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Techniques of Water-Resources Investigations of the United States Geological Survey

CHAPTER D1

WATER TEMPERATURE–INFLUENTIAL FACTORS, FIELD MEASUREMENT, AND DATA PRESENTATION

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BOOK 1

COLLECTION OF WATER DATA BY DIRECT MEASUREMENT recalibration is necessary. The systems used by Sorey (1971) were calibrated with platinum resistance and mercury thermometers to a precision of 0.005°C. Thermistor probes tend to be very stable with passage of time if properly cared for. They have drift rates of about 0.01°C/yr or less and, hence, need recalibration only occasionally.

Part 3. Data Presentation

Observation and monitoring schemes described in earlier parts of this report provide new data in a relatively crude form. Single observations by an observer or a fieldman may be penciled notes in a fieldbook or on observer forms. Charts from analog-type recorders are simply an inked or scribed line on a piece of paper. Digital recorders will produce either a magnetic or a punched tape, which is difficult to read or totally unintelligible and unusable without special processing.

On the other hand, the user of temperature data requires information in a more usable and more interpretable form. Publication of raw data is common and must be in a form that is suitable to a rather wide variety of users. Research data often have special format needs, but, again, the purpose is to provide the information in a form that it can be put to the best use.

This section presents information on the reduction of raw field data, application of corrections, and forms of publication.

Reduction and correction

An ideal temperature-measuring system would produce data ready to publish without exerting additional effort. However, considering the state of the art of instrumentation today, this dream is probably not to be realized for some time.

The job of reducing temperature data breaks down into two basic operations—removal of error caused by imperfect equipment and conversion of the recorded instrument output to numeric values. The procedures differ with types of equipment, but the following discussion is designed to provide some general guidelines.

Correcting instrument error

Perfectly operating instruments that are serviced by a careful operator generally require very little correction in their record. Realistically, however, there are errors that creep into all the records, owing to drift of the instrument or to failure of different parts of the mechanism, such as the timing devices. The most common error probably is drift between servicing. An instrument may be left operating in good calibration but will drift out of calibration over several days of operation. This is the reason that it is important to make a calibration check of an instrument before it is readjusted.

Figure 21 shows two examples of the type of error that may be found when an instrument is calibrated. Constant error through the calibration range is most common, with a displacement of the same number of degrees at all temperatures. Nonuniform error is not so common but is found frequently enough that the two-point calibration is justified. (See p. 28.) Not shown, but also possible, is a curvilinear calibration whereby an instrument is nearly in calibration over part of its range, but deviates significantly in another part. This type of error is rather infrequent and, therefore, generally does not justify calibrating at more than two points in the instrument range.

Corrections can be applied to the records of analog recorders at the same time the records are reduced. If a constant error of 2°C is found at the end of a 2-week period, and if the instrument was in adjustment at the beginning of the period, the 2°C error should be prorated over time, in increments of 0.5°C. Nonuniform error over the calibration range is a little more difficult to correct, and the correction usually is best applied by assuming a constant rate of drift at each end of the calibration curve. For example, if the nonuniform error shown in figure 21 developed over a period of 2 weeks, the 2°C error at 15°C could be assumed to have been 1°C at the end of the first week.

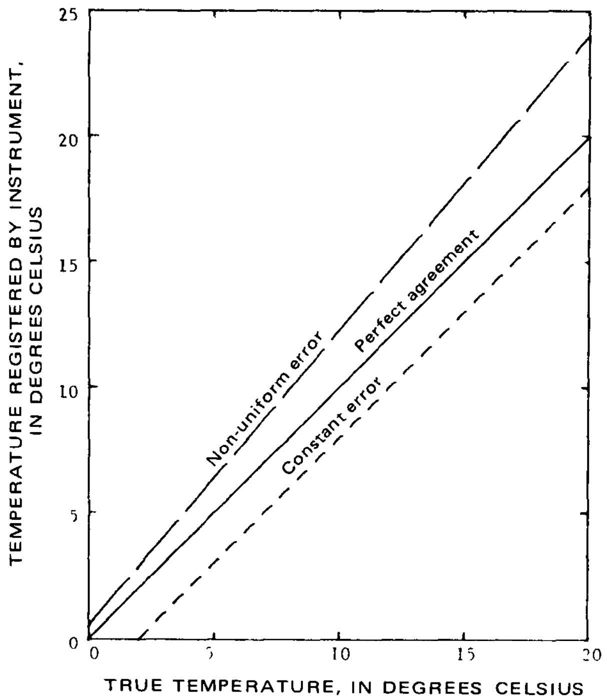


Figure 21.—Types of thermometer calibration curves.

Records from digital- and magnetic-recording instruments are corrected in many different ways, depending upon the types of programs available. The systems are too complex and too widely varied to allow detailed discussion in this report. However, everyone who prepares programs for reducing the data from these types of instruments should (1) provide for correcting uniform and non-uniform errors over the range of the instrument and (2) provide for time distribution of the error over the periods between times of calibration of the instrument.

Faulty timers, skipped punches, and other equipment weaknesses frequently cause time errors in recorded data. These usually are corrected by assuming that the drift took place at a constant rate between the times the instrument was serviced. For example, an instrument that was found running 2 hours slow after 2 weeks of operation would be assumed to have lost time at the rate of about 8.6 minutes per day. An instrument found with it's clock stopped generally is assumed to have operated on time until the clock stopped. The most difficult problem to correct probably is the one caused by a clock which stopped and then restarted during the period of operation. This phenomenon is rather common in cold weather. Unless correlations with other kinds of data can be provided to determine approximately when the clock stopped and started, there is no good way to correct the record.

Although temperature corrections can be complex, they are rather easy to apply. For example, if daily mean temperatures are being determined, the daily range is relatively small, and the rate of drift is linear, corrections can be applied directly to the mean without breaking down the record on an hour-by-hour basis. On the other hand, if the temperature records are being used to determine such things as the mean temperature of a lake, the vertical temperature curve should be corrected before the weighting according to volumes at different temperatures is made.

Data reduction

Conversion of chart traces, punched tapes, or magnetic signals to numeric values falls under the general title of data reduction. Magnetic and punch tapes have the advantage of being machine reducible, but a cretain amount of editing and error correction almost always is necessary. Programs for reduction by machine are complex and vary too much from one machine to another to discuss in considerable detail here. Most include provisions for correcting recorder error and for editing data when pieces are missing or questionable. Most programs for reduction by machine allow for listing data for short intervals, determining daily means, and listing daily maximums and minimums. In principal, they are not unlike the procedures for reduction of chart records by hand, as described in the following paragraph.

