EVALUATION OF THERMOGRAPH DATA FOR CALIFORNIA STREAMS

By J. T. Limerinos

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ABSTRACT

Statistical analysis of water-temperature data from California streams indicates that, for most purposes, long-term operation of thermographs (automatic water-temperature recording instruments) does not provide a more useful record than either short-term operation of such instruments or periodic measurements. Harmonic analyses were made of thermograph records 5 to 14 years in length from 82 stations. More than 80 percent of the annual variation in water temperature is explained by the harmonic function for 77 of the 82 stations. Harmonic coefficients based on 8 years of thermograph record at 12 stations varied only slightly from coefficients computed using two equally split 4-year records. At five stations where both thermograph and periodic (10 to 23 measurements per year) data were collected concurrently, harmonic coefficients for periodic data were defined nearly as well as those for thermograph data. Results of this analysis indicate that, except where detailed surveillance of water temperatures is required or where there is a chance of temporal change, thermograph operations can be reduced substantially without significantly affecting the usefulness of temperature records.

INTRODUCTION

In California, the U.S. Geological Survey has collected stream-temperature data since 1944. From water years 1944 through 1973, data have been published for 253 stations in California. During this period, thermograph (automatic water-temperature recording instrument) data were collected at 175 stations, with concurrent periodic stream-temperature measurements at 62 of these stations. Periodic stream-temperature measurements (8 to 12 values per year) were made for varying lengths of time at 78 other stations. Periodic measurements usually were made in conjunction with visits to stations to make discharge measurements or to collect water-quality samples.

Current economic conditions and the emphasis on protecting the environment are forcing water-resources managers to review the efficiency and effectiveness of all hydrologic data-collection programs. This study is intended to provide those who develop and evaluate water-temperature data-collection programs with guidelines and standards for duration and frequency of sampling needed to characterize water-temperature variations in California streams.

Meteorological and geophysical factors affect ambient water temperatures of natural streams. The factors include air temperature, solar radiation, wind velocity, vapor pressure, water-surface area, shading, orientation, and inflow water temperature. Cluis (1972) and Anderson and Faust (1973) indicate that air temperature and solar radiation are the two major factors affecting change in water temperature.

Changes in streamwater temperature can affect many biological and physical processes. Several effects of water-temperature changes on aquatic life have been well documented. Iverson (1972), Wurtsbaugh (1973), and Davis (1974) showed that increased water temperature can adversely affect aquatic life. For industrial processes, where water is used for cooling, increased water temperature reduces plant efficiency. In agriculture, where all plant species have an optimum temperature range, Raney (1963) showed that release of colder (bottom) water from reservoirs adversely affected rice crops irrigated with this cold water. Investigations in several major river systems, including the Colorado River, have shown an increase in sediment load with decreasing water temperatures (Robbins, 1973).

Purpose and Scope

The primary purpose of this study is to evaluate water-temperature data that have been collected on California streams to determine whether thermograph stations have operated for a sufficient period of time to characterize seasonal water-temperature variations. A mathematical model and statistical tests were used to define stream-temperature characteristics at 82 stations in California where thermographs have been operated for 5 to 14 years. Results of this study may serve as a basis for determining the minimum length of record needed to define the water-temperature regimen; moreover, given network objectives, data collection might be discontinued at several stations.

Secondary objectives are (1) to detect and assess significant time trends in stream temperatures, (2) to determine the cause for the changes, and (3) to evaluate the utility of characterizing water-temperature conditions from periodic measurements.

Collection of Temperature Data

Temperature data were obtained at each site by thermographs that automatically record the signal from a temperature-sensing element installed at a fixed location in the stream. Records were produced on analog recorders (continuous) or on digital recorders (usually 1-hour intervals). Thermograph data for this study were limited to use of the daily maximum and minimum recorded water temperatures. Periodic water-temperature measurements were obtained using a hand-held thermometer and reading the scale with the bulb immersed. These measurements were usually made at different times of the day. The estimated error limit for thermograph data is ± 1°C; hand-held thermometers are rated to be within 0.5°C. A study by Jones (1965) of the relation between average stream temperature in a cross section and the point temperature at the thermograph sensor for 24 stations on California streams showed that 99 percent of the point water-temperature observations were within ± 0.6°C of the average stream temperature at the 95 percent confidence level.

Water-temperature data for California streams used in this study are published in a series of water-supply papers, "Quality of Surface Waters of the United States--Part 11, Pacific Slope Basins in California" (U.S. Geological Survey, 1959-1962), and in annual reports, "Water Resources Data for California--Part 2, Water Quality Records" (U.S. Geological Survey, 1963-1973).

Ten open-file reports by Blodgett (1970, 1971a, 1971b, 1971c, 1971d, 1971e, 1971f, 1972a, 1972b, 1972c) contain water-temperature data summaries through 1968 for California streams. These reports summarize data for the 11 hydrologic subregions of California (California Region Framework Study Committee, 1968). They include the maximum and minimum water temperatures for the period of record, the January and August (the January and July in two subregions) monthly means, and the 95-percent confidence interval for those means.

Station Selection

Selection of water-temperature recording stations for this study was based on two factors--availability of at least 5 years of record and completeness of data. Thermograph stations selected had between 300 and 350 daily maximum and minimum temperature values for each year.

Available data for 175 stations stored in the Daily Values File[1] were screened for this study; 82 sets of station data were selected on the basis of the criteria given above. The 82 stations selected had 5 to 14 years of record, with an average of 7.5 years for all stations.

The locations of thermograph stations used in this study are shown in figure 1. A summary by hydrologic subregion of available data is given in table 1. Periods of record for the 82 stations used in the study are given at the end of this report in table 5. Concurrent periodic water-temperature data were available for five of these stations.

[1]The Daily Values File is part of the U.S. Geological Survey computer system where water-data parameters (maximum, minimum, or mean values) measured once a day, or more frequently, are stored. Water-temperature data for California streams stored in this file include the daily maximum and minimum recorded values.

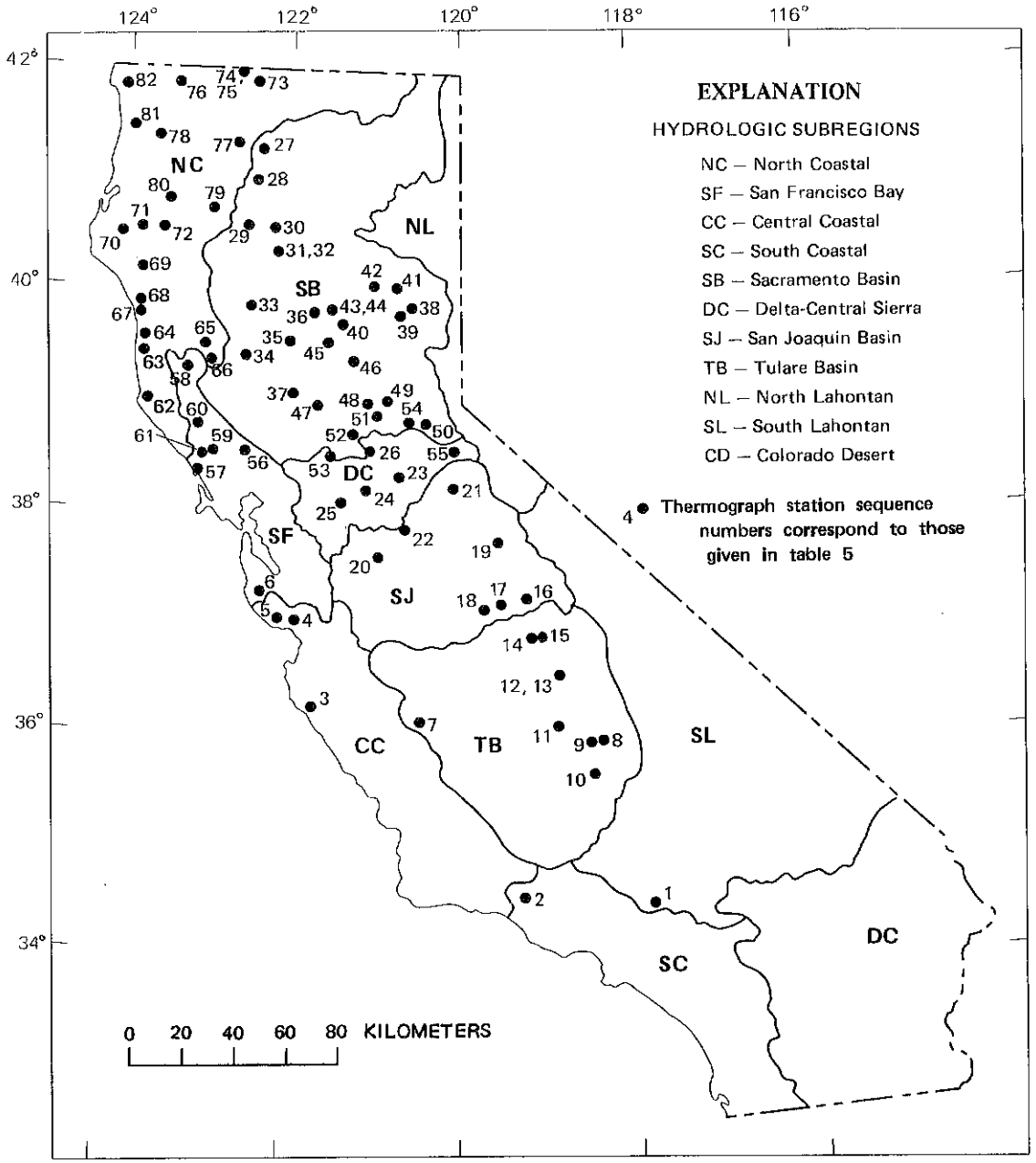

FIGURE 1.--Location of thermograph stations used in the study. (Subregions from California Region Framework Study Committee, 1968)

