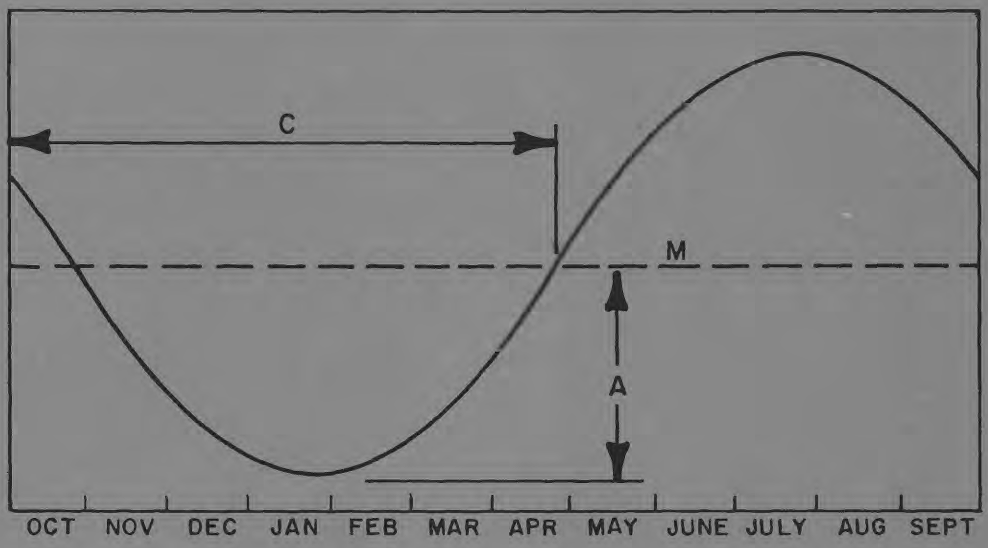
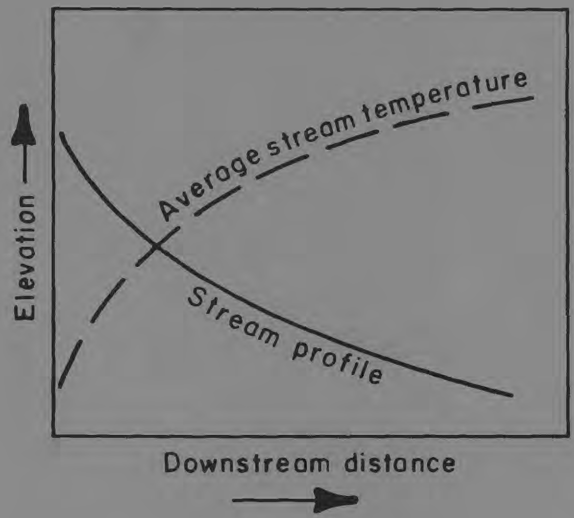
AN ANALYSIS OF STREAM TEMPERATURES, GREEN RIVER BASIN, WYOMING

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-13





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Application of the above equation for estimating temperatures at unmeasured sites requires regionalized estimates of M, A, and C. Regional estimates were developed with the aid of multiple-regression techniques, whereby the calculated harmonic coefficients were regressed against physical and climatic characteristics of the stream-temperature stations. Stream elevation was found to be a significant factor affecting water temperature.

Analysis of areal and temporal variations in temperature showed that springs, irrigation return flows, and reservoir storage were affecting reaches of several major streams.

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CONVERSION FACTORS

The following factors may be used to convert the U.S. customary units published herein to the International System of Units (SI).

Multiply U.S. customary units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
acre	.004047	square kilometer (km^2)
	.4047	hectare (ha)
mile (mi)	1.609	kilometers (km)
square mile (mi^2)	2.590	square kilometers (km^2)
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)

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ABSTRACT

This report presents a method for estimating temperatures of streams in the Green River Basin, Wyoming. The procedure utilizes a regional model for estimating mean daily temperatures of streams at unmeasured sites. The regional model was developed by describing annual temperature patterns at 43 measured sites in the basin and by applying the harmonic function

$$T = M + A [\sin (0.0172 t + C)]$$

where T is mean daily temperature,
M, A, and C are harmonic coefficients calculated from data for each stream-temperature station, and
t is the day of the water year.

Application of the above equation for estimating temperatures at unmeasured sites requires regionalized estimates of the coefficients M, A, and C. Regional estimates were developed with the aid of multiple-regression techniques. Harmonic coefficients calculated from measured station data were regressed against physical and climatic characteristics of the stream-temperature stations. The harmonic mean (M) was found to be related to stream elevation (E): $M = 19.5 - 0.0019 E$. Useable regression equations could not be developed for describing regional values of harmonic amplitude (A) and phase coefficient (C). However, station values of A were found to have certain areal patterns, and a map showing regional values was developed for estimating A at unmonitored sites. Variation in station values of C was small (range 2.47 to 3.36 radians), and an average value of 2.68 radians is used for estimating C at unmeasured sites. Examples are presented for utilizing the model to estimate temperatures at unmeasured sites.

Analysis of areal and temporal variations in temperature showed that springs, irrigation return flows, and reservoir storage were affecting reaches of several major streams.

INTRODUCTION

This report presents an analysis of water-temperature records for streams in the Green River Basin, Wyoming. Water demands in this area are increasing rapidly as a result of extensive mineral development (Lowham and others, 1976). The main purpose of this report is to provide a method for estimating stream temperatures at unmeasured sites. This information would aid planning and management of the basin surface waters.

The procedure for developing a technique for estimating stream temperatures consisted of (1) compiling available stream-temperature data for measured sites of the basin, (2) mathematically describing temperature characteristics at each measured site, and (3) developing a regional model for estimating stream temperatures at unmeasured sites throughout the area.

In addition to describing the estimating technique, this report also includes (1) example problems that describe in detail how the estimating technique may be applied, (2) results of stream-reach profile studies that show downstream changes in temperature characteristics of four major streams in the study area, and (3) results of a trend analysis that was made to detect possible year-to-year (long-term) changes in stream temperature.

Acknowledgements

The advice of Timothy D. Steele and his assistance in the regional analysis and report preparation is gratefully acknowledged. The author is also grateful to James F. Kircher, Deborah K. Wells, and Chantel P. Blevins for assistance in compiling and preparing the temperature data for analysis.

Data Available

Temperature data with two different collection frequencies--periodic and daily--were available for this analysis. Periodic data were available for 44 streamflow stations in and near the study area. The periodic data consist of temperature measurements that are made at streamflow stations when discharge is measured by hydrographers of the U.S. Geological Survey. These temperature measurements have been made about monthly since about 1960. Lengths of the periodic records used in this analysis vary from 3 to 15 years. Daily temperature observations, collected by hired observers, were available for six water-quality stations in the study area. Lengths of the daily records vary from 8 to 25 years. Figure 1 shows locations of the stream-temperature stations. Table 1 lists the stream-temperature stations, periods of record, and types of data available for the analysis. Of the 44 stations listed in the table, 43 are sites on perennial streams with headwaters originating in

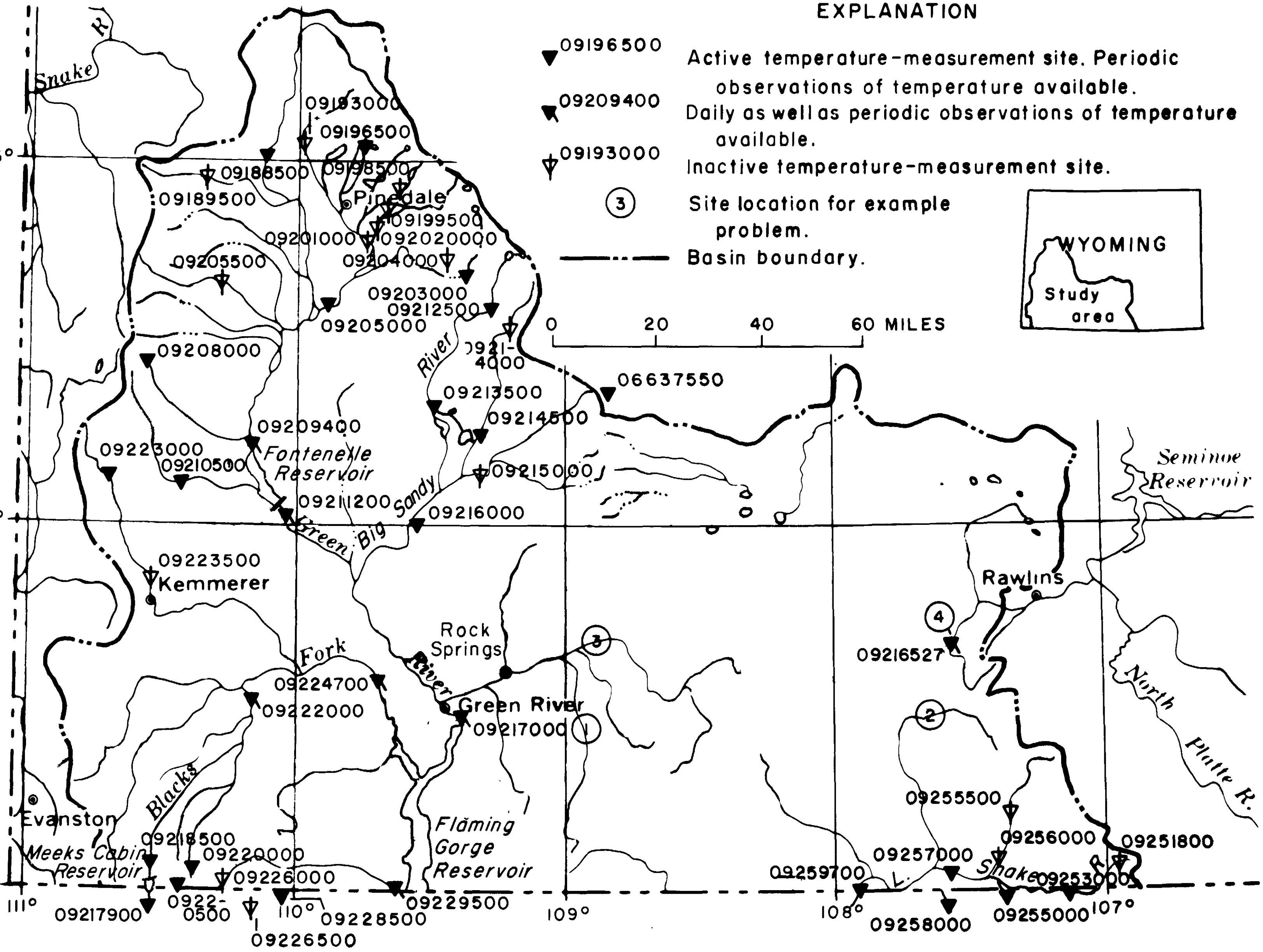

Figure 1.—Locations of stream-temperature stations.

mountainous areas. Only one site (station 09215000) is located on an intermittent stream with headwaters that originate in the interior plains area. A shortage of data exists for intermittent and ephemeral streams of the plains. To help overcome this data shortage, eight new stations have been recently (1976 water year) installed on plains streams (Lowham and others, 1976, p. 40).

METHOD OF ANALYSIS

Temperature changes occur in streams mainly as a result of net gains or losses in heat from convection, radiation, evaporation, and solar radiation. Stream temperatures in the study area may vary annually from as low as 0°C during winter periods to over 25°C in late summer, depending on local meteorologic and hydraulic conditions. Seasonal stream-temperature patterns typically exhibit a cyclical pattern through the year. As an example, figure 2 shows the cyclical pattern in periodic observations of water temperature at station 09217000 on the Green River for water years 1961-74.

Harmonic Function

The annual variation of stream temperatures is approximately sinusoidal and has been depicted by the following harmonic function (Ward, 1963; Collings, 1969; Steele and Gilroy, 1972)

$$T = M + A\,[\sin\,(0.0172\,t + C)] \qquad (1)$$

where T = stream temperature, in °C (degrees Celsius) on day t of the water year (October 1 is $t = 1$);
M = mean of the harmonic function, in °C;
A = amplitude of the harmonic function, in °C;
t = day of the water year (table 2); and
C = phase angle of the harmonic function, in radians.

