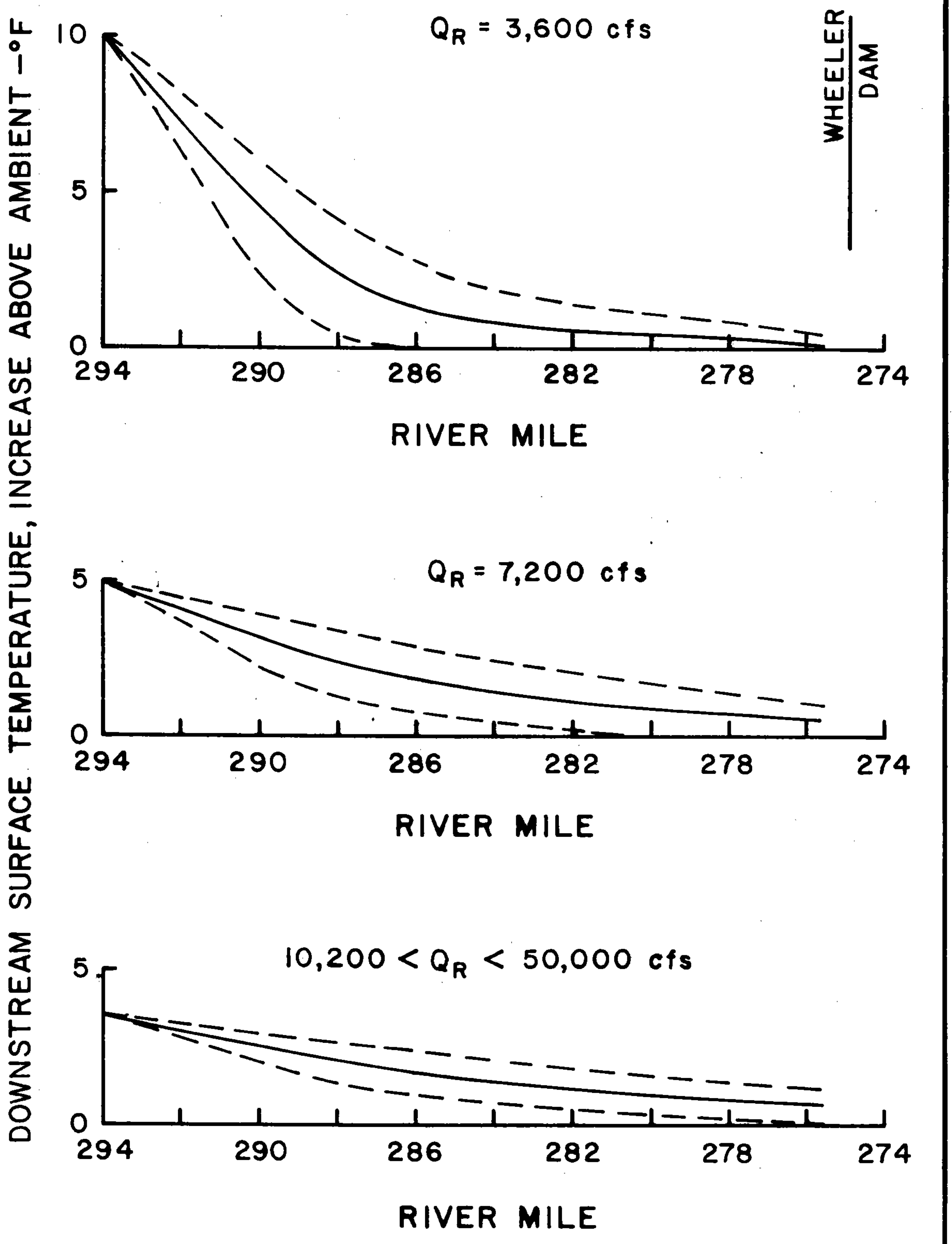
EFFECT OF PLANT ON DOWNSTREAM TEMP. SEPTEMBER, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEERED	NORRIS	4-20-72	67	EL 920	A-142
CHECKED	APPROVED					

N0670-5616-0-40-30-11

PLATE 20



——— MEAN

- - - - 95% CONFIDENCE LIMITS

DRAWN JMC	ENGINEERED
CHECKED	APPROVED

TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. OCTOBER, 1 UNIT

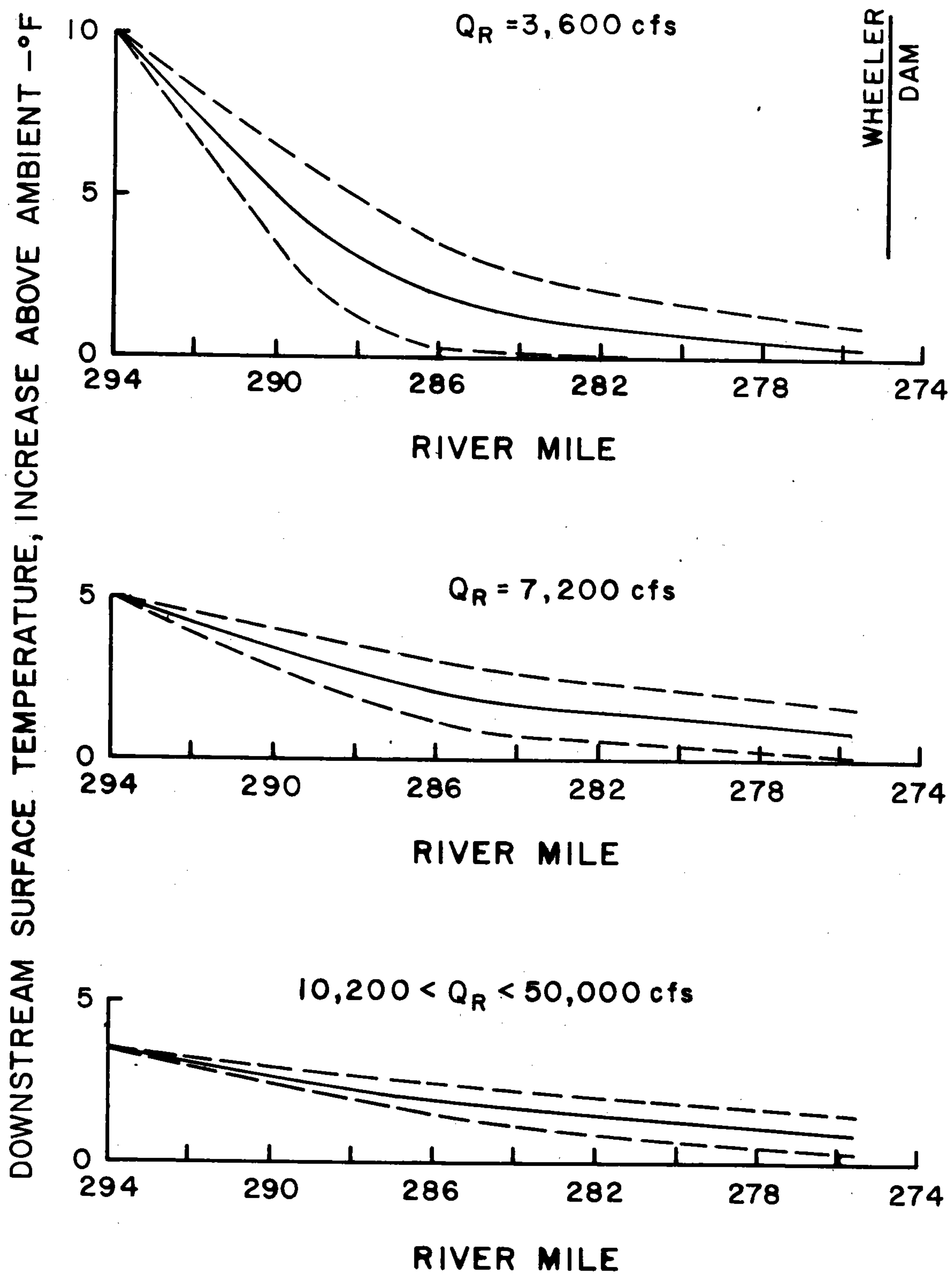
BROWNS FERRY NUCLEAR PLANT

TENNESSEE VALLEY AUTHORITY

DIVISION OF WATER CONTROL PLANNING

ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-145



——— MEAN

- - - - 95% CONFIDENCE LIMITS

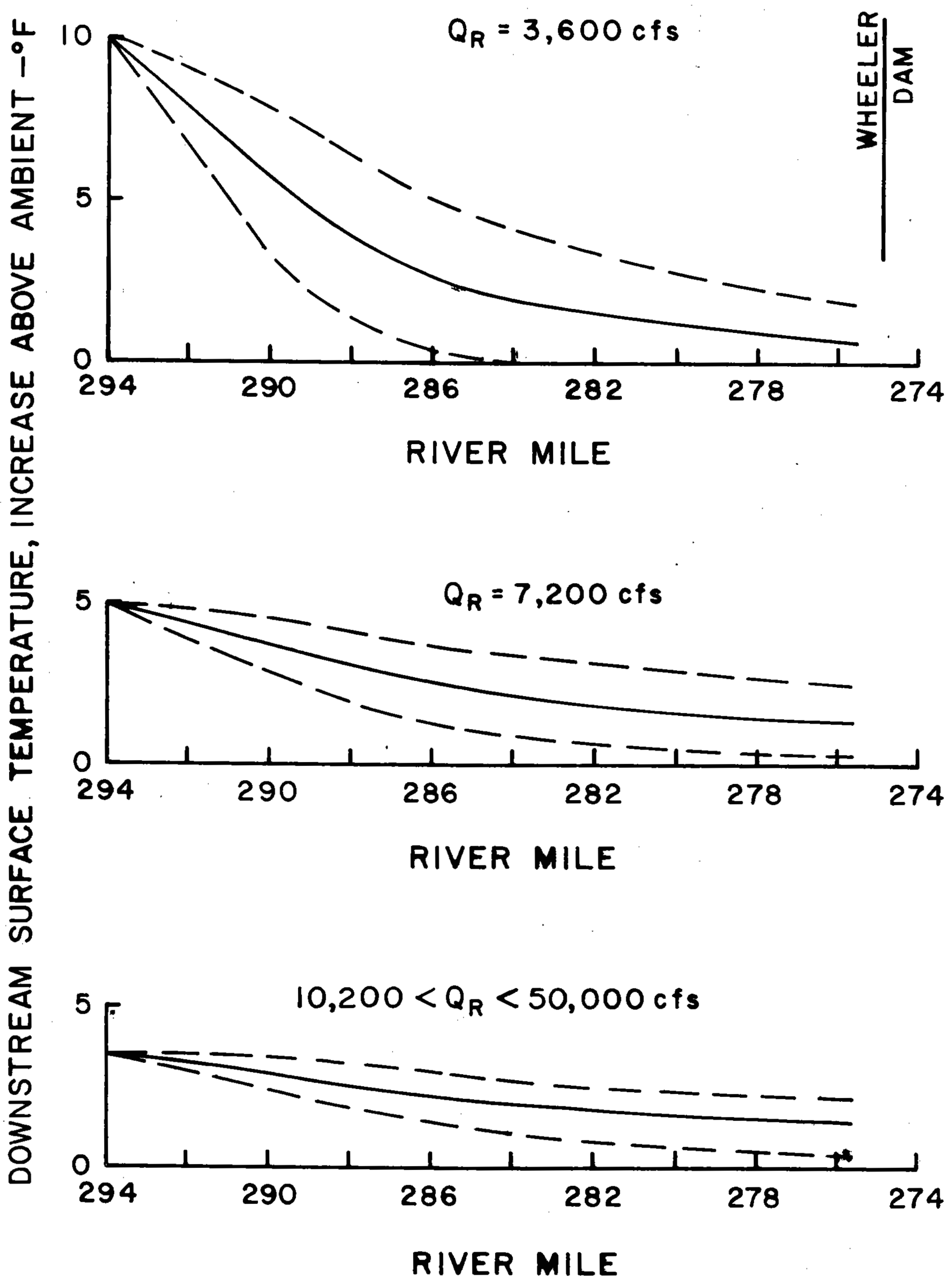
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. NOVEMBER, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-148

DRAWN	ENGINEER
WRH	[illegible]
CHECKED	APPROVED
[illegible]	[illegible]