Chart data often can be reduced rather rapidly if the instruments record at a workable scale suitable to meeting the intended format of the report. For example, a chart record obtained in order to determine daily maximum and minimum, and mean, can

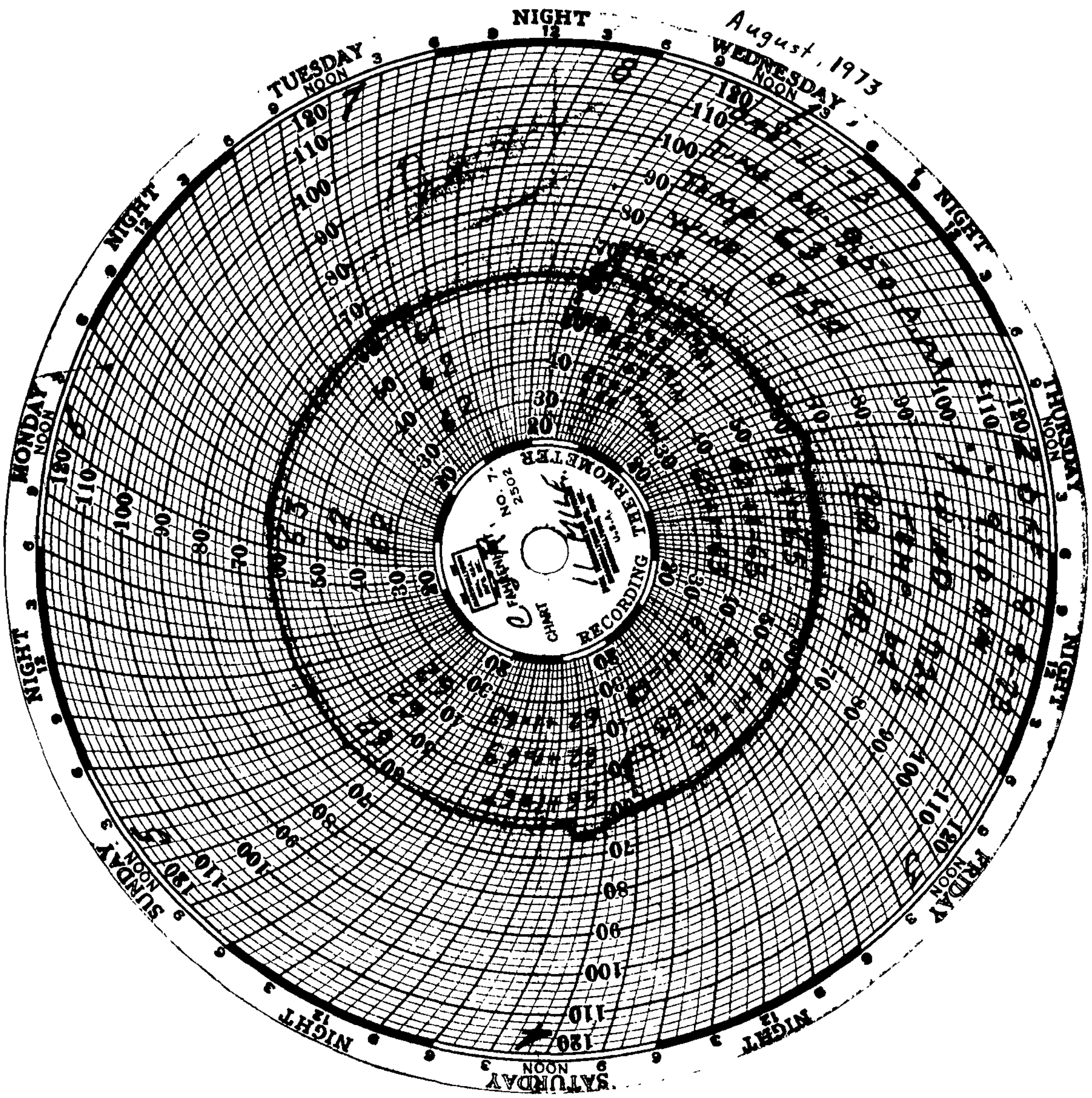


Figure 22 —Circular chart showing data reduced by hand for daily maximum, minimum, and mean temperature.

operate at a relatively slow speed. Figure 22 shows a circular chart from which the data have been reduced for daily maximum, minimum, and mean. Daily fluctuations are relatively small, and the mean can be determined rather quickly by inspection of the chart.

When data on a body of water are collected by several recording instruments or by observations at several sites, the reduction of data from each recording instrument should be treated separately. Procedures for computing mean temperature in a cross section or in a lake, or for making analyses of the data are included in the earlier section of this report on field applications (p. 34) or in the following subsection on publications.

Presentation and publication

What to publish

There obviously is great variability in the needs for temperature data. As a consequence, there will be a rather broad set of rules as to what type of data the investigator should present to his readers. Research or interpretive reports often contain a great deal of data from a relatively small area, such as a reach of stream, a lake, or an estuary. Investigators may wish to show that streams have diurnal or cross-sectional variation and to report these, but in other streams simple daily means may be adequate to represent the phenomenon they are discussing. Temperatures in estuaries vary in three spatial dimensions and in time. They are extremely complex to report if the whole four-dimensional picture is to be presented. In ground-water studies, the long-term variations are often important, but, at times, the simple variations with depth adequately represent what the investigator is trying to show. At times, very very small temperature differences are important in ground-water studies, but the actual temperatures of the water are relatively unimportant.

Lakes, like estuaries, may need to have differences shown in three dimensions and over either short or long time periods. For other types of needs, lake reports may need to show only mean surface-temperature data.

Data reports representing information on many stations are different from the research reports in that they often have to compromise and present information for someone else's interpretation. The researcher in writing a paper on temperature can choose which data are relevant to the phenomenon he is demonstrating, but the person preparing a data report should arrange the data so that they can be interpreted by someone else. User needs are important but are widely variable. Data reports, because they contain a great deal of material, often must consider economy of preparation and presentation. It also is important that the information contained in data reports represent field conditions and show anomalous conditions, such as unusually hot or cold spots.

The following paragraphs present some guidelines that might be used in deciding what types of temperature data to be published.

Stream temperatures.—If diurnal variations and variations in the cross section at the measuring station do not exceed 2.0°C more than 5 percent of the time, publish time-weighted daily mean temperatures. Report to the nearest 0.5°C.

If diurnal variations are greater than 2.0°C more than 5 percent of the time, publish maximum, minimum, and time-weighted mean temperatures for each day. Report to the nearest 0.5°C.

If cross-section temperatures at a stream station vary more than 2°C for more than 5 percent of the time, publish records for more than 1 measuring point (p. 32), and treat each record as a separate station record. Use the 2°C-diurnal-variation criterion stated previously in deciding whether or not to publish maximum and minimum values for the day.

In the case of multiple channels, where sufficient data are available, report temperature measured in each channel and the discharge-weighted mean. The format shown in figure 23 may be used to present data from a stream with measurements in two different channels. Note that the table allows for reporting maximum and minimum at station 2 where the diurnal variation is greater than 2.0°C. The right-hand column on the table is used to report the discharge-weighted mean temperature for the cross section. This type of presentation allows the showing of extreme data in a divided channel; it also presents heat-load data which may be important.

Temperature-profile data collected in a stream cross section may be included as a supplementary table in the report or (as noted in the report) held in the files for inspection. The format shown in figure 24 may be used to present data comparing temperature at the sensor with maximum, minimum, and mean values in the cross section.