Figure 3 is an example of a harmonic function fitted to periodic observations of water temperatures. For streams where water temperatures reach 0°C for prolonged periods in the winter, the harmonic curve becomes discontinuous (fig. 3). Harmonic-function estimates of stream temperatures less than 0°C are disregarded and temperature estimates of 0°C are prevalent during this period.

The harmonic coefficients (M, A, and C) were derived for each station record by regression analysis of equation 1. The analysis procedure was accomplished through the use of a computer program documented by Steele (1974). Harmonic coefficients were calculated for (1) the period of available record for stations having periodic observations; and (2) individual years for stations having daily observations. The resultant harmonic coefficients from this analysis are listed in tables 3 and 4.

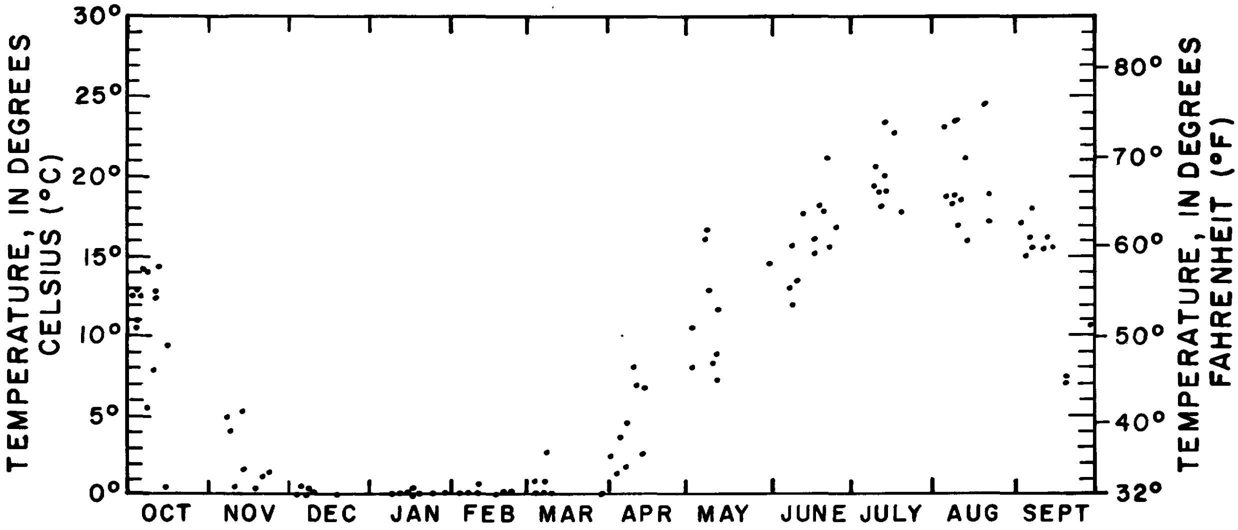

Figure 2.—Periodic observations of water temperatures, station 09217000 Green River near Green River (1961–74 water years).

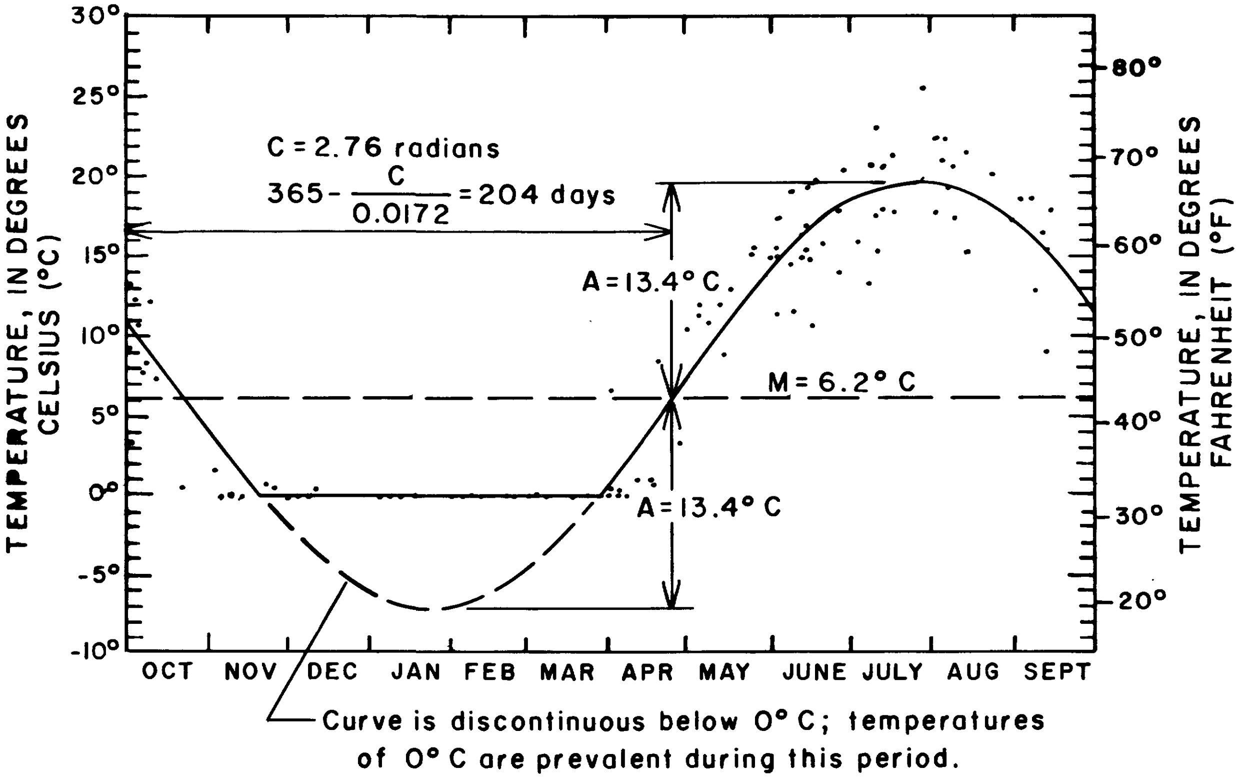

Figure 3.—Harmonic function fitted to periodic observations of water temperatures, station 09214500 Little Sandy Creek above Eden. Harmonic curve represents mean daily stream temperatures, averaged from observations made during water years 1961–74.

The RSQD (root mean square) term listed in tables 3 and 4 is a measure of the percentage of annual variability in the temperature data explained by the harmonic function. The SE (standard error of estimate) term is a measure of the scatter of data points about the harmonic curve. On the average, two-thirds of the data points will fall within plus or minus one SE of the estimated value. For example, from the harmonic curve shown in figure 3, estimates of mean daily temperatures are obtained from observations made on 82 days during water years 1961-74. Daily temperatures during any particular year would deviate from the mean daily values shown by the curve. From table 3, RSQD = 81.92 and SE = 2.87°C for the harmonic fit of station 09214500. Thus, the harmonic equation explains for 81.92 percent of the annual variability in stream temperature, and about two-thirds of the periodic observations made during water years 1961-74 plot within ±2.87°C of the curve.

Regional Analysis

A regional model, from which stream temperatures at unmeasured sites can be estimated, was developed by relating the harmonic coefficients calculated for measured sites to physical and climatic characteristics of the respective streams. Multiple-regression techniques were used to determine which of the selected physical and climatic characteristics significantly affect stream temperature. In this procedure, the harmonic coefficients M, A, and C (dependent variables) were regressed against the following physical and climatic characteristics (independent variables):

a. Elevation of stream-temperature site (E), in feet.

b. Average growing season of upstream drainage basin (AGS), in days.

c. Drainage area (A), in square miles.

d. Mean annual discharge (Q_a), in cubic feet per second.

e. Annual peak flow with average recurrence interval of 2 years (P_2), in cubic feet per second.

f. Width of the stream channel during bankfull flow (W), in feet.

g. Mean depth of the main channel during bankfull flow (D), in feet.

h. Amount of irrigation upstream from site (IRRIG), in acres.

i. Latitude of the site (LAT), in degrees.

j. Average direction of the stream (AP), expressed as 2.0 + COS θ, where θ is the angle between south and a line passing in the average direction of flow.

Table 5 lists values of the above physical and climatic characteristics for the stream-temperature stations used in the regional analysis.

Data Used

Only data for stations having periodic observations were used in the regional analysis. Data for stations with daily observations were not used, because observers who make the observations usually do so at a particular time each day. Thus, the daily observations might not accurately depict daily mean temperatures. The periodic observations are made at various times throughout the day; therefore, in aggregate they more closely depict daily mean temperatures. Most of the observations are made during daylight hours. Depending on the size of the stream and time of year, the periodic observations may represent slightly higher than daily mean temperatures. Variation of temperature within a day is greatest during late summer and least during winter. Diurnal variation has been observed by the author to be as much as 20°C in small plains streams, but it is generally less than about 5°C in large perennial streams.

Data for station 09211200 were not used in the regional analysis because they were known to be affected by Fontenelle Reservoir. Likewise, data for station 09218500 were not used for years later than 1971 when storage in Meeks Cabin Reservoir began.

Harmonic Mean

Results of the regional regression analysis showed an arithmetic function of site elevation (E) to be the most significant independent variable for estimating annual harmonic-mean stream temperature (M). The other physical and climatic characteristics were not found significant enough (at the 1.0 percent level) to warrant inclusion in the estimating relation. The computed equation

$$M = 19.5 - 0.0019\ E \qquad (2)$$

has a correlation coefficient (r) of 0.87 and a standard error of estimate (SE) of 0.88°C. Figure 4 is a graph of the above relation exhibiting the data used for its development.

Amplitude

The regional regression analysis also showed site elevation (E) to be the most significant independent variable for estimating amplitude (A). However, regression statistics of the computed equation were poor ($r = .49$, $SE = 1.5$°C), and the equation was considered inadequate for prediction purposes. Station values of coefficient A subsequently were plotted on a map, and regional patterns were observed that had not been described by the regression. Using the map plot of station values, lines of equal A were constructed as shown by figure 5. For prediction purposes, the regionalized value of A for an unmeasured site can be determined from figure 5.

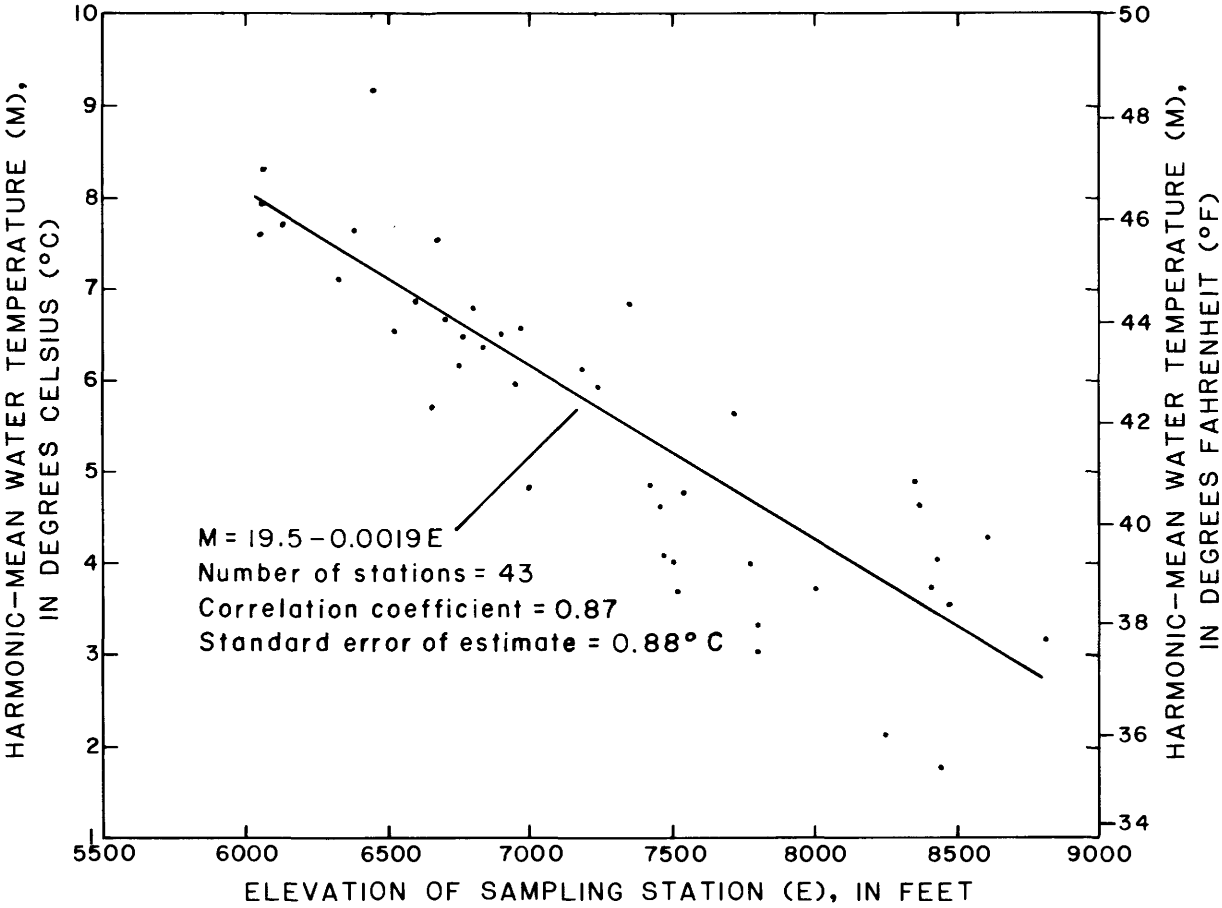

Figure 4.—Relation of the annual harmonic-mean water temperature versus elevation of sampling station for streams in the Green River Basin, Wyoming.