TABLE 1.--*Summary of thermograph station data used in the study*

Hydrologic subregion and abbreviation shown in figure 1	Total stations with available data[1]	Number of stations used in analysis	Number of thermograph stations for given years of record									
			14	13	12	11	10	9	8	7	6	5
South Lahontan (SL)	2	1								1		
South Coastal (SC)	13	1							1			
Central Coastal (CC)	3	3								1	1	1
Tulare Basin (TB)	20	9		1				1	2	1	2	2
San Joaquin Basin (SJ)	19	7						1	2	2	1	1
Delta-Central Sierra (DC)	8	4				1		1		2		
Sacramento Basin (SB)	51	29		1	2	3	5	1	2	4	5	6
San Francisco Bay (SF)	12	7							2	1	2	2
North Coastal (NC)	43	21	1			1		5	3	2	4	5
North Lahontan (NL)	4	0										
Colorado Desert (CD)	0	0										
State total	175	82	1	2	2	5	5	9	12	14	15	17
Station-year total		619	14	26	24	55	50	81	96	98	90	85

[1]Daily maximum and minimum water temperatures in Daily Values File (computer).

WATER-TEMPERATURE DATA ANALYSIS

Harmonic Analysis

The water-temperature fluctuation for most California streams follows a cyclic pattern during the year that can be described by a simple harmonic function,

$$T=M+A[\sin(bt+c)], \quad (1)$$

where T is the water temperature in degrees Celsius (°C), on day "t";
M is the harmonic mean water temperature for the period;
A is the amplitude of the harmonic function, or one-half the estimated variation for the period;
b is a constant used to convert the day of the year to an angle, in radians (one day equals $2\pi \div 365$ or 366);
t is the day of the water year; for October 1, t=1; for September 30 of the following year, t=365 or 366; and
c is the phase coefficient of the harmonic, in radians, measured from the origin or zero degrees.

Equation 1 is a least-squares fit of the annual temperature variability. The technique was proposed by Ward (1963), and applied by Collings (1969), Steele and Gilroy (1972), Steele, Gilroy, and Hawkinson (1974), and others in stream water-temperature studies.

Water-temperature data for the 82 stations were analyzed using a computer program documented by Steele (1974). The harmonic coefficients in equation 1, M, A, and c, were computed to give a gross measure of the annual variability in stream temperatures at each station. Output from this program, assuming random distribution of temperature values, includes the standard error of estimate (SE), which is a temperature value in degrees Celsius for which two-thirds of the daily observed temperatures are within plus or minus one SE of the computed harmonic curve; and the variance term RSQD which is the percentage of temperature variability explained by the harmonic function. The RSQD is the square of the correlation coefficient times 100.

An RSQD value of 81 indicates a comparable correlation coefficient of 0.9.

Because of the large volume of data analyzed in this study, the specific harmonic coefficient results for the annual analyses are not included in this report. These results are on file in the office of the U.S. Geological Survey, Water Resources Division, Menlo Park, Calif. Multiyear harmonic-analysis results for the 82 thermograph records used in this study are shown at the end of this report in table 6. Although annual increments were used in this study, multiyear analyses provide one value for each coefficient that represents the entire period of record.

Harmonic coefficients and related statistics for water-temperature data for stations not showing a significant trend (see section "Trend Analysis") were computed on a multiyear basis for the entire period of record and for equally split periods. For simplicity, the selected stations had an even number for the total period of record. The multiyear harmonic analyses of daily maximum water-temperature data for 12 stations with 8 years of record show that the maximum difference in standard error of estimate between the first and second 4-year period was 0.50°C (station 11208000). The overall average difference in standard error of estimate for the equally split periods and the entire 8-year record was 0.12°C. This difference is not significant for the assumed measurement-error limit for thermographs of $\pm$1.0°C.

The average standard error of estimate for annual increments of the daily maximum water temperature for the 82 station records was 1.67°C, with a range from 3.72°C to 0.58°C. For the daily minimum water temperatures the average standard error of estimate was 1.57°C, with the range between 2.87°C and 0.49°C.

To demonstrate use of the harmonic-analysis technique, 5 years of record were used from the station Sacramento River below Wilkins Slough, near Grimes (11390500). Figure 2 shows the multiyear harmonic function and data points for the daily maximum water temperatures at this site. The SE and RSQD values were 1.39°C and 87.81 percent. Therefore, on the average, the recorded daily maximum water temperature was within 1.39°C of the value computed by equation 1 for more than 240 days each year. Similarly, figure 3 shows the multiyear data for the daily minimum water-temperature records at the same station. The SE and RSQD values were 1.42°C and 86.96 percent. The resultant harmonic function for the daily maximum water-temperature values (fig. 2) is,

$$T = 14.16 + 5.30[\sin(0.0172t + 2.77)], \quad (2)$$

and for the daily minimum water-temperature values (fig. 3) is,

$$T = 13.61 + 5.21[\sin(0.0172t + 2.75)]. \quad (3)$$

Note that the mean of the harmonic function differed by 0.55°C between the maximum and minimum temperature records, whereas the other two coefficients are nearly the same. The scatter of the data values for the 5-year period of record exceeds this difference and is reflected in the SE values for the two functions.

The annual daily maximum or minimum water temperature can be estimated from the harmonic coefficients. The annual daily maximum temperature can be estimated by adding the mean (M) and the amplitude (A). The annual daily minimum temperature can be estimated by subtracting the amplitude from the mean. For station 11390500 the estimated annual daily maximum is

$$14.16 + 5.30 = 19.46 \text{ or } 19.5°C,$$

and the estimated annual daily minimum is

$$13.61 - 5.21 = 8.40°C.$$

In cold climates with prolonged freezing conditions, the amplitude may exceed the mean. In these cases the minimum is set to zero.

The daily maximum or minimum water temperature, T, on a specified day, t, can be estimated by using multiyear harmonic equations. For example, for station 11390500 the daily maximum water temperature on July 30 (where t is 303, assuming t for October 1 is 1), computed by equation 2, is

$$T = 14.16 + 5.30[\sin(0.0172 \times 303 + 2.77)],$$
$$T = 19.41 \text{ or } 19.4°C.$$

Note that the value in parentheses must be converted from radians to degrees. Actual recorded daily maximum water temperatures for July 30 for the 5 years of record ranged from 19°C to 19.5°C.

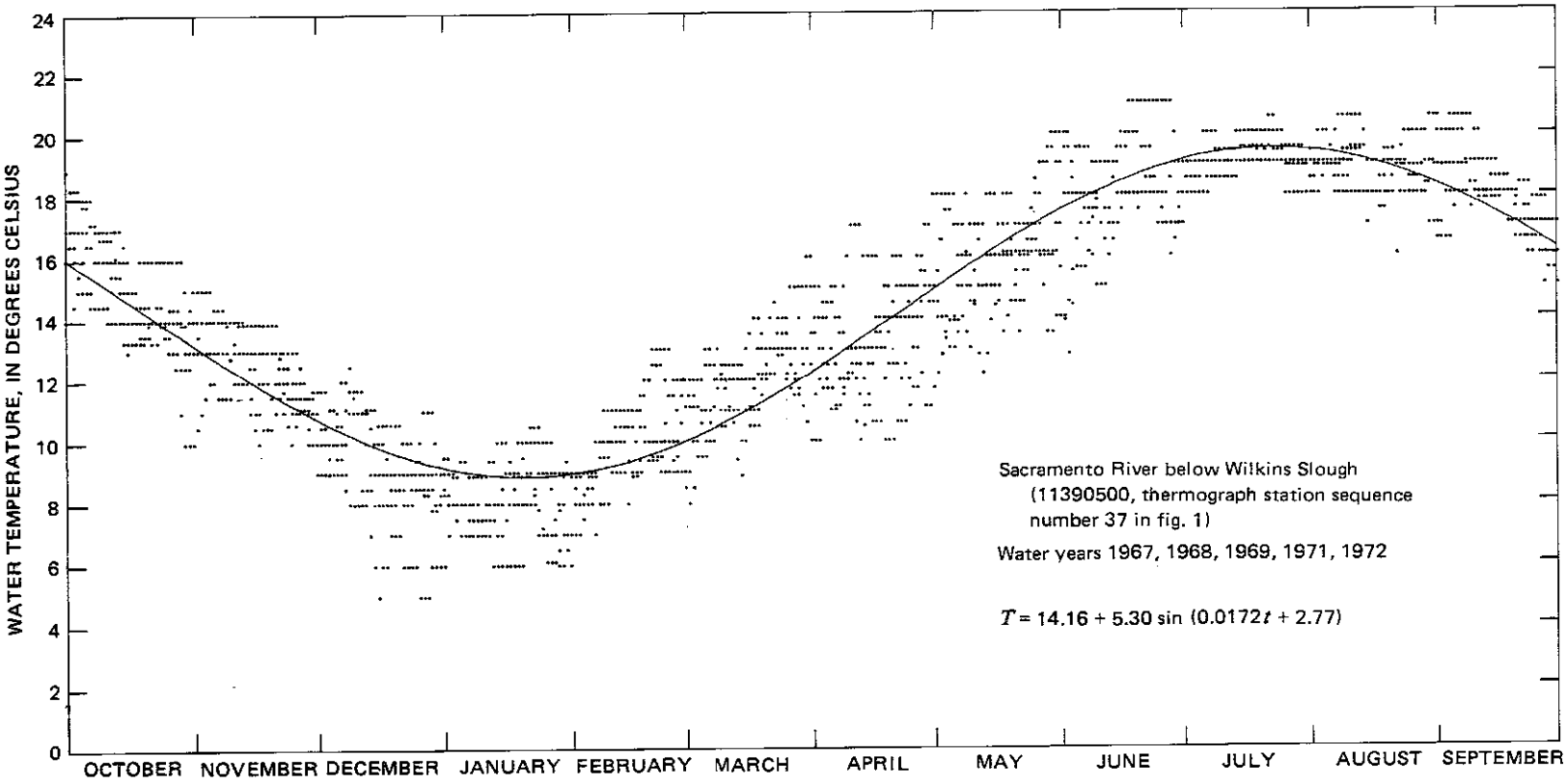

FIGURE 2.--Harmonic curve for daily maximum water temperatures at Sacramento River below Wilkins Slough, near Grimes (11390500).

