The Effect of the Addition of Heat from a Powerplant on the Thermal Structure and Evaporation of Lake Colorado City, Texas

By G. EARL HARBECK, Jr., G. E. KOBERG, *and* G. H. HUGHES

STUDIES OF EVAPORATION

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PREFACE

This report was prepared in the Water Resources Division of the Geological Survey under the direct administrative supervision of R. W. Davenport, Chief, Technical Coordination Branch, followed by C. C. McDonald, Chief, General Hydrology Branch, and under the technical guidance of W. B. Langbein. Most of the fieldwork and data processing was performed by personnel of the Surface Water Branch, J. V. B. Wells, Chief, under the supervision of Trigg Twitchell, District Engineer. The study was conducted in cooperation with the Board of Water Engineers, State of Texas, H. A. Beckwith, Chairman, succeeded by R. M. Dixon.

The cooperation of the Texas Electric Service Co., Fort Worth, Tex., who assisted with the installation of equipment and whose personnel made many of the routine daily observations, is greatly appreciated.

The help of the U. S. Weather Bureau in installing a pan evaporation station at the reservoir is gratefully acknowledged. These data have been furnished to the Weather Bureau for analysis and the results are to be published in a separate report.

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By G. Earl Harbeck, Jr., G. E. Koberg, and G. H. Hughes

ABSTRACT

Lake Colorado City, a reservoir in north-central Texas, is used as a source of cooling water for a thermal-electric powerplant. Evaporation from the lake was determined by the energy-budget method for the period July 1954 to October 1955. Annual evaporation from Lake Colorado City was 93 inches, of which 85 inches was natural evaporation and 8 inches resulted from addition of heat to the lake by the powerplant.

Analyses indicate that if no heat had been added by the powerplant, the water-surface temperature would have been only 0.8° C lower than that observed. The temperature rise is almost directly proportional to the heat input, so that doubling the quantity of heat added by the powerplant would raise the temperature an additional 0.8° C, if the volume of water in the reservoir was the same as in 1954–55. The temperature rise in a nearly empty reservoir, of course, would be much greater, and in a full reservoir, less.

The increase in evaporation from Lake Colorado City, when expressed as a volume, is directly proportional to the amount of heat added and is practically independent of reservoir contents. During 1954–55 the volume of forced evaporation resulting from the heat added by the powerplant, 910 acre-feet, was almost exactly the same as the volume of water diverted to Colorado City for municipal purposes.

The entire lake is being effectively utilized in disposing of heat. Water temperatures in the lower basin of the lake were higher in winter than those in the upper basin of the lake; no appreciable differences were observed in summer. Density differences between the two parts of the lake were very small at all times.

A comparison between average lake temperatures (as determined from the thermal surveys) and plant intake water temperatures indicates that water is withdrawn from all levels of the lake above the pump intakes. The average withdrawal temperature to be expected, if the amount of heat added by the powerplant is increased, probably will be about equal to the anticipated surface temperature, which can be determined from graphs in the text.

INTRODUCTION

Many thermal electric powerplants in the United States withdraw water from a stream or lake, use it to condense steam, and return it to the stream or lake, practically undiminished in quantity, but with its temperature substantially raised. Obviously, evaporation from the water body is increased. This usually is of little consequence where water supplies are ample, but it may be of considerable importance where supplies are short, as in the arid West.

If ample supplies of water are available from a lake, perennial stream, or well, the decision whether to use cooling towers would be based only upon economy of construction and operation of the cooling system. If the amount of water consumed must be minimized, a reservoir or cooling pond will use less water than a cooling tower. Where natural streamflow is not adequate at all times, storage must be provided.

The design of cooling ponds has long been based on empirical formulas and on the judgment and experience of the designers. The prediction of water temperatures in a lake or cooling pond has been largely educated guesswork. The purpose of this report is to devise ways to predict the increase in evaporation and in water temperature of a reservoir when it is used as a cooling pond to dispose of given amounts of heat.

Representatives of the Texas Board of Water Engineers and the Geological Survey agreed that Lake Colorado City in north-central Texas would be suitable for a field study. This reservoir, which is owned by the Texas Electric Service Co. of Fort Worth, seemed to have many advantages as a site for the study. For example, measurements of water volumes and temperatures could be made with adequate accuracy, and employees of the power company were available and eager to cooperate in making many of the routine daily observations.

DESCRIPTION OF THE RESERVOIR AND DAM

Lake Colorado City is situated on Morgan Creek, a small tributary to the Colorado River in north-central Texas (fig. 3). The dam was built in 1949 by the Texas Electric Service Co. to provide a supply of cooling water for a steam-electric powerplant constructed

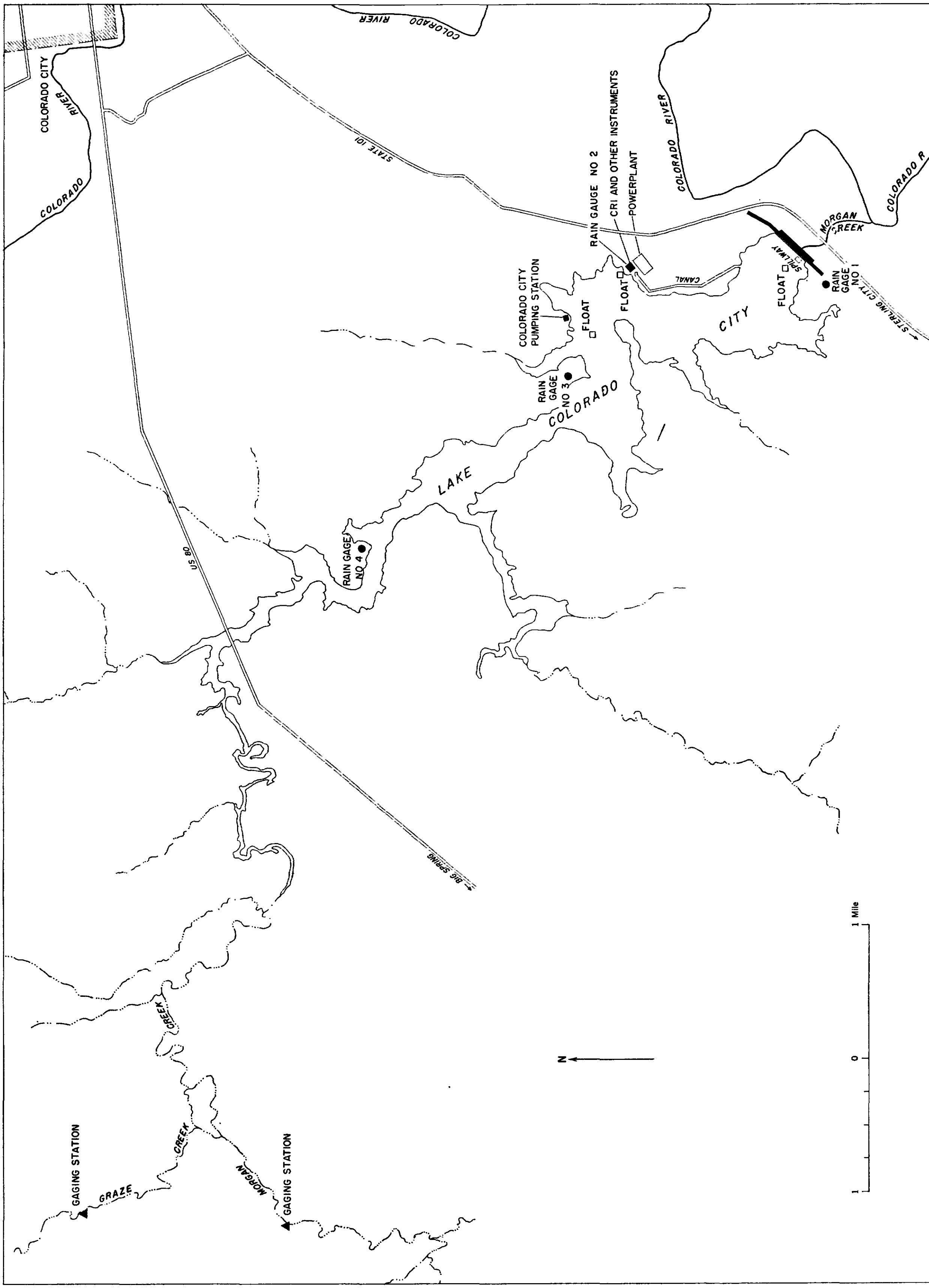


FIGURE 3.—Map of Lake Colorado City, Tex., showing location of instruments.

at the same time on the shore of the lake. The reservoir area, is owned by the power company, but recreational use of the upper half of the lake is encouraged. Access to the lower half of the lake is restricted.

The capacity of the reservoir at service spillway level is 31,800 acre-feet, and the corresponding surface area is 2,030 acres. Since its construction in 1949, the reservoir has not spilled. Water is pumped from the reservoir to Colorado City for municipal use.

The dam is a rolled-earth structure approximately 4,800 feet long. A morning glory spillway near the southwest end of the dam is designed to handle most flood discharges For larger floods there is a long emergency spillway between the plant and the dam that is designed to handle floods above the capacity of the morning glory spillway.

Water is taken from Lake Colorado City at the powerplant, pumped to the plant where it is used for cooling, and returned to the lake through a canal. The canal discharges into the reservoir at a point nearly a mile distant from the plant. Water flows over a weir and falls freely into the reservoir.

The drainage area of Morgan Creek above the dam is 267 square miles. Average inflow for the period 1948–55, as determined from records obtained at a former gaging station on Morgan Creek and from records of change in contents of the reservoir, was estimated to be 17.3 cubic feet per second (cfs). Average inflow during the period July 1954 to October 1955 was 13.4 cfs. For periods as long as several months, however, inflow is practically nil, so that natural streamflow could not have been relied upon as a source of cooling water, and it was necessary that storage be provided.

CLIMATOLOGY

According to Thornthwaite (1948) the climate of the Colorado City area is semiarid. The average annual temperature at San Angelo is 66.2° F, normal rainfall is 19.8 inches, and average wind speed is 10.4 miles per hour. San Angelo, the nearest Weather Bureau station, is approximately 75 miles south-southeast of Lake Colorado City. Approximately one-fourth of the annual rainfall occurs in April and May, another one-fourth in September and October, with the remainder fairly well distributed among the other 8 months.

The data obtained at Lake Colorado City during the period July 1954 to October 1955, provide a basis for comparison between climatic conditions at Lake Colorado City and San Angelo. There is no appreciable difference between air temperature at the two locations (fig. 4). Wind speed at Lake Colorado City is approximately 75 percent of that measured at San Angelo (fig. 5), but the anemometer at San Angelo is 63 feet above the ground, as compared to approximately 40 feet above the water surface at Lake Colorado City, which could account for the difference. The correlation between vapor pressures at the two locations is poor (fig. 6), but there appears to be no significant bias.

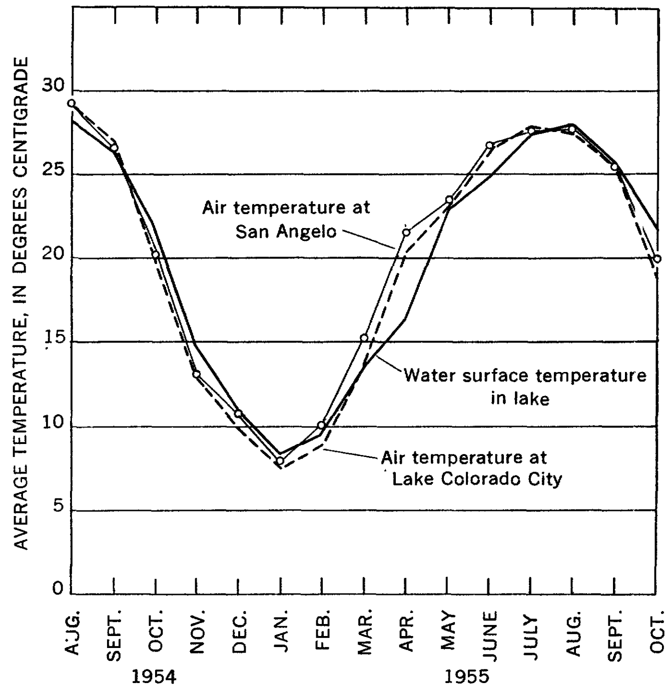


FIGURE 4.—Monthly average temperatures of air at Lake Colorado City and at San Angelo, Tex., and of water surface of Lake Colorado City, Tex.

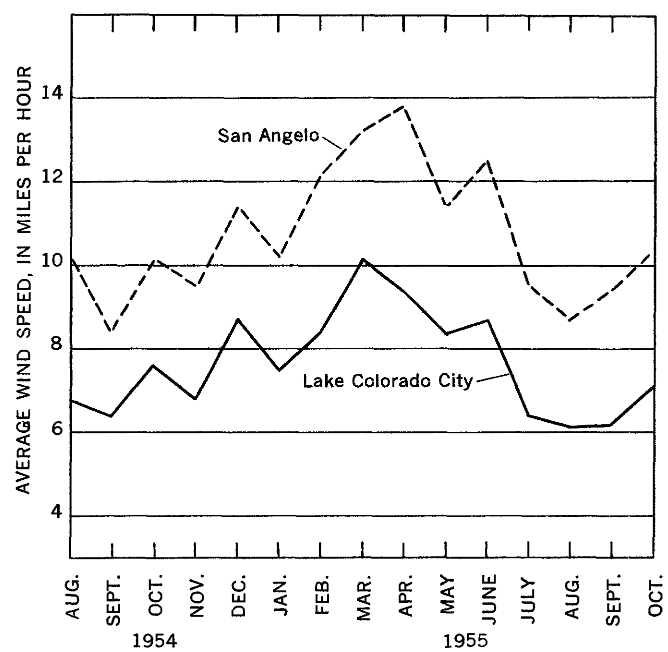


FIGURE 5.—Monthly average wind speeds at Lake Colorado City and at San Angelo, Tex.

During the period July 1954 to October 1955, the air temperature at San Angelo was generally slightly above normal, as was wind speed. Wind direction was not measured at Lake Colorado City, but during the same period monthly prevailing wind direction at Abilene, approximately 75 miles east of the lake, was south to south-southeast, and at San Angelo south to west-southwest. Humidity was slightly below normal.

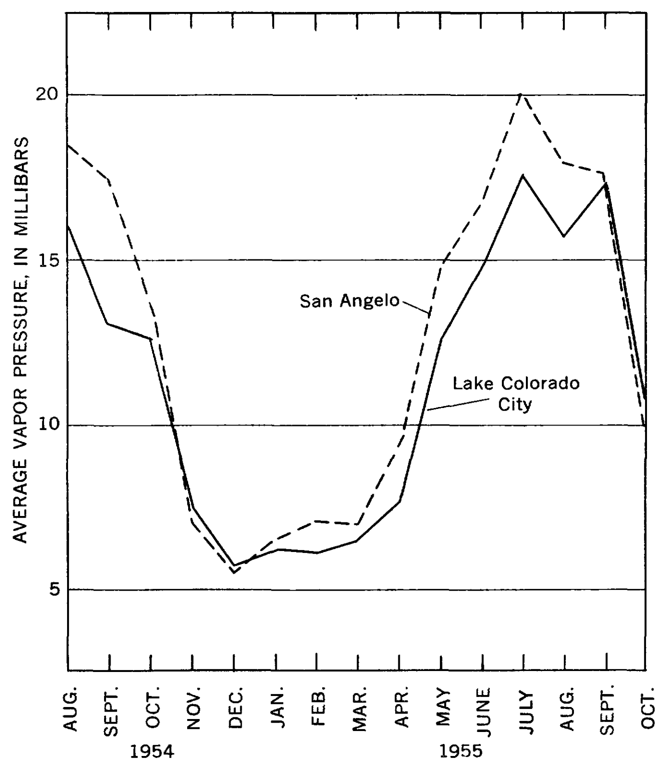


FIGURE 6.—Monthly average vapor pressures at Lake Colorado City and at San Angelo, Tex.

Although rainfall at San Angelo during this period was only slightly more than half of normal, rainfall at Abilene was nearly normal. From these data it was concluded that weather conditions at Lake Colorado City were not greatly different from normal and that the period was reasonably representative of average conditions.

INSTRUMENTATION

WATER BUDGET

Although the evaporation from Lake Colorado City was computed by the energy-budget method it was necessary to obtain a reasonably accurate water budget to evaluate the advection and storage terms of the energy budget, and as an approximate check to guard against gross errors in the computed figures of evaporation.

INFLOW

Morgan Creek is the principal source of surface inflow to Lake Colorado City. Records of inflow are available at two stream-gaging stations, Morgan Creek near Westbrook, Tex., and Graze Creek near Westbrook, Tex. The stations are located about 10 miles upstream from the bridge on U. S. Highway 80 which crosses the upper end of the lake (fig. 3). Standard stream-gaging techniques, as described by Corbett (1943), were used. Streamflow records for the two stations were classified as good, which means that the error in daily records is believed to be less than 10 percent.

During the 468 days of observation, surface flow occurred on 71 days; flows of 2 acre-feet or more per day occurred on 52 days. Figure 7 shows the monthly in-

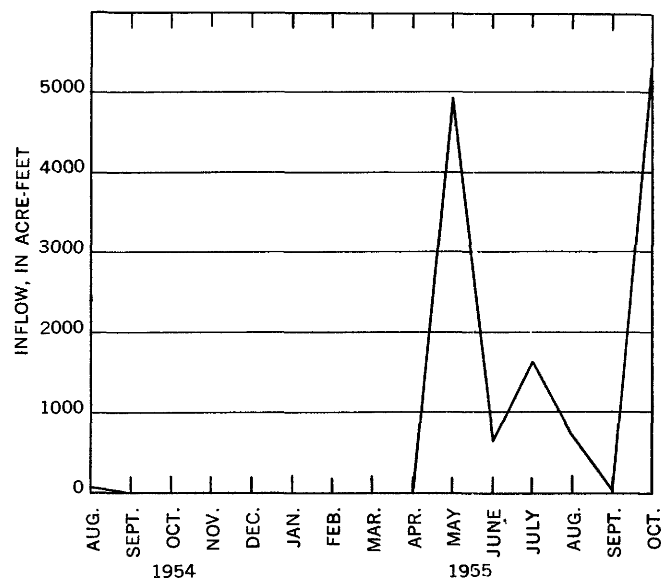


FIGURE 7.—Monthly inflow to Lake Colorado City, Tex.

flow to Lake Colorado City during the period of observation. During 5 periods of from 2 to 5 days measured inflow was more than 700 acre-feet. Comparison with the change in contents at Lake Colorado City during these periods indicates that some of the measured inflow apparently did not reach the reservoir. This will be discussed later.

Surface inflow from the drainage area downstream from the gaging stations was not measured. Much of this area is under cultivation and little runoff results from light rains. Estimates were made of unmeasured inflow from storm rainfalls of more than 0.5 inch.

OUTFLOW

There was no surface outflow from Lake Colorado City during the period of observation. The reservoir has not filled to spillway level since the dam was constructed in 1949, nor has any water been released since hat time. Provision was made to obtain a rating for he uncontrolled service spillway by relating discharge neasurements, to be made below the dam, to the lake levation, in the event that spill occurred.

Periodic estimates of surface seepage below the dam, ndicate that this loss never exceeded 0.1 acre-foot per lay, and it was therefore disregarded. The possibility f deep seepage losses of any appreciable magnitude was onsidered remote. Hydrologic studies to be described ater confirmed that there were no measurable unaccounted-for losses from the reservoir.

CHANGE IN RESERVOIR CONTENT

The area and capacity curves used to determine hange in contents of Lake Colorado City were furnished y Texas Electric Service Co., Fort Worth, Tex. (fig. 8).

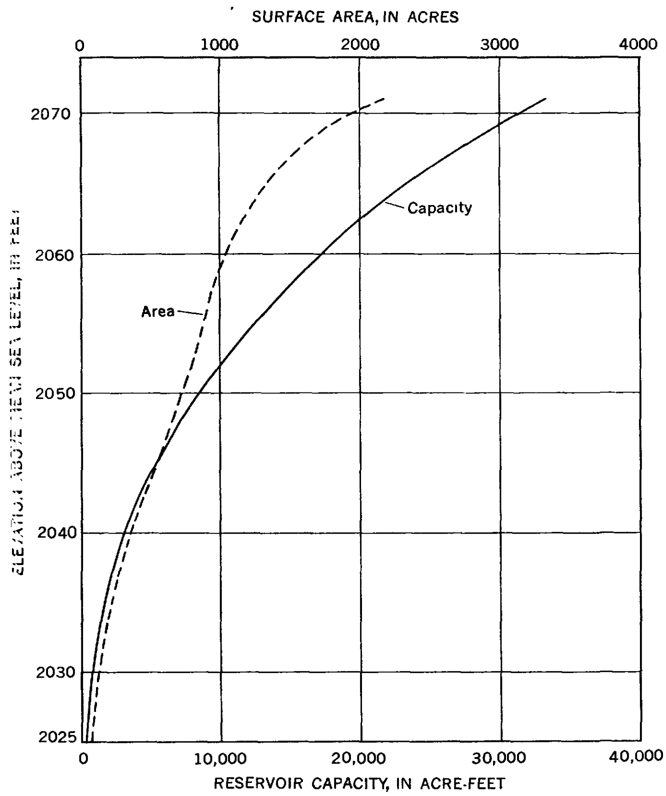


FIGURE 8.—Area and capacity curves for Lake Colorado City, Tex. (Furnished by Texas Electric Service Co.).

The curves are based on areas computed from four aerial photographs of the reservoir area, taken with lake surface at elevations of 2,047.3, 2,053.3, 2,061.2, and 2,068.2 feet above mean sea level. The aerial photographs were corrected for length on the basis of transmission alinement maps. Available also was the area at the 2,070-foot contour, determined from deed records based on field surveys.

The area and capacity curves used in the computations agree closely with previous curves, furnished by the engineering firm that designed the dam, and are accepted as accurate. The surface area of the canal was considered insignificant and was not taken into account.

Changes in lake stage were measured with a Stevens A–35 waterstage recorder located in the Colorado City pumping station on the north shore of the lake about 1.5 miles north of the dam (fig. 3). The stilling well for the recorder was a 2-foot concrete pipe attached to the outside of the pumping station.

The staff gage attached to the stilling well was read to hundredths of a foot and the midnight elevations used in computing changes in stage were taken from the recorder chart. Figure 9 shows the monthly contents of Lake Colorado City.

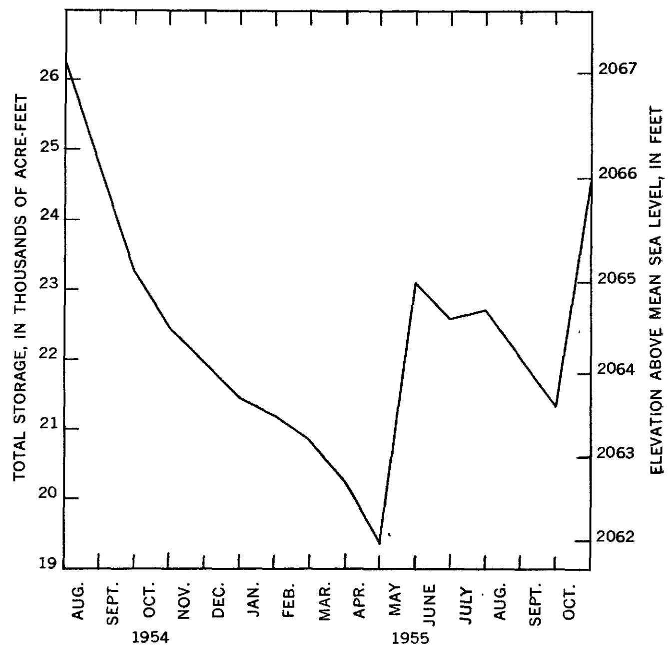


FIGURE 9.—Monthly contents of Lake Colorado City, Tex.

