TEMPERATURE OF SURFACE WATERS IN THE CONTERMINOUS UNITED STATES

By
J. F. Blakey

INTRODUCTION

Temperature is probably the most important, but least discussed, parameter in determining water quality. The purpose of this report is to present the average or most probable temperatures of surface waters in the conterminous United States and to cite factors that affect and are affected by water temperature. Temperature is related, usually directly, to all the chemical, physical, and biological properties of water. The ability of water to dissolve or precipitate materials is temperature dependent, the ability of water to transport or deposit suspended material is temperature dependent, and the aquatic life of a lake or stream may thrive or die because of the water temperature.

Everyone is concerned, though often unknowingly, about water temperature. The amount and type of treatment necessary for a municipal supply are temperature dependent; therefore it affects the consumer cost. Temperature determines the volume of cooling water needed for industrial processes and steampower generation. Conservation and recreation practices are affected by water temperature, and the farmers' irrigation practices and livestock production may be affected by the water temperature.

PRESENT STUDY

At present (1965), the Geological Survey has 345 continuous recording thermographs measuring surface-water temperatures in the United States. The Stevens thermograph is the recorder commonly used by the Survey and it is accurate to ± 2°F. In addition to these thermograph records, water temperature is measured one or more times each day at 440 stations. The thermometers used for these measurements are accurate to ± 0.5°F. Including weekly, monthly, and intermittent measuring stations, the Survey collects temperature data on surface water at 1,360 points. Records from 240 thermograph stations and 60 daily temperature stations were selected as the nucleus for this report. All the records were collected in 1960-62 water years (October 1, 1959 - September 30, 1962), and all the yearly records are at least 80 percent complete. This 3-year period was selected because the data were prepared for automatic processing and they could be analyzed rapidly in many different ways by electronic computer. The period of record is short for determining temperature means and extremes, but with the rapid industrial and municipal growth and the increasing number of impoundments and diversions these current data may be more representative of present and future conditions than long-term means and extremes.

Sheet 1 shows the most prevalent temperature of surface waters in the conterminous United States; sheet 2 shows the average number of days per year when surface-water temperatures are 80°F or greater; and sheet 3 shows the average number of days per year when temperatures are at or near the freezing point (32° - 34°F). Some streams or areas where abnormal water temperatures exist are shown on these sheets. However, many more exceptions undoubtedly exist in each of the generalized areas. The most prevalent surface-water temperature for the conterminous United States is about 55°F and the range of most prevalent temperatures is from the middle thirties in northern Michigan, Wisconsin, and Minnesota to the low eighties in southern Florida. While some streams in northern States have temperatures in the 32° - 34°F range more than 150 days each year, streams in the Everglades in southern Florida have water temperatures of at least 80°F for as many as 250 days each year.

COMPARISON WITH A PREVIOUS INVESTIGATION

In 1925, Collins (p. 97) reported on temperature of water available for industry in the United States. By comparing data on surface-water temperature with data on air temperature, he concluded that mean monthly temperatures of surface water are generally within a few degrees of the mean monthly air temperature, except when the air temperature is below freezing. A few examples of the water-air temperature relationship in 1962 are shown in table 1. A diagram by Collins for the Mississippi River at Minneapolis, Minn., for 1923 shows that water temperature extremes were about 81°F and 33°F and the mean annual water temperature was 51°F. The 1923 mean annual air temperature was 46°F. As shown in table 1, the 1962 extremes for the Mississippi River at St. Paul were 77°F and 34°F and the mean annual water temperature was 54°F. The 1962 mean annual air temperature at Minneapolis was 42°F. A comparison of the two annual records shows a 3° higher mean annual water temperature in 1962 than in 1923, but a 4° lower mean air temperature. Differences between these 1-year records, made 40 years apart, may be due more to the climatic conditions of the individual years and different techniques of measurement than to historical changes (true conditions changing with time). However, man's activities have undoubtedly had some effect on the water temperature.

The water and temperature data in table 1 are shown not to take exception to the conclusions by Collins, but to show actual water-air temperature relations at selected sites in the United States in 1962.

The effects of extended periods of sub-32°F air temperatures on the water-air temperature relationship are shown by the Maine site, effects of thermal loading are shown by the Ohio site, and effects of impoundments are shown by the Arizona-California site.

Collins qualifies his conclusion by pointing out that man's activities were affecting the mean water-air temperature relationship at many places. Since 1925, the number of affected places probably has doubled several times.

TABLE 1.-Water and air temperatures at selected sites in the United States, 1962
(in degrees Fahrenheit)

Recording site	Annual extremes				Annual averages		July–August averages		Remarks
	Water		Air		Water	Air	Water	Air	
	Max.	Min.	Max.	Min.					
Sheepscot River at North Whitefield, Maine	70	32	88	−12	50	43	64	64	Air temperatures at Portland
Delaware River at Wilmington, Del.	82	32	95	−1	58	52	78	73	
Miami River at Miamisburg, Ohio	90	32	98	−11	61	51	82	72	Air temperatures at Dayton
Mississippi River at St. Paul, Minn.	77	34	95	−32	54	42	74	68	Air temperatures at Minneapolis
Clear Fork Trinity River at Fort Worth, Tex.	91	39	104	7	67	66	84	86	
Rio Grande near San Ildefonso, N. Mex.	88	32	98	−6	53	56	70	77	Air temperatures at Albuquerque
Gila Gravity Main Canal at Imperial Dam, Ariz.-Calif.	88	48	117	28	69	75	84	94	Air temperatures at Yuma
Sacramento River at Freeport, Calif.	72	41	104	25	58	61	70	75	Air temperatures at Sacramento
Clark Fork below Missoula, Mont.	68	32	96	−23	45	43	60	64	
Willamette River at Salem, Oreg.	72	35	97	8	53	51	67	64	