Many periodic or nonrecording data are collected on streams by investigators, hydrographers, and observers. These data should be presented as they are recorded and not be assumed to be mean daily or mean cross-sectional data. Proper qualifications should be made in the report to describe how the data were collected. If a tabular form of presentation is used, reporting of time of observation should be considered if there is reason to believe that the temperature has a diurnal

Date	Water temperatures in °C				
	Station 1 mean	Station 2			Discharge-weighted mean
		Maximum	Minimum	Mean	

Figure 23 —Tabular format for presenting stream temperatures from two measuring stations in a cross section Station 1 has a diurnal variation less than 2°C, and station 2 varies more than 2°C at least 5 percent of the time.

Date	Discharge (cfs)	Width (ft)	Mean depth (ft)	Water temperatures (°C)			
				In cross section			At thermograph sensor
				Maximum	Minimum	Mean	

Figure 24.—Tabular format for comparing temperatures at the sensor with maximum, minimum, and mean temperatures in the cross section

variation. Formats of presentation are discussed in the subsection that follows, and examples are given in figures 28 and 29.

Lakes and reservoirs.—Report the surface temperatures measured at a raft or shore station, with a description of the site where the data were collected. Report as daily mean temperature to the nearest 0.5°C. If diurnal variations at the station are greater than 2.0°C for 5 percent of the time or more, report maximum, minimum, and daily mean temperatures.

If conditions on the lake require more than one recording station for surface temperature, report the data from each station separately.

When subsurface temperatures are recorded on a continuing basis, report only as daily mean temperatures at the depth of observation. Occasionally, large variations may occur from internal waves (vertical movement of the thermocline); however, these data are generally not valuable to the data user and should not be reported.

Intermittent measurements of lake temperatures at several stations and several depths are common, such as with thermal surveys. These data should be published as they are collected, reporting to the accuracy of the temperature-measuring system (usually to the nearest 0.5° or 0.1°C). If areal variations in the lake are relatively small, it often is possible to combine the measurements from several stations into one mean vertical profile of lake temperature.

Estuary temperatures.—When temperature in an estuary is measured at a single station, criteria for reporting data are basically the same as for reporting data in streams. That is, if diurnal variations and variations in the cross section at the measuring station do not exceed 2°C more than 5 percent of the time, publish daily mean temperatures. Report to the nearest 0.5°C. Generally, diurnal fluctuations will be greater than 2.0°C more than 5 percent of the time, in which case publish maximum, minimum, and daily mean temperatures. Report to the nearest 0.5°C.

If an estuary station records temperatures at more than one level or at more than one point in the estuary, report each point of measurement as a separate table of data, or combine into the same table using a format similar to that shown in figure 23. The discharge-weighted mean column shown in figure 23 will not apply to an estuary situation.

If temperature profiles have been measured in an estuary cross section, include those data as a supplementary table in the report.

Periodic or spot measurements of temperatures normally are not collected at an estuary site, because they do not have a great deal of value unless they are related to the variations with time and space. As a general rule, do not report periodic or spot measurements made at an estuary station.

Ground-water temperatures.—The safest rule to follow in reporting ground-water temperatures is report all data. The variations in temperatures from the top to the bottom of a well may be considerable, and sufficient recorder-chart data to define the temperature variation or all of the point-measurement data should be shown. The same is true in reporting data from several different wells. Do not attempt to average data from several different wells; rather, report them on a map or in a table.

Tabular format

Usually it is easier and more economical to publish temperature data in tables than in any other format. The formats are easy for readers to grasp, tables can often be compiled by computer and printed from computer copy, and hand-typed tables can be typed on preprinted columnar formats.

A previous subsection of this report outlined criteria for selection of the kind of data to publish. The examples and brief discussions that follow are designed to guide the investigator in presenting those data in tabular form.

Daily values.—Figure 25 is an example of the format used in the data reports on water quality published for each state by the U.S. Geological Survey. Note that the headnotes of the table show details on the period of available record, extremes, and other remarks. The record shown is part of a continued table

PLATTE RIVER BASIN

06764000 SOUTH PLATTE RIVER AT JULESBURG, COLO.--Continued

EXTREMES, 1970-71.--Continued
Water temperatures: Maximum, 21.0°C Aug. 22, 23; minimum, freezing point on many days during December to March.
Period of record.--Specific conductance: Maximum daily, 3,270 micromhos Jan. 12, 1971; minimum daily, 348 micromhos Aug. 15, 1968.
Water temperatures (1946-49, 1950-71): Maximum, 34°C July 28, Aug. 1, 1953, July 7, 18, 1963; minimum, freezing point on many days during winter period.

REMARKS.--Samples for specific conductance and temperature collected from channel no. 2 (06763990). For monthly chemical analyses considered applicable to this site, see record for South Platte River near Julesburg, Colo. (sta. 06764200).

TEMPERATURE (°C) OF WATER, WATER YEAR OCTOBER 1970 TO SEPTEMBER 1971

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	14.5	4.5	4.5	1.0	1.0	3.5	6.5	10.0	8.0	11.0	10.0	11.0
2	12.0	3.5	2.0	0.0	0.0	2.0	12.0	4.5	9.0	14.5	14.5	12.0
3	14.5	2.0	3.5	0.0	1.0	1.0	10.0	5.5	10.0	10.0	9.0	15.5
4	13.5	3.5	1.0	0.0	0.0	4.5	6.5	5.5	9.0	13.5	8.0	10.0
5	13.5	3.5	1.0	0.0	0.0	4.5	5.5	4.5	8.0	11.0	8.0	15.5
6	13.5	4.5	4.5	0.0	0.0	4.5	12.0	2.0	10.0	11.0	8.0	20.0
7	9.0	10.0	3.5	1.0	0.0	0.0	9.0	2.0	6.5	12.0	6.5	14.5
8	4.5	5.5	2.0	0.0	0.0	0.0	14.5	4.5	9.0	8.0	8.0	5.5
9	5.5	4.5	3.5	0.0	1.0	8.0	15.5	4.5	8.0	10.0	8.0	11.0
10	8.0	4.5	1.0	0.0	4.0	8.0	11.0	4.5	8.0	9.0	14.5	5.5
11	8.0	9.0	1.0	0.0	3.5	6.5	10.0	1.0	8.0	15.5	9.0	8.0
12	6.5	6.5	1.0	0.0	2.0	4.5	12.0	2.0	10.0	11.0	10.0	10.0
13	10.0	8.0	0.0	0.0	4.0	8.0	15.5	4.5	9.0	10.0	10.0	4.5
14	9.0	4.5	0.0	0.0	5.5	2.0	11.0	4.5	8.0	10.0	18.0	4.5
15	5.5	2.0	2.0	0.0	5.5	3.5	18.0	4.5	5.5	13.5	9.0	4.5
16	4.5	3.5	0.0	1.0	4.5	4.5	14.5	10.0	5.5	10.0	10.0	4.5
17	12.0	4.5	1.0	0.0	3.5	10.0	15.5	9.0	10.0	11.0	10.0	3.5
18	8.0	8.0	1.0	1.0	4.5	4.5	15.5	4.5	10.0	13.5	11.0	9.0
19	10.0	8.0	0.0	0.0	4.5	1.0	13.5	2.0	12.0	8.0	10.0	9.0
20	9.0	2.0	0.0	1.0	3.5	4.5	13.5	4.5	12.0	9.0	10.0	4.5
21	10.0	4.5	0.0	1.0	1.0	5.5	15.5	10.0	11.0	10.0	9.0	13.5
22	10.0	3.5	0.0	1.0	0.0	4.5	10.0	8.0	14.5	9.0	21.0	10.0
23	10.0	0.5	0.0	1.0	0.0	2.0	9.0	5.5	12.0	9.0	21.0	6.5
24	9.0	2.0	0.0	1.0	0.0	1.0	13.5	4.5	14.5	9.0	9.0	10.0
25	9.0	4.5	0.0	0.0	5.5	1.0	10.0	5.5	14.5	10.0	10.0	12.0
26	5.5	4.5	0.0	2.0	3.5	12.0	4.5	5.5	13.5	6.5	12.0	11.0
27	5.5	4.5	1.0	0.0	0.0	14.5	6.5	5.5	11.0	8.0	10.0	12.0
28	6.5	4.5	0.0	4.5	0.0	4.5	9.0	5.5	10.0	8.0	15.5	13.5
29	9.5	3.5	1.0	2.0	---	9.0	11.0	6.5	9.0	6.5	11.0	11.0
30	12.0	4.5	1.0	4.5	---	8.0	3.5	6.5	10.0	4.5	11.0	13.5
31	4.5	---	0.0	1.0	---	15.5	---	5.5	---	6.5	10.0	---