——— MEAN

– – – – 95% CONFIDENCE LIMITS

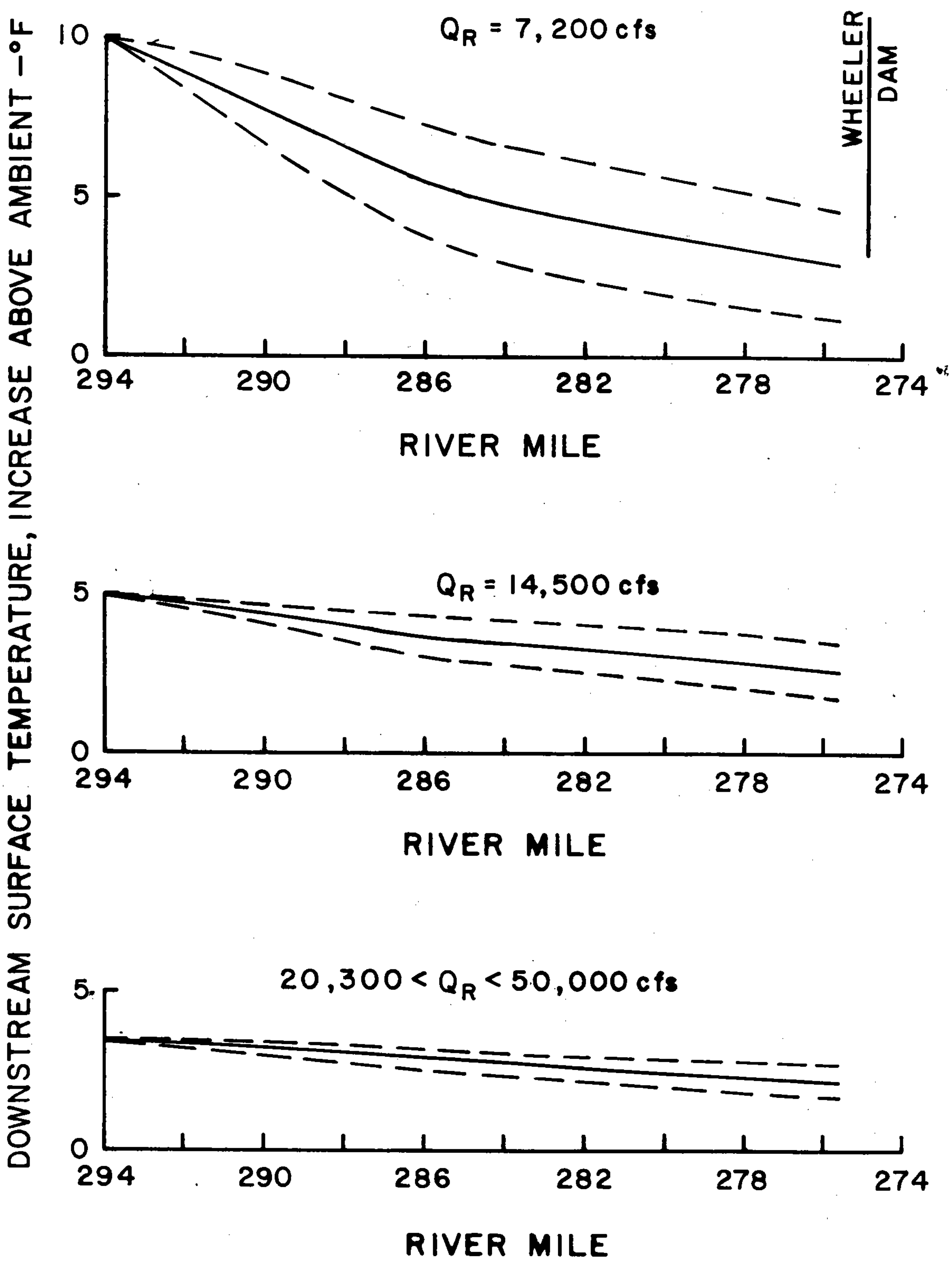
DRAWN	ENGINEER
CHECKED	APPROVED

TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. DECEMBER, 1 UNIT

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-151



——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

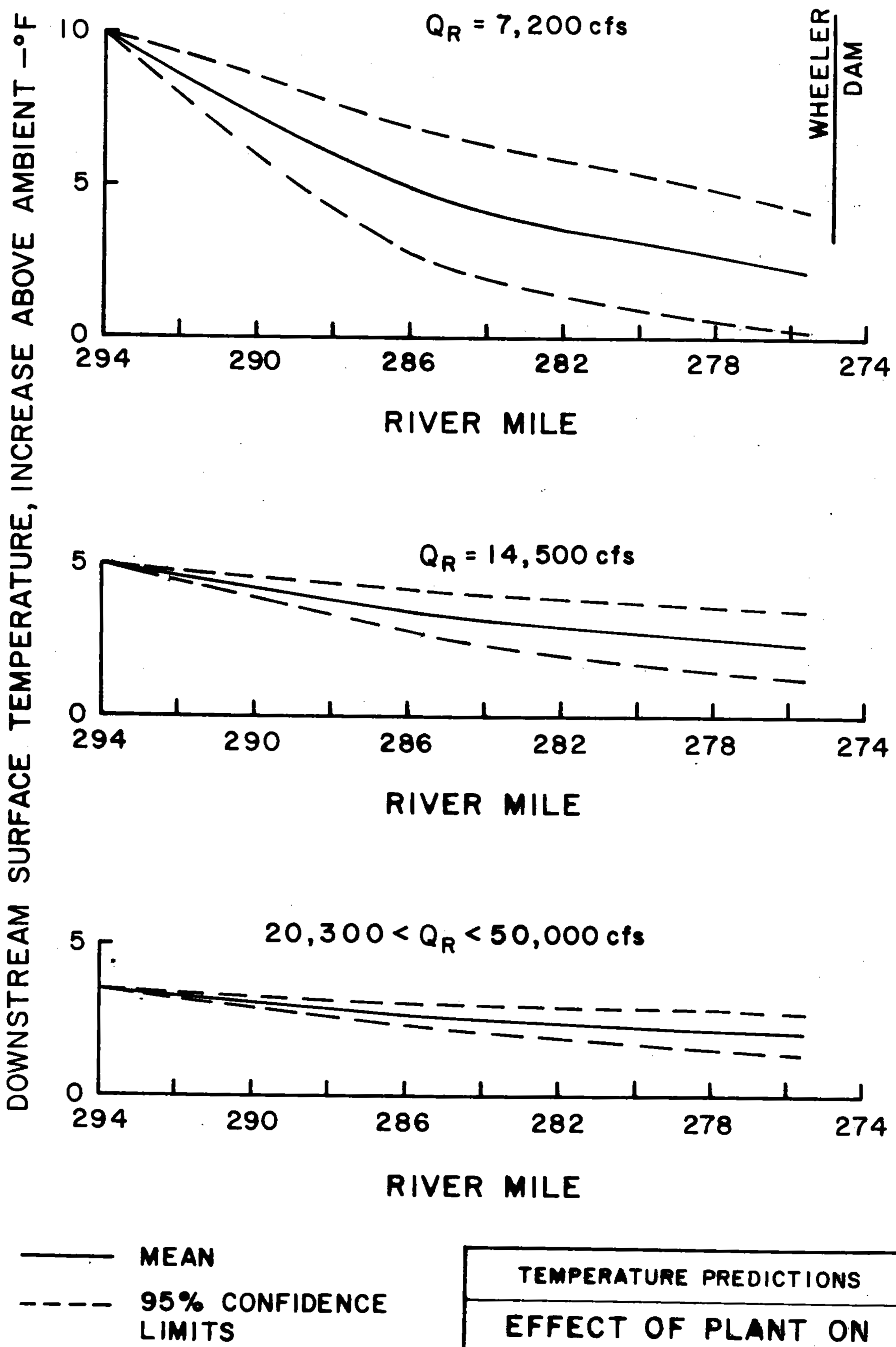
EFFECT OF PLANT ON DOWNSTREAM TEMP. JANUARY, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEERED	CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-119

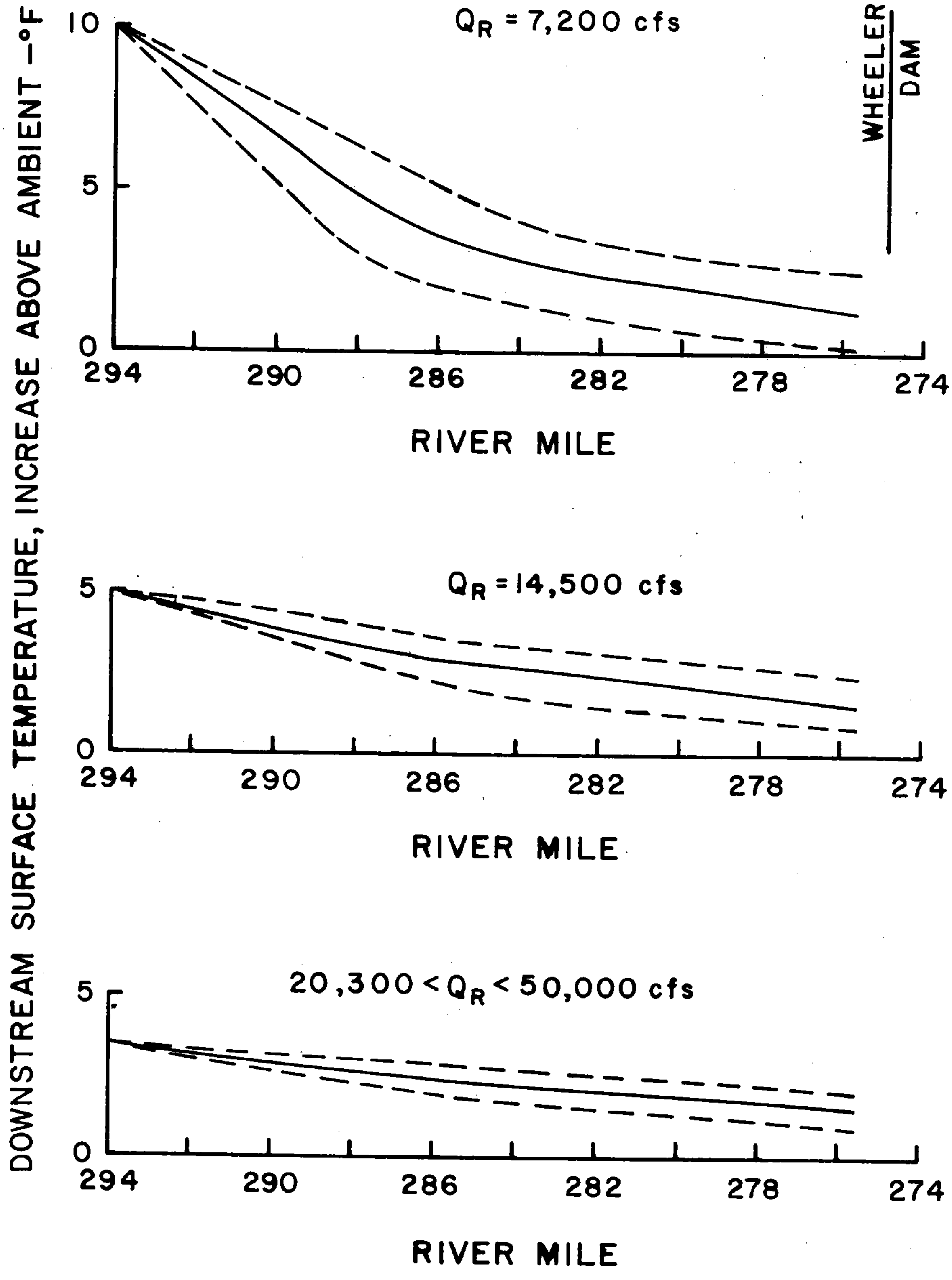
N2670-5616-0-40-30-11



TEMPERATURE PREDICTIONS	
EFFECT OF PLANT ON DOWNSTREAM TEMP. FEBRUARY, 2 UNITS	
BROWNS FERRY NUCLEAR PLANT TENNESSEE VALLEY AUTHORITY DIVISION OF WATER CONTROL PLANNING ENGINEERING LABORATORY	
NORRIS 4-20-72 67 EL 920	A-122

DRAWN / ENGINEER / CHECKED / APPROVED

N0670-5516-3-40-33-11



——— MEAN

- - - - 95% CONFIDENCE LIMITS

DRAWN	UMC
CHECKED	
ENGINEER	
APPROVED	

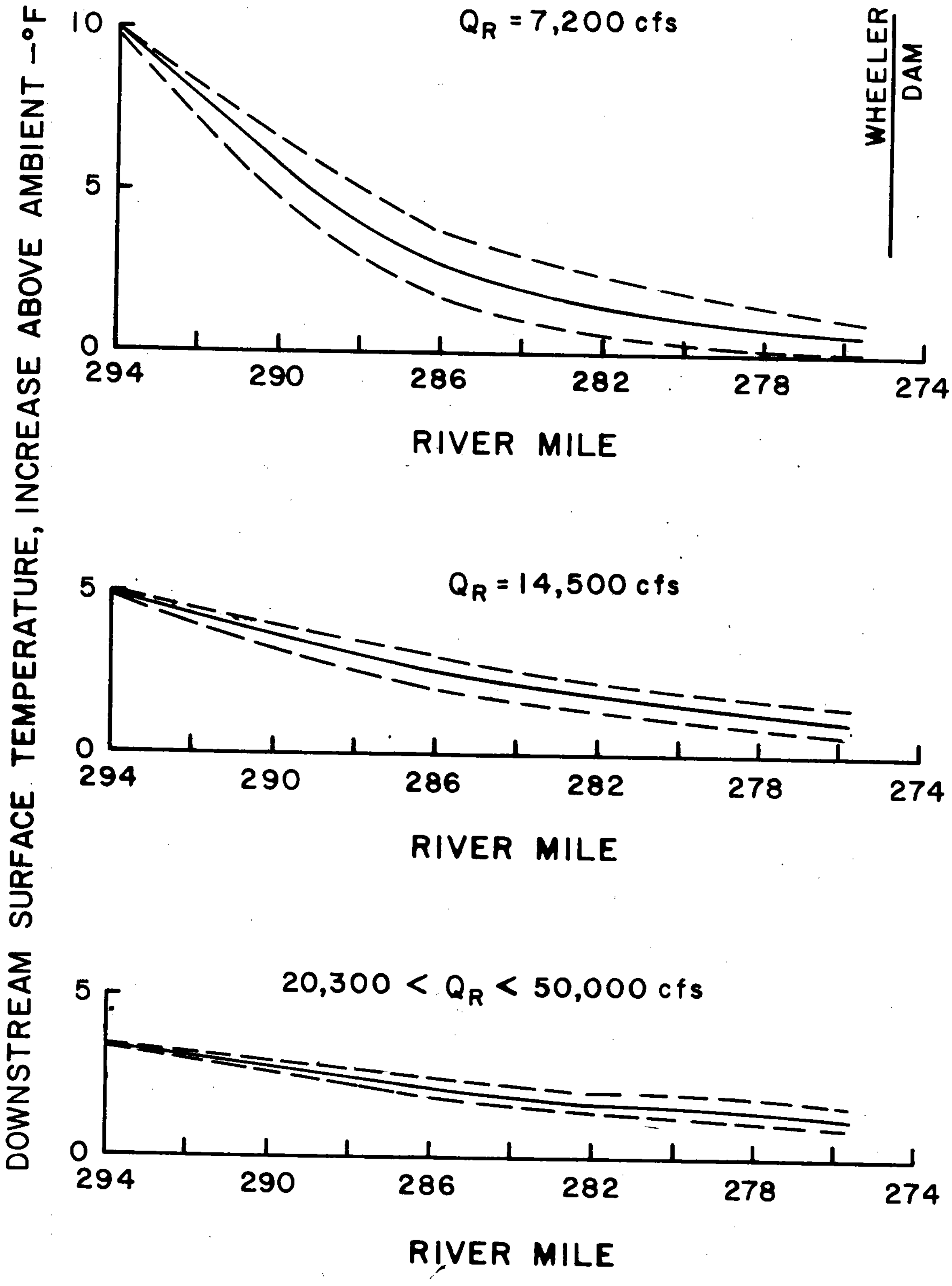
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. MARCH, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-125