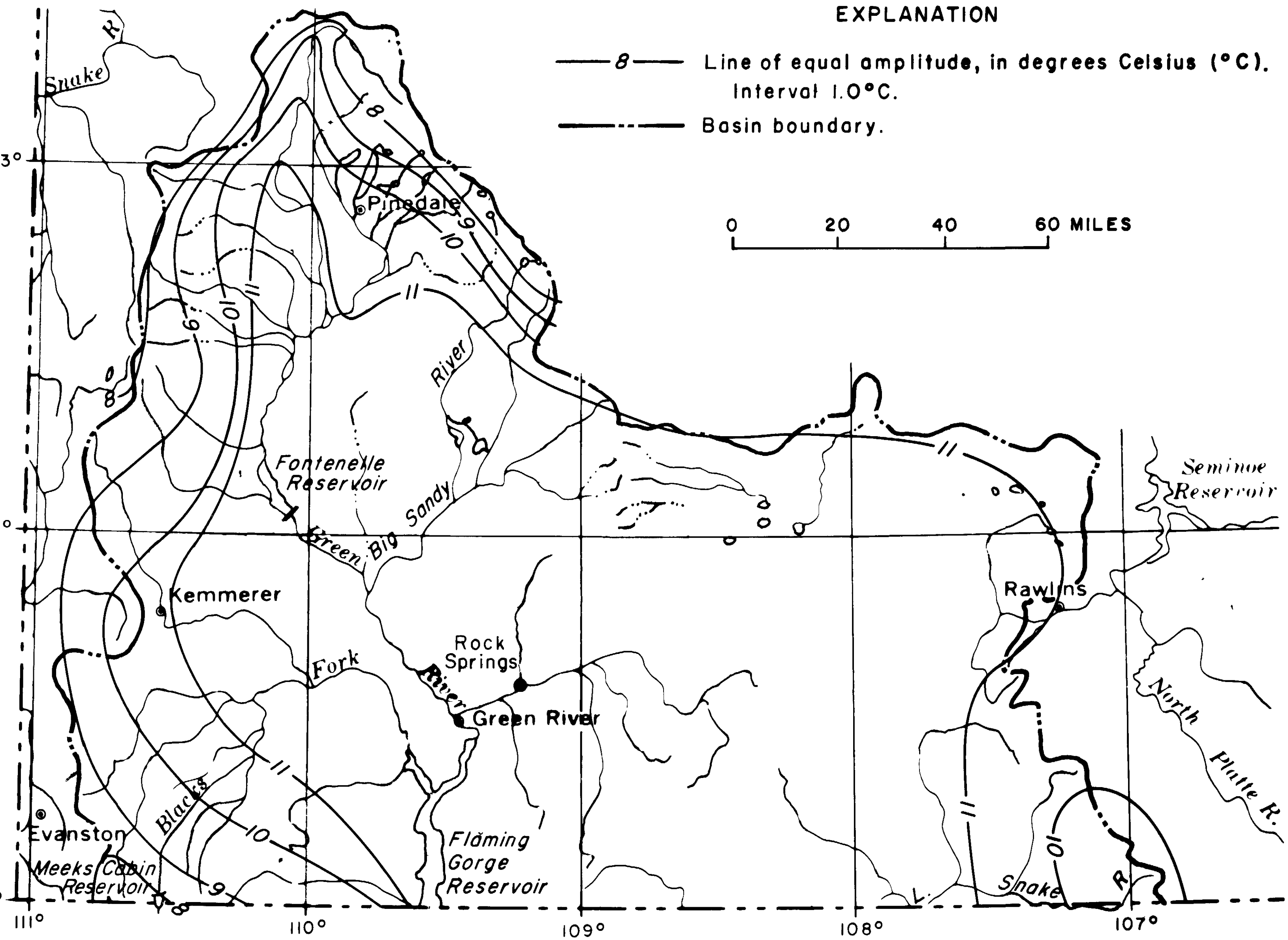

Figure 5.—Regionalized values of harmonic amplitude for estimating stream temperatures at unmeasured sites.

Values of A for the 44 stations listed in table 3 range from 5.66 to 13.38°C. A comparison was made of the predicted A values from figure 5 with the measured values from table 3. Eighty-two percent (36 of 44) of the stations listed in table 3 had predicted values within 1.5°C of the measured values.

Phase Coefficient

The regional regression analysis did not yield a relation significantly accurate for estimating the phase coefficient (C). A map plot of C showed no regional trends. As shown by figure 3, C is a measure of when the rising part of the harmonic curve intersects M. This may be calculated in days of the water year by the following equation

$$t = 365 - \frac{C}{0.0172} . \qquad (3)$$

Values of C in table 3 have a range from 2.47 to 3.36, an average of 2.68, and a standard deviation of 0.14. For the average C of 2.68 radians, t = 209 days or April 27 (table 2). Eighty-two percent of the C values in table 3 are within plus or minus one standard deviation (0.14 radians or 0.14/0.0172 ≃ 8 days) of the mean. Considering the low range of variability of this coefficient, it was decided the best estimate of C for prediction purposes would be to use an average regional value of 2.68 radians.

APPLICATION

The harmonic coefficients M, A, and C can be determined and used with equation 1 to estimate mean daily stream temperatures for sites throughout the Green River Basin, Wyoming. The technique applies to relatively natural streams whose temperature characteristics are not appreciably affected by manmade works or ground-water inflows. The technique should not be used to estimate stream temperature just downstream from major dams or from relatively large agricultural, industrial, or municipal return flows. However, it could be applied in these cases to determine what natural stream temperatures would be if certain manmade works were not there.

Care should be exercised when using the technique for sites where substantial ground-water inflows may occur. It is advised that a field visit be made to determine the relative magnitude of such inflow. Several periodic field measurements of stream temperature should be made over a range of conditions to verify estimates from the temperature model. Use of the regional model yields average values that would be expected to occur on a long-term basis.

The following examples demonstrate several applications of the study results:

Example 1: Estimating Annual Maximum and Minimum Temperatures

The annual maximum and minimum daily temperatures (T_{max} and T_{min}) likely to occur in a stream are determined by the following equations

$$T_{max} = M + A \qquad (4)$$

and

$$T_{min} = M - A. \qquad (5)$$

Consider a situation where estimates of T_{max} and T_{min} are desired for Salt Wells Creek at a site about 18 miles southeast of Rock Springs (site 1, fig. 1). The elevation (E) of the stream site is determined from a topographic map to be 6,600 feet. The harmonic mean (M) is determined as

$$M = 19.50 - 0.0019\ E \qquad (2)$$

$$M = 19.50 - 0.0019\ (6{,}600)$$

$$M = 7.0°C.$$

From figure 5, the amplitude (A) is shown to be 11.0°C. Using equations 4 and 5

$$T_{max} = 7.0 + 11.0 = 17.0°C$$

and

$$T_{min} = 7.0 - 11.0 = -4.0°C \rightarrow 0°C.$$

[Harmonic-function estimates of temperatures less than 0°C are disregarded and temperatures of 0°C are used; minimum temperature of fresh water as a fluid is 0°C.]

The above calculations of T_{max} and T_{min} yield mean daily temperatures. They represent average maximum and minimum values that would be expected to occur over a period of many years. Diurnal variation could cause momentary temperatures different from the mean daily temperatures calculated.

Example 2: Estimating Temperature for a Given Day

Stream temperature for a particular day is estimated by determining the harmonic coefficients M, A, and C for the site and applying them to equation 1

$$T = M + A\,[\sin\,(0.0172\ t + C)]. \qquad (1)$$

Consider a situation where an estimate of mean daily temperature is desired for June 15 at a site on Muddy Creek about 30 miles southwest of Rawlins (site 2, fig. 1). Elevation (E) of the site is 6,800 feet. The harmonic mean (M) is determined as

$$M = 19.50 - 0.0019\ E \qquad (2)$$

$$M = 19.50 - 0.0019\ (6{,}800)$$

$$M = 6.6°C.$$

From figure 5, the amplitude (A) is shown to be 11.0°C. The average phase coefficient (C) is 2.68 radians. Table 2 (p. 34) shows t = 258 for June 15. Using equation 1, and keeping in mind that the sine function is in radian measure

$T = 6.6 + 11.0\ [\sin\ (0.0172 \times 258 + 2.68)] =$ ~~7.3~~ 14.7°C.

Similiar estimates may be calculated for other days of the year.

Example 3: Estimating When a Given Temperature Will Occur

Mean daily temperatures between T_{max} and T_{min} occur at least twice on the harmonic curve--once as the temperature is increasing, and once as it is decreasing. The two dates of occurrence of a specified temperature may be calculated by modifying equation 1 (Shampine, 1977, p. 14-16), such that

$$t = \frac{[(-1^{k})\ \text{arc sin}\ (\frac{T - M}{A}) + k] - C}{0.0172} + 365. \qquad (6)$$

When k = 0 the calculated day represents T when daily temperatures are increasing; when k = 1 the day represents T when daily temperatures are decreasing.

Assume an estimate is desired of when mean daily temperature is 5.0°C or greater at a site on Bitter Creek about 18 miles east of Rock Springs (site 3, fig. 1). Elevation of the site is 6,400 feet. The harmonic mean (M) is determined as

$$M = 19.50 - 0.0019\ E \qquad (2)$$

$$M = 19.50 - 0.0019\ (6{,}400)$$

$$M = 7.3°C.$$

From figure 5, the amplitude (A) is estimated to be 11.0°C. The average phase coefficient (C) is 2.68 radians. Using equation 6, k = 0 for the rising occurrence

$$t = \frac{[(-1^k)\ \text{arc sin}\ (\frac{T - M}{A}) + k] - C}{0.0172} + 365 \qquad (6)$$

$$t = \frac{[(1)\ \text{arc sin}\ (\frac{5.0 - 7.3}{11.0}) + (0)] - 2.68}{0.0172} + 365$$

t = 197 or April 15 (table 2)

and

k = 1 for the falling occurrence

$$t = \frac{[(-1)\ \text{arc sin}\ (\frac{5.0 - 7.3}{11.0}) + (1)] - 2.68}{0.0172} + 365$$

t = 404.

[If t is computed to be greater than 365, subtract 365. This will happen when the falling occurrence is before the rising occurrence during the water year.]

t = 404 - 365 = 39 or November 8 (table 2).

