Impact of Flow Regulation and Powerplant Effluents on the Flow and Temperature Regimes of the Chattahoochee River— Atlanta to Whitesburg, Georgia

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Impact of Flow Regulation and Powerplant Effluents on the Flow and Temperature Regimes of the Chattahoochee River—Atlanta to Whitesburg, Georgia

By R. E. FAYE, H. E. JOBSON, *and* L. F. LAND

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

[Factors for converting inch-pound units to metric units are shown to four significant figures. However, in the text, the metric equivalents are shown only to the number of significant figures consistent with the values for the inch-pound]

Inch-pound units	*Multiply by*	*Metric*
ft (foot)	3.048×10^{-1}	m (meter)
ft (foot)	3.048×10^{2}	mm (millimeter)
ft/s (foot per second)	3.048×10^{-1}	m/s (meter per second)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic meter per second)
in. (inch)	2.540×10^{-2}	m (meter)
in. (inch)	2.540×10^{1}	mm (millimeter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
tons (tons, short)	9.072×10^{-1}	t (metric tons)
tons/d (tons per day)	9.072×10^{-1}	t/d (metric tons per day)
$tons/ft^3$ (tons per cubic foot)	3.204×10^{-1}	t/m^3 (metric tons per cubic meter)
tons/yr (tons per year)	9.072×10^{-1}	t/yr (metric tons per years)
°F (degrees Fahrenheit)	5/9 (F−32)	°C (degrees Celsius)

IMPACT OF FLOW REGULATION AND POWERPLANT EFFLUENTS ON THE FLOW AND TEMPERATURE REGIMES OF THE CHATTAHOOCHEE RIVER—ATLANTA TO WHITESBURG, GEORGIA

By R. E. FAYE, H. E. JOBSON, and L. F. LAND

ABSTRACT

A calibrated and verified transient flow-temperature model was used to evaluate the effects of flow regulation and powerplant loadings on the natural temperature regime of the Chattahoochee River in northeast Georgia. Estimates were made of both instantaneous and average natural temperatures in the river during an 8-day period in August 1976. Differences between the computed average natural temperature and an independent estimate of natural temperature based on observed equilibrium temperatures were less than 0.5°C. Downstream of the powerplants, the combined thermal effects of flow regulation and powerplant effluents resulted in mean daily river temperatures about equal to or less than computed mean natural temperatures. Thus the thermal impact of heated effluents was offset by the cooling effects of structural regulation. An independent analysis of historical river- and air-temperature data, although considerably less accurate than model computations, provided substantially the same result. The range and rates of change of computed natural diurnal temperature fluctuations were considerably less than those in the river at the time of this study in 1976. The models also were used to simulate summer river temperatures using estimated year 2000 flow conditions and meteorologic data collected during 1976. Except during periods of peak water-supply demand, differences between computed year 2000 river temperatures and observed 1976 temperatures were less than 2°C.

INTRODUCTION

This study is one part of the U.S. Geological Survey's Intensive River-Quality Assessment of the upper Chattahoochee River basin (Cherry and others, 1976). The upper Chattahoochee River (fig. 1) drains an area of 3,550 mi^2 and extends from the northern basin divide to West Point Dam, a distance of about 250 river miles. The specific reach of interest to this study is about 40 mi long and is bounded on the upstream and downstream ends by the Atlantic and Whitesburg gages, respectively (table 1, fig. 1). About 980 mi^2 of the upper basin drain to this reach, including a large part of the Atlanta metropolitan area. River flow and river temperature in the reach of interest are influenced mostly by tributary inflows, by effluents from wastewater-treatment facilities (WTF's) and thermal powerplants, by water-supply demands, and by regulation of the Chattahoochee River at Buford Dam (fig. 1).

On occasion in this text points on the Chattahoochee River will be designated by river mile (RM). Zero river mile (RM 000.00) is defined as the confluence of the Flint and Chattahoochee Rivers near the Georgia–Florida border (fig. 1).

Study results summarized in this report include an evaluation of the impact of flow regulation and heated effluents on the flow and temperature regimes of the Chattahoochee River. The methods of evaluation include the comparison of 1976 river temperatures with historical data as well as the use of transient, flow-temperature models.

DESCRIPTION OF THE PROBLEM

Since 1956, flow in the Chattahoochee River between Lake Sidney Lanier and West Point Lake (fig. 1) has been regulated and, to a large extent, dominated by hydropower releases from Buford Dam (fig. 1). Waves generated by such releases can be observed at gaging stations along the entire reach of the river between the reservoirs, a distance of more than 100 river miles. In the reach of interest (Atlanta gage to Whitesburg gage), regulated flows have fundamentally altered the "natural" flow and temperature regimes of the river. Examples of flow alteration include a general reduction in annual peak discharges and the enhancement of minimum low flows. Stream-temperature alterations occur because the turbine intake structures at Buford Dam use water from the hypolimnion and metalimnion zones of Lake Sidney Lanier. Consequently, winter stream temperatures downstream of the dam are warmer,

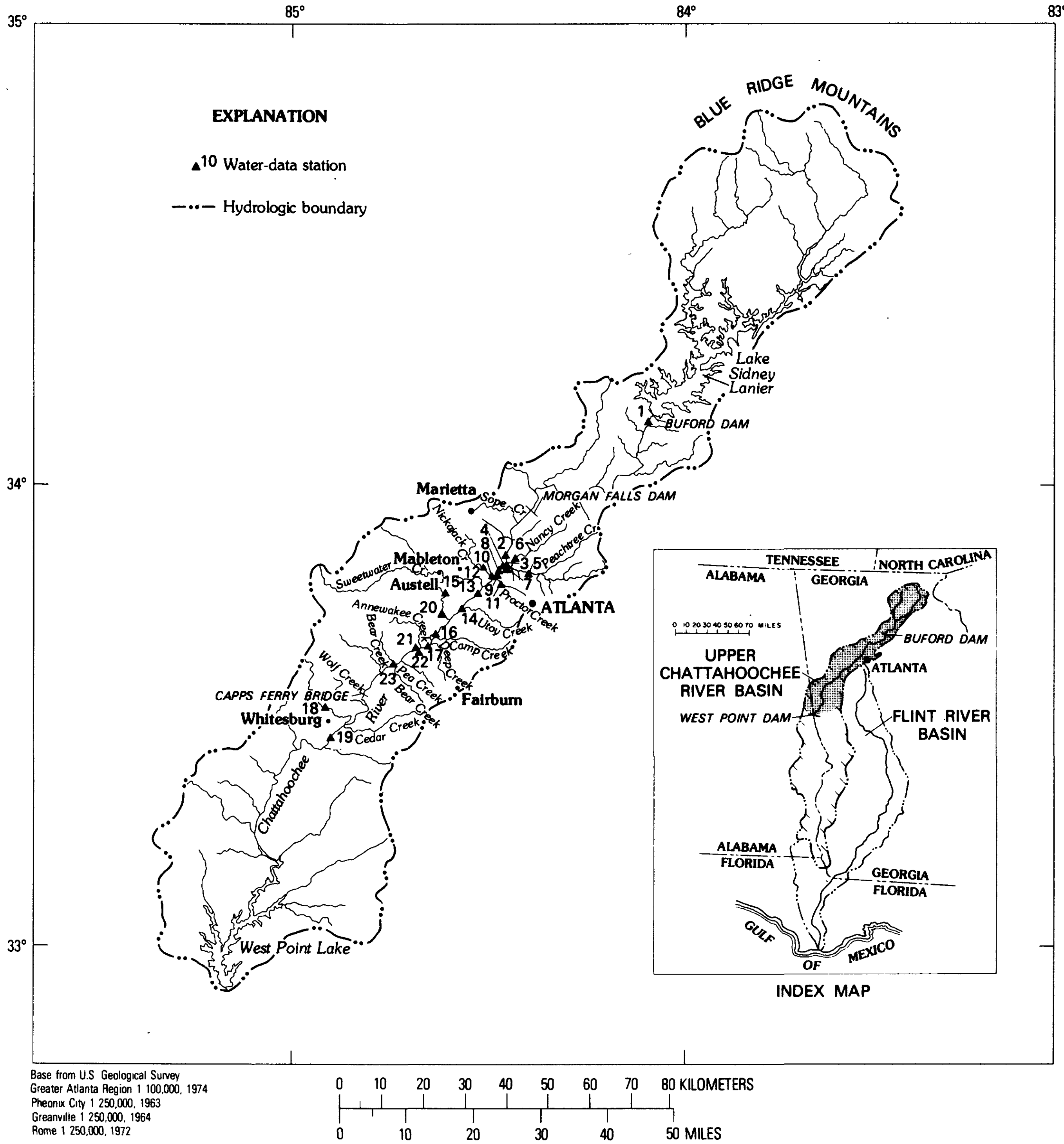


FIGURE 1.—Study area showing data-collection sites.

and summer temepratures are cooler than corresponding "natural" temperatures.

Morgan Falls Dam and Georgia Power's Plants Atkinson-McDonough (table 1, fig. 1) also effect river flows and river temperatures in the study reach. Morgan Falls Dam, located about 40 mi downstream of Buford Dam, is a "run-of-the-river" hydropower facility that partially regulates river flows. The impact of such regulation on flow and stream temperatures in the study reach, however, is minimal. The Plants Atkinson-McDonough are thermal electric power facilities, that utilize river water in their operations. Heated effluents from boilers at the plants can raise stream temperatures by as much as 8°C immediately downstream of their outfalls. In addition, quantities of river water are consumed in plant operation. The amounts consumed, however, are small and river flows downstream of the plants are not noticably effected.

Water-resource managers and regulatory agencies are concerned with stream temperatures under present (1976) and future conditions of water-supply and waste-load allocations and the impact of such temperatures on stream quality. Of particular interest to resource managers are stream temperatures during the late spring and summer months when tributary flows are low and ambient air temperatures are highest. Any negative impact of high stream temperatures on stream quality would be most evident during such periods. Also of interest are stream temperatures during a critical drought period when tributary contributions to the Chattahoochee River would be extremely low and the proportion of waste discharges in the total streamflow correspondingly high.

Of interest to regulatory agencies are comparisons of 1976 stream temperatures with "natural" temperatures; that is, temperatures occurring prior to construction of the powerplants and Buford Dam. On the one hand, the combined effects of stream regulation and powerplant heat loads may presently produce lower than "natural" stream temperatures; even during the critical spring and summer months. On the other hand, heated effluents from the powerplants could be increasing stream temperatures excessively above "natural" conditions. The degree of future regulation of powerplant effluents may depend on which situation prevails.

The objectives of this study are to provide some insight into these problems and to investigate the relationship between transient flows and stream temperatures in the Chattahoochee River. Specific study objectives apply only to the reach between the Atlanta and Whitesburg gages and include:

1. The calibration and verification of deterministic, transient, flow and temperature models.
2. Use of the transient models to determine the impact of flow regulation and powerplant heat loadings on river temperatures using present (1976), future, and critical drought flow conditions.
3. A comparison of 1976 and computed "natural" stream temperatures.

SCOPE OF THE STUDY

Most of the data used in this study were collected by the U.S. Geological Survey and other agencies as part of routine data-collection programs. Such

TABLE 1.—*Periodic data-collection sites*

USGS station No.	Station name	Map reference No. (fig. 1)	River mile	Data
02334430	Chattahoochee River at Buford Dam	1	348.10	Temperature
02336000	Chattahoochee River at Atlanta (Atlanta gage)	2	302.97	Stage, temperature
02336020	Chattahoochee River at the Atlanta water-supply facility.	3	300.62	Stage, mean daily withdrawal
02336021	Chattahoochee River at the Cobb County wastewater-treatment facility outfall.	4	300.56	Mean daily discharge
02336300	Peachtree Creek at Atlanta	5	---------	Mean daily discharge
02336380	Nancy Creek at Atlanta	6	---------	Mean daily discharge
02336450	Chattahoochee River at the R. M. Clayton wastewater-treatment facility outfall.	7	300.24	Mean daily discharge
02336479	Chattahoochee River at the Plant McDonough intake.	8	299.23	Temperature
02336480	Chattahoochee River at the Plant McDonough outfall.	9	299.15	Stage
02336490	Chattahoochee River at Georgia Highway 280	10	298.77	Temperature
02336526	Proctor Creek at Atlanta	11	---------	Mean daily discharge
02336610	Nickajack Creek near Mableton	12	---------	Mean daily discharge
02336651	Chattahoochee River at the South Cobb County wastewater-treatment facility outfall.	13	294.28	Mean daily discharge
02336653	Chattahoochee River at the Utoy Creek wastewater-treatment facility outfall.	14	291.48	Mean daily discharge
02337070	Sweetwater Creek near Austell	15	---------	Mean daily discharge
02337073	Chattahoochee River at the Camp Creek wastewater-treatment facility outfall.	16	283.78	Mean daily discharge
02337170	Chattahoochee River near Fairburn (Fairburn gage).	17	281.79	Stage, temperature
02337500	Snake Creek near Whitesburg	18	---------	Mean daily discharge
02338000	Chattahoochee River near Whitesburg (Whitesburg gage).	19	259.85	Stage

data are listed by type and station in table 1. Time series data were obtained for two 8-day periods in July and August 1976. These data include: (1) Hourly stage and stream temperatures at several stations on the Chattahoochee River; (2) hourly meteorologic data at one station; (3) mean daily effluent discharges at five wastewater-treatment facilities; (4) mean daily discharge at several gaged tributary streams; and (5) mean daily withdrawals from the Chattahoochee River at the Atlanta water-supply facility. Hourly meteorlogic data were collected at the R. M. Clayton WTF (table 1 and fig. 1) and include wet and dry bulb air temperatures, long and short wave radiation, wind speed and direction, and rainfall. Meteorologic data used in this study are listed by parameter in the Summary of Data Section at the end of this report (table 10). Mean daily flows at the various WTF outfalls and at the water-supply facility were treated as tributary contributions and diversions, respectively. Measurements of streamflow in the larger tributaries draining to the study reach were made on July 12, 1976.

River cross-section and bed-elevation data at 36 locations were obtained originally from the U.S. Army Corps of Engineers (1973). Channel widths and bed elevations at most of these locations were corrected using data collected during a field reconnaissance in May 1977 when flow conditions were low and generally steady. Cross-section data at five additional locations were collected during this reconnaissance along with the shading or barrier heights of the river banks and the trees lining the banks. Coordinates and barrier heights for all cross sections used in this study are listed in the Summary of Data Section at the end of this publication.

In general, data used in this report are dimensioned according to the units in which the data were reported or collected. Thus, river temperatures and most meteorologic data are expressed in metric units, and channel, stages, and discharge data are given in inch-pound units. A list of metric to inch-pound conversion factors is provided at the front of this report.

Symbols in this report are defined where they first appear in the text.

DESCRIPTION OF THE STUDY AREA

The area of interest to this study is the watershed draining to the Chattahoochee between the Atlanta and Whitesburg gages (fig. 1). Fenneman (1938) places this entire area within the southern Piedmont physiographic province and, more specifically, within the Atlanta Plateau. The topography of the study area is characterized by low hills separated by narrow valleys. Small mountains do occur along the northern divide, but summit elevations do not exceed 2,000 ft. The stream channel network draining to the Chattahoochee River is slightly dendritic and is not particularly influenced by basin geology. The channel of the Chattahoochee River, however, is extensively controlled by geologic structures and occupies or directly parallels the Brevard Fault through most of the study reach (Higgins, 1968). Alluvial "bottomlands" are common along the Chattahoochee River and its major tributaries but generally are less than 1 mi in width. Total basin area drained by the study reach is 980 mi^2.

Climate on the Atlanta Plateau is significantly influenced by the proximity of the area to the Gulf of Mexico (fig. 1) and to a lesser degree by the Blue Ridge Mountains northeast of the study area (fig. 1). In general, the Gulf of Mexico is a moderating influence on area temperatures and is a source of moisture-laden winds that provide rainfall to the basin. The mountains affect the climate most directly by serving as partial barriers to the flow of air masses.

Summer temperatures on the Atlanta Plateau are generally mild. Daytime temperatures are highest from June through August but rarely exceed 100°F. Summer nights are cool with minimum temperatures seldom below 65°F. During the winter, the mountain barriers inhibit the southerly flow of polar air masses into the Chattahoochee River basin. Thus winter temperatures are moderate and extended periods of excessively cold weather are rare. Daytime temperatures are lowest from November through January and rarely exceed 60°F. Subfreezing temperatures ($<$32°F) occur frequently but subzero ($<$0°F) temperatures are rare.

Average annual precipitation in the study area is in excess of 45 in. Most rainfall occurs in the winter and early spring months. Frozen precipitation in the form of sleet and snow is rare. During the summer, convective storms with short periods of intense rainfall are common. A summary of climatologic data for Atlanta is listed in table 2.

Land use in the study area is presently (1976) characterized by the urbanization of forests and agricultural lands. Urban, agricultural, and forest lands occupy 25, 13, and 59 percent of the land area, respectively. The remaining 3 percent of the area consists of wetlands and reservoirs. Major urban

TABLE 2.—*Summary of climatologic data for Atlanta, 1941–70*

Month	Temperature (°F)				Precipitation (in)	
	Mean daily maximum	Mean daily minimum	Record high	Record low	Average daily mean	Record daily high
January	51.4	33.4	72	−3	4.34	3.91
February	54.5	35.5	79	8	4.41	5.67
March	61.1	41.1	85	21	5.84	5.08
April	71.4	50.7	88	26	4.61	4.26
May	79.0	59.2	93	37	3.71	5.13
June	84.6	66.6	98	48	3.67	3.41
July	86.5	69.4	98	53	4.90	5.44
August	86.4	68.6	98	56	3.54	5.05
September	81.2	63.4	93	36	3.15	5.46
October	72.5	52.3	88	29	2.50	3.27
November	61.9	40.8	84	14	3.43	4.11
December	52.7	34.3	77	1	4.24	3.85
Record totals			98	−3	48.34	5.67
Yearly Averages.	70.3	51.3				

centers include Atlanta and Marietta (fig. 1) and are characterized by extensive residential communities separated by commercial, industrial, and transportation centers. Agricultural lands are generally located within the flood plains of the Chattahoochee River and its major tributaries. Grazing, row cropping, poultry feeding, and orcharding comprise the majority of agricultural activities. Forests consist mostly of oak, pine, and hickory. Forest undergrowth is extensive and includes dogwood, greenbriar, sassafras, and blackberry briars.

STREAM NETWORK AND CHANNEL DESCRIPTION

Through the study reach, the Chattahoochee River channel is oriented to the southwest and is contained mostly within the zone of cataclasis of the Brevard Fault (Higgins, 1968). The channel between the gages at Atlanta and near Fairburn (table 1, fig. 1) drains most of the Atlanta metropolitan area and receives inflows from tributaries and wastewater-treatment facilities. Diversions from this reach occur at the Atlanta water-supply facility and at the Atkinson-McDonough powerplants. Between the Fairburn and Whitesburg gages the Chattahoochee River drains mostly forests and farmlands and receives only tributary inflows. Each significant tributary and municipal and power facility in the study reach plus the locations of each respective confluence, outfall, or intake are listed in table 3.

Channel cross sections are rectangular to trapezoidal in shape and are characterized by high, steep banks and sand beds. Shoals and rock beds do occur, however, and are common in the vicinity of the

TABLE 3.—*Tributary network and mean discharges during specified periods*

Name	River mile	Discharge July 12–19, 1976 (ft³/s)	Discharge August 1–8, 1976 (ft³/s)	Discharge 1954 Drought (ft³/s)
Atlanta water-supply facility	300.62	−141	−141	
Cobb County wastewater-treatment facility.	300.56	12	12	
Peachtree Creek	300.52	65	24	8
R. M. Clayton wastewater treatment facility.	300.24	76	124	
Plant Atkinson intake	299.46			
Plant McDonough intake	299.23			
Plant Atkinson outfall	299.19			
Plant McDonough outfall	299.15			
Proctor Creek	297.50	8	7	1
Nickajack Creek	295.13	26	17	1
South Cobb County wastewater-treatment facility.	294.28	11	11	
Utoy Creek wastewater-treatment facility.	291.60	22	22	
Utoy Creek	291.57	20	13	1
Sweetwater Creek	288.58	299	100	2
Camp Creek wastewater-treatment facility.	283.78	7	7	
Camp Creek	283.54	20	15	1
Deep Creek	283.27	24	17	2
Annewakee Creek	281.48	29	23	6
Pea Creek	277.70	15	10	1
Bear Creek (right bank)	275.95	23	17	3
Bear Creek (left bank)	274.49	25	16	1
Dog River	273.46	100	70	1
Wolf Creek	267.34	22	16	1
Snake Creek	261.72	67	33	3
Cedar Creek	261.25	40	27	3

Atlanta gage, downstream of the confluence with Nickajack Creek, and between Capps Ferry Bridge and the Whitesburg gage (fig. 1). Typical channel cross sections are shown in figure 2. Profiles of the channel thalweg and the water-surface altitude during steady, low flow are shown in figure 3. Several discontinuities occur in the profile—in particular at RM 300.62 and RM 299.10. At these locations, weirs have been constructed to create pumping pools for the intake structures of the Atlanta water-supply facility and the Atkinson-McDonough powerplants. Other discontinuities are the result of bedrock controls or the rapid decline of channel altitudes across a shoal or series of shoals.

STREAMFLOW AND TEMPERATURE CHARACTERISTICS

Streamflow through the study reach is greatly influenced by regulation at Buford Dam. During a typical week, hydropower is produced at the dam for several hours each weekday and infrequently on weekends. Each period of hydropower production is accompanied by the movement of water downstream in the form of a wave or pulse. The flow characteristics of each wave are directly related to the quantity of power produced and the length of the power-production period.

Hydrographs of mean daily discharge in the Chattahoochee River at Atlanta, near Fairburn, and near

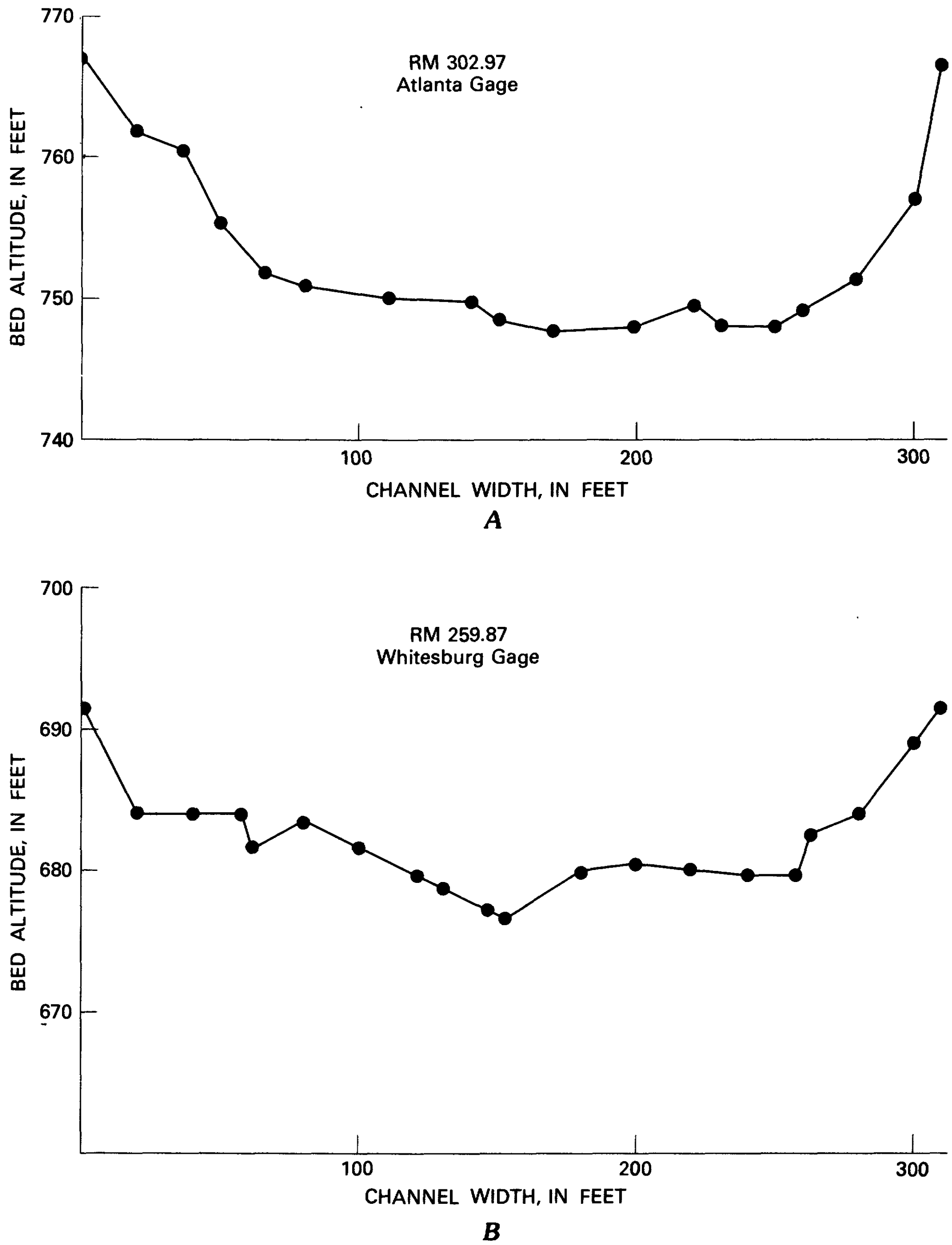


FIGURE 2.—Selected channel cross sections of the Chattahoochee River from Atlanta to Whitesburg. *A*, RM 302.97. *B*, RM 259.87.

Whitesburg are shown in figures 4 through 6. The cyclic nature of the flows is apparent and reflects the weekly (7-day) period characterized by 5 days of power production at Buford Dam followed by 2 days with little or no production. Anomalously high peaks on the hydrographs correspond to periods of high rainfall runoff.

The long term effects of regulation on streamflow are indicated by the flow duration curves in figure 7. Since regulation, peak flows are smaller in both magnitude and duration, and minimum flows are larger.

Mean daily river temperatures at several stations on the Chattahoochee River are shown in figures 8 through 12. Each graph represents mean daily river temperature computed from hourly measurements recorded during water year 1976. At most stations, the annual variation of river temperatures generally

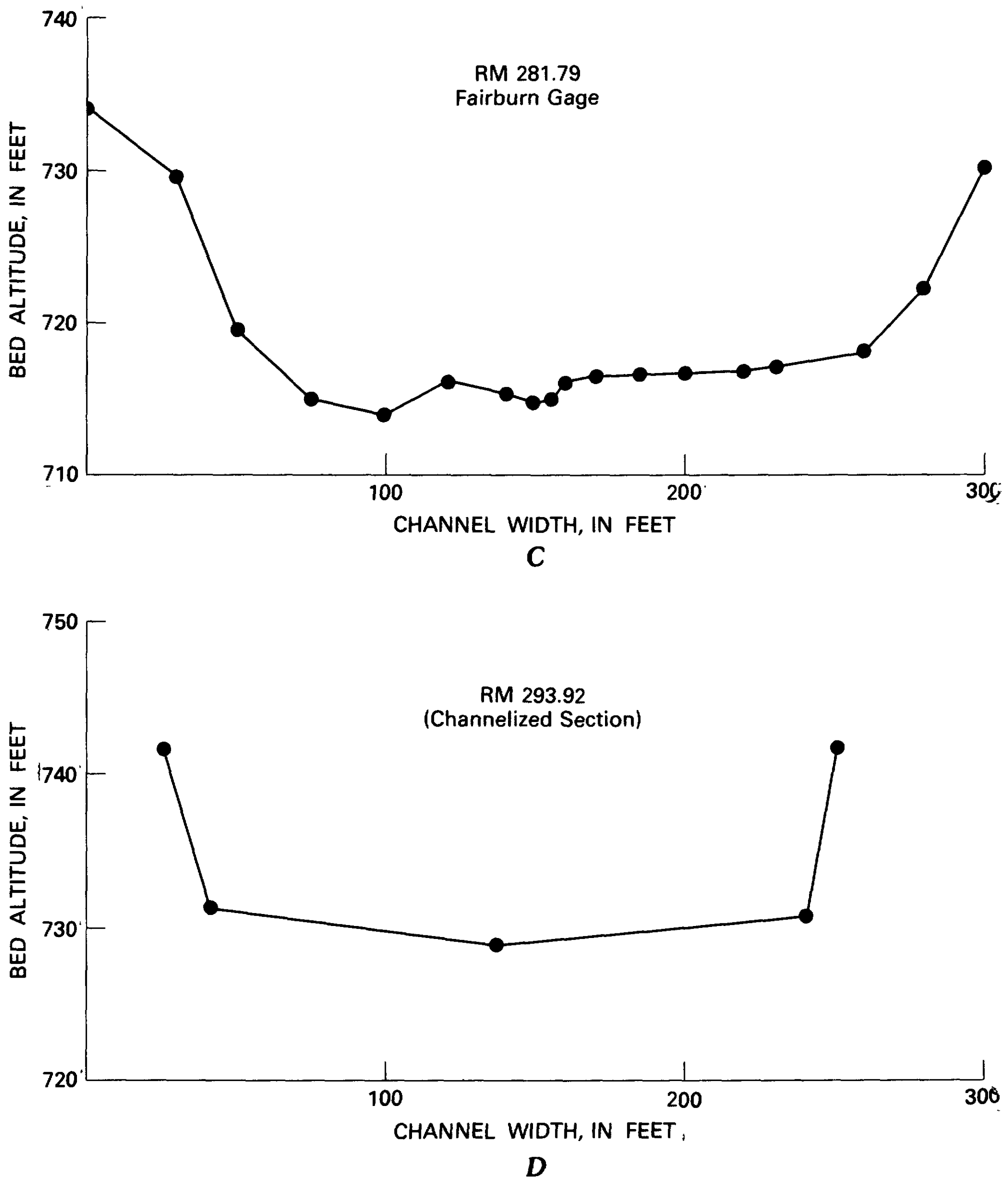


FIGURE 2.—Continued. *C*, RM 281.79. *D*, RM 293.92.

conforms to the monthly air-temperature trends indicated in table 2 and ranges from a low of about 4°C in January to a high of about 24°C in July or August. Those temperatures showing the least variation (7 to 13°C) are at Buford Dam (fig. 8) and are most influenced by the metalimnion and hypolimnion temperatures of Lake Sidney Lanier. River temperatures at Georgia Highway 280 show the largest annual variation (7° to 28°C) and are influenced to a great extent by heat loads from the Atkinson-McDonough powerplants. At any station, short term variations in river temperature can be large and are caused mostly by flow regulation, the occurrence of storm runoff, cloud cover, and day-to-day changes in air temperature.

Changes in mean daily river temperature between stations can also be large and are influenced primarily by exchanges of thermal energy between the river and the atmosphere.