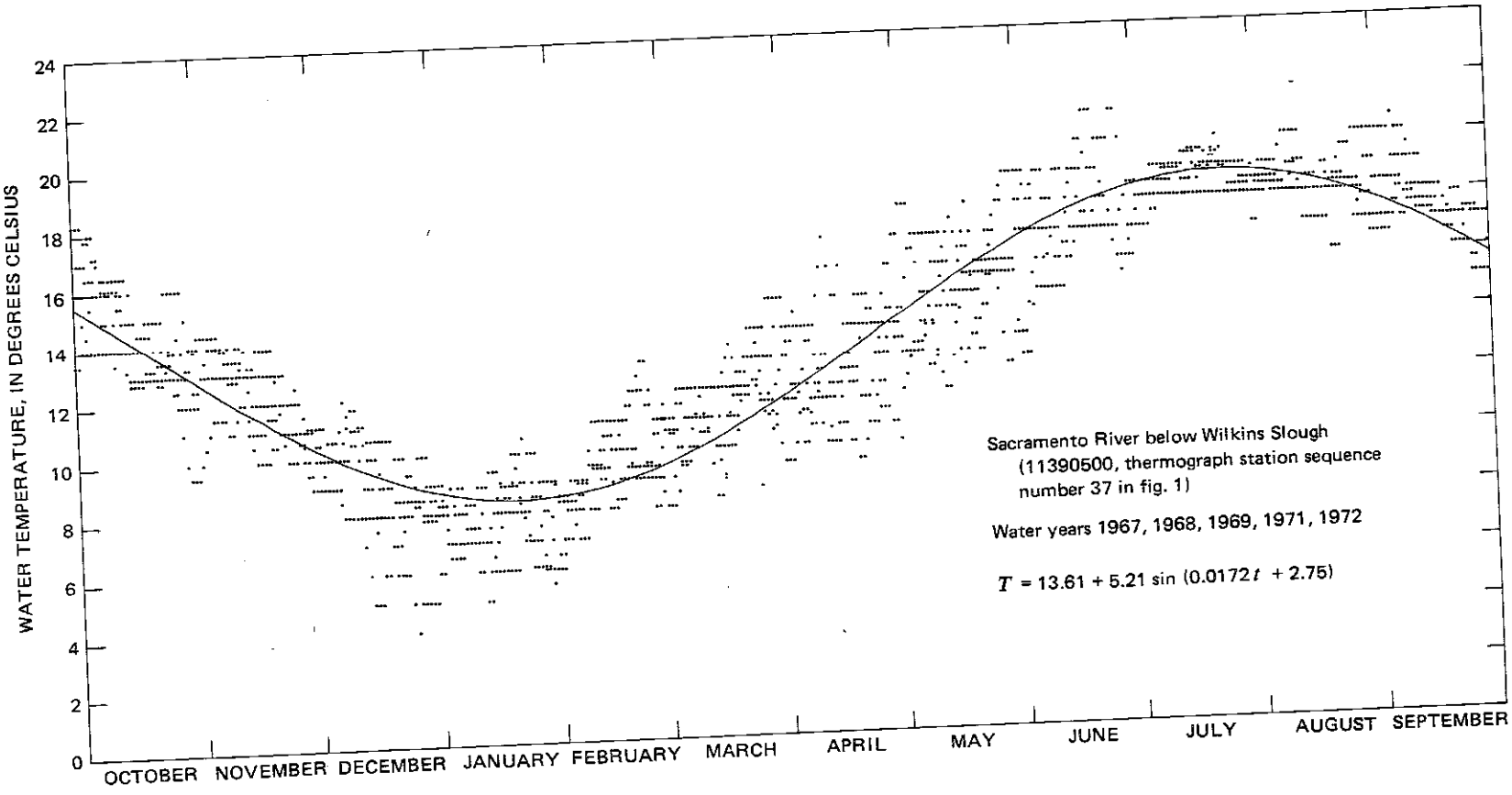

FIGURE 3.--Harmonic curve for daily minimum water temperatures at Sacramento River below Wilkins Slough, near Grimes (11390500).

The days on which a specified temperature, T, will probably occur can be computed by a modification of equation 1, in the form,

$$t = \frac{\left[-1^{k} \text{ arc sin } \left(\frac{T-M}{A}\right) + k\pi\right] - c}{0.0172} \qquad (4)$$

where k determines the quadrant of the function and is 0 and 1 if the given temperature occurs twice in the yearly cycle.

For station 11390500, solution of equation 4 results in a given daily maximum water temperature of 14°C occurring on October 23 and April 20, confirming the plotting of this temperature on the harmonic function shown in figure 2.

Trend Analysis

To detect temporal changes in the harmonic coefficients for annual increments of the daily maximum water-temperature data, a nonparametric statistical test was used. Nonparametric tests require no specified mathematical form of the probability distribution function of the data. A trend in any of the harmonic coefficients may be detected when values toward the end of an annual time-series sequence tend to be greater or smaller than those at the beginning. The test procedure is two-tailed (test for either increase or decrease in water temperature) with a null hypothesis of no trend in the harmonic coefficients. The test used was Kendall's tau test (Conover, 1971), applied to sequences of the three harmonic coefficients (M, A, and c) using a special-purpose computer program developed by E. J. Gilroy (T. D. Steele, written commun., 1975) to detect significant time trends. This procedure was applied in a nationwide study for the Council on Environmental Quality (Steele, Gilroy, and Hawkinson, 1974).

Kendall's tau test showed that records for 11 of the 82 stations evaluated in this study had significant time-related trends in one or more harmonic coefficients at 0.01 significance level. Stations having time-related trends in water temperature, based on harmonic analysis of annual increments of recorded daily values, are listed in table 2. Columns 1 through 5 show sequence number, station number, years of record, type of data (daily maximum or minimum water temperature), and harmonic coefficient showing trend. The remaining columns in table 2 relate to the Mann-Whitney test statistic (Conover, 1971) for determining the confidence interval and confidence level for the difference of the means for each period of split-sample testing. A time trend will be significant at a specified confidence level if the difference of the means between the first and second periods does not include the value of zero. In column 12 (table 2) the value of zero is not included in any instance.

TABLE 2.--*Thermograph stations showing significant*

[Sequence numbers correspond to those in table 5. Trend with absolute changes are in degrees Celsius (°C) for amplitude, coefficient. For "Type of Coefficient," annual maximum

Sequence number	U.S. Geological Survey station number	Years of record	Type of data	Type of coefficient	First period	
					Number of years	Mean
1	2	3	4	5	6	7
1	10263500	7	Daily maximum	Annual maximum	3	16.28
2	11111500	8	Daily minimum	Annual mean	4	10.28
5	11160500	6	Daily maximum	Phase	3	2.61
5	11160500	6	Daily minimum	Annual maximum	3	15.14
23	11319500	9	Daily maximum	Amplitude	5	4.69
23	11319500	9	Daily maximum	Annual maximum	5	15.42
33	11382000	10	Daily minimum	Annual mean	5	11.56
36	11390000	10	Daily minimum	Phase	5	2.58
45	11407000	11	Daily maximum	Amplitude	6	8.48
45	11407000	11	Daily maximum	Annual mean	6	13.06
45	11407000	11	Daily maximum	Annual maximum	6	21.54
51	11445500	10	Daily minimum	Annual maximum	5	17.66
66	11471000	5	Daily maximum	Annual maximum	2	20.90
72	11480500	9	Daily minimum	Annual mean	5	10.73
79	11525500	14	Daily maximum	Amplitude	7	5.13
79	11525500	14	Daily maximum	Annual mean	7	10.48
79	11525500	14	Daily maximum	Annual maximum	7	15.61
79	11525500	14	Daily minimum	Amplitude	7	3.87
79	11525500	14	Daily minimum	Annual mean	7	9.32
79	11525500	14	Daily minimum	Annual maximum	7	13.20

changes in one or more harmonic coefficients

significance level equal to or less than 0.01. Means and annual mean, and annual maximum; and in radians for phase is the sum of mean and amplitude]