N0670-5612-2-42-30-11



—— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. APRIL, 2 UNITS

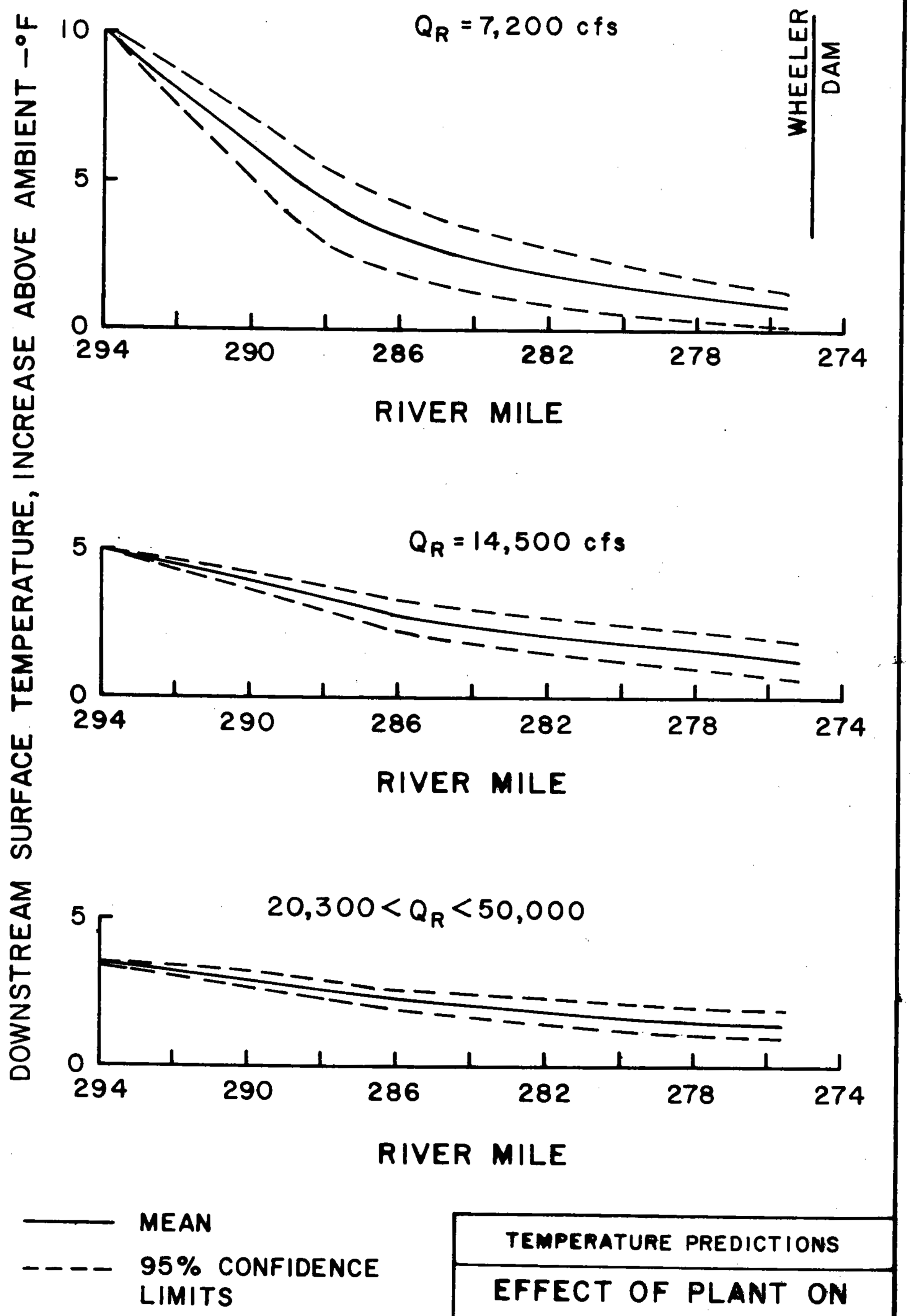
BROWNS FERRY NUCLEAR PLANT

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-128

DRAWN / ENGINEER / CHECKED / APPROVED

N0670-5616-0-40-20-11



TEMPERATURE PREDICTIONS

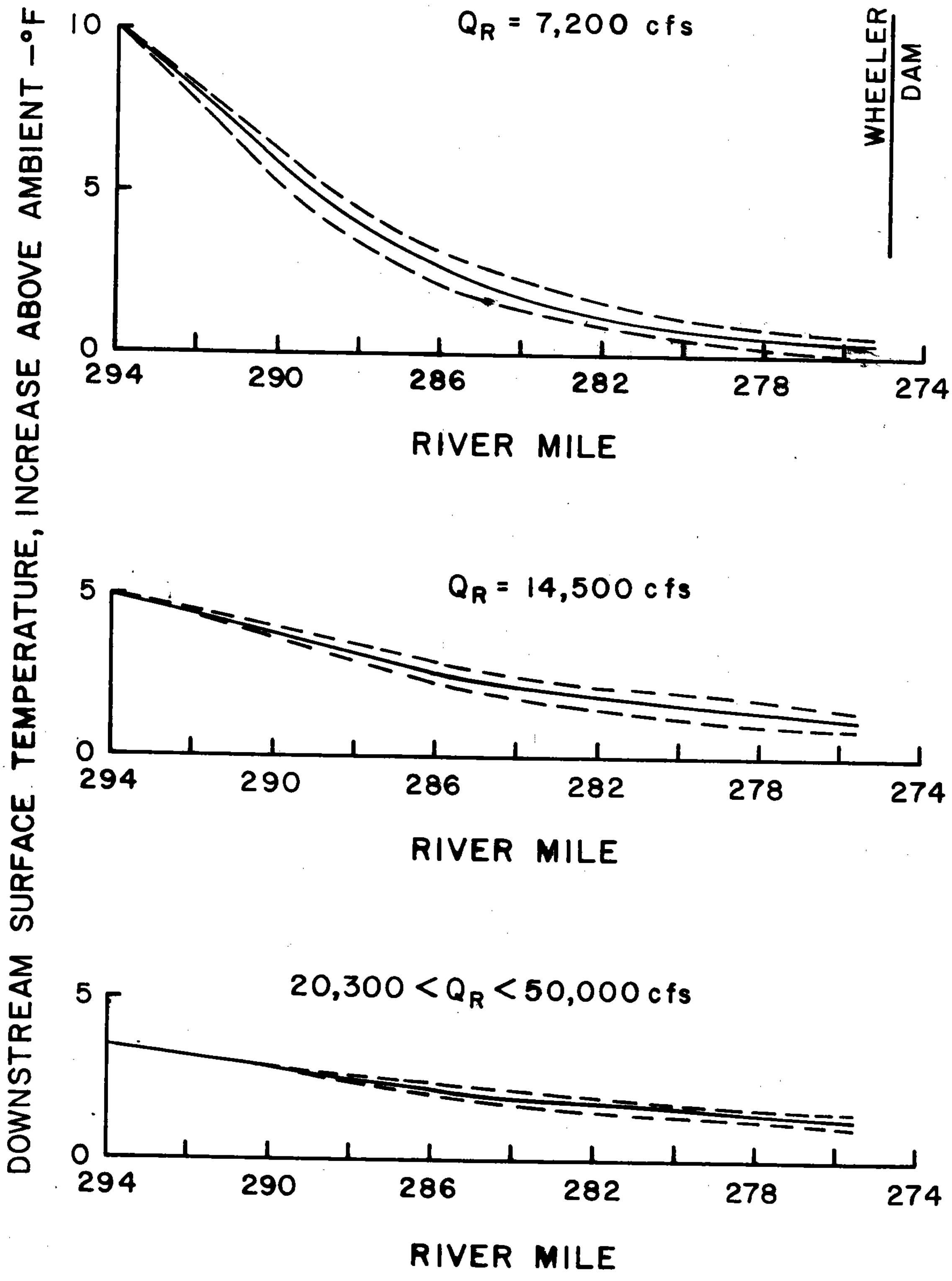
EFFECT OF PLANT ON DOWNSTREAM TEMP. MAY, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-131

DRAWN	ENGINEER
JMC	[illegible]
CHECKED	APPROVED
J.W.H.	[illegible]

N0670-5616-0-40-30-11



——— MEAN

– – – – 95% CONFIDENCE LIMITS

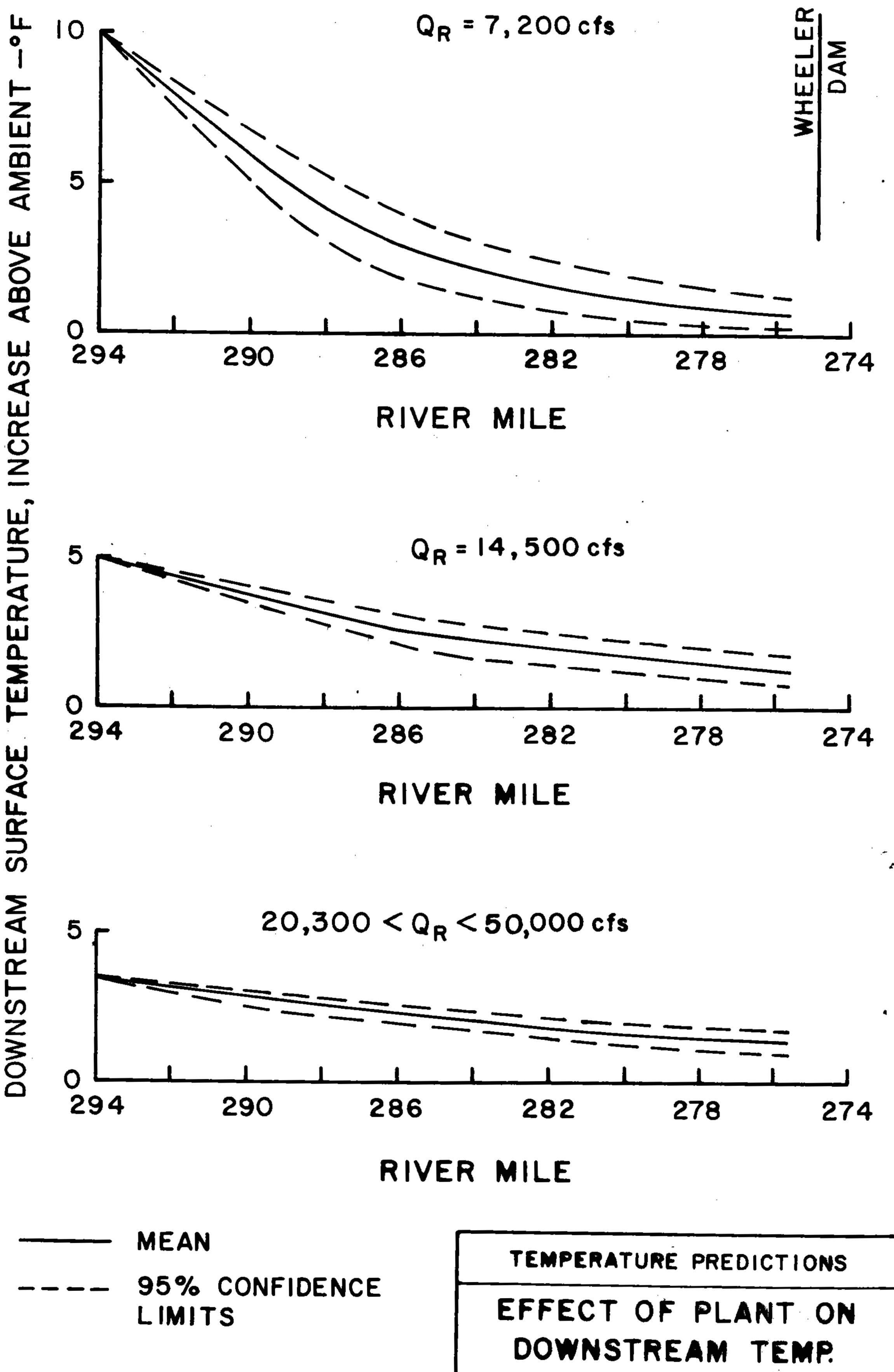
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. JUNE, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-134

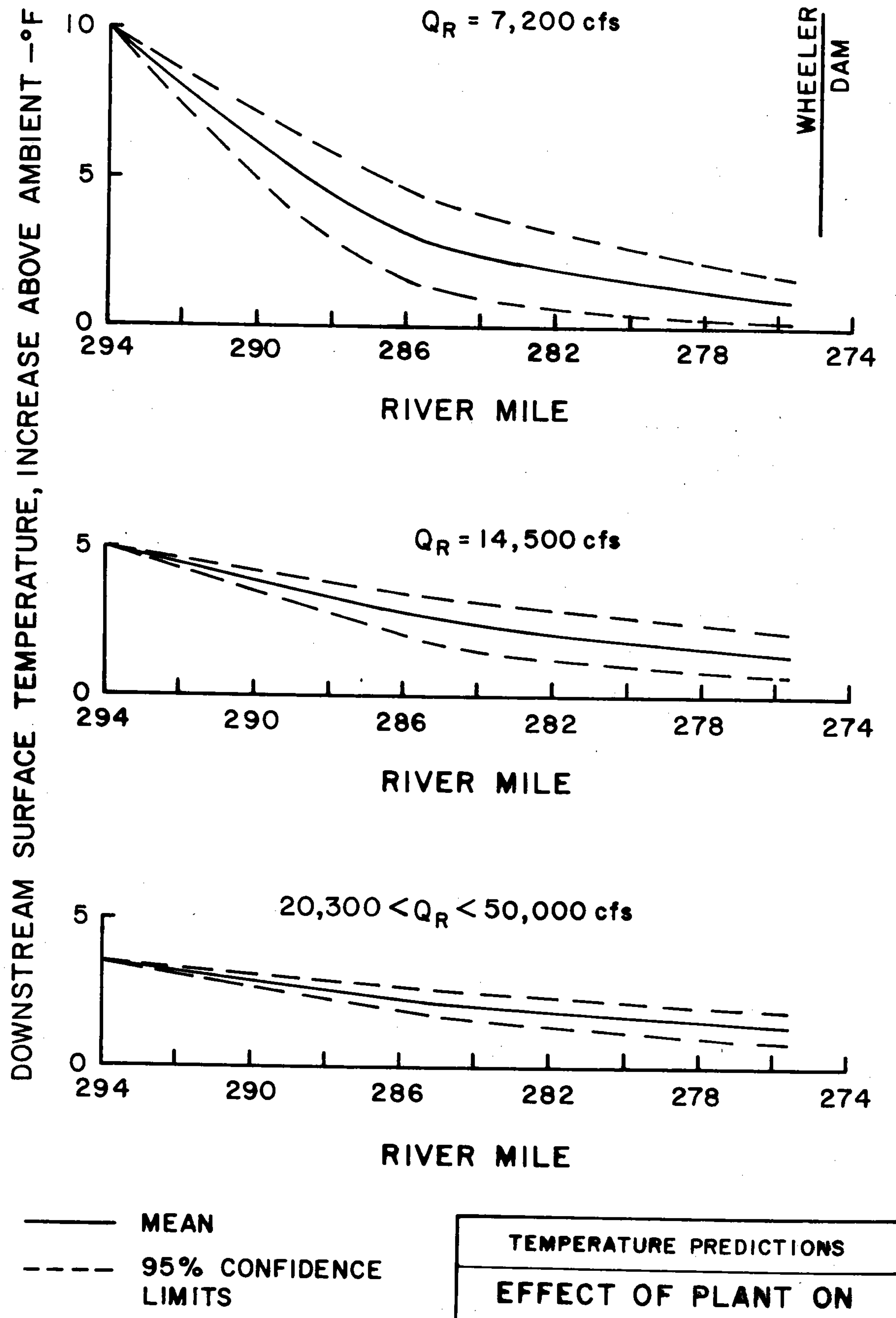
DRAWN JMC | ENGINEER | CHECKED | APPROVED