EFFECTS OF NATURE'S ACTIVITIES

Stream temperature at most of the 300 stations, as would be expected, is greatly influenced by the air temperature. Other factors that affect the stream temperature, in conjunction with or in opposition to air temperature, are: 1, the shape of the channel, amount of water surface exposed to air and sunlight; 2, the amount of flow, the larger the volume the slower the temperature change; 3, the amount and rate of absorption and irradiation of solar heat; 4, evaporation by sun and wind, and 5, the temperature and volume of ground-water inflow.

Most of the streams in the northeast, because of their deep-shaded channels and few days of exposure to 90°F plus air temperatures, have a small range in daily and annual water temperature extremes. The 1962 extremes for the Hudson River at Mechanicville, New York, were 78°F and 32°F. The greatest range in daily extremes was 4°F and the range between the mean monthly extremes seldom exceeded 2°F.

Water temperature characteristics of streams in the Southeast are much like those in the Northeast. The annual extremes are usually about 82°F and 38°F, and diurnal ranges are seldom more than 4°F. One of the principal exceptions is the Everglades area in southern Florida. Diurnal ranges of 20°F are common in this hot, sunny area, and the 1962 annual extremes of one Everglades stream were 108°F and 60°F. The mean monthly water temperature extremes for July were 100°F and 82°F.

The Niobrara River near Verdel, Nebr., is a wide, shallow stream that adjusts rapidly to wide ranges in air temperature (1962 annual air temperature extremes at Norfolk, Nebr., were 98°F and -26°F) and rapidly absorbs and irradiates solar heat. As shown by figure 1, there is a wide range in daily water temperature extremes for this station as well as in the annual extremes (99°F to 32°F). Diurnal fluctuations may be as much as 20°F. Stream temperature characteristics of many of the Midwest streams are similar to those of the Niobrara River and, except for fewer 32°F days in winter, many of the Southwest streams have similar characteristics.

Many of the streams in the Northwest interior are frozen over for 100 days or more each winter. An exception is Bluewater Creek near Bridger, Mont. This small stream has a sustained ground-water inflow. Zimmerman (1964) reports that from April 1960 to September 1961 the maximum streamflow at this station was 104 cfs (cubic feet per second), the minimum was 19 cfs, and the mean discharge was 27 cfs. He states that Bluewater Creek is the only perennial stream in this semiarid area (annual precipitation is 10 inches), and its flow is sustained by ground water with a temperature near 56°F, reportedly the optimum temperature for trout rearing. The purpose of his study was to collect data for the expansion of the State fish hatchery operations in the basin. The water-temperature duration curve for Bluewater Creek (fig. 2) shows a wide range in diurnal extremes; the apparent results of a struggle between the ground-water inflows and the air temperature to control the temperature of the stream. On July 16, 1962, the stream temperature ranged from 70°F to 44°F. The annual extremes for 1961-62 were 75°F and 32°F, but the stream temperature reached the 32°F reading on only 2 days during the 2-year record.

Many of the streams along the coast of northern California, Oregon, and Washington have annual maximums in the high sixties or low seventies and minimums in the high thirties. The 1962 extremes for the Chehalis River near Grand Mound, Wash., were 74°F and 36°F, and water temperature was in the 40° - 60°F