Figure 25.—Tabular presentation of daily mean temperatures in a stream (From U.S. Geological Survey, 1972, p 24.)

which showed records of specific conductance on a previous page. The previous page of the table also contained details on station location and drainage area. Sizes of differences in day-to-day temperatures shown in figure 25 suggest that maximum and minimum daily values should be shown for this station in order to satisfy the 2°C variation criterion specified in this manual.

Figure 23 showed an example of a tabular format for showing maximum, minimum, and mean daily temperatures for stations having diurnal variations of more than 2°C. In contrast, figure 26 is an example of a table showing only maximum and minimum values for each day and is a less desirable format than the one shown in figure 23. The example in figure 26 shows a simple way of reporting data for more than one data point (surface and bottom), but when using such a technique the writer should be careful to define where the measuring points are located.

Daily values of temperature measured at several levels in a reservoir are shown in the example in figure 27. Values shown in the example are readings taken once a day rather than daily means, and the time the readings were made is also shown.

Observations at irregular intervals.—Temperature of streams, lakes,

STATISTICAL SUMMARIES

UNITED STATE

GEOLOGICAL

TABLE 1.—WATER QUALITY AT PATUXENT RIVER BRIDGE, MARYLAND

				TEMPERATURE DEG C			
	DATE			SURFACE		BOTTOM	
WEEK	MO	DA	YR	MAX	MIN	MAX	MIN
01	01	01	66	7.3	5.5	6.8	5.4
01	01	02	66	7.8	6.7	7.3	6.3
01	01	03	66	7.3	6.7	7.4	6.6
01	01	04	66	7.1	6.2	7.1	6.5
01	01	05	66	6.7	5.7	6.8	6.3
01	01	06	66	6.9	6.3	6.7	6.4
01	01	07	66	6.7	6.3	6.7	6.5
EXTREME				7.8	5.5	7.4	5.4
AVERAGE				7.1	6.2	6.9	6.2

Figure 26.—Tabluar presentation of maximum and minimum daily temperatures of an estuary. Note that weekly mean values also are shown (From Cory and Nauman, 1968, p 29)

estuaries, and ground water often are measured by observers who visit measuring stations at irregular intervals of time. When these observations are published, it is necessary to show the date of each measurement, and, often, the time of the measurement. Decisions of whether to show time in the published records should be based on criteria similar to the 2° rule used in deciding if maxima and minima should be shown for daily values. If, in the judgement of the investigator, the diurnal variation at the station exceeds 2°C on more than 5 percent of the days of observation, time should be shown. Figures 28 and 29 show examples of tables listing measurements at irregular intervals. Figure 28 includes two forms of presentation, and it can be assumed that the 2° rule was not used in selecting the format of presentation. The upper part of figure 29 includes a graphical presentation which will be described in more detail in a later subsection of this manual.

Summary reports.—It often is necessary to summarize records over rather long periods of time by presenting mean, maximum, and minimum temperatures on weekly, monthly, or even annual basis. Computer printouts of the temperature data shown in figure 26 included weekly extremes and averages. The example in figure 30 is a summary of maximum, minimum, and mean values on a monthly basis for several years of record. Care has been taken in the example to distinguish that the data shown represent different methods of measuring or recording, so that the data user can decide for himself the extent of sampling error in the data.

Remarks concerning accuracy.—In order to provide the reader with information on the accuracy of reported data, it is recommended that a statement on accuracy be included with each published record. Such a statement could go with "Remarks" in the heading of tables like those shown in figures 25 or 29.

A suggested wording of a remark on accuracy is "Records represent water temperature at sensor within 0.5°C. Temperature at the sensor was compared with the average for the river by temperature cross-section on (give date or dates). A maximum variation of 2.5°C was found within the cross

TABLE 116

WATER TEMPERATURE (°F)
Detroit Reservoir, Oregon

Day	Observed		Thermohm Elevations (Upstream Face of Dam)																Reservoir Surface						
	Hour	Pool																	At Dam at Hours of						@ I
	(PST)	elev.	1192	1217	1242	1267	1292	1317	1342	1367	1392	1417	1442	1467	1492	1517	1542	1567	06	10	14	18	20	Ave.	Bo
1	1625	1503.7	44	44	43	43	45	45	51	54	54	54	55	56	56							57			
2	1715	1502.3	44	44	43	44	45	46	51	53	54	55	55	55	55							56			
3	1715	1500.6	44	44	43	44	45	45	51	53	54	55	55	55	55							56			
4	1645	1498.2	44	44	43	44	45	46	51	54	54	54	55	55	55							54			
5	1610	1496.9	43	44	44	44	45	46	51	54	54	54	54	55	54							54			
6	1640	1495.6	44	43	43	44	45	46	51	53	54	54	54	54	54							54			
7	1630	1493.7	44	43	43	44	45	49	50	52	53	53	54	55	54							54			
8	1635	1492.3	44	44	44	44	45	47	50	52	53	53	54	54	54							54			
9	1800	1490.9	44	44	44	44	45	47	50	52	53	53	53	54											
10	1800	1489.7	44	44	44	44	45	48	50	52	53	53	53	53											
11	1735	1490.4	44	43	44	44	45	48	50	52	52	53	53	53											
12	1800	1489.9	43	42	44	44	45	48	50	[illegible]			[illegible]	[illegible]											
						44	45	[illegible]																	

Figure 27 —Tabular presentation of temperatures measured once daily at several different depths in a reservoir. (From U S. Corps of Engineers, 1968, table 116.)