WITHDRAWALS FOR MUNICIPAL USE

Withdrawals by Colorado City for municipal use were the only appreciable diversion from Lake Colorado City. Records of daily withdrawals were computed from pumping records furnished by Colorado City Water Department. Figure 10 shows the total monthly diversion by Colorado City. Withdrawals averaged 2.4 acre-feet per day and ranged between 0 and 5.8 acre-feet per day. As the total of 1,130 acre-feet withdrawn amounted to less than 9 percent of the computed evaporation over the period of observation, even a 10 percent error in the pumping record, which is not likely, would not have an appreciable effect on the results. Consumptive use by the powerplant and by residents along the lake shore was minor in comparison to the diversion to Colorado City and was neglected.

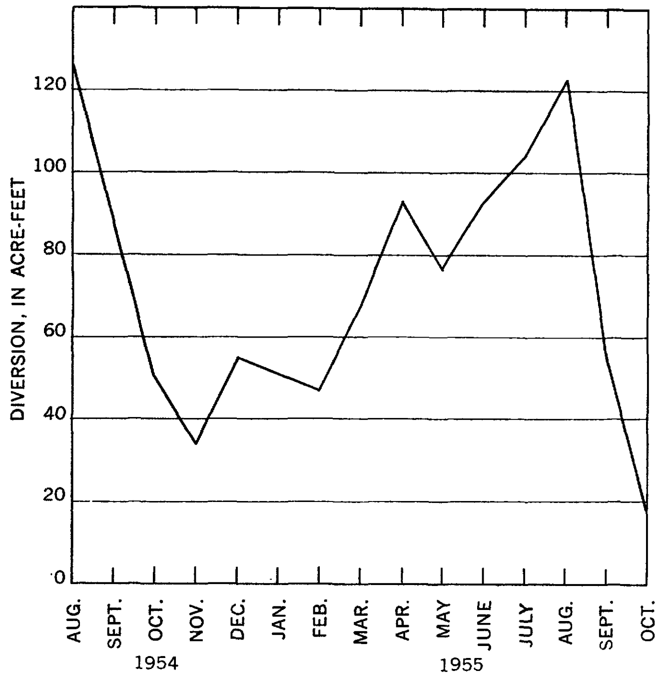


FIGURE 10.—Monthly diversion from Lake Colorado City for municipal use by Colorado City, Tex.

RAINFALL ON THE LAKE SURFACE

Rainfall was measured in four 8-inch nonrecording gages located around the lake (see fig. 3). A simple average of the catches of the four gages was taken as the mean rainfall on the lake surface. A Weather Bureau recording gage located at the powerplant was used to determine the time and duration of the rainfall.

Figure 11 shows the monthly rainfall for the four nonrecording gages. Total average rainfall on the lake surface during the period of observation was 14.8 inches, which added 1,562 acre-feet to the reservoir. Rainfall of 0.05 inch or more occurred on 41 days during the 468 days of observation. On 10 days the rainfall was more than 0.5 inch; on only 1 day was there more than 1 inch of rain.

Although the total rainfall on the lake surface amounted to 13 percent of the measured inflow and was a significant item in the water budget, there were many periods in which no rainfall occurred.

ENERGY BUDGET

Net solar and atmospheric radiation at Lake Colorado City were measured by the Cummings radiation integrator (CRI), a pan of water heavily insulated to minimize heat transfer through the sides and bottom. Records obtained during the Lake Hefner studies (Harbeck, 1954) and the Lake Mead studies (Koberg, 1958) showed that the CRI gave accurate results and was a reliable substitute for the conventional radiation

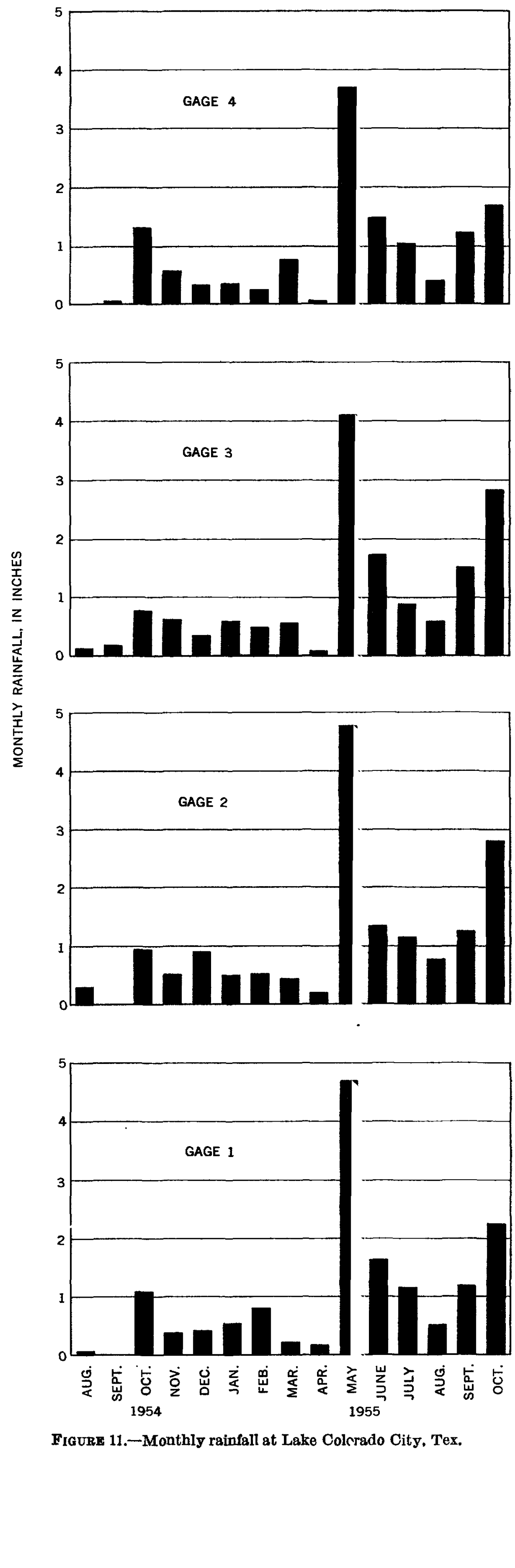
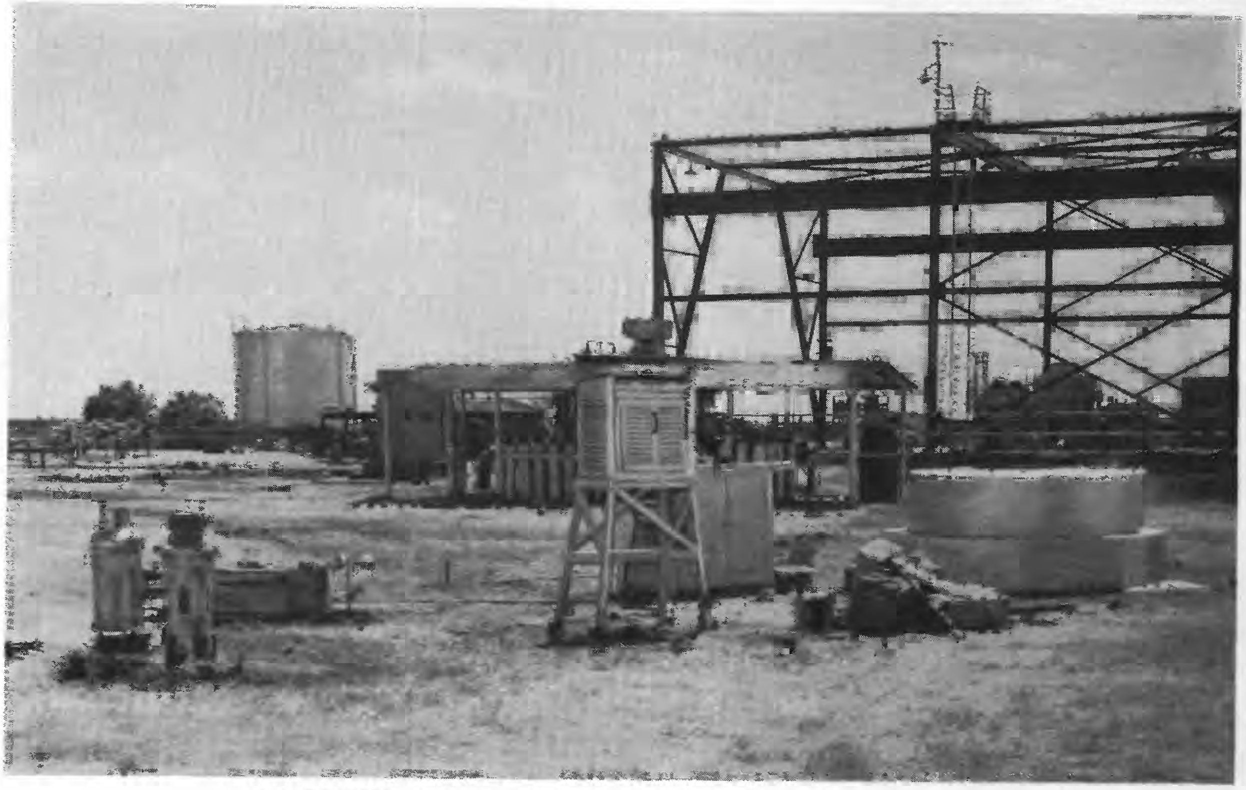
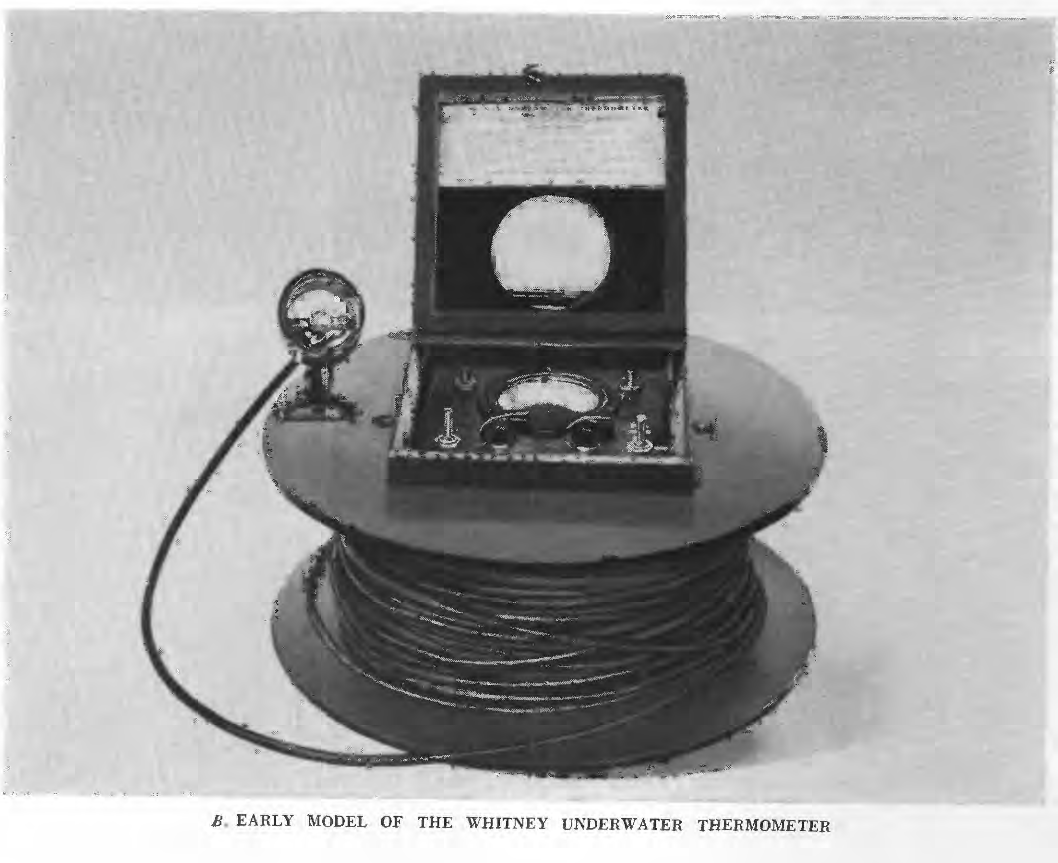


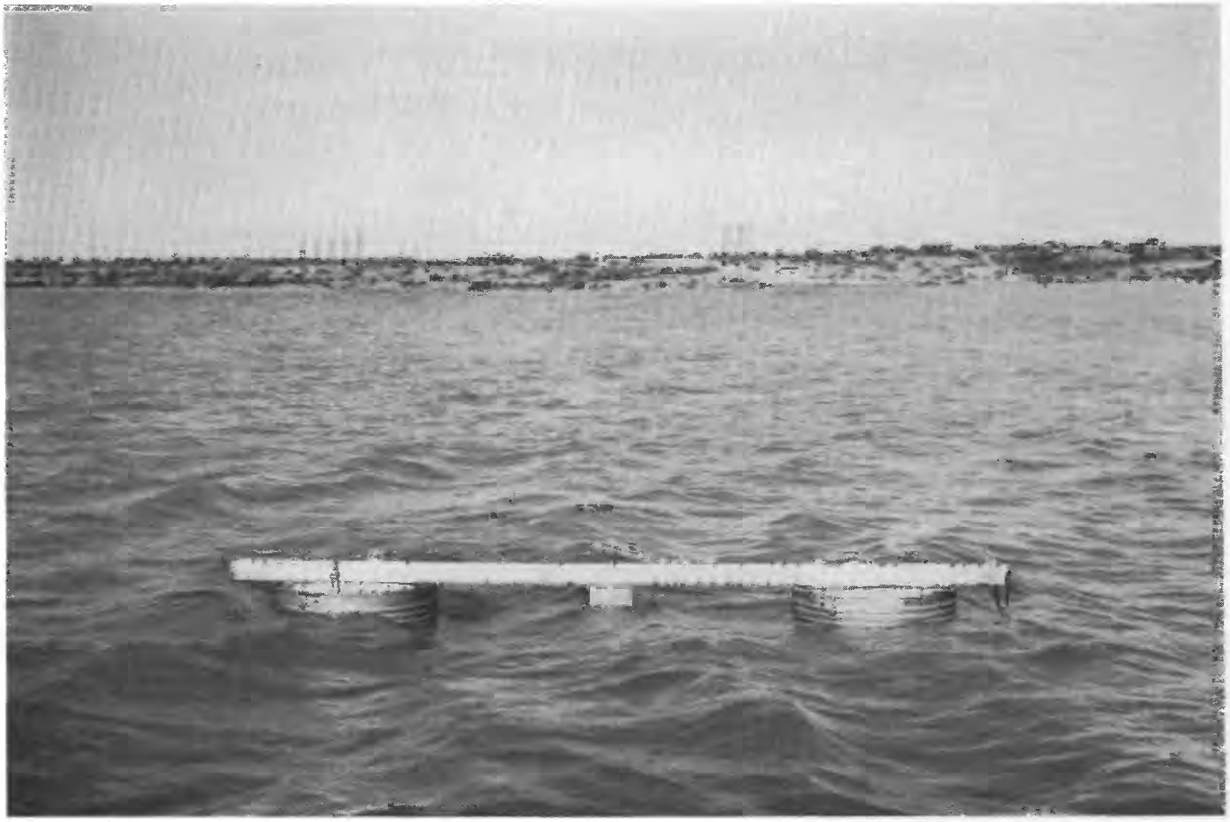
FIGURE 11.—Monthly rainfall at Lake Colorado City, Tex.



A. INSTRUMENTS LOCATED NEAR THE TEXAS ELECTRIC SERVICE CO. PLANT



B. EARLY MODEL OF THE WHITNEY UNDERWATER THERMOMETER



SMALL FLOAT USED TO SUPPORT SIX'S MAXIMUM-MINIMUM THERMOMETER equipment, which is expensive and requires much more attention.

RADIATION MEASUREMENTS

The CRI was located near the Texas Electric Service Co. intake structure where 110-volt alternating current was available. Daily inspections and occasional servicing were made by plant personnel. Figure 3 shows the location of the CRI installation. A complete description of the CRI is presented in the Lake Hefner studies by Harbeck (1954, p. 120). The CRI was placed in operation on July 21, 1954, and was continued in operation until October 31, 1955. Plate 1*A* shows the completed CRI installation.

The CRI was serviced at approximately 10-day intervals, using the technique developed at Lake Hefner (Harbeck, 1954, p. 121–122) except that plant personnel occasionally added water, when the water level in the pan was below an arbitrarily selected reference point, which was about 1 inch below the reference point gage. The volume and temperature of the water added were measured.

The recording of temperature data was the principal maintenance problem, and it is discussed in the section on mass-transfer instrumentation.

TEMPERATURE PROFILES OF THE LAKE

Temperature profiles were obtained with a Whitney underwater thermometer, which uses an electrical circuit with a small battery to supply the power requirements. The circuit is a Wheatstone bridge, of which the underwater sensing element is one arm. The underwater sensing element is a small thermistor which responds rapidly to changes in temperature.

Temperatures are read directly from a calibrated scale. The depth of water is measured by the length of line from the sensing element to the water surface. Plate 1*B* shows one of the earlier models of the Whitney underwater thermometer.

Although the instrument is nonrecording, it is portable, and for some purposes is therefore preferable to the bathythermograph (Spilhaus, 1938) and the temperature profile recorder (TPR) (Anderson and Burke, 1951) because it is portable. The bathythermograph winch and the TPR are not portable and require a semi-permanent installation in the boat.

The calibration of the Whitney underwater thermometer was checked just before the investigation began and immediately after completion. The calibration checks agreed within 0.1°C, which is satisfactory for evaporation computations. Occasionally field checks were made by placing the sensing element in a bucket of water and measuring the temperature of the water with a calibrated thermometer. These checks always agreed within 0.1°C.

The only maintenance problem of the Whitney underwater thermometer occurred when the sensing element was broken during a sounding and had to be returned to the manufacturer for repairs.

MASS TRANSFER

The mass-transfer instrumentation at Lake Colorado City was considerably simpler than that used at Lake Hefner and Lake Mead. Equipment was provided for measuring wind speed and wet- and dry-bulb temperatures at only one height, and for measuring water surface temperatures. Copper-constantan thermocouples were used for most temperature measurements.

The thermocouple voltages were recorded on a Minneapolis-Honeywell multiple-record Brown recording potentiometer. The recorder used has a strip type chart and a print wheel for printing six different records in sequence at 30-second intervals. The calibrated accuracy of the chart scale is within ±0.02 mv (millivolt) or ±0.5°C and is sensitive to a change of 0.004 mv or 0.1°C. Power is supplied from a 110-volt alternating current source. The thermocouple psychrometer (Bellaire and Anderson, 1951) used successfully at Lake Hefner and Lake Mead was also used at Lake Colorado City.

Wind speed was measured with a standard 3-cup Robinson-type contact anemometer. A 4-digit electric reset counter was used to record wind movement. The counter was read daily and the dial reset to zero.

Two Six's maximum-minimum thermometers were used to study the areal variation in water-surface temperature. These thermometers were supported by floats just below the water surface with a small radiation shield above the thermometer bulb, as shown in Plate 2. Observations of maximum and minimum water-surface temperature were made once each day.

The thermocouple psychrometer and the anemometer were mounted on a mast attached to the vertical member at the left of the ladder leading to the top of the plant intake structure, as shown in Plate 1*A*. A float was anchored in the lake near the intake structure with a thermocouple mounted just below the water surface. Two thermocouples were mounted on the CRI, 1 for measuring the water surface temperature in the CRI and 1 for measuring the temperature of the overhanging rim. The thermocouples were all connected to the Minneapolis-Honeywell recorder located near the CRI. Figure 3 shows the location of this installation which was placed in operation on July 20, 1954, and was continued in operation until October 31, 1955.

Figure 3 also shows the location of the two floats with the Six's maximum-minimum thermometers. One is located near the dam and the other in midlake. It would have been desirable to have had one of the floats nearer the north end of the lake, but this part of the lake is open to the public and vandalism was feared. These floats were installed on July 20, 1954, and temperatures will be observed until the need for these data no longer exists.

In addition to the mass-transfer instrumentation, a standard Weather Bureau class A evaporation pan was installed near the CRI by Weather Bureau employees. Figure 3 shows the location of the class A pan which was placed in operation on July 15, 1954.

PERFORMANCE AND MAINTENANCE OF EQUIPMENT

ACCURACY CHECKS

Periodic checks of the equipment in the field were made to maintain prescribed accuracy requirements. The temperature and humidity data were checked 2 or 3 times a week with a calibrated sling psychrometer. The sling psychrometer readings agreed with the thermocouple psychrometer records within 0.5°C. After dust storms, greater discrepancies were noticed, but after the wet-bulb wick was cleaned the readings agreed within 0.5°C.

The anemometer assembly was replaced and overhauled at intervals of about 30 days.

The thermocouple reference bath was contained in a 4,300 milliliter (ml) vacuum flask. It was essential that a temperature of 0°C be maintained at all times. During the first summer, the reference temperature was found to be above 0°C on several occasions. After this was noted, the reference bath was inspected daily and ice added when necessary.

The Six's maximum-minimum thermometers were checked during thermal surveys by holding a calibrated thermometer just under the water surface and comparing with the indicated temperature of the Six's thermometer. These checks agreed within 0.3°C.

USABLE DATA

Table 1 shows that the yield of usable data was excellent. The maintenance crew was inexperienced in maintaining and servicing this type of equipment, but quickly learned to remedy any malfunction and is to be complimented on the excellent yield of usable data.

MAINTENANCE PROBLEMS

The Minneapolis-Honeywell recorder, which was the heart of the temperature-recording scheme, performed exceptionally well. No loss of data could be attributed to any malfunction of the recorder. The recorder required very little servicing and maintenance compared with the recording system used at Lake Hefner and Lake Mead, but of course it requires 110 volt alternating current power, which was unavailable at the othe[r] places.

TABLE 1.—*Percentage of usable data obtained from meteorologica[l] equipment*

Month	Temperature	Humidity	Wind	Maximum minimum water surface temperature
1954				
July 21-31	100	82	91	[illegible]
August	75	100	90	[illegible]
September	80	65	77	[illegible]
October	84	100	90	[illegible]
November	91	93	93	[illegible]
December	100	74	94	[illegible]
1955				
January	100	100	81	[illegible]
February	100	75	100	[illegible]
March	100	94	94	[illegible]
April	100	87	100	[illegible]
May	100	100	90	[illegible]
June	100	87	90	[illegible]
July	100	100	81	[illegible]
August	100	100	94	[illegible]
September	100	100	97	[illegible]
October	100	100	97	[illegible]

The wet-bulb reservoir was filled twice a week an[d] was found dry twice during the period of operatio[n]. In the winter on cold days, the wet-bulb reservoi[r] was frozen for a few hours. The main maintenanc[e] problem in connection with the wet-bulb was keepin[g] the wick clean whenever dust was blowing. Durin[g] these periods, the maintenance crew inspected an[d] cleaned the wick daily or twice daily if needed.

The anemometer operated satisfactorily and the lo[ss] of wind data was attributed to having an inadequat[e] battery for the electrical counter.

The Six's maximum-minimum thermometer require[d] very little maintenance except for removing alga[e]. The loss of maximum-minimum temperature data wa[s] caused by inability to read and reset the thermomete[r] indexes each day, as sometimes occurred when the boa[t] was temporarily out of service or when the lake wa[s] unsafe for navigation because of high winds.

The lake-surface thermocouple assembly require[d] very little maintenance. During the first 4 months [of] operation, trouble resulted from the insulation on th[e] thermocouple leads cracking and causing the leads [to] short, but it was remedied by installing thermocoup[le] wire with better insulation.

SUMMARY

The instrumentation program at Lake Colora[do] City was considerably simpler than that used at La[ke] Hefner and Lake Mead with no loss of accurac[y]. The program effected savings in manpower and equi[p]ment at a considerable savings in cost.

The Whitney underwater thermometer perform[ed] exceptionally well. Thermal surveys were ma[de] quickly and easily.