Second period		Estimate of change		98 percent confidence interval	Confidence level (percent)
Number of years	Mean	Absolute	Percent		
8	9	10	11	12	13
4	20.52	4.24	26.0	3.50, 5.00	90
4	8.88	-1.38	-13.4	-0.30, -2.20	90
3	2.91	.30	11.5	0.10, 0.60	90
3	15.67	.53	3.5	0.20, 0.90	80
4	5.64	.95	20.3	0.20, 1.40	80
4	17.33	1.91	12.4	0.10, 4.00	98
5	10.34	-1.22	-10.6	-0.30, -2.50	90
5	2.76	.18	7.0	0.10, 0.30	80
5	4.76	-3.72	-43.9	-0.60, -5.10	98
5	11.79	-1.27	-9.7	-0.40, -2.00	98
5	18.55	-2.99	-13.9	-1.00, -6.80	98
5	15.49	-2.17	-12.3	-0.20, -5.80	90
3	21.77	.87	4.2	0.40, 1.40	80
4	9.76	-.97	-9.0	-0.10, -2.20	95
7	2.52	-2.61	-50.9	-0.10, -7.20	98
7	8.64	-1.84	-17.6	-0.60, -2.20	95
7	11.16	-4.45	-28.5	-0.50, -11.0	98
7	1.78	-2.09	-54.0	-0.10, -3.10	90
7	7.68	-1.64	-17.6	-0.40, -2.90	98
7	9.46	-3.74	-28.3	-0.40, -9.60	98

For 8 of the 11 stations (table 2) that showed significant trends during the period of record, the probable causes for time-related changes in harmonic coefficients were upstream regulation or reservoir releases. For five stations, the trend showed a change toward lower water temperatures; for two stations the trend was toward higher water temperatures. At one station, the phase coefficient showed a slight time-related change toward the left (earlier seasonal minimum and maximum temperatures) in the harmonic function for daily minimum temperature values. Natural effects associated with meteorological or geophysical changes were not investigated to determine whether water-temperature changes could be attributed to these factors. A brief explanation of the trend analysis results for specific stations follows.

Big Rock Creek near Valyermo (10263500).--The annual maximum of the daily maximum water temperature for the last 4 years of record increased by 26.0 percent over the preceding 3 years of record. There is no regulation or diversion above the station and no apparent reason for the increase in temperature.

Sespe Creek near Wheeler Springs (11111500).--The annual mean of the daily minimum water temperatures decreased 13.4 percent. There is no regulation or diversion upstream from the gaging station and no apparent reason for the decrease in temperature.

San Lorenzo River at Big Trees (11160500).--A minor decrease (3.5 percent) in the annual maximum of the daily minimum water temperatures and an 11.5 percent change in the phase coefficient may be related to regulation upstream. The positive increase in the phase coefficient indicates a harmonic curve shift to the left; the annual maximum value occurs about 17 days earlier.

Mokelumne River near Mokelumne Hill (11319500).--A 20.3 percent increase in the amplitude and an associated 12.4 percent increase in the daily maximum water temperature in the last 4 years of the 9-year record can probably be attributed to releases from Salt Springs Reservoir.

Thomes Creek near Paskenta (11382000).--The 1.22°C (10.6 percent) decrease in the annual mean of the daily minimum water temperature in the last 5 years compared to the preceding 5 years of record is unexplained. Streamflow is not regulated.

Butte Creek near Chico (11390000).--A slight trend of the harmonic curve toward the left results in a 10-day earlier occurrence of the annual maximum temperature for daily minimum values. Flow in Butte Creek is regulated slightly by Magalia Reservoir.

Feather River at Oroville (11407000).--Significant decreases in amplitude, annual mean, and annual maximum of the daily maximum water temperatures are attributed to regulation by Lake Oroville.

South Fork American River near Lotus (11445500).--A 12.3-percent decrease in the annual maximum of the daily minimum water temperatures may be attributed to regulation by several reservoirs upstream from the station. The daily maximum water temperatures apparently were not affected significantly.

Potter Valley powerhouse tailrace near Potter Valley (11471000).--The annual maximum of the daily maximum water temperatures showed a small increase of 0.9°C (4.2 percent) in the last 3 years of the 5-year period of record. Flow is regulated by Lake Pillsbury and Van Arsdale Dam.

Mad River near Forest Glen (11480500).--The annual mean of the daily minimum water temperatures decreased 0.97°C (9.0 percent) in the last 4 years of the 9-year record. The daily maximum water temperature showed no trend at the 0.01 significance level. Flow is regulated by Ruth Reservoir.

Trinity River at Lewiston (11525500).--There were significant time-related decreases in amplitude, annual mean, and annual maximum values for both the daily maximum and daily minimum water temperatures. These changes reflect the effect of cold-water releases from Clair Engle Lake.

Variation of Harmonic Coefficients with Length of Thermograph Record

To evaluate the effect of a reduction in length of thermograph record on the calculated water temperature characteristics, harmonic coefficients for 12 stations using eight of the available years of record were compared with corresponding values computed for two equally split 4-year periods of record. Stations used in this comparison are listed in table 3. The selected stations showed minimal time-related trends for the harmonic coefficients, according to the results of the Kendall tau tests, described in a preceding section. The average percentage difference (absolute) between the first or second 4-year period of record and the total 8-year period was 2.2, 1.5, and 1.9 for amplitude, annual mean, and phase coefficient. In absolute terms this represents 0.15°C, 0.18°C, and 0.05 radians or about 3 days.

The maximum difference between 4- and 8-year periods was 5.0 percent or 0.48°C for amplitude; 4.0 percent or 0.52°C for the annual mean; and 5.9 percent or 0.17 radians (9.9 days) for the phase coefficient.

It is apparent from this comparison that estimating water temperature characteristics from a shorter record at these stations (for this study, 4 years) would not introduce an appreciable error.

TABLE 3.--*Comparison of variations of harmonic coefficients with length of record*

[Sequence number corresponds to those given in table 5]

Sequence number	Station number	Period	Number of years	Type of record [1]	Mean (*M*)	Amplitude (*A*)	Phase coefficient (*C*)	Standard error (SE)	Variance (RSQD)
2	11111500	1963-65, 1967, 1969-72	8	Max	14.24	8.07	2.82	2.29	86.16
				Min	-	-	-	-	-
		1963-65, 1967	4	Max	14.31	7.89	2.68	2.19	86.92
				Min	-	-	-	-	-
		1969-72	4	Max	14.20	8.32	2.86	2.26	87.00
				Min	-	-	-	-	-
7	11185350	1966-73	8	Max	9.28	6.69	2.71	2.11	83.28
				Min	7.43	5.95	2.69	1.79	84.42
		1966-69	4	Max	9.17	6.44	2.62	2.24	80.35
				Min	7.36	5.69	2.60	1.93	80.94
		1970-73	4	Max	9.39	7.00	2.81	1.85	87.60
				Min	7.48	6.26	2.78	1.54	89.02
13	11208000	1964-71	8	Max	11.41	7.28	2.41	2.22	84.42
				Min	9.68	6.59	2.27	2.17	82.23
		1964-67	4	Max	11.39	7.11	2.41	2.13	84.87
				Min	9.67	6.43	2.24	2.07	82.98
		1968-71	4	Max	11.42	7.46	2.44	2.30	84.09
				Min	9.70	6.78	2.32	2.26	81.77
16	11237000	1963-70	8	Max	7.84	6.30	2.36	1.59	88.53
				Min	6.00	5.37	2.18	1.36	88.45
		1963-66	4	Max	8.05	6.23	2.41	1.49	89.35
				Min	6.09	5.24	2.21	1.28	88.97
		1967-70	4	Max	7.66	6.33	2.33	1.63	88.29
				Min	5.93	5.47	2.16	1.41	88.23
17	11246500	1963-67, 1969, 1971-72	8	Max	14.63	9.22	2.66	2.70	84.98
				Min	11.97	7.60	2.61	2.30	84.11
		1963-66	4	Max	14.88	9.14	2.60	2.51	86.73
				Min	12.22	7.63	2.54	2.14	86.20
		1967, 1969, 1971-72	4	Max	14.37	9.33	2.63	2.82	83.86
				Min	11.70	7.60	2.59	2.39	82.82
41	11401180	1965-68, 1970-73	8	Max	8.28	6.89	2.76	1.87	87.35
				Min	6.27	5.45	2.65	1.88	80.77
		1965-68	4	Max	8.30	6.65	2.76	1.81	87.38
				Min	6.25	5.29	2.63	1.81	81.26
		1970-73	4	Max	8.29	7.14	2.80	1.89	87.74
				Min	6.32	5.64	2.72	1.91	81.05

See footnote at end of table.