Figure 6 is a graph of the harmonic curve and estimated temperature characteristics for this site.

Estimates of the average lengths of time daily temperatures exceed, or are less than, a specified temperature are determined as follows. Using the above example, mean daily temperatures are estimated to be 5°C or greater during the period April 15 to November 8 (208 days per water year). Conversely, mean daily temperatures are estimated to be 5°C or less during the period November 8 to April 15 (159 days per water year).

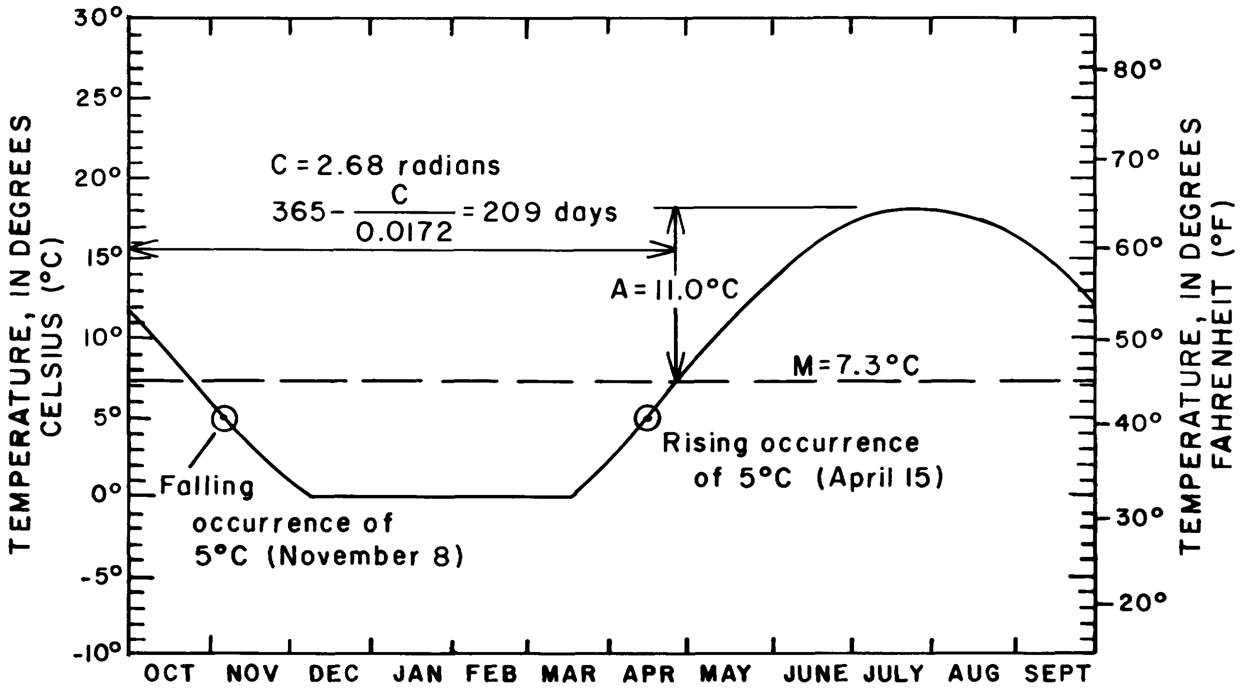

Figure 6.—Harmonic curve and estimated temperature characteristics for Bitter Creek at a site 18 miles west of Rock Springs.

Example 4: <u>Comparison of estimated versus measured temperatures for a site</u>

A streamflow and water-quality station was established at the beginning of the 1976 water year on Separation Creek at a site about 18 miles southwest of Rawlins (site 4, fig. 1). The station has an instrument that continuously measures and records stream temperature. Elevation (E) of the site is 6,810 feet. Using the regional model, streamflow characteristics are determined as follow. The harmonic mean (M) is determined as

$$M = 19.50 - 0.0019\ E \qquad (2)$$

$$M = 19.50 - 0.0019\ (6{,}810)$$

$$M = 6.6°C.$$

From figure 5 the amplitude (A) is shown to be 11.0°C. The average phase coefficient (C) is 2.68 radians. Substituting the above coefficients into equation 1

$$T = 6.6 + 11.0\ [\sin\ (0.0172\ t + 2.68)].$$

Figure 7 is a graph showing the harmonic curve of the above function along with daily mean temperatures that were recorded during the 1976 water year.

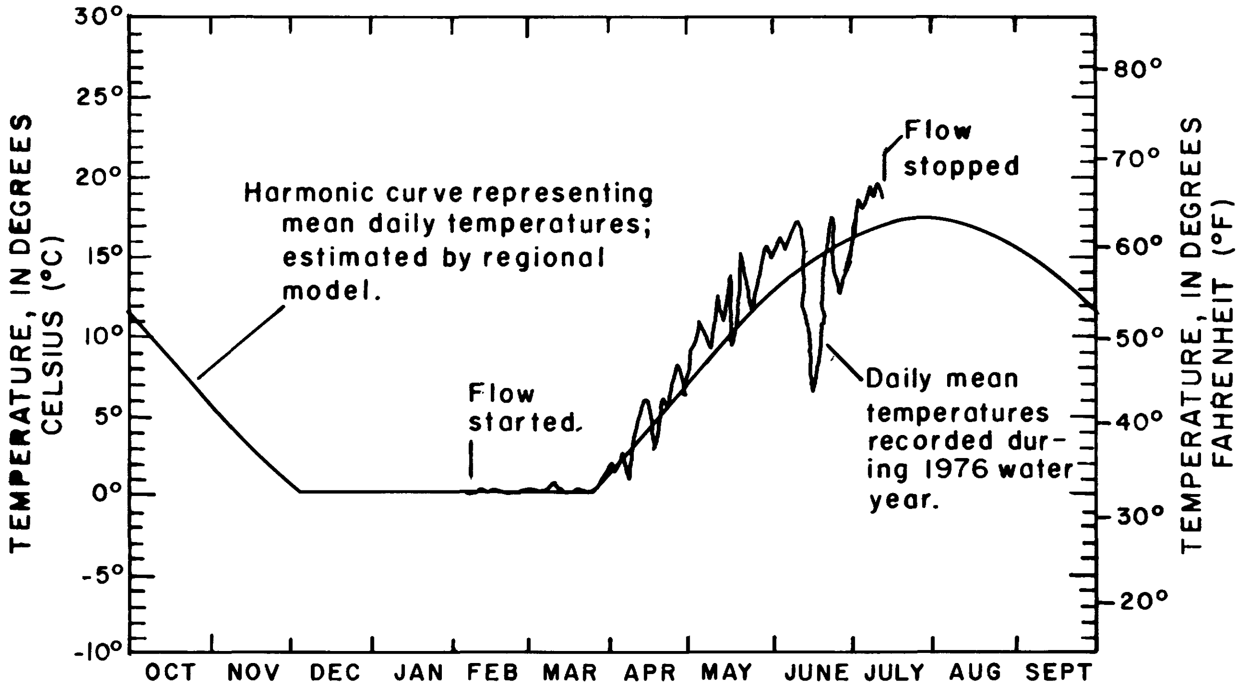

Figure 7.— Comparison of estimated versus measured temperatures, station 09216527 Separation Creek near Riner.

DOWNSTREAM TEMPERATURE CHARACTERISTICS OF MAJOR STREAMS

Stream-reach profiles showing downstream changes in water-temperature characteristics were determined for several major streams of the study area. Harmonic coefficients calculated from individual station data (table 3) were compared with coefficients estimated by the regional temperature model. In general, the estimates are close to the station values. Considerable differences may occur when stream temperature is affected by ground-water inflows or by manmade developments.

Green River

Figure 8 shows elevation and water-temperature characteristics in relation to downstream distance for the Green River. The effects of Fontenelle Reservoir on the harmonic coefficients M and A at station 09211200 are shown on the graph. Figure 9 shows effects of the reservoir on mean daily stream temperatures at station 09211200, which is located about 1.0 mile downstream from Fontenelle Dam. Comparison of estimates from the regional model with calculated values using data from station 09211200 indicates M has increased and A has decreased due to the reservoir.

Figure 8 shows that the calculated temperature characteristics are close to the estimated values at station 09217000, which is about 71 miles downstream from Fontenelle Dam. Thus, the reservoir does not appear to be affecting stream temperatures as far downstream as station 09217000. The actual stream distance for which stream temperatures are influenced varies with meteorologic and hydraulic conditions.

A deterministic temperature model such as the one developed by Jobson (1973) could be used to predict the downstream effect of the reservoir on temperature of the Green River for any particular day of the year. The model utilizes stream velocity, depth, and local wind speed to determine the downstream persistence of manmade stream-temperature changes. The model could be applied to other streams as well, and could be used in conjunction with the regional model of this report to predict effects of return flows and reservoirs on downstream temperature. Effects of proposed as well as existing developments could be analyzed through the use of such models.

Big Sandy River

Figure 10 shows elevation and water-temperature characteristics in relation to downstream distance for the Big Sandy River. Comparison of the calculated versus estimated values shows anomalies in A at station 09213500 and in M at station 09216000. The high value of A at station 09213500 is apparently the result of high summertime temperatures. There is relatively little irrigation upstream from the station. Also, a review of streamflow records shows average annual runoff to be 86.0 ft^3/s at station 09212500 and 86.5 ft^3/s at station 09213500. These values indicate there is little inflow between the stations.

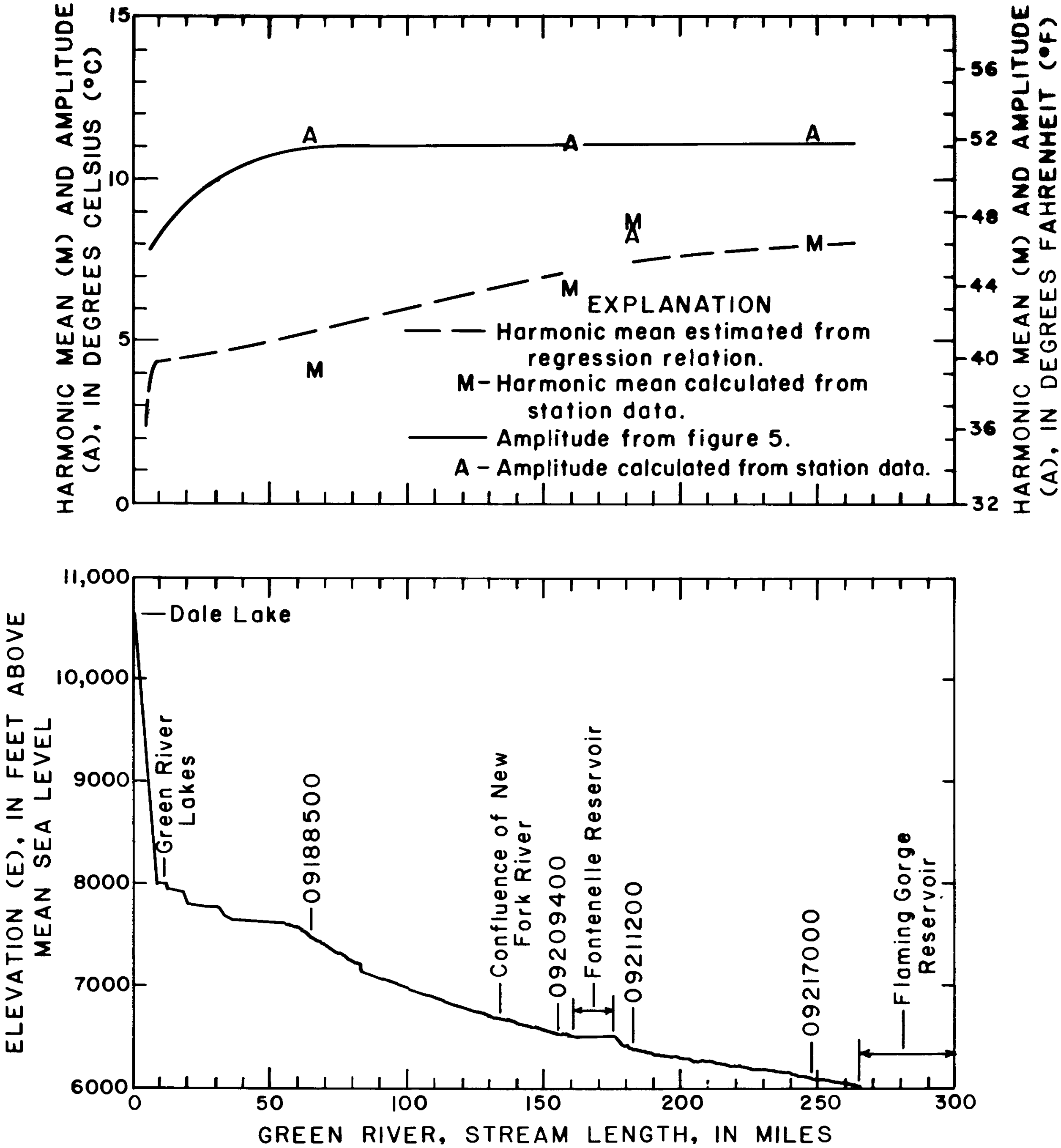

Figure 8.—Elevation and water-temperature characteristics in relation to downstream distance, Green River, Wyoming.