Temperatures of the Chattahoochee River at the Atlanta gage during the period July 1937 to May 1938 were reported by Lamar (1944) and are shown in figure 13. A total of 294 daily temperature measurements were recorded. Each measurement was reportedly made between 1300 and 1930 h. Hourly temperature data collected at the Atlanta gage dur-

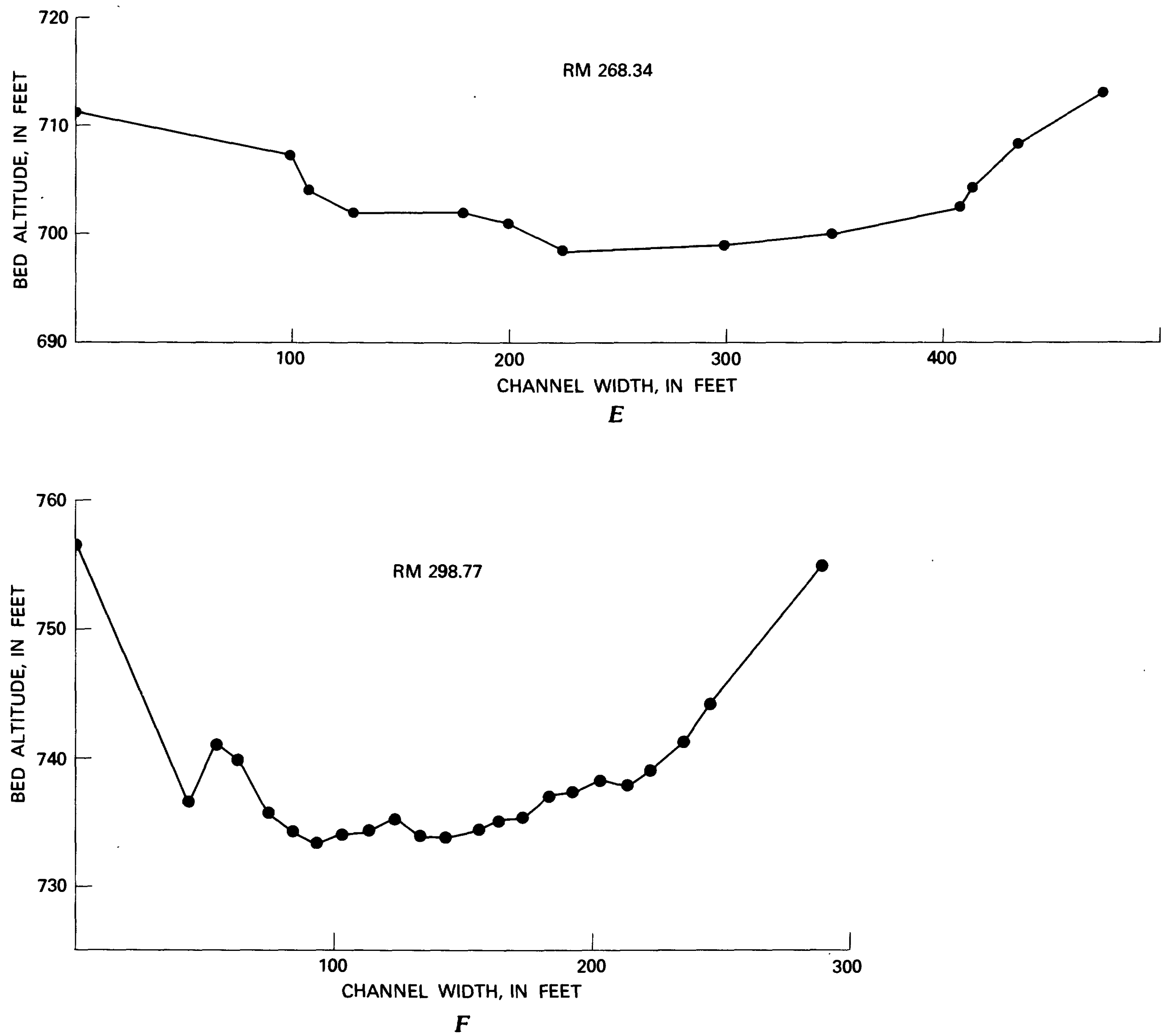


FIGURE 2.—Continued. *E*, RM 268.14. *F*, RM 298.77.

ing water year 1976 indicate that stream temperatures during the afternoon and early evening depart from mean daily stream temeprature by 1.5°C or less. The same criterion applied to the 1937–38 temperatures indicates that these data are representative of mean daily stream temperature within an error of 1.5°C and, for comparative purposes, are treated accordingly in this text.

The comparision of river-temperature data at the Atlanta gage collected before (fig. 13) and after (fig. 9) the construction of Buford Dam provides some insight into the impact of flow regulation on river temperatures. During water years 1937–38, annual variations in river temperature at Atlanta were considerably greater than those measured in water year 1976—ranging from 1.5 to 31°C compared to 4.5 to 21.5°C. Also, annual extremes occurred at different times of the year. During water year 1976, the annual low and high temperatures occurred in January and August, respectively; corresponding months for the 1937–38 temperature extremes were December and July.

Some of the variability in river temperature attributed to flow regulation could also be caused by differences in meteorologic conditions. The actual meteorologic contribution to river temperatures cannot be determined; however, estimates can be made by comparing mean monthly air temperatures at At-

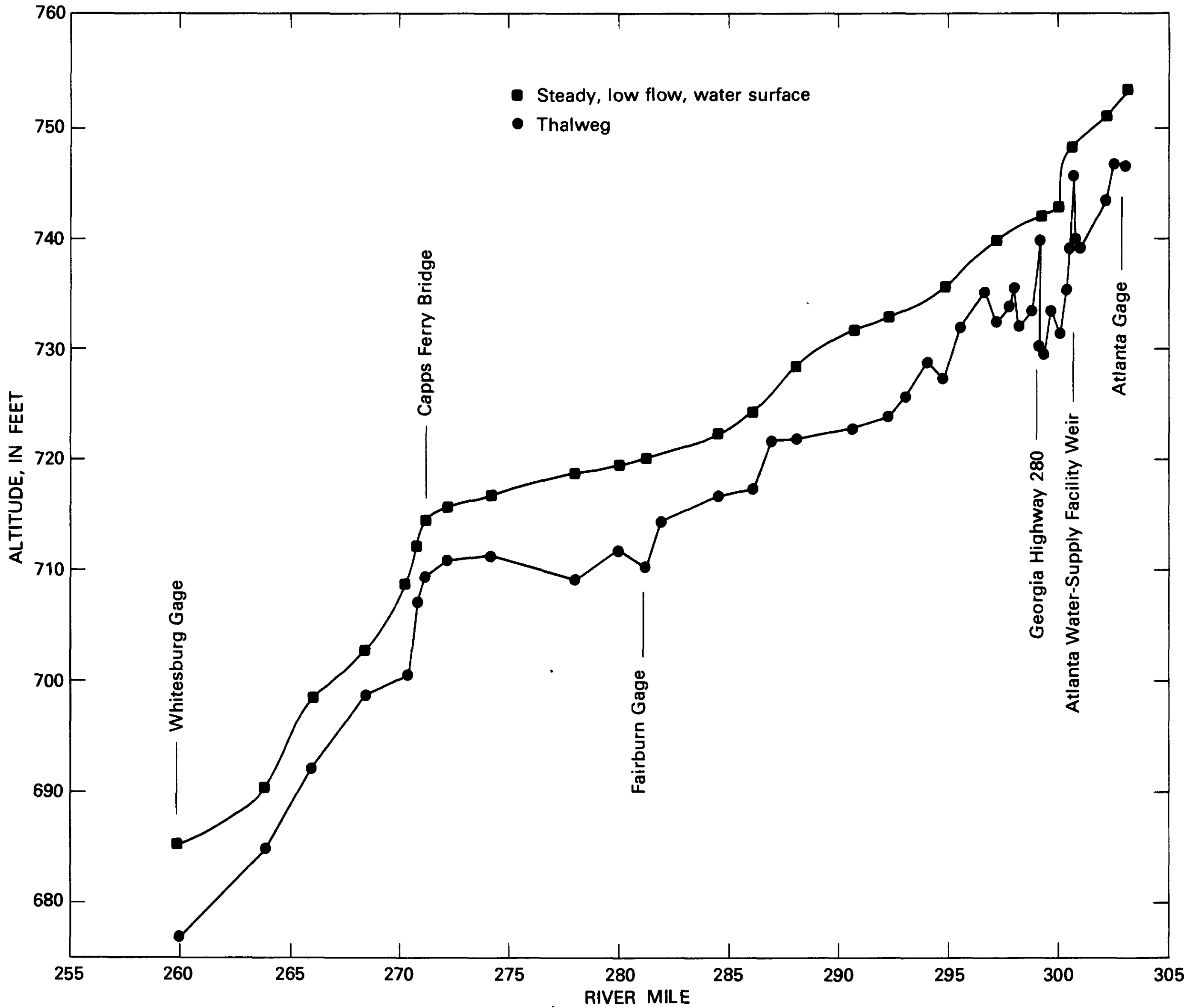


FIGURE 3.—Thalweg and low-flow profile of the Chattahoochee River—Atlanta to Whitesburg.

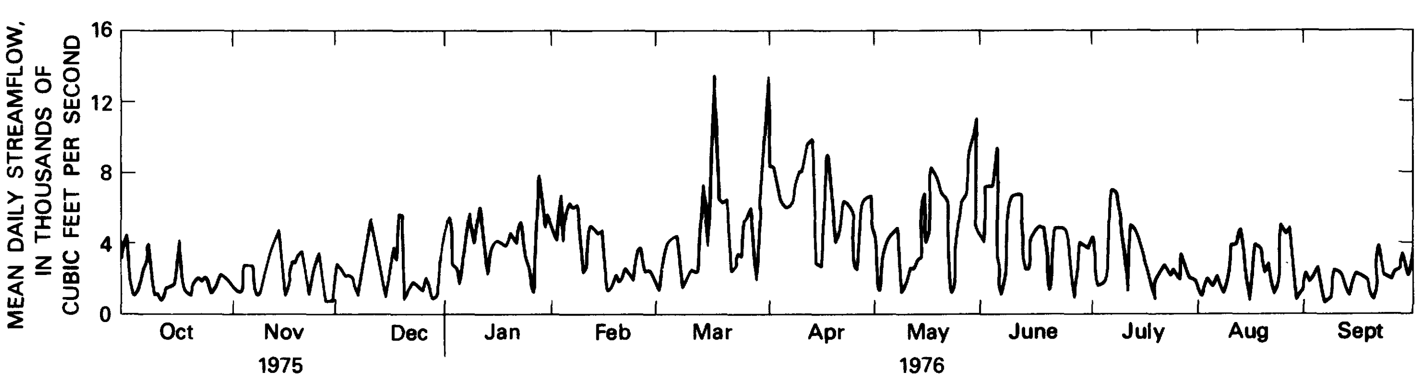


FIGURE 4.—Mean daily streamflow in the Chattahoochee River at Atlanta during water year 1976.

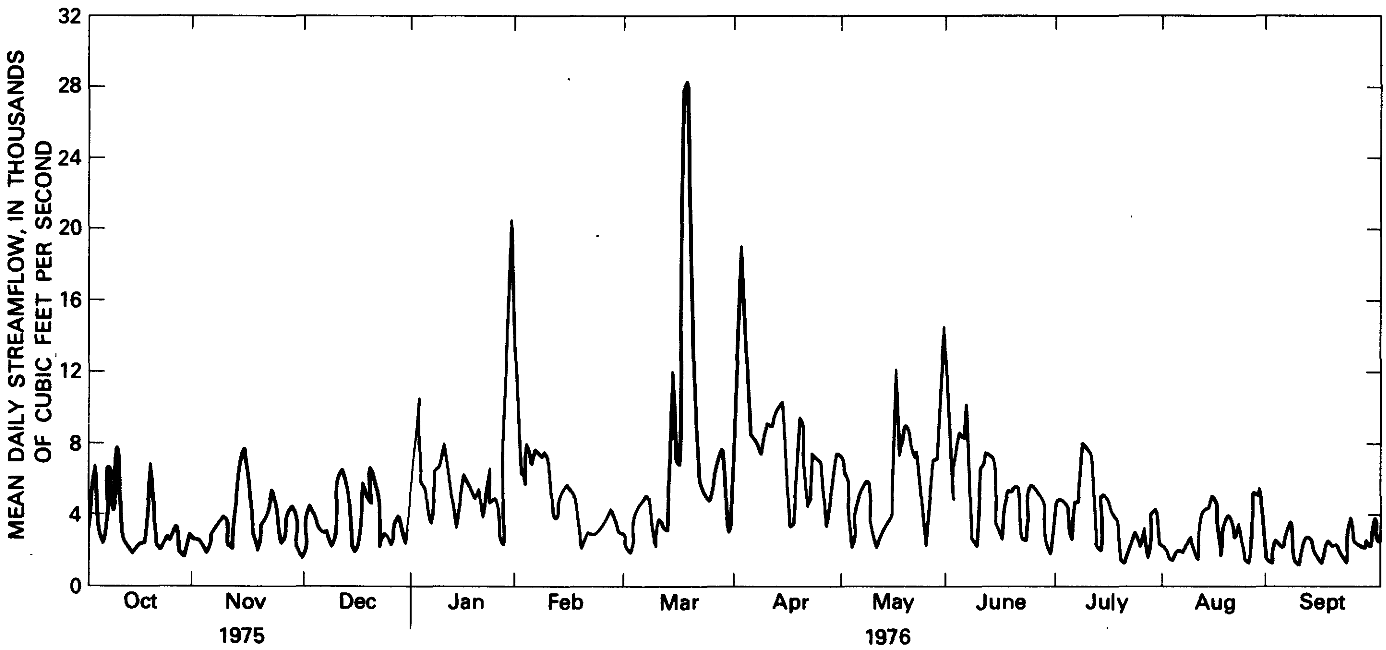


FIGURE 5.—Mean daily streamflow in the Chattahoochee River near Fairburn during water year 1976.

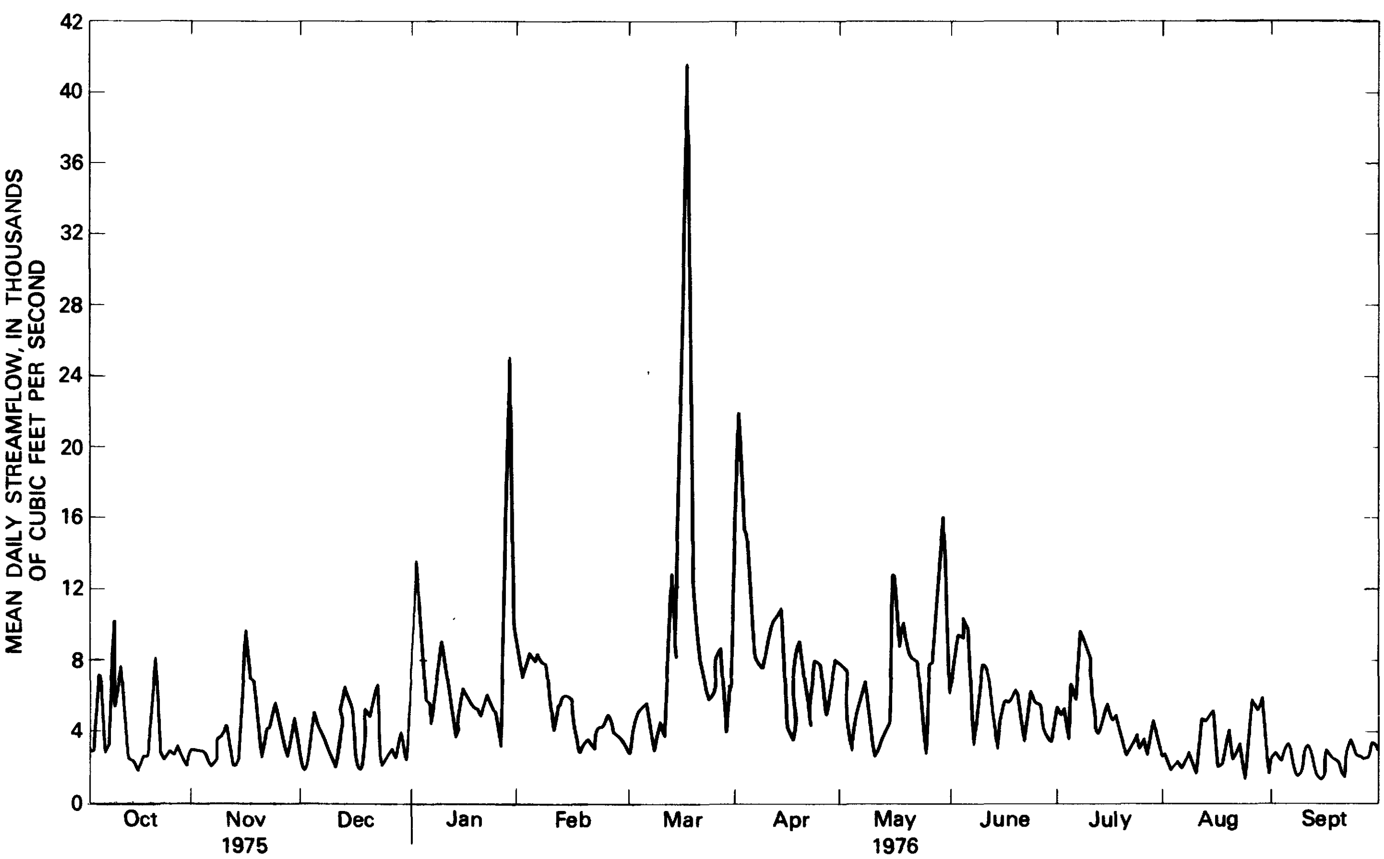


FIGURE 6.—Mean daily streamflow in the Chattahoochee River near Whitesburg during water year 1976.

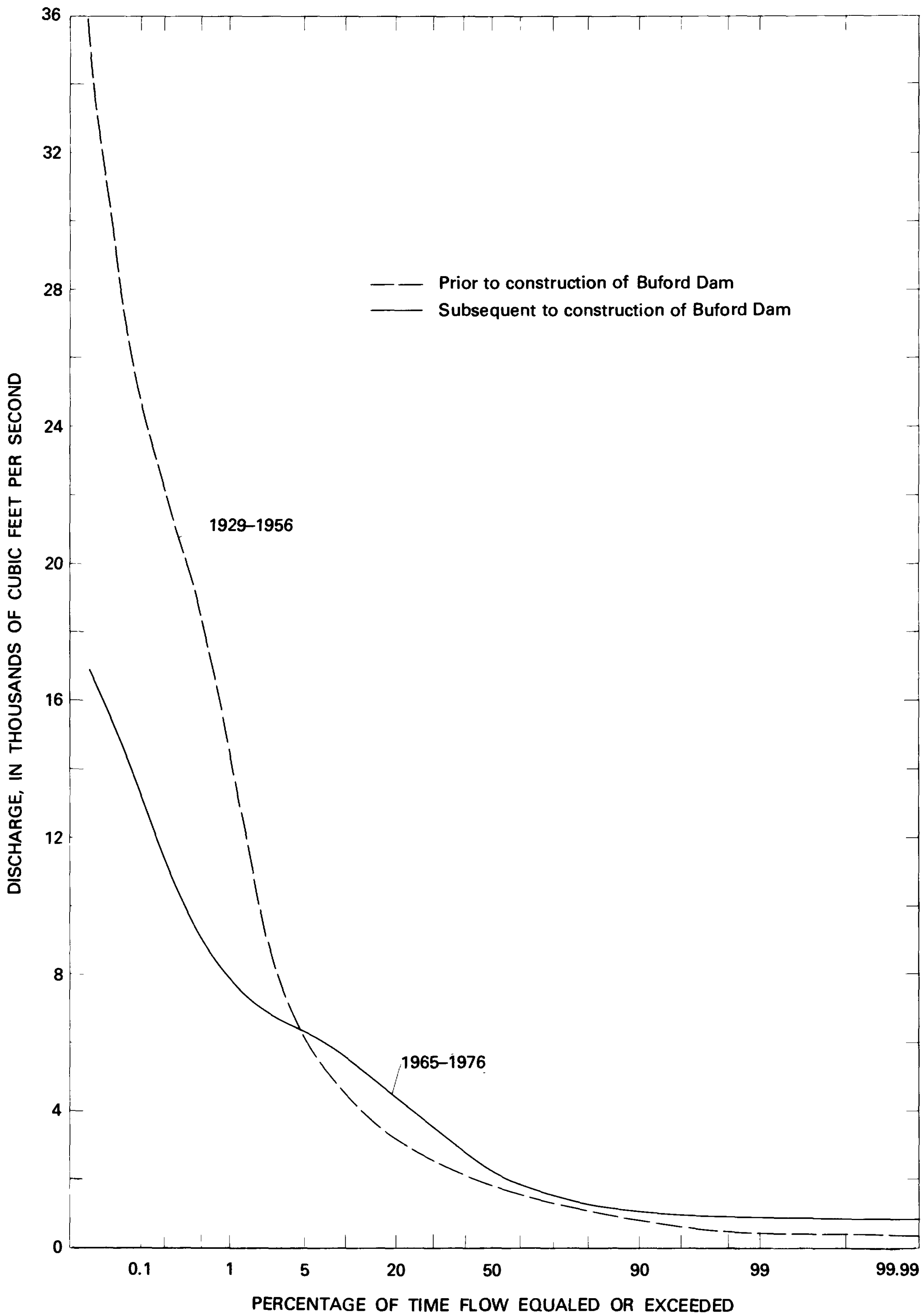


FIGURE 7.—Flow duration characteristics of the Chattahoochee River at Atlanta prior to and subsequent to the construction of Buford Dam.

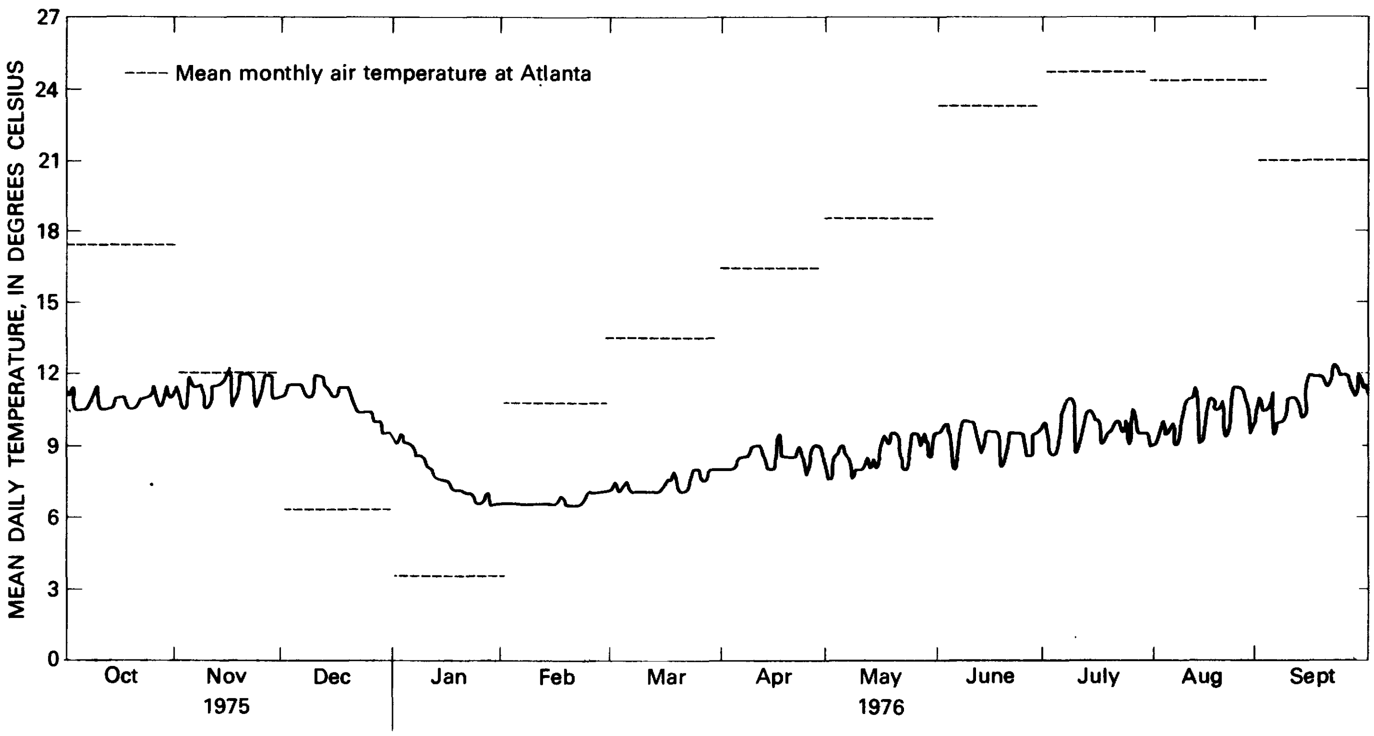


FIGURE 8.—Observed mean daily temperature of the Chattahoochee River at Buford Dam and mean monthly air temperature at Atlanta during water year 1976.

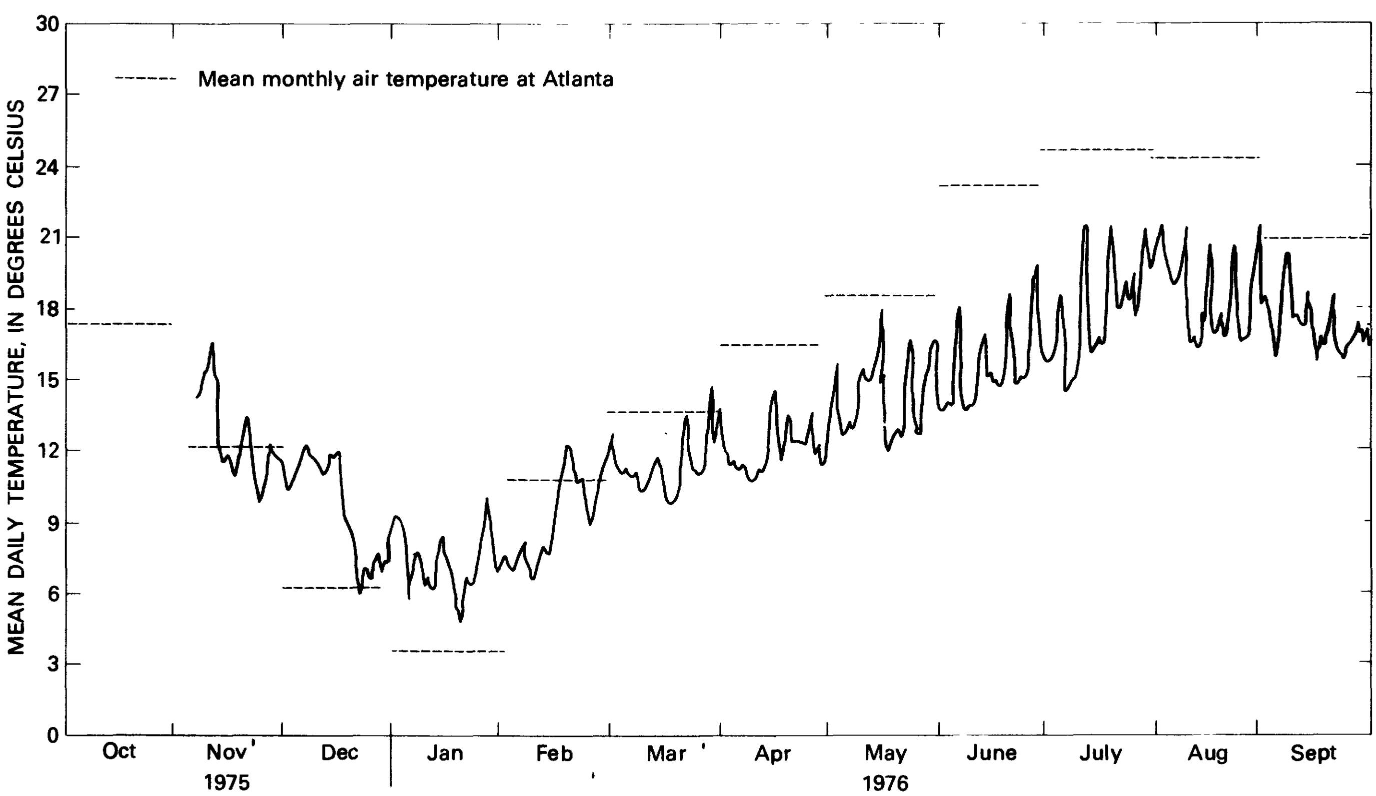


FIGURE 9.—Observed mean daily temperature of the Chattahoochee River at Atlanta and mean monthly air temperature at Atlanta during water year 1976.

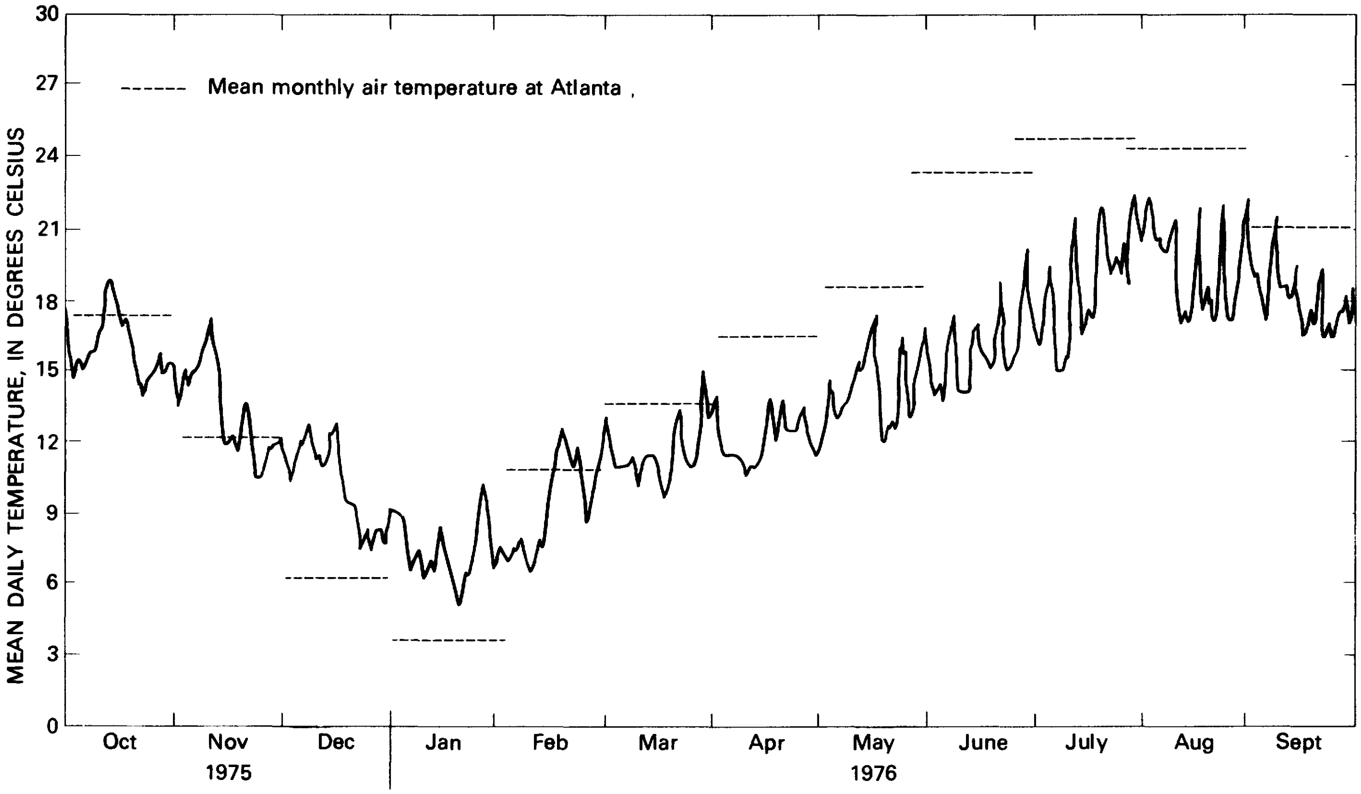


FIGURE 10.—Observed mean daily temperature of the Chattahoochee River at the Plant McDonough intake and mean monthly air temperature at Atlanta during water year 1976.