TABLE 3.--*Comparison of variations of harmonic coefficients with length of record*--Continued

Sequence number	Station number	Period	Number of years	Type of record[1]	Mean (*M*)	Amplitude (*A*)	Phase coefficient (*C*)	Standard error (SE)	Variance (RSQD)
46	11417500	1966-73	8	Max	13.42	9.47	2.73	2.58	87.04
				Min	11.40	8.16	2.67	2.45	84.68
		1966-69	4	Max	13.19	9.32	2.66	2.64	86.19
				Min	11.15	8.00	2.60	2.48	83.91
		1970-73	4	Max	13.67	9.66	2.81	2.42	88.88
				Min	11.68	8.37	2.76	2.31	86.69
56	11456000	1962-63, 1967-69, 1971-73	8	Max	16.48	6.79	3.07	2.05	84.36
				Min	14.00	5.30	2.84	1.94	78.50
		1962-63, 1967-68	4	Max	16.75	7.04	3.06	2.10	84.88
				Min	14.51	5.25	2.87	2.00	77.41
		1969, 1971-73	4	Max	16.19	6.51	3.13	1.92	84.83
				Min	13.48	5.31	2.87	1.72	82.04
60	11464500	1966-73	8	Max	18.95	9.24	2.79	2.07	90.92
				Min	13.57	5.56	2.73	1.84	82.13
		1966-69	4	Max	19.16	9.40	2.75	2.22	89.94
				Min	13.50	5.47	2.69	1.94	79.81
		1970-73	4	Max	18.79	9.11	2.84	1.87	92.32
				Min	13.66	5.65	2.79	1.72	84.53
64	11468600	1965, 1967-73	8	Max	12.98	4.65	2.78	1.46	83.63
				Min	11.45	3.63	2.69	1.45	75.70
		1965, 1967-69	4	Max	12.91	4.63	2.71	1.42	84.22
				Min	11.60	3.64	2.63	1.41	77.00
		1970-73	4	Max	13.02	4.69	2.88	1.45	84.03
				Min	11.27	3.61	2.78	1.45	75.33
67	11475500	1961-65, 1967-68, 1970	8	Max	13.79	7.82	2.70	2.40	83.96
				Min	11.86	5.72	2.69	2.03	79.71
		1961-64	4	Max	13.39	7.75	2.75	2.21	85.76
				Min	11.65	5.77	2.75	1.90	82.04
		1965, 1967-68, 1970	4	Max	14.16	7.89	2.72	2.50	83.19
				Min	12.05	5.68	2.69	2.12	78.11
78	11523000	1966-73	8	Max	13.71	9.15	2.68	2.35	88.15
				Min	12.03	7.85	2.67	2.26	85.44
		1966-69	4	Max	13.89	9.14	2.70	2.39	87.92
				Min	12.42	8.22	2.69	2.45	84.85
		1970-73	4	Max	13.52	9.16	2.68	2.28	88.50
				Min	11.63	7.44	2.68	1.95	87.43

[1]Max is daily maximum water temperature.
Min is daily minimum water temperature.

Comparison of Harmonic Coefficients for Thermograph Record With Periodic Measurements of Water Temperature

Harmonic coefficients for water-temperature records at five thermograph stations were compared with those for a concurrent period when discrete water-temperature measurements were made. Average values of daily maximum and minimum water temperature harmonic coefficients for thermograph data during the 1972 water year were compared with the averages for periodic measurements made during the same year. Overall percentage differences for the five stations were 2.9 for the mean, 7.9 for the amplitude, and 0.7 for the phase coefficient, representing absolute values for the differences of 0.41°C, 0.80°C, and 0.03 radians (1.7 days). The SE and RSQD statistics for the thermograph data were only slightly improved over the periodic data. Consistent results from this small sample comparison showed that using as few as 10 to 23 discrete temperature measurements per year resulted in harmonic coefficients defined nearly as well as a complete year of thermograph record. Harmonic coefficients (amplitude, phase coefficient, and mean) for periodic data for the 1972 water year are shown in table 4. SE and RSQD statistics are also shown, as well as daily maximum and minimum statistics for the 1972 water year thermograph record.

Gilroy and Steele (1972) made a similar analysis, comparing harmonic coefficients computed from data collected at several temperature-sampling frequencies (periodic data) with those for long-term daily records. They found the year-to-year variations of harmonic coefficients to be small for water-temperature sampling done as infrequently as 12 times a year, inferring only a minimal loss of water-temperature information if sampling was done only monthly instead of with a thermograph. Consideration of this conclusion in network design and operation would substantially reduce the cost of operating a station. However, continuous monitoring can be justified if the network objective is surveillance of thermal loadings or if the objective is to assess time changes.

Shampine (1976) made a study of variations of harmonic coefficients for an Indiana stream measured at 1- to 45-day intervals. His results substantiate those of Gilroy and Steele and those reported in this report. The calculated values for amplitude, mean, and phase coefficients were reasonably close for all sample frequencies, considering the random variation in the time of day the samples were collected.

TABLE 4.--*Comparison of harmonic coefficients for thermograph and periodic water-temperature data, 1972 water year*

[Sequence number corresponds to those given in table 5. Harmonic coefficients for thermograph data are average of daily maximum and minimum coefficients]

Sequence number	Station number	Number of days of record		Harmonic mean (*M*)		Amplitude (*A*)		Phase coefficient (*C*)		Standard error of estimate (SE)			Percentage of variance explained (RSQD)		
										Thermograph			Thermograph		
		Thermograph	Periodic	Thermograph	Periodic	Thermograph	Periodic	Thermograph	Periodic	Maximum	Minimum	Periodic	Maximum	Minimum	Periodic
11	11203200	334	23	17.52	16.53	10.62	11.99	2.91	3.00	2.27	2.06	2.79	92.66	90.20	90.52
48	11427000	360	10	14.75	14.66	10.02	8.55	2.57	2.54	1.58	1.63	1.80	94.72	94.37	92.12
50	11439500	341	12	7.92	7.81	8.30	8.51	2.70	2.70	2.51	2.04	3.17	86.95	86.07	76.84
73	11516530	361	19	11.53	11.50	10.34	9.46	2.83	2.85	1.32	1.36	1.57	96.68	96.27	94.98
76	11520500	339	14	12.06	12.87	9.87	9.95	2.82	2.83	1.79	1.63	1.80	94.42	93.64	95.11

SUMMARY AND CONCLUSIONS

Eighty-two selected stations in California, each having 5 to 14 years of thermograph record, were studied to determine whether thermograph stations should be operated for a finite period of time. Fifty of these stations were located in two hydrologic subregions, Sacramento Basin and North Coastal. The 82 stations represented 619 years of record, or an average of 7.5 years of record for all stations.

Harmonic analyses were used to characterize annual stream-temperature variability. Both continuous data from thermograph operation (daily maximum and minimum temperatures) and selected periodic data from discrete water-temperature measurements were used in these analyses. For annual increments of water-temperature data, more than 80 percent of the variance was explained by the harmonic function.

Multiyear harmonic analysis, where data for several years were combined, is a useful method for testing for time trends, and for estimating the long term mean, amplitude, annual maximum and minimum water temperatures, and phase coefficient. The harmonic function can be used to compute the expected water temperature for a particular day or days.

Kendall's tau, a nonparametric statistical test, was applied to yearly values of four harmonic coefficients, amplitude, mean, phase coefficient, and annual maximum for daily maximum and minimum water temperatures, at the 82 stations. Trends were found in one or more of the coefficients at 11 stations. The probable causes for these changes at eight stations were regulation or reservoir releases upstream from the gaging station. No apparent or obvious cause could be found for changes in the stream temperature regimen at the three other stations.

Harmonic analysis of records for 12 stations, each with 8 years of thermograph record, showed that the full 8-year record did not provide harmonic coefficients significantly different from those obtained when these records were split into two 4-year periods. The maximum differences in harmonic coefficients between 4- and 8-year periods of record were 0.48°C for amplitude, 0.52°C for annual mean, and 9.9 days for phase coefficient. From statistical computations (SE and RSQD) the same conclusion was evident--there was only a minor improvement in harmonic coefficients using 8 years of record over either 4-year period of record.

Water-temperature data collected on a periodic basis, 10 to 23 times per year for the year studied (1972), showed small differences in harmonic coefficients when compared to data from continuous thermographs. For five stations studied, the overall percentage differences were 2.9 for mean, 7.9 for amplitude, and 0.7 for phase coefficient, representing absolute values of 0.41°C, 0.80°C, and 1.7 days for these coefficients.

This study indicates that the standard error for thermograph records is not significantly reduced by long-term (4 years for this study) operation. Further, the standard error for once- or twice-monthly periodic measurements is less than 1°C for both the mean and amplitude. Thermograph operations can be substantially reduced if the standard error values computed for stations in this study are acceptable for the designated purposes for which information is obtained. Thermographs may need to be operated where continual monitoring of water temperature is necessary, or if there is a possibility of temporal change in stream-temperature regime.

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TABLE 5.--*Gaging-station thermograph records used in the evaluation*

Sequence number	U.S. Geological Survey gaging station number	Hydrologic subregion	Station name	Thermograph record	
				Number of years	Water years
1	10263500	South Lahontan	Big Rock Creek near Valyermo	7	1963-65 1968 1971-73
2	11111500	South Coastal	Sespe Creek near Wheeler Springs	[1]8	1963-65 1967 1969-72
3	11143000	Central Coastal	Big Sur River near Big Sur	7	1966 1968-73
4	11160000	Central Coastal	Soquel Creek at Soquel	5	1968-69 1971-73
5	11160500	Central Coastal	San Lorenzo River at Big Trees	6	1967 1969-73
6	11162500	San Francisco Bay	Pescadero Creek near Pescadero	5	1969-73
7	11185350	Tulare Basin	Kern River near Quaking Aspen Camp	[1]8	1966-73
8	11185500	Tulare Basin	Kern River no. 3 Canal near Kernville	7	1963-69
9	11187000	Tulare Basin	Kern River at Kernville	9	1963-64 1966 1968-73
10	11187500	Tulare Basin	Borel Canal below Isabella Dam	13	1959-71
11	11203200	Tulare Basin	Tule River near Springville	[2]5	1966-67 1971-73
12	11206500	Tulare Basin	Middle Fork Kaweah River near Potwisha Camp	5	1959-62 1972
13	11208000	Tulare Basin	Marble Fork Kaweah River at Potwisha Camp	[1]8	1964-71
14	11213500	Tulare Basin	Kings River above North Fork, near Trimmer	6	1967 1969-73
15	11218500	Tulare Basin	Kings River below North Fork, near Trimmer	6	1967 1969-73

See footnotes at end of table.