TEMPERATURE PREDICTIONS
EFFECT OF PLANT ON DOWNSTREAM TEMP. JULY, 2 UNITS
BROWNS FERRY NUCLEAR PLANT TENNESSEE VALLEY AUTHORITY DIVISION OF WATER CONTROL PLANNING ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-137

DRAWN	ENGINEER
ELI	BBE
CHECKED	APPROVED
Lwk	



TEMPERATURE PREDICTIONS

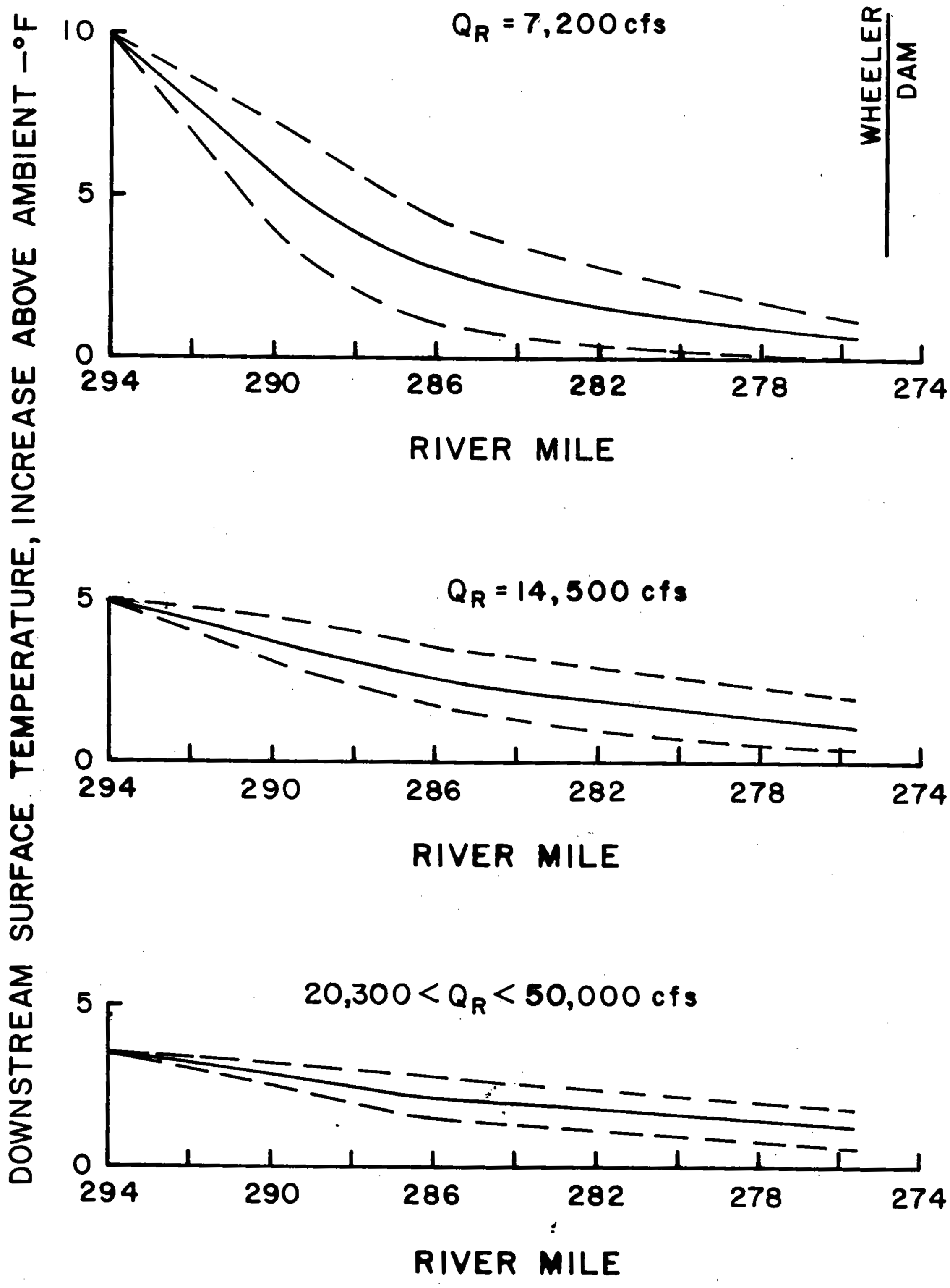
EFFECT OF PLANT ON DOWNSTREAM TEMP. AUGUST, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-140

DRAWN | ENGINEER | CHECKED | APPROVED

N0670-5616-0-40-30-11



——— MEAN

– – – – 95% CONFIDENCE LIMITS

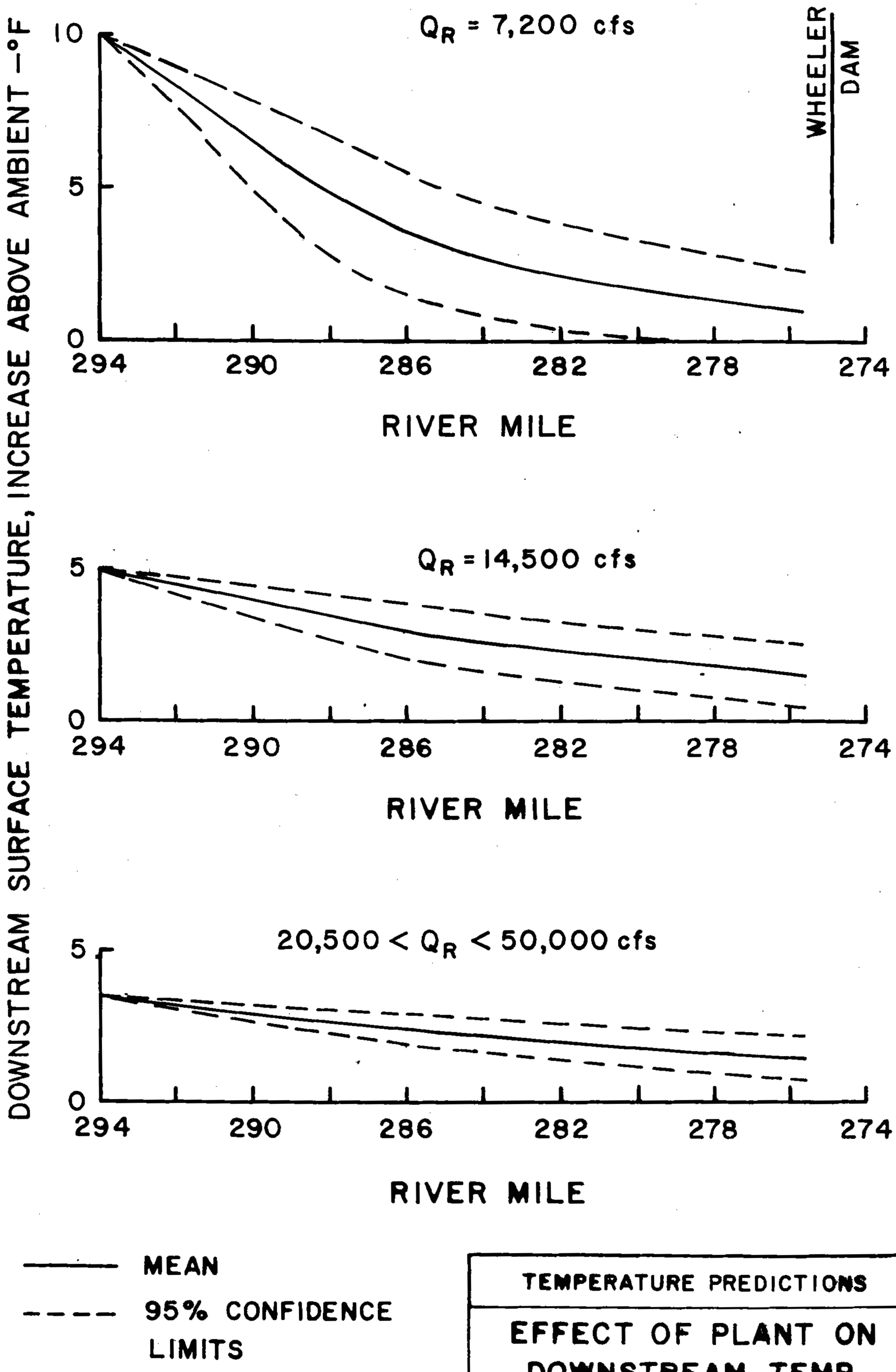
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. SEPTEMBER, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	CHECKED
EJJ	
CHECKED	APPROVED
LWM	

NORRIS	4-20-72	67	EL	920	A-143



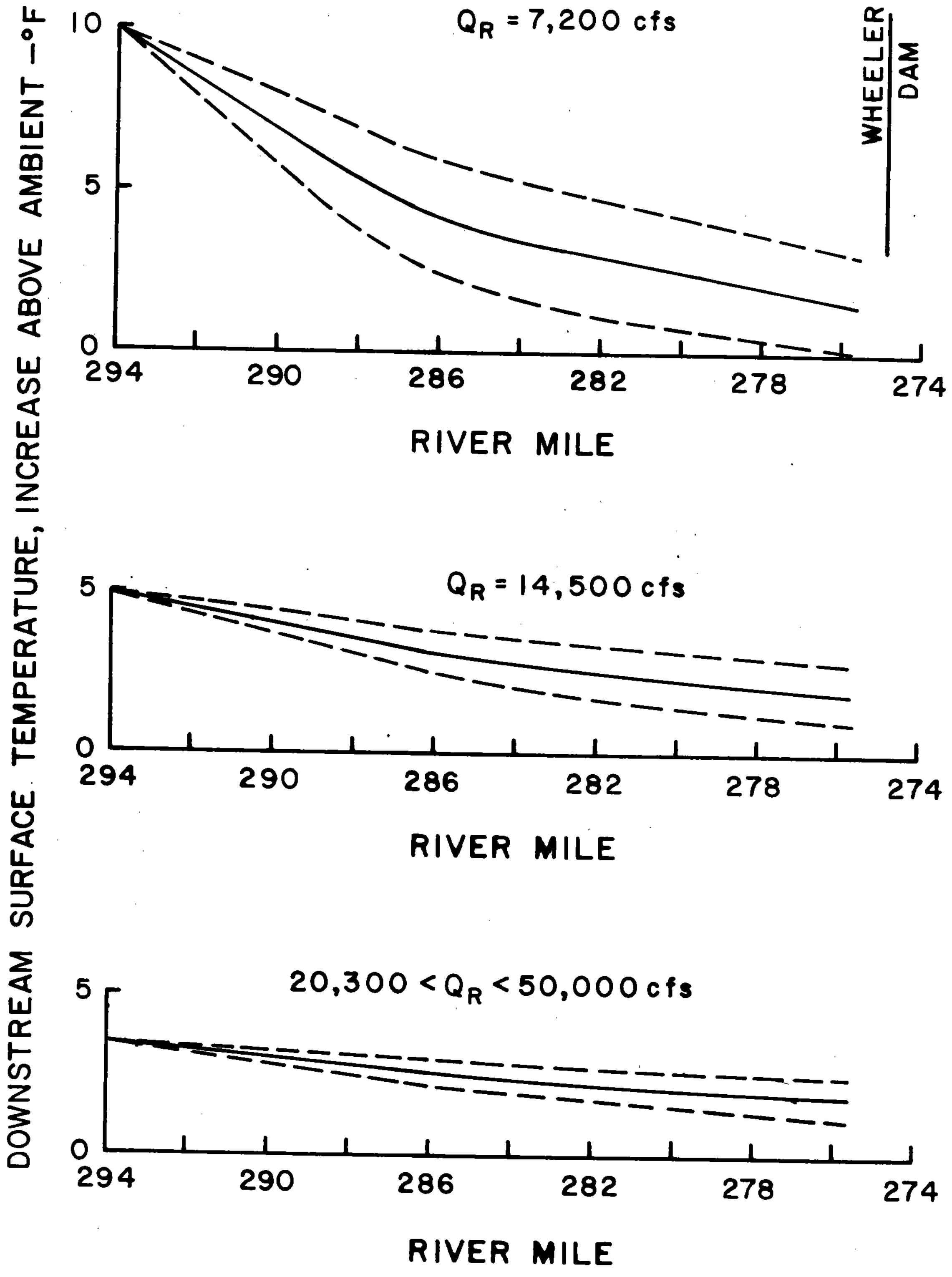
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. OCTOBER, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-146