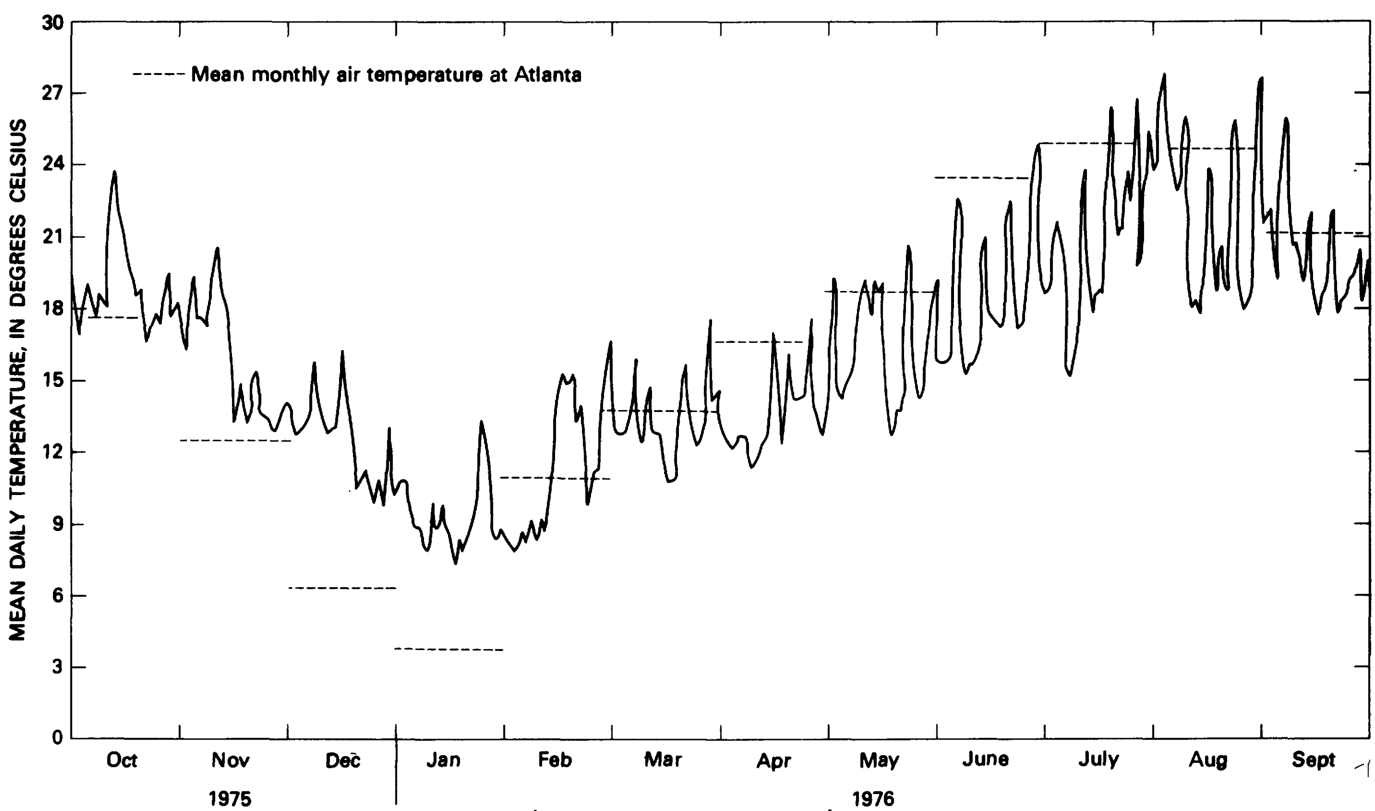


FIGURE 11.—Observed mean daily temperature of the Chattahoochee River at Georgia Highway 280 and mean monthly air temperature at Atlanta during water year 1976.

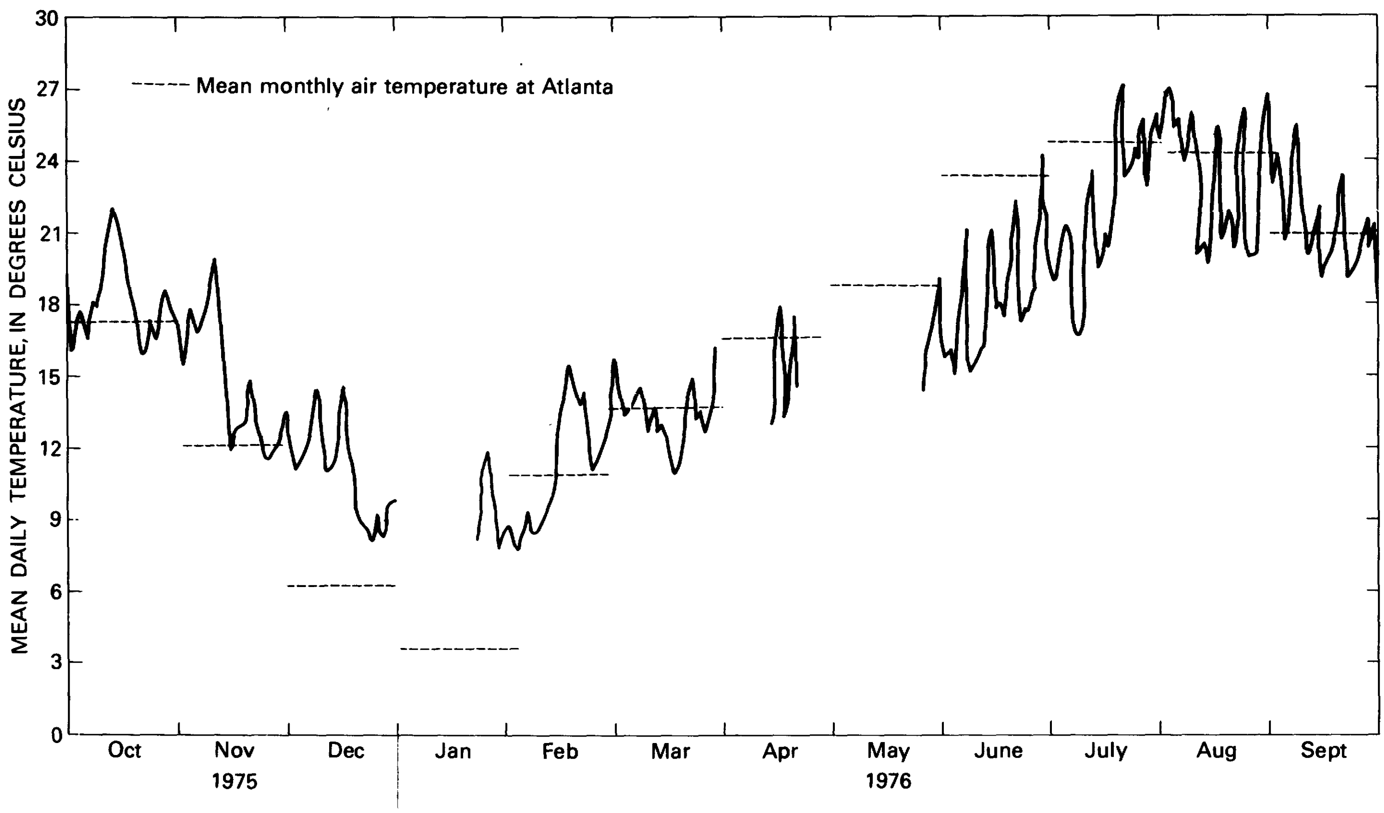


FIGURE 12.—Observed mean daily temperature of the Chattahoochee River near Fairburn and mean monthly air temperature at Atlanta during water year 1976.

lanta for the periods 1937–38 and 1975–76 (NOAA, 1976). These data are listed in table 4 for the coincident months of river-temperature record. Winter air temperatures during 1975–76 were generally colder than corresponding temperatures for the period 1937–38 and summer and fall air temperatures were about the same or warmer. River temperatures at the Atlanta gage, however, show nearly opposite trends—being warmer during the winter of 1975–76 and cooler during the summer and early fall. Thus, observed differences in river temperature at Atlanta during the periods 1937–38 and 1975–76 would at best have been dampened or minimized by the prevailing meteorologic conditions and have for the most part been correctly attributed to flow regulation at Buford Dam.

For purposes of this study, "natural" river temperatures at a station are defined as those temperatures resulting from the combined thermal effect of atmospheric exchange and tributary inflow on stream waters between the headwaters and the station. Thus, by definition, "natural" temperatures cannot be significantly affected by upstream artificial heat sources or sinks. Application of this definition to the observed river-temperature data described previously (figs. 8–13) indicates that the 1937–38 stream temepratures at the Atlanta gage (fig. 13) probably closely approximate natural temperatures and are considered as such in this text.

Mean monthly air temperatures at Atlanta are listed in table 4 and are shown graphically by horizontal lines on figures 8 to 13. Corresponding mean

TABLE 4.—*Mean monthly air temperatures at Atlanta for the period of record and for specified months during 1937–38 and 1975–76, in degrees Celsius*

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937	--	---	---	---	---	---	26.4	26.4	21.8	14.9	8.6	6.2
1938	6.1	10.8	14.7	16.3	---	---	---	---	---	---	---	---
1975	--	---	---	---	---	---	---	---	---	17.4	12.2	6.3
1976	3.6	10.8	13.6	16.5	18.6	23.2	24.7	24.4	21.0	---	---	---
1879–1975	6.3	7.6	11.4	16.3	20.8	24.6	25.8	25.4	22.8	17.1	11.1	7.0

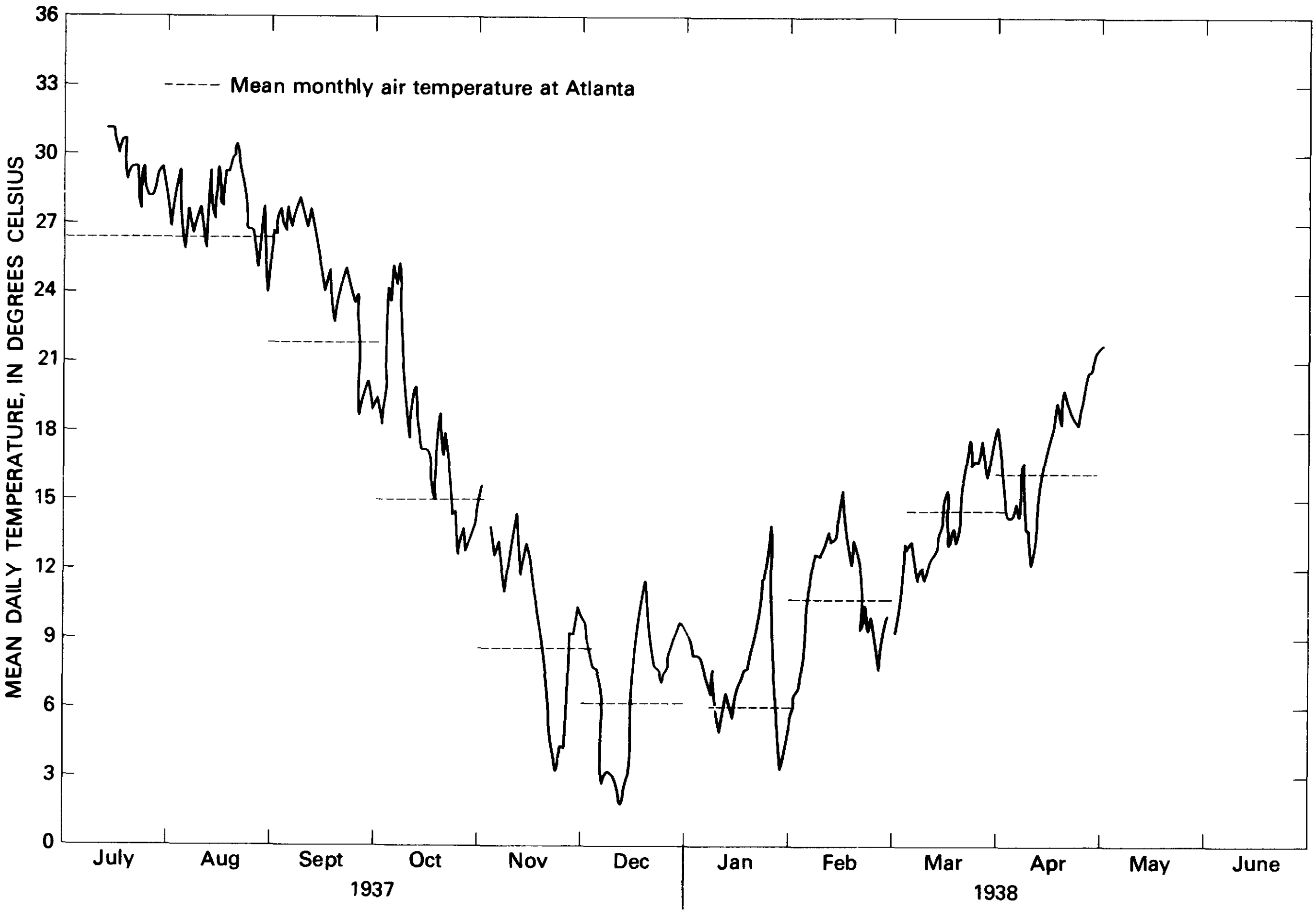


FIGURE 13.—Observed mean daily temperature of the Chattahoochee River and mean monthly air temperature at Atlanta—July 1937 to May 1938.

TABLE 5.—*Mean monthly water temperatures during 1937–38 and 1975–76, in degrees Celsius*

Month	Buford Dam (1975–76)	Atlanta gage (1937–38)	Atlanta gage (1975–76)	Plant McDonough intake (1975–76)	Georgia Highway 280 (1975–76)	Fairburn gage (1975–76)
October	11.0	17.7	-----	16.0	18.5	18.5
November	11.5	10.2	13.0	13.5	15.5	15.0
December	11.0	7.2	10.0	10.5	12.5	11.0
January	7.5	7.4	7.0	7.5	9.0	-----
February	6.5	11.3	9.0	9.5	11.0	11.0
March	7.5	14.4	11.5	11.5	13.0	13.0
April	8.5	17.4	12.0	12.0	13.5	-----
May	8.5	-----	14.0	14.5	16.5	-----
June	9.5	-----	15.5	16.0	18.5	18.0
July	9.5	29.4	18.0	18.5	21.0	22.0
August	10.5	27.6	18.5	19.5	22.0	23.5
September	11.5	24.7	17.5	18.0	20.0	21.5

monthly river temperatures are listed by location and period of record in table 5. Comparison of mean monthly air and water temperatures at the Atlanta gage during 1937–38 (fig. 9, tables 4 and 5) indicates that mean monthly natural stream temperatures are within ±3°C of mean monthly air temperatures. Similar relations have also been observed for the Severn River in England and for the Illinois River in data presented by Langford (1970) and Kothandaraman and Evens (1972), respectively. Application of this relation to the temperature data collected during 1975–76 implies that differences between mean monthly air and river temperatures in excess of 3°C result partly from artificial thermal alteration; that is from flow regulation and powerplant effluents. Thus, hydropower production appears to have a significant cooling effect on river temperatures at Buford Dam, especially through the period March to September, and warms the river significantly during the months of December and January (fig. 8). At the Atlanta gage (fig. 9), much of the cooling effect noted at Buford Dam has been dissipated, and the river temperatures more closely approximate a natural, annual pattern. The cooling effects of hydropower production are still noticable, however, especially during the period April through September. Only slight differences in mean monthly river temperatures were noted between the Atlanta gage and the Plant McDonough intake (figs. 9 and 10). These differences should be expected given the short distance between the stations and the absence of significant heat sources or sinks in the intervening reach. Comparison of mean monthly air and river temperatures at Georgia Highway 280 (fig. 11, tables 4 and 5) indicates that the combined effect of flow regulation and powerplant effluents results in mean river temperatures approximately equal to mean natural temperatures throughout most of the period February to October and greater than natural temperatures during December and January. Similar results were noted at the Fairburn gage (fig. 12).

Thus, in summary, comparisons of mean monthly air and river temperatures have indicated both the occurrence and magnitude of river temperature alterations that result from flow regulation at Buford Dam and heat loadings from the Atkinson-McDonough powerplants. Significant cooling below natural temperatures was noted downstream of Buford Dam, at the Atlanta gage, and at the Plant McDonough intake during the spring and summer months. Flow regulation produced warmer than natural river temperatures at the same stations during the winter. Downstream from the powerplants, the combined effect of flow regulation and powerplant heat loads was shown to produce river temperatures approximating natural conditions during much of the spring and summer and warmer than natural temperatures during the early winter months.

FLOW AND TEMPERATURE MODELS

Detailed descriptions of the flow and temperature models, their uses, and solution techniques are presented by Jobson and Keefer (1979) and Land (1978). Aspects of the models pertinent to this study are discussed below.

The flow model is a finite-difference approximation of the one-dimensional continuity and momentum equations for gradually varied flow. The forms used are identical to those presented by Amein and Fang (1970). The numerical technique used to solve the equations is referred to as fully forward, linear, implicit which computes the spatial derivatives at the forward time level and simultaneously solves for the unknown depths and velocities at the end of each time step.

Boundary conditions for the flow model were defined at the Atlanta and Whitesburg gages as discharge and stage, respectively. Discharge at the Atlanta gage was estimated from a rating curve and hourly stage measurements. Stability criteria, based on the variable distances between cross sections (table 8 in the Summary of Data) and expected flow velocities, required that boundary data be applied to the flow model at 15-min intervals. Such data were obtained by linear interpolation between the given hourly data.

Tributary inflows applied to the model were assumed constant during the various simulation periods.

Flow-geometry data are required by the model as a function of depth and include values of top width, wetted perimeter, and area of flow at each cross section. Top widths were computed by linear interpolation between data pairs of top width and depth provided for each cross section. Flow areas at each depth were computed by integrating the curve defined by the top width-depth relation. Wetted perimeters were determined using computed values of top width and depth and a skew coefficient. A detailed description of these techniques is provided by Land (1978).

The temperature model solves a finite-difference approximation of the one-dimensional equation describing the continuity of thermal energy in open channels. Jobson and Keefer (1979) present this equation in the form:

$$\frac{\partial T}{\partial t}+\frac{U\partial T}{\partial x}=\frac{D_x\partial^2 T}{\partial x^2}+\frac{\phi_T W}{C_p\rho A}+\frac{\phi_B P}{C_p\rho A} \qquad (1)$$

where T = stream temperature, t = time, U = stream velocity, x = distance along the channel, D_x = a dispersion coefficient, ϕ_T = the flux of thermal energy from the atmosphere to the water, C_p = the specific heat of water, ρ = the density of water, W = the top width of flow, A = the flow area, P = the wetted perimeter, and ϕ_B = the flux of thermal energy from the bed to the water. The solution technique used to solve this equation is a slight variation of the six-point implicit scheme of Stone and Brian (1963).

Data input from the flow model to the temperature model included top width, velocity, cross sectional area and tributary inflow at each section for each time step.

The solution scheme of the temperature model requires subreaches of equal length. In order to make the output of the flow model compatible with the temperature model, the flow data were interpolated to an equal grid spacing by use of a processor program. The logic of this program assured that the total instantaneous volume of water within any subreach was the same for both models.

Observed river temperatures at the Atlanta gage served as the necessary boundary condition for the temperature model. Temperatures of the tributary inflows were unavailable but were estimated by regression from the equation:

$$T_i = 1.82 \quad (T_{wb_{i-8}}) - 12.25 \qquad (2)$$

where T_i = instantaneous tributary temperature, T_{wb} = instantaneous wet bulb temperature, and i is a time step indicator. Development of this equation was based on 41 instantaneous tributary temperature measurements made in the study area during the summer of 1976. Standard error of estimate of this regression is 3.2°C.

The flux of thermal energy between the bed and the water is small compared to other heat flux and was computed using the procedure outlined by Jobson and Keefer (1979).

The flux of thermal energy from the atmosphere to the water, ϕ_T, is the result of several processes and is generally described by the relation:

$$\phi_T = \phi_N - \phi_b - \phi_e - \phi_h + \phi_R + \phi_q \qquad (3)$$

where ϕ_N = net heat flux caused by incoming radiation from the sun and atmosphere, ϕ_b = heat flux caused by longwave radiation emitted by the water, ϕ_e = heat utilized by evaporation, ϕ_h = heat conducted from the water as sensible heat, ϕ_R = heat added by rain falling directly on the surface, and ϕ_q = heat added to the river by tributary inflow. Only the flux of incoming solar radiation could be measured directly by meteorologic instruments. The flux of incoming atmospheric radiation was computed using the procedure outlined by Koberg (1964). The radiation flux emitted by the water surface (ϕ_b) was computed using the Steffan-Boltzman equation (Jobson and Keefer, 1979). Three percent of the incoming atmospheric radiation was assumed to be reflected while the percentage of solar radiation reflected was estimated from a complex relation between the azimuth and height of the sun, the azimuth of the subreach, width of the subreach, and the effective shading height of the riverbanks and trees along the banks (Jobson and Keefer, 1979). The heat flux caused by evaporation and conduction was computed using meteorologic data, Dalton's Law, and the analog of mass and heat transfer as explained by Bowen's ratio (Jobson and Keefer, 1979). The wind function used in Dalton's Law is proportional to the wind function derived by Jobson (1977a and b) from thermal data collected on the San Diego Aqueduct in southern California.

The combined heat load from the Atkinson-McDonough powerplants to the Chattahoochee River was not measured directly. Computation of instantaneous loads was originally accomplished using the observed temperature differential across the outfalls (Plant McDonough intake and Georgia Highway 280) and corresponding instantaneous river flows computed by the flow model. Unfortunately, at low flow, it was determined that the recorded temperatures at the Plant McDonough intake were affected, to some extent, by the hot water discharges. The heat loads applied to the temperature model, therefore, were computed using the difference between the observed temepratures at Georgia Highway 280 and the model computed temperatures at the Plant McDonough intake.

CALIBRATION AND VERIFICATION

Flow, temperature, and meteorologic data collected during two 8-day periods beginning July 12, 1976, and August 1, 1976, respectfully, were used to calibrate and verify the flow and temperature models.

FLOW MODEL

Calibration of the flow model was accomplished in two steps using stage data for the period July 12–19, 1976, and discharge and flow-depth data collected during the May 1977 reconnaissance. The first step utilized the discharge and flow-depth data collected during the reconnaissance. The maximum measured depth at each cross section was added to the "known" thalweg altitude (U.S. Army Corps of Engineers, 1973) to form an "observed" water-surface profile. A smooth curve was then drawn through the plotted points matching the observed water-surface altitudes at bridges and gages where accurate altitude measurements were available. The measured depths were then subtracted from the smoothed profile to determine corrected bed altitudes. Starting at the downstream end of the study reach, individual Manning's roughness coefficients were selected on a trial and error basis at each cross section such that the flow model, run to steady state, accurately reproduced the observed depths and the "smoothed" water-surface profile. The roughness coefficients obtained in this way insured that the model computed realistic depths and velocities at low flow and provided a basis for computing corresponding coefficients during transient flow.

The second step of the calibration process was the development of a linear rate of change of roughness with stage at each cross section, which would allow the model to best predict the observed July 12–19 stages in the river. Such rates were determined by trial and error. The range of computed Manning's n values for each cross section is listed in Table 9 in the Summary of data.

The results of the flow-model calibration are illustrated in figure 14. Computed and observed stages are plotted at the Atlanta gage, the Atlanta water-supply facility, the Plant McDonough outfall, the Fairburn gage, and the Whitesburg gage. Phase differences between computed and observed stages are minimal and stage values are closely matched at both high and low flow. The model consistently overpredicts intermediate stage values at all stations, which suggests that the rate of change of roughness with stage is not linear as originally assumed. This error is largest at the Atlanta water-supply facility (0.5 ft) and progressively decreases downstream to the Fairburn gage (0.2 ft).

Both rated and computed discharges at the Fairburn gage are shown in figure 15. In general, the agreement is good but the two discharges appear to be out of phase by about 2 h. In evaluating this apparent phase shift, it is well to remember that a rated discharge is dependent on an assumed unique relation between stage and discharge. For unsteady flow, such relations do not generally exist. For example, figure 16 shows the rating curve and the simulated stage-discharge relation at the Fairburn gage for the hydropulse of July 13, 1976. The model predicts greater discharges than the rating curve on the rising limb and smaller discharges on the falling limb, just as one would expect. The phase shift between rated and computed discharge at the river gage near Whitesburg is shown in figure 17. A shift of about 5 h is noted and at a given instant, can result in discharge differences of nearly 20 percent. Arbitrary manipulation of geometry and Manning's n data at several sections upstream of the Whitesburg gage indicated that the size of the phase shift is insensitive to changes in both channel volume and roughness. The simulated stage-discharge relation for flow at the Whitesburg gage during July 13–14, 1976, is shown on figure 18.

Tributary inflows during the calibration period are listed in table 3 and were based on measured discharges obtained on July 12, 1976, adjusted to a weekly average using records at gaged streams.

The calibrated flow model was verified using measured stage data for the period August 1–8, 1976. Simulated and observed stages are shown on figure 19. Flow variations were less extreme in August than in July, and no stage data were available at the Plant McDonough outfall. A maximum error of 0.7 ft between computed and observed stages occurred at the Atlanta water-supply facility on August 7. Differences between observed and computed stages at the Atlanta and Fairburn gages were less than 0.4 ft.

Plots of simulated and rated discharge for the verification period were similar to those presented for model calibration and are not shown in this text. A phase shift of about 2 h was observed at the Fairburn gage with a maximum difference between simulated and rated discharge of about 8 percent. The phase shift at Whitesburg was also about 2 h with a corresponding maximum difference between discharge of about 13 percent. The reduction in phase shift between the calibration and verification periods is not unexpected because the hysteretic nature of the stage-discharge relation usually decreases in proportion to the dynamic nature of the flow.

Although phase shifts occurred between comparisons of instantaneous computed and rated discharge at both the Fairburn and Whitesburg gages, computation of the total volume of water passing by each station using both the model and the rating curve produced nearly equal values for both the calibration and verification periods.

Roughness relations, bed elevations, and channel geometry data at each cross section were exactly the same for the calibration and verification of the flow model. Tributary inflows during the verification period (table 3) were based on average daily discharges at the gaged streams and extrapolated discharges at ungaged streams.

Overall, the results of the calibration and verification of the flow model are considered to be good, and the flow model is considered an adequate predictive tool.

TEMPERATURE MODEL

The only parameter in the temperature model which could reasonably be varied for calibration purposes is the empirical wind function. The wind function is used in conjunction with the quasi-empirical Dalton's Law to compute heat flux due to evaporation (Jobson and Keefer, 1979). The effect of the wind function is highly variable but generally is largest for high river temperatures and low discharges. Consequently, river-temperature and meteorologic data collected for the period August 1–8, 1976, were used to calibrate the temperature model,

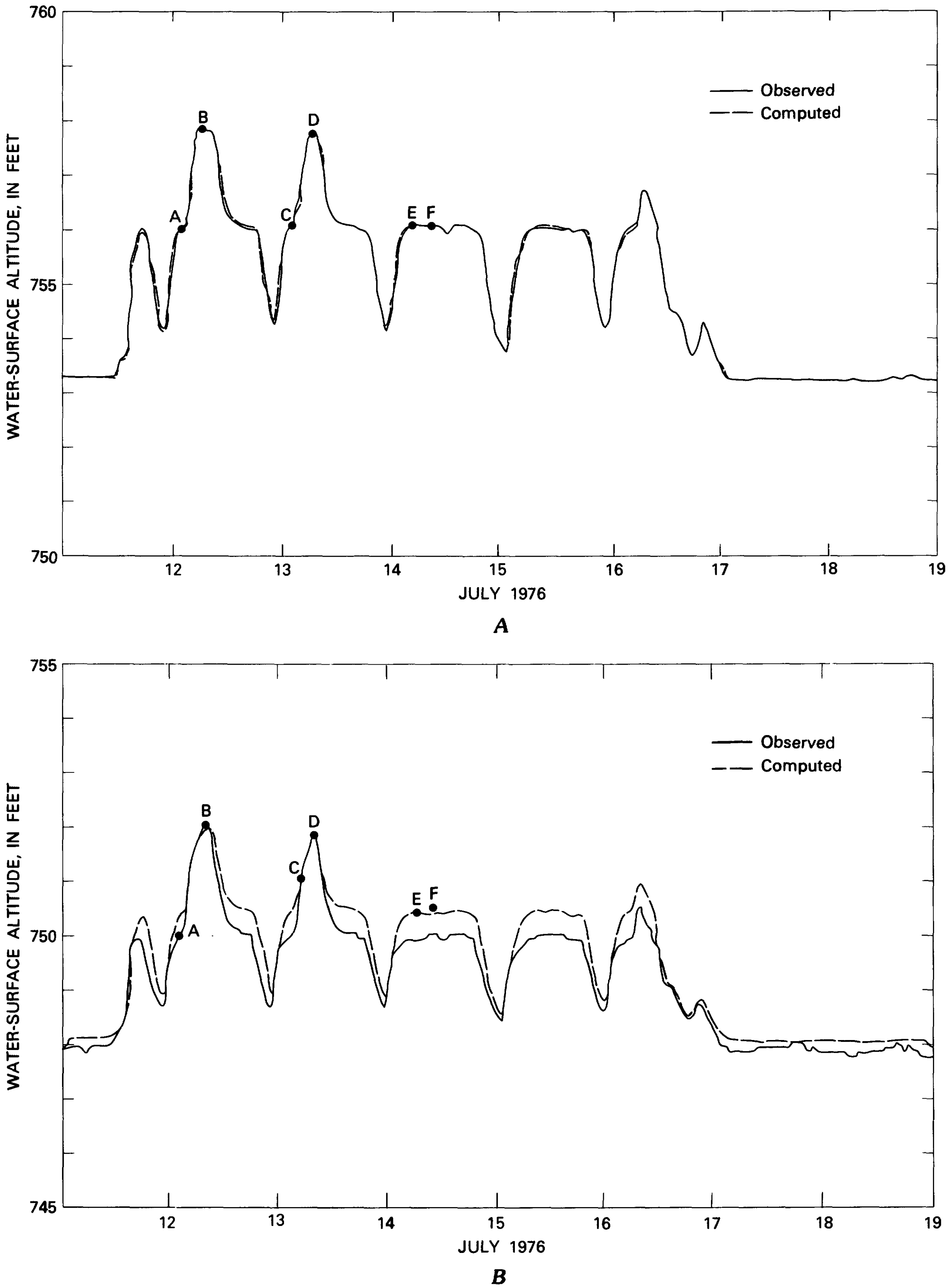
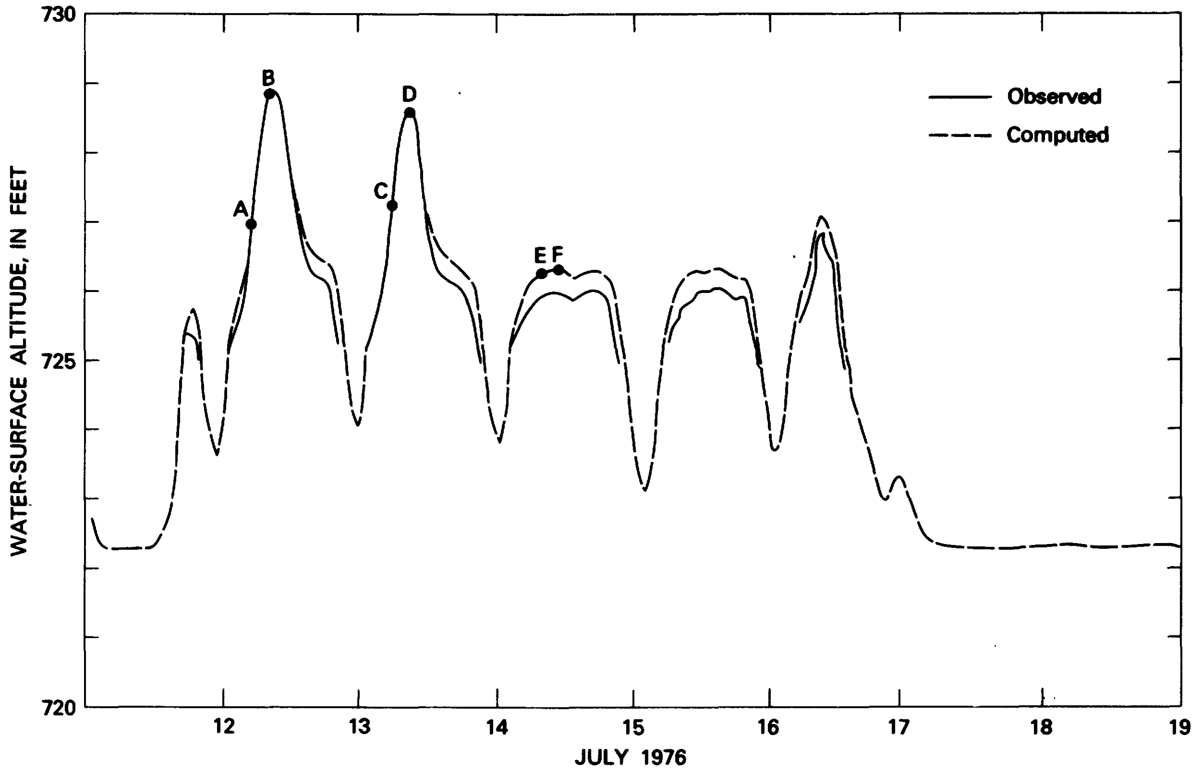


FIGURE 14.—Observed and computed stages of the Chattahoochee River during the period July 12–19, 1976. *A*, At Atlanta. *B*, At Atlanta water-supply facility. *C*, At the Plant McDonough outfall. *D*, Near Fairburn. *E*, Near Whitesburg. Points A–F on each graph represent water particles traced through the study reach (see p. 24).