The Minneapolis-Honeywell recording unit eliminated much of the maintenance problem encountered with the battery powered thermocouple amplifier used at Lake Hefner and Lake Mead. The initial cost was slightly higher, but the saving in manpower and loss of record was adequate compensation.

ENERGY-BUDGET STUDIES

The energy budget per unit area of a reservoir per unit time may be expressed as follows:

$$Q_s - Q_r + Q_a - Q_{ar} - Q_{bs} + Q_v - Q_e - Q_h - Q_w = Q_\vartheta \qquad (1)$$

in which Q_s=solar radiation incident to the water surface
- Q_r=reflected solar radiation
- Q_a=incoming long-wave radiation from the atmosphere
- Q_{ar}=reflected long-wave radiation
- Q_{bs}=long-wave radiation emitted by the body of water
- Q_v=net energy advected into the body of water other than that contained in evaporated water
- Q_e=energy utilized by evaporation
- Q_h=energy conducted from the body of water as sensible heat
- Q_w=energy advected by the evaporated water
- Q_ϑ=increase in energy stored in the body of water

Conduction of energy through the bottom, heating due to chemical and biological processes, and transformation of kinetic energy into thermal energy are neglected because of their small magnitude. For a thorough discussion of each term in equation 1, the reader is referred to the report by E. R. Anderson (1954, p. 74–110).

For computational purposes, use is made of the following relations:

$$Q_e = \rho_e E L;\ Q_h = R\ Q_e;\ \text{and}\ Q_w = \rho_e\, c\, E\, (T_e - T_b)$$

in which E=volume of evaporated water
- ρ_e=density of evaporated water
- L=latent heat of vaporization
- R=the Bowen ratio
- c=specific heat of water
- T_e=temperature of evaporated water
- T_b=arbitrary base temperature

Substituting the above in equation 1 results in the following:

$$E = \frac{Q_s - Q_r + Q_a - Q_{ar} - Q_{bs} - Q_\vartheta + Q_v}{\rho e[L(1+R) + c(T_e - T_b)]} \qquad (2)$$

The value of T_b, the base temperature, is immaterial provided that same base temperature is used in computing Q_ϑ and Q_v, and provided further that a balanced water budget is used in making the computations.

The method of determining each of the quantities in equation 1 is described in the sections that follow.

NET INCOMING RADIATION

At Lake Hefner and Lake Mead solar radiation (Q_s) and long-wave radiation from the atmosphere (Q_a) were measured directly using conventional radiation instruments. Reflected solar radiation (Q_r) was measured directly at Lake Hefner using radiation instruments; at Lake Mead it was evaluated from relationships developed during the Lake Hefner studies by Anderson (1954, p. 78). The reflected long-wave radiation was computed on the basis of laboratory determinations of emissivity and absorbtivity. For the purpose of determining evaporation it is not necessary to measure each of these items separately. Only their sum, which is the net incoming radiation ($Q_s - Q_r + Q_a - Q_{ar}$), is needed and that can be obtained conveniently using a Cummings radiation integrator (CRI).

Comparisons between the sum ($Q_s - Q_r + Q_a - Q_{ar}$) determined using the CRI and the sum of the same items measured separately, have been made using data obtained in more than 2 years of record at Lake Hefner and Lake Mead. The correlations were excellent, the maximum deviation being approximately 5 percent. Because of the limitations of the flat-plate radiometer, it is not known whether these deviations are the fault of the CRI or the flat-plate radiometer.

In this investigation the net incoming radiation was computed for each period of approximately 10 days between thermal surveys of the lake. The CRI was serviced each time a thermal survey was made. The computational methods used are almost identical to those used in the energy budget for the lake and which are explained subsequently.

The basic assumption is that the sum ($Q_s - Q_r + Q_a - Q_{ar}$) is the same for a pan on the shore of a lake as it is for the lake itself. For short periods of time, say an hour or less, this assumption is probably not acceptable because of possible transient cloud effects, but for periods of a week or more it appears reasonable. Evaporation from the CRI is measured, and from this and other data, it is possible to solve equation 1 for the sum ($Q_s - Q_r + Q_a - Q_{ar}$). This computed value is then used in equation 2 to solve for evaporation from the lake.

RADIATION FROM THE LAKE

Long-wave radiation (Q_{bs}) emitted by the lake was computed using the Stefan-Boltzman law for black-body radiation, with an emissivity of 0.970 for water as determined by Gier and Dunkle (Anderson 1954, p. 96–98).

The variation with temperature of long-wave radiation emitted by the lake is nearly linear over the range in water-surface temperature experienced in any energy-budget period. For this reason an average value of long-wave radiation emitted from the lake for any period was computed from the average lake-surface temperature per period.

The average lake-surface temperature for each period was computed from the average daily lake-surface temperatures. The average daily lake-surface temperature is an average of the daily lake-surface temperatures at each float station. As the three float stations were located in the lower half of the lake, which was usually warmer than the upper half, a correction was applied to the daily average. This correction is based on the 26 lake-surface observations taken during the thermal surveys, and observations of lake-surface temperatures taken at each float station during the thermal survey. The correction varied from −0.1°C in summer to −0.7°C in winter.

BOWEN RATIO

The Bowen ratio, which has been widely used as a measure of the ratio of the energy conducted to or from the lake as sensible heat to the energy utilized for evaporation, is expressed as follows:

$$R=\frac{\gamma(T_o-T_a)P}{(e_o-e_a)\,1{,}000} \tag{3}$$

in which γ = a coefficient

T_o = water surface temperature in °C

T_a = air temperature in °C

P = atmospheric pressure in millibars

e_o = saturation vapor pressure corresponding to the water surface temperature in millibars

e_a = vapor pressure of the air in millibars

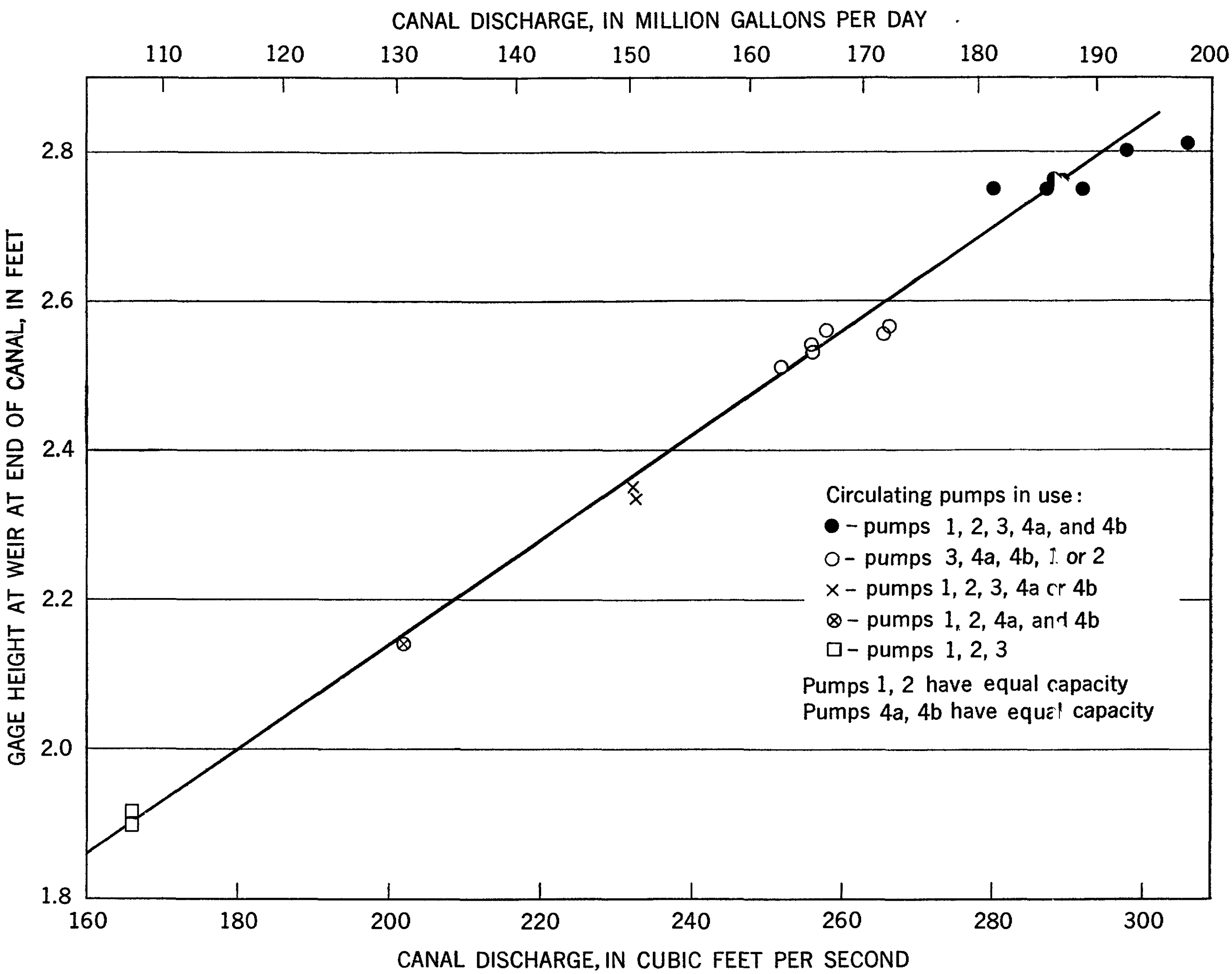


FIGURE 12.—Discharge rating curve for weir in canal for return of steam-condenser cooling water.

According to Bowen (1926) the value of the coefficient, γ, in the above equation varies between 0.58 and 0.66 but has a most probable value of 0.61.

The Lake Mead studies (Koberg, 1958) showed that the height at which both air temperature and humidity are measured makes very little difference insofar as the Bowen ratio is concerned. In the computations of Bowen ratios for Lake Colorado City the air temperature and humidity measured at the plant intake structure were used in all the computations. T_o and e_o were taken from the corrected average daily lake-surface temperature.

ADVECTED ENERGY

Advected energy (Q_v) is defined as the net energy gained by a body of water resulting from volumes of water entering and leaving the lake. It includes sub-

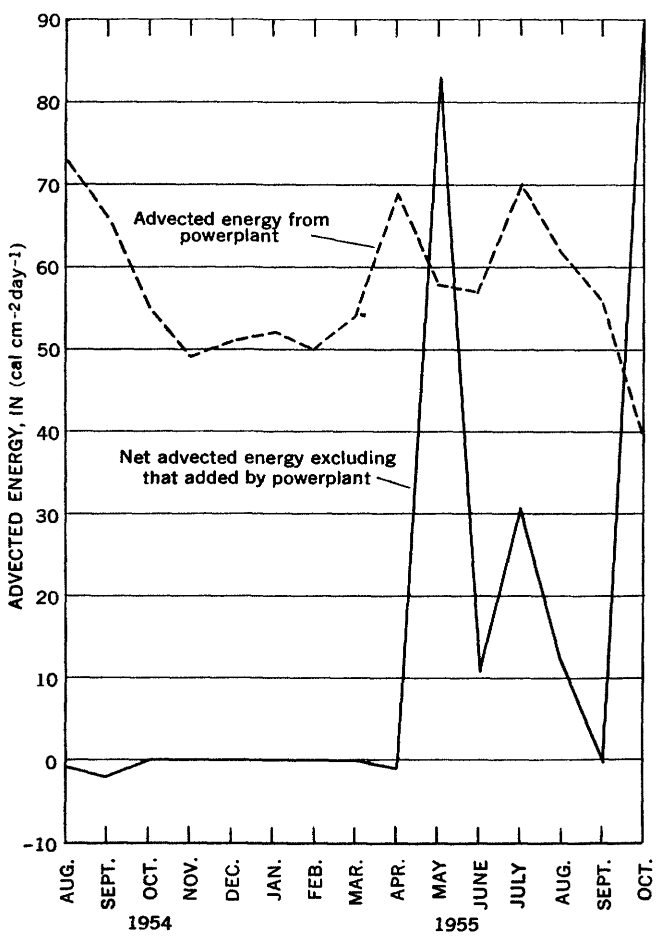


FIGURE 13.—Monthly advected energy into Lake Colorado City, using a base temperature of 0°C.

surface inflow and outflow and rainfall on the lake surface, and in the Lake Colorado City investigations it included the heat added to the lake by the powerplant. It does not include the energy contained in the evaporated water.

The various methods of determining inflow, outflow, change in storage, and rainfall are described in the instrumentation section. The flow diverted through the plant was taken from the Texas Electric Service Co. pump ratings. Occasional discharge measurements were made in the canal through which the water flows back into the lake (fig. 12). Based on these measurements, corrections were applied to the pump ratings, the maximum correction being a reduction of 7 percent in the pump rating. Actually, if no corrections had been applied the error in computed evaporation would have been less than 1 percent. The temperatures of these various items were computed in the following manner: temperatures of the inflow and the diversion to Colorado City were measured using a Stevens thermograph attachment to a water-stage recorder. Rainfall temperatures were assumed to equal the wet-bulb temperature at the time the rain was falling, on the basis of data obtained at Lake Hefner (Harbeck, 1954, p. 123). Temperature of the water diverted to the plant for cooling and the temperature of the return flow to the lake were taken from plant records. Periodic checks were made of these temperatures using the Whitney underwater thermometer. These checks agreed within 0.5°C.

Advected energy was computed on a daily basis. Density and specific heat were assumed constant for all computations. Figure 13 shows the advected energy for each month of the investigation.

ENERGY STORAGE

Energy storage (Q_ϑ) in Lake Colorado City was computed from temperature profiles of the lake taken approximately every 10 days at 26 stations located throughout the lake. The selection of these 26 stations was based on a survey made May 4, 1954, at 45 stations.

For each thermal survey the lake was divided into layers 3 feet thick. The temperatures in each layer were averaged to obtain the mean for the layer. The energy content in each layer was computed using the mean temperature and the volume. The sum of these values gave the total energy content above an arbitrary base temperature of 0°C. Density and specific heat were considered constant, as in the computation of advected energy. Figure 14 shows the energy storage by months.

SUMMARY OF MEASUREMENTS OF ENERGY-BUDGET TERMS

Table 2 was prepared to illustrate the relative magnitudes of the various items in the energy budget for Lake Colorado City and to show their seasonal variation. The sum $(Q_s - Q_r + Q_a - Q_{ar})$ was computed from the CRI data. Q_{bs}, the long-wave radiation emitted by the water surface, is an important term in the energy budget, and it is obvious that an accurate determination of average water-surface temperature for the entire lake is necessary. Except during infrequent periods of storm inflow, the magnitude of Q_v, the advected energy term is determined primarily by the amount of heat added by the powerplant. During the period July 21, 1954, to July 19, 1955, the amount of heat added by the powerplant averaged 59 cal cm^{-2} day^{-1}.

RESULT OF STUDIES

The figures of evaporation from Lake Colorado City using the energy-budget method are given in table 3. For the 363-day period, July 21, 1954, to July 19, 1955, evaporation was 92.78 inches, or 10,057 acre-feet—equivalent to 93.3 inches, or 10,100 acre-feet, for a full year.

TABLE 2.—*Average values, by periods, for each term in the energy budget for Lake Colorado City, in calories per square centimeter per day*

Period: From—	Period: To—	$Q_s-Q_r+Q_a-Q_{ar}$	Q_{bs}	Q_v	Q_e	Q_h	Q_w	Q_θ
July 21, 1954	July 30, 1954	1,448	944	82	617	−28	31	−34
July 30	Aug. 9	1,512	940	66	650	17	32	−61
Aug. 9	Aug. 19	1,478	937	74	674	−34	33	−58
Aug. 19	Sept. 1	1,336	930	74	494	−17	24	−21
Sept. 1	Sept. 13	1,330	928	72	546	−3	26	−95
Sept. 13	Sept. 23	1,267	912	58	511	−10	24	−112
Sept. 23	Oct. 4	1,213	886	57	388	−18	16	−2
Oct. 4	Oct. 15	1,179	883	57	474	24	20	−165
Oct. 15	Oct. 26	1,087	848	54	365	32	13	−117
Oct. 26	Nov. 5	948	804	57	384	101	11	−295
Nov. 5	Nov. 16	881	784	48	98	11	3	33
Nov. 16	Nov. 26	924	775	46	254	18	6	−83
Nov. 26	Dec. 6	917	761	50	259	−7	6	−52
Dec. 6	Dec. 21	843	739	51	248	25	5	−123
Dec. 21	Jan. 3, 1955	750	724	49	75	0	1	−1
Jan. 3, 1955	Jan. 13	736	719	53	85	27	2	−44
Jan. 13	Jan. 24	813	708	51	163	38	2	−47
Jan. 24	Feb. 4	831	708	53	82	−15	1	108
Feb. 4	Feb. 14	876	726	51	208	48	4	−59
Feb. 14	Mar. 1	931	726	50	166	2	3	84
Mar. 1	Mar. 11	1,084	760	55	303	−57	7	126
Mar. 11	Mar. 23	1,083	777	51	356	10	9	−18
Mar. 23	Apr. 4	1,142	757	55	429	25	9	−23
Apr. 4	Apr. 15	1,182	779	65	402	−34	10	90
Apr. 15	Apr. 25	1,241	814	68	436	−113	13	159
Apr. 25	May 5	1,328	843	74	475	−106	17	173
May 5	May 16	1,227	878	177	322	6	13	185
May 16	May 26	1,350	873	167	526	20	21	77
May 26	June 6	1,270	873	53	405	−22	16	51
June 6	June 17	1,375	885	68	554	−10	23	−9
June 17	June 27	1,476	907	76	568	−37	25	89
June 27	July 7	1,501	914	66	677	−52	31	−3
July 7	July 19	1,420	931	83	550	7	26	−11
July 19	July 29	1,386	929	118	481	7	23	64
July 29	Aug. 8	1,472	936	79	535	−3	26	57
Aug. 8	Aug. 19	1,350	937	56	512	9	25	−77
Aug. 19	Aug. 29	1,431	929	92	540	4	26	24
Aug. 29	Sept. 8	1,339	912	53	554	24	25	−123
Sept. 8	Sept. 19	1,293	906	57	454	−6	20	−24
Sept. 19	Sept. 29	1,213	901	57	365	7	16	−19
Sept. 29	Oct. 20	1,112	879	137	353	32	14	−29
Oct. 20	Oct. 31	1,092	830	41	453	41	15	−206
July 21, 1954	**July 19, 1955**	**1,142**	**827**	**66**	**379**	**−4**	**14**	**−8**

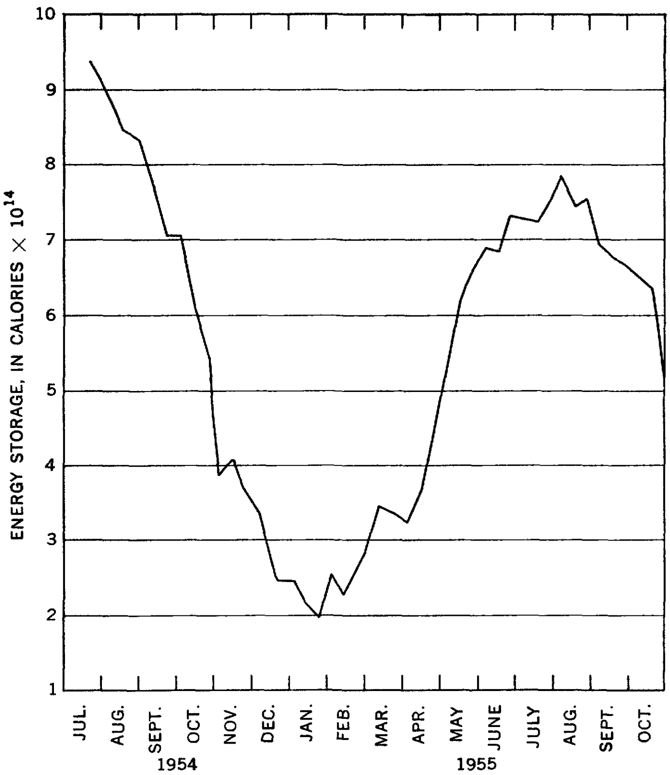


FIGURE 14.—Monthly energy storage in Lake Colorado City using a base temperature of 0°C.

TABLE 3.—*Evaporation from Lake Colorado City as computed for energy-budget periods, July 21, 1954, to October 31, 1955*

Period		Number of days in period	Evaporation	
From—	To—		Inches	Acre-feet
July 21, 1954	July 30, 1954	9	3.77	485
July 30	Aug. 9	10	4.41	551
Aug. 9	Aug. 19	10	4.57	556
Aug. 19	Sept. 1	13	4.34	515
Sept. 1	Sept. 13	12	4.45	515
Sept. 13	Sept. 23	10	3.46	392
Sept. 23	Oct. 4	11	2.89	321
Oct. 4	Oct. 15	11	3.51	383
Oct. 15	Oct. 26	11	2.70	291
Oct. 26	Nov. 5	10	2.59	277
Nov. 5	Nov. 16	11	.73	76
Nov. 16	Nov. 26	10	1.69	179
Nov. 26	Dec. 6	10	1.74	182
Dec. 6	Dec. 21	15	2.48	256
Dec. 21	Jan. 3, 1955	13	.65	67
Jan. 3, 1955	Jan. 13	10	.57	58
Jan. 13	Jan. 24	11	1.20	124
Jan. 24	Feb. 4	11	.59	60
Feb. 4	Feb. 14	10	1.39	141
Feb. 14	Mar. 1	15	1.66	168
Mar. 1	Mar. 11	10	2.01	201
Mar. 11	Mar. 23	12	2.86	284
Mar. 23	Apr. 4	12	3.44	338
Apr. 4	Apr. 15	11	2.98	288
Apr. 15	Apr. 25	10	2.93	280
Apr. 25	May 5	10	3.20	302
May 5	May 16	11	2.41	236
May 16	May 26	10	3.60	377
May 26	June 6	11	2.99	330
June 6	June 17	11	4.06	442
June 17	June 27	10	3.84	419
June 27	July 7	10	4.59	492
July 7	July 19	12	4.48	471
July 19	July 29	10	3.23	340
July 29	Aug. 8	10	3.69	397
Aug. 8	Aug. 19	11	3.80	403
Aug. 19	Aug. 29	10	3.66	389
Aug. 29	Sept. 8	10	3.74	392
Sept. 8	Sept. 19	11	3.37	349
Sept. 19	Sept. 29	10	2.48	255
Sept. 29	Oct. 20	21	5.00	584
Oct. 20	Oct. 31	11	3.35	393
July 21, 1954	July 19, 1955	363	92.78	10,057
July 21, 1954	Oct. 31, 1955	467	125.10	13,559

WATER-BUDGET STUDIES

The inflow to Lake Colorado City during the 363-day period July 21, 1954, to July 19, 1955, was 6,422 acre-feet. The only outflow was the diversion to Colorado City for municipal purposes, which totalled 891 acre-feet. Using observed stages on July 21, 1954, and July 19, 1955, and the area table, the decrease in storage was 4,632 acre-feet, using the prismatoid formula. From these figures, water-budget evaporation was 6,422−891+4,632, or 10,163 acre-feet, compared with 10,057 acre-feet determined using the energy-budget method. Such close agreement is doubtless partly coincidental, for an error of only a few percent in measuring some of the water-budget or energy-budget quantities would make a much larger difference than was here indicated. For example, during the entire 16-month period, the energy-budget evaporation was 13,559 acre-feet as compared with water-budget evaporation of 15,061 acre-feet, a difference of approximately 10 percent.