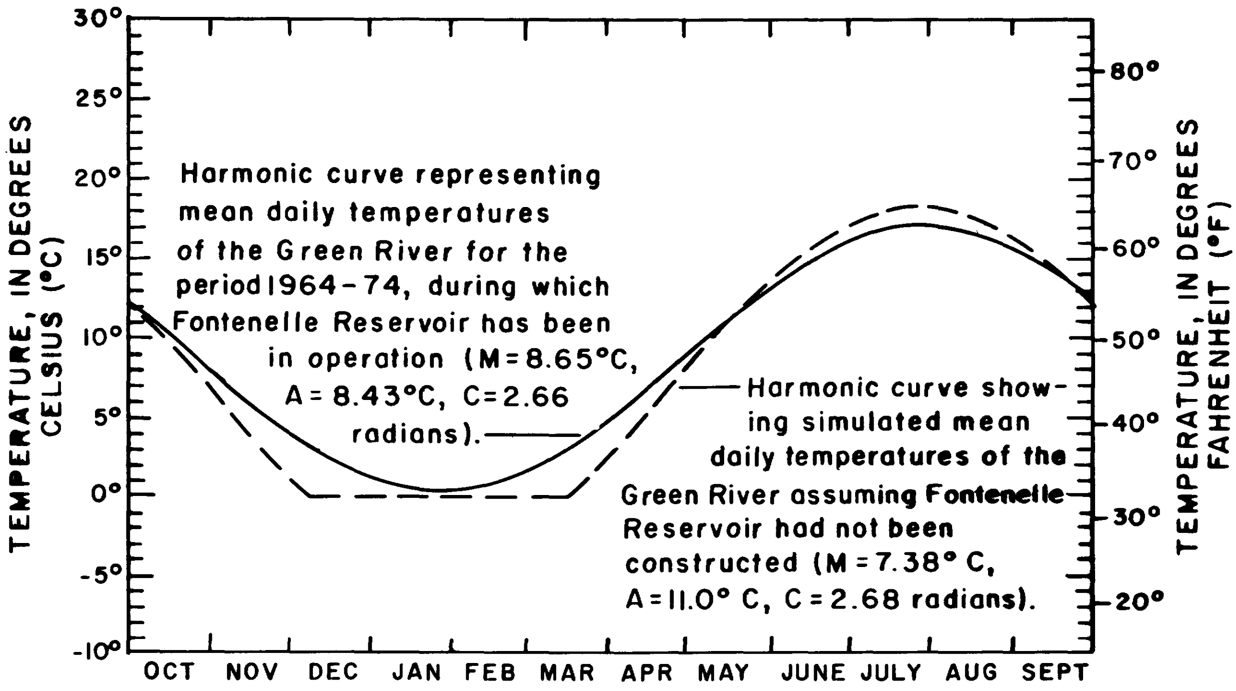

Figure 9.—Effect of reservoir storage and operation on mean daily stream temperatures at station 09211200 Green River below Fontenelle Reservoir.

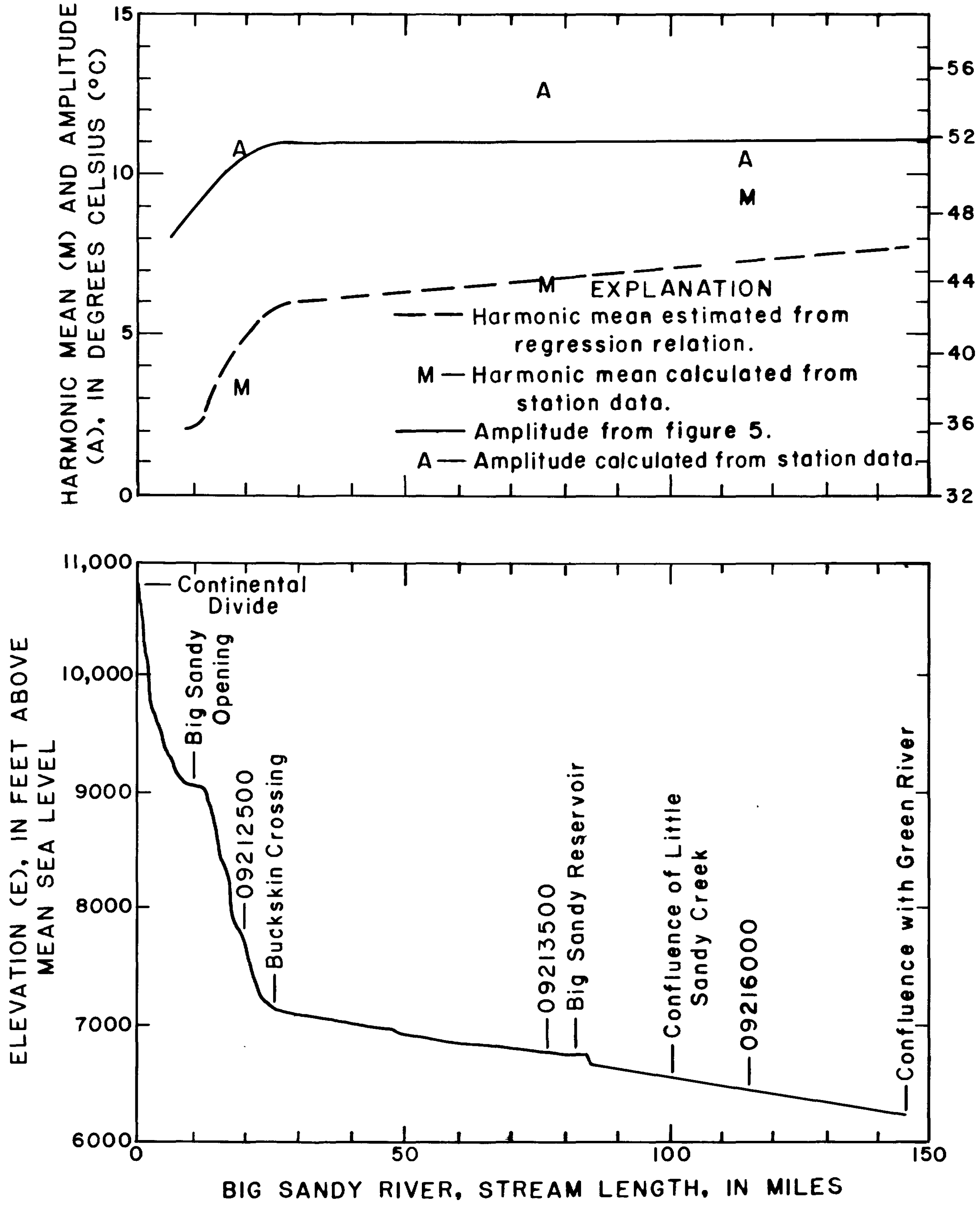

Figure 10.—Elevation and water-temperature characteristics in relation to downstream distance, Big Sandy River.

Thus, neither irrigation nor ground-water inflows appear to be the cause of the high A. However, from Buckskin Crossing to station 09213500, the stream crosses a plains area where streambank vegetation is sparse. The high summertime temperatures are evidently the result of high ambient air temperatures, coupled with a scant amount of shade along the stream.

Significant ground-water inflows occur in the lower reach of the Big Sandy River, and the increase in the value of M at station 09216000 is attributed to these inflows. Base-flow measurements of the Big Sandy River were made by the author and others during November 17 and 18, 1976. Discharge of the Big Sandy River increased from 29.0 ft^3/s just downstream from the confluence of Little Sandy Creek to 71.8 ft^3/s just upstream from the confluence with the Green River. This increase of almost 43 ft^3/s was noted to occur as a result of ground-water inflows to the Big Sandy River. Temperatures of these inflows averaged about 9.0°C.

Blacks Fork

Figure 11 shows elevation and water-temperature characteristics for the Blacks Fork in relation to downstream distance. The calculated temperature coefficients at station 09217900 are appreciably different from the estimated values. The calculated M is about 2.0°C higher than the value estimated with the regional model; whereas, A is almost 4.0°C lower. These differences may be attributed to large spring inflows in the headwaters of the stream. Stream temperatures at the station have not had sufficient time to equalize to surrounding meteorologic conditions.

Values of M and A for station 09218500 are shown for both the period of record before construction of Meeks Cabin Dam (1961-70) and the period after (1971-74). It is evident that the reservoir has reduced A and increased M in the reach just downstream from the dam.

The high value of A calculated for data at station 09222000 is apparently caused by high summertime temperatures. There are diversions for irrigation of about 62,200 acres above the station. The high value of A for the station is attributed largely to the effects of this irrigation on stream temperatures.

Little Snake River

Figure 12 shows elevation and water-temperature characteristics in relation to downstream distance for the Little Snake River. The estimated harmonic coefficients compare closely with the station values, except for A at station 09259700. The higher value of A is attributed to high summertime temperatures caused by irrigation diversions and return flows upstream from the station.