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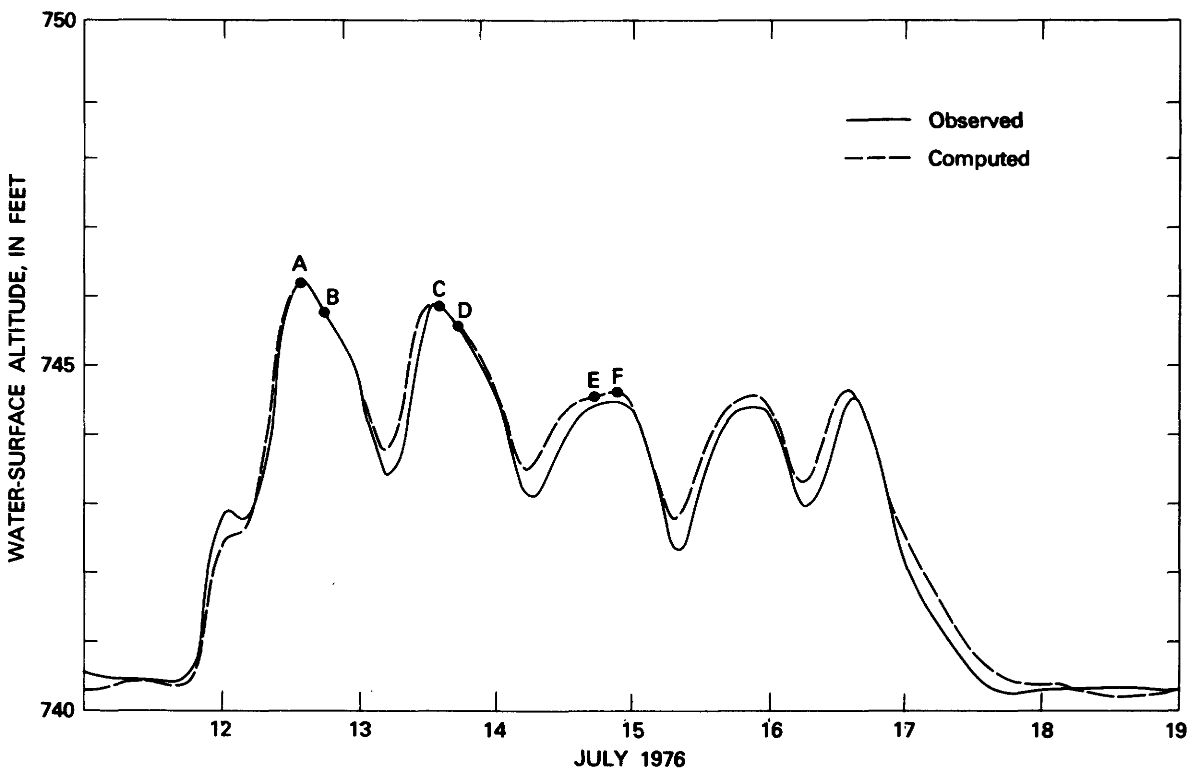

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FIGURE 14.—Continued.

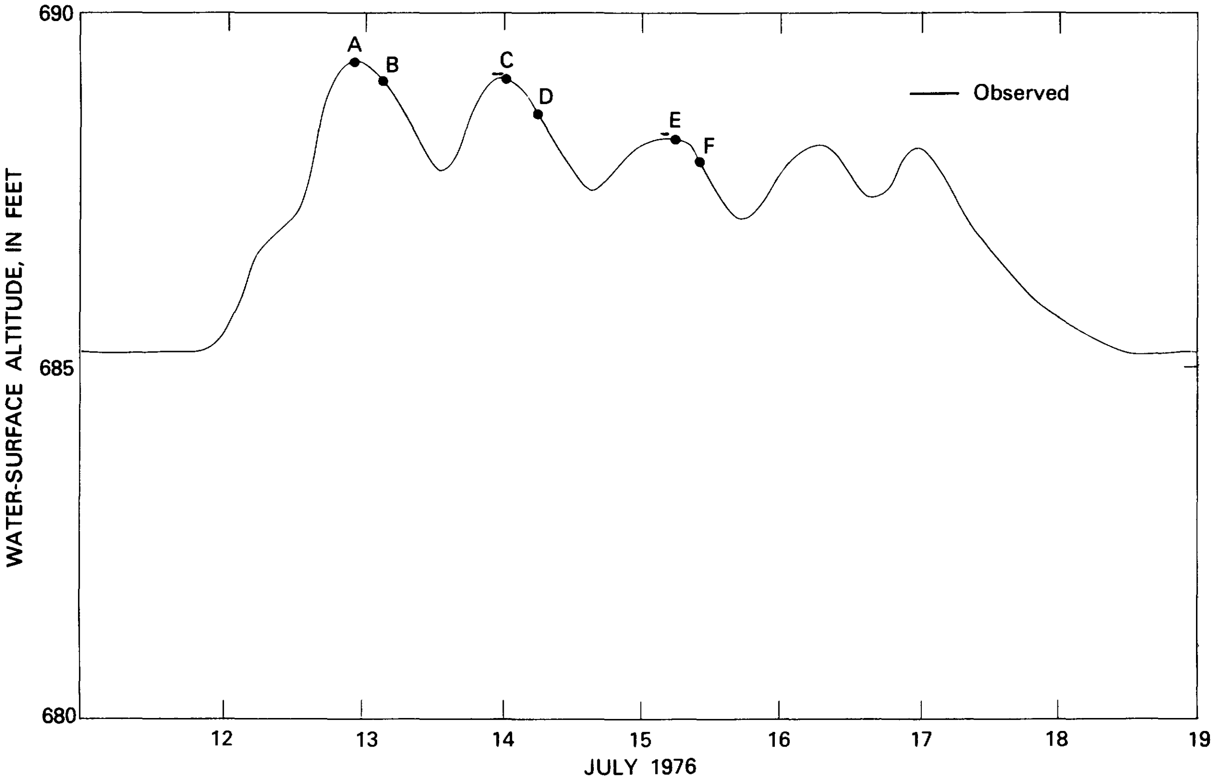

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FIGURE 14.—Continued.

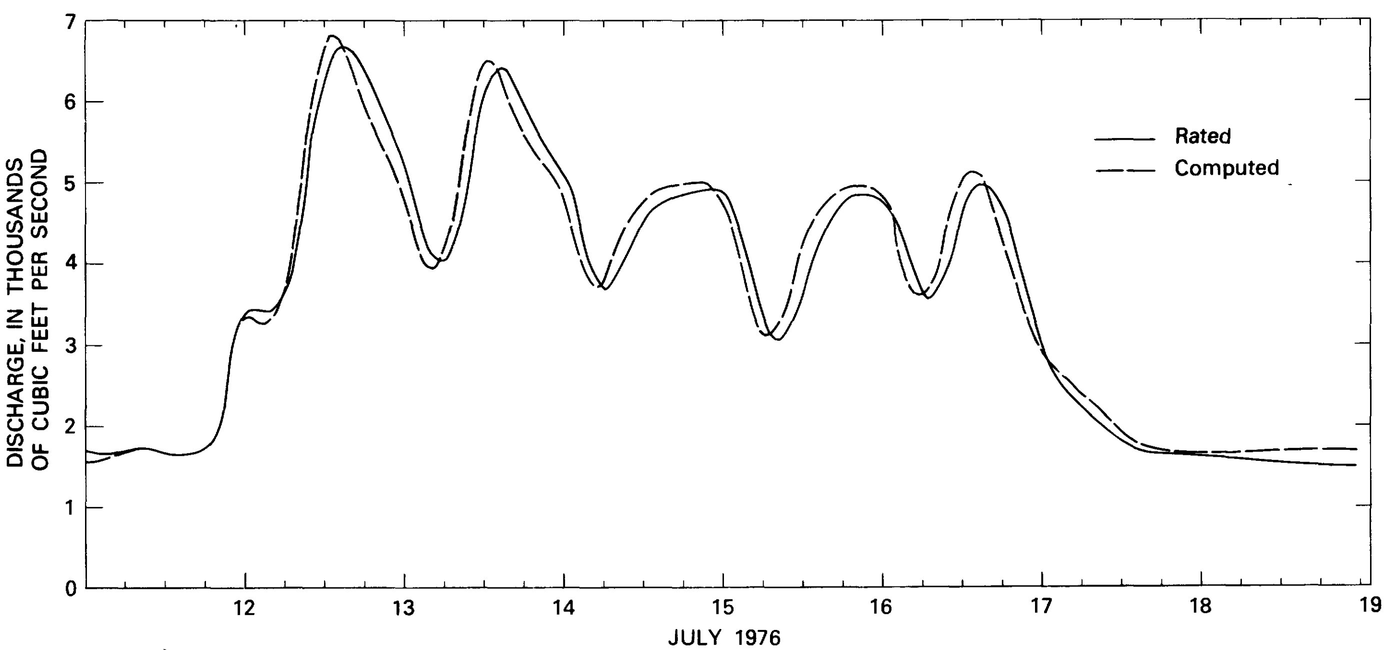


FIGURE 15.—Rated and computed discharge at the Chattahoochee River near Fairburn, July 12–19, 1976.

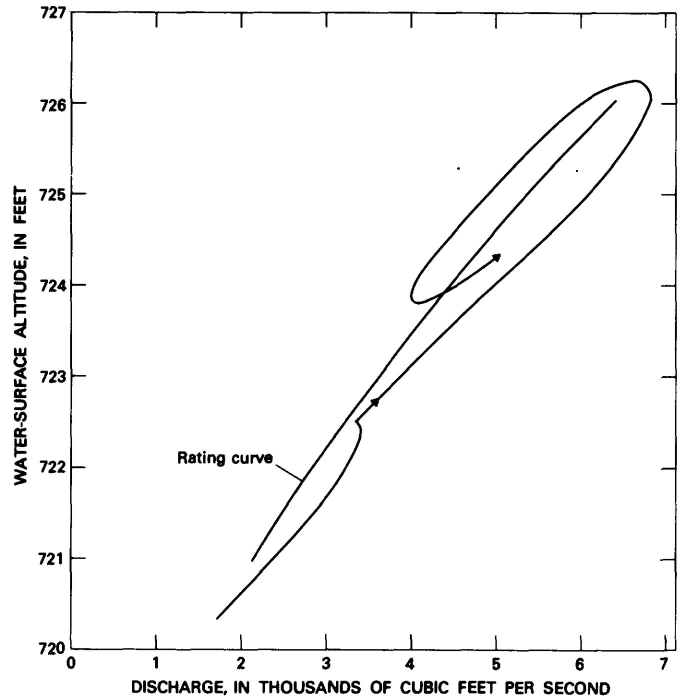


FIGURE 16.—Computed stage-discharge relation for the Chattahoochee River near Fairburn, July 13, 1976.

and corresponding data for the period July 12–19, 1976, were used for model verification.

A wind function derived from thermal data collected on the San Diego Aqueduct in southern California has been shown to be satisfactory for model-

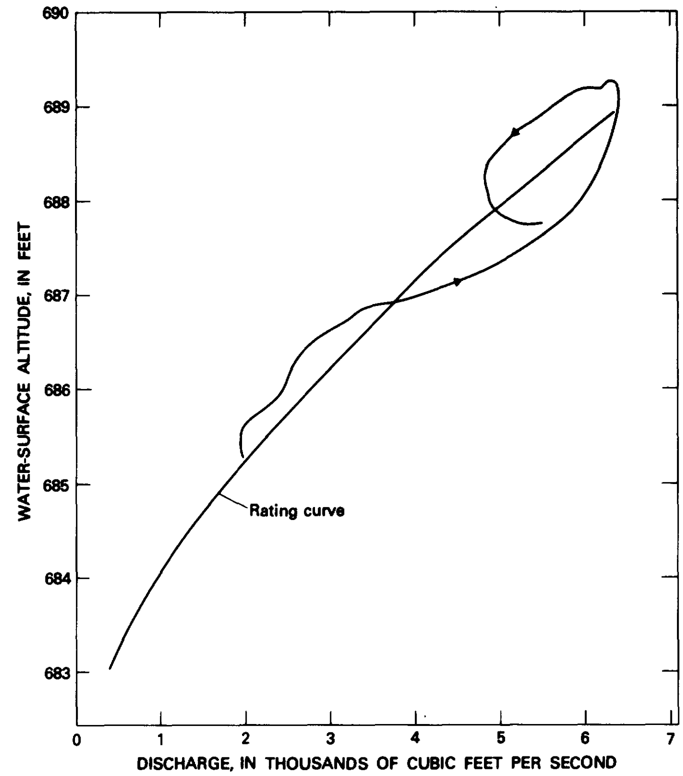


FIGURE 18.—Computed stage-discharge relation for the Chattahoochee River near Whitesburg, July 13–14, 1976.

ing river temperatures in the Chattahoochee River upstream of Atlanta (Jobson and Keefer, 1979). Optimum calibration of the temperature model for

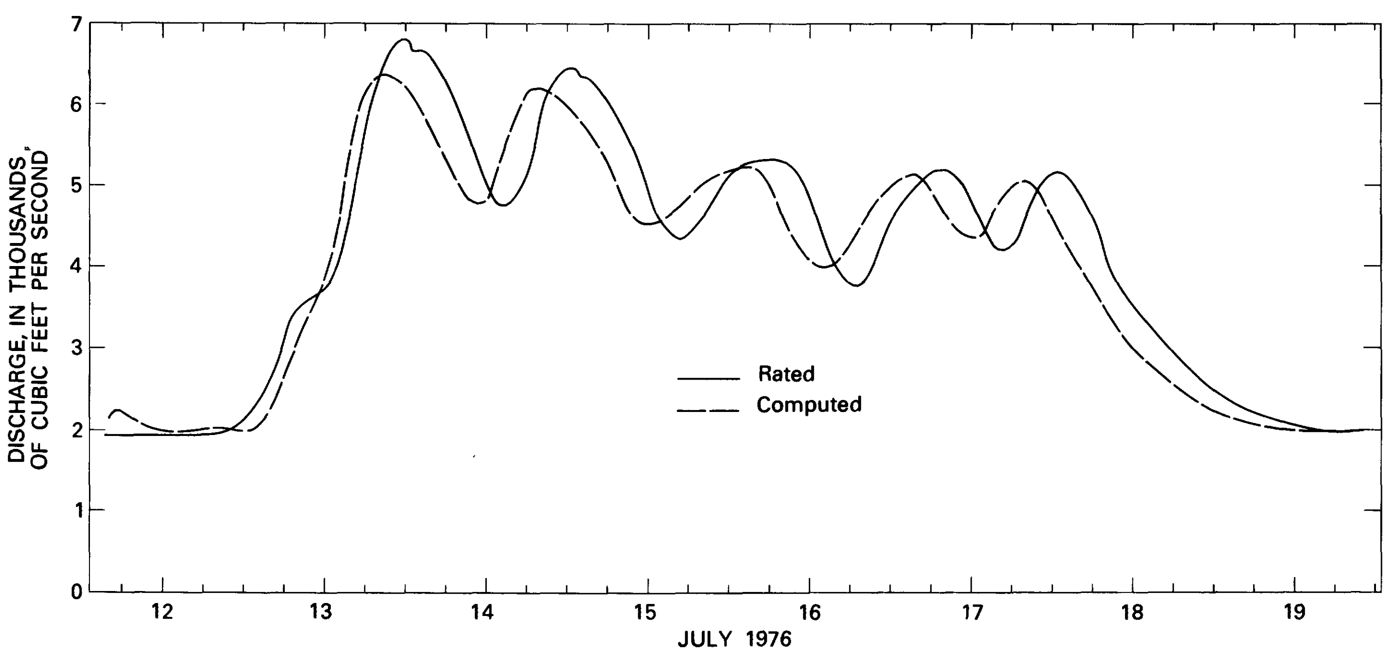


FIGURE 17.—Rated and computed discharge at the Chattahoochee River near Whitesburg, July 12–19, 1976.

this study was achieved by reducing this wind function by 30 percent.

The measured and computed temperatures for the calibration period are shown on figure 20. The computed and observed temperatures at Georgia Highway 280 are identical because the model used the observed temperature at this point to determine the heat loading from the Atkinson-McDonough powerplants. Unfortunately, no acceptable observed-temperature record was available at Whitesburg, and only the computed record is shown.

The first comparison of interest is at the Plant McDonough intake (fig. 20*B*). Comparing the computed temperature at the intake to the observed temperature at the Atlanta gage (fig. 20*A*) indicates that a maximum warming of about 1°C occurs around noon, but little cooling occurs at night. These results are expected because of the short travel times associated with the 3.8-mi reach between the intake and the Atlanta gage. On the other hand, a relatively large difference exists between the observed and computed temperatures at the intake. The observed values tend to be larger than expected, especially at night when, because of diminished surface exchange, the model results should be most accurate. A comparison of these occurrences with the stage data on figure 19*A* indicates that the maximum differences almost always occur at low flow. As discussed previously, both powerplant intakes and outfalls are located in a reach of the river ponded during low flow by a control structure (fig. 3, table 3). It was concluded, therefore, that some recirculation of heated river water occurs at low flow and that this recirculation influences the observed river temperatures at the plant McDonough intake. For this reason, the computed rather than the measured temperatures upstream of the powerplants were used to determine the instantaneous powerplant heat loads.

Comparison of the observed river temperatures at Georgia Highway 280 and the computed intake temperatures indicates the powerplants increased river temperatures by as much as 8.4°C during the calibration period (fig. 20).

The only independent measure of the adequacy of the temperature model is the difference between observed and computed river temperatures at the Fairburn gage. Comparison of these temperatures (fig. 20*D*) indicates the model consistently predicts lower then observed temperatures throughout the calibration period with the greatest differences occurring at the lower temperatures. The mean computation error for the 8-day period was 0.35°C with a standard deviation of 0.65°C. Phase differences between observed and computed temperatures were minimal. In assessing the accuracy of the temperature model the following points should be kept in mind:

1. Instrumentation error in measuring river temperatures was ±0.5°C.
2. Only hourly meterological data were available. Thus, on partly cloudy days, the measured solar radiation may not have been representative of actual conditions.
3. No measured tributary temperatures were available and, at low flow, tributary inflows between Georgia Highway 280 and the Fairburn gage amounted to 39 percent of the flow at Georgia Highway 280.

The temperature model was verified using river-temperature and meteorologic data collected during the period July 12–19, 1976. Observed and computed river temperatures during the verification period are shown in figure 21. Diurnal variations in flow and temperature were more regular during July than in August. Low flows at the Atlanta gage, for example, always occurred between 2000 and 2400 h. At the Plant McDonough intake, the tendency for the observed temperatures to be larger than computed temperatures during low flow (0100 h or 0500 h) is obvious (fig. 21*B*). It again appears that recirculation occurred at low flow and that heated effluent water affected the observed temperatures.

Heated effluents from the Atkinson-McDonough powerplants increased river temperatures by as much as 6°C during the verification period.

A comparison of observed and computed temperatures at the Fairburn gage again serves as the model verification. The poorest comparisons at Fairburn occurred at 0300 h on July 17, 1976, and at midnight between July 17 and 18 (fig. 21*D*). Maximum differences between computed and observed temperatures during these periods were −1.34°C and −1.77°C, respectively. Inspection of the meteorologic and flow-transport data relating to the water at Fairburn at the given times provides no satisfactory explanation for these large temperature differences. During the remainder of the calibration period computed river temperatures closely resemble observed temperatures. The mean computation error at the Fairburn gage during the verification period was −0.36°C with a standard deviation of 0.72°C. Phase differences between observed and computed temperatures were minimal.

Simulation of various river temperature anomalies during the verification period serves as an indirect verification of the flow model. Consider the rapid re-

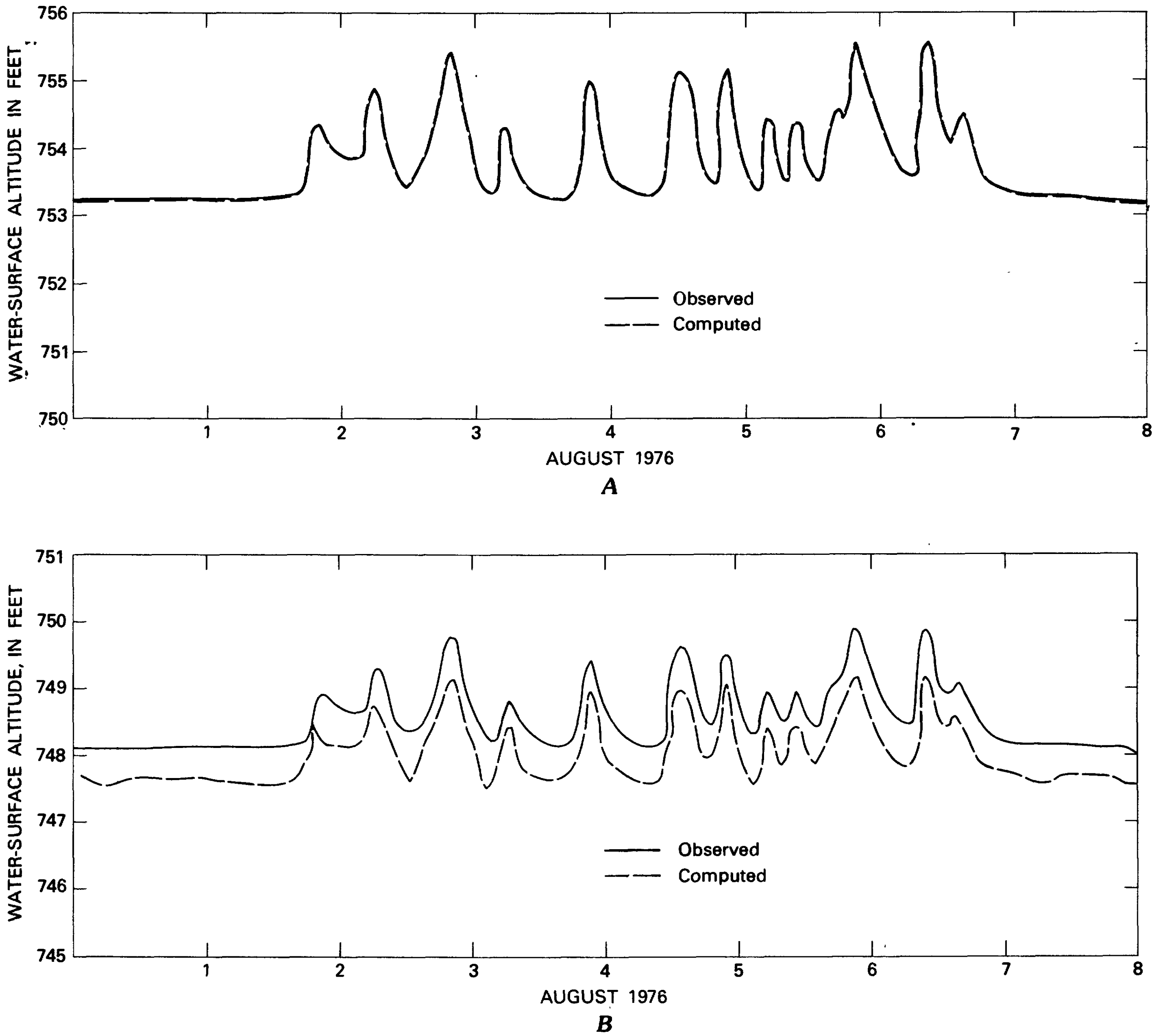
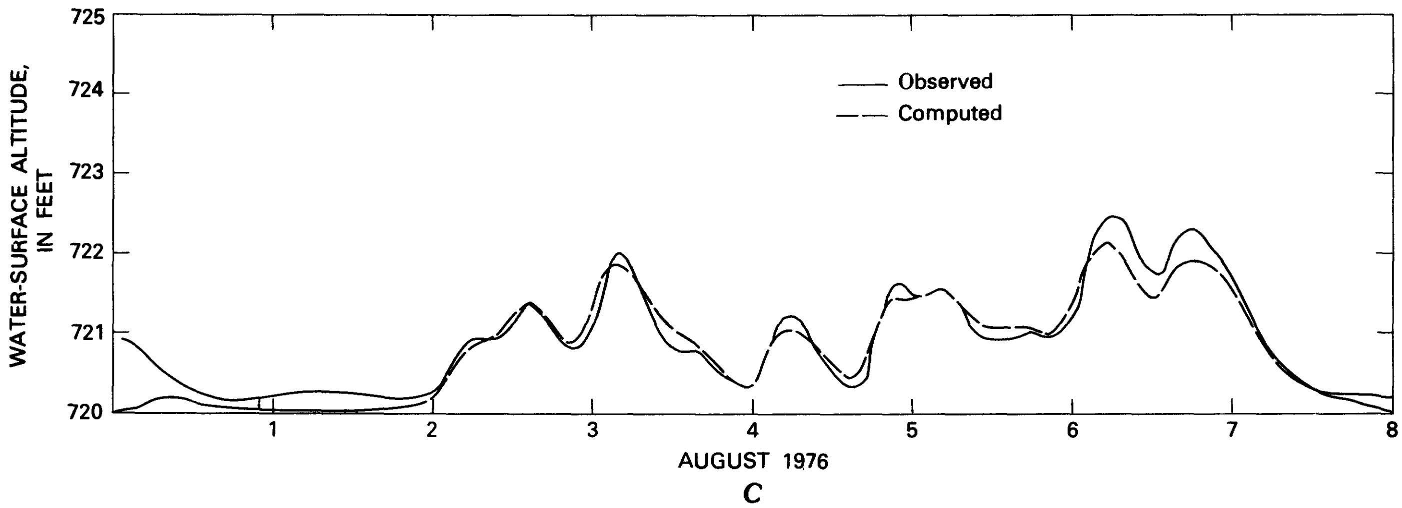


FIGURE 19.—Observed and computed stages of the Chattahoochee River during the period August 1–8, 1976. *A*, At Atlanta. *B*, At the Atlanta water-supply facility.

ductions in temperature that occurred at the Atlanta gage on July 13–15, 1976, and that are noted on figure 21*A* by points A–B, C–D, and E–F. These temperature anomalies were traced through the study reach by analytically "tagging" individual fluid particles (points A, B, C, D, E, and F) and by noting the time of arrival of each particle at the various downstream stations. For example, the water that passed the Atlanta gage at 0100 h on July 13 is identified as "A" on figure 21*A*, and its arrival time at each downstream station (figs. 21*A–E*) is similarly identified. The spatial distribution of each particle relative to the given anomaly at the Atlanta gage is shown to be maintained throughout the study reach. Thus travel times are being closely simulated, and velocities computed by the flow model are close to the actual values. For reference purposes, the temporal locations of these water particles are also noted on figure 14. Note that water particles represented by points A, B, C, and D traversed the reach under relatively high flow conditions and that water particles represented by points E and F traversed



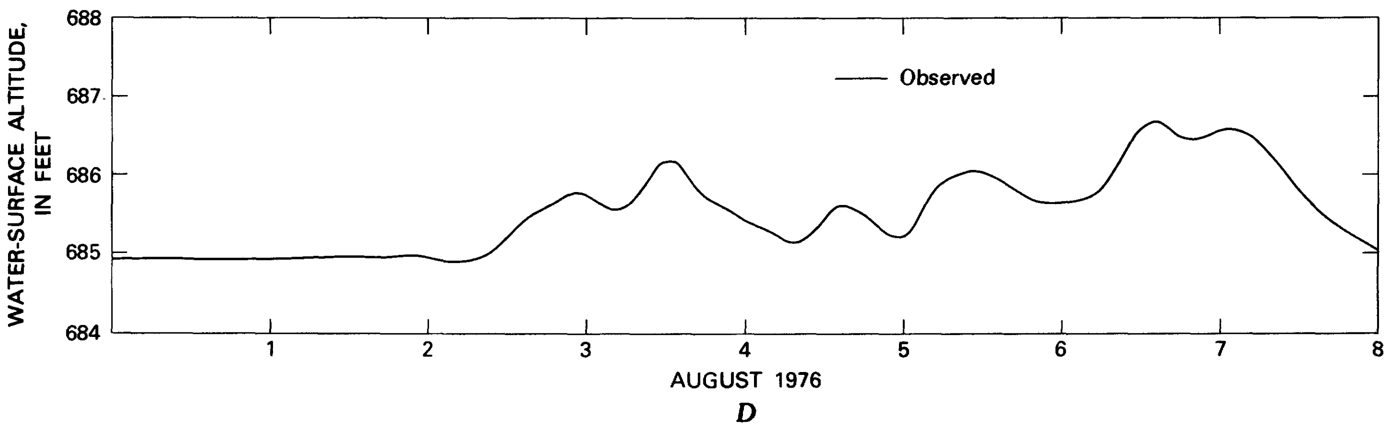


FIGURE 19.—Continued. *C*, Near Fairburn. *D*, Near Whitesburg.

the reach when discharge was intermediate and nearly steady.

Given the temperature comparisons discussed previously and the limitations of the flow, meteorologic and river temperature data, the temperature model is considered calibrated and verified and suitable for use as a predictive tool.

IMPACT OF POWERPLANT EFFLUENTS ON RIVER TEMPERATURES—AUGUST 1–8, 1976

Heatloads from the Atkinson-McDonough powerplants were determined using computed flows and temperatures from the models and the observed river temperatures at Georgia Highway 280. Figure 22 shows computed, instantaneous powerplant heat loads for the period August 1–8, 1976. Larger heat loads correspond to periods of greater electrical power demand, which for the period of interest includes most of the afternoon and evening hours when peak air-conditioning demands occurred.