WATER QUALITY DATA, WATER YEAR OCTOBER 1970 TO SEPTEMBER 1971

DATE	DIS- CHARGE (CFS)	TEMP- ERATURE (DEG C)	SILICA (SIO2) (MG/L)	DIS- SOLVED CAL- CIUM (CA) (MG/L)	DIS- SOLVED MAG- NE- SIUM (MG) (MG/L)	SODIUM (NA) (MG/L)	PO- TAS- SIUM (K) (MG/L)	BICAR- BONATE (HCO3) (MG/L)	SULFA (SO (MG
OCT.									
08...	896	6.0	13	53	15	19	2.0	144	
NOV.									
05...	602	3.0	14	64	19	23	2.2	164	
DEC.									
22...	389	2.0	14	43	13	19	1.9	176	
JAN.									
19...	449	2.0	13	61	19	28	2.9	162	
FEB.									
16...	312	8.5	15	67	21	28	2.6	177	
MAR.									
05...	344	3.0	13	62	19	26	3.1	162	
13...	324	13.0	12	65	21	31	2.8	17'	
APR.									
06...	515	11.0	11	47	14	20	2.6	'	
MAY									
17...	966	15.0	8.7	36	9.6	14	1.8		
JUNE									
03...	1320	18.5	9.7	33	8.8	11	1.3		
JULY									
09...	1860	19.0	8.0	25	6.3	8.5	1.4		
AUG.									
30...	1250	20.0	10	39	9.8	13	2.2		
SEP.									
14...	417	20.0	13	61	18	25	2.6		

INSTANTANEOUS SUSPENDED SEDIMENT AND PARTICLE SIZE, WATE
(METHODS OF ANALYSIS: B, BOTTOM WITHDRAWAL TUBE; C, CHEMICALLY D
V, VISUAL ACCUMULATION TUBE; W, I

DATE	TIME	WATER TEMP- ERA- TURE (°C)	DISCHARGE (CFS)	CONCEN- TRATION (MG/L)	SUSPENDED SEDIMENT DISCHARGE (TONS/DAY)	PERCE .0
OCT 8, 1970	1130	6.0	896	84	203	
21......	1345	10.0	820	42	93	
NOV 5......	1100		602	35	57	
20......	1100	4.0	510	557	76'	
DEC 3......	1340		477	21	'	
8......	1500		500	35		
23......	1430		397	114		
JAN 8, 1971	1400		248	40		
19......	1030	2.0	449	72		
FEB 7......	1615	1.5	282	32		
16......	1435	8.0	312	25		
MAR 5......	1015	3.0	344	20		
15......	1325	7.0	324	26		
APR 6......	1345	11.0	515	61		
29......	1230	18.0	397	29		
MAY 14......	1600	16.5	723	61		
25......	1200		644	24'		
JUN 3......	1400	18.5	1200	2'		
14......	1315	16.5	1490	'		
JUL 9......	1545	19.0	1880			
19......	1215		1810			
AUG 10......	1200		924			
30......	1820	20.0	1210			
SEP 14......	1530	20.0	417			
28......	1500	17.0	401			

Figure 28.—Tabular presentations of stream temperatures measured at irregular intervals Note that bottom table shows time of the instantaneous values. (From U.S. Geological Survey, 1972, p 30.)

section." If measurements are available for several different dates, it is advisable to include a summary in the format of figure 24 as part of the record.

Graphical presentation

Data presented in graphical form are almost always easier for the reader to understand and interpret than tables of data. This

YELLOWSTONE RIVER BASIN

194. Tongue River at Miles City, Mont. (6-3085)

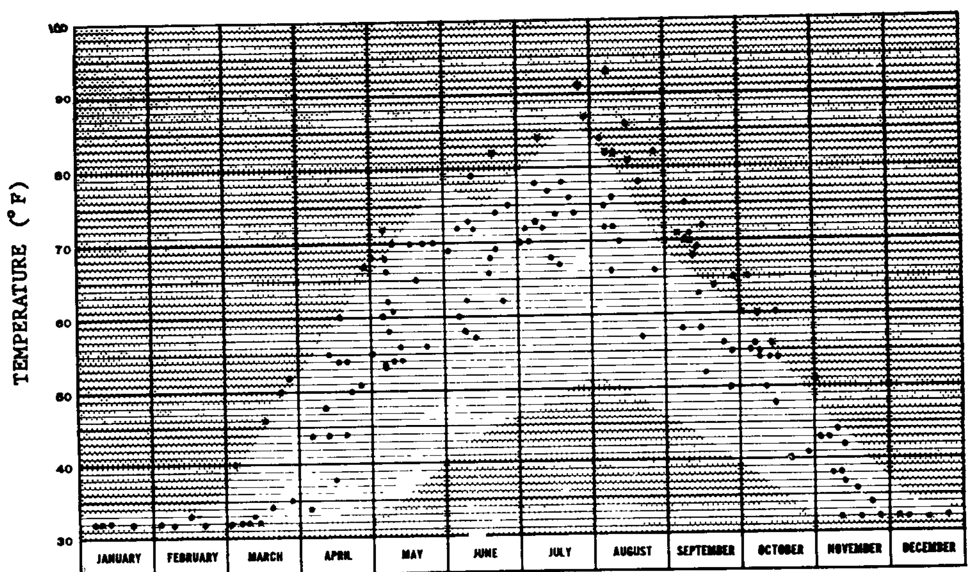
Location.--At gaging station, lat 46°21', long 105°48', in SE¼ sec.23, T.7 N., R.47 E., on right bank 4 miles south of Miles City and 8 miles upstream from mouth. Altitude of gage is 2,370 ft (by barometer).

Drainage area.--5,379 sq mi.

Water temperature records available.--157 spot observations made at time of discharge measurements during period April 1949 to December 1965. Once-daily observations made during period April 1949 to December 1965 published in reports of the Geological Survey.

Extremes.--Discharge 1938-42, 1946-66: Maximum, 13,300 cfs June 15, 1962; no flow July 9-19, Aug. 13, 14, Sept. 28, 1940.

Water temperatures 1949-65: Maximum observed, 93°F Aug. 8, 1961; minimum, freezing point on many days during winter months.



Spot observations of water temperatures, 1949-65.
The unshaded area delineates the range between the highest and lowest monthly temperatures from once-daily observations, 1949-65.