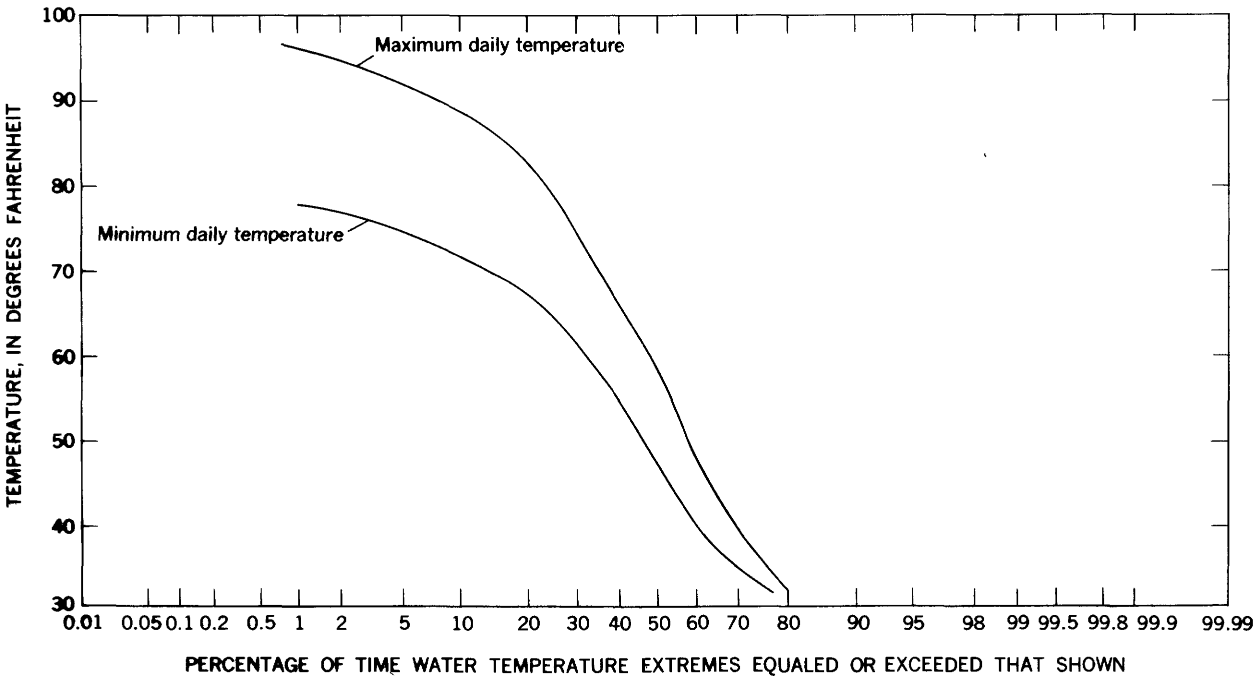

Figure 1.-Temperature-duration curve, Niobrara River near Verdel, Nebraska

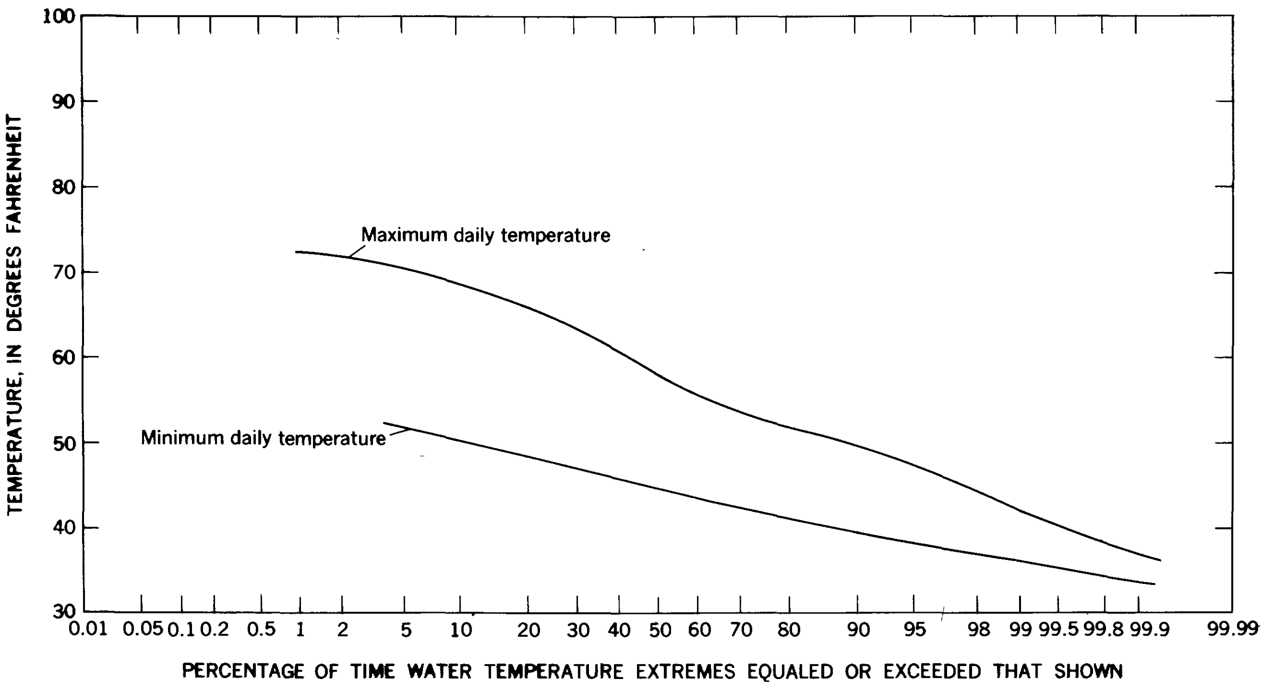

Figure 2.-Temperature-duration curve, Bluewater Creek near Bridger, Montana

range, more than 70 percent of the time.

EFFECTS OF MAN'S ACTIVITIES

Although most of the major streams in the United States are affected to some degree by man, the examples cited above are of streams whose temperatures are controlled primarily by natural conditions. The following examples depict streams or reaches of streams where water temperatures have been greatly affected by man's activities.

The Mahoning River in Ohio is probably the best historical example of thermal pollution in the United States. Collins (1925, p. 100) compares water temperatures of the Mahoning River at Youngstown in 1918-23 to air temperature at nearby Warren, Ohio, and he concludes that industrial use of the river was increasing the temperature of the water approximately 20°F above normal temperature expected in an area stream