TABLE 5.--*Gaging-station thermograph records used in the evaluation*--Continued

Sequence number	U.S. Geological Survey gaging station number	Hydrologic subregion	Station name	Thermograph record	
				Number of years	Water years
16	11237000	San Joaquin Basin	Big Creek below Huntington Lake	[1]8	1963-70
17	11246500	San Joaquin Basin	Willow Creek at Mouth near Auberry	[1]8	1963-67 1969 1971-72
18	11247000	San Joaquin Basin	San Joaquin River below Kerckhoff Powerhouse, near Prather	9	1962-66 1968 1971-73
19	11264500	San Joaquin Basin	Merced River at Happy Isles Bridge, near Yosemite	7	1967-73
20	11290000	San Joaquin Basin	Tuolemne River at Modesto	7	1966-67 1969-73
21	11292700	San Joaquin Basin	Middle Fork Stanislaus River at Hells Half Acre Bridge, near Pinecrest	6	1967-71 1973
22	11302000	San Joaquin Basin	Stanislaus River below Goodwin Dam, near Knights Ferry	5	1968 1970-73
23	11319500	Delta - Central Sierra	Mokelumne River near Mokelumne Hill	9	1962-64 1967 1969-73
24	11323500	Delta - Central Sierra	Mokelumne River below Camanche Dam	7	1962-64 1967 1971-73
25	11325500	Delta - Central Sierra	Mokelumne River at Woodbridge	11	1962-63 1965-73
26	11335000	Delta - Central Sierra	Consumnes River at Michigan Bar	7	1966-68 1970-73
27	11341400	Sacramento Basin	Sacramento River near Mt. Shasta	6	1966-68 1970-71 1973
28	11342000	Sacramento Basin	Sacramento River at Delta	11	1963-73
29	11372000	Sacramento Basin	Clear Creek near Igo	7	1966-72

See footnotes at end of table.

TABLE 5.--*Gaging-station thermograph records used in the evaluation*--Continued

Sequence number	U.S. Geological Survey gaging station number	Hydrologic subregion	Station name	Thermograph record	
				Number of years	Water years
30	11374000	Sacramento Basin	Cow Creek near Millville	7	1966-71 1973
31	11376550	Sacramento Basin	Battle Creek below Coleman Hatchery, near Cottonwood	5	1967-71
32	11378000	Sacramento Basin	Sacramento River near Red Bluff	6	1962-63 1965-68
33	11382000	Sacramento Basin	Thomes Creek at Paskenta	10	1962-64 1966-67 1969-73
34	11384600	Sacramento Basin	Little Stony Creek near Lodoga	5	1968-70 1972-73
35	11389000	Sacramento Basin	Sacramento River at Butte City	6	1963-64 1966-67 1970-71
36	11390000	Sacramento Basin	Butte Creek near Chico	10	1963-64 1966-73
37	11390500	Sacramento Basin	Sacramento River below Wilkins Slough	5	1967-69 1971-72
38	11391500	Sacramento Basin	Big Grizzly Creek at Grizzly Valley Dam, near Portola	5	1963-67
39	11392500	Sacramento Basin	Middle Fork Feather River near Clio	7	1964-66 1969-70 1972-73
40	11394500	Sacramento Basin	Middle Fork Feather River near Merrimac	10	1963-72
41	11401180	Sacramento Basin	Little Grizzly Creek near Genesee	[1]8	1965-68 1970-73
42	11401500	Sacramento Basin	Indian Creek near Crescent Mills	10	1963-65 1967-73
43	11404500	Sacramento Basin	North Fork Feather River at Pulga	6	1963-64 1967 1969 1972-73
44	11405300	Sacramento Basin	West Branch Feather River near Paradise	11	1963-73

TABLE 5.--*Gaging-station thermograph records used in the evaluation*--Continued

Sequence number	U.S. Geological Survey gaging station number	Hydrologic subregion	Station name	Thermograph record	
				Number of years	Water years
45	11407000	Sacramento Basin	Feather River at Oroville	11	1959-61 1964-67 1970-73
46	11417500	Sacramento Basin	South Yuba River at Jones Bar, near Grass Valley	[1]8	1966-73
47	11425000	Sacramento Basin	Feather River at Nicolaus	7	1963-68 1973
48	11427000	Sacramento Basin	North Fork American River at North Fork Dam	[2]12	1962-73
49	11433400	Sacramento Basin	Canyon Creek near Georgetown	5	1967-71
50	11439500	Sacramento Basin	South Fork American River near Kyburz	[2]6	1967-69 1971-73
51	11445500	Sacramento Basin	South Fork American River near Lotus	10	1961-62 1964-68 1971-73
52	11446500	Sacramento Basin	American River at Fair Oaks	9	1964 1966-73
53	11447650	Sacramento Basin	Sacramento River near Freeport	12	1962-73
54	11453500	Sacramento Basin	Putah Creek near Guenoc	13	1961-73
55	11454000	Sacramento Basin	Putah Creek near Winters	5	1967-68 1970-72
56	11456000	San Francisco Bay	Napa River near St. Helena	[1]8	1962-63 1967-69 1971-73
57	11460920	San Francisco Bay	Salmon Creek at Bodega	5	1965 1967-68 1970-71
58	11461500	San Francisco Bay	East Fork Russian River near Calpella	6	1966-67 1969-70 1972-73
59	11464000	San Francisco Bay	Russian River near Healdsburg	6	1967-69 1971-73

See footnotes at end of table.

TABLE 5.--*Gaging-station thermograph records used in the evaluation*--Continued

Sequence number	U.S. Geological Survey gaging station number	Hydrologic subregion	Station name	Thermograph record	
				Number of years	Water years
60	11464500	San Francisco Bay	Dry Creek near Cloverdale	[1]8	1966-73
61	11467000	San Francisco Bay	Russian River near Guerneville	7	1965-71
62	11467600	North Coastal	Garcia River near Point Arena	9	1964-68 1970-73
63	11468500	North Coastal	Noyo River near Fort Bragg	5	1967 1969 1971-73
64	11468600	North Coastal	Middle Fork Tenmile River near Fort Bragg	[1]8	1965 1967-73
65	11470500	North Coastal	Eel River below Scott Dam, near Potter Valley	9	1964-65 1967-73
66	11471000	North Coastal	Potter Valley Powerhouse Tailrace near Potter Valley	5	1969-73
67	11475500	North Coastal	South Fork Eel River near Branscomb	[1]8	1961-65 1967-68 1970
68	11475800	North Coastal	South Fork Eel River at Leggett	6	1966-69 1972-73
69	11476500	North Coastal	South Fork Eel River near Miranda	6	1964 1966-68 1972-73
70	11477000	North Coastal	Eel River at Scotia	9	1963-64 1967-73
71	11477500	North Coastal	Van Duzen River near Dinsmores	5	1966-67 1971-73
72	11480500	North Coastal	Mad River near Forest Glen	9	1962-66 1968 1971-73
73	11516530	North Coastal	Klamath River below Iron Gate Dam	[2]11	1963-73

See footnotes at end of table.

TABLE 5.--*Gaging-station thermograph records used in the evaluation*--Continued

Sequence number	U.S. Geological Survey gaging station number	Hydrologic subregion	Station name	Thermograph record	
				Number of years	Water years
74	11516600	North Coastal	Cottonwood Creek near Hornbrook	5	1965 1967-69 1971
75	11517500	North Coastal	Shasta River near Yreka	6	1967 1969-73
76	11520500	North Coastal	Klamath River near Seiad Valley	[2]9	1964 1966-73
77	11522500	North Coastal	Salmon River at Somesbar	6	1966 1969-73
78	11523000	North Coastal	Klamath River at Orleans	[1]8	1966-73
79	11525500	North Coastal	Trinity River at Lewiston	14	1960-73
80	11527000	North Coastal	Trinity River near Burnt Ranch	7	1963-64 1967 1969-71 1973
81	11530300	North Coastal	Blue Creek near Klamath	7	1967-73
82	11532500	North Coastal	Smith River near Crescent City	5	1967-70 1973

[1]Used for split-sample testing of harmonic coefficients (see table 3).
[2]Used for comparison of daily versus periodic harmonic analysis results (see table 4).

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (maximums only)*

STATION NUMBER	SE-QUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
10-2635.00	1	7	1963-65, 1968, 1971-73	2476	4.35	2.71	14.18	2.18	66.51
11-1115.00	2	4	1963-65, 1967	1405	7.89	2.68	14.31	2.19	86.92
11-1115.00	2	4	1969-72	1435	8.32	2.86	14.20	2.26	87.00
11-1430.00	3	7	1966, 1968-73	2303	4.25	2.81	13.82	1.58	78.67
11-1600.00	4	5	1968-69, 1971-73	1631	6.92	2.78	16.98	2.62	77.57
11-1605.00	5	6	1967, 1969-73	1674	5.81	2.77	14.77	1.95	82.09
11-1625.00	6	5	1969-73	1725	5.29	2.78	13.27	1.78	81.31
11-1853.50	7	4	1966-69	1390	6.44	2.62	9.17	2.24	80.35
11-1853.50	7	4	1970-73	1397	7.00	2.81	9.39	1.85	87.60
11-1855.00	8	7	1963-69	2458	7.25	2.58	10.09	2.15	84.96
11-1870.00	9	9	1963-64, 1966, 1968-73	3105	7.74	2.63	12.00	2.15	86.57
11-1875.00	10	13	1959-71	4621	7.73	2.56	14.28	2.12	87.00
11-2032.00	11	5	1966-67, 1971-73	1684	9.75	2.64	17.60	3.34	81.03
11-2065.00	12	5	1959-62, 1972	1797	8.55	2.68	12.14	2.35	86.92
11-2080.00	13	4	1964-67	1446	7.11	2.41	11.39	2.13	84.87
11-2080.00	13	4	1968-71	1456	7.46	2.44	11.42	2.30	84.09
11-2135.00	14	6	1967, 1969-73	2043	6.48	2.55	12.68	2.54	76.43
11-2185.00	15	6	1967, 1969-73	1961	4.95	2.51	11.08	2.56	66.01
11-2370.00	16	4	1963-66	1269	6.23	2.41	8.05	1.49	89.35
11-2370.00	16	4	1967-70	1450	6.33	2.33	7.66	1.63	88.29
11-2465.00	17	4	1963-66	1363	9.14	2.60	14.88	2.51	86.73