The computations of advected energy as originally made were based to a large extent upon records for the gaging station Morgan Creek near Westbrook, Tex. Figures of energy-budget and water-budget evaporation during periods of storm inflow were not in good agreement for the period September 29 to October 20, 1955. During this period, runoff into the lake was extremely heavy; approximately 40 percent of the total inflow into Lake Colorado City in the 16-month period occurred during these 21 days. The difference between energy-budget and water-budget evaporation for this one period prompted a study of all major storm periods, which indicated that a substantial part of the inflow measured at the Morgan Creek gaging station did not reach the reservoir. Inflow to the reservoir was computed from change in contents of the reservoir during the storm period, diversions to Colorado City, and estimated evaporation losses. These last were computed using the mass-transfer formula, to be described in a subsequent chapter. Although the daily figures thus computed are admittedly subject to error, an error of even 100 percent would not affect the general conclusion. The results of the computations are given in table 4.

Table 4 indicates that there was a substantial reduction in flow between the gaging stations and the reservoir. Morgan Creek accounted for approximately 90 percent of the total volume of inflow during the periods studied, and this gaging station record was therefore scrutinized carefully to detect any possible errors. The stage-discharge relation for the gaging station on Morgan Creek is illustrated in figure 15. The peak stage attained during the rise of October 2,

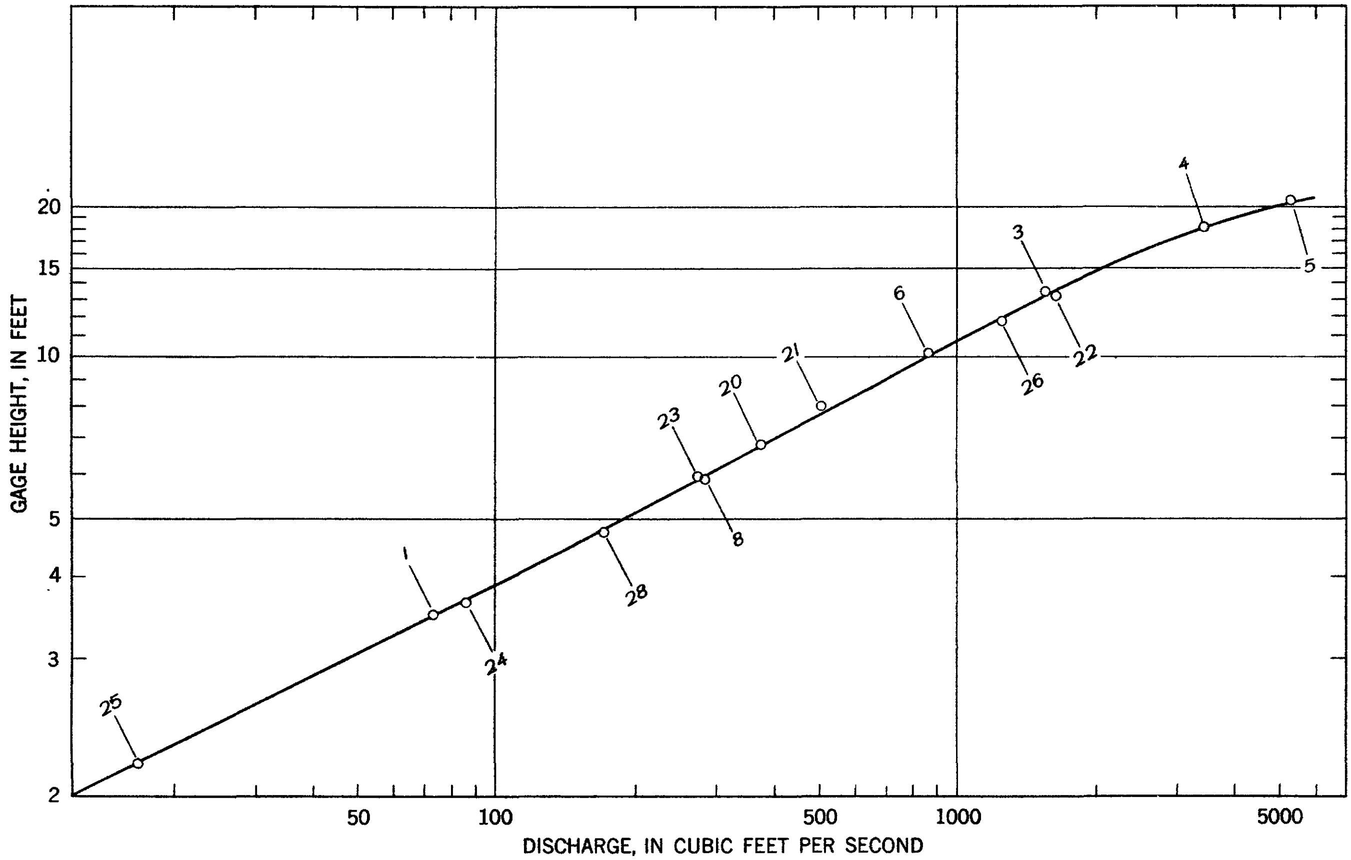


FIGURE 15.—Stage-discharge relation for Morgan Creek near Westbrook, Tex.

1955, was 16.25 feet, well below the stages at which discharge measurements were obtained during the rise of May 11, 1954, shortly before the gaging station was established. The fact that the stage-discharge relation is so well defined by current meter measurements at high stages indicates that the reduction in flow between the gaging station and the reservoir is real and not the result of inaccurate stream gaging.

TABLE 4.—*Comparison between computed and measured inflow to Lake Colorado City during major storm periods*

Period	Diversion to Colorado City (acre-ft)	Evaporation (acre-ft)	Gain in storage (acre-ft)	Computed inflow [1] (acre-ft)	Measured inflow [2] (acre-ft)
1955					
May 11–13	7	78	2,011	2,096	2,251
May 23–26	10	196	1,996	2,202	2,534
July 28–30	11	87	818	916	1,303
Aug. 21–24	13	125	369	507	729
Oct. 1–7	4	227	3,918	4,149	5,579

[1] Sum of three preceding columns.
[2] Sum of flow of Morgan Creek near Westbrook, Tex., flow of Graze Creek near Westbrook, Tex., rainfall on the reservoir surface, and a very small estimated volume of unmeasured inflow.

Another analysis was made using obsolete area and capacity curves to determine whether the discrepancy might result from errors in the stage-area relation. The differences between measured and computed inflow were slightly less than those illustrated in table 4, but not enough less to indicate that errors in the area and capacity curves could be responsible for the differences between measured and computed inflow.

The possibility was considered that bank storage in Lake Colorado City might account for the discrepancy. If this were true, the water thus stored would be released during periods of zero inflow, when lake levels were falling as a result of evaporation and diversion to Colorado City. However, during these periods the agreement between water-budget and energy-budget evaporation was usually excellent, indicating that substantial unaccounted-for volumes of water were not reaching the reservoir, as would result if there were a return of bank storage. Two other periods prior to the time of the present study were also investigated. During both of these periods inflow was high, but of short duration, and the lake stage rose 7 feet or more in 1 day during each period. It did not appear likely that the entire bank storage capacity, if any, could be utilized in 1 day; it was believed that water would continue to enter into bank storage for at least a few days after the rise. This would result in a greater fall in reservoir stage than could be reasonably accounted for by evaporation and diversion. Such was not the case, however; the recession appeared to be normal after each rise. Since the studies indicated that appreciable volumes of water were neither being released from bank storage during periods of falling reservoir stages nor were being taken into bank storage immediately after sharp rises, it was concluded that bank storage in Lake Colorado City is negligible.

A reconnaissance was made of the Morgan Creek channel between the gaging station and the reservoir to determine whether geologic and hydrologic conditions are such as to provide an explanation of the channel losses. Above the mouth of Graze Creek, the average depth of the Morgan Creek channel is approximately 20 feet and its width is approximately 75 feet. Below this point the channel is somewhat wider, reaching perhaps 150 feet in a few places, and the banks are lower, the average depth being approximately 15 feet or less.

No evidence of any highly permeable beds was observed. Many outcrops of the Dockum group of Triassic age occur in the area, including the stream channel. The Dockum group along the eastern edge of the Llano Estacado to the south, in Borden, Scurry, Howard, and Mitchell Counties as described byHoots (1926) "has a total thickness of 300 to 450 feet and consists largely of dark-red clay with interbedded layers of gray cross-bedded sandstone and coarse sandstone conglomerate. The sandstone is invariably micaceous * * * The lower part of the Dockum group near Colorado City, in Mitchell County, though predominantly red clay, contains numerous beds of massive gray cross-bedded sandstone."

The outcrops seen in the Morgan Creek channel were substantially as described by Hoots. At one place well above the channel, but still within the flood plain of Morgan Creek, some poorly cemented sandstone was exposed; it was about 15 feet thick and the outcrop was not of great areal extent.

The geologic reconnaissance did not provide an explanation of the loss of water in the Morgan Creek channel. The alluvium in the stream channel appears to be quite permeable, and it is probable that during flood periods some of the water, apparently lost, enters the alluvium, to be returned later to the channel where it evaporates. Many such pools were observed during the reconnaissance on April 16, 1956, even though there had been no rain since April 5 when 0.66 inch was measured at San Angelo and 0.50 inch at Abilene. It does not seem reasonable that the entire loss could be accounted for in this manner, however. The Dockum group dips to the west, and any water entering the formation must drain away from Lake Colorado City. The same conclusion was reached on the basis of hydrologic studies of reservoir levels.

Since it appears that during periods of storm runoff there is a substantial loss of water in Morgan Creek between the gaging station and Lake Colorado City, inflow to the reservoir during the brief storm periods was computed from records of change in contents of the reservoir. Allowances were made for diversion to Colorado City and for evaporation. The latter was computed, but it was so small in comparison with inflow that even a 100 percent error in estimating it would have caused no significant change in the computed volume of inflow, which was used only in the computation of advected energy.

With storm period inflow computed as described, the agreement between energy-budget and water-budget evaporation is considered excellent on an annual basis. For the individual periods, the agreement is not nearly so good, but the differences tend to compensate over longer periods and show no correlation with season. For short periods of time, errors in water-budget evaporation may be caused by errors in measuring mean lake stage. Only one water-stage recorder was used, and substantial errors may result from the fact that the reservoir surface is not level at times of high winds or high inflow. For example, if the stage is in error by 0.02 foot, the error in computing change in reservoir storage is approximately 25 acre-feet, an amount significant on a daily or even a weekly basis but not for longer periods. Errors from this source are not cumulative.

The close agreement between energy-budget and water-budget figures is corroborative evidence of the validity of the energy-budget method for the determination of evaporation from reservoirs. Results previously obtained at Lake Hefner and at Lake Mead showed this to be true, and the Lake Colorado City study confirmed the previous findings.

MASS-TRANSFER STUDIES

Data obtained at Lake Colorado City for the determination of evaporation using the mass-transfer method are: wind speed, wet- and dry-bulb temperatures, and water-surface temperature. No effort was made to place the anemometer and wet- and dry-bulb thermocouples at any standard height (such as 8 meters) above the water surface. For convenience these instruments were placed atop the superstructure for the travelling crane over the intake canal, plate 1*A*, approximately 40 feet above the water surface, the exact distance depending on reservoir stage. Moreover the instruments were on shore, not on a barge in midlake.

It was anticipated that an empirical coefficient, valid only for this particular installation at Lake

Colorado City, could be obtained for use in a simplified form of mass-transfer equation, as follows:

$$E=N\,n\,u\,(e_o-e_a) \qquad (4)$$

in which E=total evaporation in depth units for period of n days
u=wind speed
N=an empirical coefficient
e_o=saturation vapor pressure correpending to the temperature of the water surface
e_a=vapor pressure of the air

In mass-transfer theory some equations have been derived to give evaporation at a particular point. Others have been proposed for the purpose of computing evaporation from the entire lake surface, thus taking into account the downwind decrease in evaporation. Practically all of the mass-transfer equations are of the same general type as equation 4. The coefficient N may be replaced by a complicated mathematical expression involving gamma functions or Pearson's function, and the wind term may have an exponent different from unity, but the general form of equation is the same.

For Lake Hefner a quasi-empirical equation of the same type as equation 4 was found to give good results (Marciano and Harbeck, 1954, eq. 58, p. 65). The effect of atmospheric stability was found to be insignificant, at least for figures of daily evaporation. At Lake Mead the value of N derived from the Lake Hefner data was found to give good results on an annual basis. For shorter periods of time the effect of atmospheric stability was clearly evident. An empirical stability adjustment parameter, roughly proportional to the Richardson number (Marciano and Harbeck, 1954, p. 52), was therefore used. The possible effect of atmospheric stability at Lake Colorado City could not be estimated in advance. It was anticipated that other seasonal effects might be noticeable. For example, both wind speed and vapor pressure might show a seasonal variation if there were a marked seasonal trend in wind direction, so that at certain seasons offshore and onshore winds might prevail. This would not present a problem if the instruments were mounted on a raft in midlake, but might with a shore installation as at Lake Colorado City.

ANALYSIS OF THE DATA

The relation between energy-budget evaporation and the product $n\,u\,(e_o-e_a)$ is shown in figure 16. The energy-budget evaporation is for periods between thermal surveys, which averaged about 10 days in length. The wind speed, u, is the average daily wind speed in miles per hour; n is the number of days. The vapor pressure difference (e_o-e_a) is based on the average daily values of e_o and e_a during the period. All

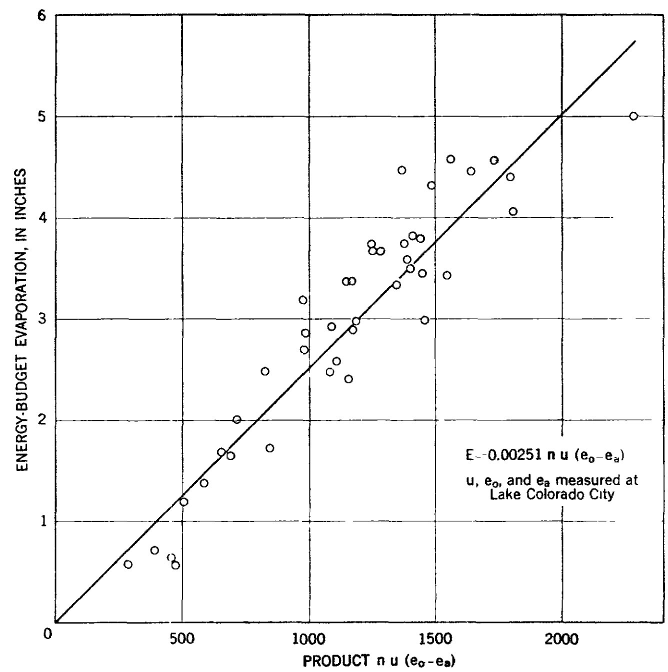


FIGURE 16.—Relation between energy-budget evaporation and the product $n\,u\,(e_o-e_a)$ using data obtained at Lake Colorado City, Tex.

the data were obtained at Lake Colorado City. The correlation between energy-budget evaporation and the product $n\,u\,(e_o-e_a)$ is fairly good. The value of N to be used in equation 4 was found to be 0.00251, obtained by dividing energy-budget evaporation for the period July 21, 1954 to July 19, 1955, (363 days) by $\Sigma n\,u\,(e_o-e_a)$ for the same periods. The resulting equation is

$$E=0.00251\,n\,u\,(e_o-e_a) \qquad (5)$$

in which E is in inches for the period of n days and u and (e_o-e_a) are computed as described above.

The data were smoothed by grouping 10-day energy-budget periods in threes. Using equation 5, evaporation was computed for each group of 3 periods and compared with the energy-budget evaporation for the same group of periods. The residuals, or differences between the two figures, exhibit a rather poorly defined seasonal variation. Energy-budget evaporation is less than mass-transfer evaporation for the period October 26, 1954, to February 4, 1955. The reverse is true for the periods July 21, 1954, to October 26, 1954, and June 17, 1955, to September 19, 1955. The differences cannot be accounted for by the effects of atmospheric stability. In winter, water temperature is generally higher than air temperature. Because the lapse rate is unstable, evaporation should be greater than that given by equation 5, which is theoretically correct only for neutral stability. Thus the differences cannot be attributed to the effects of stability. It was previously suggested that a seasonal variation in wind direction might cause a seasonal variation in vapor pressure. Examination of the records at the Weather Bureau stations at San Angelo and Abilene shows no such variation, although prevailing winds at those stations are consistently from different directions.

Figure 16 indicates that the relation between energy-budget evaporation and the product $n\ u\ (e_o-e_a)$ may be closely approximated by a straight line, but that the line does not necessarily go through the origin. A computed least-squares line does have a small negative intercept (only 0.10 inch) on the evaporation axis, but the intercept is so small that it was disregarded, and evaporation is considered to be directly proportional to the product $n\ u\ (e_o-e_a)$. A possible explanation of the intercept will be given later.

The use of equation 5 for computing evaporation from Lake Colorado City on a continuing basis would require that all of the mass-transfer instruments be operated indefinitely. In order to determine whether satisfactory results might be obtained using data already being obtained, analyses were made substituting data normally collected in connection with routine plant operations and at nearby Weather Bureau stations.

In the first of these, the intake water temperature at the plant was used to determine e_o. The vapor pressure of the air, e_a, was obtained from Weather Bureau records at Big Spring, Tex. The wind speed, u, was taken from the anemometer record at Lake Colorado City. The resulting equation was

$$E=0.00260\ n\ u\ (e_o-e_a) \qquad (6)$$

Another analysis was made using both wind speed and vapor pressure of the air measured at the Weather Bureau station at San Angelo, Tex. Other data were the same as in equation 6. The new equation is

$$E=0.00201\ n\ u\ (e_o-e_a) \qquad (7)$$

The relation between energy-budget evaporation and the products $n\ u\ (e_o-e_a)$ as computed from the data described above is shown in figures 17 and 18.

All three figures, 16, 17, and 18, indicated a negative intercept on the evaporation axis. This is partly owing to the computational methods used. In figure 16, the wind speed, u, is the average wind speed for the period. The saturation vapor pressure, e_o, is that corresponding to the average water surface temperature for the period. The vapor pressure, e_a, is the average vapor pressure for the period. The product, therefore, is the product of average values. A similar least squares computation was made using the average of the daily values of each product instead of the product of the average values for a period of a year. The intercept was found to be -0.03 inch. Although the intercept was negligible using the least squares technique, the conclusion is misleading, as a result of minimizing the deviations in the vertical direction. The data used for the independent variable in figures 16, 17, and 18 are not the

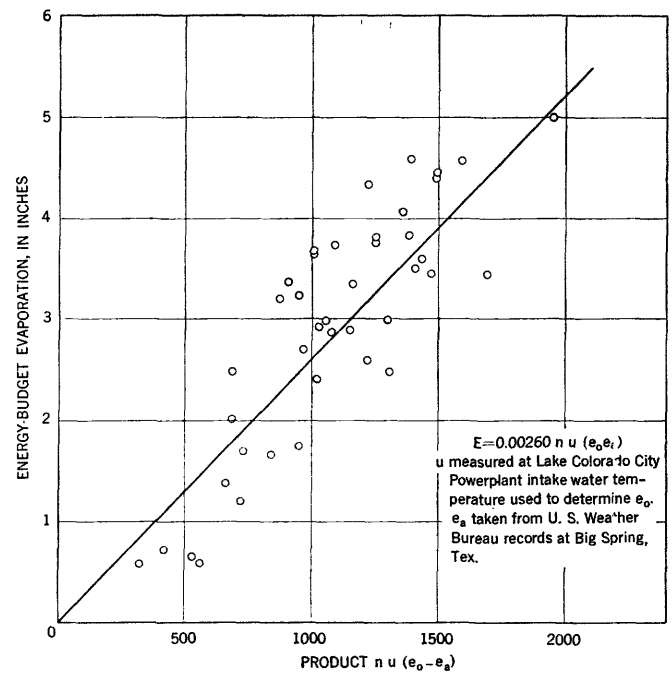


FIGURE 17.—Relation between energy-budget evaporation and the product $n\ u\ (e_o-e_a)$ using data obtained at Lake Colorado City and Big Spring, Tex.

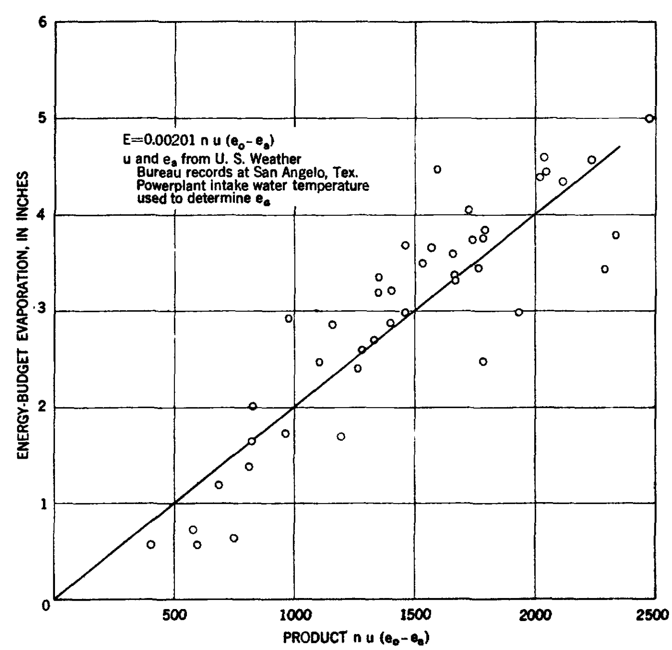


FIGURE 18.—Relation between energy-budget evaporation and the product $n\ u\ (e_o-e_a)$ using data obtained at Lake Colorado City and San Angelo, Tex.

same, and a negative intercept is indicated in each case. It must be concluded that the negative intercept results from errors in the energy-budget evaporation. A negative intercept, if real, would indicate that substantial volumes of seepage were entering the lake, even during prolonged dry periods. Because of the excellent agreement between energy-budget and water-budget evaporation during dry periods, this hypothesis must be disregarded.

The comprehensive tests of the CRI made at Lake Mead (Koberg, 1958) indicate that although on the average the CRI measured net radiation received by the lake very accurately, there is a slight seasonal bias. Net radiation as measured by the CRI is slightly less than that measured by conventional radiation instruments in winter and slightly greater in summer. The maximum deviation was approximately 5 percent. Studies are underway to eliminate the seasonal bias, if possible. It is believed to result, at least in part, from the variation with sun angle in the effect of the overhanging rim. Although the error from this source is small, it could account for computed figures of energy budget evaporation being slightly smaller in winter and larger in summer than computed figures of mass-transfer evaporation.

The seasonal bias in net radiation measured by the CRI, is too poorly defined to permit any corrections on the basis of the Lake Mead studies. It was therefore concluded that the negative intercept indicated by figures 16, 17, and 18 is not real but probably results from small errors in measuring net radiation. The applicable value of the coefficient to be used in equations 5, 6, and 7 was therefore determined from annual mean values of energy-budget evaporation and the product $n\ u\ (e_o - e_a)$.

RESULT OF COMPUTATIONS

Evaporation was computed using equations 5, 6, and 7 for energy-budget periods of approximately 10 days each. The results are shown in table 5; figures of energy-budget evaporation are also given for comparative purposes. The seasonal bias is evident, for energy-budget evaporation is consistently less than mass-transfer evaporation during winter, and vice versa in summer. Despite the bias, the average difference without regard to sign is only 11 percent for equation 5, 18 percent for equation 6, and 15 percent for equation 7. Because the difference is believed to result in part from a slight seasonal error in measuring net radiation, the error is believed to be less than that given above. The percentage errors given are for periods of approximately 10 days; the comparable error for a period of a month is approximately 8 percent for equation 5 and slightly more for the other 2 equations.

There appears to be little difference in the accuracy of the results obtained using the various mass-transfer equations. For figures of monthly evaporation, the average error without regard to sign (assuming the energy-budget figures to be correct) can be taken to be approximately 10 percent for all 3 equations. Using equation 6 or 7 would eliminate the need for any psychrometric observations at Lake Colorado City. Equation 6 requires wind measurements at the reservoir, but operation of a totalizing anemometer presents no problem. Although equations 6 and 7 do not provide 2 completely independent estimates because some of the same data are used in each, they do use different wind and humidity data, and an average of the results obtained with the 2 equations might well be considered the best estimate of evaporation obtainable with a minimum of instruments, observations, and computations.