Water temperatures at time of discharge measurements

Date	Time	°F	Date	Time	°F	Date	Time	°F	Date	Time	°F	Date	Time	°F	Date	Time	°F
January			February			March			April			May			June		
5-61	1450	32	13-61	1750	32	30-52	1630	35	26-49	1600	67	26-49	1600	70	9-49	1130	72
16-62	1700	32	11-63	1600	33	27-53	1200	50	17-50	1530	54	11-50	0950	54	19-49	1100	62
8-63	1350	32	5-64	0930	32	17-54	1500	46	11-51	1000	38	25-50	0830	56	6-50	1420	72
8-64	1455	32	2-65	1600	32	11-55	1430	33	23-51	1400	51	1-51	1745	68	20-50	1440	75
6-65	1530	32				24-56	0930	34	16-54	1600	60	9-51	1430	62	8-51	0845	62
						30-60	1545	52	9-55	1830	55	16-51	1600	70	2-53	1630	69
						10-61	0830	32	18-56	1130	50	7-52	1700	66	17-53	1930	74
						13-62	1600	32	8-57	1600	48	18-53	1600	65	17-54	1610	69
						4-63	1505	40	8-58	0900	44	7-54	1730	72	9-55	1645	57
						2-64	1630	32	17-59	1600	44	6-55	1400	60	8-56	1430	73

Figure 29.—Combined tabular and graphical presentations of stream temperatures measured at irregular intervals (From Aagaard, 1969, p. 438.)

WATER TEMPERATURES FROM ONCE DAILY DATA, DEGREES CELSIUS

YEAR		OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1958	MAXIMUM:	19	12	9	9	11	11	17	20	27	29	30	26
	MEAN:	13	9	7	7	9	8	12	16	21	26	26	23
	MINIMUM:	11	4	5	4	7	5	6	10	15	20	24	18
1959	MAXIMUM:	24	16	11	14	11	11	17	21	27	29	27	25
	MEAN:	19	11	9	8	7	9	13	18	24	27	25	20
	MINIMUM:	14	7	7	4	3	7	10	13	21	24	23	17
1961	MAXIMUM:	18	12	9	10	11	12	13	17	27	28	27	24
	MEAN:	15	8	7	7	8	8	11	13	22	27	25	21
	MINIMUM:	13	6	3	3	6	7	7	9	16	24	23	19
1962	MAXIMUM:	16	10	8	7	9	10	13	19	25	28	27	26
	MEAN:	13	7	5	4	7	7	11	14	22	24	24	21
	MINIMUM:	12	3	3	2	2	4	9	12	18	22	21	18
1963	MAXIMUM:	18	14	11	11	11	11	13	19	27	28	27	26
	MEAN:	13	10	7	4	10	9	9	14	22	25	24	23
	MINIMUM:	9	6	2	1	8	7	7	8	17	20	22	20
1964	MAXIMUM:	21	14	9	7	8	11	17	22	27	28	27	23
	MEAN:	16	9	7	5	7	8	12	16	22	25	25	22
	MINIMUM:	12	6	4	3	4	6	7	10	16	21	22	18
1965	MAXIMUM:	19	16	12	9	9	12	15	16	26	24	26	26
	MEAN:	16	8	6	6	7	10	11	13	21	23	24	23
	MINIMUM:	15	3	4	3	6	7	7	9	18	21	21	21
1966	MAXIMUM:	19	16	8	8	8	12	15	22	25	27	27	26
	MEAN:	17	10	5	5	6	8	10	15	21	24	25	22
	MINIMUM:	14	5	2	3	5	3	8	11	15	21	23	18
1968	MAXIMUM:	20	15	8	9	11	13	17	22	24	27	28	28
	MEAN:	16	12	5	5	9	9	12	17	21	23	24	21
	MINIMUM:	13	7	2	2	6	7	9	13	16	20	18	16
1958-	MAXIMUM:	24	16	12	14	11	13	17	22	27	29	30	28
1968	MEAN:	15	9	6	6	8	8	11	15	22	25	25	22
	MINIMUM:	9	3	2	1	2	3	6	8	15	20	18	16
	DAYS OF RECORD:	88	172	208	223	224	252	216	170	106	85	82	65

WATER TEMPERATURES FROM THERMOGRAPH DATA, DEGREES CELSIUS

YEAR		OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1967	MAXIMUM:	24	16	**	7	**	12	12	16	17	**	**	**
	MEAN:	17	13	**	5	**	8	9	12	13	**	**	**
	MINIMUM:	12	10	**	1	**	4	6	8	10	**	**	**
1967	MAXIMUM:	24	16	**	7	**	12	12	16	17	**	**	**
	MEAN:	17	13	**	5	**	8	9	12	13	**	**	**
	MINIMUM:	12	10	**	1	**	4	6	8	10	**	**	**
	DAYS OF RECORD:	31	19	0	10	0	29	30	31	7	0	0	0

WATER TEMPERATURES FROM PERIODIC DATA, DEGREES CELSIUS

PERIOD OF RECORD		OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1956-68	MAXIMUM:	21	16	12	13	11	12	17	19	27	27	28	27
	MEAN:	16	9	7	6	7	8	10	13	20	24	25	22
	MINIMUM:	13	6	2	3	4	4	7	8	13	21	17	18
	DAYS OF RECORD:	14	35	46	47	44	16	17	17	23	24	24	12

Figure 30 —Tabluar presentation of several years' temperature data from a stream Note that the data are divided according to the measurement techniques (From Blodgett, 1970, p 35)

subsection presents some examples of graphical presentation of temperature data which are intended to provide guidance in preparing reports.

Temperatures of streams.—Thermographs showing temperature on the ordinate scale and time on the abscissa scale probably are the most common way of presenting stream temperatures. Data from recording thermographs or a plot of daily mean temperatures can be presented as a continuous line on the graph, but intermittent readings should be shown as plotted points. Figure 29 is an example of a way of presenting the results of spot measurements as well as showing the long-term extremes.

Variations in temperature along the length of a stream also can be advantageously shown graphically. Figure 31 is an example of a simple form of presentation showing data from several stations collected at different times. Figure 32 depicts a more complex form of showing temperature variations both with time and with distance along a stream.

Cumulative-frequency distribution of water temperatures might be considered in analyzing to determine effectiveness of a stream for cooling, for use as a fishery, or for other uses. Ward (1963) has adapted a method of cumulative analyses to stream temperature data to make the type of presentation shown in figure 33. Techniques similar to those described by Searcy (1959) for constructing flow-duration curves can be applied to temperature data to construct cumulative-frequency relationships.