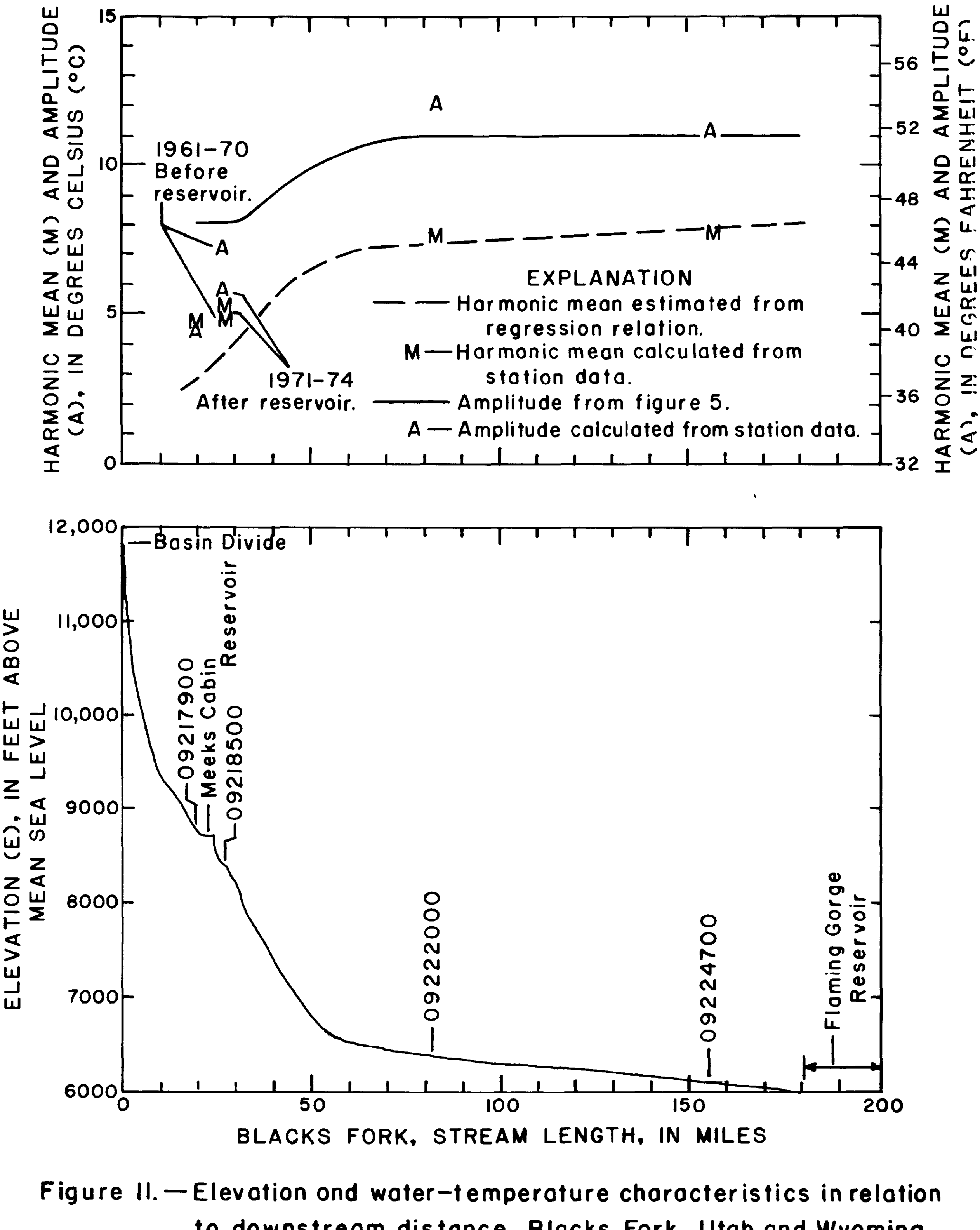

Figure 11.—Elevation and water-temperature characteristics in relation to downstream distance, Blacks Fork, Utah and Wyoming.

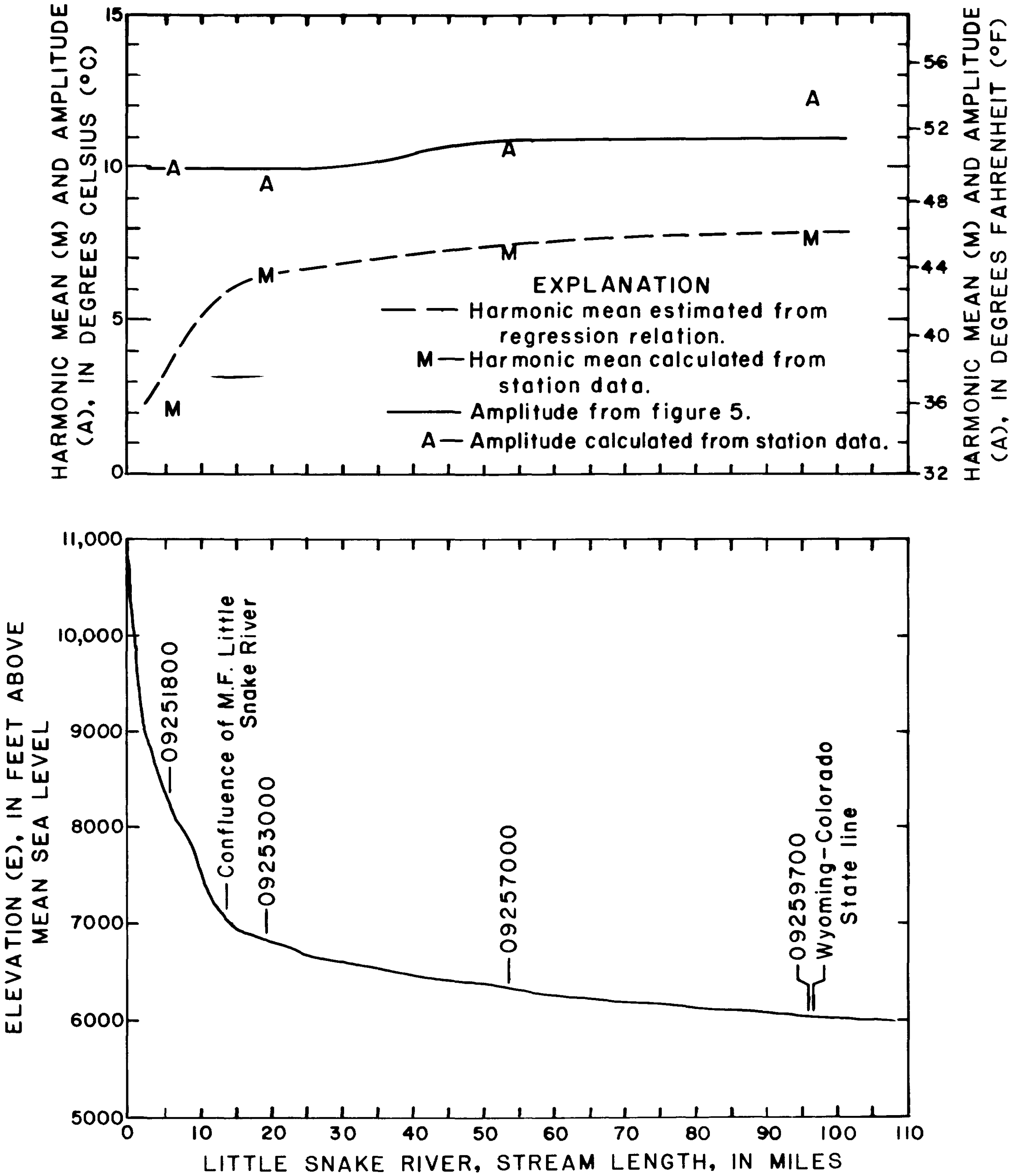

Figure 12 — Elevation and water-temperature characteristics in relation to downstream distance, Little Snake River, Wyoming.

TRANSIENT COMPONENTS IN STREAM TEMPERATURES

The harmonic coefficients based upon annual incremental records can be used to study year-to-year (long-term) variation in stream-temperature characteristics. For example, figure 13 shows annual values of M for the six water-quality stations having daily observations of temperatures. Visual inspection and statistical analyses of the coefficients M, A, and C were made to detect possible trends or changes caused by factors other than natural variation. Kendall's tau test for trend analysis (Steele and others, 1974, p. 43-47) was applied to the data listed in table 4. No significant trends (at the 99 percent level of confidence) were detected at any of the six daily-record stations.

The trend analyses would not detect manmade influences that have existed during the periods of records. For example, data for station 09211200 (Green River below Fontenelle Reservoir) have been obtained only since the reservoir was constructed. Had preconstruction data been available, the effect of the reservoir on stream temperatures would have been apparent. (See Bolke and Waddell (1975, p. A21-A24) for example of the effect of Flaming Gorge Reservoir on the Green River.)

Stream temperatures at station 09211200 were shown previously in the report to be affected by Fontenelle Reservoir. However, annual values of harmonic-mean temperatures at the downstream station 09217000 (Green River near Green River) did not appear to be affected by the reservoir since storage began in 1964. (See fig. 9.) Figure 14 shows annual values of harmonic-mean water temperatures for station 09217000 along with mean air temperatures for the National Weather Service station at Green River. Cumulative moving averages of the means also are shown in the figure. Inspection of the harmonic-mean water temperatures indicates no apparent trends. However, mean air temperatures appear to have decreased since about 1960. An investigation of the air-temperature data revealed that the weather station was moved in November 1957 from the post office in town to the water plant along the river. The new location is closer to the river, which would account for lower temperature readings.

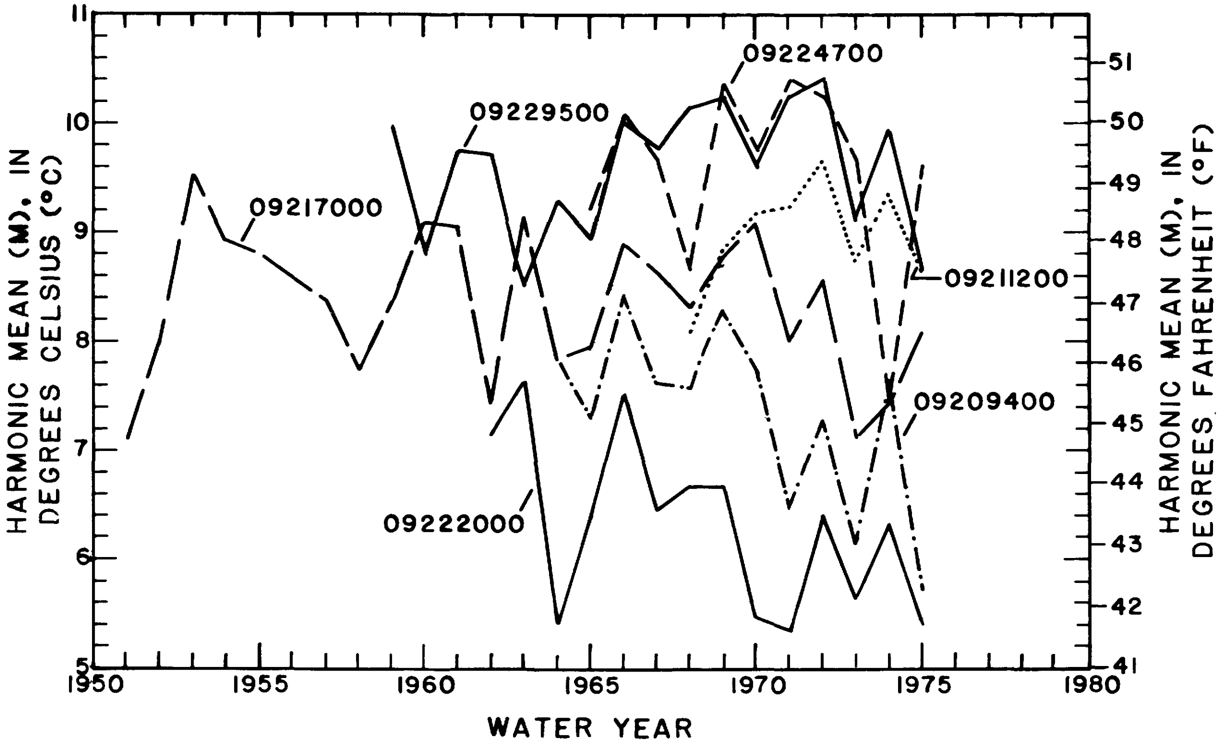

Figure 13.—Annual values of harmonic-mean temperatures for stations having daily observations of temperatures.