River temperatures without heat loads from the powerplants were computed for the period August 1–8, 1976, using the flow-temperature models. Figure 23 shows computed, instantaneous river temperatures, with and without powerplant heat loads, at Georgia Highway 280 and at the Fairburn and Whitesburg gages. As expected, the impact of the heat loads was most severe at Georgia Highway 280 and progressively decreased downstream with increasing distance from the heat source. At Georgia Highway 280, the maximum temperature difference between heated and unheated water was 8°C. Corresponding values at the Fairburn and Whitesburg gages were about 6°C and 2°C, respectively. A reach profile of computed river temperatures, with and without powerplant heat loads, is shown in figure 24 for August 8, 1976, at 0000 h. Temperature differences

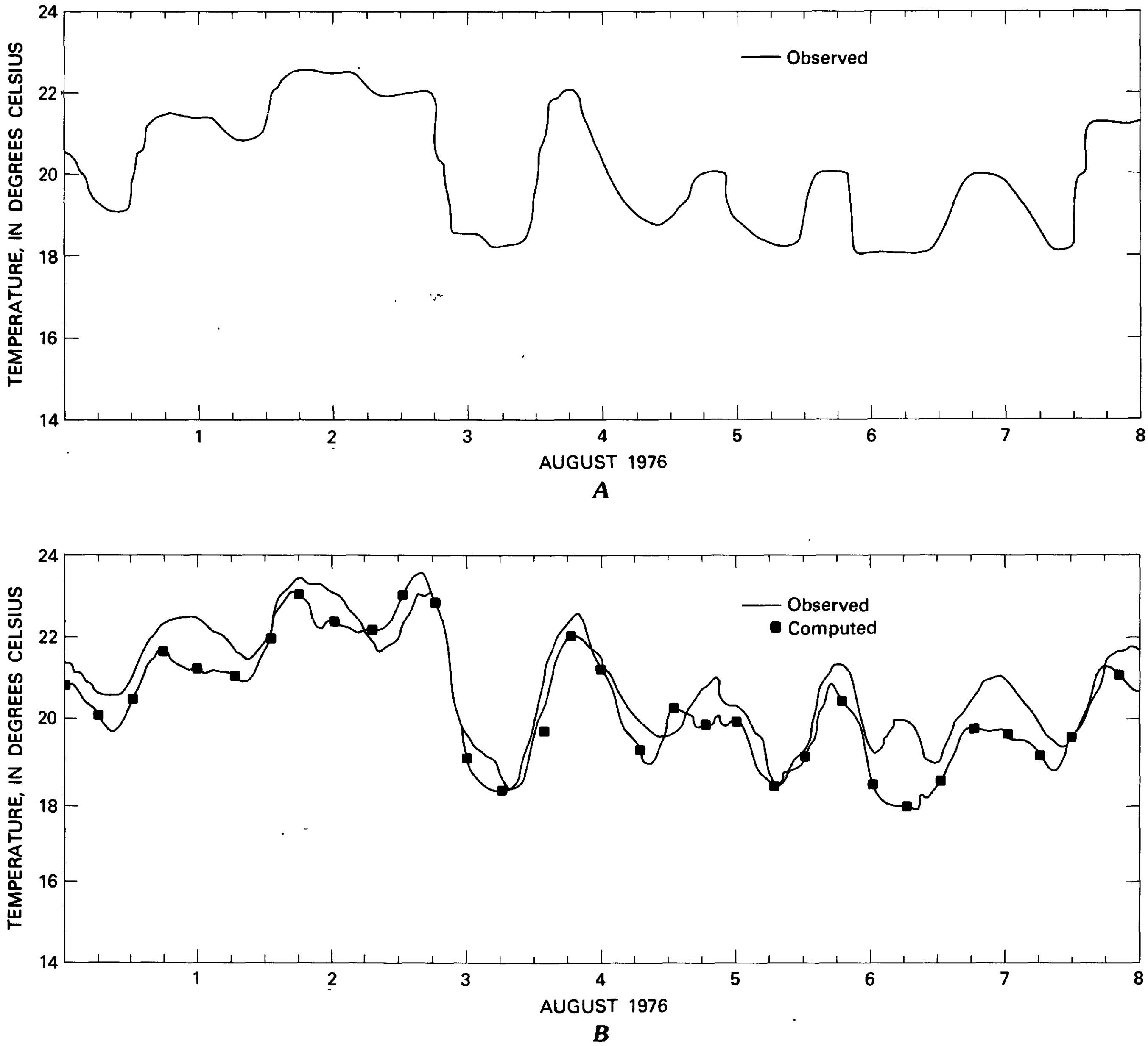


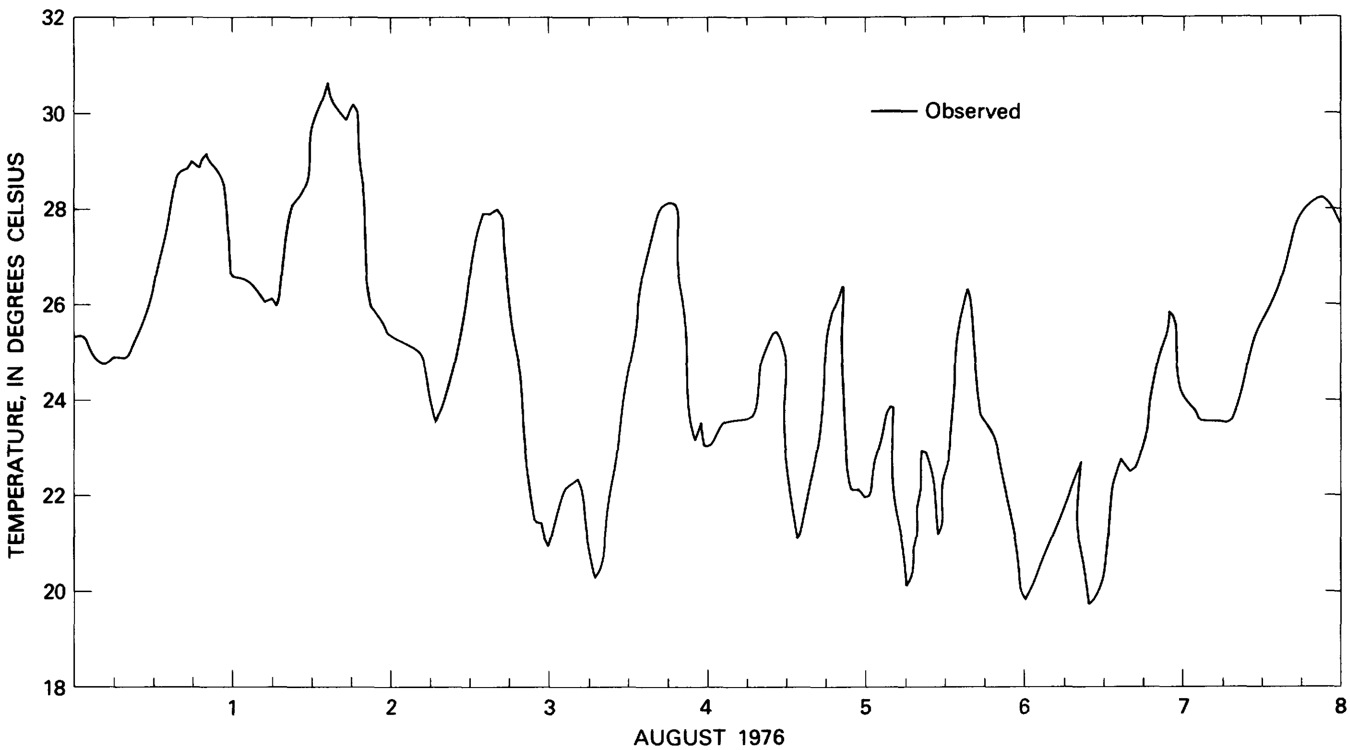
FIGURE 20.—Observed and computed temperatures of the Chattahoochee River during the period August 1–8, 1976. *A*, At Atlanta. *B*, At the Plant McDonough intake.

between the curves represent the distribution of residual heat in the river at the given time due to powerplant effluents.

COMPUTATION OF NATURAL RIVER TEMPERATURES

Before discussing the computation of natural temperature conditions in the Chattahoochee River, some general relations and concepts important to the interpretation of forthcoming information will be reviewed. Once a particle of water obtains a given temperature by whatever process, it will remain at that temperature unless energy is transferred to or away from it. The major process by which thermal energy in river water can be gained or lost is through heat exchange with the atmosphere. Several physical processes are involved in this exchange, but the combined effect of all these processes can be approximated by the expression:

$$H_T = -K\ (T - T_E) \qquad (4)$$



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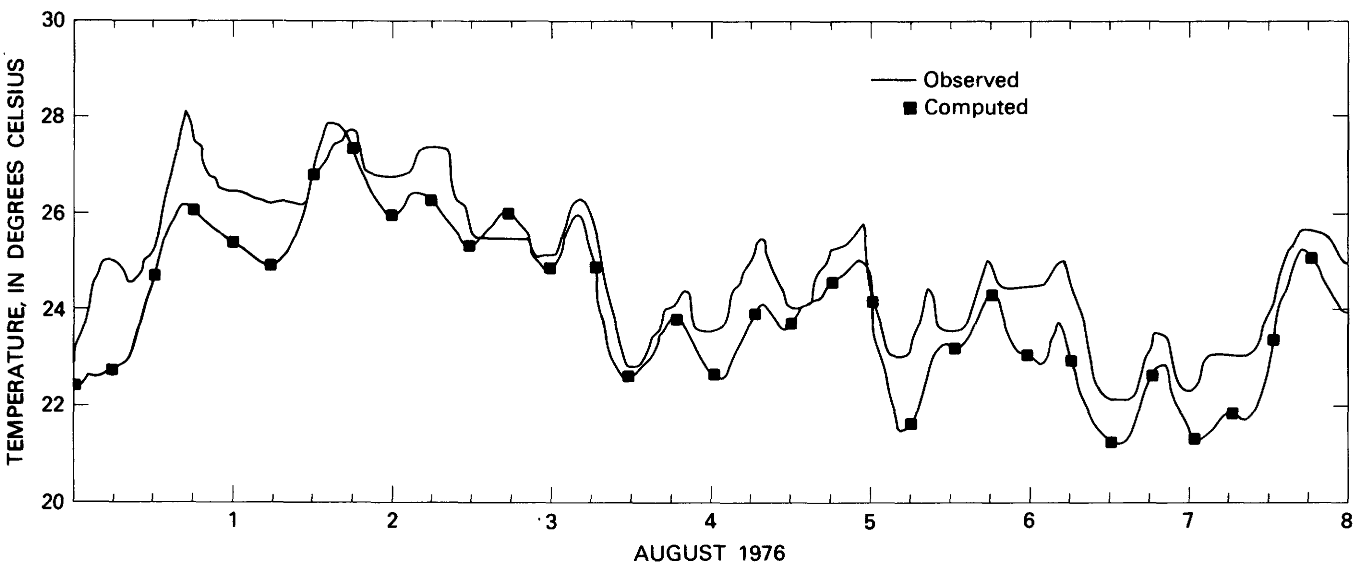


D

FIGURE 20.—Continued. *C*, At Georgia Highway 280. *D*, Near Fairburn.

where H_T=total heat transfer from the atmosphere to the water; K=a positive surface exchange coefficient, T=the observed water temperature, and T_E=the equilibrium temperature of the water. The surface exchange coefficient (K) is dependent on the temperature of the water as well as several meteorologic variables. The equilibrium temperature is the temperature toward which the observed water temperature will always move. It is also highly dependent on meteorologic conditions but independent of flow variables such as depth. Conversely, the observed water temperature is sensitive to flow depth

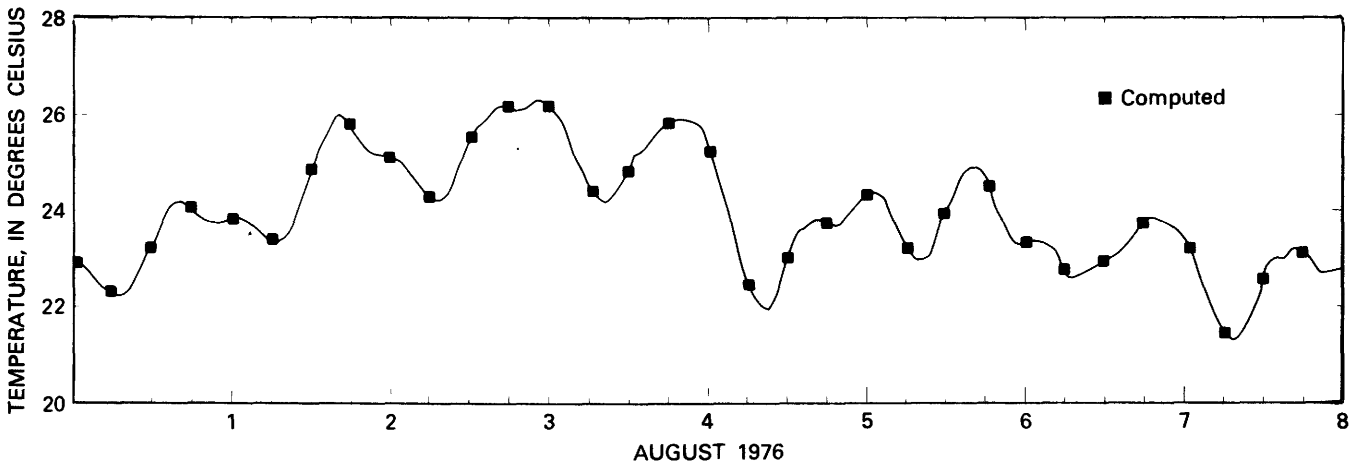


FIGURE 20.—Continued. *E*. Near Whitesburg.

as well as meteorologic conditions. Consequently, equilibrium and observed river temperatures at any instant can be quite different.

Where the stream system is not subject to artificial thermal alteration, observed water temperatures equal natural river temperatures. Under these conditions, mean daily observed and mean daily equilibrium temperatures are nearly equal.

Where a river system is influenced by artificial heat sources or sinks, observed and natural river temperatures differ by some amount that will be called the excess temperature. Under such conditions, total heat exchange between the water and the atmosphere is a function of the natural heat exchange and the excess temperature. The magnitude of excess temperature at a particular station is a function of the magnitude of the artificial alteration and the distance to its source. Just as the observed river temperature always seeks the equilibrium temperature, artifically altered water temperatures tend to return to natural temperatures. This process is conveniently expressed by the relation:

$$H_e = -K(T - T_n)$$

where H_e = heat exchange between the water and the atmosphere due to excess temperature and T_n = the natural river temperature.

Natural river temperatures tend to decrease with increasing altitude and latitude so it is probable that the long term natural river temperature at Whitesburg is slightly higher than at Atlanta. The model depends on meteorologic data collected at Atlanta, however, and all meteorologic conditions throughout the study reach are assumed to be uniform. It is also assumed that any variation in natural temperature with distance from Atlanta is negligible.

Direct measurements of natural river temperatures during the calibration period of August 1–8, 1976, were impossible to obtain. On the other hand, information about natural temperatures can be obtained from available temperature data. Figure 25 shows a plot of the observed river temperatures at Georgia Highway 280. Superimposed on these temperatures are the observed temperatures of the same water particles when they arrived at the Fairburn gage. Estimates of time of travel between the two stations were obtained from the flow model. The difference between the two curves represents the observed temperature change experienced by a water particle as it traveled the 17.0 mi from Georgia Highway 280 to the Fairburn gage. In the 8 days of record, 18 time periods occurred during which the water experienced no net temperature change as it traversed this reach of the river. These points are circled on figure 25. Because no net surface exchange occurred during these periods, the river temperature and the equilibrium temperature must have been equal. In other words, each time the curves intersect on figure 25, a direct measurement of the equilibrium temperature is available, averaged over the time of passage through the reach. The mean time of travel for the water particles represented by these intersections was 14.91 h with a standard deviation of 1.83 h. The mean of the equilibrium temperatures was 24.8°C with a standard deviation of 1.37°C.

Except for times of travel, these equilibrium temperatures were obtained independently of the flow and temperature models. The 18 points of intersection (fig. 25) are also more or less randomly distributed in time. Thus, the mean of these 18 temperatures (24.8°C) is considered a reasonably good estimate of the mean natural temperature of the Chattahoochee River between Atlanta and Whitesburg during the period August 1–8, 1976.

The average impact of flow regulation and powerplant effluents on river temperatures during the period August 1–8, 1976, is shown on figure 26. The short-dashed line connects the mean observed temperatures during the 8-day period. The 8-day mean computed river temperatures, which would have occurred without powerplant heat loads, are represented by the longer dashes and were computed from data presented in figure 23. The horizontal solid line at the top of the figure represents the mean natural temperature of 24.8°C, estimated from the 18 measurements of equilibrium temperature. During the given 8-day period, mean observed river temperatures downstream of the powerplants are shown to nearly equal natural temperatures. Thus, on the average, the heat added by the Atkinson-McDonough powerplants almost balanced the cooling effect of flow regulation. The average warming effect of the plants is estimated to have been 0.5°C at the Plant McDonough intake, 4.2°C at Georgia Highway 280, 2.9°C at the Fairburn gage, and 1.6°C at the Whitesburg gage. Likewise, the average cooling that resulted from flow regulation at Buford Dam is estimated to have been 4.8°C at the Atlanta gage, 4.4°C at the McDonough intake, 4.3°C at Georgia Highway 280, 2.9°C at the Fairburn gage, and 1.9°C at the Whitesburg gage. Note, that excess temperatures resulting from both a heat sink (Lake Sidney Lanier) and a heat source (powerplants) are shown to approach natural temperatures with increasing distance from the point of thermal alteration.

The average combined thermal impact of flow regulation and powerplant effluents on river temperatures has been shown to be small when compared to natural temperatures. Equally important, however, are the instantaneous effects. One way to estimate the natural instantaneous temperature through the study reach is by use of the flow and temperature models. Computation of natural temperatures is complicated, however, by the fact that the upstream boundary condition is unknown and must also be simulated. Simulation of this boundary is accomplished by solving the thermal energy equation (equation 1) for a channel of infinite length upstream of the station of interest. Such a solution effectively removes the spatial derivatives from consideration and computes river temperatures only as a function of depth and surface exchange. Such temperatures are by definition natural temperatures. These assumptions were used in conjunction with the flow and temperature models to solve the thermal energy equation for a long channel where geometry, flow, and meteorologic conditions at each cross section were identical and equal to observed conditions at the Atlanta gage during the period August 1–8, 1976. Computed instantaneous river temperatures at the downstream end of this long reach were considered equal to natural temperatures at the Atlanta gage during the given period.

The set of computed natural river temperatures at the Atlanta gage was used to drive the temperature model and compute instantaneous natural river temperatures through the study reach for the period August 1–8, 1976. Graphs of natural and observed temperatures at the Atlanta gage, at the Plant McDonough intake, at Georgia Highway 280, and at the Fairburn gage are shown in figure 27. Only computed temperatures are shown for the Whitesburg gage.

The computed mean natural temperature for the entire reach during the 8-day period was 24.9°C and is considered to be in excellent agreement with the previously determined estimate of 24.8°C. This close agreement between two independently determined mean natural temperatures indicates that the total surface exchange was accurately modeled and that the computed instantaneous temperature values are reasonably accurate.

Based on these comparisons, flow regulation upstream of Atlanta lowered the temperature of the Chattahoochee River by an average 4.8°C during the first 8 days of August 1976. Heated effluents from the Atkinson-McDonough powerplants raised the mean river temperature about 4.2°C during the same period. Thus, the net average combined effect of flow regulation and heat loads was small. On the other hand, dirurnal variations and associated rates of change for both natural and artifically altered water temperatures were large and quite different. In general, the larger variations and rates were associated with the altered temperatures and decreased downstream.

These results and conclusions based on model studies compare favorably with the conclusions drawn from previous comparisons of historical river- and air-temperature data. In both cases, significant cooling effects due to flow regulation at Buford Dam were noted at the Atlanta gage and the Plant McDonough intake during August 1976 (figs. 9, 10, 27). Also noted, in both cases, was the close approximation of mean natural to mean observed temperatures at Georgia Highway 280 (figs. 11, 27).

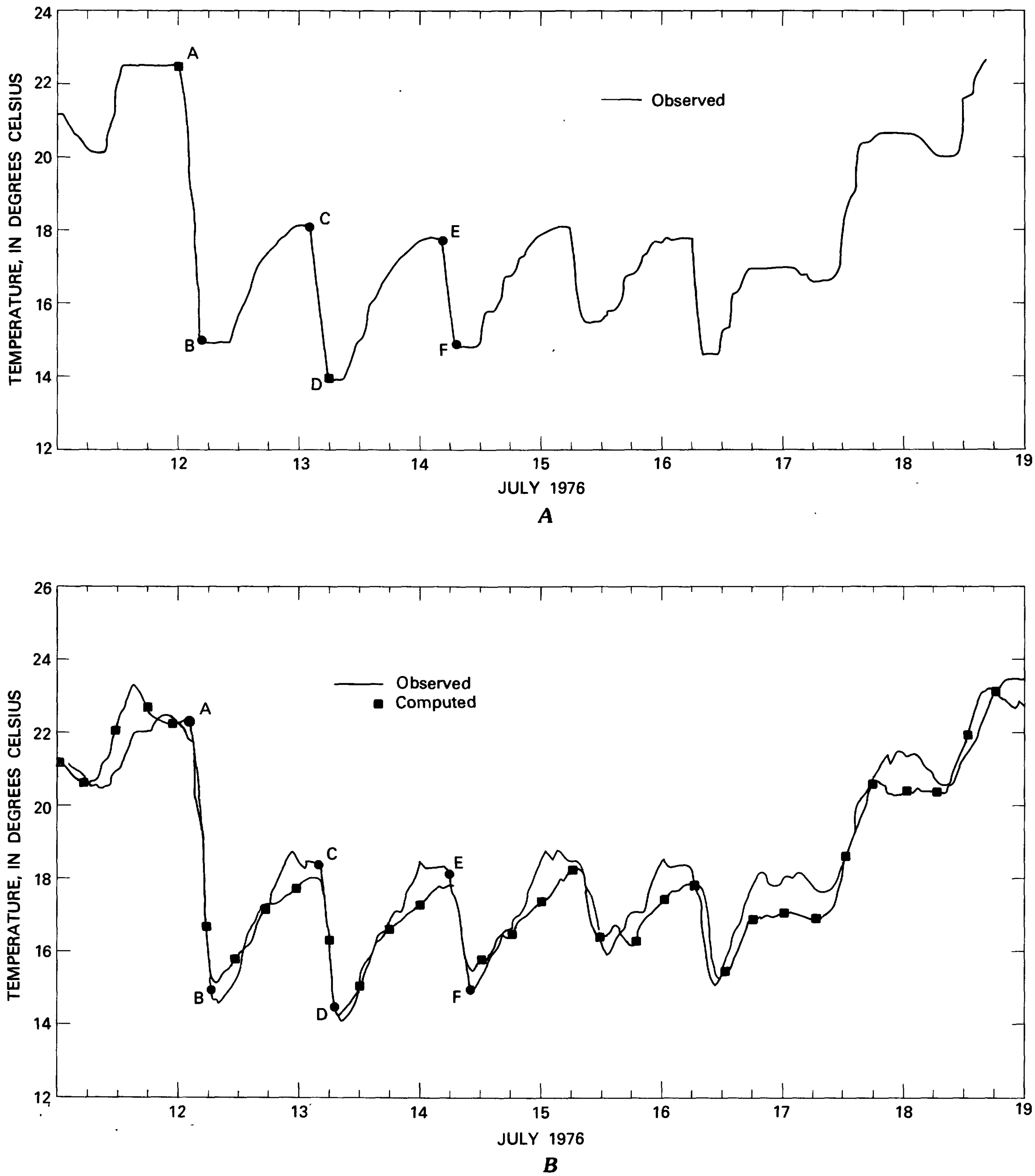
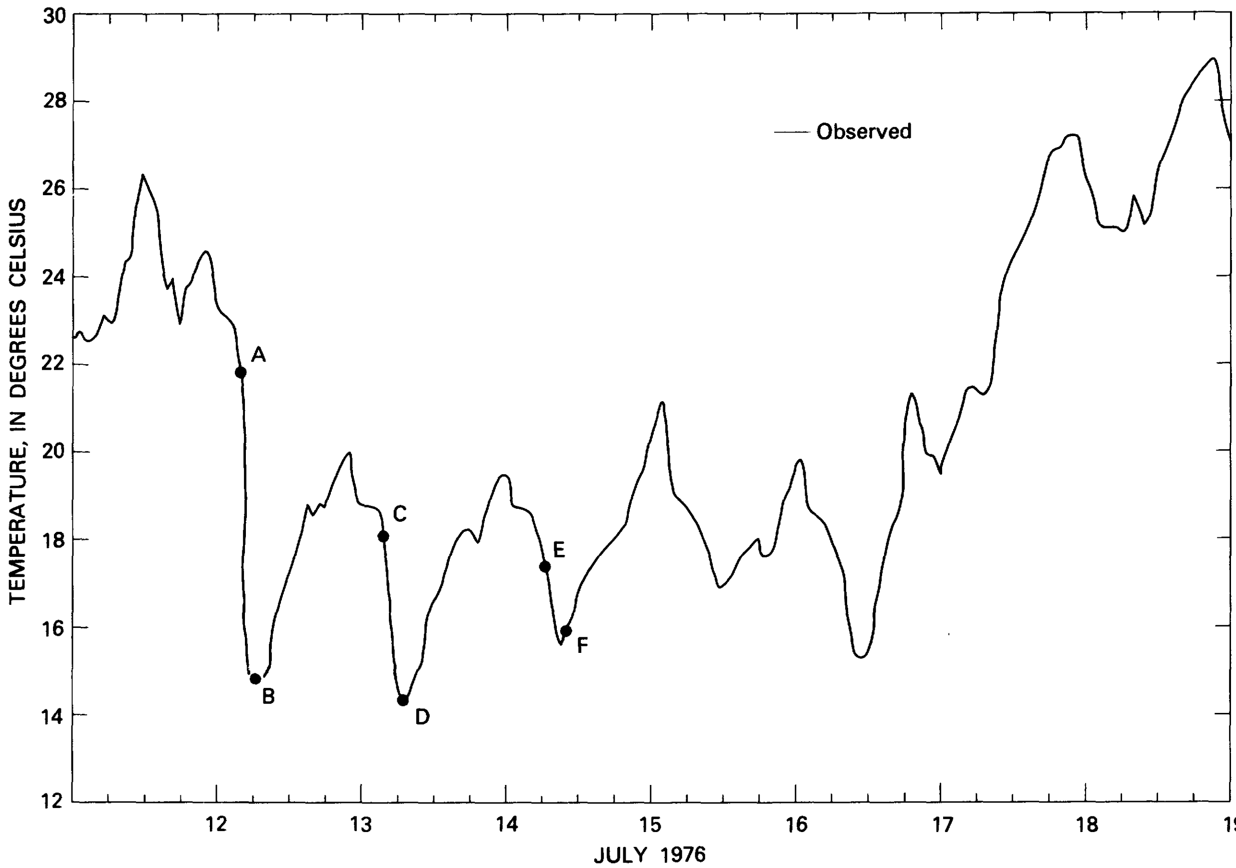
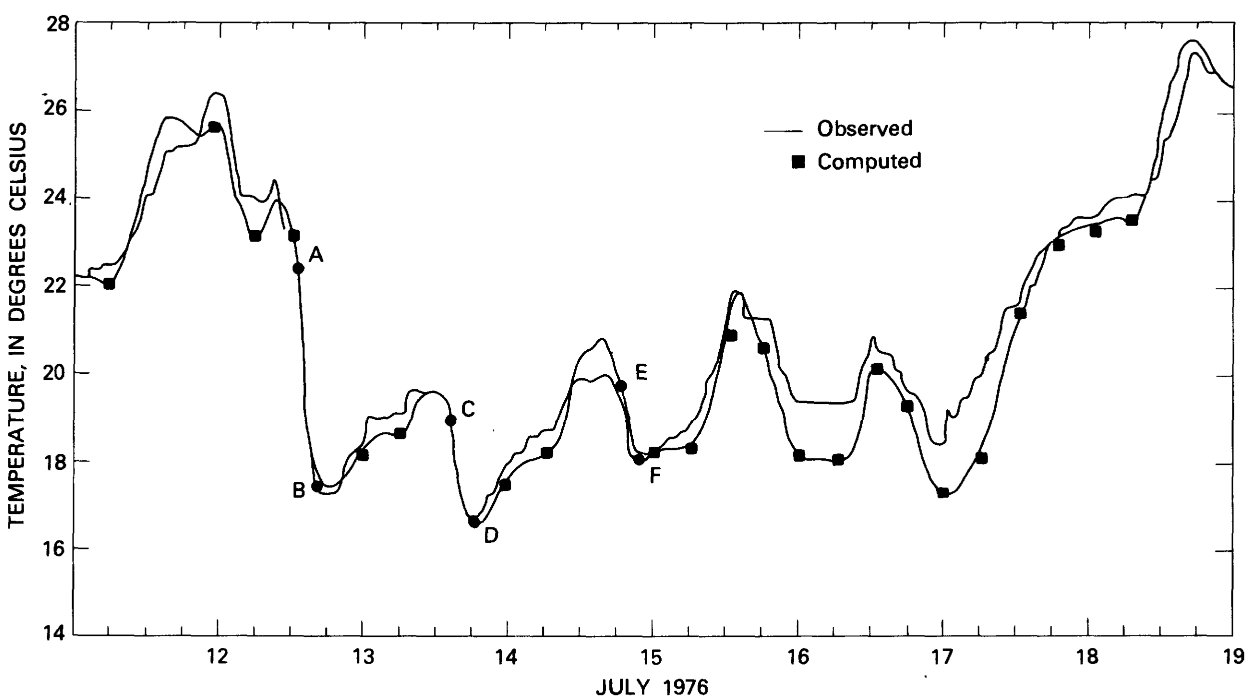


FIGURE 21.—Observed and computed temperatures of the Chattahoochee River during the period July 12–19, 1976. *A*, At Atlanta, *B*, At the Plant McDonough intake. *C*, At Georgia Highway 280. *D*, Near Fairburn. *E*, Near Whitesburg. Points A–F on each graph represent water particles traced through the study reach (see p. 24).

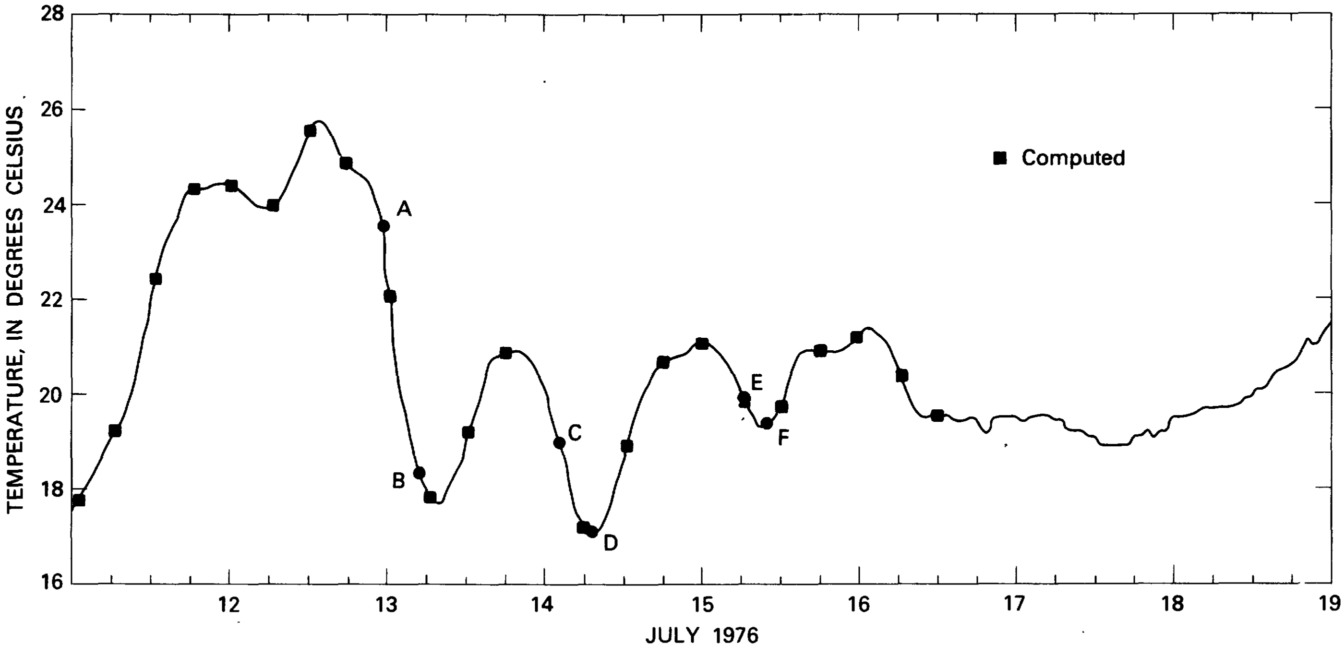


C



D

FIGURE 21.—Continued.



E

FIGURE 21.—Continued.