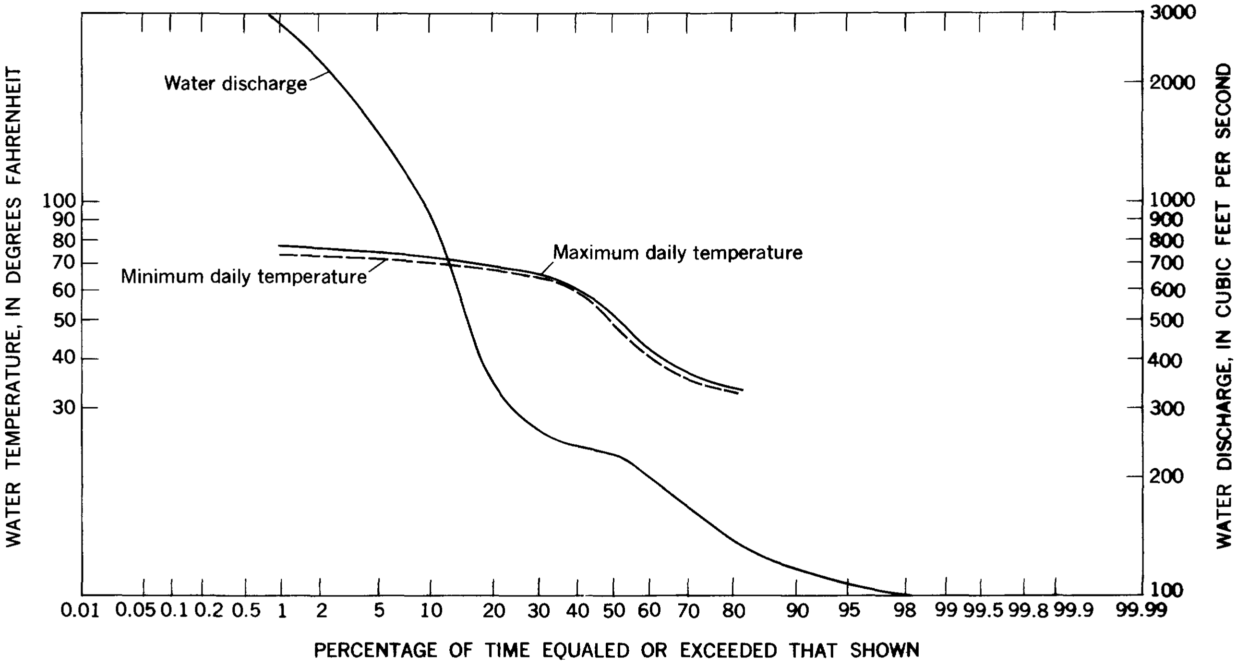

Figure 3.-Temperature and flow duration curves, Mahoning River at Leavittsburg, Ohio

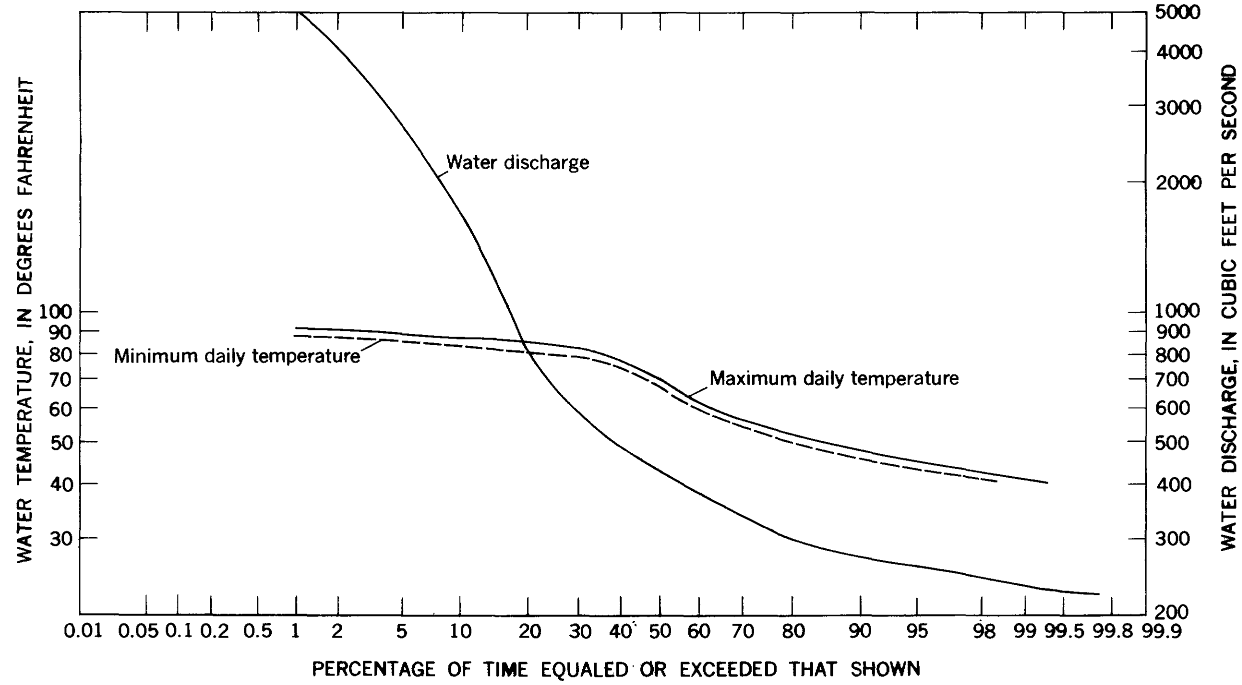

Figure 4.-Temperature and flow duration curves, Mahoning River at Lowellville, Ohio

in July, and 25°F above the normal temperature in August.