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (maximums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-2465.00	17	4	1967, 1969, 1971-72	1340	9.33	2.63	14.37	2.82	83.86
11-2470.00	18	9	1962-66, 1968, 1971-73	3239	5.64	2.14	11.65	1.51	87.49
11-2645.00	19	7	1967-73	2386	6.76	2.64	7.93	1.77	87.84
11-2900.00	20	7	1966-67, 1969-73	2182	8.33	2.70	17.87	2.67	82.73
11-2927.00	21	6	1967-71, 1973	1937	7.49	2.52	10.12	2.22	85.02
11-3020.00	22	5	1968, 1970-73	1689	8.55	2.48	16.08	1.93	90.61
11-3195.00	23	9	1962-64, 1967, 1969-73	3262	4.90	2.52	11.16	1.70	80.57
11-3235.00	24	7	1962-64, 1967, 1971-73	2426	3.18	2.30	13.16	1.59	66.49
11-3255.00	25	11	1962-63, 1965-73	3938	5.76	2.58	14.58	2.18	78.04
11-3350.00	26	7	1966-68, 1970-73	2410	9.71	2.66	15.80	2.36	89.41
11-3414.00	27	6	1966-68, 1970-71, 1973	2034	5.69	2.59	9.57	1.23	91.22
11-3420.00	28	11	1963-73	3964	8.23	2.68	13.50	2.45	84.95
11-3720.00	29	7	1966-72	2401	5.11	2.87	12.56	1.35	87.57
11-3740.00	30	7	1966-71, 1973	2247	10.78	2.74	17.47	2.39	90.84
11-3765.50	31	5	1967-71	1765	5.47	2.79	13.02	1.53	86.39
11-3780.00	32	6	1962-63, 1965-68	2176	2.03	2.63	11.03	1.26	56.88
11-3820.00	33	10	1962-64, 1966-67, 1969-73	3519	12.14	2.64	17.19	3.25	87.64
11-3846.00	34	5	1968-70, 1972-73	1535	10.89	2.79	16.35	2.43	90.86
11-3890.00	35	6	1963-64, 1966-67, 1970-71	2135	4.91	2.72	13.64	1.28	88.24
11-3900.00	36	10	1963-64, 1966-73	3406	7.30	2.65	12.41	1.94	87.78
11-3905.00	37	5	1967-69, 1971-72	1786	5.30	2.77	14.16	1.39	87.81

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (maximums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-3915.00	38	5	1963-67	1719	10.84	2.69	10.38	2.58	89.73
11-3925.00	39	7	1964-66, 1969-70, 1972-73	2449	10.41	2.84	11.09	2.11	92.37
11-3945.00	40	10	1963-72	3351	7.98	2.70	10.97	2.03	88.57
11-4011.80	41	4	1965-68	1351	6.65	2.76	8.30	1.81	87.38
11-4011.80	41	4	1970-73	1355	7.14	2.80	8.29	1.89	87.74
11-4015.00	42	10	1963-65, 1967-73	3355	9.17	2.72	11.62	2.46	87.53
11-4045.00	43	6	1963-64, 1967, 1969, 1972-73	1872	8.06	2.58	12.72	1.99	88.68
11-4053.00	44	11	1963-73	3902	9.68	2.49	12.66	2.97	83.97
11-4070.00	45	11	1959-61, 1964-67, 1970-73	3928	6.58	2.59	12.46	2.23	81.31
11-4175.00	46	4	1966-69	1447	9.32	2.66	13.19	2.64	86.19
11-4175.00	46	4	1970-73	1392	9.66	2.81	13.67	2.42	88.88
11-4250.00	47	7	1963-68, 1973	2349	9.41	2.65	15.91	2.24	89.56
11-4270.00	48	12	1962-73	4317	8.62	2.47	15.18	2.07	89.66
11-4334.00	49	5	1967-71	1804	6.66	2.79	11.98	1.73	88.16
11-4395.00	50	6	1967-69, 1971-73	2049	8.14	2.53	9.42	2.85	79.76
11-4455.00	51	10	1961-62, 1964-68, 1971-73	3644	6.88	2.62	11.88	2.02	85.37
11-4465.00	52	9	1964, 1966-73	3136	4.84	2.30	13.50	1.31	87.16
11-4476.50	53	12	1962-73	4375	6.85	2.70	14.80	1.32	93.10
11-4535.00	54	13	1961-73	4688	8.68	2.78	18.24	1.85	91.62
11-4540.00	55	5	1967-68, 1970-72	1703	1.04	2.96	11.67	1.36	22.28
11-4560.00	56	4	1962-63, 1967-68	1428	7.04	3.06	16.75	2.10	84.88

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (maximums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-4560.00	56	4	1969, 1971-73	1373	6.51	3.13	16.19	1.92	84.83
11-4609.20	57	5	1965, 1967-68, 1970-71	1446	3.90	3.11	14.03	2.26	61.96
11-4615.00	58	6	1966-67, 1969-70, 1972-73	2021	7.21	2.69	14.34	2.01	86.46
11-4640.00	59	6	1967-69, 1971-73	2004	7.26	2.76	17.01	1.79	89.02
11-4645.00	60	4	1966-69	1306	9.40	2.75	19.16	2.22	89.94
11-4645.00	60	4	1970-73	1335	9.11	2.84	18.79	1.87	92.32
11-4670.00	61	7	1965-71	2371	7.75	2.74	17.05	1.88	89.39
11-4676.00	62	9	1964-68, 1970-73	3134	4.79	2.69	15.14	1.33	86.70
11-4685.00	63	5	1967, 1969, 1971-73	1686	5.67	2.75	13.79	1.56	86.77
11-4686.00	64	4	1965, 1967-69	1389	4.63	2.71	12.91	1.42	84.22
11-4686.00	64	4	1970-73	1326	4.69	2.88	13.02	1.45	84.03
11-4705.00	65	9	1964-65, 1967-73	3007	5.59	2.31	12.25	2.05	79.09
11-4710.00	66	5	1969-73	1539	7.18	2.68	14.31	1.63	91.04
11-4755.00	67	4	1961-64	1346	7.75	2.75	13.39	2.21	85.76
11-4755.00	67	4	1965, 1967-68, 1970	1442	7.89	2.72	14.16	2.50	83.19
11-4758.00	68	6	1966-69, 1972-73	2157	8.57	2.71	15.58	1.75	92.37
11-4765.00	69	6	1964, 1966-68, 1972-73	2021	8.86	2.72	16.39	2.13	89.70
11-4770.00	70	9	1963-64, 1967-73	3151	6.96	2.61	14.58	1.71	89.27
11-4775.00	71	5	1966-67, 1971-73	1478	8.74	2.70	13.22	1.96	90.76
11-4805.00	72	9	1962-66, 1968, 1971-73	3085	7.17	2.63	12.52	1.75	89.28
11-5165.30	73	11	1963-73	3976	8.94	2.64	11.84	1.29	96.01

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (maximums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-5166.00	74	5	1965, 1967-69, 1971	1778	9.76	2.69	13.51	2.68	86.79
11-5175.00	75	6	1967, 1969-73	1943	10.59	2.90	15.25	2.39	90.45
11-5205.00	76	9	1964, 1966-73	3057	9.56	2.67	12.93	1.94	92.27
11-5225.00	77	6	1966, 1969-73	2019	8.45	2.60	12.75	2.55	84.68
11-5230.00	78	4	1966-69	1341	9.14	2.70	13.89	2.39	87.92
11-5230.00	78	4	1970-73	1359	9.16	2.68	13.52	2.28	88.50
11-5255.00	79	14	1960-73	5053	3.67	2.83	9.56	2.32	55.64
11-5270.00	80	7	1963-64, 1967, 1969-71, 1973	2328	7.31	2.54	13.04	2.30	83.56
11-5303.00	81	7	1967-73	2543	6.31	2.48	13.23	1.56	89.04
11-5325.00	82	5	1967-70, 1973	1745	6.79	2.65	13.48	1.77	88.01