DRAWN	ENGINEER
JMC	[illegible]
CHECKED	APPROVED
[illegible]	[illegible]



——— MEAN

– – – – 95% CONFIDENCE LIMITS

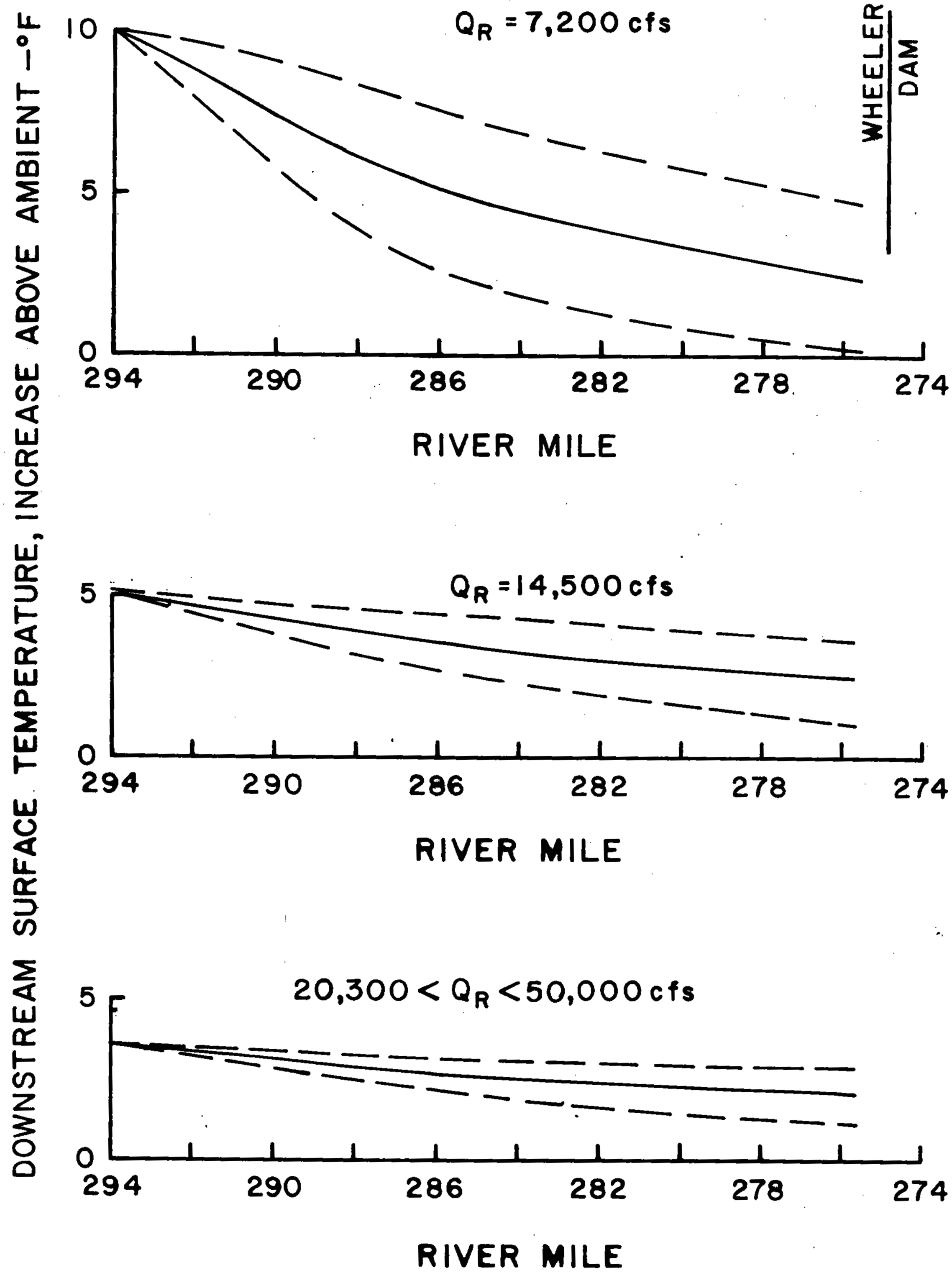
DRAWN	ENGINEER
CHECKED	APPROVED

TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. NOVEMBER, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-149



——— MEAN

- - - - 95% CONFIDENCE LIMITS

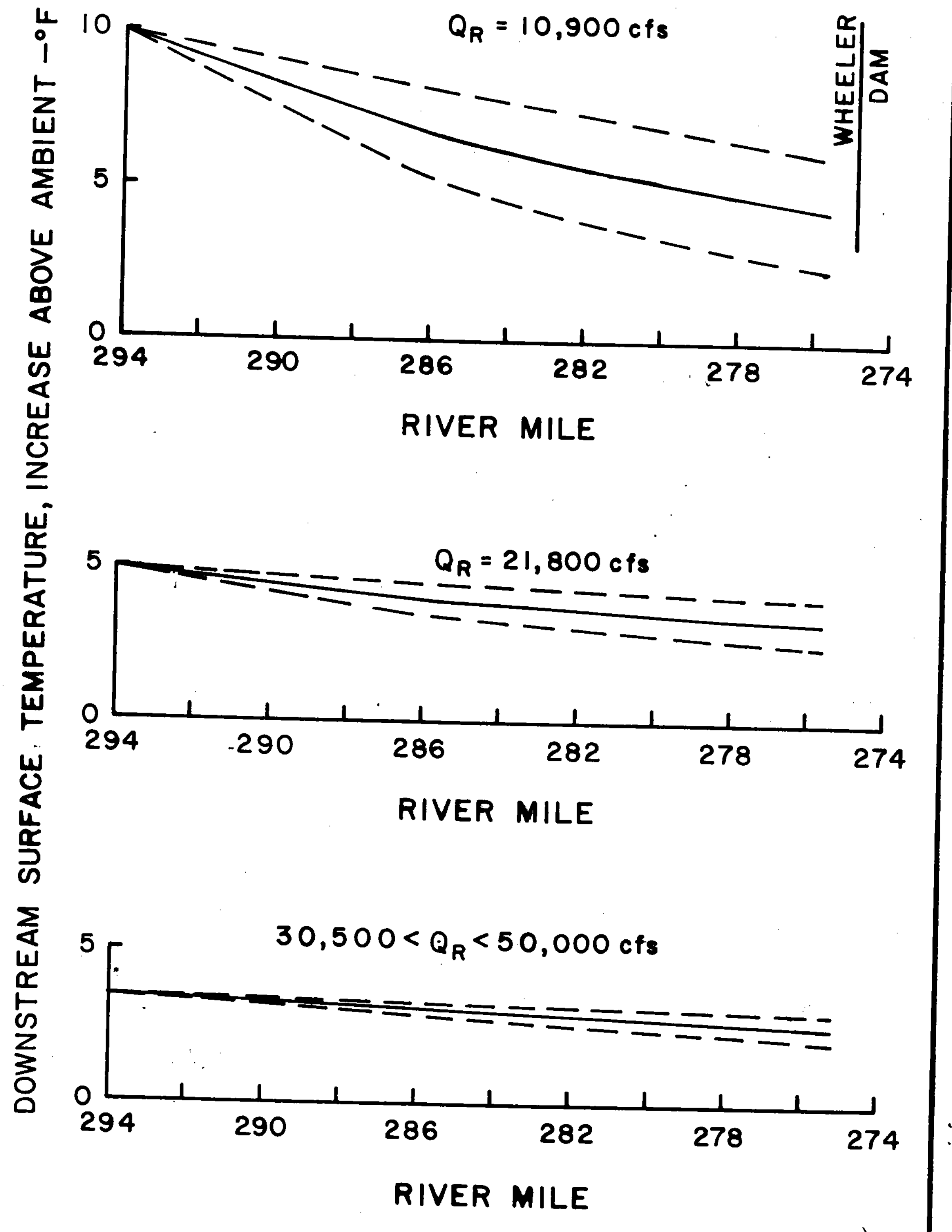
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. DECEMBER, 2 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-152

DRAWN | ENGINEER | CHECKED | APPROVED



——— MEAN

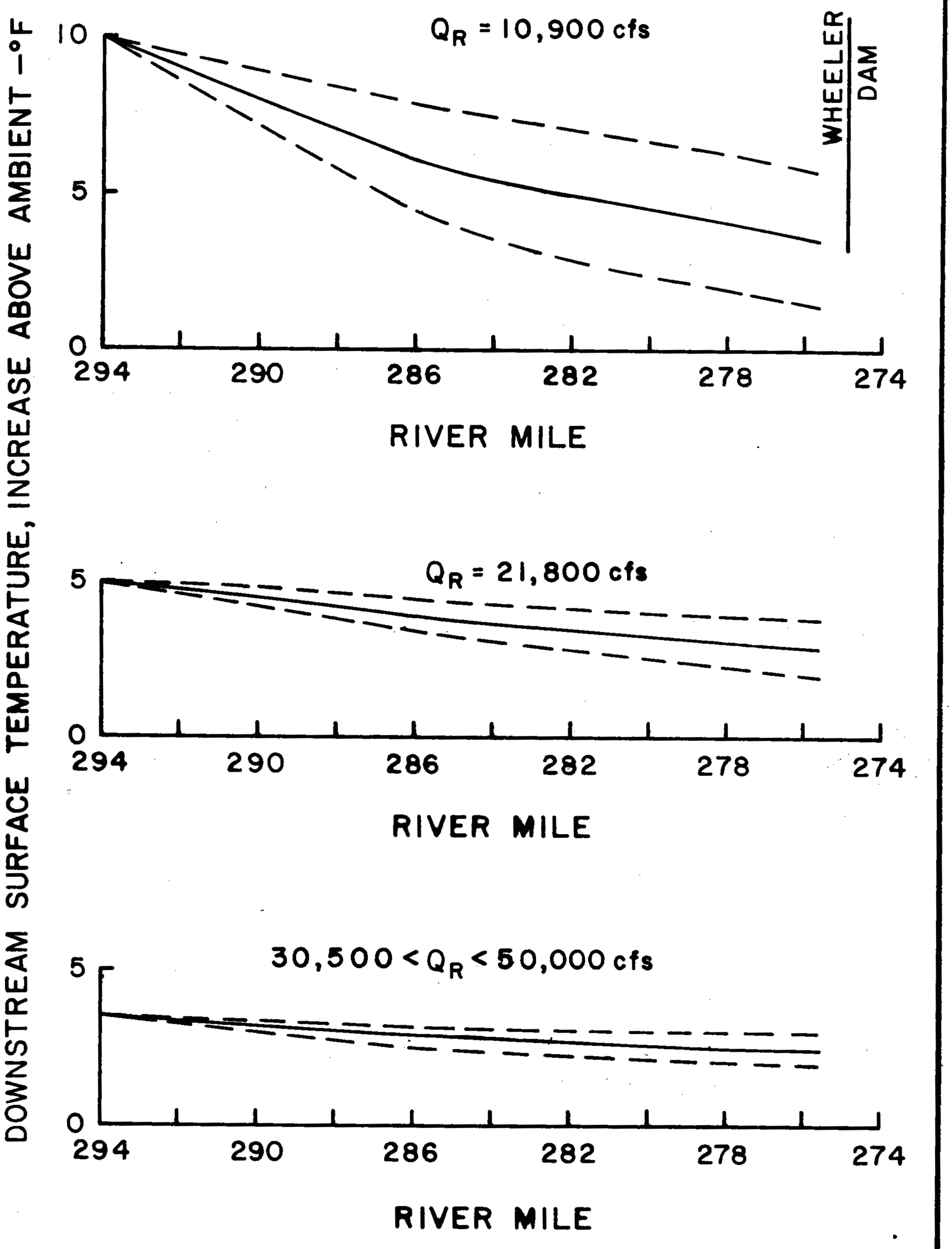
– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS
EFFECT OF PLANT ON DOWNSTREAM TEMP. JANUARY, 3 UNITS
BROWNS FERRY NUCLEAR PLANT TENNESSEE VALLEY AUTHORITY DIVISION OF WATER CONTROL PLANNING ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-120

DRAWN	ENGINEER
CHECKED	APPROVED

N0570-5616-0-40-30-11



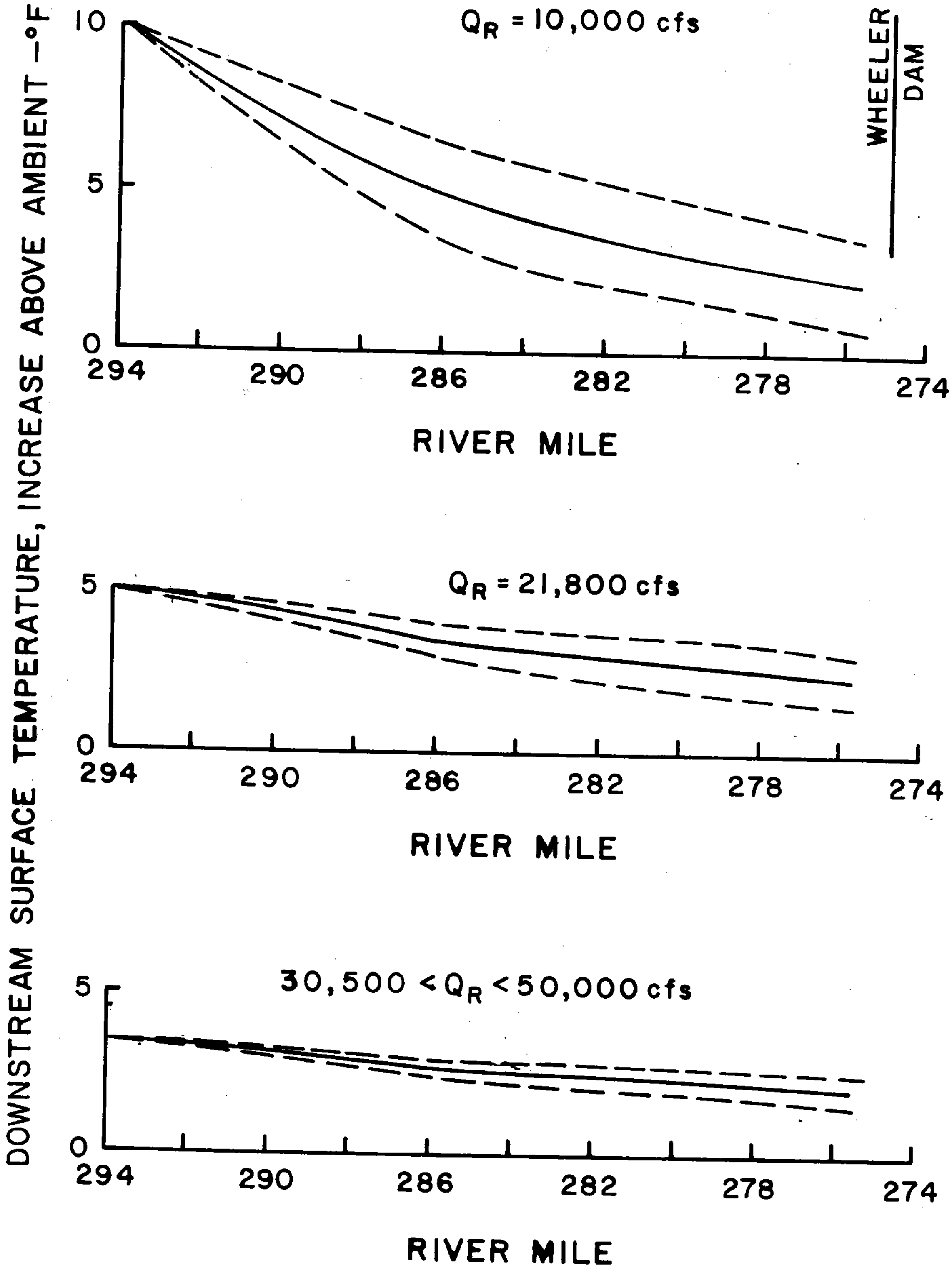
——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS
EFFECT OF PLANT ON DOWNSTREAM TEMP. FEBRUARY, 3 UNITS
BROWNS FERRY NUCLEAR PLANT TENNESSEE VALLEY AUTHORITY DIVISION OF WATER CONTROL PLANNING ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-123