TABLE 5.—*Comparison between energy-budget evaporation and mass-transfer evaporation computed from three empirical formulas*

Period		Energy-budget evaporation (inches)	Mass-transfer evaporation (inches)		
From—	To—		eq 5	eq 6	eq 7
July 21, 1954	July 30, 1954	3.77	3.46	3.26	3.59
July 30	Aug. 9	4.41	4.52	3.88	4.06
Aug. 9	Aug. 19	4.57	4.35	4.13	4.49
Aug. 19	Sept. 1	4.34	3.73	3.17	4.24
Sept. 1	Sept. 13	4.45	4.11	3.87	4.10
Sept. 13	Sept. 23	3.46	3.64	3.84	3.54
Sept. 23	Oct. 4	2.89	2.95	2.98	2.82
Oct. 4	Oct. 15	3.51	3.51	3.67	3.07
Oct. 15	Oct. 26	2.70	2.47	2.52	2.67
Oct. 26	Nov. 5	2.59	2.78	3.16	2.57
Nov. 5	Nov. 16	.73	1.00	1.08	1.16
Nov. 16	Nov. 26	1.69	1.65	1.89	2.39
Nov. 26	Dec. 6	1.74	2.11	2.46	1.93
Dec. 6	Dec. 21	2.48	2.72	3.39	3.57
Dec. 21	Jan. 3, 1955	.65	1.15	1.37	1.51
Jan. 3, 1955	Jan. 13	.57	.71	.83	.81
Jan. 13	Jan. 24	1.20	1.26	1.87	1.38
Jan. 24	Feb. 4	.59	1.20	1.45	1.20
Feb. 4	Feb. 14	1.39	1.46	1.71	1.62
Feb. 14	Mar. 1	1.66	1.72	2.18	1.65
Mar. 1	Mar. 11	2.01	1.79	1.78	1.66
Mar. 11	Mar. 23	2.86	2.49	2.80	2.32
Mar. 23	Apr. 4	3.44	3.89	4.40	4.60
Apr. 4	Apr. 15	2.98	2.98	2.72	2.94
Apr. 15	Apr. 25	2.93	2.74	2.69	1.96
Apr. 25	May 5	3.20	2.45	2.28	2.72
May 5	May 16	2.41	2.91	2.65	2.53
May 16	May 26	3.60	3.75	3.73	3.33
May 26	June 6	2.99	3.66	3.39	3.88
June 6	June 17	4.06	4.53	3.53	3.46
June 17	June 27	3.84	3.54	3.59	3.59
June 27	July 7	4.59	3.92	3.61	4.07
July 7	July 19	4.48	3.44	2.87	3.19
July 19	July 29	3.23	2.93	2.47	2.81
July 29	Aug. 8	3.69	3.15	2.63	2.94
Aug. 8	Aug. 19	3.80	3.61	3.25	4.69
Aug. 19	Aug. 29	3.66	3.21	2.62	3.15
Aug. 29	Sept. 8	3.74	3.13	2.83	3.49
Sept. 8	Sept. 19	3.37	2.89	2.37	3.33
Sept. 19	Sept. 29	2.48	2.09	1.78	2.21
Sept. 29	Oct. 20	5.00	5.73	5.07	6.17
Oct. 20	Oct. 31	3.35	3.38	3.02	2.72
July 21, 1954	July 19, 1955	92.78	92.59	92.75	92.62
July 21	Oct. 31	125.10	122.71	118.79	124.13

EFFECT ON EVAPORATION OF ADDING HEAT TO THE RESERVOIR

It is common practice to withdraw water from a reservoir or stream, use it for cooling in a steam powerplant, and return the heated water to the reservoir or stream. In the humid regions of the United States, the actual consumptive use of water is of little consequence. In the arid or semiarid regions of the West, however, the resulting increase in evaporation from the stream or reservoir must be considered. Moreover in these Western regions, the variability of streamflow is considerably greater than in the relatively well-watered

East, so that natural streamflow cannot always be relied upon to provide adequate amounts of water during dry periods.

Water storage must therefore be provided, and frequently it has been found possible to locate a steam plant on the shore of an existing reservoir or natural lake. Occasionally it is necessary to construct a dam and reservoir solely for the purpose of providing a dependable source of cooling water.

The effect of adding heat to a lake or reservoir has been studied by many investigators, including Lima (1936), Throne (1951), and Harbeck (1953). Until the Lake Hefner studies (U. S. Geological Survey, 1954) continuous measurements of atmospheric radiation had not been made, and it was impossible previous to that time to evaluate properly all the terms in the energy-budget equation, thus preventing a direct computation of the effect of the addition of heat.

Based on the Lake Hefner studies, Harbeck (1953) presented a general method for the determination of the effect on evaporation resulting from adding heat to a reservoir. The theory was derived by combining the energy-budget equation and a simplified mass-transfer equation.

BASIC THEORY

The energy budget for a reservoir is given in equation 1, page 15. For a reservoir to which heat is being added by a steam powerplant, it is convenient to consider that Q_v, the energy advected into the reservoir, is composed of three parts, namely: Q_c, the heat added by the powerplant, Q_{vi}, the energy added by volumes of water entering the lake as inflow, and Q_{vo}, the energy removed by volumes of water leaving the lake as outflow. Equation 1 then becomes

$$Q_s - Q_r + Q_a - Q_{ar} - Q_{bs} - Q_e - Q_h - Q_w + Q_{vi} - Q_{vo} + Q_c = Q_\vartheta \quad (8)$$

The addition of heat to a lake will not affect the first four terms, $(Q_s - Q_r + Q_a - Q_{ar})$ as their sum is the net supply of energy received as solar and atmospheric radiation. Nor will it affect Q_{vi}. The amount of water actually consumed in the plant is usually negligible, but could easily be taken into account in the computation of Q_c, which is the additional energy contained in the water returned to the lake over that contained in the water diverted from the lake. It is assumed that after equilibrium has been reached, over a long period of time, the increase in energy storage, Q_ϑ, is negligible. If the amount of heat added by the plant is suddenly increased, some of the additional heat would be utilized in increasing the amount of energy stored in the lake, and its full effect on evaporation would not be realized until equilibrium is reached. Conversely, if the amount of heat being added were suddenly decreased, stored energy would be released, and evaporation would continue at an accelerated rate until a new equilibrium temperature is reached.

Thus from equation 8 it follows that when heat is added to a lake

$$(Q'_{bs} - Q_{bs}) + (Q'_e - Q_e) + (Q'_h - Q_h) + (Q'_w - Q_w) + (Q'_{vo} - Q_{vo}) = Q_c \quad (9)$$

in which the unprimed symbols refer to the lake in its natural condition and the primed symbols to the lake after heat has been added.

At Lake Colorado City the term $(Q'_{vo} - Q_{vo})$ was negligible. The only outflow from the lake was that diverted to Colorado City for municipal purposes. The amount of energy removed was extremely small compared with other items in the energy budget, and the difference, $(Q'_{vo} - Q_{vo})$ resulting from the fact that the temperature of water diverted to Colorado City was increased slightly by the addition of heat from the plant was of no consequence.

For computational purposes the equation may be rewritten in a more simple form as

$$\Delta Q_{bs} + \Delta Q_e + \Delta Q_h + \Delta Q_w = Q_c \quad (10)$$

in which Δ indicates the increment from the unprimed to the primed figures.

COMPUTATION METHODS

The various terms in equation 10 can be computed as follows (units: calories per square centimeter per day)

$$\Delta Q_{bs} = 0.970\sigma[(T_o' + 273)^4 - (T_o + 273)^4] \quad (11)$$

in which σ = Stefan-Boltzman constant for black-body radiation [$= 1.171 \times 10^{-7}$ calories per square centimeter per (degree)^4 per day].

$$\Delta Q_e = \rho E'L' - \rho EL \quad (12)$$

in which ρ = average density of evaporated water ($\doteq 1$ gram per cubic centimeter)

E = average daily evaporation in grams per square centimeter per day ($\doteq$ centimeters per day)

and L = latent heat of vaporization in calories per gram at $T_o (= 595.9 - 0.545 T_o$, very closely).

$$\Delta Q_h = R'Q'_e - RQ_e = R'\rho E'L' - R\rho EL \quad (13)$$

in which R = the Bowen ratio $= \frac{Q_h}{Q_e} = \frac{0.61P(T_o - T_a)}{1{,}000(e_o - e_a)}$ (14)

and P = atmospheric pressure in millibars

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$$\Delta Q_w = c\rho(E'T_o' - ET_o) \qquad (15)$$

in which c=specific heat of water ($\doteq$1 calorie per gram per degree).

But from mass-transfer theory, assuming no change in wind speed and that the possible effect of changes in atmospheric stability resulting from an increase in water temperatures is negligible

$$\frac{E'}{E} = \frac{e_o' - e_a}{e_o - e_a} \qquad (16)$$

e_o=saturation vapor pressure at T_o in *mb*

e_a=vapor pressure of the air in mb, determined from T_a and T_w.

Equations 10 and 16 make it possible to compute natural evaporation from Lake Colorado City, or the evaporation that would have occurred if no heat had been added by the powerplant. They also can be used to compute the evaporation that would occur if the amount of heat added by the powerplant is substantially increased. The effect of varying reservoir water content can also be investigated.

Because the variation of the terms in equation 10 with water-surface temperature is not linear, a direct solution combining the two equations is not practicable. A successive approximation technique is employed, as follows:

Suppose that it is desired to compute what would have been the natural evaporation, E, from Lake Colorado City had no heat been added by the powerplant (Q_c=0). The following data are available:

- Q_c, the amount of heat added by the powerplant
- E', computed evaporation, using equation 8, with a known amount of heat (Q_c) being added by the plant
- T'_o, the observed water surface temperature
- T_a, the observed air temperature
- e_a, the observed vapor pressure of the air
- P, the standard barometric pressure corresponding to the altitude of Lake Colorado City

It can be reasoned that without the addition of heat, Q_c, the water surface temperature (T_o), would be lower than that observed (T'_o). As a first approximation, an estimated value of T_o is used to determine e_o from saturation vapor pressure tables, and E is computed from equation 16. Using these values of E and T_o in equations 11, 12, 13, and 15, the various terms in equation 10 can be computed, and their sum should be equal to Q_c. If not, other values of T_o must be assumed and the computations repeated until a check is obtained.

RESULT OF STUDIES

The relative magnitudes of the values of ΔQ_e, ΔQ_h, ΔQ_w, and ΔQ_{bs} indicate the efficiency of the various physical processes in disposing of heat. Computations were made as described above for the period July 21, 1954, to July 19, 1955. During this period the powerplant added 59 cal cm^{-2} day^{-1} (equivalent to 1.3 billion kilowatthours per year of heat added to the lake). For this period ΔQ_e=34, ΔQ_h=15, ΔQ_w=2, and ΔQ_{bs}=8 (all in cal cm^{-2} day^{-1}). Of the total energy added to the lake by the powerplant, 58 percent was utilized to increase evaporation, 25 percent was conducted to the air above the reservoir, 3 percent was carried away by the evaporated water, and 14 percent was radiated to the atmosphere.

The results of the energy-budget studies showed that for the same 363-day period, evaporation from the lake was 92.78 inches, equivalent to 93.3 inches for a full year. Expressed in units of volume, the annual loss was 10,100 acre-feet. Average content of the reservoir was 22,300 acre-feet, so that the evaporation loss was 45 percent of the water remaining in the reservoir after evaporation demands were satisfied. The computations described on page 26 yielded the result that E'/E=1.099 or that the evaporation loss directly attributable to addition of heat by the powerplant (E'–E) was 910 acre-feet. Natural evaporation expressed in depth units, as is customary, was 85.0 inches, or slightly more than 7 feet.

Average water-surface temperature during the 363-day period studied was 18.8°C (65.8°F). The computations show that if no heat had been added by the powerplant, average water-surface temperature would have been 18.0°C (64.4°F). The addition of heat by the powerplant thus had little effect on the water-surface temperature. The effect on the thermal structure of the lake will be discussed in the chapter that follows.

EFFECT OF INCREASING THE AMOUNT OF HEAT ADDED

The preceding analysis outlined the method used to determine the water-surface temperature and evaporation loss that would have been observed if no heat had been added by the powerplant. During the 363-day period selected for study, heat was added by the powerplant at a rate of approximately 1.3 billion kilowatthours (kwhr) per year. Similar computations were made for rates of 1.5, 2, and 3 billion kwhr per year to determine the resulting water-surface temperatures and the increase in evaporation from the lake. The reservoir content was variously assumed to be 25, 50, 75, and 100 percent of capacity. The greatest increase in water-surface temperature and the highest percentage increase in evaporation obviously would occur when large quantities of heat are added to a nearly empty reservoir.

The results are illustrated in figure 19. It has previously been determined that the average water surface temperature would have been 18.0°C if no heat had been added to the reservoir. If the reservoir had been full during the entire year, the average water surface temperature would have been 18.5°C; if it had been 25 percent full, the temperature would have been 19.4°C. The observed temperature was 18.8°C. If 3 billion kwhr were added during a year, which is more than twice the energy added to the lake during 1954–55, the average water surface temperature would be 21.2°C

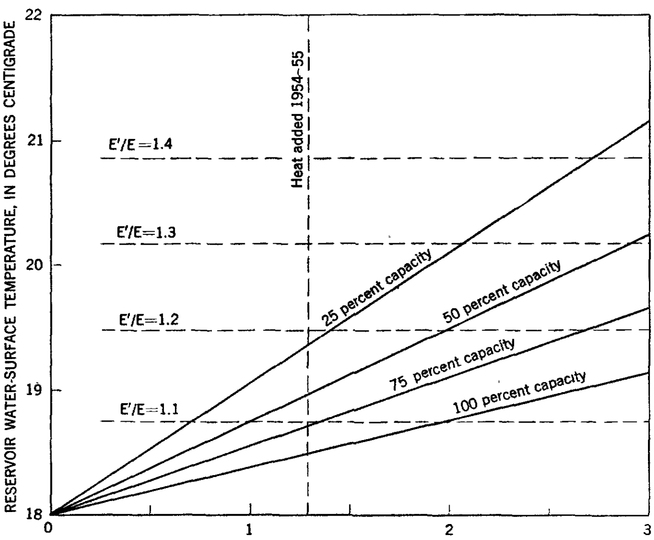

FIGURE 19.—Relation between amount of heat added to Lake Colorado City and water surface temperature for various reservoir contents. Computations are based on meteorological limnological data obtained 1954-55.

if the reservoir were 25 percent full and 19.2°C if full.

The relation between the amount of heat added and the temperature rise, as shown in figure 19, is not exactly linear, although it may appear to be, over the limited range shown. The error in straight-line extrapolation to a value of 6 billion kwhr per year would be less than 0.1°C if the reservoir were full.

The preceding computations were based on the assumption that incoming radiation, air temperature and humidity, and water-surface temperature during 1954–55 were reasonably representative of average conditions at Lake Colorado City.

Similar computations were made for 2 selected shorter periods, 1 in summer and 1 in winter, to investigate seasonal effects on the expected temperature rises and increase in evaporation for various amounts of heat added to the reservoir. The summer period, June 27 to September 8, 1955, was 73 days in length, and the winter period, December 21, 1954, to March 1, 1955, was 70 days in length. During the summer period reservoir contents averaged 71 percent of capacity, and during the winter period 68 percent.

Figure 20 indicates that the temperature rise resulting from any given quantity of heat added by the powerplant is approximately twice as great in winter as in summer. The percent increase in evaporation is 3 times as great in winter as in summer, but natural summer evaporation was 4.5 times as much as in winter, so that the actual increase in evaporation, expressed in volumes of water, is greater in summer than in winter. The fact that the temperature rise is greater in winter than in summer is of little practical consequence because even the increased water temperatures in winter are much lower than summer water temperatures.

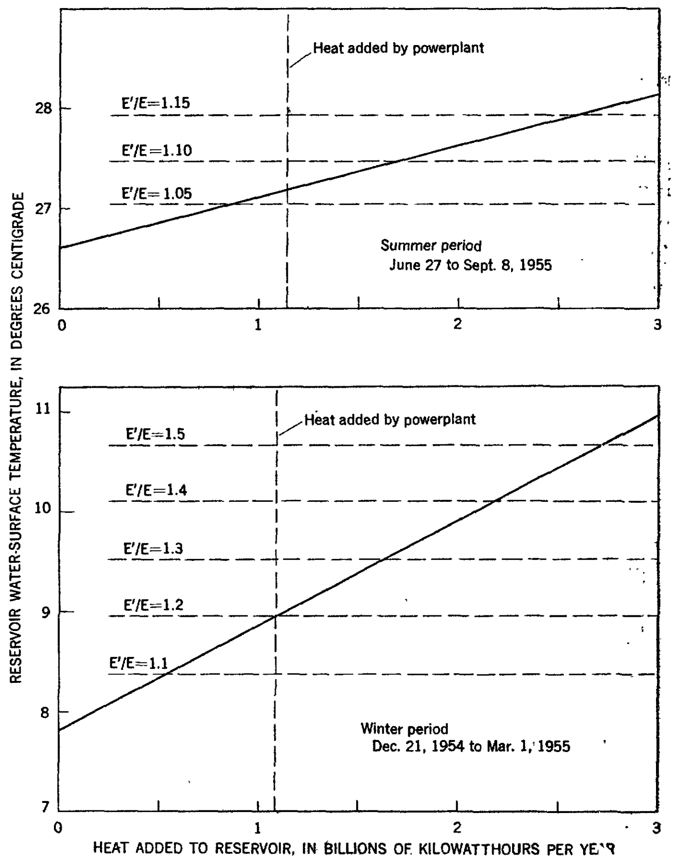

FIGURE 20.—Comparison between expected temperature rises and increase in evaporation during winter and summer periods for various amounts of heat added by the powerplant based on meteorological and limnological data obtained 1954-55.

Figure 21 illustrates the effect on evaporation of adding heat to the reservoir. The increase in evaporation, expressed in water volumes, is practically independent of the content of the reservoir. The heat added by the plant is disposed of principally by evaporation, back radiation, and conduction, all of which are surface phenomena. With other variables held constant, the total amount of heat thus disposed of is therefore

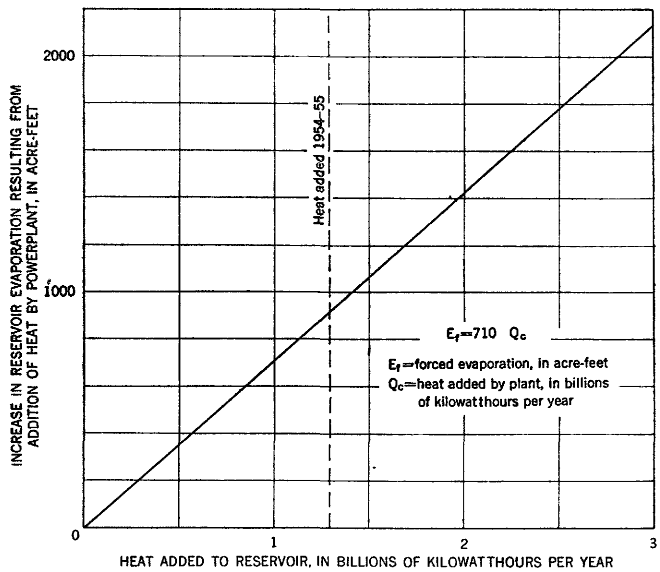

FIGURE 21.—Relation between the amount of heat added to Lake Colorado City and the resulting increase in reservoir evaporation.

proportional to the surface area of the reservoir. The increase in evaporation expressed as the ratio E'/E increases markedly as the reservoir content decreases (see fig. 19), but at the same time the reservoir area is decreasing, so that the product of the increase in evaporation (expressed in depth units) times the surface area is practically constant at Lake Colorad City.

Average inflow to Lake Colorado City for the period 1948–55 was 12,540 acre-feet. If the natural evaporation figure of approximately 7 feet during 1954–55 is considered representative of average conditions, natural evaporation (E_n) from a full reservoir would be 14,210 acre-feet. Evaporation resulting from the addition of heat by the plant (E_f) in 1954–55 was 910 acre-feet (see fig. 21). The amount of water diverted for municipal use by Colorado City was nearly 900 acre-feet during this same period. The diversion plus total evaporation loss from a full reservoir under these conditions would be 16,020 acre-feet, which is greater than average inflow. Contents would then decrease until equilibrium was reached, or when $E_f+E_n+900=12{,}540$. Using 7 feet as the amount of natural evaporation, $E_n=7A$, in which A is surface area in acres. From figure 21, $E_f=710\ Q_c$, assuming that it is not affected by reservoir area and contents as explained above.

$$7A+710\ Q_c+900=12{,}540 \qquad (17)$$

Equation 17 and the area and capacity curves for the reservoir were used to compute the volume of

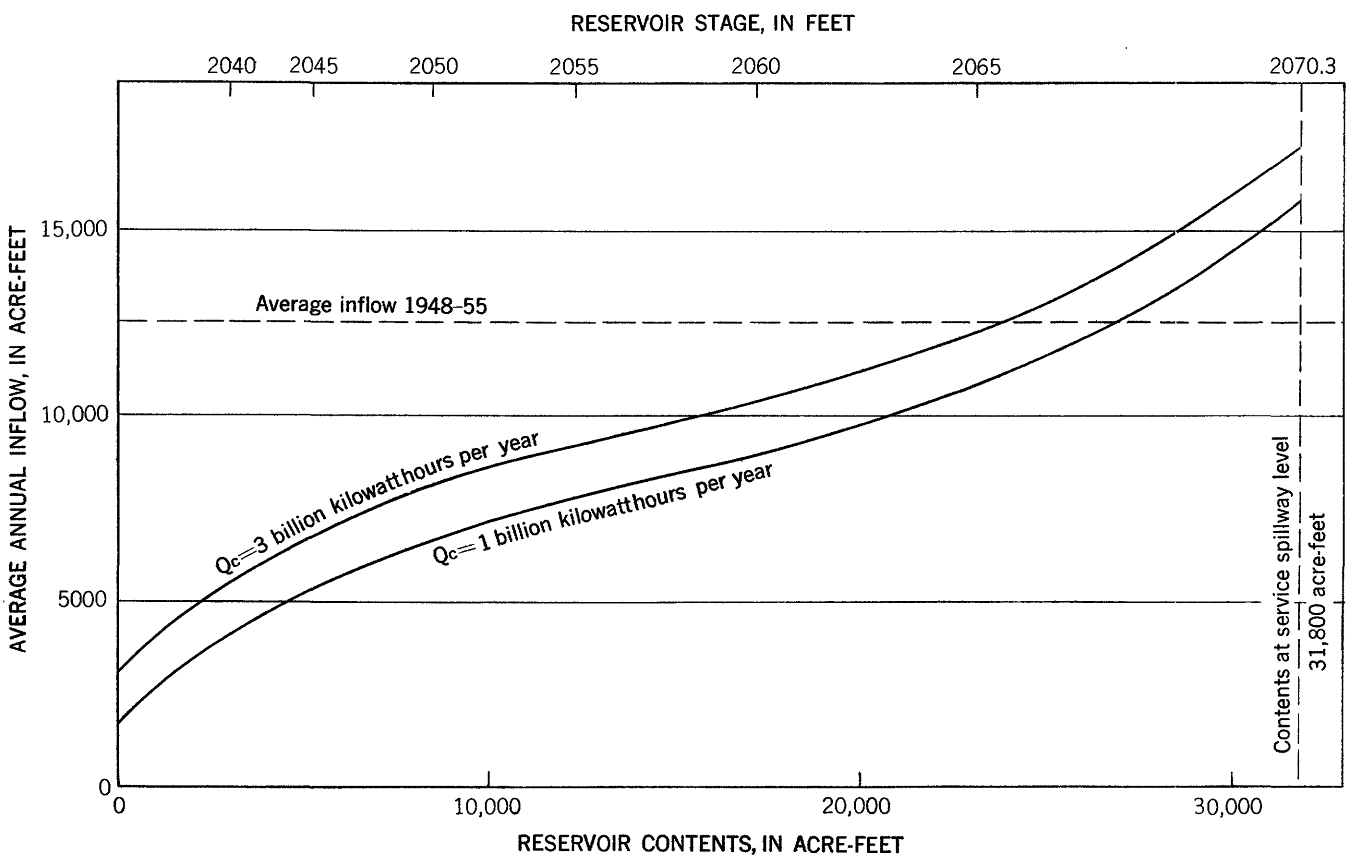

FIGURE 22.—Relation between average annual inflow and storage in Lake Colorado City, Tex.

water that Lake Colorado City would contain under various assumptions concerning the volume of average annual inflow and the amount of heat added to the reservoir. The results are shown in figure 22. If inflow over a period of years was exactly 12,540 acre-feet per year (the average for 1948–55), and if the heat added by the plant were 1.3 billion kwhr per year, reservoir contents would remain constant at about 25,000 acre-feet. If the heat added were increased to 3 billion kwhr per year, the reservoir stage would drop 2 feet. If inflow averaged only 5,000 acre-feet, which is considerably below average (but much greater than the figure of 990 acre-feet recorded in 1951), and if the amount of heat added were increased to 3 billion kwhr per year, reservoir contents would in time decrease to about 2,000 acre-feet. Figure 22 indicates that the volume of inflow is of much greater importance than the amount of heat added in determining the stage that the reservoir will reach.