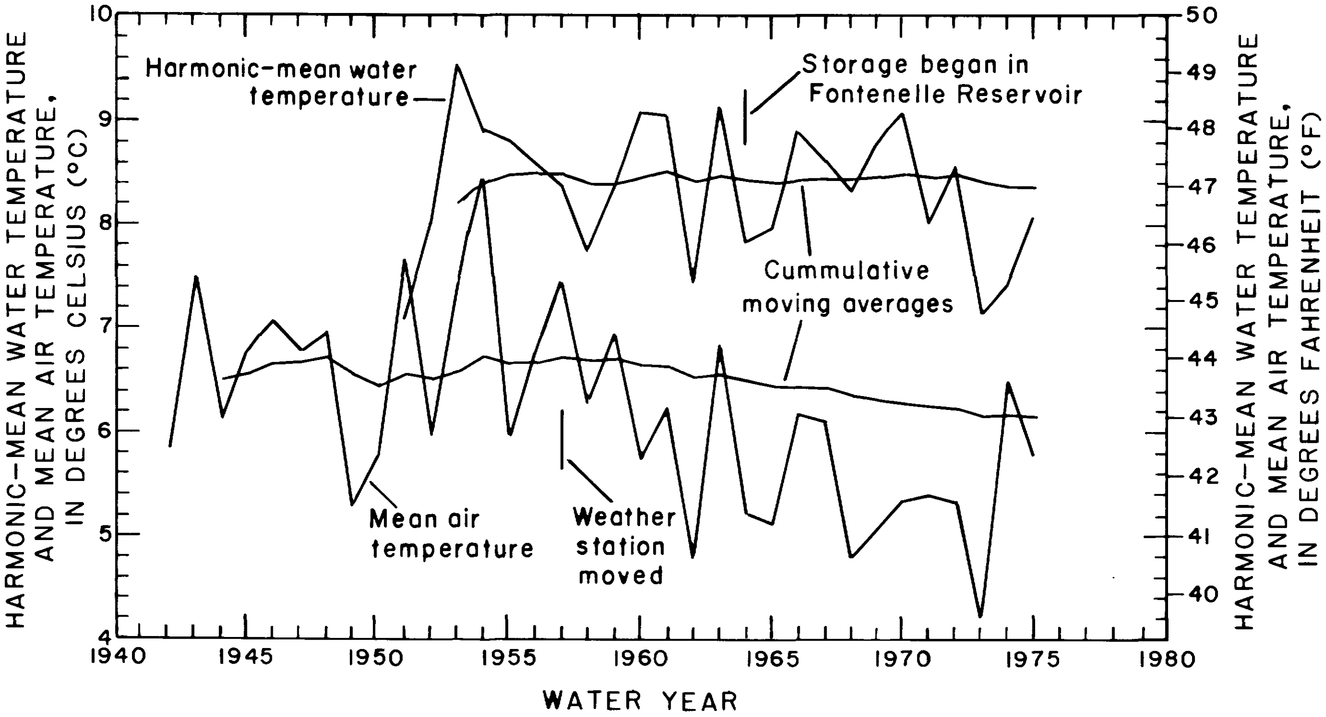

Figure 14.—Annual values of harmonic-mean water temperatures for station 09217000 and mean air temperatures for National Weather Service station at Green River.

SUMMARY AND CONCLUSIONS

Mean daily temperatures of streams at unmeasured sites in the Green River Basin may be estimated using the regional technique presented in this report. The technique utilizes the harmonic function

$$T = M + A \left[\sin \left(0.0172\ t + C\right)\right] \qquad (1)$$

where T is the estimated mean daily temperature,
M, A, and C are regionalized harmonic coefficients, and
t is the day of the water year.

Regional values of the harmonic mean (M) are determined from the relation $M = 19.5 - 0.0019\ E$, where E is stream elevation. Regionalized values of the harmonic amplitude (A) are determined from figure 5. An average value of 2.68 is used for the regional value of the phase coefficient (C). By knowing the location and elevation of a stream site, an estimate of mean temperature may be calculated for any day of the year. Example problems were presented that describe in detail how the estimating technique is applied.

Except for reaches downstream from ground-water inflows or from municipal and (or) industrial return flows, streams in the study area are likely to have minimum wintertime temperatures of 0°C along with an associated ice cover. Maximum daytime temperatures in late summer are dependent upon local meteorlogic and hydraulic conditions. High summertime temperatures occur in small plains streams in the interior of the basin. Daytime temperatures of these streams occasionally exceed 25°C.

Diurnal variation of small plains streams has been observed to be as much as 20°C in summer, but for large perennial streams it is generally less than about 5°C. The regional technique does not define diurnal variation at unmeasured sites. Several field measurements, made at different seasons of the year, are necessary to define diurnal variation.

Stream-reach profiles were presented that showed downstream changes in water-temperature characteristics of four major streams in the study area. These profiles verified the regional temperature model. They also indicated that ground-water inflows, irrigation, and reservoir storage are affecting temperatures in reaches of several of the streams.

A statistical analysis of temperature data for six daily-record sites showed that no general trends or changes have occurred since data collection began. However, local changes have occurred as a result of manmade developments. The most noticible changes in stream temperatures are caused by reservoir storage, such as by Meeks Cabin Reservoir (since 1971) and by Fontenelle Reservoir (since 1963).

For this analysis, much temperature data were available for perennial streams whose headwaters are in mountainous areas. Little data were available for plains streams originating in the interior of the basin. However, eight new streamflow stations have been recently (1976 water year) installed on plains streams; these stations will help overcome these data shortages. Two of the stations have continuous-recording temperature monitors that will obtain needed information on diurnal variation.

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Table 1. - Stream-temperature stations

Station number	Station name	Records analyzed (water years)	Observations p, periodic d, daily
06637550	Sweetwater River near South Pass City	1963-73	p
09188500	Green River at Warren Bridge, near Daniel	1961-74	p
09189500	Horse Creek at Sherman ranger station	1961-74	p
09193000	New Fork River below New Fork Lake, near Cora	1961-72	p
09196500	Pine Creek above Fremont Lake, near Pinedale	1961-74	p
09198500	Pole Creek below Little Half Moon Lake, near Pinedale	1961-71	p
09199500	Fall Creek near Pinedale	1961-71	p
09201000	New Fork River near Boulder	1966-69	p
09202000	Boulder Creek below Boulder Lake, near Boulder	1961-73	p
09203000	East Fork River near Big Sandy	1961-74	p
09204000	Silver Creek near Big Sandy	1961-71	p
09205000	New Fork River near Big Piney	1961-74	p
09205500	North Piney Creek near Mason	1961-72	p
09208000	LaBarge Creek near LaBarge Meadows ranger station	1961-74	p
09209400	Green River near LaBarge	1964-74 1964-75	p d
09210500	Fontenelle Creek near Herschler Ranch, near Fontenelle	1961-74	p

Table 1. - Stream-temperature stations--continued

Station number	Station name	Records analyzed (water years)	Observations p, periodic d, daily
09211200	Green River below Fontenelle Reservoir	1964-74 1968-75	p d
09212500	Big Sandy River at Leckie Ranch, near Big Sandy	1961-74	p
09213500	Big Sandy River near Farson	1961-74	p
09214000	Little Sandy Creek near Elkhorn	1961-71	p
09214500	Little Sandy Creek above Eden	1961-74	p
09215000	Pacific Creek near Farson	1961-73	p
09216000	Big Sandy River below Eden	1961-74	p
09217000	Green River near Green River	1961-74 1951-75	p d
09217900	Blacks Fork near Robertson	1968-76	p
09218500	Blacks Fork near Millburne	1961-74	p
09220000	East Fork of Smith Fork near Robertson	1961-74	p
09220500	West Fork of Smith Fork near Robertson	1961-73	p
09222000	Blacks Fork near Lyman	1962-74 1962-75	p d
09223000	Hams Fork below Pole Creek, near Frontier	1961-74	p
09223500	Hams Fork near Frontier	1961-72	p
09224700	Blacks Fork near Little America	1962-74 1965-75	p d

Table 1. - Stream-temperature stations--continued

Station number	Station name	Records analyzed (water years)	Observations p, periodic d, daily
09226000	Henrys Fork near Lonetree	1961-72	p
09226500	Middle Fork Beaver Creek near Lonetree	1968-70	p
09228500	Burnt Fork near Burntfork	1961-74	p
09229500	Henrys Fork near Manila, Utah	1961-74 1959-75	p d
09251800	North Fork Little Snake River near Encampment	1961-66	p
09253000	Little Snake River near Slater, Colo.	1961-74	p
09255000	Slater Fork near Slater, Colo.	1961-74	p
09255500	Savery Creek at upper station near Savery	1961-72	p
09256000	Savery Creek near Savery	1961-69	p
09257000	Little Snake River near Dixon	1963-73	p
09258000	Willow Creek near Dixon	1961-75	p
09259700	Little Snake River near Baggs	1962-68	p

Table 2.--Sequence number conversion, date to water-year day

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1	1	32	62	93	124	152	183	213	244	274	305	336
2	2	33	63	94	125	153	184	214	245	275	306	337
3	3	34	64	95	126	154	185	215	246	276	307	338
4	4	35	65	96	127	155	186	216	247	277	308	339
5	5	36	66	97	128	156	187	217	248	278	309	340
6	6	37	67	98	128	157	188	218	249	279	310	341
7	7	38	68	99	130	158	189	219	250	280	311	342
8	8	39	69	100	131	159	190	220	251	281	312	343
9	9	40	70	101	132	160	191	221	252	282	313	344
10	10	41	71	102	133	161	192	222	253	283	314	345
11	11	42	72	103	134	162	193	223	254	284	315	346
12	12	43	73	104	135	163	194	224	255	285	316	347
13	13	44	74	105	136	164	195	225	256	286	317	348
14	14	45	75	106	137	165	196	226	257	287	318	349
15	15	46	76	107	138	166	197	227	258	288	319	350
16	16	47	77	108	139	167	198	228	259	289	320	351
17	17	48	78	109	140	168	199	229	260	290	321	352
18	18	49	79	110	141	169	200	230	261	291	322	353
19	19	50	80	111	142	170	201	231	262	292	323	354
20	20	51	81	112	143	171	202	232	263	293	324	355
21	21	52	82	113	144	172	203	233	264	294	325	356
22	22	53	83	114	145	173	204	234	265	295	326	357
23	23	54	84	115	146	174	205	235	266	296	327	358
24	24	55	85	116	147	175	206	236	267	297	328	359
25	25	56	86	117	148	176	207	237	268	298	329	360
26	26	57	87	118	149	177	208	238	269	299	330	361
27	27	58	88	119	150	178	209	239	270	300	331	362
28	28	59	89	120	151	179	210	240	271	301	332	363
29	29	60	90	121	(152)	180	211	241	272	302	333	364
30	30	61	91	122	---	181	212	242	273	303	334	365
31	31	--	92	123	---	182	---	243	---	304	335	---

Note: For months of March through September add one (1) to number in table for sequence conversion of days for leap years.

Table 3.--Harmonic coefficients for period of record - stations with periodic observations

STA NO = Station number, located on figure 2; YEARS = Water years;
N = Number of nonzero observations; A = Amplitude; C = Phase coefficient;
M = Harmonic mean; SE = Standard error of estimate; RSQD = Root mean square.

STA NO	YEARS	N	A	C	M	SE	RSQD
06637550	1963-73	66	10.58	2.64	4.86	3.23	70.79
09188500	1961-74	70	11.44	2.63	4.11	2.42	83.29
09189500	1961-74	78	10.08	2.60	4.01	3.41	69.51
09193000	1961-72	62	9.98	2.63	5.64	3.32	73.36
09196500	1961-74	74	6.68	2.50	4.78	2.63	72.89
09198500	1961-71	59	10.10	2.58	6.85	3.25	76.62
09199500	1961-71	56	9.79	2.75	5.95	2.81	81.40
09201000	1966-69	27	9.85	2.86	6.51	2.69	77.99
09202000	1961-73	75	9.96	2.64	6.14	3.03	78.35
09203000	1961-74	80	10.83	2.64	3.05	2.77	75.50
09204000	1961-71	52	9.35	2.63	4.04	3.14	71.56
09205000	1961-74	80	10.64	2.75	6.81	2.63	82.30
09205500	1961-72	52	9.86	2.70	3.72	2.79	68.14
09208000	1961-74	72	5.76	2.67	3.74	3.26	51.44
09209400	1964-74	72	11.03	2.71	6.55	3.02	78.30
09210500	1961-74	81	9.36	2.77	5.98	3.58	62.96
09211200	1964-74	96	8.43	2.66	8.65	2.98	79.50
09212500	1961-74	67	10.78	2.68	3.34	2.61	77.40
09213500	1961-74	71	12.62	2.73	6.49	3.46	72.72
09214000	1961-71	51	10.00	2.66	3.73	2.91	61.11
09214500	1961-74	82	13.38	2.76	6.17	2.87	81.92
09215000	1961-73	39	11.34	3.36	5.72	3.81	39.55
09216000	1961-74	99	10.40	2.84	9.17	3.60	76.46
09217000	1961-74	78	11.32	2.78	7.96	2.44	87.26
09217900	1968-76	62	7.29	2.51	3.17	2.47	64.14
09218500	1961-70	51	7.18	2.56	4.75	2.78	81.40
09218500	1971-74	38	5.66	2.34	5.11	1.70	92.10
09220000	1961-74	66	10.17	2.57	3.56	2.99	67.88
09220500	1961-73	63	12.08	2.64	4.28	3.09	72.14
09222000	1962-74	70	12.08	2.75	7.65	3.86	69.28
09223000	1961-74	70	9.80	2.71	4.64	3.79	63.25
09223500	1961-72	64	11.09	2.75	6.58	2.65	83.68
09224700	1962-74	71	11.23	2.78	7.71	3.19	84.40
09226000	1961-72	63	8.14	2.69	4.91	2.97	67.74
09226500	1968-70	22	6.26	2.62	1.77	2.48	56.33
09228500	1961-74	66	8.68	2.67	4.06	3.16	60.94
09229500	1961-74	79	10.33	2.76	8.31	3.63	74.10
09251800	1961-65	18	9.98	2.52	2.13	3.41	28.63
09253000	1961-74	103	9.56	2.48	6.38	3.57	73.28

Table 3.--Harmonic coefficients for period of record - stations with periodic observations--continued

STA NO	YEARS	N	A	C	M	SE	RSQD
09255000	1961-74	117	9.86	2.63	6.88	3.10	80.28
09255500	1961-71	64	13.56	2.64	4.83	2.65	80.59
09256000	1961-72	60	10.78	2.59	7.54	3.25	78.96
09257000	1963-73	79	10.65	2.57	7.13	3.31	78.16
09258000	1961-75	92	10.06	2.68	6.69	3.51	70.00
09259700	1962-68	61	12.35	2.71	7.60	3.36	78.19

Table 4.--Harmonic coefficients for individual years - stations with daily observations

STA NO = Station number, located on figure 2; YEAR = Water year;
N = Number of nonzero observations; A = Amplitude; C = Phase coefficient;
M = Harmonic mean; SE = Standard error of estimate; RSQD = Root mean square.