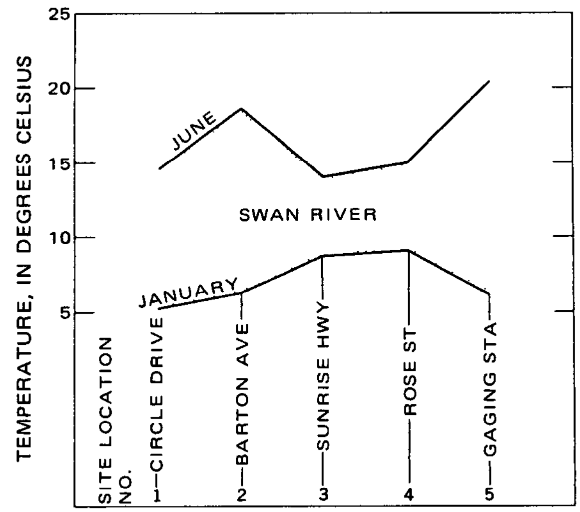


Figure 31 —Graphic presentation of longitudinal temperature profiles in a stream. (From Pluhowski, 1970, p. D42)

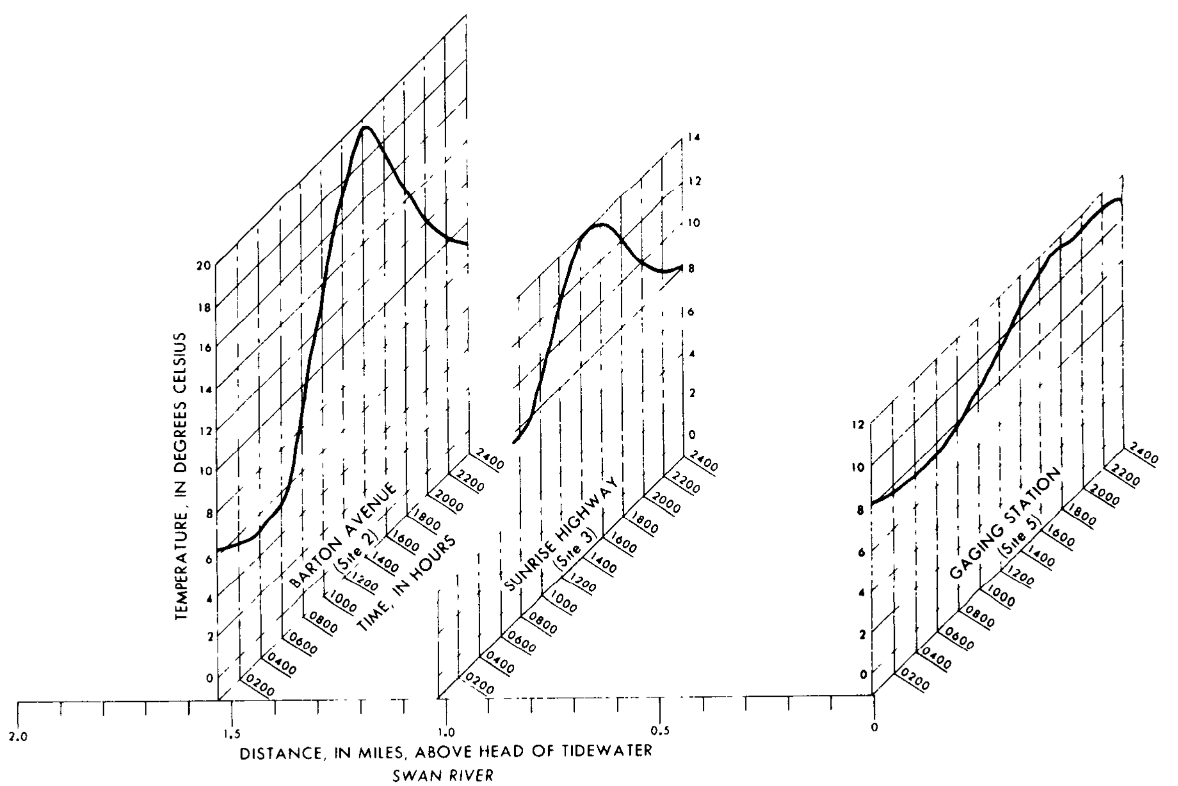


Figure 32 —Complex graphical depiction of variations of stream temperature with time at several sites. (From Pluhowski, 1970, p. D35.)

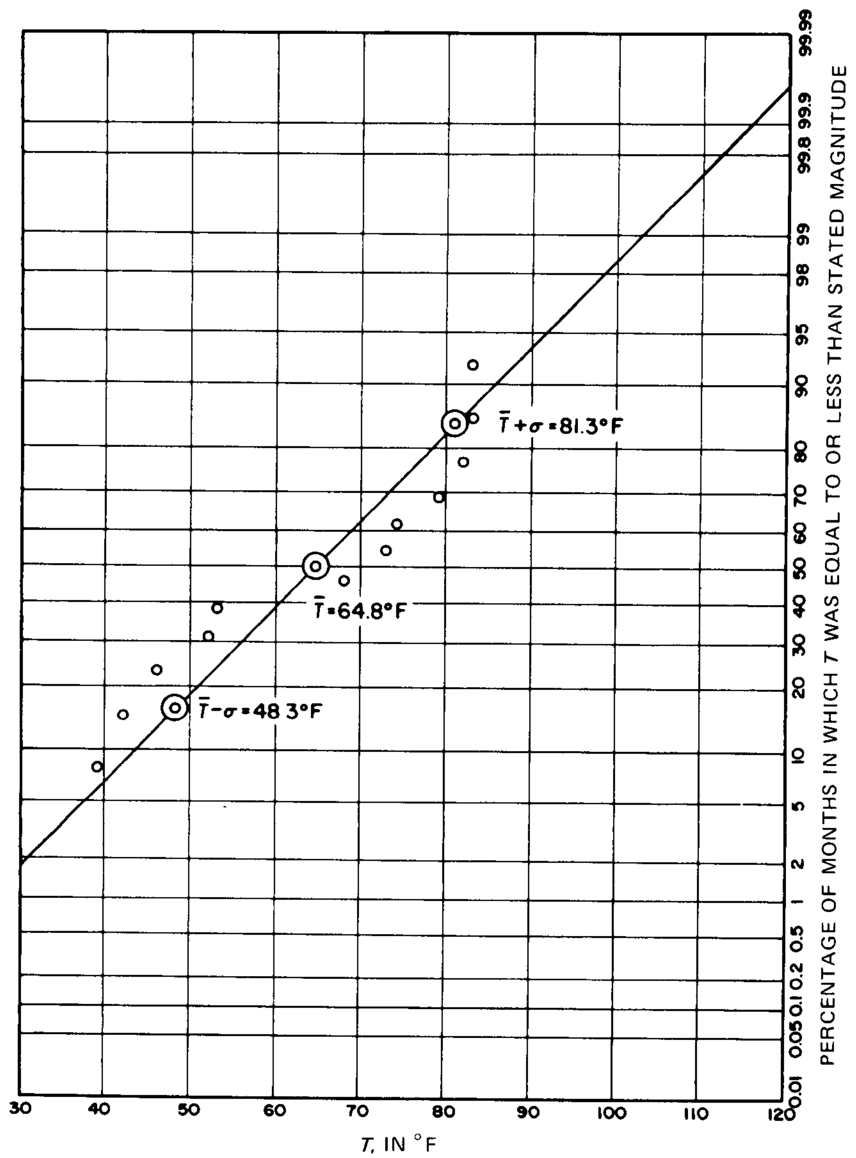


Figure 33.—Cumulative frequency of stream temperature (From Ward, 1963, p. 10.)

Lakes.—Variations of temperature with time at the surface of a lake, or at other points in the lake can be represented by a temperature versus time plot of the type described for streams. These data also can be subjected to frequency analyses of the type reported in the preceding paragraph.