In a report by Hubble and Collier (1960, p. 37) on the quality of Ohio surface waters, they discuss the heat pollution of the Mahoning River. Their water-temperature-duration curves for 1950-58 indicate that the temperature of the Mahoning River at Leavittsburg was 70°F, or less, 80 percent of the time, and that downstream at Lowellville it was 70°F, or less, only 32 percent of the time.

Figure 3 for the Mahoning River at Leavittsburg shows a maximum daily water temperature of 70°F, or higher, and a water discharge of 500 cfs, or more, 15 percent of the time. About 40 miles downstream at Lowellville (fig. 4), 15 percent of the time the water temperature was 86°F, or higher, and water discharge was 1,100 cfs, or greater. On the basis of these values, the thermal loading between these two points could be 50 billion Btu (British thermal units) per day.

Abnormal increase in water temperature is a complex problem that concerns many people in many ways. The dissolved-oxygen content of water is inversely related to temperature. At 34°F the saturation value for dissolved oxygen in water is 14 ppm (parts per million); at 80°F the saturation value is less than 8 ppm. Therefore, the warmer the water the less capacity it has to neutralize (oxidize) municipal and industrial wastes. Aquatic life may be able to adjust to the warm waters, but it is destroyed by lack of oxygen.

Reservoirs have a big effect on downstream temperatures. Daily temperature measurements of the Illinois River near Gore, Okla., just below Tenkiller Ferry Dam are excellent examples. The 1962 extremes were 71°F and 41°F, and over 60 percent of the time the temperature was between 48°F and 58°F. The 1962 air temperature extremes for nearby Tulsa were 102°F and 0°F.

Hoak (1965, p. 10) defines the effect of reservoirs on stream temperatures in the summer as negative thermal loading and cites the following example: A hydroelectric dam on the Chattahoochee River has lowered the summer water temperature downstream as much as 50°F. Some species of fish have disappeared and the water is much too cold for swimming. Cold water is desirable for drinking and for industrial cooling, but conversely, the colder the water entering a municipal treatment plant, the more difficult and expensive it is to treat, and the more heat is necessary to produce hot water and steam.

Figures 5 and 6 show water temperature and discharge duration curves for two stations on the San Joaquin River in California. Streamflow at both these stations is highly regulated (written communication, Willard W. Dean, 1965). Reservoirs above the station at Kerckhoff Powerhouse are filled during periods of snowmelt, and the water is released for power production in the fall and winter. This operation produces a fairly uniform pattern of temperature and discharge. Downstream at the Vernalis station, streamflow and water-temperature records show the effects of storage, diversions into and out of the basin, and irrigation return flows. The regimen produced has little resemblance to natural conditions.

TEMPERATURE OF LAKES AND RESERVOIRS

A single temperature reading at any point in a lake or reservoir may represent only a small fraction of the water body. Air temperature, wind action, inflow, and outflow or any combination of these factors can cause fluctuations. Inflows having temperatures different from lake temperatures and seasonal changes in air temperatures are probably the principal factors.

Temperature changes and stratification follow a seasonal pattern in many lakes, especially in areas where the surface temperature of the lake is at or near the freezing point in the winter. Figure 7 is a diagram of these characteristic patterns. In summer, the warmer water is near the surface (epilimnion), in the middle