STA NO	YEAR	N	A	C	M	SE	RSQD
09209400	1964	258	10.73	2.68	7.79	2.58	85.78
09209400	1965	249	10.25	2.77	7.30	2.04	88.72
09209400	1966	271	11.37	2.74	8.40	2.26	90.00
09209400	1967	272	10.95	2.73	7.61	2.30	88.86
09209400	1968	281	10.37	2.81	7.56	2.07	90.36
09209400	1969	261	10.58	2.76	8.27	2.26	89.07
09209400	1970	270	11.18	2.80	7.76	2.47	88.75
09209400	1971	240	11.79	2.81	6.47	2.12	88.63
09209400	1972	216	11.12	2.81	7.26	1.82	89.51
09209400	1973	221	12.49	2.69	6.14	2.26	85.95
09209400	1974	257	10.61	2.79	7.57	2.09	88.01
09209400	1975	250	10.16	2.64	5.75	1.92	89.24
09211200	1968	350	8.29	2.70	8.06	1.82	90.95
09211200	1969	363	8.34	2.56	8.82	1.47	94.15
09211200	1970	365	8.01	2.60	9.15	1.61	92.10
09211200	1971	365	8.40	2.64	9.22	1.39	94.64
09211200	1972	359	8.87	2.63	9.63	1.44	94.93
09211200	1973	365	8.09	2.49	8.70	1.42	93.70
09211200	1974	365	9.27	2.60	9.34	1.42	95.16
09211200	1975	365	8.28	2.47	8.65	1.76	91.32
09217000	1951	147	10.75	2.71	7.10	1.98	61.03
09217000	1952	296	11.37	2.80	8.00	2.51	89.96
09217000	1953	349	10.89	2.76	9.53	2.36	91.57
09217000	1954	355	9.55	2.74	8.92	2.15	90.85
09217000	1955	356	10.23	2.77	8.81	2.39	90.30
09217000	1956	328	9.40	2.82	8.59	2.15	90.20
09217000	1957	279	10.68	2.87	8.39	2.59	87.43
09217000	1958	208	12.60	2.78	7.76	1.96	90.64
09217000	1959	257	10.47	2.78	8.37	2.46	87.35
09217000	1960	201	12.85	2.89	9.09	2.49	88.60
09217000	1961	183	13.67	2.83	9.06	1.91	92.74
09217000	1962	205	11.53	2.78	7.46	2.22	85.99
09217000	1963	290	11.56	2.79	9.15	1.93	93.47
09217000	1964	244	12.07	2.66	7.84	2.40	87.57
09217000	1965	314	10.15	2.76	7.95	2.10	90.99
09217000	1966	294	11.75	2.76	8.90	1.90	93.92
09217000	1967	344	10.16	2.75	8.63	2.02	92.41

Table 4.--Harmonic coefficients for individual years - stations with daily observations--continued

STA NO	YEAR	N	A	C	M	SE	RSQD
09217000	1968	313	10.07	2.81	8.32	2.18	90.11
09217000	1969	246	11.47	2.69	8.79	2.24	87.55
09217000	1970	297	10.12	2.81	9.08	2.19	89.68
09217000	1971	270	10.54	2.77	8.02	2.67	83.71
09217000	1972	234	10.01	2.63	8.57	1.83	89.54
09217000	1973	250	10.18	2.79	7.14	2.27	83.17
09217000	1974	274	10.59	2.77	7.43	2.65	84.74
09217000	1975	283	10.06	2.60	8.08	2.34	87.59
09222000	1962	149	11.62	2.65	7.14	3.78	37.92
09222000	1963	286	9.16	2.71	7.60	3.20	76.50
09222000	1964	248	10.57	2.69	5.38	2.62	81.34
09222000	1965	278	9.17	2.84	6.35	2.52	83.51
09222000	1966	257	11.35	2.82	7.50	3.59	73.94
09222000	1967	270	10.11	2.77	6.44	3.37	75.94
09222000	1968	271	9.40	2.75	6.65	3.29	76.16
09222000	1969	233	13.35	2.80	6.65	3.51	76.25
09222000	1970	226	12.24	2.77	5.46	3.49	76.91
09222000	1971	230	10.10	2.81	5.34	2.51	81.02
09222000	1972	242	10.03	2.84	6.39	2.85	78.13
09222000	1973	222	11.58	2.68	5.63	2.76	76.50
09222000	1974	243	9.28	2.86	6.30	3.40	63.93
09222000	1975	230	9.93	2.71	5.41	3.00	70.81
09224700	1965	231	10.02	2.56	9.19	2.57	89.66
09224700	1966	245	12.50	2.72	10.05	1.67	95.66
09224700	1967	321	12.11	2.71	9.65	2.82	89.40
09224700	1968	274	11.48	2.80	8.66	2.47	88.06
09224700	1969	339	11.62	2.74	10.34	2.41	92.01
09224700	1970	358	11.41	2.80	9.75	2.73	89.76
09224700	1971	341	11.94	2.81	10.37	2.51	91.67
09224700	1972	328	11.22	2.91	10.24	1.83	94.84
09224700	1973	326	10.51	2.70	9.67	2.55	89.27
09224700	1974	190	14.51	2.83	7.40	2.55	88.88
09224700	1975	360	9.59	2.66	9.60	2.72	86.21
09229500	1959	281	10.28	2.76	9.97	2.43	87.94
09229500	1960	274	12.49	2.63	8.80	2.80	87.43
09229500	1961	267	11.96	2.92	9.74	2.23	89.92
09229500	1962	281	10.46	2.82	9.71	2.48	88.50
09229500	1963	326	9.75	2.44	8.50	2.26	90.59
09229500	1964	305	11.51	2.59	9.30	2.32	91.56
09229500	1965	331	8.88	2.79	8.94	2.23	88.58
09229500	1966	346	9.82	2.78	10.00	2.17	91.05

Table 4.--Harmonic coefficients for individual years - stations with daily observations--continued

STA NO	YEAR	N	A	C	M	SE	RSQD
09229500	1967	320	11.37	2.74	9.74	2.69	89.11
09229500	1968	326	9.89	2.80	10.13	2.34	89.76
09229500	1969	324	10.58	2.82	10.23	2.40	90.89
09229500	1970	325	9.68	2.84	9.60	2.44	89.12
09229500	1971	350	9.91	2.86	10.24	3.02	84.14
09229500	1972	311	10.09	2.95	10.40	2.85	84.72
09229500	1973	357	9.04	2.72	9.11	2.36	87.85
09229500	1974	362	9.29	2.86	9.94	2.36	88.50
09229500	1975	275	9.40	2.64	8.68	2.55	82.26

Table 5.--Physical and climatic characteristics of stream-temperature sites

[See p. 7 for explanation of abbreviated column headings.]

STA NO	E	AGS	A	Q_a	P_2	W	D	IRRIG	LAT	AP
06637550	7420	90	177	65.4	586	63	2.6	950	42.38	2.90
09188500	7468	70	468	515	2960	158	3.4	4100	43.02	2.60
09189500	7771	70	43.0	69.6	1120	62	2.7	360	42.94	2.20
09193000	7720	70	36.2	51.3	391	57	2.0	0	43.08	2.30
09196500	7540	60	75.8	181	1750	89	3.5	0	43.03	2.90
09198500	7350	70	87.5	109	936	96	2.6	100	42.88	2.80
09199500	7240	70	37.2	40.0	424	51	2.1	0	42.86	2.80
09201000	6900	70	552	392	2670	125	6.0	40000	42.75	3.00
09202000	7180	70	130	195	1980	160	4.6	0	42.82	2.10
09203000	7800	70	79.2	104	1300	89	3.7	0	42.67	2.90
09204000	7500	70	45.4	44.1	713	61	2.2	30	42.75	2.40
09205000	6800	75	1230	729	5290	225	4.5	62100	42.57	3.00
09205500	7520	70	58.0	57.1	392	40	1.9	100	42.66	2.20
09208000	8410	65	6.30	14.3	135	28	1.8	0	42.51	2.90
09209400	6520	85	3910	1657	9990	325	5.5	19800	42.19	3.00
09210500	6950	75	152	71.3	469	48	2.8	780	42.10	2.90
09212500	7800	70	94.0	86.0	930	75	2.5	750	42.58	2.90
09213500	6770	85	322	86.5	829	99	2.6	1000	42.32	2.80
09214000	8000	75	20.9	21.2	201	32	1.8	680	42.53	2.90
09214500	6750	85	170	18.4	186	37	2.4	1070	42.24	1.10
09215000	6660	95	500	4.99	258	55	2.1	50	42.13	2.60
09216000	6450	100	1610	46.0	503	98	1.9	19300	42.01	1.00
09217000	6060	130	10000	1724	9720	350	5.7	223000	41.52	1.00
09217900	8804	70	130	174	1650	72	2.9	0	40.97	1.00
09218500	8370	80	156	159	1490	102	2.6	0	41.06	1.00
09220000	8470	85	53.0	47.1	531	34	2.5	0	41.05	1.00
09220500	8615	85	37.2	21.5	461	47	1.8	0	41.02	1.00
09222000	6380	115	821	152	1650	115	3.5	62200	41.45	2.95
09223000	7455	70	128	101	815	61	2.7	0	42.11	3.00
09223500	6970	100	298	147	1150	110	2.9	4960	41.86	2.90
09224700	6128	125	3100	374	2900	150	4.6	76100	41.55	1.20
09226000	8350	85	56.0	40.8	609	50	2.1	0	41.01	1.10
09226500	8450	100	28.0	23.0	318	26	1.9	0	40.94	1.10

Table 5.--Physical and climatic characteristics of stream-temperature sites--continued

STA NO	E	AGS	A	Q_a	P_2	W	D	IRRIG	LAT	AP
09228500	8430	90	52.8	31.1	301	31	1.8	0	40.95	1.00
09229500	6060	130	520	83.0	904	105	2.2	19819	41.01	2.00
09251800	8250	90	9.64	26.3	374	34	1.8	0	41.05	2.40
09253000	6831	110	285	226	2210	70	3.9	2000	41.00	2.30
09255000	6600	110	161	73.5	866	31	4.8	500	40.98	1.50
09255500	7000	110	200	45.0	485	42	2.5	470	41.22	2.70
09256000	6680	115	330	104	1140	84	2.9	640	41.10	2.90
09257000	6331	110	988	514	4710	170	5.6	9500	41.03	1.80
09258000	6700	110	24.0	9.53	129	17	1.9	2	40.92	1.40
09259700	6050	115	3020	523	4620	185	5.4	15000	41.00	1.80

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