Variations with depth often must be shown in reporting lake temperatures. Figure 6 is an example of a common way of reporting temperatures of lake water. The particular example shown presents data for several different times, which usually is easy to accomplish because of the systematic way in which the temperatures in lakes change. Figure 34 is another form for showing changes of lake temperatures with time. The type of presentation in figure 34 is particularly well suited to showing annual patterns.

Estuaries.—Depending upon conditions,

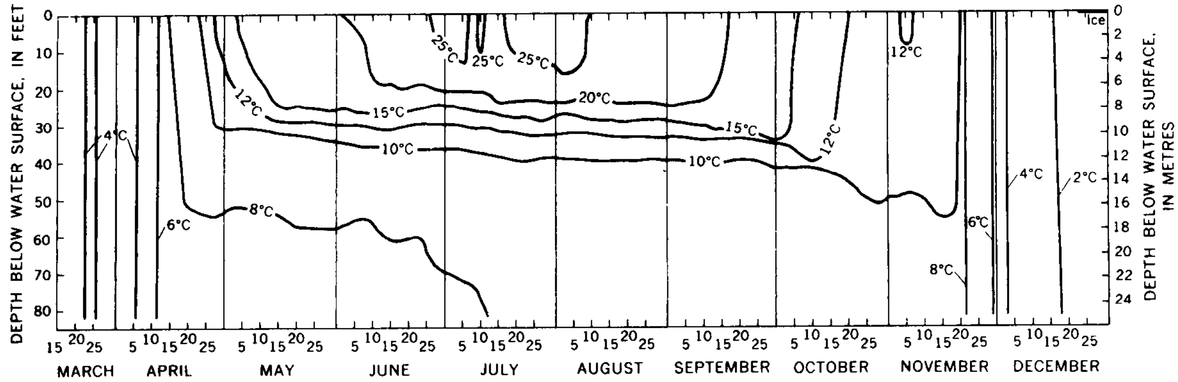


Figure 34.—Temperature variations in a lake represented by isothermal lines in a depth versus time graph. (From Ficke, 1972, p. A5.)

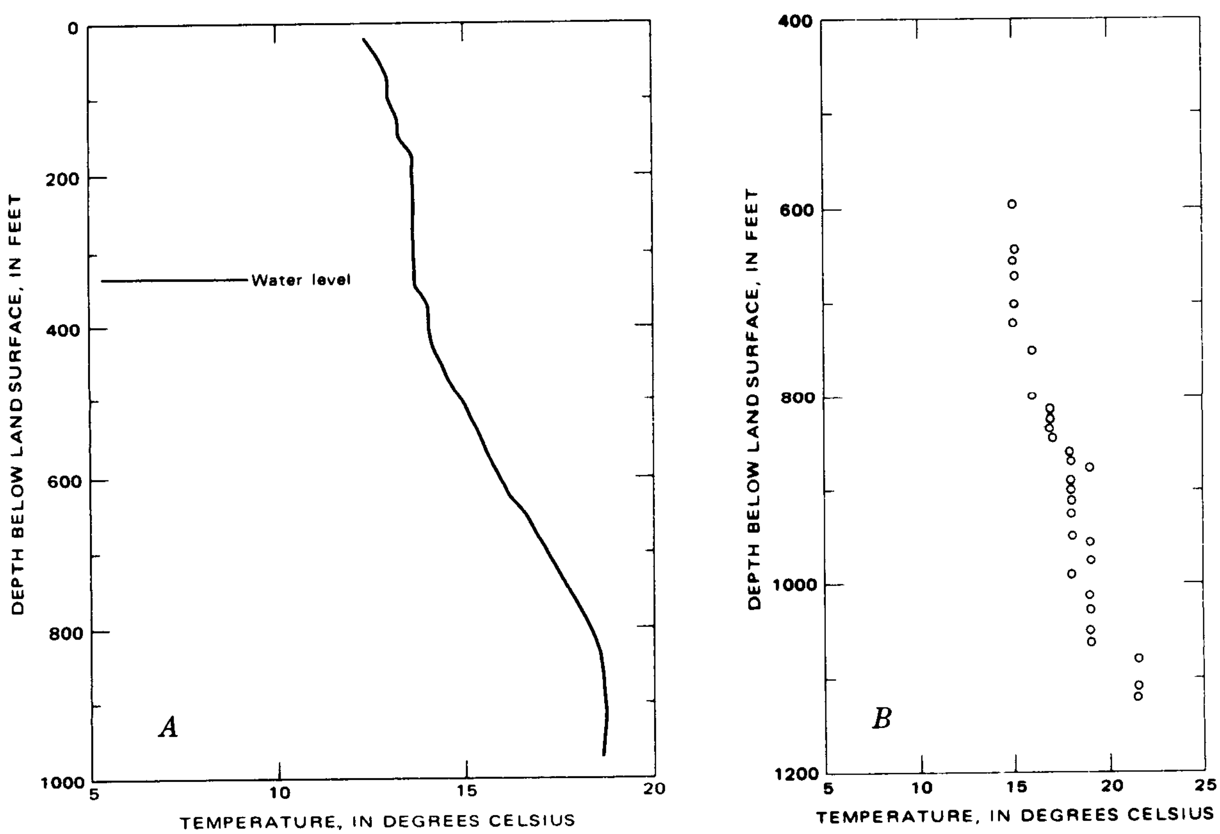


Figure 35.—Graphical presentation of temperature variations in well. *A*, Continuous trace from a recording logger. *B*, Observations of temperature of water discharged during the drilling of a well. (From Ficke and others, 1974, p. 62, 110.)

temperatures of estuaries can be reported using the methods presented for reporting stream or lake data, or a combination of these. Figure 32 is well adapted to estuary data and can be modified to show temperature at more than one depth or at more than one point in the cross section simply by adding additional lines to the isometric graphs. The format of figure 34 also can be applied to estuarine data to show variations in a tidal cycle, using a greatly expanded time scale.

Ground water.—Graphs often are far superior to tables in showing temperatures of ground water because they can show small, subtle changes which would require elaborate tables. Temperatures in wells often are recorded by logging devices, rather than by measurements at discrete points, and it is a relatively simple task to reduce the logs to page-size graphs. Graphical presentations of data from loggers should show continuous lines. Data from measurements at discrete points can be shown as continuous lines if the measurements are closely spaced, but should be shown as plotted points if the author feels they cannot be reasonably connected. Examples in figure 35 include both data from a logger and data at specific depths. In fact, the data in figure 35*B* do not represent temperature of water at a particular depth, but instead show temperatures of water discharged from a drillhole at the depth shown on the ordinate scale. The water actually entered the hole at several levels, and the data help point out the zones that contribute water.

Data from different times of measurement can be shown in the same graph, as was done in figure 6, provided there are great enough changes between times of measurement to keep the curves from plotting on top of each other. In addition to temperature profiles in wells, a graphical presentation commonly used is a map showing temperatures at a given depth or geologic horizon. Other graphical presentations include thermal gradient versus depth, areal variation in thermal gradient for a given depth range, and temporal variations in temperature of a spring or well. A great opportunity still exists for authors to apply imagination in developing new techniques to present temperature data for ground water.

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