DRAWN	ENGINEERED
CHECKED	APPROVED



——— MEAN

- - - - 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

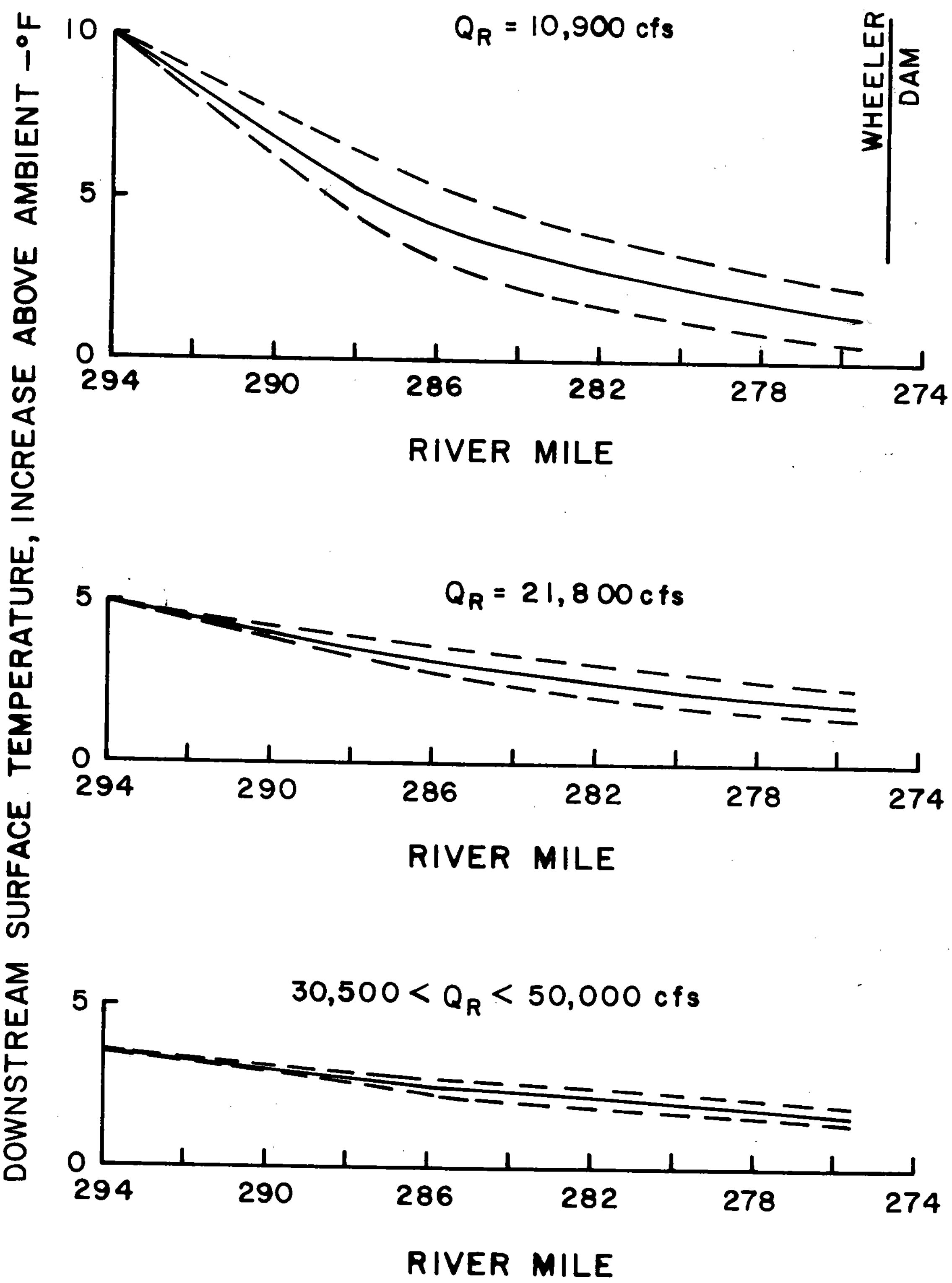
EFFECT OF PLANT ON DOWNSTREAM TEMP. MARCH, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER
CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-126

N0670-5610-0-40-30-11



——— MEAN

– – – – 95% CONFIDENCE LIMITS

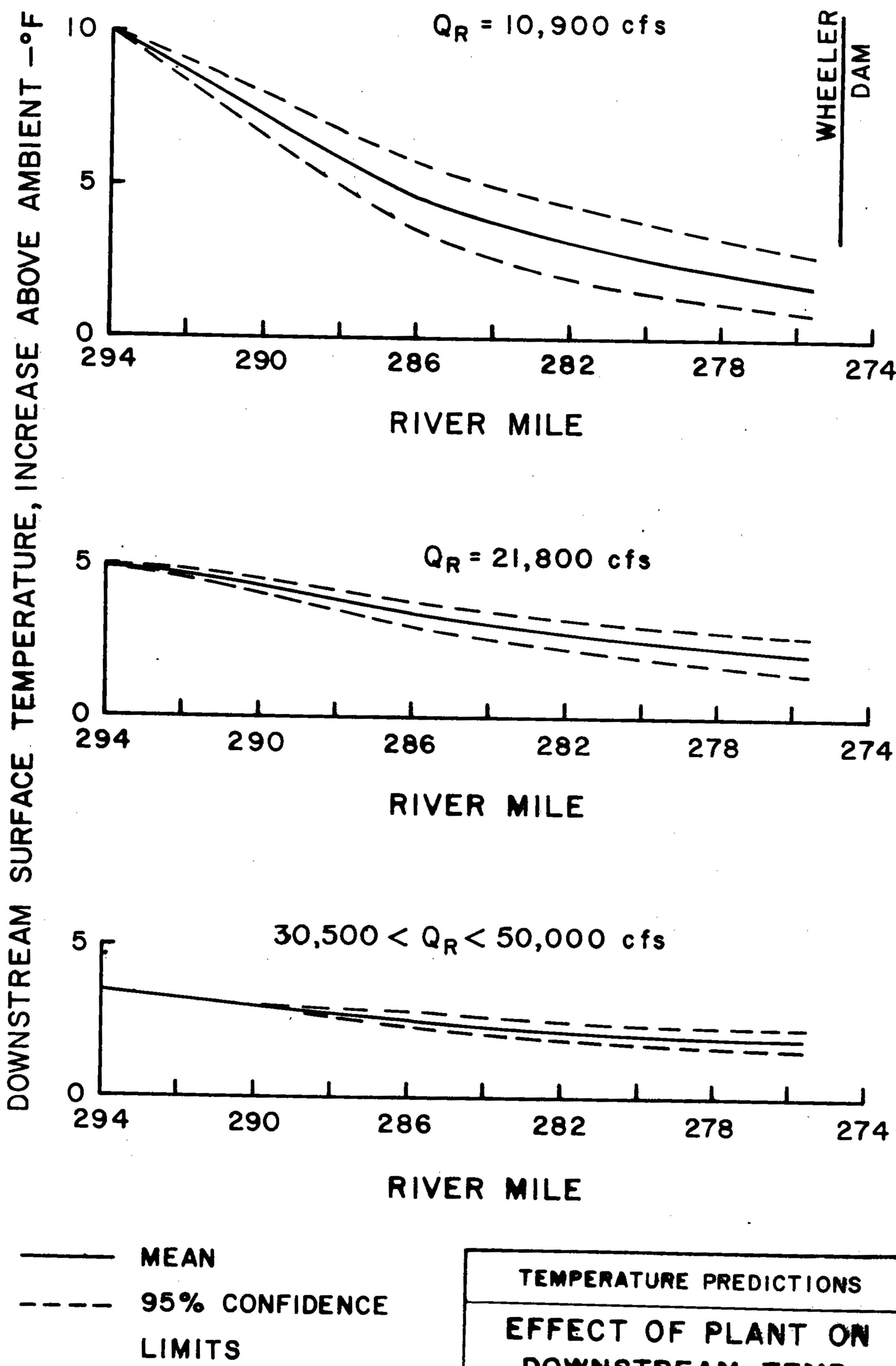
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. APRIL, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-129

DRAWN	ENGINEER
CHECKED	APPROVED



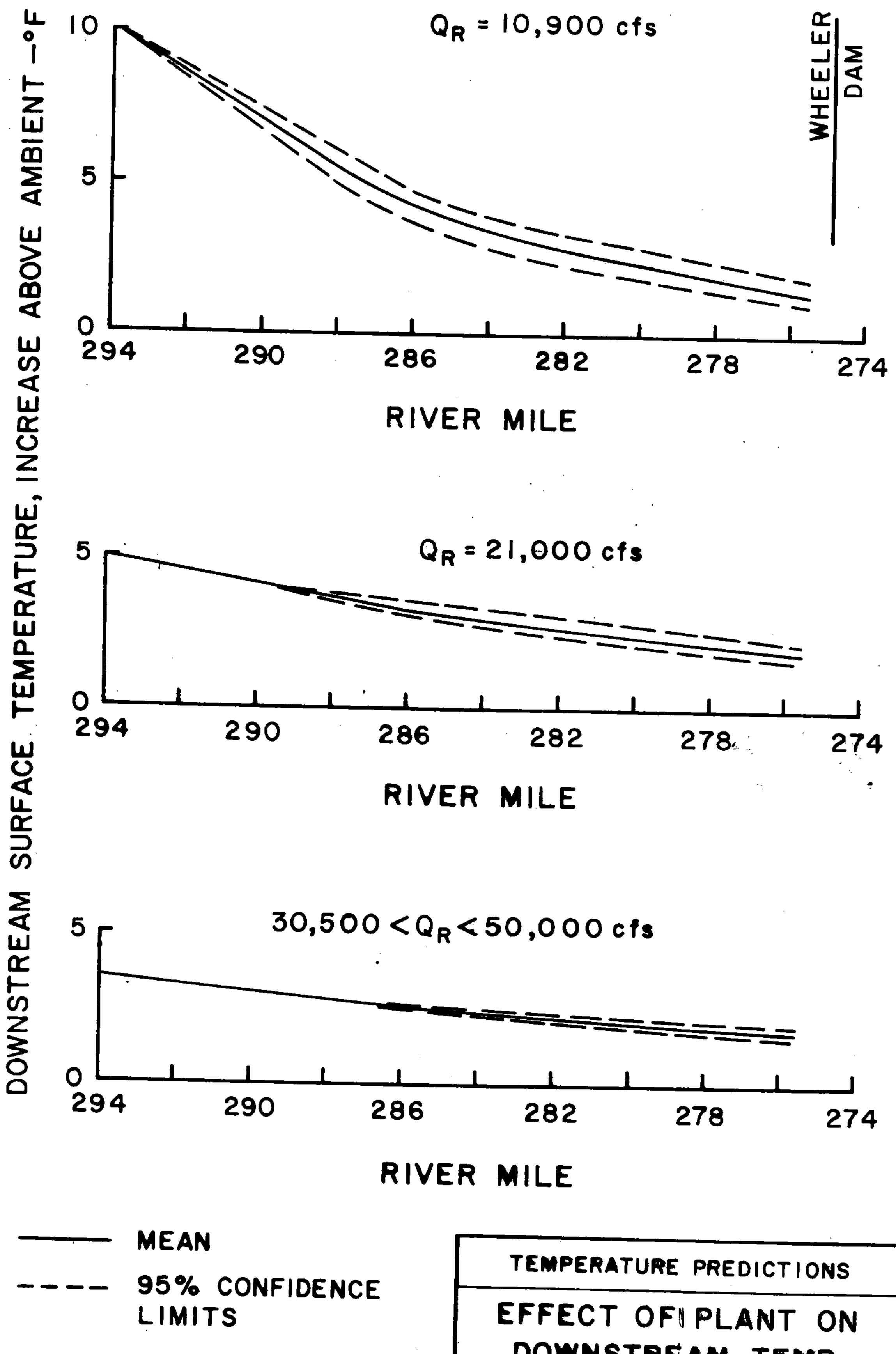
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. MAY, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER
JMC	
CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-132