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (minimums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
10-2635.00	1	7	1963-65, 1968, 1971-73	2470	3.34	2.46	10.49	1.51	70.85
11-1115.00	2	4	1963-65, 1967	1405	5.65	2.62	10.28	1.84	82.92
11-1115.00	2	4	1969-72	1428	4.87	2.85	8.88	1.90	76.42
11-1430.00	3	7	1966, 1968-73	2303	3.97	2.72	12.75	1.62	75.27
11-1600.00	4	5	1968-69, 1971-73	1631	4.46	2.75	12.07	1.70	77.50
11-1605.00	5	6	1967, 1969-73	1674	3.73	2.78	11.63	1.73	70.43
11-1625.00	6	5	1969-73	1725	4.43	2.80	11.43	1.89	73.21
11-1853.50	7	4	1966-69	1371	5.69	2.60	7.36	1.93	80.94
11-1853.50	7	4	1970-73	1390	6.26	2.78	7.48	1.54	89.02
11-1855.00	8	7	1963-69	2409	6.72	2.57	8.52	2.13	83.14
11-1870.00	9	9	1963-64, 1966, 1968-73	3104	7.39	2.63	10.63	1.87	88.60
11-1875.00	10	13	1959-71	4621	7.43	2.58	13.15	2.37	83.13
11-2032.00	11	5	1966-67, 1971-73	1684	8.01	2.59	13.59	2.50	83.67
11-2065.00	12	5	1959-62, 1972	1795	7.63	2.58	10.17	2.44	82.99
11-2080.00	13	4	1964-67	1446	6.43	2.24	9.67	2.07	82.98
11-2080.00	13	4	1968-71	1452	6.78	2.32	9.70	2.26	81.77
11-2135.00	14	6	1967, 1969-73	2041	5.98	2.48	10.66	2.48	74.33
11-2185.00	15	6	1967, 1969-73	1943	4.46	2.57	8.58	2.04	71.25
11-2370.00	16	4	1963-66	1265	5.24	2.21	6.09	1.28	88.97
11-2370.00	16	4	1967-70	1424	5.47	2.16	5.93	1.41	88.23
11-2465.00	17	4	1963-66	1363	7.63	2.54	12.22	2.14	86.20

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (minimums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-2465.00	17	4	1967, 1969, 1971-72	1340	7.60	2.59	11.70	2.39	82.82
11-2470.00	18	9	1962-66, 1968, 1971-73	3239	5.55	2.13	11.21	1.40	88.71
11-2645.00	19	7	1967-73	2330	6.11	2.48	6.02	1.82	84.58
11-2900.00	20	7	1966-67, 1969-73	2182	7.00	2.65	16.00	2.14	84.09
11-2927.00	21	6	1967-71, 1973	1884	6.41	2.38	7.57	1.91	84.78
11-3020.00	22	5	1968, 1970-73	1689	8.03	2.47	15.31	1.87	90.08
11-3195.00	23	9	1962-64, 1967, 1969-73	3262	4.40	2.51	10.17	1.57	79.76
11-3235.00	24	7	1962-64, 1967, 1971-73	2426	3.12	2.24	12.60	1.52	67.70
11-3255.00	25	11	1962-63, 1965-73	3938	5.46	2.56	14.12	1.99	79.30
11-3350.00	26	7	1966-68, 1970-73	2410	9.03	2.68	14.61	2.25	88.90
11-3414.00	27	6	1966-68, 1970-71, 1973	2034	4.72	2.56	8.31	1.25	87.42
11-3420.00	28	11	1963-73	3948	6.48	2.62	10.11	2.19	81.33
11-3720.00	29	7	1966-72	2400	4.59	2.73	10.72	1.41	84.02
11-3740.00	30	7	1966-71, 1973	2243	9.65	2.68	14.65	2.40	88.72
11-3765.50	31	5	1967-71	1765	4.68	2.72	11.35	1.60	81.04
11-3780.00	32	6	1962-63, 1965-68	2176	2.02	2.59	10.82	1.27	56.04
11-3820.00	33	10	1962-64, 1966-67, 1969-73	3466	8.50	2.52	10.95	3.38	76.15
11-3846.00	34	5	1968-70, 1972-73	1528	8.36	2.77	12.53	2.56	84.01
11-3890.00	35	6	1963-64, 1966-67, 1970-71	2135	4.33	2.67	12.78	1.20	86.85
11-3900.00	36	10	1963-64, 1966-73	3406	6.24	2.63	10.73	1.82	85.66
11-3905.00	37	5	1967-69, 1971-72	1786	5.21	2.75	13.61	1.42	86.96

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (minimums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-3915.00	38	5	1963-67	1615	6.50	2.59	6.09	2.16	81.73
11-3925.00	39	7	1964-66, 1969-70, 1972-73	2393	7.89	2.81	8.46	1.74	90.90
11-3945.00	40	10	1963-72	3351	7.54	2.69	10.18	1.95	88.20
11-4011.80	41	4	1965-68	1323	5.29	2.63	6.25	1.81	81.26
11-4011.80	41	4	1970-73	1313	5.64	2.72	6.32	1.91	81.05
11-4015.00	42	10	1963-65, 1967-73	3284	7.55	2.70	8.99	1.97	87.90
11-4045.00	43	6	1963-64, 1967, 1969, 1972-73	1872	6.83	2.53	10.95	1.73	88.19
11-4053.00	44	11	1963-73	3902	8.30	2.48	11.19	2.51	84.37
11-4070.00	45	11	1959-61, 1964-67, 1970-73	3928	6.34	2.58	11.97	2.27	79.69
11-4175.00	46	4	1966-69	1431	8.00	2.60	11.15	2.48	83.91
11-4175.00	46	4	1970-73	1380	8.37	2.76	11.68	2.31	86.69
11-4250.00	47	7	1963-68, 1973	2349	8.39	2.62	14.35	1.96	89.96
11-4270.00	48	12	1962-73	4317	8.51	2.45	14.88	2.12	88.98
11-4334.00	49	5	1967-71	1804	5.83	2.74	10.47	1.70	85.65
11-4395.00	50	6	1967-69, 1971-73	2019	6.64	2.49	7.66	2.41	78.56
11-4455.00	51	10	1961-62, 1964-68, 1971-73	3644	5.66	2.56	10.30	2.07	79.04
11-4465.00	52	9	1964, 1966-73	3138	4.66	2.26	12.96	1.22	87.91
11-4476.50	53	12	1962-73	4375	6.80	2.70	14.60	1.29	93.29
11-4535.00	54	13	1961-73	4688	7.09	2.63	15.10	1.65	90.13
11-4540.00	55	5	1967-68, 1970-72	1703	0.92	2.94	11.13	1.39	17.65
11-4560.00	56	4	1962-63, 1967-68	1428	5.25	2.87	14.51	2.00	77.41

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (minimums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-4560.00	38	4	1969, 1971-73	1373	5.31	2.87	13.48	1.72	82.04
11-4609.20	39	5	1965, 1967-68, 1970-71	1435	4.01	2.78	9.79	2.36	59.87
11-4615.00	40	6	1966-67, 1969-70, 1972-73	2021	5.84	2.58	12.18	1.72	85.24
11-4640.00	41	6	1967-69, 1971-73	2004	6.52	2.73	14.82	1.69	87.99
11-4645.00	41	4	1966-69	1307	5.47	2.69	13.50	1.94	79.81
11-4645.00	42	4	1970-73	1335	5.65	2.79	13.66	1.72	84.53
11-4670.00	43	7	1965-71	2371	6.76	2.73	15.86	1.65	89.24
11-4676.00	44	9	1964-68, 1970-73	3134	3.49	2.47	12.23	1.24	79.77
11-4685.00	45	5	1967, 1969, 1971-73	1686	3.88	2.67	11.27	1.62	73.90
11-4686.00	46	4	1965, 1967-69	1389	3.64	2.63	11.60	1.41	77.00
11-4686.00	46	4	1970-73	1326	3.61	2.78	11.27	1.45	75.33
11-4705.00	47	9	1964-65, 1967-73	3007	5.37	2.24	11.78	2.06	77.59
11-4710.00	48	5	1969-73	1539	6.07	2.58	12.15	1.71	86.92
11-4755.00	49	4	1961-64	1346	5.77	2.75	11.65	1.90	82.04
11-4755.00	50	4	1965, 1967-68, 1970	1442	5.68	2.69	12.05	2.12	78.11
11-4758.00	51	6	1966-69, 1972-73	2157	6.48	2.64	13.32	1.58	89.47
11-4765.00	52	6	1964, 1966-68, 1972-73	2021	6.86	2.65	13.55	2.01	85.33
11-4770.00	53	9	1963-64, 1967-73	3151	5.88	2.62	13.43	1.60	87.14
11-4775.00	54	5	1966-67, 1971-73	1476	7.52	2.58	9.78	1.82	89.41
11-4805.00	55	9	1962-66, 1968, 1971-73	3083	5.56	2.49	10.26	1.77	82.98
11-5165.30	56	11	1963-73	3976	8.58	2.61	11.35	1.28	95.72

TABLE 6.--*Multiyear harmonic coefficients for thermograph records used in this study (minimums only)*--Continued

STATION NUMBER	SEQUENCE NUMBER	NUMBER OF YEARS	PERIOD	NUMBER, OBSERVED VALUES	AMPLITUDE	PHASE COEFFICIENT	MEAN	STANDARD ERROR OF ESTIMATE	RSQD
11-5166.00	74	5	1965, 1967-69, 1971	1757	7.61	2.58	9.19	2.33	83.95
11-5175.00	75	6	1967, 1969-73	1941	7.54	2.84	11.43	1.98	87.55
11-5205.00	76	9	1964, 1966-73	3059	7.88	2.64	11.23	1.67	91.59
11-5225.00	77	6	1966, 1969-73	2013	7.22	2.57	10.84	2.26	83.71
11-5230.00	78	4	1966-69	1339	8.22	2.69	12.42	2.45	84.85
11-5230.00	78	4	1970-73	1359	7.44	2.68	11.63	1.95	87.43
11-5255.00	79	14	1960-73	5053	2.70	2.74	8.50	2.07	46.18
11-5270.00	80	7	1963-64, 1967, 1969-71, 1973	2323	6.54	2.45	11.53	2.03	83.93
11-5303.00	81	7	1967-73	2543	4.62	2.32	10.88	1.35	85.42
11-5325.00	82	5	1967-70, 1973	1745	6.02	2.55	11.91	1.76	85.21

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