Another analysis was made to determine what would happen during an extreme drought. It was assumed that inflow was zero, and that the reservoir was full at the beginning of the drought period. The amount of heat added by the plant was taken as 1.3 billion kwhr per year, and the diversion to Colorado City as 900 acre-feet per year. At the end of 4 years, the reservoir would be practically empty. At the end of 3 years, storage would be reduced to approximately 4,000 acre-feet, or 13 percent of capacity. At this reservoir level the water surface temperature would be 20.4°C. Although reservoir contents might decrease from 100 percent to 13 percent of capacity, the rise in water surface temperature would only be about 2°C.

CONCLUSIONS

The effect on evaporation caused by the addition of heat to Lake Colorado City was to increase evaporation from 85 inches to 93 inches during the 1-year period selected for study. In terms of volume, natural evaporation was 9,190 acre-feet, and the forced evaporation was 910 acre-feet. The increase in evaporation was approximately equal to the volume of water diverted by Colorado City for municipal use. The water-surface temperature was 0.8°C higher than it would have been if no heat had been added. The rise in water-surface temperature (relative to the temperature that would be observed if no heat were added to the lake) is almost directly proportional to the amount of heat added, for a given surface area. This relation is approximately correct for temperature rises of a few degrees under conditions of low humidity.

Some engineering handbooks give estimated quantities of heat that can be disposed of by cooling ponds in terms of British thermal units (Btu) per square foot of pond area per hour per degree Fahrenheit difference between the water and air temperature. The temperature-difference theory thus expressed is incorrect; the temperature difference should be that between the water-surface temperature in the pond if no heat were added and the surface temperature resulting from the addition of heat. The fact that the air-water temperature-difference theory is erroneous may easily be demonstrated. The average annual water-surface temperature of lakes that do not freeze is usually somewhat lower than average annual air temperature because of the cooling effect of evaporation. Suppose that just enough heat is added to cause the water temperature to equal the air temperature. According to this theory no heat could be dissipated, which is not correct.

Apparently some of the empirical formulas and rules-of-thumb were based on some work by Ruggles (1912). His results were expressed in terms of the air-water temperature difference, but his temperature differences were approximately 35°F owing to the large amount of heat added. This use of the air-water temperature difference introduced little error. Normally, however, the difference between natural water temperatures and air temperatures is but a few degrees, so that when the amount of heat added is relatively small, the resultant temperature rise also is small and the error may be considerable.

Computations were made using data obtained at Lake Hefner during the interagency investigations of 1950–51. To cause a water-surface temperature rise of 1°F required the addition of only 5.8 Btu per square foot per hour as compared with 6.7 for Lake Colorado City.

In a report by Harbeck (1953) data were given for a hypothetical reservoir located in a place whose climate was similar to that of southeastern Colorado. Several different assumed values of average annual relative humidity were used. The amount of heat required for a water-surface temperature rise of 1°F ranged from 4.6 Btu per square foot per hour for an assumed relative humidity of 30 percent to 8.7 Btu per square foot per hour for an assumed relative humidity of 70 percent. As humidity increases, a larger portion of the heat added is disposed of by evaporation and conduction.

It is impossible to give any average figure of the amount of heat required to cause a water surface temperature rise of 1° that would be generally applicable to all lakes and reservoirs. For any particular lake, the climatologic data required may usually be obtained from published Weather Bureau records. Hydraulic data for the lake, if not available, must be estimated. The computations required have been described above, and since they are neither difficult nor laborious, it appears preferable that an estimate of the effect of adding heat be made for each reservoir concerned instead of using average values.

Previous studies were made using the Lake Hefner data to compare the increased evaporation resulting from the addition of heat to a reservoir with the amount of water that would have been consumed by a cooling tower in disposing of the same quantity of heat (Harbeck, 1953). Those studies indicated that the increase in water evaporated from a reservoir would be less than half the water that would be consumed by a cooling tower. This finding is strictly applicable only to Lake Hefner, but the computational procedures described herein can be used to make a similar comparison for any reservoir. A discussion of the economics of the cooling tower versus the cooling pond method of disposing of excess heat is beyond the scope of this report, but it is obvious that the saving in water that might be effected by the use of a cooling pond is only one of many factors that must be considered.

At Lake Colorado City it was found that the volume of forced evaporation is directly proportional to the amount of heat added regardless of the contents of the reservoir. The amount of heat added by the powerplant during the study period was equivalent to 1.3 billion kwhr per year. If this were increased to 3 billion kwhr per year, the forced evaporation would be increased in the same proportion. If the reservoir were full, the water surface temperature would be increased only 1.2°C, but if contents were only 25 percent of capacity, the temperature rise would be 3.2°C.

Expressed in units commonly used in engineering handbooks, the amount of heat disposed of in Lake Colorado City ranged from winter to summer between approximately 4 and 8 Btu per square foot per hour per degree difference in water-surface temperature. The average for the year was 6.7 Btu per square foot per hour per degree temperature difference. The temperature difference (in degrees Fahrenheit) is the rise in water-surface temperature, not the air-water temperature difference. These figures are not applicable to other reservoirs. Changes in humidity of the air have a marked effect on the temperature rise to be expected, thus also affecting the amount of heat disposed of, if it is expressed in terms of the temperature rise.

EFFECT OF ADDED HEAT ON THE THERMAL STRUCTURE

CIRCULATION IN THE RESERVOIR

In the preceding chapter we analyzed the effect on evaporation of adding heat to the reservoir. We also determined the water surface temperatures to be expected under various assumptions of amount of heat added and of reservoir levels. It was unnecessary to consider how adding heat to the reservoir would affect water temperatures to be expected at various depths and locations in the reservoir, because the processes through which heat is returned to the atmosphere are surface phenomena, and temperatures at depth have no effect.

Because of its midlake constriction (see fig. 3), Lake Colorado City is probably not as efficient a "mixing bowl" as it would be if it were circular in shape. The question arises, whether for practical purposes mixing might be confined to the lower basin, thereby reducing the effective size of the lake.

The point at which the canal discharges heated water is nearly a mile from the point at which water is withdrawn from the lake. Although the amount of water withdrawn depends on the powerplant load, most of the time the powerplant withdraws approximately 275 cfs from the lake. The temperature rise is approximately 4.8°C in summer and 3.7°C in winter.

Figure 23 shows the variation of water temperature with depth in the upper and lower basins for selected soundings in January and July. Although a few temperature measurements were made at depths greater than 40 feet (the lowest limit in figure 24) in the old stream channel near the dam, 98 percent of the water in the reservoir is above this depth at full pool. In July, water temperatures in the upper basin were only a few tenths of a degree different from those in the lower basin, but in winter, a difference of about 2° was observed. During fall and winter the lower basin was definitely warmer than the upper basin, but during spring and summer little difference was noted.

The two principal factors causing mixing in the lake are density differences and wind. Wind speeds during February, March, and April are usually greater than in the remainder of the year, but very low wind speeds are uncommon at any season, and doubtless much of the mixing is caused by the wind.

Figure 23 indicates that the temperature difference between the upper and lower basins is substantially greater in winter than in summer. There is also a measurable difference in density between the two basins in winter although the difference is very small—a maximum of 0.02 percent at low temperatures. This is shown in figure 24 where, using data obtained from the thermal surveys, mean water temperatures were computed for the upper basin and the lower basin and then converted to equivalent densities. At high temperatures the average densities in the two basins are almost exactly the same. At low temperatures the density in the upper basin is slightly greater than in the lower basin.

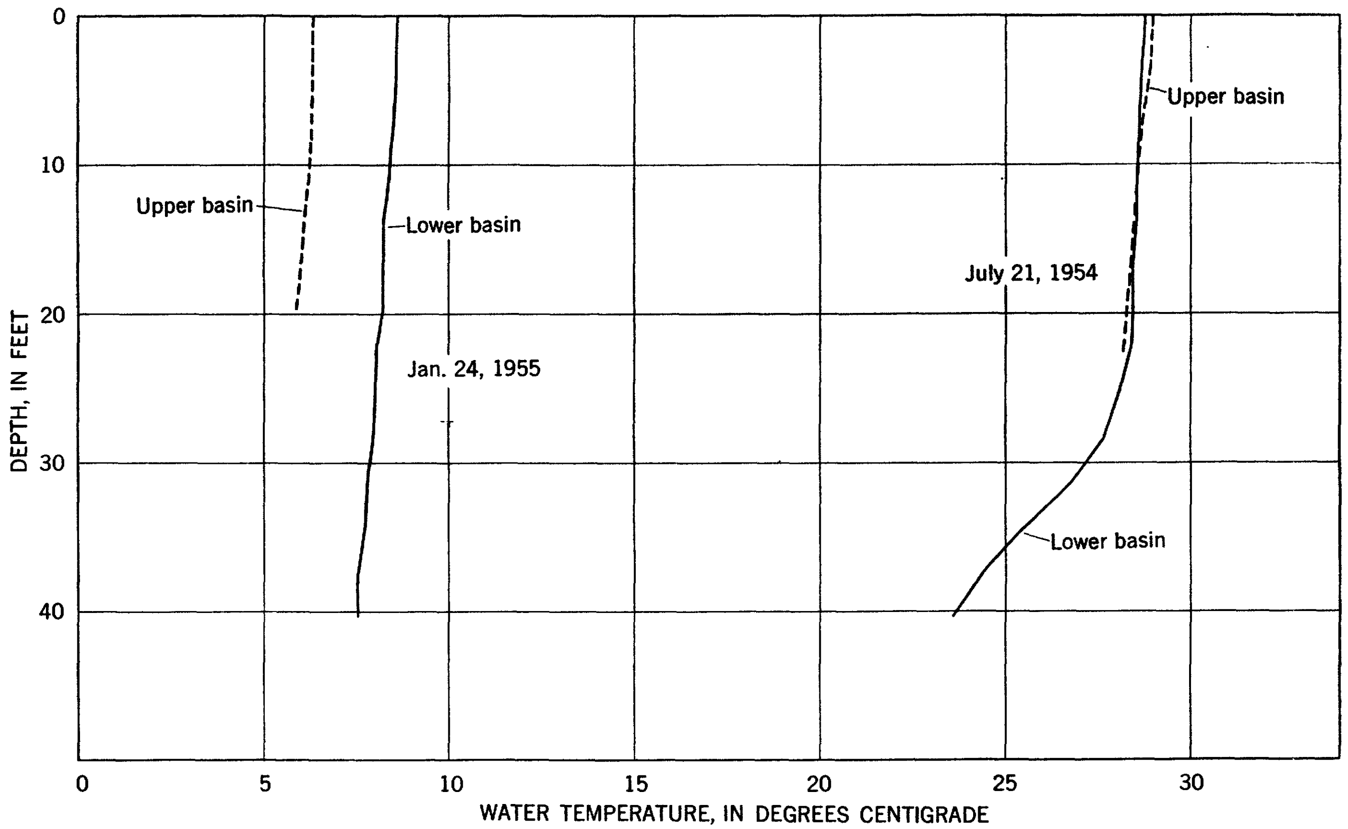

FIGURE 23.—Comparison between average water temperatures in upper and lower basins of Lake Colorado City, Tex.

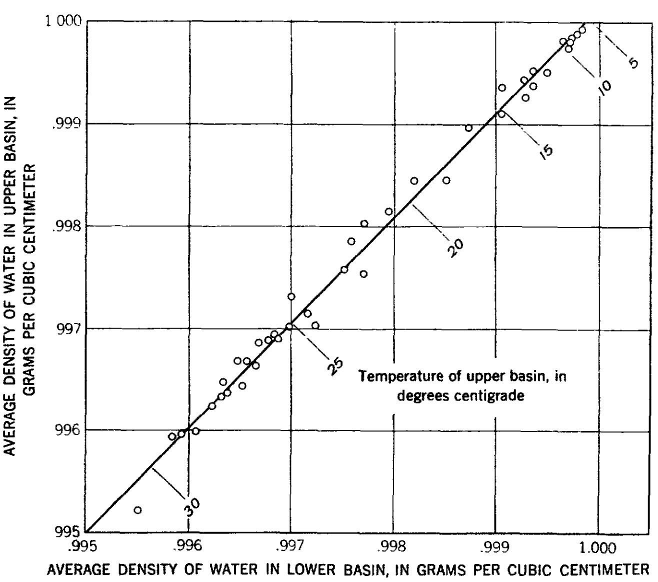

FIGURE 24.—Comparison between average densities of water in upper and lower basins, Lake Colorado City, Tex.

Little is known of the density differences required to initiate and maintain density currents, except that the differences may be extremely small. An approximate computation was made based on the following assumptions: (1) The irregular shape of Lake Colorado City was replaced by a trapezoidal trough having an equivalent volume and surface area. (2) Warm water from the powerplant was assumed to flow from the lower end to the upper end of the lake on the surface and return on the bottom. (3) The two layers of up-lake and down-lake flow were made equal in cross-sectional area at the longitudinal center of the trough.

Using commonly accepted formulas for flow in open channels, it was found that the flow caused by a difference in density between water at 20°C and at 19°C was substantially greater than the flow diverted by the powerplant for cooling purposes. The temperature difference of 1°C is the difference between the temperature of the top layer and the temperature of the bottom layer. Such a temperature difference is commonly observed, as is illustrated by the temperature profiles of figure 23. In summer the difference is much greater than 1°. In winter the difference may be less than 1°, but if the circulation is impaired by weak density currents, the effect is of no practical importance, since the water withdrawn at that time is always much colder than in the summer.

The possibility that the reservoir might be effectively divided into two parts at extremely low stages was investigated. If the two parts were connected only by a very small channel, it is conceivable that the upper part of the reservoir would not be effective in disposing of heat. The original stream channel traverses the entire reservoir bottom, however, and if the water-surface elevation is below the bankful stage of the old stream bed in the upper basin, there would remain no flooded areas of substantial size in the upper basin. The sluggish water in the old stream channel would remain, but its volume would be insignificant compared with the volume of water remaining in the lower basin. At extremely low stages, therefore, it can be reasoned that practically all the water remaining in storage, small though it may be, would be utilized in disposing of heat, providing the reservoir level does not drop below the powerplant intake.

The results of the theoretical analysis and the study of observed density difference between the upper and lower basins indicate that heat from the powerplant is being effectively dispersed over the entire lake. Although temperatures at one end of the lake may be several degrees different from those at the other end, density differences are very small

WITHDRAWAL TEMPERATURES

Previous analyses have determined the water-surface temperatures that may be expected under various assumptions of amount of heat added by the plant, and have indicated that the entire lake is being utilized to dispose of the added heat. If the amount of heat added to the reservoir should be increased, information is needed concerning the expected temperature of the water to be withdrawn from the lake.

The intake canal is quite deep in order that water may be withdrawn even at low reservoir levels. Water flows through the short intake canal to the pumps, and the volume of flow is sufficiently great to insure that the flow is turbulent at practically all times. The variation of temperature with depth in the intake canal appears to correspond exactly to that observed in the reservoir, and the average temperature of the water after it has been pumped to the plant is the same as the mean temperature of the water flowing in the intake canal. Although the pump intakes are near the bottom of the intake canal, the water is being withdrawn from all levels.

A study was made of the relation between intake water temperature and the average temperature of the entire lake, as determined from the thermal surveys. A least-squares regression analysis indicates that there is no significant seasonal variation in the relations between intake water temperatures, water-surface temperatures, and average lake temperatures. A simple comparison of average temperatures is adequate. From data obtained at the times of the thermal surveys made at approximately 10-day intervals during the entire 16-month period of observation, the average intake water temperature was found to be 20.38°C, the average water surface temperature was 20.33°C, and the average lake temperature was 19.91°C. The indicated difference of 0.05°C between intake temperature and water-surface temperature is probably instrumental error. The reason the average lake temperature is 0.47°C lower than the intake temperature is that approximately 15 percent of the water in the reservoir during 1954–55 was below the level of the intake. This bottom water is colder than the water above the intake, so that the mean temperature of the water between the intake level and the surface is slightly higher than the average lake temperature.

CONCLUSIONS

The studies of the effect on the thermal structure of adding heat to the reservoir indicate that the entire lake is being effectively utilized in disposing of the heat added by the powerplant.

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APPENDIX

TABLE 6.—*Daily lake stage and contents of Lake Colorado City, July 21, 1954, to October 30, 1955*

[Stage and content at 12:00 p. m. Add 2,000 feet to lake stage to convert to reservoir and mean sea level datum]

Day	1954												1955			
	July		August		September		October		November		December		January		February	
	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)
1	--------	--------	67.06	26,200	66.02	24,600	65.11	23,250	64.47	22,450	64.05	21,800	63.71	21,440	63.48	21,200
2	--------	--------	67.02	26,130	65.98	24,600	65.09	23,250	64.43	22,320	64.06	21,930	63.71	21,440	63.47	21,200
3	--------	--------	66.98	26,070	65.94	24,450	65.07	23,250	64.43	22,320	64.05	21,800	63.72	21,440	63.49	21,200
4	--------	--------	66.94	26,010	65.90	24,450	65.05	23,100	64.40	22,320	64.03	21,800	63.72	21,440	63.50	21,200
5	--------	--------	66.89	25,940	65.88	24,450	65.04	23,100	64.37	22,320	63.98	21,800	63.72	21,440	63.50	21,200
6	--------	--------	66.86	25,890	65.85	24,300	65.02	23,100	64.36	22,320	63.98	21,800	63.70	21,440	63.47	21,200
7	--------	--------	66.82	25,830	65.83	24,300	64.99	23,100	64.35	22,320	63.97	21,800	63.70	21,440	63.47	21,200
8	--------	--------	66.81	25,820	65.80	24,300	64.97	23,100	64.34	22,190	63.92	21,680	63.68	21,440	63.47	21,200
9	--------	--------	66.77	25,760	65.78	24,300	64.95	23,100	64.33	22,190	63.92	21,680	63.71	21,440	63.45	21,080
10	--------	--------	66.73	25,700	65.74	24,150	64.93	22,970	64.32	22,190	63.90	21,680	63.70	21,440	63.41	21,080
11	--------	--------	66.70	25,650	65.71	24,150	64.90	22,970	64.31	22,190	63.90	21,680	63.69	21,440	63.40	21,080
12	--------	--------	66.66	25,590	65.67	24,150	64.88	22,970	64.30	22,190	63.88	21,680	63.68	21,440	63.38	21,080
13	--------	--------	66.62	25,530	65.63	24,000	64.85	22,840	64.28	22,190	63.87	21,680	63.67	21,440	63.37	21,080
14	--------	--------	66.57	25,460	65.60	24,000	64.80	22,840	64.32	22,190	63.85	21,560	63.69	21,440	63.37	21,080
15	--------	--------	66.55	25,420	65.58	24,000	64.77	22,840	64.31	22,190	63.83	21,560	63.68	21,440	63.36	21,080
16	--------	--------	66.51	25,360	65.55	24,000	64.74	22,710	64.30	22,190	63.82	21,560	63.68	21,440	63.35	21,080
17	--------	--------	66.47	25,300	65.52	23,850	64.71	22,710	64.28	22,190	63.80	21,560	63.67	21,440	63.34	20,960
18	--------	--------	66.42	25,230	65.49	23,850	64.69	22,710	64.25	22,060	63.77	21,560	63.65	21,320	63.35	20,960
19	--------	--------	66.38	25,200	65.45	23,700	64.66	22,710	64.24	22,060	63.76	21,560	63.63	21,320	63.32	20,960
20	67.49	26,880	66.35	25,200	65.43	23,700	64.63	22,580	64.23	22,060	63.75	21,560	63.63	21,320	63.30	20,960
21	67.45	26,820	66.32	25,050	65.38	23,700	64.62	22,580	64.22	22,060	63.74	21,440	63.61	21,320	63.29	20,960
22	67.40	26,740	66.28	25,050	65.35	23,700	64.60	22,580	64.20	22,060	63.73	21,440	63.60	21,320	63.28	20,960
23	67.37	26,690	66.26	25,050	65.31	23,550	64.58	22,580	64.18	22,060	63.73	21,440	63.58	21,320	63.26	20,960
24	67.34	26,640	66.25	24,900	65.27	23,550	64.56	22,580	64.17	22,060	63.72	21,440	63.57	21,320	63.25	20,960
25	67.31	26,600	66.22	24,900	65.25	23,400	64.55	22,580	64.15	22,060	63.70	21,440	63.55	21,320	63.23	20,840
26	67.27	26,530	66.19	24,900	65.22	23,400	64.53	22,450	64.15	22,060	63.70	21,440	63.54	21,200	63.23	20,840
27	67.23	26,470	66.16	24,900	65.19	23,400	64.58	22,580	64.14	21,930	63.70	21,440	63.53	21,200	63.22	20,840
28	67.20	26,420	66.13	24,750	65.16	23,400	64.57	22,580	64.11	21,930	63.75	21,560	63.52	21,200	63.21	20,840
29	67.16	26,360	66.10	24,750	65.13	23,250	64.53	22,450	64.08	21,930	63.74	21,440	63.51	21,200	--------	--------
30	67.12	26,290	66.09	24,750	65.11	23,250	64.51	22,450	64.06	21,930	63.73	21,440	63.50	21,200	--------	--------
31	67.09	26,240	66.07	24,750	--------	--------	64.49	22,450	--------	--------	63.72	21,440	63.49	21,200	--------	--------

[Stage and content at 12:00 p. m. Add 2,000 feet to lake stage to convert to reservoir and mean sea level datum]