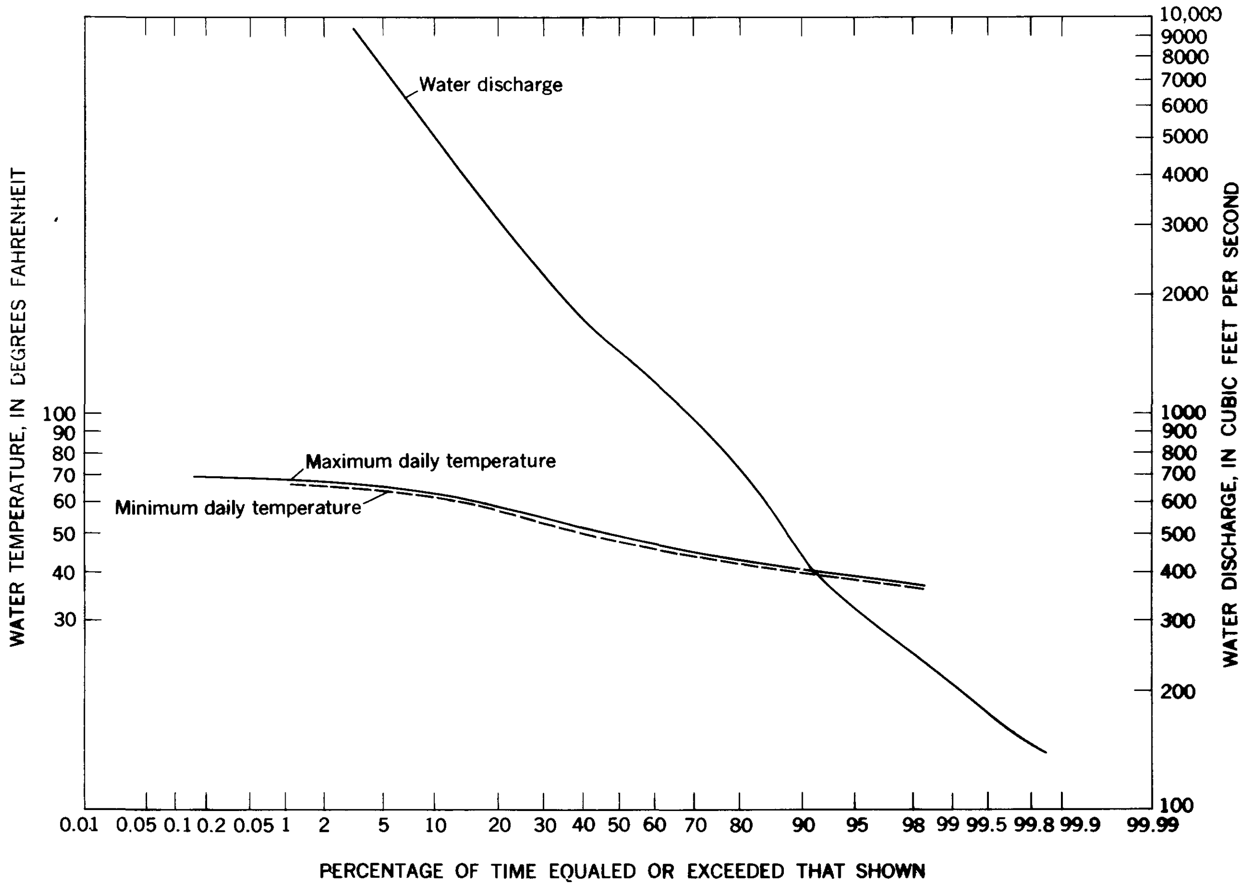

Figure 5.-Temperature and flow duration curves, San Joaquin River below Kerckhoff Powerhouse, California

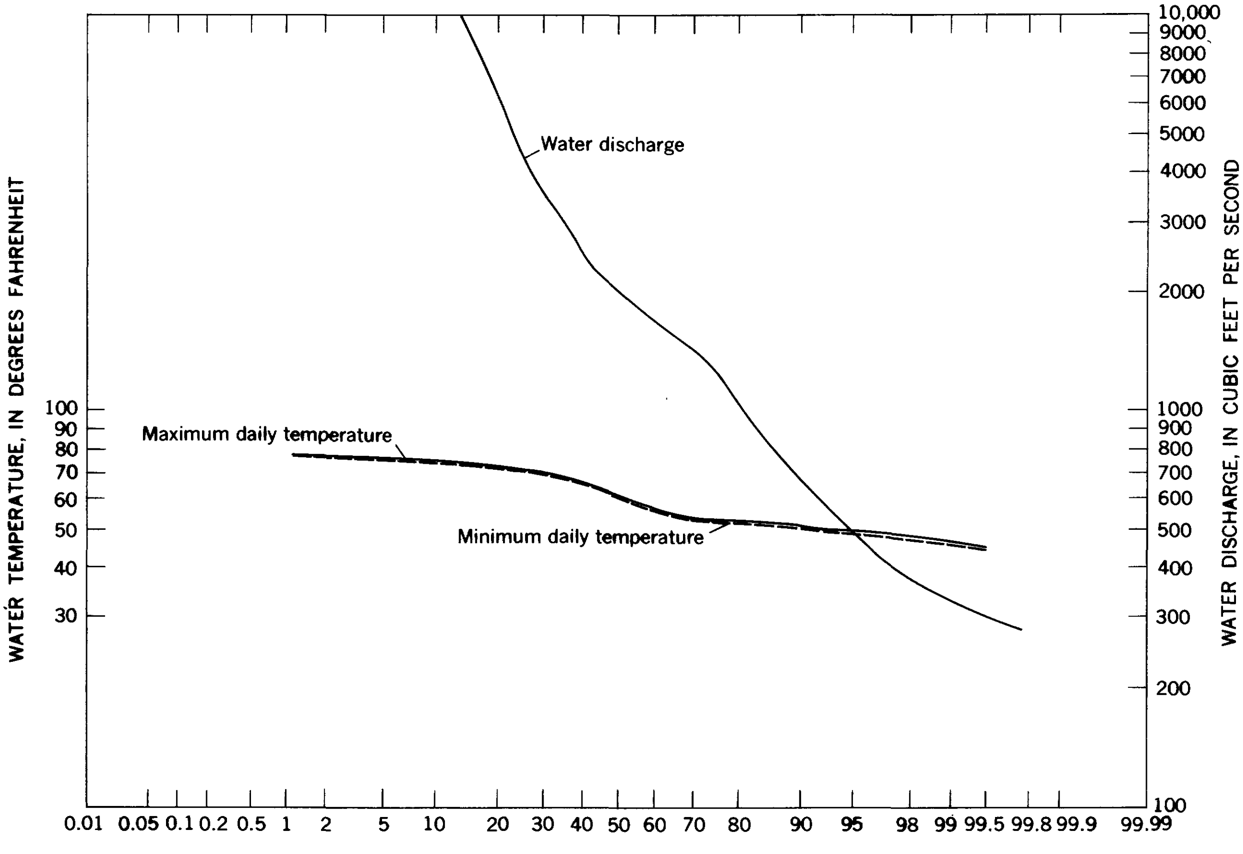

Figure 6.-Temperature and flow duration curves, San Joaquin River near Vernalis, California