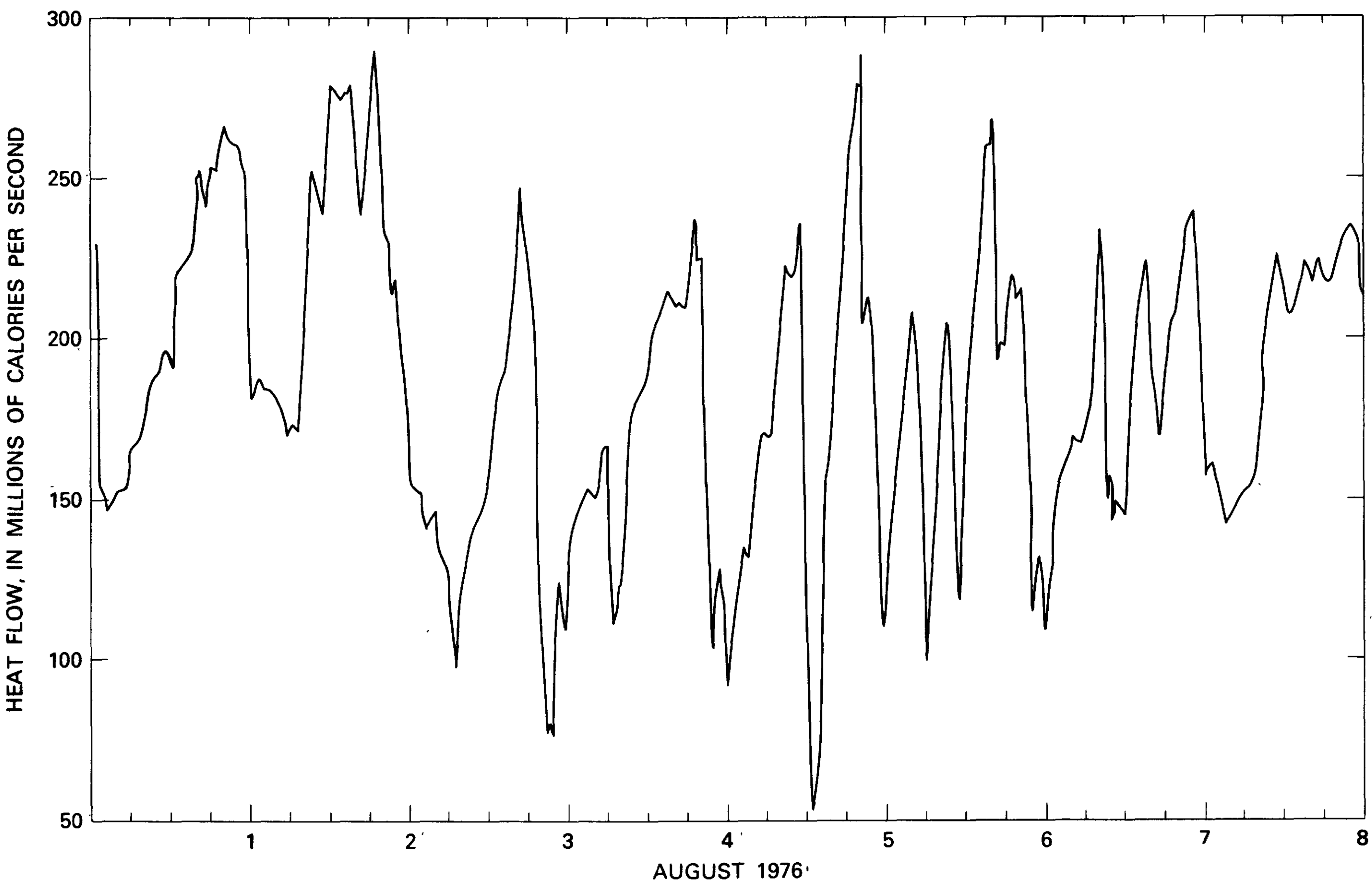


FIGURE 22.—Heat added to the Chattahoochee River from Plants Atkinson-McDonough, August 1–8, 1976.

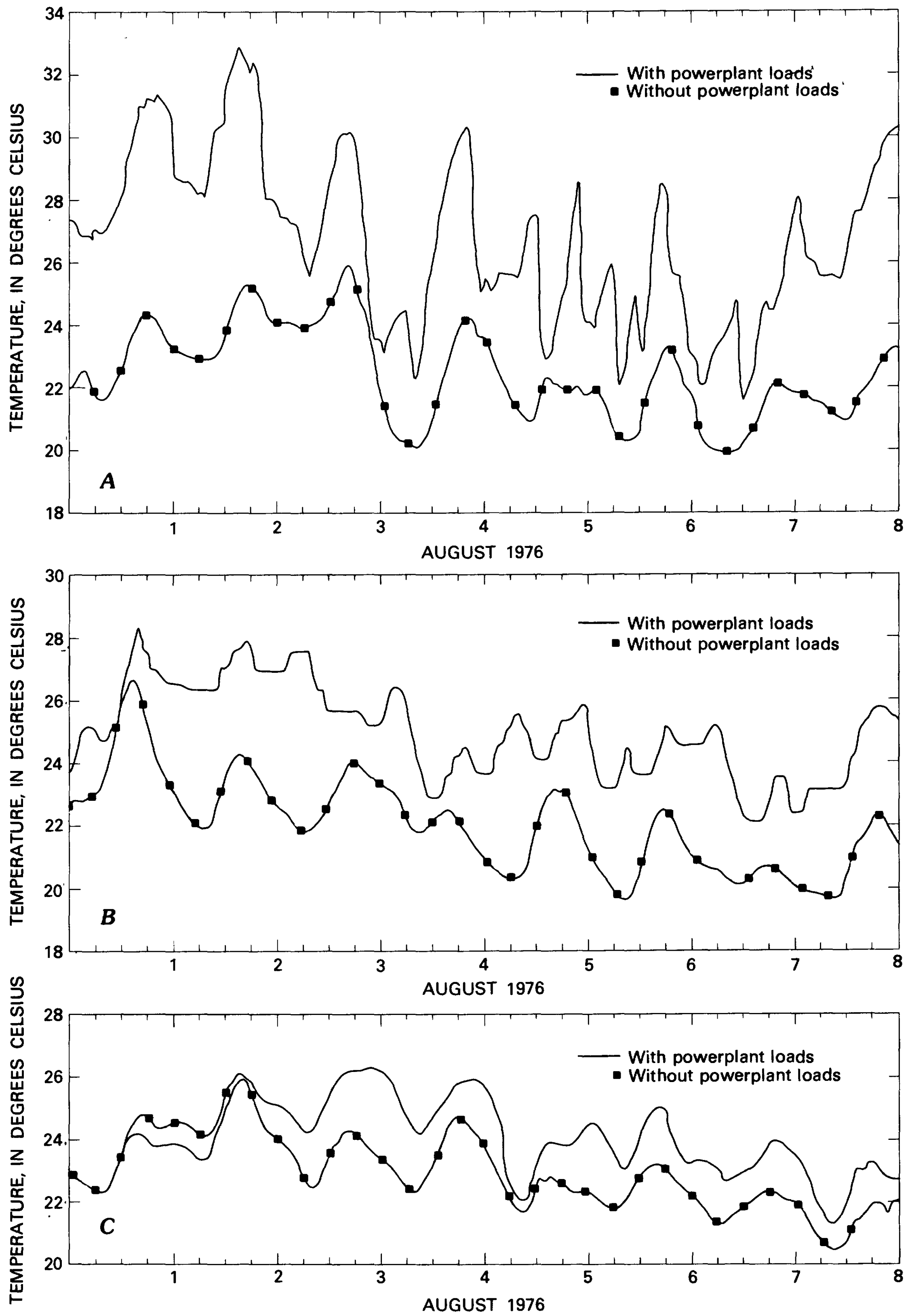


FIGURE 23.—Temperature of the Chattahoochee River with and without heat loads from Plants Atkinson-McDonough during the period August 1–8, 1976. *A*, At Georgia Highway 280. *B*, Near Fairburn. *C*, Near Whitesburg.

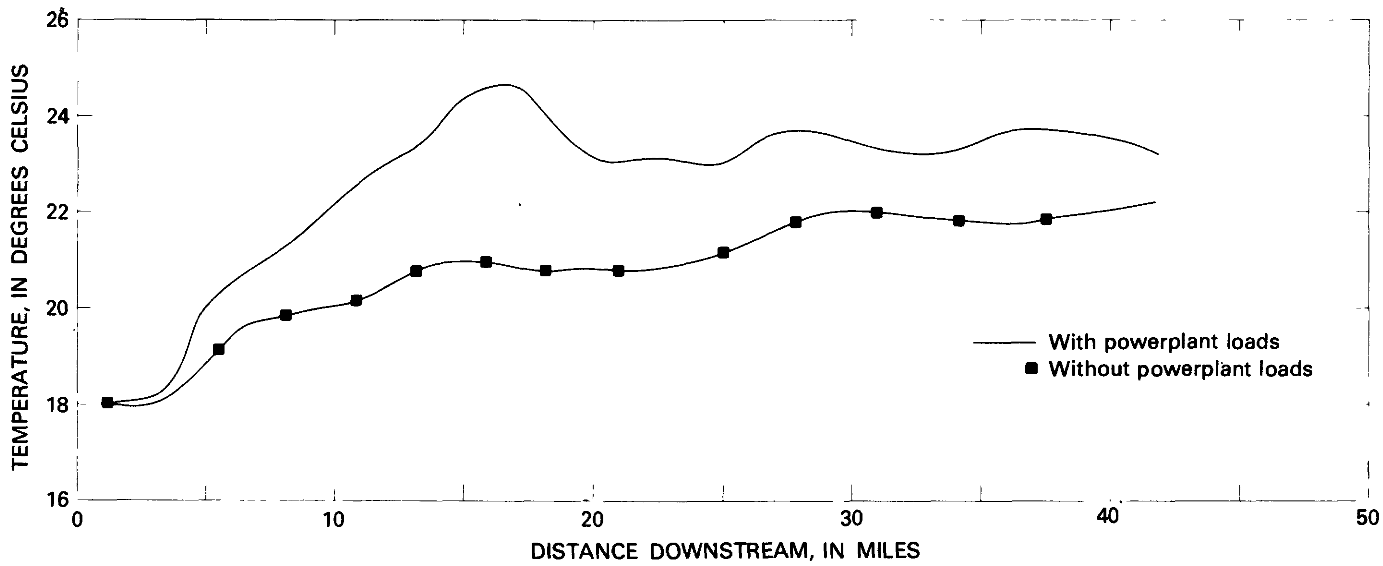


FIGURE 24.—Computed longitudinal temperature profiles in the study reach with and without heat loads from Plants Atkinson-McDonough, 0000 e.s.t., August 8, 1976.

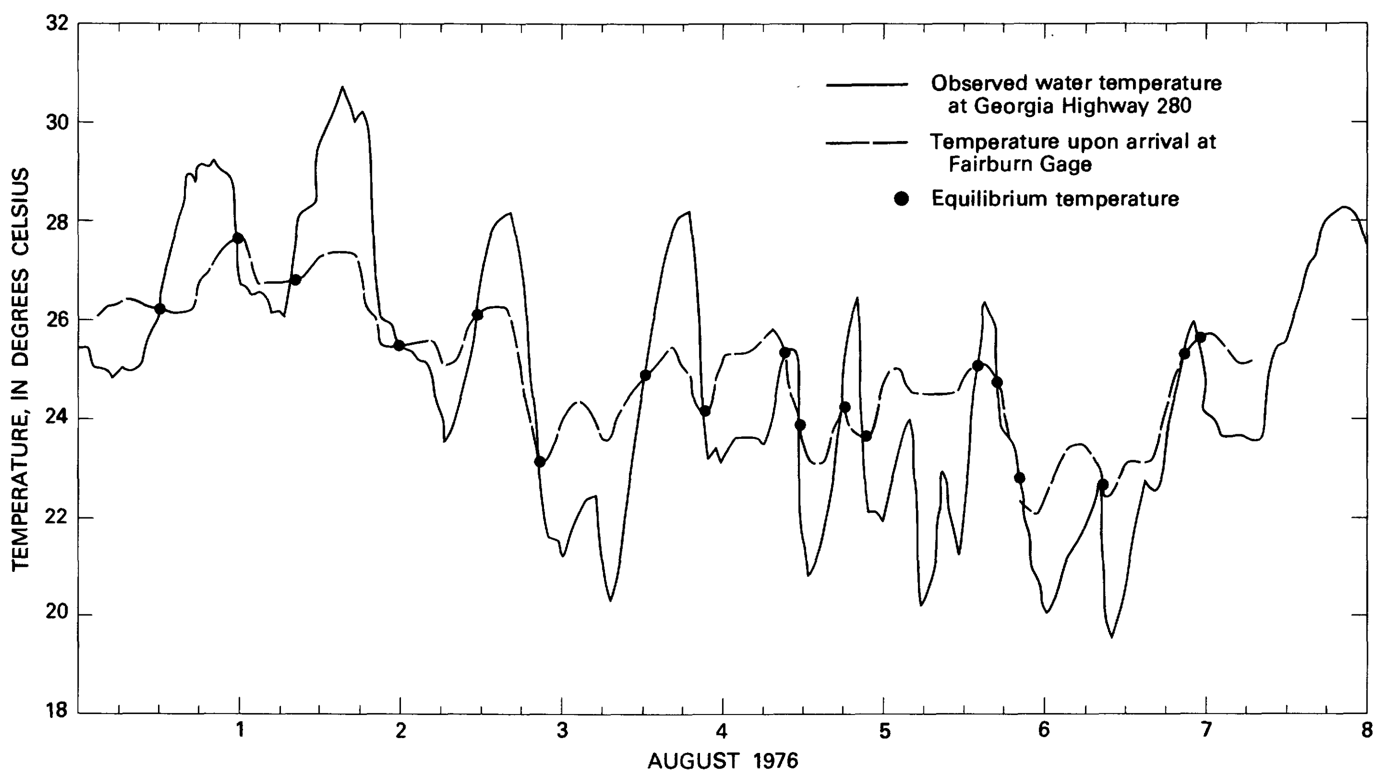


FIGURE 25.—Observed temperature of the Chattahoochee River at Georgia Highway 280 and the observed temperature of the same water upon arrival at the Fairburn gage.

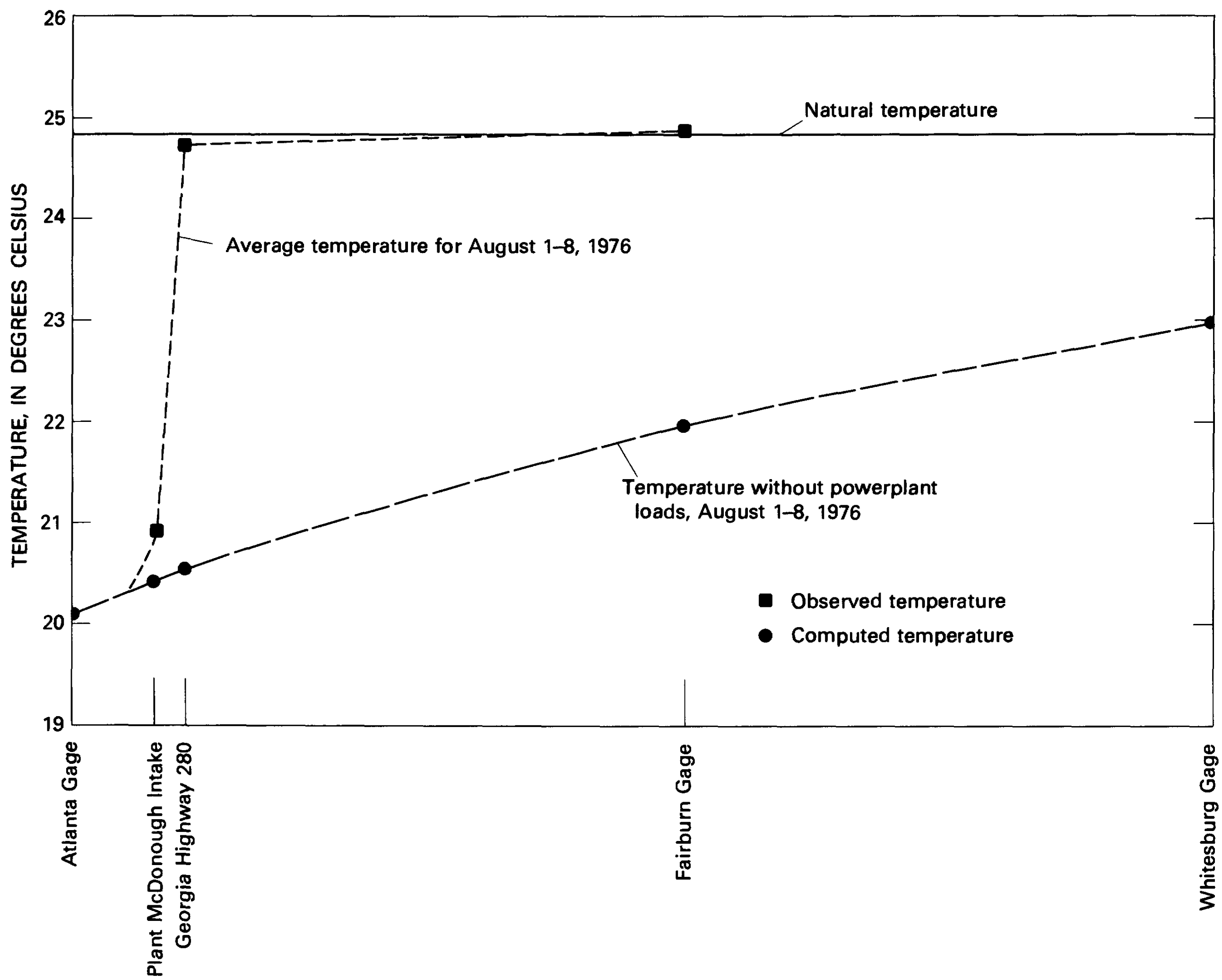


FIGURE 26.—Eight-day mean natural and thermally altered temperatures of the Chattahoochee River from Atlanta to Whitesburg, August 1–8, 1976.

Thus, both the analysis of historical data and the model studies, albeit grossly different in accuracy and sophistication, provided similar conclusions regarding the impact of flow regulation and powerplant loadings on stream temperatures in the study reach.

COMPUTED RIVER TEMPERATURES USING YEAR 2000 AND CRITICAL DROUGHT FLOW CONDITIONS

The flow-temperature models were used to predict future river temperatures using year 2000 and critical drought flow conditions. Representative future water-supply demands and wastewater flows were obtained from the Atlanta Regional Commission (1976) and are listed in table 6. Additional wastewater treatment facilities to be added to the network by the year 2000 include Sweetwater Creek

TABLE 6.—*Estimated water-supply and wastewater flows for the year 2000*

Station	River mile	Map reference No. (fig. 1)	Peak water-supply demand (ft^3/s)	Average water-supply demand (ft^3/s)	Average waste-water return (ft^3/s)
Buford Dam to Atlanta gage	--------	-----	840	560	36.0
Atlanta water-supply facility	300.62	3	164	109	----
Cobb County wastewater-treatment facility.	300.56	4	------	------	31
R. M. Clayton wastewater-treatment facility.	300.56	7	------	------	162
South Cobb County waste-water-treatment facility.	294.28	13	------	------	49
Utoy Creek wastewater-treatment facility.	291.48	14	------	------	44
Sweetwater Creek waste-water-treatment facility.	288.57	20	------	------	2.6
Camp Creek wastewater-treatment facility.	283.78	16	------	------	27
Annewakee Creek waste-water-treatment facility.	281.46	21	------	------	6.0
Regional interceptor	281.45	22	------	------	43
Bear Creek wastewater-treatment facility.	274.48	23	------	------	7.8

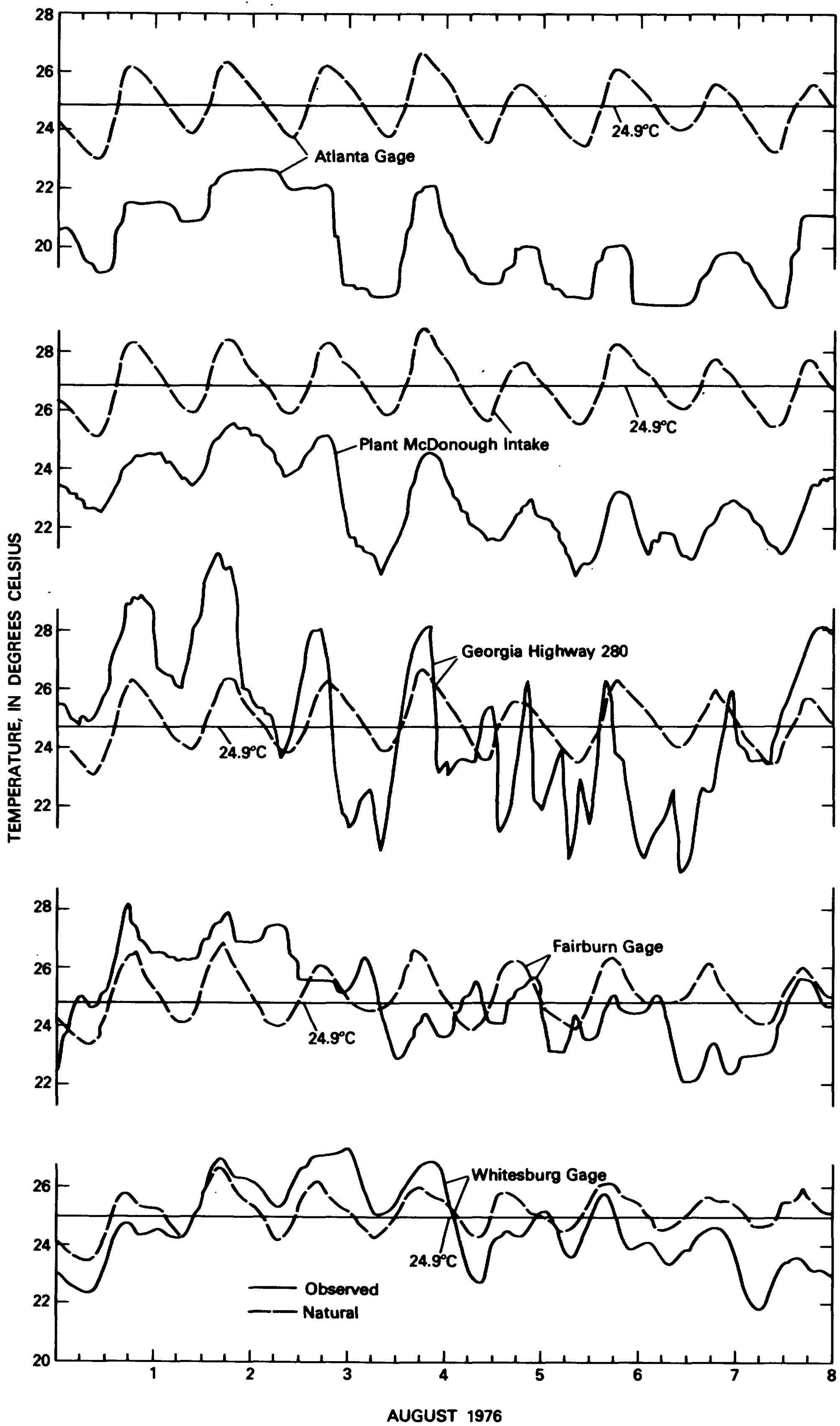


FIGURE 27.—Computed natural and observed temperatures of the Chattahoochee River, August 1–8, 1976.

WTF, Annewakee Creek WTF, Bear Creek WTF, and a regional interceptor (fig. 1, table 6). Tributary flows used to predict future conditions are those listed in table 3 for the 1954 drought and for the period August 1–8, 1976. Observed tributary discharges during the 1954 drought were obtained from Thompson and Carter (1955). The various flow conditions used to simulate year 2000 temperatures in the Chattahoochee River are listed below. The letter designation for each condition is used later in this text to define various flow combinations The average projected wastewater flow for the year 2000 (table 6) was used in each simulation. The letter designations are as follows:

Flow condition	*Letter designation*
1954 drought tributary flows	A
August 1–8, 1976, tributary flows	B
Year 2000 peak water-supply demand	C
Year 2000 average water-supply demand	D

Boundary conditions used to compute future flow conditions are listed in table 7. Estimated discharges at the Atlanta gage were based on a minimum regulated discharge from Buford Dam of 1,717 ft^3/s proposed for the year 2000 (Atlanta Regional Commission, 1976). Tributary inflows between the dam and the Atlantic gage of 0 and 25 ft^3/s were used and represent 1954 drought and August 1976 flow conditions, respectively. Discharge at the Whitesburg gage for the various flow combinations (table 7) was based on the given Atlanta gage discharge and a mass balance of tributary and flow diversion data listed in tables 3 and 6. All simulations of year 2000 flows and river temperatures are based on steady-state flow conditions. Such conditions are represented, for the most part, by the discharge data in tables 3, 6, and 7 and by the water-surface profile in figure 3. All future river temperatures were predicted using temperature and meteorologic data observed during the period August 1–8, 1976.

Year 2000 river temperatures computed with the various flow combinations listed above are shown in figures 28 to 31. Temperatures at Georgia Highway 280 and at the Fairburn and Whitesburg gages are shown with and without heat loads from Plants Atkinson-McDonough (fig. 22). Heat loadings from

TABLE 7.—*Estimated discharge at the Atlanta and Whitesburg gages using selected tributary and year 2000 water-supply demands and wastewater flows*

	Discharge (ft^3/s)			
Flow combination ----	C–B	C–A	D–B	D–A
Locations:				
Atlanta gage ----	940	910	1,220	1,190
Whitesburg gage -	1,590	1,150	1,920	1,490

the powerplants impact river temperatures most significantly when river flows are lowest. Maximum temperature at Georgia Highway 280 is nearly 34°C using powerplant loads, peak water-supply demands, and 1954 drought flow conditions. Temperatures at the same station using the same flow conditions without powerplant loads are about 10°C cooler. River temperatures computed using August 1976 tributary inflows, and average water-supply demands are not significantly different from those observed during the period August 1–8, 1976.

SUMMARY AND CONCLUSIONS

Transient flow-temperature models and independent comparisons of historical river- and air-temperature data were used to evaluate some of the effects of flow regulation and powerplant effluents on Chattahoochee River temperatures between Atlanta and Whitesburg, Ga. The flow-temperature models were used to estimate instantaneous and mean natural temperatures in the river during an 8-day period in August 1976. These, in turn, were compared to observed, thermally altered river temperatures. Such comparisons indicated that the combined thermal effects of flow regulation and powerplant effluents resulted in mean daily river temperatures downstream of the powerplants about equal to or less than computed natural temperatures. An independent analysis of historical river and air-temperature data provided the same basic conclusion.

The models were also used to simulate river temperatures using estimated year 2000 flow conditions and temperature and meteorologic data collected during 1976. Except for periods of peak water-supply demand, simulated year 2000 river temperatures were little changed from observed 1976 temperatures.

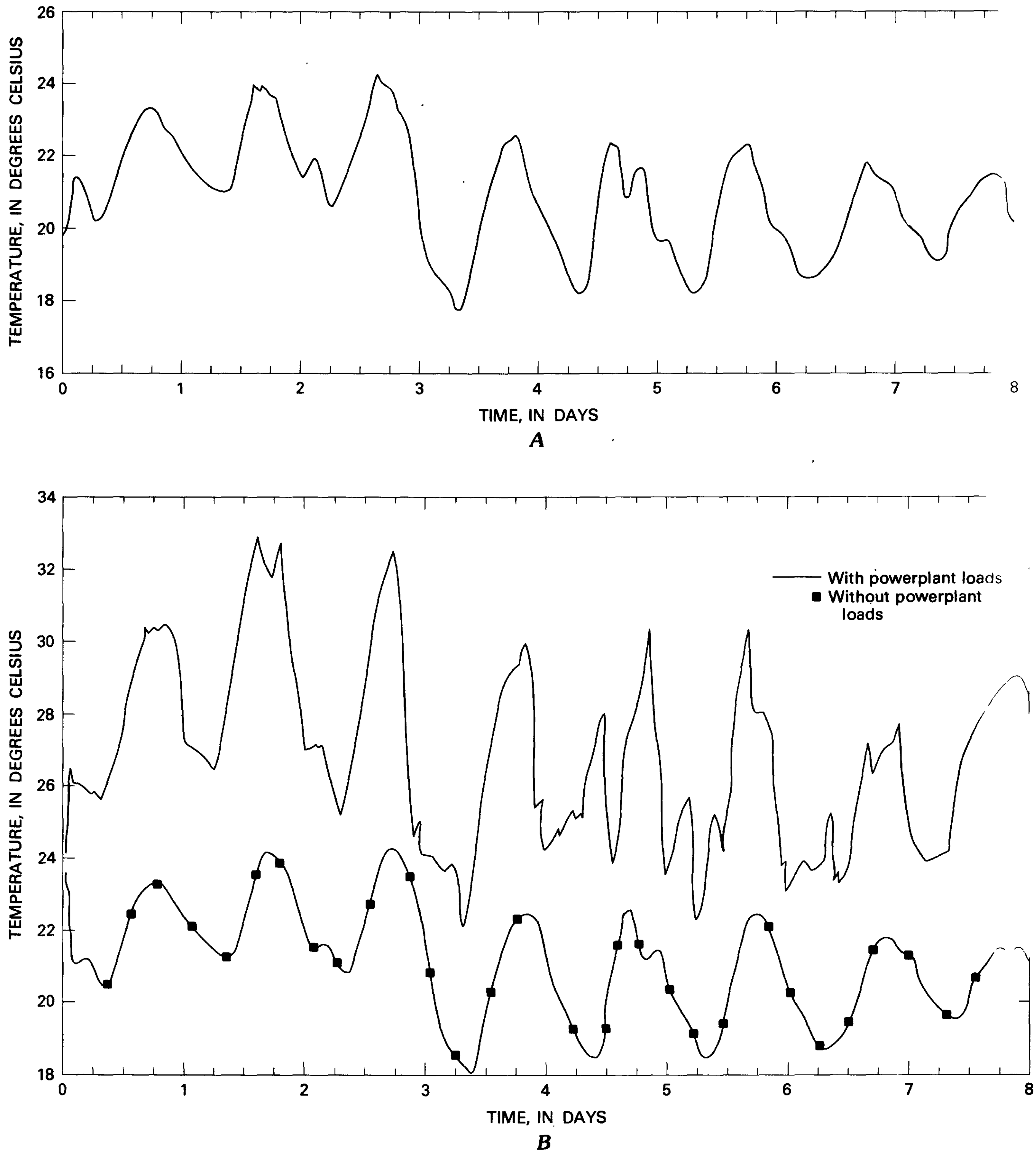


FIGURE 28.—Computed temperatures of the Chattahoochee River using flows representing year 2000 peak water-supply demands, year 2000 average wastewater returns, and August 1976 tributary flows. *A*, At the Plant McDonough intake. *B*, At Georgia Highway 280.

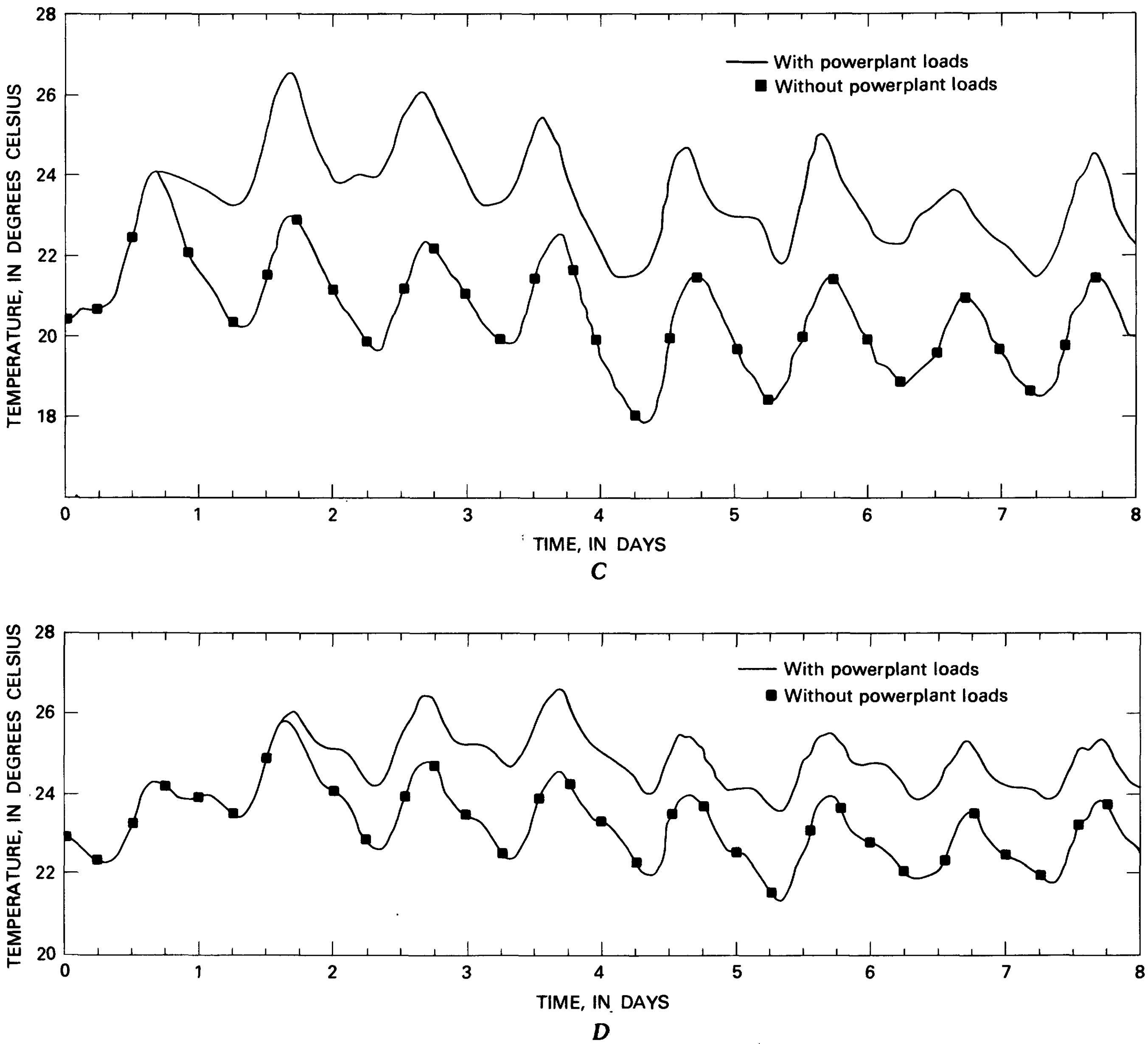


FIGURE 28.—Continued. *C*, Near Fairburn. *D*, Near Whitesburg.