TEMPERATURE PREDICTIONS

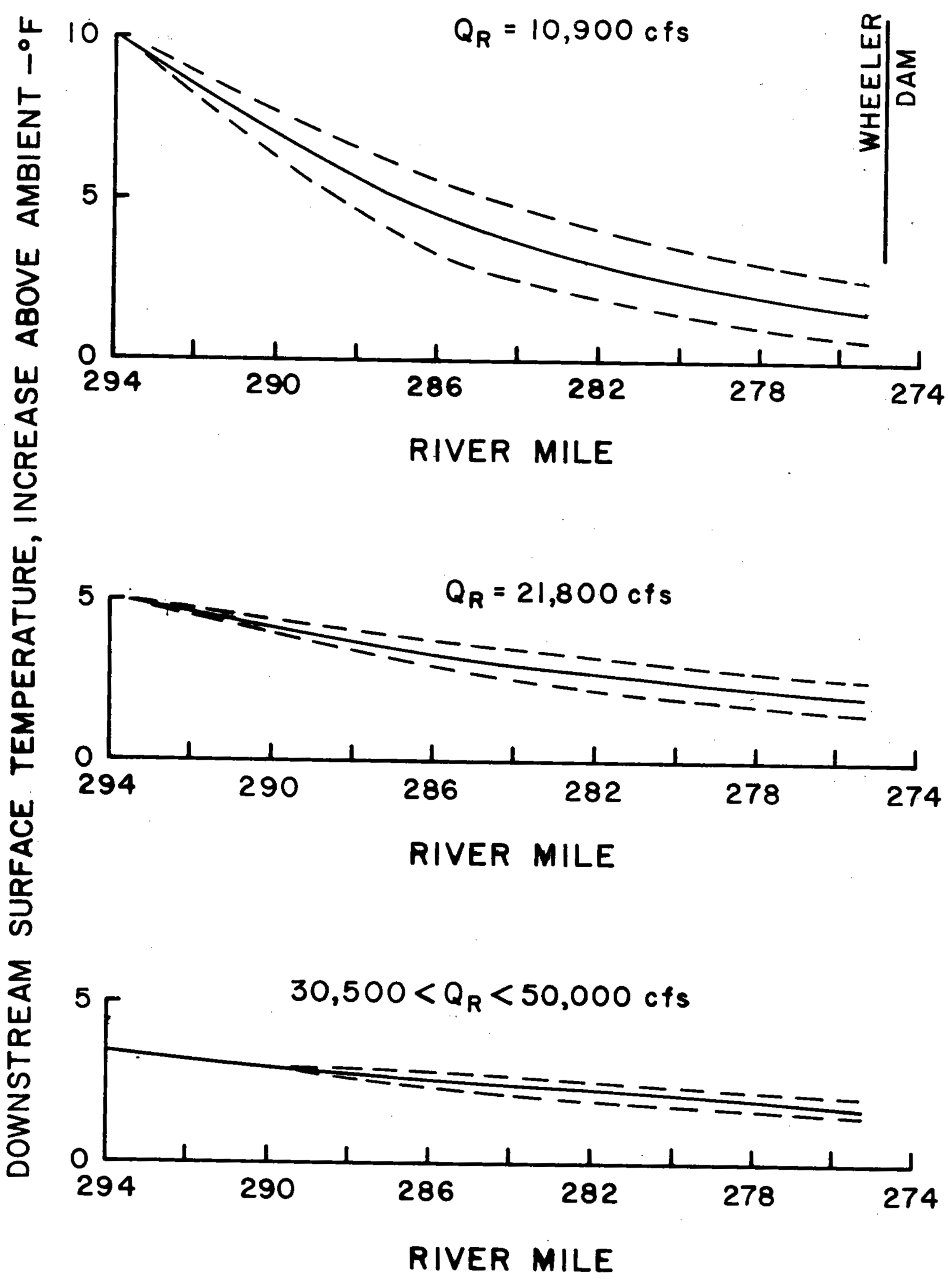
EFFECT OF PLANT ON DOWNSTREAM TEMP. JUNE, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER
WRH	
CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-135

N0670- 5616-0-40-30-11



——— MEAN

- - - - 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

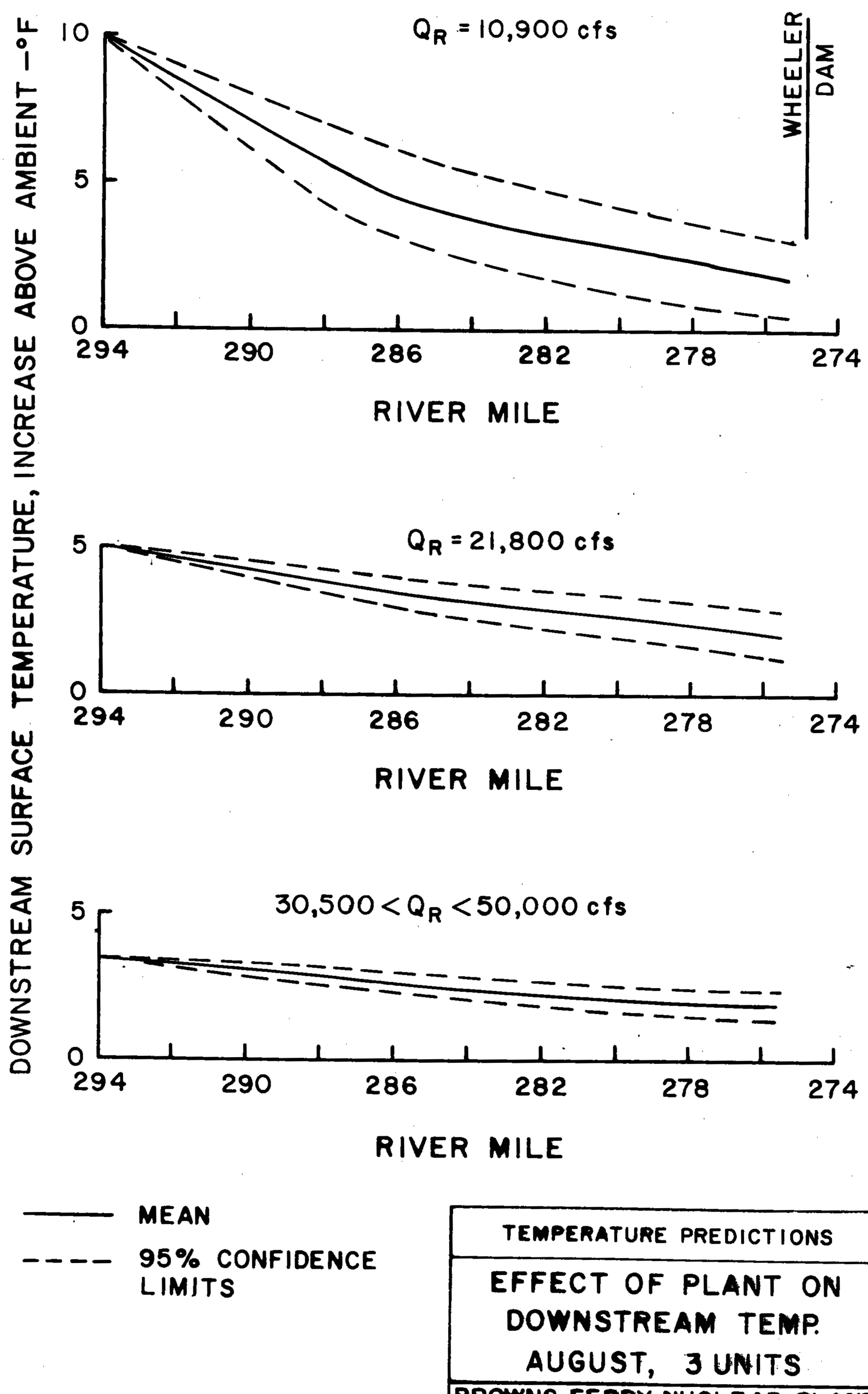
EFFECT OF PLANT ON DOWNSTREAM TEMP.
JULY, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-138

DRAWN	ENGINEER
JMC	[illegible]
CHECKED	APPROVED
[illegible]	[illegible]

N0670-5616-2-40-30-11



TEMPERATURE PREDICTIONS

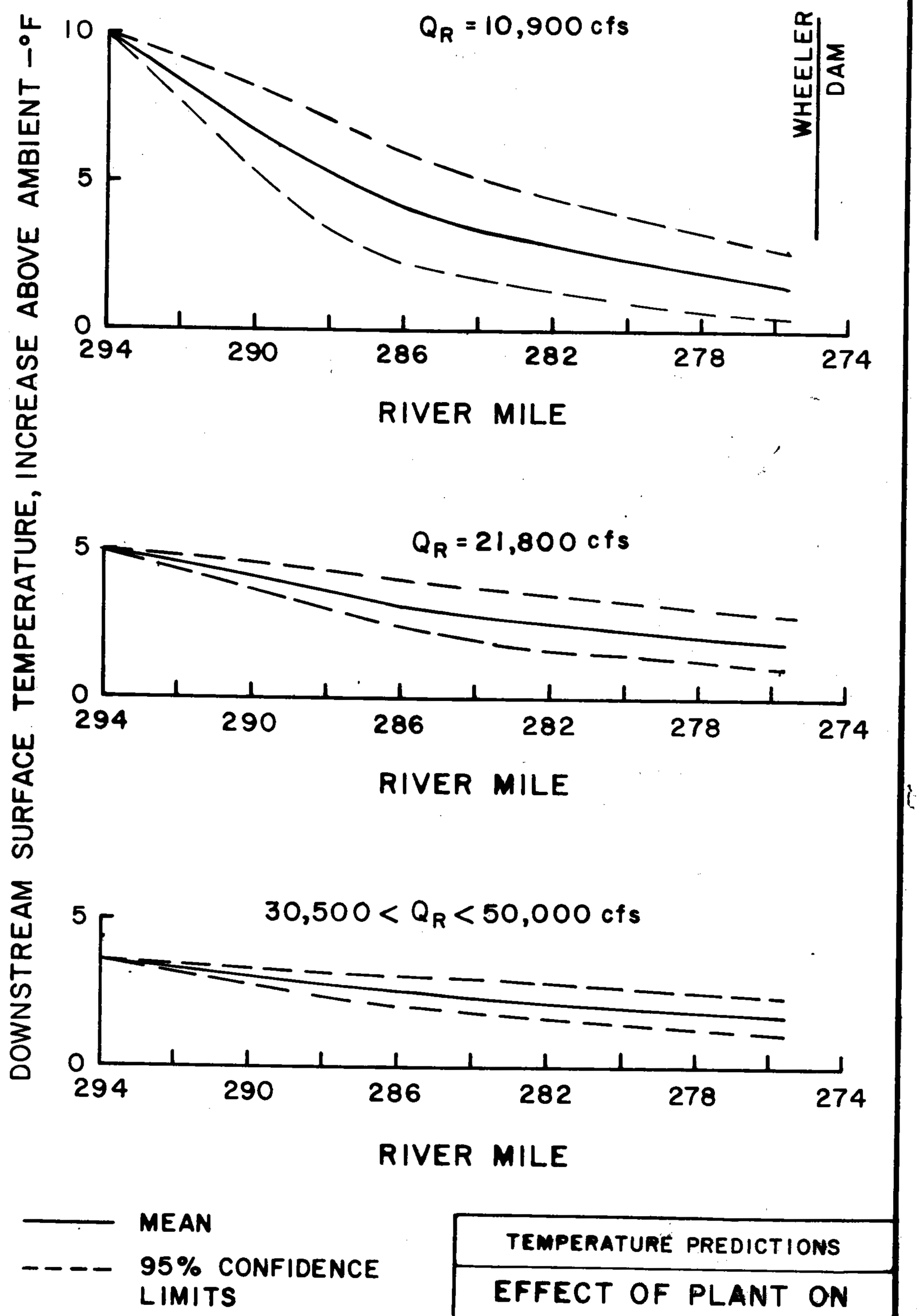
EFFECT OF PLANT ON DOWNSTREAM TEMP. AUGUST, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-20-72	67	EL	920	A-141

DRAWN JMC	ENGINEER EEW
CHECKED LWH	APPROVED

N0670-5616-0-40-30-11



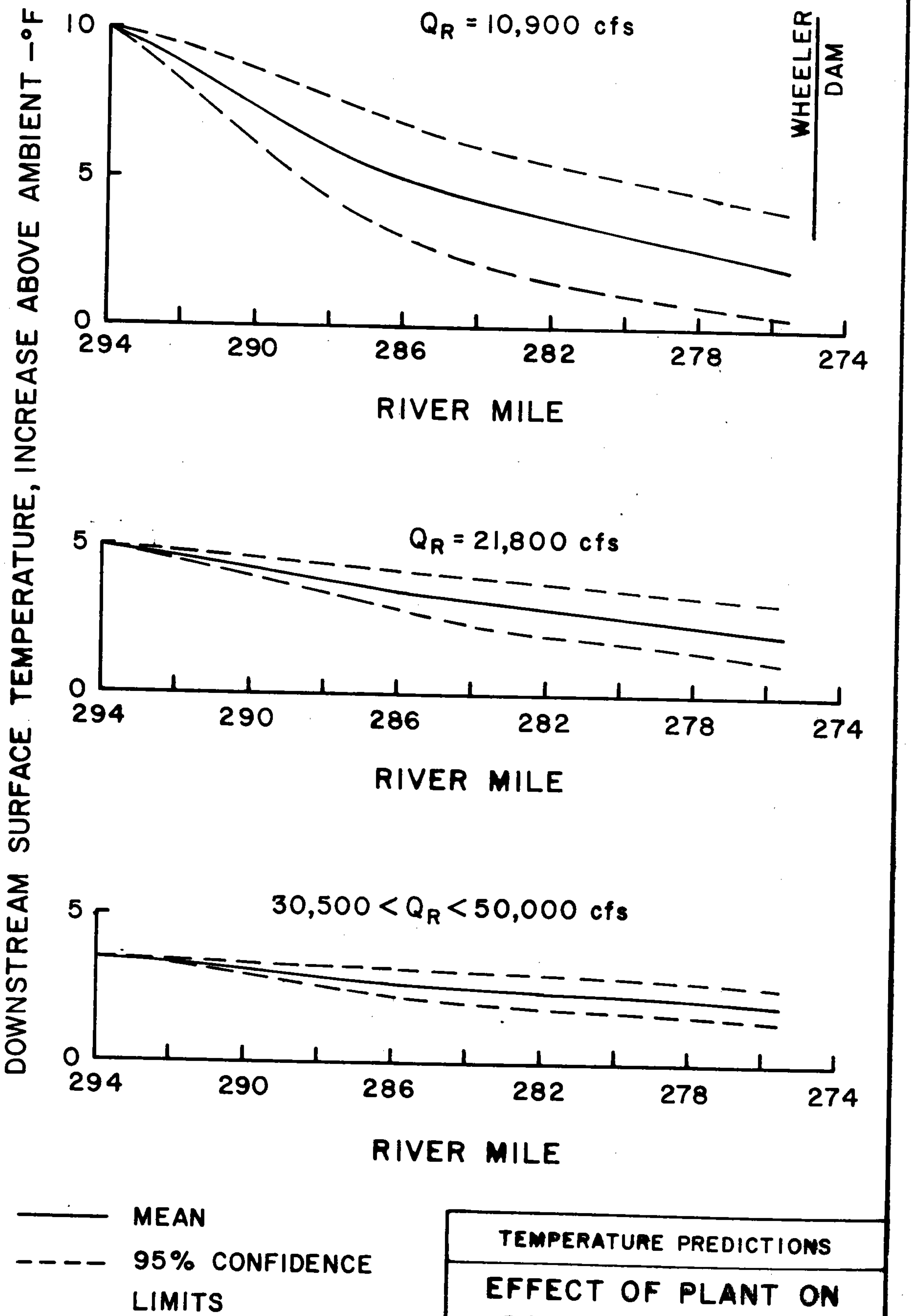
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. SEPTEMBER, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER	CHECKED	APPROVED	NORRIS	4-20-72	67	EL	920	A-144