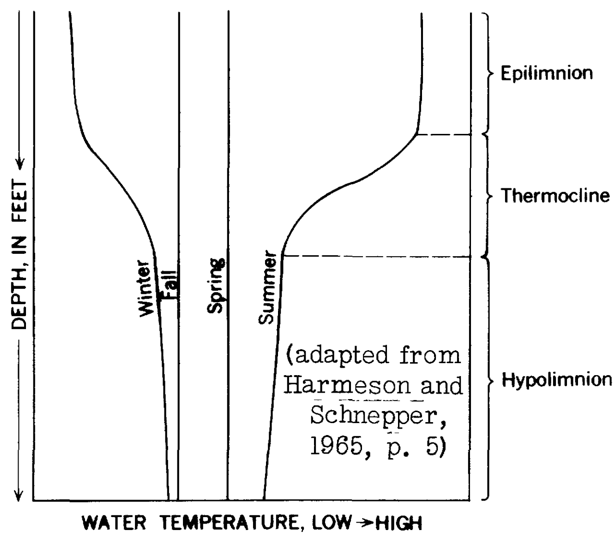

Figure 7.-Seasonal temperature variations in lakes and reservoirs

zone (thermocline) temperature decreases with depth, and in the lower zone (hypolimnion) there is little circulation and the temperature approaches uniformity. In the fall, the epilimnion temperature drops until the lake is nearly uniform from top to bottom and mixing, or turnover, occurs. In winter as the epilimnion temperature drops to or near the freezing point, the temperature slowly increases with depth, until it approaches maximum density (39°F) in the hypolimnion. In the spring, as the epilimnion temperature approaches 39°F, mixing occurs again. As the surface temperature continues to rise, the summer stratification pattern develops and the cycle begins again. Vertical temperature measurements in Lake Ontario show these characteristic patterns (fig. 8). However, these patterns may be less distinct or may not exist in lakes or reservoirs with a high percentage of inflow or in reservoirs where water is discharged, as through a hydroelectric dam, causing circulation near the bottom of the reservoir. Higher winter air temperatures in the southern States stop the development of these patterns in many southern lakes and reservoirs. Temperature profiles for Possum Kingdom Reservoir in Texas (fig. 8) show surface temperatures higher than bottom temperatures in all seasons of the year. If the surface temperature does not cool below 39°F, the characteristic winter stratification patterns do not develop, and reservoir mixing does not occur. Also, the density of water due to dissolved materials may be so great that temperature effects are small in proportion, and characteristic temperature patterns do not develop.

INCREASING INTEREST AND CONCERN

Federal, State, and local agencies are becoming more aware of water temperature and how it affects