Day	1955															
	March		April		May		June		July		August		September		October	
	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)	Lake stage (feet)	Content (acre-ft)
1	63.20	20,840	62.67	20,240	62.02	19,400	65.05	23,100	64.56	22,580	64.65	22,580	64.15	22,060	64.05	21,800
2	63.20	20,840	62.65	20,120	61.96	19,400	65.04	23,100	64.52	22,450	64.62	22,580	64.13	21,930	65.73	24,150
3	63.19	20,840	62.63	20,120	61.93	19,290	65.03	23,100	64.48	22,450	64.58	22,580	64.09	21,930	66.28	25,050
4	63.18	20,840	62.60	20,120	61.91	19,290	64.99	23,100	64.45	22,320	64.57	22,580	64.06	21,930	66.34	25,050
5	63.15	20,840	62.60	20,120	61.96	19,400	64.97	23,100	64.42	22,320	64.55	22,580	64.06	21,930	66.47	25,350
6	63.13	20,720	62.55	20,120	61.96	19,400	64.96	23,100	64.39	22,320	64.52	22,450	64.03	21,800	66.48	25,350
7	63.11	20,720	62.55	20,120	61.94	19,290	64.94	22,970	64.33	22,190	64.50	22,450	64.01	21,800	66.50	25,350
8	63.10	20,720	62.54	20,000	61.97	19,400	64.89	22,970	64.29	22,190	64.48	22,450	63.98	21,800	66.48	25,350
9	63.08	20,720	62.52	20,000	62.01	19,400	64.87	22,970	64.24	22,060	64.43	22,320	63.95	21,800	66.46	25,350
10	63.06	20,720	62.52	20,000	62.03	19,400	64.85	22,840	64.21	22,060	64.41	22,320	63.90	21,680	66.45	25,200
11	63.05	20,600	62.50	20,000	62.76	20,360	64.80	22,840	64.18	22,060	64.38	22,320	63.95	21,800	66.42	25,200
12	63.04	20,600	62.47	20,000	63.66	21,440	64.77	22,840	64.15	22,060	64.34	22,190	63.93	21,680	66.38	25,200
13	63.02	20,600	62.40	19,880	63.73	21,440	64.74	22,710	64.15	22,060	64.30	22,190	63.91	21,680	66.38	25,200
14	63.01	20,600	62.39	19,880	63.72	21,440	64.70	22,710	64.12	21,930	64.27	22,190	63.90	21,680	66.38	25,200
15	62.99	20,600	62.36	19,880	63.70	21,440	64.68	22,710	64.12	21,930	64.23	22,060	63.87	21,680	66.34	25,050
16	62.96	20,600	62.35	19,880	63.68	21,440	64.76	22,840	64.10	21,930	64.20	22,060	63.83	21,560	66.30	25,050
17	62.95	20,600	62.34	19,760	63.68	21,440	64.91	22,970	64.08	21,930	64.17	22,060	63.80	21,560	66.29	25,050
18	62.94	20,480	62.33	19,760	63.65	21,320	64.94	22,970	64.15	22,060	64.16	22,060	63.78	21,560	66.27	25,050
19	62.93	20,480	62.30	19,760	63.64	21,320	64.93	22,970	64.21	22,060	64.14	21,930	63.77	21,560	66.24	24,900
20	62.99	20,600	62.29	19,760	63.65	21,320	64.91	22,970	64.24	22,060	64.14	21,930	63.73	21,440	66.21	24,900
21	62.94	20,480	62.28	19,760	63.65	21,320	64.89	22,970	64.22	22,060	64.37	22,320	63.70	21,440	66.20	24,900
22	62.91	20,480	62.29	19,760	63.62	21,320	64.87	22,970	64.20	22,060	64.47	22,450	63.68	21,440	66.18	24,900
23	62.90	20,480	62.19	19,640	64.38	22,320	64.83	22,840	64.18	22,060	64.46	22,450	63.66	21,440	66.11	24,750
24	62.88	20,480	62.18	19,640	65.15	23,400	64.79	22,840	64.15	22,060	64.43	22,320	63.65	21,320	66.12	24,750
25	62.83	20,360	62.14	19,520	65.17	23,400	64.75	22,840	64.11	21,930	64.40	22,320	63.64	21,320	66.11	24,750
26	62.80	20,360	62.15	19,640	65.18	23,400	64.71	22,710	64.07	21,930	64.37	22,320	63.63	21,320	66.10	24,750
27	62.80	20,360	62.10	19,520	65.15	23,400	64.69	22,710	64.07	21,930	64.34	22,190	63.62	21,320	66.06	24,750
28	62.77	20,360	62.05	19,400	65.09	23,250	64.67	22,710	64.51	22,450	64.30	22,190	63.60	21,320	66.03	24,600
29	62.73	20,240	62.02	19,400	65.08	23,250	64.64	22,580	64.71	22,710	64.27	22,190	63.58	21,320	65.97	24,600
30	62.71	20,240	62.02	19,400	65.05	23,100	64.60	22,580	64.71	22,710	64.20	22,060	63.55	21,320	65.98	24,600
31	62.71	20,240	--------	--------	65.01	23,100	--------	--------	64.68	22,710	64.17	22,060	--------	--------	--------	--------

TABLE 7.—*Daily withdrawals from Lake Colorado City for municipal purposes, July 21, 1954, to October 30, 1955, in acre-feet*

Date	1954						1955									
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
1	--------	2.6	3.6	.8	1.3	0	1.5	1.9	2.6	2.2	2.1	1.3	4.6	4.7	3.4	1.7
2	--------	3.9	3.3	2.1	.9	0	1.8	1.7	1.9	3.1	3.5	1.9	4.0	4.4	2.6	0
3	--------	4.1	3.5	1.7	.9	0	1.9	1.4	2.9	1.9	4.8	2.8	2.5	4.8	3.2	0
4	--------	4.6	3.2	2.7	1.1	0	2.0	1.6	2.8	1.5	4.6	2.7	3.4	3.7	1.6	0
5	--------	4.4	2.8	2.0	1.2	2.0	1.5	1.6	2.0	2.7	2.0	2.2	4.3	4.3	2.6	.7
6	--------	4.6	3.3	1.1	1.2	2.5	1.4	1.3	1.4	2.2	1.9	2.6	4.3	4.4	3.5	1.2
7	--------	4.7	1.8	1.3	.9	2.4	1.7	.6	2.4	2.8	3.3	3.8	4.2	5.1	3.3	0
8	--------	3.0	2.1	1.8	1.4	2.5	1.7	0	2.4	2.9	2.6	2.5	4.2	3.0	3.7	.3
9	--------	3.1	1.8	2.1	1.2	2.6	1.3	2.2	2.7	2.0	2.0	1.0	4.3	5.3	3.3	0
10	--------	4.5	2.5	1.7	1.2	2.3	1.3	1.5	2.6	1.9	1.6	2.6	3.5	5.2	3.2	.9
11	--------	4.3	2.6	2.3	1.3	2.5	1.8	1.7	3.2	4.1	2.0	2.0	4.1	3.0	.8	.6
12	--------	4.4	2.4	2.1	1.2	1.5	1.9	1.7	2.6	2.4	1.9	2.4	3.4	4.1	1.0	0
13	--------	4.0	3.5	2.8	2.2	1.8	1.8	1.0	2.1	3.2	2.6	4.3	2.0	4.3	0	1.0
14	--------	4.5	3.8	1.6	.9	1.4	1.4	2.4	3.4	3.3	2.3	3.9	2.8	3.5	1.3	0
15	--------	3.2	3.8	1.6	2.0	1.8	1.5	3.0	3.0	3.5	2.3	4.0	2.0	3.9	1.8	.6
16	--------	4.8	3.3	1.8	1.7	1.8	1.5	2.0	1.5	3.7	3.3	2.5	3.0	4.4	1.2	0
17	--------	4.3	2.8	1.4	1.8	1.9	1.7	1.7	2.5	3.1	2.1	2.7	1.7	4.4	1.7	.4
18	--------	4.5	3.0	1.6	.9	1.8	1.8	1.6	1.6	4.0	2.5	3.3	1.4	3.7	1.7	0
19	--------	4.5	2.6	1.9	1.6	1.4	1.7	1.4	1.6	3.6	1.6	2.9	1.9	2.8	1.6	1.4
20	--------	4.2	3.7	1.7	1.6	2.8	1.5	1.3	1.8	3.0	1.7	2.9	1.9	3.5	2.6	.4
21	5.0	3.7	2.9	1.9	1.4	2.1	1.5	2.0	1.4	3.5	2.1	3.0	3.5	2.1	2.7	1.5
22	5.0	3.8	2.8	1.5	2.4	1.8	1.4	1.7	1.5	3.6	2.6	3.8	3.3	2.8	1.8	1.0
23	4.9	4.3	2.8	1.5	1.3	2.3	1.4	1.7	1.9	1.7	1.7	4.4	4.1	4.1	1.2	0
24	4.5	4.4	2.6	1.1	2.1	1.7	1.7	1.6	2.2	3.3	2.0	3.9	3.3	4.4	.8	1.1
25	4.9	4.7	2.8	1.1	0	2.2	1.9	1.9	1.6	4.4	3.1	3.9	3.6	3.0	0	1.6
26	5.8	4.1	2.2	1.4	0	2.2	1.7	2.0	1.4	3.2	2.7	3.6	3.7	3.6	.9	.9
27	5.5	4.4	3.0	1.5	0	1.7	1.6	2.3	1.8	4.6	2.9	4.2	3.2	4.6	0	.6
28	4.9	3.4	3.4	.6	0	1.8	1.8	2.4	2.1	4.1	2.5	3.4	2.8	3.4	.6	.9
29	3.6	3.3	2.3	1.6	0	2.1	1.4	--------	2.5	3.5	1.6	3.7	4.1	4.7	1.5	1.1
30	5.0	3.8	2.3	1.2	0	1.5	1.8	--------	1.7	3.9	3.0	4.4	4.5	3.9	1.5	0
31	3.9	3.4	--------	0.8	--------	2.5	2.0	--------	2.4	--------	2.3	--------	4.3	2.4	--------	--------

TABLE 8.—*Daily rainfall in inches at Lake Colorado City, Tex.*

[T=trace]

Date	Nonrecording gages				
	1	2	3	4	Average
1954					
July 31	0	0.02	0	0	0.005
Aug. 8	.03	.23	.10	T	.090
30	0	.06	T	0	.015
31	0	.01	0	0	.002
Sept. 7	T	T	.15	.05	.050
Oct. 1	.18	.18	.10	T	.115
2	0	0	.05	0	.012
5	.13	.17	0	0	.075
6	0	0	0	.21	.052
8	0	0	.10	0	.025
25	0	T	0	0	.000
27	.76	.61	.50	1.10	.742
Nov. 14	.38	.51	.60	.55	.510
Dec. 11	.14	.12	.05	T	.078
28	.25	.76	.27	.31	.398
1955					
Jan. 5	.05	.04	0	0	.022
9	.26	.23	--------	.35	.280
14	.19	.20	.22	0	.152
15	.01	.01	0	0	.005
17	.02	T	T	T	.005
Feb. 3	.77	.50	.46	.24	.492
18	.02	.02	0	0	.010
Mar. 18	T	.01	.01	T	.005
20	.20	.41	.52	.75	.470
Apr. 8	.01	.04	T	T	.012
22	.06	.05	.05	.06	.055
May 5	.85	.87	.47	.33	.630
8	.87	.94	.08	T	.472
9	.44	.49	.82	.47	.555
1955					
May 10	0.35	0.28	0.35	0.13	0.278
11	.89	.85	.90	1.32	.990
16	.18	.39	.44	.27	.320
17	.17	.09	.04	T	.075
19	.16	.08	.10	.10	.110
20	.08	.02	.09	.10	.072
23	.41	.47	.52	.57	.492
25	.28	.30	.30	.42	.325
June 1	.62	.64	.71	.62	.648
8	.04	.03	--------	.05	.040
9	.12	.06	--------	.03	.070
16	.32	.44	.72	.61	.522
19	0	0	0	.05	.012
28	.53	.19	.20	.12	.260
July 12	0	.06	.05	.06	.042
18	.45	.40	.12	.18	.288
19	.51	.54	.52	.60	.542
27	.18	.17	.18	.18	.178
Aug. 4	.18	.40	.22	.12	.230
19	.33	.28	.07	T	.170
20	0	.10	.28	.28	.165
Sept. 4	.18	.34	.40	.50	.355
11	.65	.61	.75	.60	.652
23	.14	.22	0	0	.090
24	.22	.08	0	.12	.105
Oct. 1	1.72	2.25	1.86	1.12	1.738
2	.06	.07	.50	.20	.208
3	0	.04	--------	.37	.137
4	.41	.32	.47	0	.300
5	.07	.13	0	0	.050

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre-ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
July 1954									
21	30. 2	-----------	28. 5	29. 7	29. 2	7. 9	28. 9	35. 0	614
22	30. 8	-----------	27. 0	28. 9	28. 9	8. 5	28. 3	35. 6	614
23	29. 2	18. 5	26. 5	28. 9	29. 2	5. 4	28. 3	35. 0	614
24	30. 5	17. 2	27. 2	28. 6	28. 9	4. 2	28. 3	35. 0	614
25	32. 7	18. 5	29. 2	30. 0	30. 3	-----------	28. 3	35. 0	614
26	34. 2	19. 2	29. 8	-----------	30. 0	4. 6	28. 9	36. 1	614
27	33. 2	20. 7	28. 8	-----------	29. 4	7. 6	28. 9	36. 7	614
28	29. 5	19. 2	27. 5	-----------	29. 4	7. 6	28. 9	36. 1	614
29	28. 8	18. 0	26. 5	30. 8	29. 7	6. 9	28. 9	35. 6	614
30	27. 7	16. 5	26. 5	-----------	-----------	6. 0	28. 3	35. 0	614
31	24. 8	18. 8	25. 5	-----------	-----------	6. 9	28. 9	33. 3	614
August 1954									
1	25. 5	19. 5	-----------	-----------	-----------	7. 3	28. 3	33. 3	574
2	27. 0	19. 0	-----------	-----------	-----------	6. 9	28. 3	33. 3	614
3	26. 0	16. 6	-----------	-----------	-----------	5. 6	28. 3	34. 4	614
4	26. 6	17. 0	-----------	30. 3	28. 9	7. 8	28. 9	35. 0	614
5	28. 0	17. 4	-----------	28. 9	29. 2	8. 7	28. 3	33. 9	614
6	30. 2	18. 2	-----------	29. 2	28. 9	8. 6	28. 3	34. 4	614
7	31. 8	19. 4	-----------	29. 7	28. 9	8. 0	28. 3	33. 9	614
8	27. 8	20. 0	-----------	27. 7	29. 4	6. 9	28. 3	32. 8	614
9	27. 5	20. 0	-----------	27. 2	28. 3	9. 8	27. 8	33. 3	614
10	31. 0	20. 0	-----------	29. 7	28. 9	6. 1	27. 8	33. 3	614
11	30. 5	19. 2	-----------	28. 9	28. 3	6. 8	28. 3	33. 9	614
12	30. 2	18. 5	-----------	28. 9	28. 6	6. 8	28. 3	34. 4	614
13	31. 5	19. 2	-----------	28. 9	28. 6	-----------	27. 8	35. 0	614
14	31. 5	19. 5	-----------	28. 9	28. 6	-----------	27. 8	35. 6	568
15	31. 0	19. 5	-----------	29. 2	28. 9	-----------	28. 3	33. 9	514
16	30. 0	20. 0	-----------	29. 4	28. 9	7. 8	28. 3	33. 9	614
17	29. 8	20. 0	-----------	29. 4	28. 9	8. 0	28. 3	34. 4	614
18	29. 5	20. 0	-----------	28. 1	28. 1	8. 2	28. 3	34. 4	614
19	29. 7	19. 7	-----------	29. 2	28. 9	8. 4	27. 8	33. 9	614
20	28. 9	20. 7	-----------	27. 2	28. 1	6. 8	27. 8	33. 3	614
21	29. 1	20. 1	-----------	27. 5	28. 3	7. 8	27. 2	32. 2	614
22	28. 8	19. 4	-----------	28. 1	28. 1	7. 7	27. 2	31. 1	614
23	27. 1	19. 9	-----------	28. 1	27. 2	7. 7	27. 2	31. 1	614
24	29. 1	19. 8	-----------	28. 6	28. 1	6. 9	26. 7	31. 1	614
25	29. 9	20. 2	-----------	28. 9	28. 6	6. 2	26. 7	32. 8	614
26	30. 0	20. 2	-----------	28. 3	28. 1	4. 5	26. 7	33. 1	614
27	30. 8	19. 2	-----------	28. 3	27. 8	3. 1	27. 2	33. 3	614
28	29. 8	19. 5	-----------	28. 3	28. 3	3. 4	27. 2	33. 9	614
29	29. 5	19. 5	-----------	28. 3	28. 3	3. 4	27. 2	32. 2	614
30	27. 8	20. 3	-----------	28. 3	29. 6	4. 7	27. 2	33. 3	614
31	27. 0	19. 5	-----------	28. 3	28. 9	4. 8	27. 2	33. 3	614

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre-ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
September 1954									
1	28.6	18.4	27.2	28.3	27.2	---	27.2	33.9	599
2	30.7	17.6	27.8	28.3	28.6	---	27.2	33.9	599
3	31.1	17.1	---	28.1	28.1	---	27.2	33.9	599
4	28.4	17.3	---	27.5	28.3	---	27.8	32.2	599
5	27.6	17.5	---	27.8	27.2	---	27.2	31.7	599
6	27.8	18.2	---	27.8	27.2	---	27.2	32.8	599
7	---	---	---	28.9	27.5	---	27.2	33.3	599
8	---	---	---	28.6	27.5	5.9	27.2	33.3	599
9	28.9	19.4	28.6	29.2	29.4	5.1	27.2	33.3	599
10	26.2	17.2	---	29.2	26.9	11.4	27.2	33.3	599
11	25.0	13.8	---	27.5	27.5	5.2	27.2	32.2	599
12	24.5	14.2	---	27.5	26.9	5.9	26.7	30.6	599
13	26.2	---	---	27.5	26.7	7.1	26.1	31.1	599
14	27.1	---	---	---	---	5.8	26.1	30.6	599
15	28.1	---	26.0	---	---	6.8	26.1	31.7	524
16	27.3	---	26.0	27.8	27.5	5.7	26.1	31.7	524
17	27.2	---	---	28.1	27.5	4.8	26.1	31.1	524
18	28.6	---	---	27.8	27.2	6.9	26.1	31.1	524
19	29.2	---	---	27.2	26.7	7.2	26.1	30.6	524
20	30.4	---	26.3	28.3	27.2	7.8	26.1	32.2	524
21	25.6	---	---	27.5	26.4	13.0	25.6	30.6	524
22	21.9	---	---	26.4	25.0	5.1	25.0	29.4	524
23	22.9	---	---	26.1	25.3	6.2	25.0	29.4	524
24	23.4	13.1	---	25.6	24.7	6.1	24.4	28.9	524
25	24.4	14.9	---	25.6	24.7	4.8	24.4	28.9	523
26	25.8	16.0	---	25.0	24.7	5.8	23.9	28.3	593
27	26.2	16.5	---	---	---	6.3	24.4	29.4	599
28	27.6	17.8	---	---	---	9.4	24.4	29.4	577
29	25.0	18.8	---	---	---	9.6	24.4	30.0	524
30	25.2	20.2	---	25.3	24.4	8.6	24.4	29.4	524
October 1954									
1	24.4	21.1	24.6	25.0	24.4	7.0	23.9	28.9	524
2	26.4	20.0	---	24.7	24.4	7.6	24.4	28.9	524
3	26.8	20.1	---	25.3	24.7	7.5	25.0	28.3	524
4	26.5	19.2	---	25.8	24.7	6.7	24.4	30.6	524
5	22.9	19.6	---	25.6	25.0	9.2	24.4	29.4	524
6	21.5	18.3	---	25.3	24.7	11.4	24.4	29.4	524
7	18.3	16.2	---	25.0	24.2	10.8	24.4	28.9	524
8	23.0	18.6	---	25.3	24.4	6.2	23.9	28.3	570
9	23.6	18.7	---	25.0	24.4	8.1	23.9	28.3	599
10	25.2	19.3	---	25.3	24.4	7.7	24.4	28.3	599
11	25.5	17.6	---	25.8	24.4	10.1	24.4	28.3	599
12	24.5	14.0	---	23.9	24.4	5.4	23.9	28.9	599
13	26.0	15.8	---	---	---	5.4	23.9	28.9	599
14	17.8	10.4	---	---	---	15.6	23.3	27.2	599
15	14.1	6.8	---	23.1	22.2	5.7	22.8	26.1	531
16	17.4	9.2	---	23.6	22.8	---	21.7	25.6	571
17	19.1	9.0	---	22.5	21.7	---	21.7	25.0	571
18	20.2	10.5	---	22.2	21.9	---	21.1	25.6	571
19	20.1	12.7	---	22.2	21.7	6.5	21.1	25.0	571
20	22.0	14.7	---	22.2	21.7	6.5	21.1	25.0	571
21	21.6	15.0	21.6	22.8	22.8	4.5	20.6	25.0	571
22	16.3	10.9	20.4	22.8	22.2	6.8	20.6	24.4	571
23	14.9	10.6	20.0	20.0	21.1	5.4	20.0	23.9	568
24	16.9	13.3	19.6	21.1	21.1	6.9	20.0	23.9	522
25	21.4	17.5	19.6	21.4	20.6	8.5	20.0	25.0	547
26	17.0	12.5	---	21.1	20.6	11.3	20.0	24.4	571
27	9.1	6.3	---	22.2	21.4	9.1	18.9	23.3	571
28	15.3	10.2	---	---	---	6.5	18.9	23.3	571
29	11.0	6.3	---	---	---	11.6	18.3	22.2	571
30	12.0	6.9	18.0	18.9	18.0	4.8	17.8	21.7	571
31	13.0	7.1	---	18.7	17.8	7.2	17.8	21.1	571

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
November 1954									
1	11.6	6.8	17.1	--------	--------	8.2	17.2	21.7	571
2	--------	--------	--------	--------	--------	9.5	16.1	20.6	571
3	--------	--------	--------	--------	--------	8.4	15.6	20.6	571
4	8.3	4.2	15.0	--------	--------	13.1	15.0	19.4	552
5	10.8	5.2	14.8	17.0	15.8	4.2	15.0	18.9	500
6	13.0	6.4	15.2	16.7	16.7	4.2	15.0	20.0	500
7	14.4	8.3	15.0	17.0	17.5	4.1	15.0	19.4	469
8	16.3	12.3	14.7	17.0	16.7	5.8	15.0	21.1	328
9	15.0	--------	15.5	17.5	16.4	5.4	15.6	21.1	328
10	11.8	8.8	15.4	--------	--------	3.6	15.0	15.6	328
11	12.2	8.4	14.8	--------	--------	2.2	15.0	21.1	328
12	12.2	8.0	15.0	16.7	16.4	1.1	15.0	21.1	328
13	15.1	9.3	--------	16.1	15.6	4.6	15.6	20.6	328
14	13.0	11.3	--------	15.8	15.6	7.0	15.0	19.4	328
15	12.8	10.2	14.8	16.4	15.3	--------	15.0	21.1	328
16	16.1	10.0	14.7	17.0	15.6	7.6	15.0	21.1	328
17	15.6	9.0	--------	16.1	15.8	10.1	15.6	21.7	328
18	13.3	8.2	--------	15.8	15.8	11.2	15.0	21.1	328
19	12.0	6.4	--------	16.4	15.6	5.1	14.4	20.6	328
20	11.8	5.0	--------	15.8	15.3	3.5	14.4	20.6	328
21	11.6	5.7	--------	15.6	15.6	7.0	14.4	20.6	242
22	10.9	6.0	--------	16.1	14.2	4.9	14.4	21.1	328
23	16.1	8.2	--------	16.1	15.0	--------	14.4	20.6	328
24	12.0	5.9	--------	15.3	14.2	5.5	14.4	20.6	328
25	12.6	7.0	--------	15.6	14.2	5.6	13.9	18.9	328
26	16.6	8.6	--------	17.2	14.2	10.9	13.9	19.4	328
27	14.4	8.0	13.8	16.1	14.2	9.4	13.9	20.0	328
28	11.0	6.0	--------	14.7	14.4	10.4	13.3	18.9	328
29	10.3	4.0	13.3	15.3	13.3	10.4	13.3	20.0	328
30	16.8	12.6	12.4	15.6	12.8	9.9	12.8	19.4	328
December 1954									
1	8.4	5.0	12.4	13.6	13.3	3.4	13.3	17.8	453
2	11.0	7.0	13.0	13.9	13.0	7.2	12.8	16.7	555
3	16.6	10.2	13.6	15.0	14.2	2.7	13.3	18.3	417
4	19.7	--------	13.6	--------	--------	25.0	13.3	18.9	388
5	13.6	--------	13.0	--------	--------	15.9	13.9	17.2	555
6	9.0	2.9	12.7	--------	--------	4.9	12.8	17.2	555
7	12.1	5.2	12.2	14.4	13.0	7.1	12.8	16.7	555
8	10.0	5.7	11.5	13.9	12.8	9.6	12.8	16.7	555
9	7.5	2.2	12.2	12.6	12.5	4.1	12.2	16.7	555
10	12.1	8.6	12.0	13.9	12.8	7.9	12.2	16.1	555
11	13.0	11.0	12.4	13.9	13.3	9.9	12.2	16.1	555
12	5.3	3.3	11.8	13.3	12.8	14.8	11.7	15.6	555
13	7.2	2.5	11.4	--------	--------	7.6	11.7	15.0	555
14	9.6	4.4	11.2	--------	--------	10.5	11.7	15.6	555
15	8.4	3.1	10.8	--------	--------	8.8	11.1	15.6	555
16	10.4	4.9	10.7	--------	--------	15.7	11.1	14.4	555
17	6.0	1.6	10.1	--------	--------	14.1	10.0	13.9	555
18	9.8	4.5	9.8	11.1	10.3	10.9	10.0	13.3	555
19	11.5	--------	10.0	10.8	10.3	8.6	9.4	12.8	555
20	12.0	--------	11.0	11.1	10.8	--------	9.4	13.9	555
21	10.4	--------	11.1	11.9	11.7	--------	10.6	13.9	555
22	9.5	2.5	10.8	11.7	11.4	3.6	10.6	14.4	555
23	11.4	4.8	10.8	11.4	10.6	3.6	10.0	13.9	555
24	12.4	6.2	10.8	11.4	10.8	4.1	10.0	13.9	555
25	15.6	11.2	10.7	11.4	11.1	9.7	10.6	13.3	555
26	16.4	12.6	10.7	11.1	10.8	8.7	10.6	13.9	555
27	8.4	5.7	10.7	--------	--------	11.3	11.1	14.4	555
28	−0.6	--------	9.6	--------	--------	18.8	10.6	13.9	555
29	0.4	--------	9.0	--------	--------	5.4	8.9	12.8	555
30	3.4	--------	9.0	--------	--------	4.6	8.3	12.8	555
31	7.0	2.0	8.8	--------	--------	4.8	8.3	12.2	555