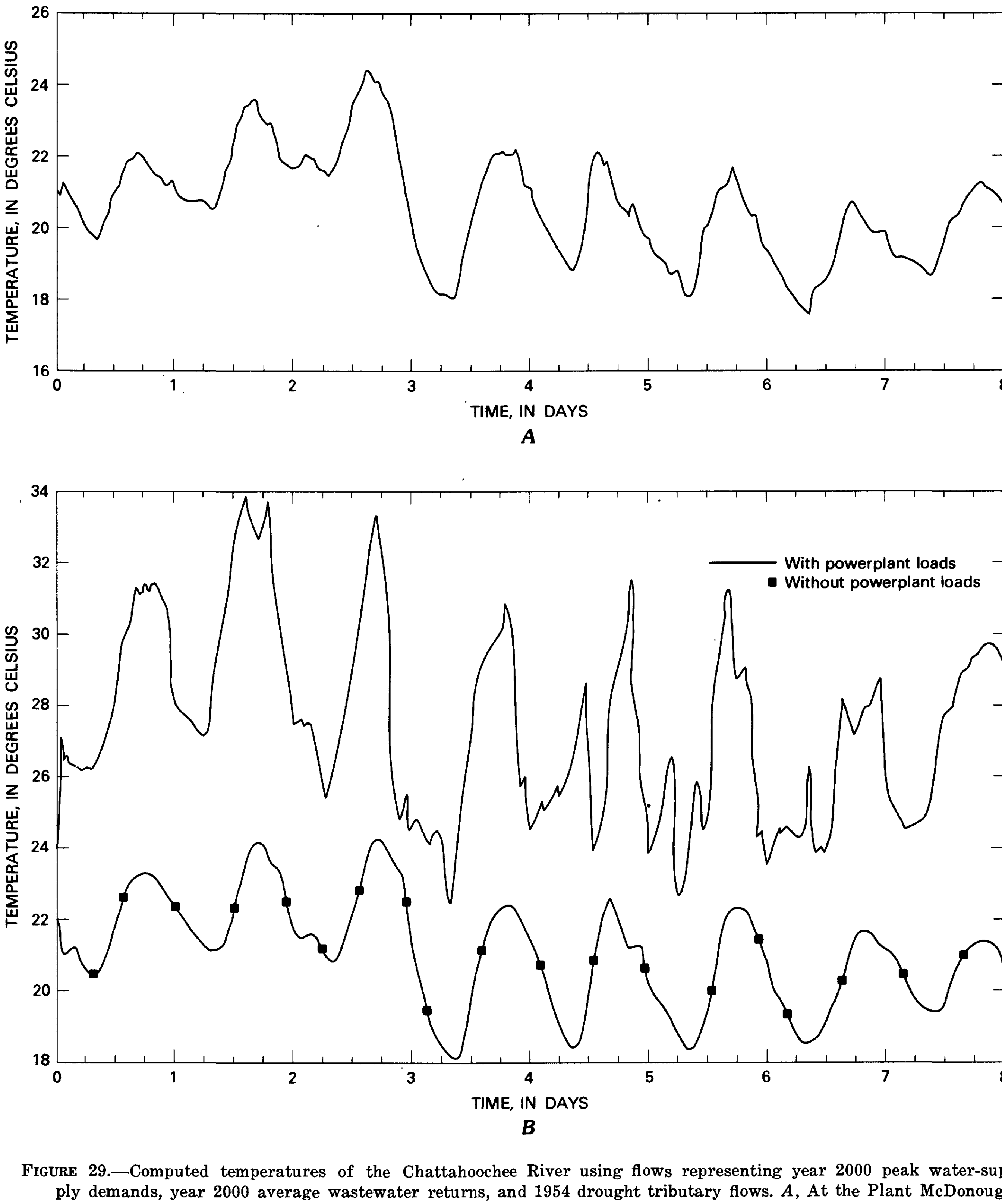


FIGURE 29.—Computed temperatures of the Chattahoochee River using flows representing year 2000 peak water-supply demands, year 2000 average wastewater returns, and 1954 drought tributary flows. *A*, At the Plant McDonough intake. *B*, At Georgia Highway 280.

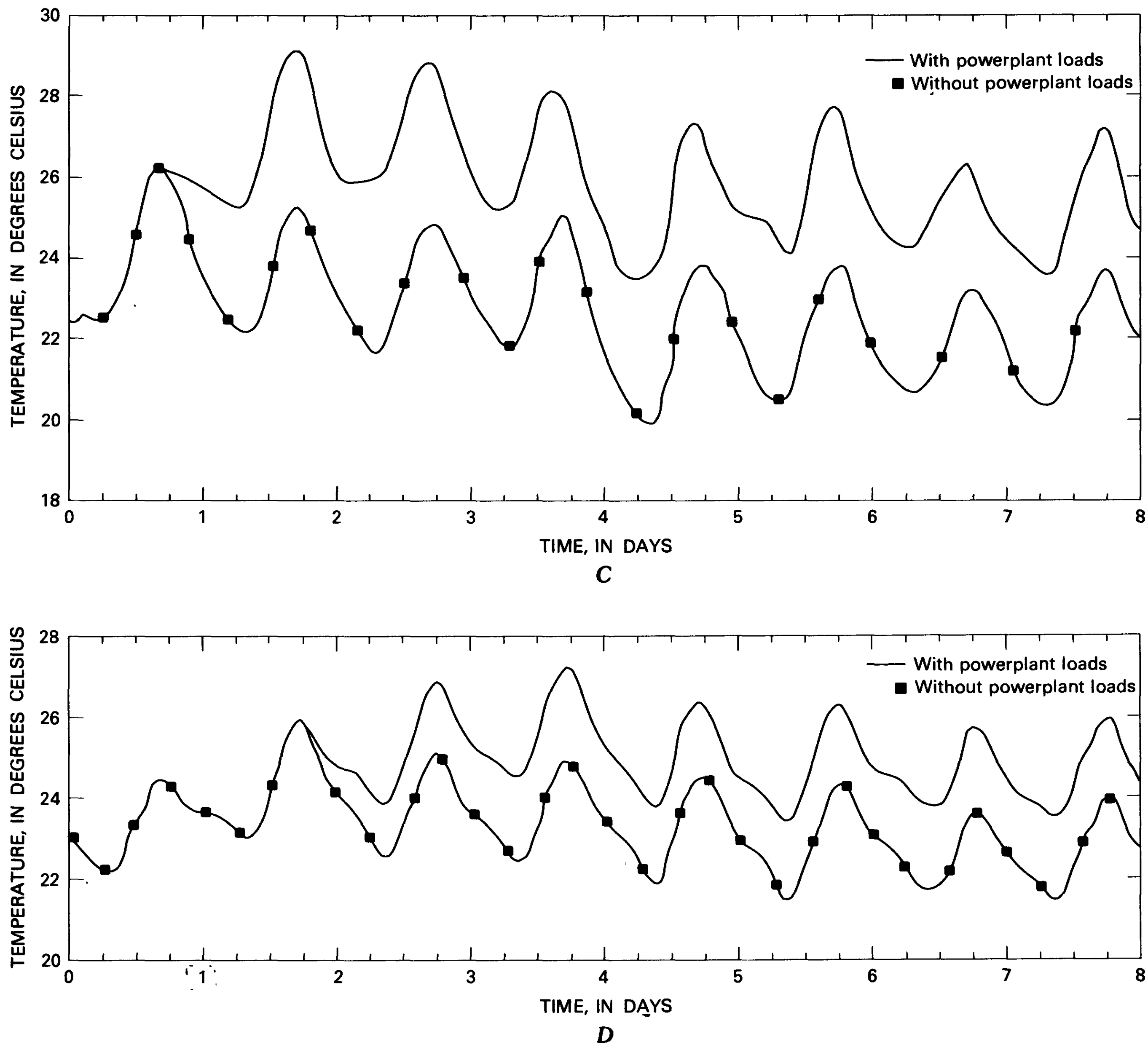
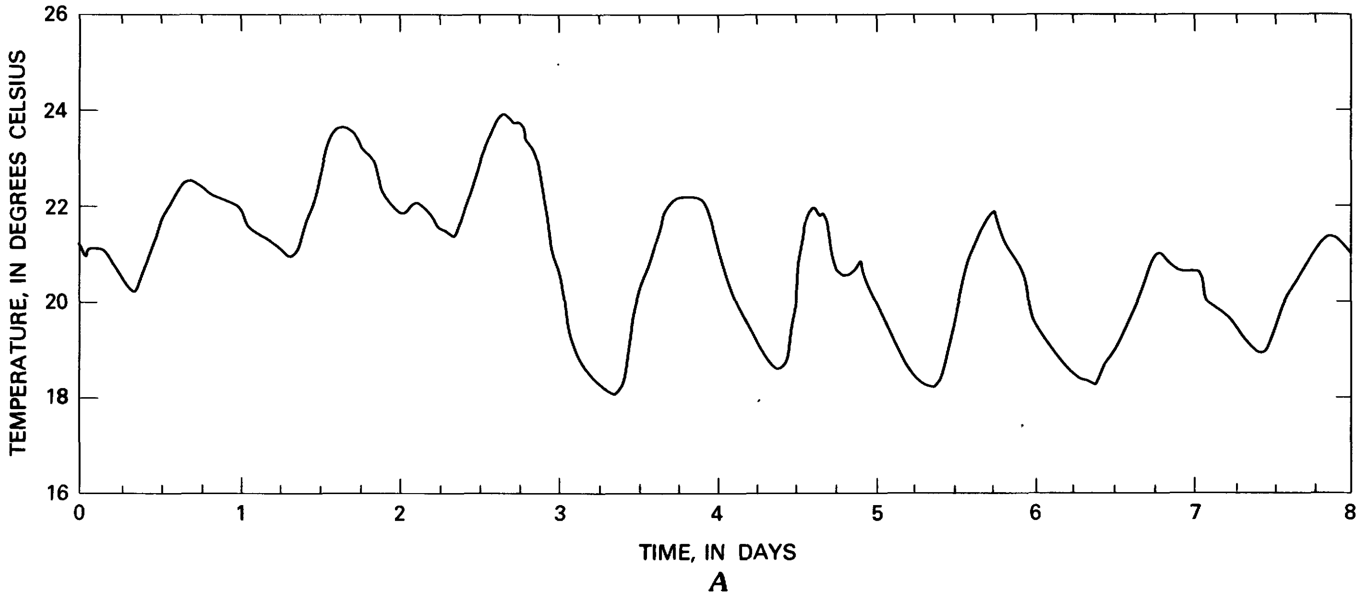


FIGURE 29.—Continued. *C*, Near Fairburn. *D*, Near Whitesburg.



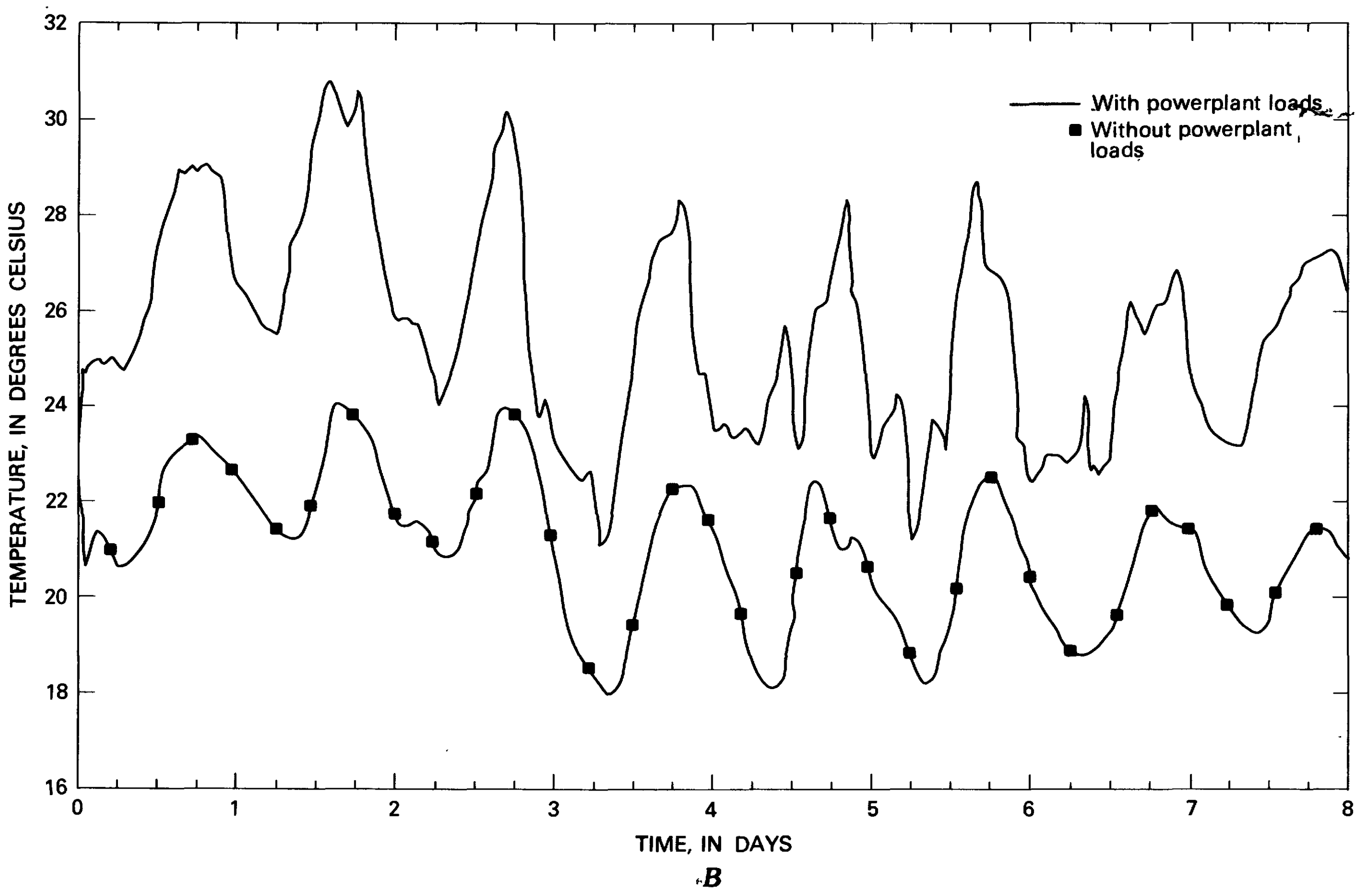


FIGURE 30.—Computed temperatures of the Chattahoochee River using flows representing year 2000 average water-supply demands, year 2000 average wastewater returns, and August 1976 tributary flows. *A*, At the Plant McDonough intake. *B*, At Georgia Highway 280.

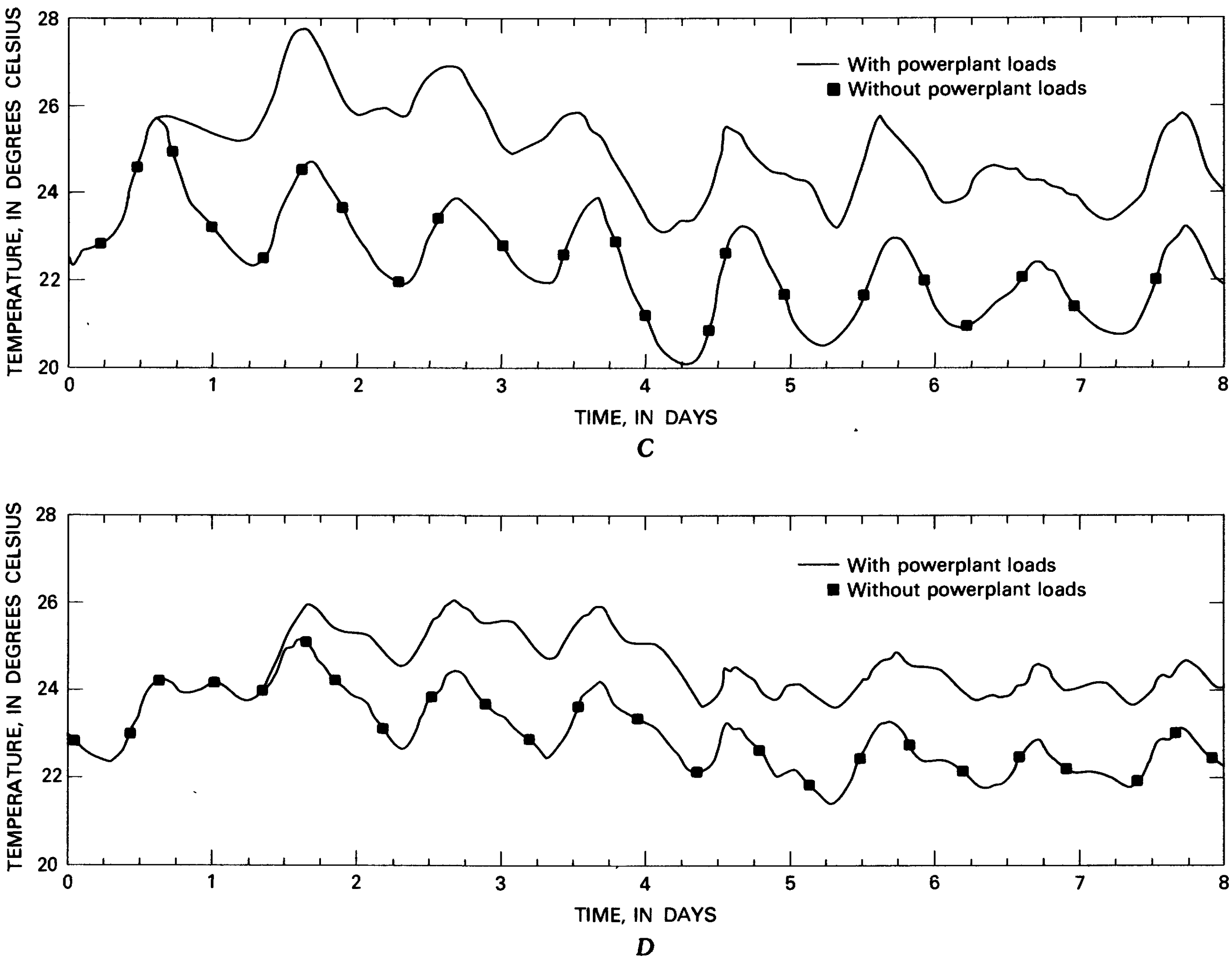


FIGURE 30.—Continued. *C*, Near Fairburn. *D*, Near Whitesburg.

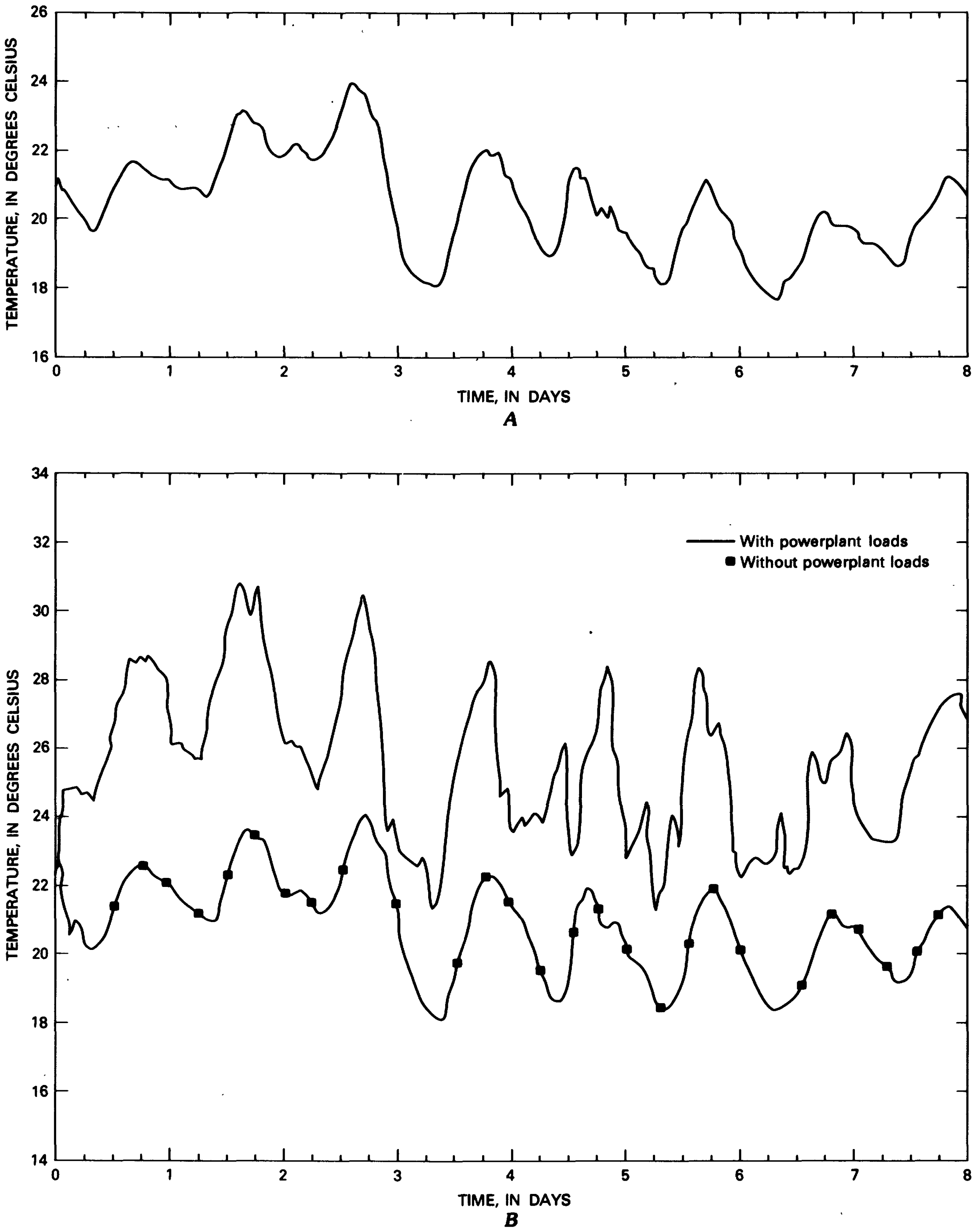


FIGURE 31.—Computed temperatures of the Chattahoochee River using flows representing year 2000 average water-supply demands, year 2000 average wastewater returns, and 1954 drought tributary flows. *A*, At the Plant McDonough intake. *B*, At Georgia Highway 280.

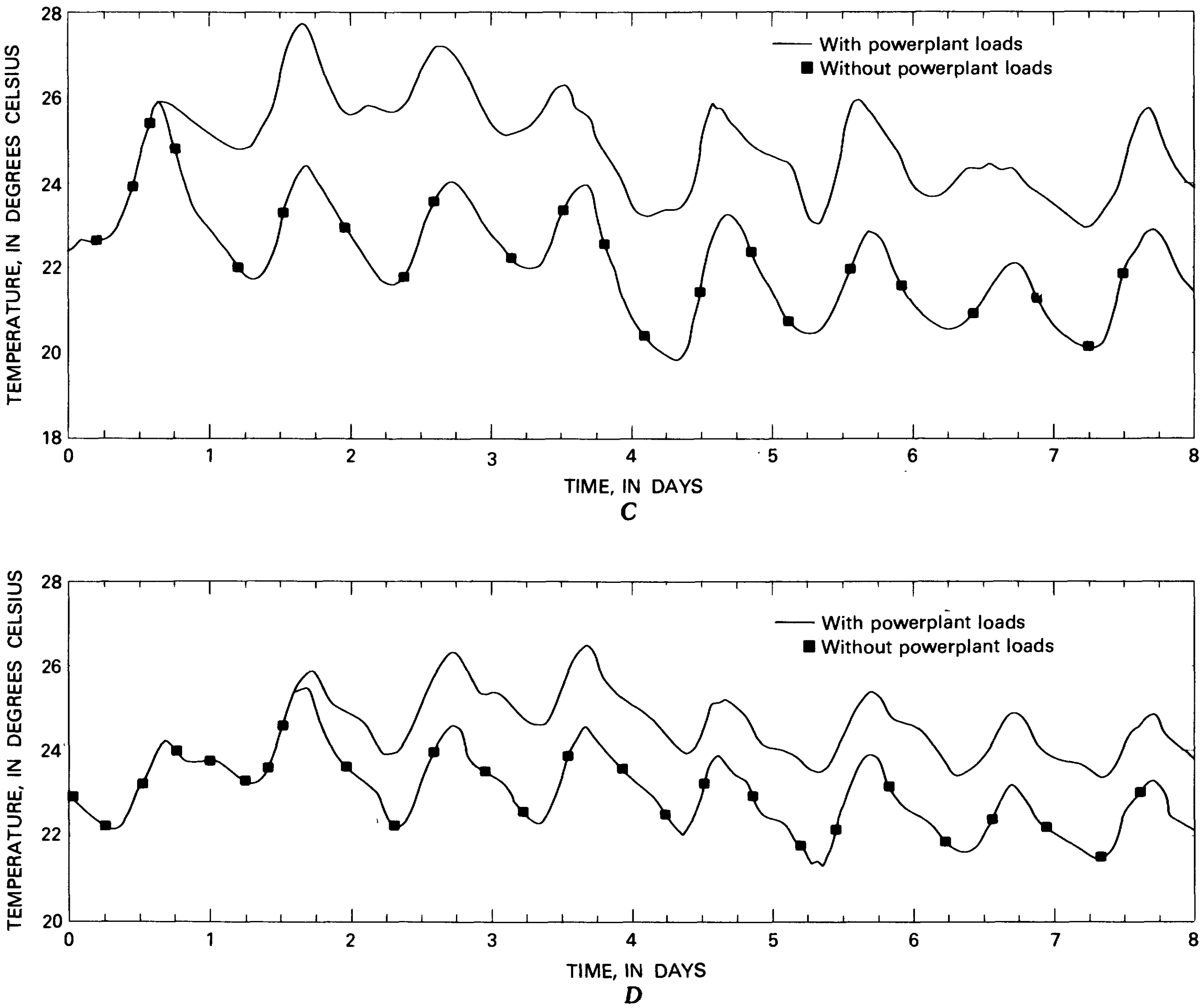


FIGURE 31.—Continued. *C*, Near Fairburn. *D*, Near Whitesburg.

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SUMMARY OF DATA—TABLES 8–10

TABLE 8.—*Cross section coordinates*

[Measurements in feet]

Horizontal distance	Altitude
RM 302.97	
20.0	767.0
40	762.0
55	760.5
70	755.3
85	751.9
100	750.7
115	750.9
130	749.7
145	749.5
160	749.6
170	748.1
180	748.4
190	747.4
200	747.4
210	747.8
220	749.4
230	750.3
240	749.7
250	747.9
260	747.7
270	747.9
280	749.0
290	750.8
300	751.3
310	753.1
320	756.8
330	766.8
RM 302.38	
0	766
10	761
20	756
22	752
30	748
50	750
100	747
200	748
300	748
400	751
430	752
500	753
520	756
540	761
560	766
RM 302.05	
0	761.5
14	752.6
40	746.5
100	743.4
140	747.1
200	747.7
220	746.8
244	752.6
264	762.3
RM 300.98	
0	761.4
14	752.0
21	747.1
29	747.0
50	746.0
70	746.0
80	741.0
100	739.0
150	739.6
190	742.0
200	744.4
236	752.0
255	762.7
RM 300.62	
0	760
42	755
62	750
82	748
100	746
120	745
160	745
200	745
240	745
280	745
320	746
340	748
360	750
373	755
386	760
RM 300.44	
364	762.6
381	760.2
409	748.9
425	748.3
439	740.1
459	740.8
510	740.8
559	739.3
610	739.0
659	739.0
687	749.7
705	761.8
RM 300.29	
23	776.0
66	763.0
82	761.2
103	750.9
118	743.3
169	741.0
216	735.0
265	735.2
309	750.9
325	760.2
405	764.2
RM 299.94	
210	756.8
240	742.2
260	734.0
280	731.2
300	731.2
320	734.7
340	734.9
360	734.5
380	735.7
400	734.1
410	740.2
430	760.3
RM 299.56	
26	765.7
75	738.1
125	733.7
175	733.5
225	733.9
256	738.5
280	752.9
325	754.9
425	753.9
460	762.4
RM 299.20	
–20	754.5
0	741.4
RM 299.20—Continued	
15	735.9
55	733.1
105	733.9
125	735.6
175	729.6
185	730.8
210	755.5
RM 299.10	
0	754
20	744
35	740
60	739
100	739
150	740
200	741
214	744
233	755
RM 298.93	
0	755.1
20	745.5
35	738.5
45	733.0
60	736.3
100	735.2
150	735.4
200	736.4
214	744.5
233	756.0
RM 298.77	
85	756.7
130	736.2
140	741.1
150	739.8
160	735.7
170	734.3
180	733.4
190	734.1
200	734.4
210	735.4
220	733.7
230	733.6
240	734.4
250	735.1
260	735.3
270	737.1
280	737.1
290	738.3
300	737.7
310	739.1
322.6	741.1
332	744.2
373	754.7
RM 298.10	
–40	762.5
–29	757.0
0	755.0
50	731.8
107	733.4
139	733.3
200	735.4
218	755.8
223	740.5
260	760.1
290	764.4
RM 297.86	
0	753.6
15	743.9
RM 297.86—Continued	
30	737.9
50	735.4
100	736.9
150	736.0
200	736.2
214	743.9
222	752.2
RM 297.73	
74	757.7
130	751.3
145	741.6
160	735.7
180	733.7
230	734.9
280	734.7
300	733.8
315	736.5
326	741.7
347	755.2
367	759.2
RM 297.06	
0	754.0
15	745.8
16	739.3
30	734.8
50	734.8
77	734.5
90	732.3
100	735.8
150	734.1
165	736.0
182	739.3
183	746.2
195	751.2
RM 296.60	
140	750.3
152	742.9
165	735.9
190	736.4
240	735.1
290	735.5
340	735.2
355	736.0
368	743.8
388	751.2
RM 295.30	
0	752.3
25	740.5
40	731.9
100	731.8
150	732.0
200	732.4
240	749.9
254	740.5
285	749.9
RM 294.70	
0	769.5
45	755.9
100	752.0
153	745.0
165	738.3
200	738.0
248	735.8
299	727.0
367	733.8
398	755.3
423	757.8
450	768.7

TABLE 8.—*Cross section coordinates*—Continued

[Measurements in feet]