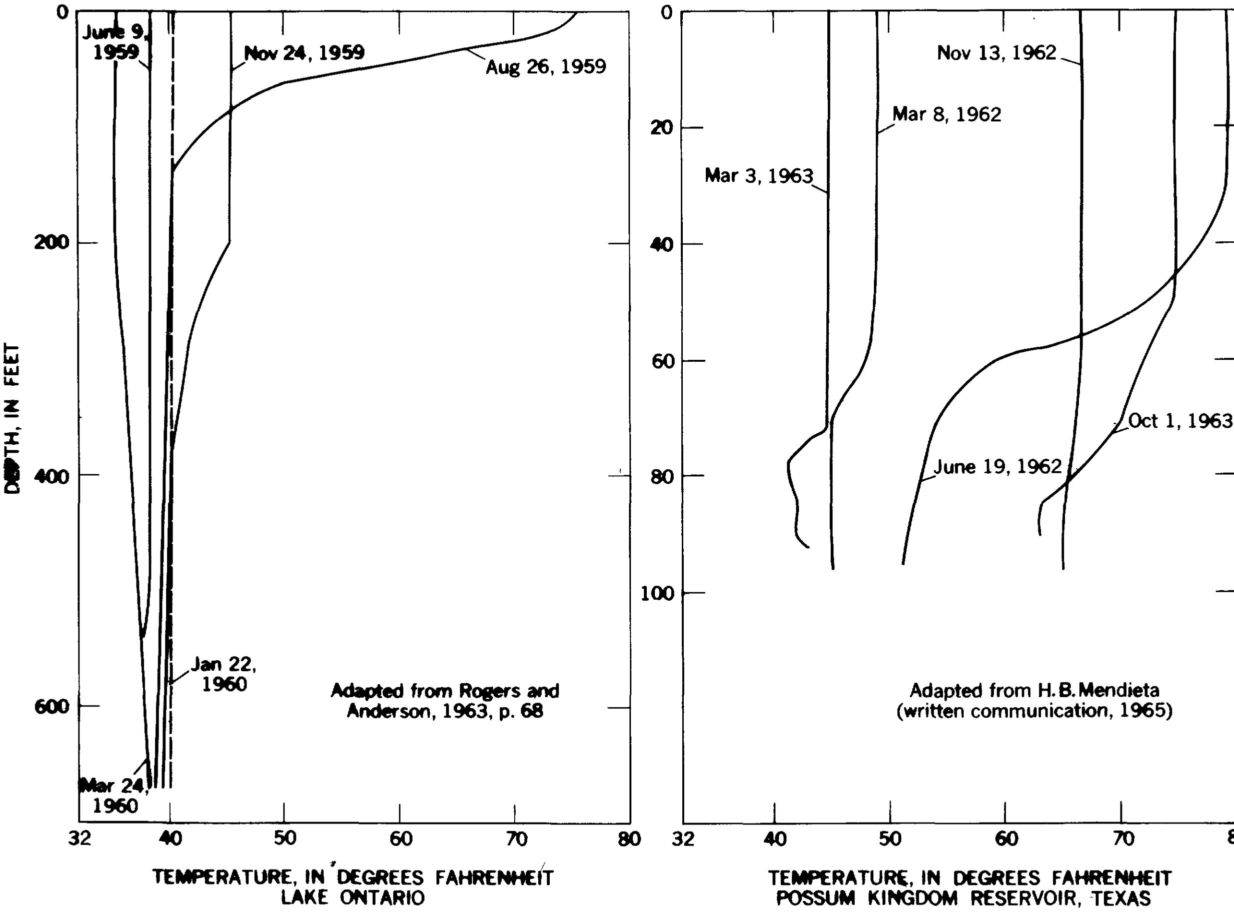

Figure 8.-Temperature profiles of lakes

and is affected by man's activities. Many of these agencies are now attempting to assess the significance of this complex characteristic of water. Industry is no longer concerned only with how much water is available; maximum, minimum, median, and mean temperatures of the water supply must be considered. Also, the cost of adjusting the temperature of waste discharges is a growing concern, because more rules and regulations on thermal pollution are undoubtedly forthcoming.

Field surveys have been made in Pennsylvania by teams from State agencies and industries to study various aspects of the surface-water temperature problem in the State. On the basis of the findings of these teams, regulations for controlling thermal pollution in streams have been drafted (Hoak, 1965, p. 13). Some of the regulations cited are: 1, Discharges should not raise the temperature of the receiving stream above 93°F; 2, where downstream uses are not affected, or where because of mine drainage there is no fish life, the temperature limit could be exceeded; 3, in existing trout streams the temperature limit would be 58°F or natural stream temperature, whichever was higher; and 4, control of discharges to estuaries would be required where necessary to protect public interest. The Pennsylvania studies are cited by Hoak as an example of State and industry working together to resolve problems in water-quality control.

The Geological Survey and the State of California have planned a continuing study to compile and analyze water-temperature data for California streams (Jones, 1965). The purpose of this study is to provide data, collected under present conditions, that can be used to evaluate future changes of stream temperatures by nature or by man.

A 1964 publication (Avrett and Carroon) by the Survey and the State of Alabama reports 20 years of stream-temperature data collected at 137 sites in the State. This report provides data for water users who must consider temperature in appraising the water-use potential of surface waters in Alabama.

SUMMARY AND CONCLUSIONS

The recognition of water temperature as an important factor in determining water quality is increasing rapidly, because of the increasing demands for more water by more people for more uses. However, probably most of the present and future studies of water temperature will be directed toward one use or one particular interest, because a study of water temperature and its complete interrelation to all factors of the hydrologic environment would approach the impossible.

The nucleus of this study is temperature data of surface water collected at 300 points in the conterminous United States during 1960-62. The illustrations were prepared on the basis of few points in some areas, such as Nevada and Utah, and the 3-year period may not agree closely with long-term values. However, these maps do give the general characteristics of water temperature under present conditions.

Air temperature and solar radiation generally control the temperature of surface water, and the conclusion of Collins (1925) that mean monthly temperatures of surface water and air are generally within a few degrees is still valid. However, the air-water temperature relationship in reaches of many streams is upset by natural conditions, such as ground-water inflows with temperatures differing from air temperature by as much as 50°F, and by man's activities, such as thermal loading in billions of Btu's per day. Some of these exceptions to the air-water temperature relationship are shown on sheets 1, 2, and 3; many others exist.

Even in areas where the air-water temperature relationship is good, the fact that this relationship is based on mean temperatures must be remembered. The mean temperature alone may be of little value in determining the usefulness of a water supply.

A few of the many factors and characteristics of water temperature that may require consideration in determining the usefulness of a water supply have been noted in this report. Hopefully, the generalized maps will be of value as a starting point in the initiation of more sophisticated project and use-oriented studies.

ACKNOWLEDGMENTS

This report was prepared under the guidance and direct supervision of Mr. W. H. Durum, Staff Hydrologist. Computer analysis of the data by the Automation and Data Management Section of the Quality of Water Branch, Mr. G. A. Billingsley, Chief, made this report possible.

REFERENCES

Avrett, J. R., and Carroon, L. E., 1964, Temperature of Alabama streams: Alabama Geol. Survey, Inf. Ser. 35, 165 p.

Collins, W. D., 1925, Temperature of water available for industrial use in the United States: U. S. Geol. Survey Water-Supply Paper 520-F, p. 97-104.

Harmeson, R. H., and Schnepper, V. M., 1965, Temperature of surface water in Illinois: Illinois State Water Survey Pub. 49, 45 p.

Hoak, R. D., 1965, Hot water—a growing industry concern: Indus. Water Eng., v. 2, 4, p. 10-14.

Hubble, J. H., and Collier, C. R., 1960, Quality of surface waters in Ohio, 1946-1958: Ohio Water Plan Inventory Rep. 14, 317 p.

Jones, E. J., 1965, Temperature of California streams; pt. 1, Evaluation of thermograph records: U. S. Geol. Survey open-file report, 31 p.

Rodgers, G. K., and Anderson, D. V., 1963, The thermal structure of Lake Ontario: Mich. Univ., Great Lakes Research Div. Pub. 10, p. 59-69.

Zimmerman, E. A., 1964, Geology and water resources of the Bluewater Springs area, Carbon County, Montana: U. S. Geol. Survey Water-Supply Paper 1779-J, 24 p.