N0670-5616-0-40-30-11



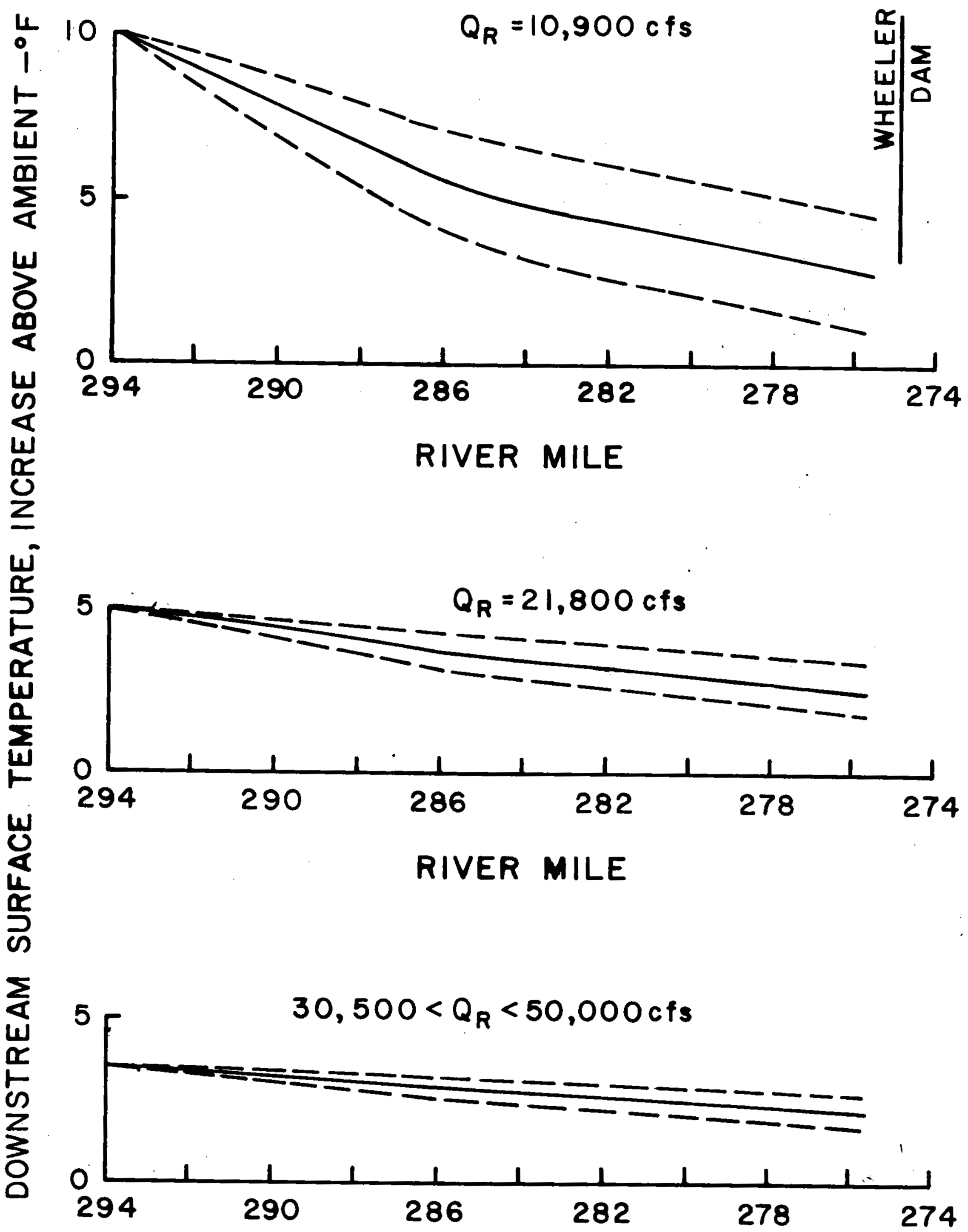
TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. OCTOBER, 3 UNITS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER
JMC	
CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-147



——— MEAN

– – – – 95% CONFIDENCE LIMITS

TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. NOVEMBER, 3 UNITS

BROWNS FERRY NUCLEAR PLANT

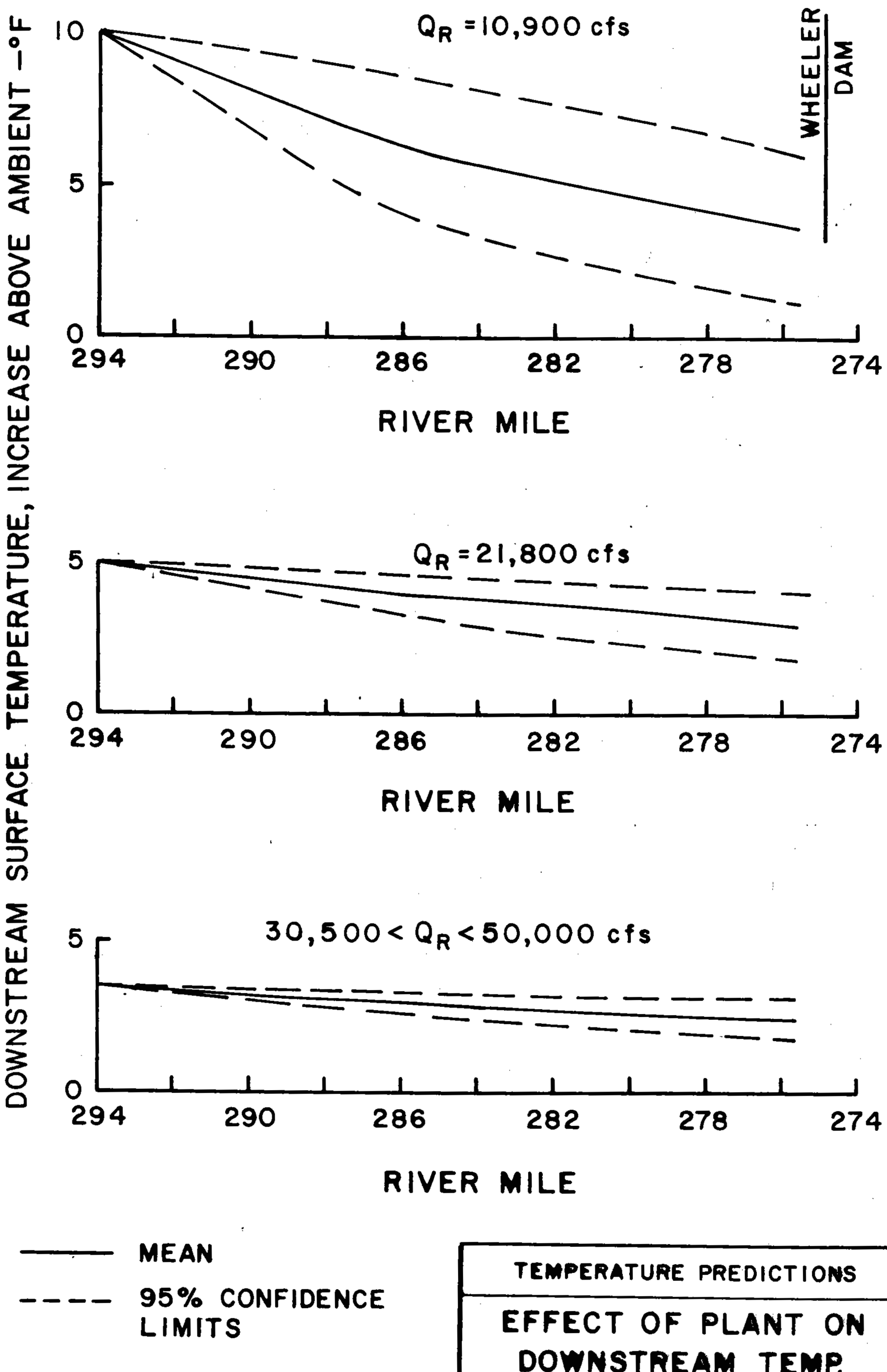
TENNESSEE VALLEY AUTHORITY

DIVISION OF WATER CONTROL PLANNING

ENGINEERING LABORATORY

DRAWN	ENGINEER						
CHECKED	APPROVED	NORRIS	4-20-72	67	EL	920	A-150

N0672-5616-0-40-30-11



TEMPERATURE PREDICTIONS

EFFECT OF PLANT ON DOWNSTREAM TEMP. DECEMBER, 3 UNITS

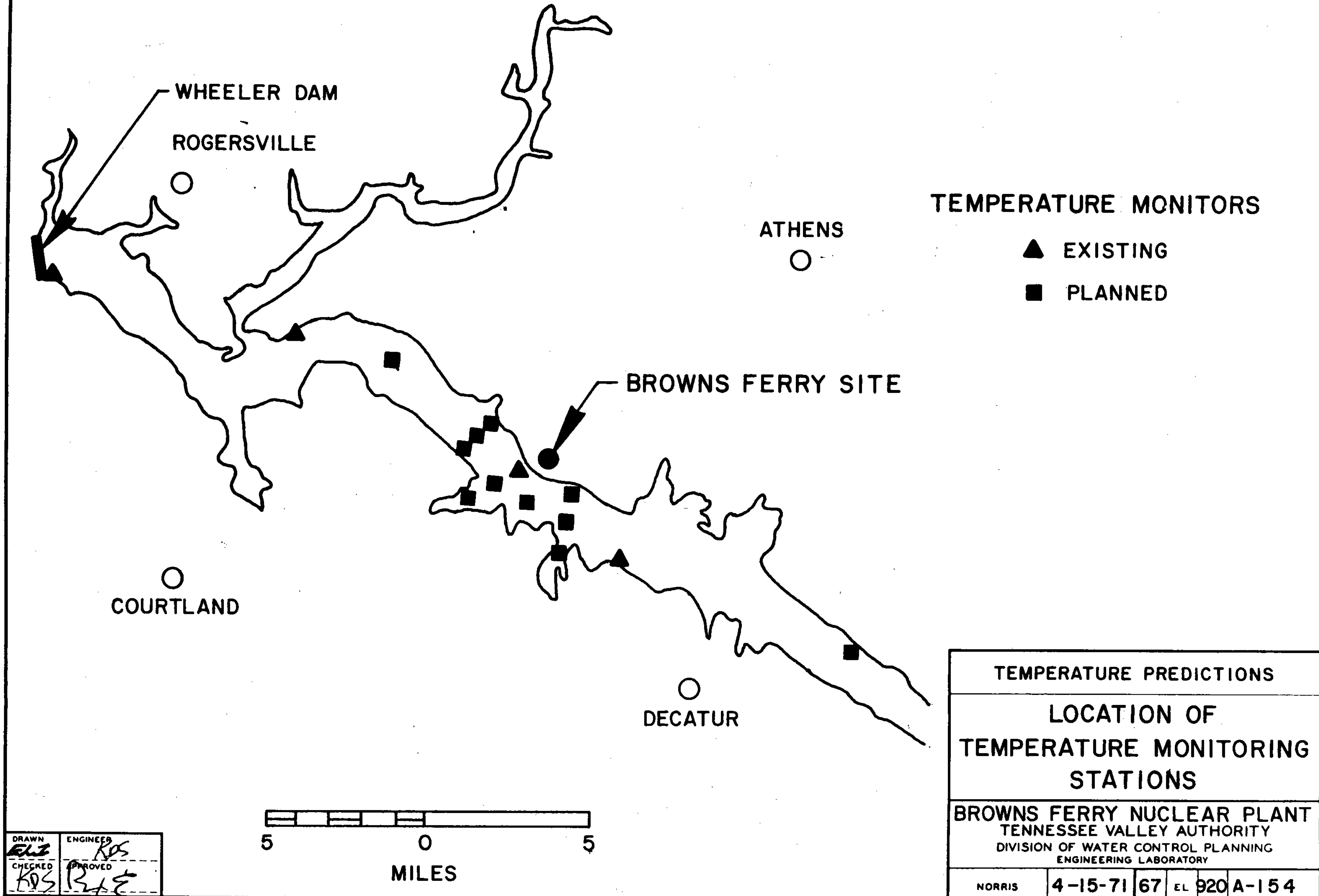
BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

DRAWN	ENGINEER	CHECKED	APPROVED

NORRIS	4-20-72	67	EL	920	A-153

N0670-5616-0-40-30-11

PLATE 47



TEMPERATURE PREDICTIONS

LOCATION OF TEMPERATURE MONITORING STATIONS

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
ENGINEERING LABORATORY

NORRIS	4-15-71	67	EL 920	A-154

DRAWN	ENGINEER
ELZ	KDS
CHECKED	APPROVED
KDS	RJE

N0670-A616-0-40-30-10