Horizontal distance	Altitude
RM 293.92	
55	753.5
86	742.0
100	731.6
197	729.0
300	730.9
311	742.0
330	749.4
400	750.4
RM 293.10	
0	751.9
15	739.3
16	733.3
30	731.1
36	727.8
50	729.2
100	728.1
104	729.3
150	727.6
167	726.6
180	729.2
199	733.2
200	739.3
215	750.3
RM 292.19	
400	751.6
420	737.9
437	729.8
450	728.2
470	725.2
494	726.2
510	726.1
560	727.4
575	723.7
586	729.5
606	737.9
659	755.6
RM 290.54	
-20	746.4
0	741.7
10	737.0
20	730.5
30	724.7
50	727.1
100	725.5
153	728.0
170	722.7
180	730.5
195	744.1
RM 287.86	
-9	744.6
2	741.5
16	732.0
28	725.1
40	721.8
50	724.6
100	724.8
150	723.8
200	724.1
210	723.8
216	725.9
233	732.0
249	741.9
270	744.2
RM 286.96	
0	742.1
15	729.8
20	727.1
30	725.8
RM 286.96—Continued	
50	722.3
100	721.9
150	722.1
200	721.8
245	727.1
255	729.8
270	741.2
RM 286.07	
220	739.9
248	718.0
270	719.9
320	720.8
370	721.1
420	720.0
435	721.0
482	738.9
RM 284.32	
0	735.1
5	720.7
30	717.8
80	718.2
95	716.7
121	718.5
150	719.2
160	719.2
190	720.7
195	739.4
RM 281.79	
20	743.9
50	738.2
80	737.4
110	736.3
140	734.6
170	734.3
200	729.8
220	719.5
245	715.0
270	714.1
290	716.5
310	715.3
330	714.7
334	714.9
337	716.3
340	716.8
355	716.8
370	716.9
390	716.8
410	717.1
430	718.0
450	722.3
470	730.4
500	736.5
530	739.2
565	741.3
580	743.8
RM 281.07	
0	737.9
12	720.2
20	722.5
40	710.2
70	716.1
100	714.5
150	714.8
200	713.1
227	720.2
235	735.6
RM 279.99	
0	733.6
5	722.1
RM 279.99—Continued	
23	714.3
35	711.7
60	714.7
100	715.5
200	715.6
210	716.2
225	722.1
230	735.1
RM 277.95	
0	734.0
10	720.8
20	710.8
30	708.3
60	710.8
180	710.8
210	711.7
235	711.8
240	713.8
245	714.7
254	720.8
264	727.8
354	729.3
RM 274.12	
-65	732.0
-48	728.5
0	725.4
20	713.7
100	713.3
150	712.9
200	712.7
260	711.2
266	719.9
271	726.8
300	732.2
RM 272.20	
-10	727.2
3	713.2
8	710.5
30	712.1
80	710.9
120	711.1
140	710.8
180	711.3
200	712.5
230	712.8
250	713.2
260	727.5
RM 271.22	
0	740.5
30	728.5
44	728.3
50	718.3
51	713.5
69	710.7
80	710.5
100	709.7
150	711.5
200	712.4
250	711.0
300	710.2
330	709.3
352	713.5
353	718.3
365	724.8
376	725.7
406	739.5
RM 270.86	
0	716.5
20	712.5
RM 270.86—Continued	
40	708.0
60	709.5
80	710.0
100	710.0
120	710.0
140	710.5
160	711.5
180	709.0
200	707.3
220	709.5
240	710.0
260	710.0
280	710.5
286	711.0
291	716.5
RM 270.43	
-86	719.3
0	715.5
10	707.8
25	701.5
76	702.4
125	701.5
165	700.9
240	700.4
246	707.8
253	716.6
RM 268.34	
800	710.8
900	707.3
910	704.1
925	701.8
975	701.6
1,000	700.6
1,050	698.3
1,100	698.6
1,150	699.7
1,210	702.4
1,215	704.1
1,235	708.2
1,275	712.7
RM 266.02	
0	702.5
14	698.1
30	692.1
80	692.7
120	693.1
170	693.4
210	692.9
222	698.1
244	704.6
RM 263.62	
0	700.2
10	690.2
33	684.9
110	687.2
200	686.4
224	684.9
229	686.4
250	690.1
264	697.6
RM 259.87	
-20	699.6
0	692.6
20	684.1
40	684.0
57	684.4
61	681.6
80	683.8

TABLE 8.—*Cross section coordinates*—Continued

[Measurements in feet]

Horizontal distance	Altitude	Horizontal distance	Altitude	Horizontal distance	Altitude	Horizontal distance	Altitude
RM 259.87—Continued		*RM 259.87—Continued*		*RM 259.87—Continued*		*RM 259.87—Continued*	
100	681.8	161	676.5	240	679.6	300	689.1
120	679.6	180	680.1	257	679.6	310	691.6
140	678.6	200	680.6	261	682.6	330	699.6
157	677.1	220	680.1	280	684.0		

TABLE 9.—*Channel roughness and barrier heights*

River mile	Manning's *n* (s/ft$^{1/3}$) Maximum	Manning's *n* (s/ft$^{1/3}$) Minimum	Effective barrier height (ft)
302.79	0.057	0.032	50
302.38	.055	.040	45
302.05	.066	.029	40
300.98	.050	.034	30
300.62	.080	.056	60
300.44	.051	.040	20
300.29	.039	.039	15
299.94	.039	.021	15
299.56	.040	.040	15
299.20	.042	.024	10
299.10	.050	.021	20
298.93	.038	.031	25
298.77	.038	.030	15
298.10	.033	.024	25
297.86	.033	.026	25
297.73	.031	.024	25
297.06	.034	.028	20
296.60	.034	.025	20
295.30	.035	.026	15
294.70	.035	.028	15
293.92	.034	.023	10
293.10	.039	.039	15
292.19	.042	.021	30
290.54	.047	.038	25
287.86	.041	.026	20
286.96	.038	.038	15
286.07	.025	.025	30
284.32	.027	.020	50
281.79	.030	.025	40
281.07	.025	.021	40
279.99	.027	.024	40
277.95	.025	.021	50
274.12	.033	.026	60
272.20	.028	.014	40
271.22	.028	.026	40
270.86	.058	.049	40
270.43	.052	.037	40
268.34	.080	.058	60
266.02	.080	.060	50
263.62	.040	.034	40
259.85	.040	.030	25

TABLE 10.—*Summary of meteorologic data, July 12–19 and August 1–8, 1976*

[Precipitation = 0.0 mm for entire period]

Time	Wind speed (m/s)	Short wave radiation (W/m²)	Long wave radiation (W/m²)	Air temperature dry bulb (°C)	Air temperature wet bulb (°C)	Vapor pressure (KPa)
			July 12, 1976			
0000	0.28	0.0	372.5	22.6	21.0	2.46
0100	.30	0.0	372.5	21.8	20.9	2.45
0200	.30	0.0	372.5	21.8	20.5	2.39
0300	.30	0.0	372.5	20.5	19.7	2.28
0400	1.33	0.0	372.5	20.8	19.7	2.27
0500	1.89	24.2	372.5	21.0	19.9	2.30
0600	.52	141.8	372.5	22.0	20.4	2.37
0700	3.47	344.0	375.5	23.3	21.0	2.45
0800	1.47	558.2	372.5	25.7	21.7	2.53
0900	4.57	727.5	372.5	26.8	22.3	2.62
1000	6.47	860.4	372.5	28.1	22.3	2.60
1100	3.70	1,023.1	372.5	29.3	22.3	2.58
1200	6.34	906.6	372.5	29.5	21.2	2.38
1300	4.40	905.5	372.5	29.9	21.4	2.41
1400	3.00	769.2	372.5	31.1	22.4	2.57
1500	3.93	647.3	372.5	29.6	21.3	2.40
1600	5.93	438.5	372.5	29.4	22.1	2.54
1700	4.11	224.2	372.5	29.4	22.4	2.59
1800	3.39	67.0	372.5	28.7	22.2	2.57
1900	2.44	0.0	372.5	27.1	22.0	2.56
2000	.81	0.0	372.5	25.8	22.0	2.58
2100	2.48	0.0	372.5	25.0	21.9	2.57
2200	2.17	0.0	372.5	23.7	21.1	2.46
2300	2.52	0.0	372.5	23.2	21.0	2.45
			July 13, 1976			
0000	2.19	0.0	371.8	22.3	20.4	2.36
0100	1.04	0.0	371.8	21.8	19.8	2.27
0200	1.12	0.0	371.8	21.2	19.9	2.30
0300	1.62	0.0	371.8	21.0	20.0	2.32
0400	.30	0.0	371.8	20.6	19.7	2.28
0500	.28	26.4	371.8	20.5	19.3	2.21
0600	.67	98.9	371.8	21.9	19.9	2.29
0700	3.60	302.2	371.8	23.5	21.2	2.48
0800	2.81	526.4	371.8	25.2	21.4	2.48
0900	4.59	738.5	371.8	26.6	21.7	2.51
1000	4.73	913.2	371.8	27.3	21.6	2.48
1100	3.00	951.6	371.8	28.0	22.1	2.56
1200	3.41	989.0	371.8	29.2	22.2	2.56
1300	2.19	286.8	371.8	29.8	21.3	2.39
1400	4.73	253.8	371.8	30.1	21.0	2.34
1500	5.89	611.0	371.8	29.6	21.5	2.43
1600	3.74	415.4	371.8	30.4	21.0	2.33
1700	2.75	254.9	371.8	30.3	20.5	2.25
1800	.50	83.5	371.8	29.4	20.3	2.23
1900	.57	0.0	371.8	25.4	19.6	2.18
2000	.73	0.0	371.8	24.1	18.4	2.02
2100	.28	0.0	371.8	22.0	18.4	2.05
2200	.28	0.0	371.8	21.0	17.6	1.95
2300	.59	0.0	371.8	19.1	16.7	1.89
			July 14, 1976			
0000	0.30	0.0	349.6	18.1	16.5	1.85
0100	.90	0.0	349.6	17.8	15.7	1.75
0200	.71	0.0	349.6	17.4	15.2	1.69
0300	1.18	0.0	349.6	16.5	15.2	1.70
0400	.79	0.0	349.6	16.4	14.5	1.62
0500	.28	9.9	349.6	15.9	14.2	1.59
0600	1.04	201.1	349.6	17.3	15.2	1.69
0700	.96	301.1	349.6	20.2	15.1	1.63
0800	.28	558.2	349.6	24.0	16.2	1.71
0900	.59	693.4	349.6	24.1	16.0	1.69
1000	.30	853.8	349.6	27.6	16.8	1.74
1100	2.83	934.1	349.6	26.7	16.7	1.74
1200	2.57	964.8	349.6	28.4	17.3	1.80
1300	1.80	925.3	349.6	30.8	17.0	1.72
1400	.90	786.8	349.6	30.7	17.8	1.83
1500	4.65	649.5	349.6	30.1	17.7	1.83
1600	1.04	453.8	349.6	30.6	18.3	1.90
1700	2.61	258.2	349.6	30.4	18.5	1.94

TABLE 10.—*Summary of meteorologic data, July 12–19 and August 1–8, 1976*—Continued

[Precipitation = 0.0 mm for entire period]

Time	Wind speed (m/s)	Short wave radiation (W/m²)	Long wave radiation (W/m²)	Air temperature dry bulb (°C)	Air temperature wet bulb (°C)	Vapor pressure (KPa)
			July 14, 1976—Continued			
1800	.36	70.3	349.6	29.3	19.9	2.17
1900	.54	0.0	349.6	25.5	19.7	2.20
2000	.28	0.0	349.6	23.4	19.7	2.23
2100	.28	0.0	349.6	22.3	19.8	2.26
2200	.28	0.0	349.6	22.0	19.3	2.19
2300	.28	0.0	349.6	20.4	18.9	2.15
			July 15, 1976			
0000	0.28	0.0	371.8	20.3	18.6	2.11
0100	.28	0.0	371.8	20.7	19.0	2.16
0200	.28	0.0	371.8	19.5	18.0	2.03
0300	.28	0.0	371.8	18.7	18.0	2.05
0400	.28	0.0	371.8	18.1	17.5	1.98
0500	.57	16.5	371.8	18.3	17.8	2.02
0600	.28	149.5	371.8	20.4	18.8	2.14
0700	.92	325.3	371.8	24.1	21.0	2.43
0800	2.13	500.0	371.8	26.0	21.9	2.56
0900	.59	579.1	371.8	27.5	22.4	2.62
1000	3.10	769.2	371.8	29.2	23.1	2.72
1100	1.91	880.2	371.8	29.6	22.6	2.63
1200	2.79	893.4	371.8	30.1	22.6	2.62
1300	1.20	627.5	371.8	31.1	22.4	2.57
1400	4.03	407.7	371.8	30.1	22.5	2.60
1500	6.96	656.0	371.8	29.8	21.5	2.43
1600	2.28	235.2	371.8	29.5	22.0	2.52
1700	2.83	146.2	371.8	28.3	21.3	2.42
1800	1.91	111.0	371.8	28.9	21.9	2.51
1900	1.37	0.0	371.8	25.7	22.3	2.63
2000	.63	0.0	371.8	24.9	21.9	2.57
2100	1.78	0.0	371.8	24.9	20.7	2.37
2200	1.20	0.0	371.8	23.8	20.1	2.29
2300	.87	0.0	371.8	22.9	19.6	2.22
			July 16, 1976			
0000	1.93	0.0	363.5	22.4	19.6	2.23
0100	.54	0.0	363.5	21.7	19.9	2.29
0200	.28	0.0	363.5	20.8	19.8	2.29
0300	1.56	0.0	363.5	20.7	19.5	2.24
0400	1.49	0.0	363.5	20.6	19.6	2.26
0500	1.39	7.7	363.5	20.3	19.5	2.25
0600	1.45	157.1	363.5	21.3	19.8	2.28
0700	2.61	350.5	363.5	23.8	21.0	2.44
0800	2.92	549.5	363.5	25.0	20.6	2.35
0900	4.11	709.9	363.5	26.5	21.0	2.39
1000	6.49	868.1	363.5	27.7	21.2	2.41
1100	5.89	307.7	363.5	28.3	21.3	2.42
1200	5.76	1,003.3	363.5	29.5	20.9	2.33
1300	5.04	985.7	363.5	29.6	20.6	2.28
1400	3.14	844.0	363.5	29.7	21.5	2.43
1500	5.43	237.4	363.5	30.1	21.0	2.34
1600	3.62	182.4	363.5	20.7	18.2	2.05
1700	1.99	130.8	363.5	22.4	19.3	2.18
1800	.30	23.1	363.5	22.4	19.4	2.20
1900	2.81	0.0	363.5	20.9	18.2	2.04
2000	.30	0.0	363.5	20.3	18.2	2.05
2100	2.48	0.0	363.5	19.6	18.3	2.08
2200	1.51	0.0	363.5	19.3	18.2	2.07
2300	1.08	0.0	363.5	19.6	18.4	2.09
			July 17, 1976			
0000	1.29	0.0	361.4	19.8	18.4	2.09
0100	.85	0.0	361.4	19.1	18.0	2.04
0200	.30	0.0	361.4	19.4	18.5	2.11
0300	1.86	0.0	361.4	18.8	17.9	2.03
0400	1.35	0.0	361.4	19.7	18.6	2.12
0500	.28	6.6	361.4	19.6	19.0	2.18
0600	1.08	83.5	361.4	19.7	19.0	2.18
0700	.34	127.5	361.4	20.2	19.4	2.23
0800	2.34	311.0	361.4	21.9	19.6	2.24

TABLE 10.—*Summary of meteorologic data, July 12–19 and August 1–8, 1976*—Continued

[Precipitation = 0.0 mm for entire period]

Time	Wind speed (m/s)	Short wave radiation (W/m²)	Long wave radiation (W/m²)	Air temperature dry bulb (°C)	Air temperature wet bulb (°C)	Vapor pressure (KPa)
			July 17, 1976—Continued			
0900	1.27	319.8	361.4	23.9	21.0	2.44
1000	.28	764.8	361.4	25.7	21.1	2.42
1100	2.85	912.1	361.4	26.9	20.7	2.34
1200	1.00	236.3	361.4	30.1	21.3	2.39
1300	4.03	760.4	361.4	28.9	19.9	2.18
1400	4.05	427.5	361.4	27.8	19.6	2.15
1500	1.35	565.9	361.4	30.5	21.4	2.40
1600	4.86	214.3	361.4	27.5	20.3	2.26
1700	2.40	42.9	361.4	25.8	19.7	2.19
1800	.28	24.2	361.4	24.6	19.6	2.20
1900	.28	1.1	361.4	23.1	19.9	2.27
2000	.28	0.0	361.4	22.2	19.5	2.22
2100	.28	0.0	361.4	20.4	18.7	2.12
2200	.30	0.0	361.4	19.8	18.7	2.13
2300	.30	0.0	361.4	19.1	18.2	2.07
			July 18, 1976			
0000	0.32	0.0	377.0	18.4	17.7	2.01
0100	.28	0.0	377.0	18.7	17.2	1.93
0200	.28	0.0	377.0	18.2	17.1	1.93
0300	.73	0.0	377.0	17.5	16.4	1.84
0400	.28	0.0	377.0	17.3	16.3	1.83
0500	.28	6.6	377.0	17.1	16.2	1.82
0600	.30	74.7	377.0	17.6	16.9	1.91
0700	.83	290.1	377.0	20.0	17.5	1.96
0800	.75	380.2	377.0	23.1	18.5	2.05
0900	1.00	475.8	377.0	26.1	19.6	2.17
1000	.38	827.5	377.0	28.3	19.9	2.19
1100	.28	887.9	377.0	31.7	20.7	2.26
1200	.67	926.4	377.0	33.4	21.6	2.39
1300	.87	924.2	377.0	35.1	22.4	2.50
1400	2.05	823.1	377.0	31.3	20.7	2.27
1500	.52	330.8	377.0	34.3	22.4	2.52
1600	1.06	469.2	377.0	33.2	22.4	2.53
1700	1.41	137.4	377.0	31.0	22.0	2.50
1800	1.12	63.7	377.0	27.8	21.0	2.37
1900	.61	0.0	377.0	25.1	21.1	2.43
2000	.28	0.0	377.0	23.5	20.2	2.31
2100	.46	0.0	377.0	21.9	19.8	2.27
2200	.28	0.0	377.0	20.9	19.3	2.21
2300	.28	0.0	377.0	20.4	19.3	2.22
			July 19, 1976			
0000	0.28	0.0	373.2	20.1	18.9	2.16
0100	.28	0.0	373.2	19.6	18.1	2.05
0200	.79	0.0	373.2	18.7	18.1	2.06
0300	.40	0.0	373.2	17.9	17.0	1.92
0400	.67	0.0	373.2	18.3	17.0	1.91
0500	.30	12.1	373.2	18.5	17.2	1.94
0600	.90	130.8	373.2	19.4	18.1	2.05
0700	.28	301.1	373.2	22.9	19.6	2.22
0800	.38	494.5	373.2	25.3	21.0	2.41
0900	1.37	667.0	373.2	27.9	21.4	2.44
1000	1.16	818.7	373.2	30.4	22.1	2.52
1100	.36	906.6	373.2	31.4	21.9	2.47
1200	.96	970.3	373.2	32.9	22.4	2.54
1300	1.43	960.4	373.2	31.6	21.2	2.35
1400	4.53	803.3	373.2	32.3	21.4	2.37
1500	3.72	275.8	373.2	32.8	21.4	2.36
1600	1.68	419.8	373.2	32.0	21.8	2.45
1700	.54	250.5	373.2	32.7	23.2	2.69
1800	1.72	18.7	373.2	28.5	22.1	2.55
1900	.81	0.0	373.2	26.9	21.5	2.47
2000	.67	0.0	373.2	25.2	21.7	2.57
2100	.54	0.0	373.2	23.5	20.6	2.38
2200	.28	0.0	373.2	22.2	20.2	2.33
2300	.28	0.0	373.2	21.8	20.1	2.32

TABLE 10.—*Summary of meteorologic data, July 12–19 and August 1–8, 1976*—Continued

[Precipitation = 0.0 mm for entire period]

Time	Wind speed (m/s)	Short wave radiation (W/m²)	Long wave radiation (W/m²)	Air temperature dry bulb (°C)	Air temperature wet bulb (°C)	Vapor pressure (KPa)
			August 1, 1976			
0000	1.22	0.0	463.0	21.1	20.0	2.32
0100	2.63	0.0	463.0	21.0	20.2	2.35
0200	4.01	0.0	463.0	21.4	20.7	2.42
0300	.73	0.0	463.0	21.1	20.5	2.40
0400	1.10	0.0	463.0	20.7	20.3	2.37
0500	.28	0.0	463.0	21.0	20.2	2.35
0600	1.45	5.5	463.0	20.6	19.9	2.31
0700	1.49	54.9	463.0	21.0	20.4	2.38
0800	1.64	153.8	463.0	22.5	21.0	2.46
0900	1.35	452.7	463.0	24.4	21.6	2.53
1000	2.25	738.5	463.0	25.9	22.5	2.67
1100	3.12	824.2	463.0	27.7	22.3	2.60
1200	1.35	338.5	463.0	29.0	22.5	2.62
1300	4.21	928.6	463.0	29.6	22.6	2.62
1400	3.51	911.0	463.0	29.8	22.7	2.64
1500	1.97	341.8	463.0	30.9	23.2	2.71
1600	2.11	339.6	463.0	31.2	22.4	2.56
1700	.29	49.5	463.0	29.5	22.4	2.59
1800	.90	202.2	463.0	24.3	22.8	2.74
1900	.46	42.9	463.0	25.0	22.9	2.75
2000	.48	0.0	463.0	23.6	22.2	2.65
2100	.44	0.0	463.0	22.7	22.0	2.63
2200	.48	0.0	463.0	22.4	21.6	2.56
2300	.77	0.0	463.0	22.3	21.4	2.53
			August 2, 1976			
0000	0.36	0.0	456.0	21.9	20.6	2.40
0100	.28	0.0	456.0	21.2	20.0	2.31
0200	.28	0.0	456.0	20.1	19.7	2.28
0300	.28	0.0	456.0	19.9	19.5	2.26
0400	1.82	0.0	456.0	19.6	19.2	2.21
0500	.38	0.0	456.0	19.5	18.7	2.14
0600	.28	7.69	456.0	19.2	18.6	2.13
0700	.48	106.6	456.0	19.5	18.9	2.17
0800	.38	270.3	456.0	21.6	19.9	2.29
0900	2.40	439.6	456.0	22.8	20.4	2.35
1000	2.21	667.0	456.0	24.8	20.4	2.32
1100	.81	731.9	456.0	28.2	22.1	2.56
1200	.28	974.7	456.0	29.8	22.2	2.55
1300	1.68	633.0	456.0	28.4	20.9	2.35
1400	.40	816.5	456.0	28.4	21.8	2.50
1500	3.86	549.5	456.0	27.4	20.6	2.31
1600	2.03	617.6	456.0	30.0	21.9	2.49
1700	1.74	144.0	456.0	26.8	21.0	2.39
1800	2.89	202.2	456.0	26.6	20.3	2.28
1900	1.47	0.0	456.0	25.6	19.8	2.21
2000	1.47	0.0	456.0	23.8	18.7	2.07
2100	.50	0.0	456.0	22.7	18.2	2.01
2200	.52	0.0	456.0	21.9	18.0	2.00
2300	2.36	0.0	456.0	21.0	17.9	2.00
			August 3, 1976			
0000	3.10	0.0	448.0	21.5	19.1	2.17
0100	.28	0.0	448.0	22.3	18.3	2.03
0200	.28	0.0	448.0	21.8	17.7	1.95
0300	2.17	0.0	448.0	21.7	16.4	1.78
0400	3.74	0.0	448.0	21.0	17.2	1.90
0500	1.31	0.0	448.0	21.1	15.7	1.69
0600	.85	0.0	448.0	20.2	16.5	1.81
0700	.83	104.4	448.0	20.8	16.9	1.86
0800	.28	242.9	448.0	21.3	17.3	1.91
0900	.28	522.0	448.0	21.8	17.6	1.94
1000	.28	772.5	448.0	23.1	18.2	2.01
1100	1.26	660.4	448.0	24.3	19.1	2.12
1200	1.53	993.4	448.0	26.1	19.4	2.14
1300	1.47	484.6	448.0	29.5	20.8	2.31
1400	1.62	865.9	448.0	27.3	18.9	2.04
1500	1.76	753.8	448.0	29.4	21.0	2.35
1600	1.51	600.0	448.0	28.4	20.5	2.28
1700	.83	405.5	448.0	29.5	20.9	2.33

TABLE 10.—*Summary of meteorologic data, July 12–19 and August 1–8, 1976*—Continued

[Precipitation = 0.0 mm for entire period]

Time	Wind speed (m/s)	Short wave radiation (W/m²)	Long wave radiation (W/m²)	Air temperature dry bulb (°C)	Air temperature wet bulb (°C)	Vapor pressure (KPa)
August 3, 1976—Continued						
1800	.77	198.9	448.0	28.6	21.2	2.39
1900	.34	38.5	448.0	26.9	20.4	2.29
2000	1.78	0.0	448.0	23.8	19.6	2.21
2100	1.00	0.0	448.0	21.3	19.4	2.22
2200	1.90	0.0	448.0	19.9	18.5	2.10
2300	1.45	0.0	448.0	19.2	18.0	2.04
August 4, 1976						
0000	0.73	0.0	448.0	19.2	18.0	2.04
0100	.36	0.0	448.0	20.0	17.9	2.01
0200	1.70	0.0	448.0	19.5	17.4	1.95
0300	.28	0.0	448.0	18.6	17.3	1.95
0400	.40	0.0	448.0	16.7	16.2	1.83
0500	1.47	0.0	448.0	16.6	16.0	1.80
0600	.32	3.3	448.0	16.0	15.8	1.79
0700	2.03	256.0	448.0	17.2	16.4	1.85
0800	1.06	327.5	448.0	20.9	17.9	2.00
0900	.98	536.3	448.0	22.4	18.4	2.05
1000	1.47	727.5	448.0	24.2	18.7	2.06
1100	.28	824.2	448.0	26.4	19.5	2.15
1200	.87	920.9	448.0	28.0	19.5	2.13
1300	.67	930.8	448.0	29.9	20.2	2.21
1400	1.16	513.2	448.0	29.3	19.8	2.15
1500	2.17	796.7	448.0	28.8	19.2	2.07
1600	.95	650.5	448.0	32.1	20.7	2.26
1700	1.72	169.2	448.0	28.8	20.0	2.19
1800	2.77	94.5	448.0	28.1	19.8	2.17
1900	1.78	15.4	448.0	26.4	19.7	2.18
2000	1.57	0.0	448.0	22.8	18.6	2.07
2100	.50	0.0	448.0	20.1	18.0	2.03
2200	.56	0.0	448.0	19.0	17.5	1.97
2300	1.74	0.0	448.0	17.8	17.0	1.92
August 5, 1976						
0000	1.72	0.0	450.0	17.3	16.4	1.84
0100	.32	0.0	450.0	16.6	16.1	1.82
0200	2.09	0.0	450.0	16.2	15.8	1.78
0300	1.00	0.0	450.0	15.8	15.3	1.72
0400	.28	0.0	450.0	15.8	15.2	1.71
0500	1.41	0.0	450.0	15.0	14.9	1.69
0600	1.16	1.1	450.0	14.9	14.9	1.69
0700	1.78	109.9	450.0	16.8	15.7	1.76
0800	.83	198.9	450.0	18.9	17.2	1.93
0900	1.37	252.7	450.0	21.9	18.9	2.13
1000	1.16	680.7	450.0	25.2	20.6	2.35
1100	.28	923.1	450.0	28.8	21.8	2.49
1200	.75	1,034.1	450.0	30.6	21.1	2.35
1300	.28	1,034.1	450.0	33.3	21.8	2.42
1400	1.70	286.8	450.0	29.8	18.8	1.99
1500	1.16	825.3	450.0	29.4	18.6	1.97
1600	.32	184.6	450.0	31.7	20.5	2.23
1700	.28	418.7	450.0	33.1	20.9	2.27
1800	.28	195.6	450.0	31.5	21.0	2.32
1900	.28	29.7	450.0	29.0	20.5	2.27
2000	1.68	0.0	450.0	24.3	19.6	2.20
2100	.28	0.0	450.0	21.3	19.1	2.17
2200	1.35	0.0	450.0	20.5	18.4	2.08
2300	.75	0.0	450.0	19.8	18.5	2.10
August 6, 1976						
0000	1.20	0.0	456.0	19.7	18.2	2.06
0100	.28	0.0	456.0	18.4	17.6	1.99
0200	.71	0.0	456.0	18.2	17.2	1.94
0300	.28	0.0	456.0	17.5	16.8	1.90
0400	1.51	0.0	456.0	17.4	17.0	1.93
0500	.28	0.0	456.0	17.1	16.5	1.86
0600	.28	2.19	456.0	17.8	17.0	1.92
0700	.28	109.9	456.0	17.9	17.2	1.94
0800	.28	284.6	456.0	23.0	19.1	2.14
0900	2.24	494.5	456.0	25.5	20.2	2.28

TABLE 10.—*Summary of meteorologic data, July 12–19 and August 1–8, 1976*—Continued

[Precipitation = 0.0 mm for entire period]

Time	Wind speed (m/s)	Short wave radiation (W/m²)	Long wave radiation (W/m²)	Air temperature		Vapor pressure (KPa)
				dry bulb (°C)	wet bulb (°C)	
			August 6, 1976—Continued			
1000	1.10	671.4	456.0	28.7	20.8	2.37
1100	.75	854.9	456.0	28.7	22.8	2.68
1200	1.51	854.9	456.0	28.6	21.6	2.46
1300	.28	917.6	456.0	29.3	22.0	2.52
1400	2.25	733.0	456.0	30.4	22.0	2.51
1500	.73	413.2	456.0	29.5	21.3	2.40
1600	.73	596.7	456.0	30.0	21.4	2.41
1700	1.00	376.9	456.0	30.3	21.3	2.38
1800	.90	188.5	456.0	26.5	20.8	2.37
1900	.79	0.0	456.0	22.7	20.3	2.34
2000	.48	0.0	456.0	19.5	18.4	2.09
2100	1.43	0.0	456.0	20.5	19.4	2.23
2200	1.55	0.0	456.0	20.5	19.7	2.28
2300	1.55	0.0	456.0	20.6	19.8	2.29
			August 7, 1976			
0000	1.51	0.0	444.0	20.8	19.7	2.27
0100	.95	0.0	444.0	19.9	19.3	2.22
0200	1.41	0.0	444.0	20.0	19.4	2.24
0300	1.12	0.0	444.0	19.6	19.1	2.20
0400	.28	0.0	444.0	19.7	19.4	2.24
0500	.28	0.0	444.0	19.1	18.8	2.16
0600	.28	0.0	444.0	19.0	18.6	2.13
0700	.90	109.9	444.0	20.2	19.6	2.26
0800	.28	271.4	444.0	20.5	19.6	2.26
0900	.77	285.7	444.0	20.7	19.9	2.30
1000	.29	281.3	444.0	21.7	20.3	2.35
1100	.29	216.5	444.0	22.9	21.1	2.47
1200	1.66	458.2	444.0	23.2	21.4	2.51
1300	2.11	735.2	444.0	24.1	21.8	2.57
1400	1.41	390.1	444.0	25.5	21.9	2.56
1500	2.09	780.2	444.0	27.6	22.2	2.58
1600	.87	609.9	444.0	28.5	22.1	2.55
1700	.36	397.8	444.0	27.3	21.6	2.48
1800	.28	159.3	444.0	27.3	21.8	2.52
1900	.50	40.7	444.0	27.7	22.3	2.60
2000	1.41	0.0	444.0	24.8	22.1	2.61
2100	1.80	0.0	444.0	23.1	21.7	2.57
2200	.59	0.0	444.0	22.1	20.2	2.33
2300	1.66	0.0	444.0	21.0	20.1	2.33
			August 8, 1976			
0000	0.81	0.0	445.0	20.4	19.5	2.25
0100	.71	0.0	445.0	19.8	19.0	2.18
0200	.90	0.0	445.0	19.8	18.9	2.16
0300	1.00	0.0	445.0	19.3	18.2	2.07
0400	.32	0.0	445.0	19.2	18.5	2.11
0500	1.28	0.0	445.0	18.5	18.1	2.06
0600	.52	0.0	445.0	18.1	17.7	2.01
0700	1.78	105.5	445.0	19.2	18.4	2.10
0800	.28	291.2	445.0	19.6	18.6	2.12
0900	2.07	487.9	445.0	21.7	19.4	2.21
1000	.65	702.2	445.0	22.9	19.5	2.21
1100	1.86	856.0	445.0	23.5	19.0	2.12
1200	.32	942.9	445.0	26.0	19.9	2.22
1300	1.97	749.5	445.0	27.2	19.5	2.14
1400	.28	224.2	445.0	26.4	19.2	2.10
1500	1.70	872.5	445.0	26.9	18.7	2.02
1600	.69	660.4	445.0	26.9	19.4	2.13
1700	.28	409.9	445.0	26.2	18.5	2.00
1800	.67	205.5	445.0	26.6	19.2	2.10
1900	.85	29.7	445.0	24.9	18.7	2.05
2000	1.04	0.0	445.0	23.1	17.9	1.96
2100	.67	0.0	445.0	21.4	17.4	1.92
2200	1.12	0.0	445.0	21.0	16.9	1.85
2300	1.68	0.0	445.0	20.1	17.1	1.90

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