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre-ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
January 1955									
1	12.7	6.6	9.2	9.4	8.9	----------	8.9	12.2	555
2	13.4	10.0	9.5	10.3	9.1	----------	8.9	12.2	555
3	18.8	15.6	10.0	10.6	9.7	----------	9.4	13.9	555
4	17.5	14.0	10.2	11.1	10.3	8.1	10.0	14.4	555
5	11.2	7.0	10.2	10.8	10.8	8.6	10.6	14.4	555
6	2.3	.8	9.6	10.6	10.6	----------	10.0	14.4	555
7	5.0	2.1	9.2	----------	----------	5.1	10.0	14.4	555
8	6.7	4.6	9.2	----------	----------	4.5	10.0	13.9	555
9	1.0	−.6	8.8	----------	----------	11.2	10.0	13.3	555
10	−1.0	−2.0	8.2	----------	----------	----------	8.9	12.8	555
11	4.3	2.1	8.8	10.6	9.1	----------	9.4	12.8	555
12	5.4	3.0	8.9	----------	----------	3.8	8.9	12.2	555
13	5.3	2.4	8.6	----------	----------	5.5	8.9	12.8	555
14	9.9	8.6	8.8	----------	----------	8.7	8.3	13.3	555
15	5.6	4.0	9.0	----------	----------	8.9	8.9	12.8	555
16	9.0	6.2	8.9	----------	----------	8.3	8.9	11.7	555
17	9.7	7.5	9.5	----------	----------	7.0	8.9	13.3	555
18	5.0	2.4	8.9	----------	----------	16.9	9.4	13.3	555
19	5.8	2.0	8.8	----------	----------	6.2	9.4	12.8	555
20	6.9	3.0	8.4	----------	----------	14.4	8.3	12.2	555
21	5.8	.8	8.0	----------	----------	12.2	8.9	12.2	555
22	2.0	−.4	7.8	----------	----------	10.5	8.3	11.7	555
23	2.1	−.6	7.6	----------	----------	7.9	8.3	11.7	555
24	4.8	.6	7.8	9.1	7.2	6.8	8.3	12.8	555
25	8.0	2.8	7.5	10.0	7.5	6.8	7.8	11.7	555
26	8.6	3.7	7.2	10.6	7.5	8.6	8.3	11.7	555
27	5.1	1.4	7.8	10.8	7.8	6.0	8.3	11.7	555
28	6.4	2.1	8.0	----------	----------	9.8	8.3	11.7	555
29	10.0	3.8	8.1	----------	----------	9.1	7.8	11.7	555
30	11.2	4.6	9.0	----------	----------	4.4	8.3	11.7	555
31	14.1	7.0	8.7	----------	----------	9.7	8.9	13.9	555
February 1955									
1	12.8	5.4	8.4	9.1	7.8	11.2	9.4	12.8	555
2	10.0	4.7	8.3	10.6	9.4	5.2	8.9	12.8	555
3	14.4	12.4	8.9	10.0	9.4	11.6	8.9	12.8	555
4	7.4	5.8	9.8	10.3	9.4	10.4	10.0	13.9	555
5	5.5	4.0	9.8	11.1	9.4	5.7	10.0	13.3	555
6	4.7	3.7	9.8	11.4	9.7	7.6	10.0	13.3	555
7	4.9	1.6	9.6	11.4	9.4	6.6	10.0	13.3	555
8	9.4	3.6	10.0	11.4	10.0	6.1	9.4	13.3	555
9	14.4	6.4	10.2	----------	----------	11.9	10.0	13.9	555
10	2.2	−.3	10.0	----------	----------	17.8	9.4	13.9	555
11	.4	−2.9	9.8	11.4	9.1	4.4	9.4	13.3	555
12	6.0	0	9.2	10.8	9.7	7.4	9.4	12.8	555
13	11.6	5.7	9.4	10.6	8.9	10.4	8.9	12.2	555
14	11.6	----------	9.5	10.8	9.1	5.3	8.9	12.8	555
15	16.1	----------	10.3	10.8	9.4	7.1	10.0	13.3	555
16	10.0	----------	10.2	10.8	10.0	7.3	10.0	13.9	555
17	11.8	----------	10.0	10.6	9.7	6.0	10.0	13.3	514
18	15.5	13.5	10.2	----------	----------	9.4	10.0	17.2	447
19	3.6	----------	10.0	----------	----------	14.6	10.6	15.6	510
20	−1.6	----------	9.5	----------	----------	7.5	10.6	13.3	555
21	1.0	----------	9.0	----------	----------	5.4	10.0	13.3	555
22	2.9	----------	9.4	----------	----------	6.4	10.0	13.3	555
23	7.6	2.6	8.9	----------	----------	7.9	10.0	13.3	555
24	3.4	.6	8.7	----------	----------	11.4	9.4	12.8	555
25	9.3	5.6	8.6	9.4	11.1	6.5	9.4	12.8	555
26	15.9	9.6	9.6	9.7	11.1	9.4	10.0	13.9	555
27	15.8	8.8	10.5	11.4	11.9	4.2	10.0	13.9	555
28	19.1	10.0	11.2	11.9	11.4	9.2	11.7	15.0	555

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre-ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
March 1955									
1	15.5	6.1	12.2	12.5	12.8	5.2	11.7	17.8	328
2	18.0	12.0	12.3	13.9	13.3	4.8	11.7	18.9	328
3	20.8	13.8	12.8	14.4	13.3	8.2	13.3	20.0	328
4	20.6	11.1	14.2	15.0	14.4	7.3	13.9	20.6	328
5	11.8	6.6	13.6	15.3	14.7	11.6	13.3	19.4	328
6	5.7	1.6	12.3	13.3	12.8	9.3	12.8	18.9	328
7	8.8	2.8	12.4	13.9	12.2	6.7	12.2	18.9	328
8	12.0	4.5	12.1	13.9	12.5	7.1	12.8	18.9	328
9	18.8	11.6	12.8	14.7	13.3	10.4	12.8	19.4	366
10	21.6	11.2	13.0	14.2	13.3	15.2	13.9	18.9	544
11	22.6	11.2	13.6	14.2	13.9	11.4	14.4	17.8	555
12	17.3	8.9	13.8	14.4	13.6	5.3	14.4	17.8	555
13	18.7	11.4	14.2	15.3	14.4	5.3	13.9	17.8	525
14	22.8	16.0	15.1	16.1	15.0	10.7	15.0	20.0	402
15	18.9	13.0	15.6	----------	----------	9.7	15.6	20.6	402
16	9.7	4.1	14.4	----------	----------	17.0	15.0	19.4	402
17	14.3	10.0	14.1	15.6	15.3	6.7	14.4	19.4	402
18	10.2	8.6	14.2	15.8	15.6	9.9	14.4	20.0	402
19	13.0	10.9	14.5	15.8	15.3	7.1	14.4	20.0	402
20	17.3	12.0	15.5	----------	----------	8.6	15.6	20.6	402
21	2.1	1.1	14.6	----------	----------	15.2	15.0	19.4	402
22	7.8	2.3	13.8	----------	----------	11.5	14.4	19.4	402
23	14.8	4.8	13.5	----------	----------	13.9	13.9	18.9	392
24	13.8	6.2	13.4	----------	----------	----------	13.9	18.9	492
25	6.5	.8	13.7	----------	----------	----------	13.9	17.8	555
26	−1.5	----------	12.2	----------	----------	14.2	12.2	16.1	555
27	2.3	----------	11.2	----------	----------	4.2	12.2	15.0	555
28	7.7	1.3	10.3	12.8	13.3	6.5	11.7	15.0	555
29	15.0	5.1	11.0	13.3	12.8	9.4	11.7	15.6	555
30	18.4	8.5	11.6	----------	----------	9.4	12.2	17.2	555
31	14.7	6.4	12.8	----------	----------	25.0	12.8	16.7	555
April 1955									
1	12.0	5.4	11.8	----------	----------	19.1	12.2	16.1	555
2	16.0	8.0	11.8	13.6	12.8	5.3	12.2	16.7	555
3	18.0	9.4	12.7	14.2	12.8	12.9	13.3	16.7	555
4	18.3	7.6	13.1	14.7	14.4	5.7	13.9	18.3	555
5	16.8	8.6	13.6	----------	----------	12.9	14.4	18.9	555
6	11.7	6.7	13.4	----------	----------	18.1	13.3	18.9	555
7	11.1	----------	13.4	15.0	14.4	9.6	13.3	18.3	555
8	13.6	----------	12.8	15.3	13.3	7.2	----------	----------	555
9	14.1	10.6	14.0	15.0	14.2	8.0	13.9	17.8	555
10	18.4	10.7	16.0	----------	----------	7.7	13.3	17.8	555
11	21.8	12.4	15.1	----------	----------	16.1	15.3	18.9	555
12	15.6	6.4	15.0	----------	----------	10.3	15.0	19.4	555
13	14.8	8.2	14.2	----------	----------	14.2	14.4	18.9	555
14	19.7	9.0	14.9	15.6	15.3	6.2	14.4	19.4	555
15	24.7	10.7	15.2	16.7	15.6	9.5	15.0	20.0	555
16	25.1	11.2	17.2	17.5	17.2	5.3	16.1	20.6	555
17	26.0	14.7	17.2	17.8	18.1	7.0	16.7	20.6	555
18	25.5	17.6	16.7	18.3	18.3	8.1	16.7	22.2	555
19	23.3	13.5	15.8	18.9	18.1	10.3	17.8	22.8	555
20	21.2	9.2	18.0	18.9	20.3	4.8	17.8	23.3	555
21	24.5	9.4	18.8	18.3	18.9	4.5	18.9	23.6	555
22	25.4	14.9	19.2	----------	----------	5.8	18.9	23.9	555
23	22.0	----------	18.0	----------	----------	23.2	18.9	22.8	555
24	21.9	----------	18.2	18.9	18.9	5.2	17.8	22.2	555
25	26.1	14.0	18.4	19.2	18.9	7.9	18.9	23.3	555
26	27.0	17.9	18.7	19.7	20.0	5.3	18.9	23.9	555
27	26.0	14.0	19.3	----------	----------	7.2	16.7	24.4	555
28	21.0	10.0	19.3	----------	----------	5.0	20.0	25.0	555
29	25.4	17.1	19.2	20.6	20.6	10.8	19.4	25.0	555
30	25.4	17.6	20.1	20.8	20.6	9.1	20.0	23.9	555

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre-ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
May 1955									
1	26.2	18.0	20.4	21.4	21.1	8.0	20.6	24.4	555
2	26.2	15.9	20.5	21.7	20.8	12.2	21.1	25.6	555
3	25.5	13.1	21.2	21.9	21.7	5.9	21.1	25.6	555
4	26.0	16.0	23.1	23.1	22.8	3.7	21.1	26.1	555
5	24.2	17.0	22.2	22.8	22.8	8.0	21.7	26.7	555
6	25.3	16.7	23.2	23.1	23.9	6.8	22.8	27.8	555
7	28.4	15.7	24.3	24.2	24.7	4.4	22.8	27.2	555
8	23.3	17.1	23.0	23.3	23.9	8.7	22.8	26.7	555
9	21.2	17.7	22.2	----------	----------	6.4	22.8	27.2	555
10	18.5	16.4	22.2	----------	----------	12.6	22.8	26.7	555
11	17.4	14.7	22.1	23.6	23.1	7.1	22.2	26.1	555
12	21.1	14.9	23.1	23.9	23.3	4.6	22.2	26.7	555
13	24.6	14.7	24.0	25.3	24.7	7.2	22.8	29.4	345
14	24.8	16.2	23.6	24.4	24.2	6.3	22.8	30.0	345
15	24.7	16.6	23.2	24.4	24.7	6.0	22.8	26.7	490
16	23.5	16.9	23.7	24.4	24.4	9.4	23.3	27.8	555
17	21.0	16.6	23.0	24.4	24.2	8.6	22.8	27.2	555
18	21.1	16.8	22.2	24.2	23.6	12.0	22.2	26.7	555
19	15.4	12.7	21.2	----------	----------	9.4	22.8	26.7	555
20	16.6	13.4	22.5	----------	----------	12.5	22.2	26.1	555
21	22.3	15.1	22.6	23.1	23.1	6.7	22.2	25.8	555
22	24.4	15.9	22.6	23.6	23.1	10.0	22.5	26.1	555
23	21.6	14.6	22.1	24.2	23.1	7.9	22.8	26.7	555
24	25.9	16.0	23.0	----------	23.9	5.4	22.8	27.8	555
25	29.2	15.9	22.8	----------	----------	12.3	23.3	27.8	555
26	23.0	12.5	22.4	23.9	23.1	12.3	23.3	27.2	555
27	25.8	12.8	22.5	----------	----------	10.0	23.0	27.2	555
28	21.9	12.6	22.1	----------	----------	----------	22.8	26.7	555
29	21.6	11.5	22.0	22.5	22.8	----------	22.2	25.6	555
30	24.8	14.1	22.1	----------	----------	----------	22.2	26.1	555
31	26.8	19.2	----------	----------	----------	11.0	22.8	26.7	555
June 1955									
1	25.3	18.6	----------	23.9	23.3	----------	22.8	26.7	555
2	25.1	18.0	22.8	24.4	23.3	7.5	23.3	27.2	555
3	26.0	17.8	----------	25.6	24.2	8.9	23.3	27.5	555
4	26.2	17.8	----------	24.7	23.9	5.2	23.9	27.8	555
5	22.8	15.8	----------	25.0	24.7	7.0	24.4	27.2	555
6	25.3	18.1	----------	25.6	25.0	9.9	23.3	27.8	555
7	27.0	20.9	24.5	25.8	25.6	7.3	23.9	28.3	555
8	24.8	18.5	25.0	26.4	25.3	11.0	24.4	28.3	555
9	16.4	11.4	23.6	----------	----------	12.6	23.9	27.2	555
10	17.8	11.3	22.7	----------	----------	15.5	22.8	26.1	555
11	20.0	13.4	23.2	22.8	23.3	5.7	22.8	26.1	555
12	26.0	15.2	23.0	23.6	23.3	7.6	22.8	26.1	555
13	28.4	16.0	23.0	23.3	23.3	9.6	23.3	27.8	555
14	27.6	----------	23.5	24.7	24.4	9.1	23.3	27.8	555
15	28.3	----------	23.8	25.0	24.4	9.5	23.9	28.9	555
16	27.9	----------	24.5	26.7	25.8	9.4	23.9	28.9	555
17	27.8	----------	24.6	----------	----------	7.8	23.9	29.4	555
18	27.9	19.8	24.6	----------	----------	11.8	24.4	28.3	555
19	25.5	19.0	24.2	25.8	25.0	10.1	24.4	29.4	555
20	23.4	18.5	24.5	25.6	25.6	8.6	24.4	28.9	555
21	26.0	18.2	25.9	27.2	26.7	5.0	24.4	29.4	555
22	26.8	17.2	26.8	27.5	27.2	5.1	25.0	30.0	555
23	28.5	17.1	26.8	28.3	27.8	5.2	25.0	30.0	555
24	29.8	17.4	25.1	----------	26.4	7.0	25.0	30.6	555
25	32.0	18.4	25.5	26.7	26.4	----------	26.1	30.0	555
26	31.5	19.0	25.2	26.4	26.4	----------	26.1	30.0	555
27	30.5	19.6	----------	27.2	27.0	----------	26.1	31.7	555
28	28.0	19.6	26.0	----------	----------	10.5	26.1	31.4	555
29	26.6	21.3	25.8	----------	----------	11.3	26.1	31.1	555
30	29.1	20.7	25.8	----------	----------	9.9	26.1	31.7	555

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
July 1955									
1	29.6	20.8	26.0	27.2	26.4	9.4	26.1	31.7	555
2	27.7	18.6	25.8	27.0	26.1	8.3	26.4	31.1	555
3	28.5	18.0	25.2	26.7	26.1	8.4	26.1	30.0	555
4	28.8	19.6	25.8	27.0	26.1	8.3	26.1	30.6	555
5	29.4	20.2	26.4	27.5	27.0	7.6	26.1	31.7	555
6	30.2	20.3	26.3	27.5	27.0	----------	26.7	32.2	555
7	30.3	19.5	26.3	27.8	27.0	8.5	26.7	32.2	555
8	30.4	18.8	26.2	27.5	26.7	8.2	26.7	32.2	555
9	29.5	20.4	26.5	27.2	26.7	7.4	26.7	32.2	555
10	27.4	19.0	26.2	27.0	27.5	----------	26.7	31.1	555
11	28.6	19.5	26.5	28.1	27.2	----------	26.7	32.2	555
12	30.2	19.6	28.2	29.2	28.9	----------	26.7	33.3	555
13	29.8	20.4	28.2	29.7	30.0	----------	26.7	33.3	555
14	28.1	20.8	27.5	28.9	29.2	5.9	27.2	33.3	555
15	26.8	19.6	28.1	29.2	28.9	4.5	27.8	32.8	555
16	24.9	18.8	28.4	28.9	28.9	----------	27.8	32.8	555
17	23.2	19.3	27.2	28.3	28.3	----------	27.2	31.7	555
18	23.6	20.2	26.2	28.9	28.3	6.1	26.7	31.1	555
19	23.6	19.6	26.4	28.1	27.0	6.3	26.7	30.8	555
20	25.2	18.7	26.4	27.8	27.2	6.4	26.7	31.1	555
21	26.9	19.2	27.0	28.6	27.5	6.3	26.7	31.7	555
22	28.5	19.6	27.0	28.1	28.1	5.0	27.2	32.2	555
23	29.0	19.5	27.5	28.9	28.9	5.1	27.2	32.2	555
24	26.9	20.3	26.8	28.1	28.1	5.8	27.2	32.8	555
25	28.8	19.6	27.0	27.8	27.8	7.7	27.2	32.8	555
26	29.0	20.0	26.3	28.6	28.1	7.9	27.2	32.8	555
27	25.6	21.0	26.2	27.8	27.5	6.5	27.2	31.7	555
28	26.6	19.2	27.0	28.6	28.3	5.4	27.2	32.2	555
29	28.5	20.3	27.5	29.2	29.2	5.3	27.2	32.2	555
30	29.0	20.0	27.8	28.3	29.2	5.1	27.2	33.9	555
31	30.2	19.8	26.8	28.6	28.6	5.4	27.2	32.2	555
August 1955									
1	28.5	19.8	27.0	28.6	29.4	----------	27.2	32.2	555
2	28.0	19.8	27.2	28.3	28.9	7.7	27.8	32.0	555
3	28.8	19.2	27.8	29.4	28.6	4.6	27.8	33.3	555
4	26.0	19.8	27.0	29.4	28.3	6.8	28.3	33.3	555
5	28.2	20.8	27.0	29.2	28.6	6.3	27.8	33.3	555
6	29.0	19.2	27.0	28.6	27.8	6.5	27.8	32.8	555
7	27.9	17.4	26.4	29.2	28.9	4.2	27.8	32.2	555
8	29.9	18.8	27.4	30.3	30.3	3.6	27.8	33.3	555
9	31.0	19.2	28.0	30.0	30.0	3.4	28.3	33.9	555
10	29.0	20.8	27.8	30.0	29.7	6.6	28.9	33.3	555
11	27.3	19.8	27.2	28.3	28.1	8.8	27.8	32.1	555
12	26.5	17.6	27.0	28.6	27.8	7.7	27.5	31.7	555
13	26.9	18.4	27.5	28.9	28.3	5.8	27.8	31.1	555
14	26.7	17.0	27.2	29.2	28.6	5.6	27.5	31.1	555
15	26.2	16.0	26.9	28.6	27.8	5.9	27.2	31.4	555
16	27.4	16.1	27.4	28.3	28.3	3.2	27.2	31.7	555
17	29.2	17.7	27.8	28.9	28.9	2.3	27.2	31.1	555
18	27.2	20.2	27.4	28.9	28.9	6.4	27.2	31.7	555
19	24.3	18.7	26.8	28.3	28.1	5.7	27.2	31.1	555
20	23.1	19.1	26.0	27.5	28.1	6.6	26.7	30.6	555
21	25.4	20.1	25.8	27.8	27.2	6.4	26.7	30.6	555
22	26.9	19.7	25.4	28.3	28.1	----------	26.7	31.7	555
23	28.0	19.0	26.3	28.6	28.1	6.0	27.2	32.2	555
24	29.4	18.6	27.0	28.3	28.1	5.8	27.2	32.2	555
25	30.2	19.6	27.2	28.3	29.2	6.5	27.8	32.8	555
26	28.6	18.1	26.4	28.3	28.3	7.0	27.8	32.8	555
27	28.0	16.7	27.0	28.3	28.3	5.6	27.2	32.2	555
28	27.0	16.7	26.1	29.4	29.2	4.8	27.2	31.1	555
29	29.9	19.6	28.0	28.9	29.2	4.8	27.2	32.8	555
30	25.1	18.2	26.2	27.5	27.5	12.1	27.2	31.7	555
31	23.4	15.2	25.2	27.5	27.0	9.4	26.7	30.6	555

TABLE 9.—*Daily averages of air and water temperatures, wind speed, and flow and temperatures of water used for cooling purposes, from July 1954 to October 1955*—Continued

Date	Average air temperature (°C) at plant intake structure		Average water-surface temperature (°C)			Average wind speed at plant intake structure (mph)	Temperature (°C) of plant cooling water		Flow of plant cooling water (acre-ft)
	Dry bulb	Wet bulb	Intake structure float	Dam float	Buoy line float		Inflow	Outflow	
September 1955									
1	21. 8	13. 3	24. 9	29. 2	27. 0	4. 6	26. 1	30. 0	555
2	24. 8	14. 5	26. 8	28. 3	28. 1	6. 6	25. 6	29. 4	555
3	27. 2	17. 4	25. 7	27. 0	26. 4	7. 3	26. 1	29. 4	555
4	23. 4	15. 6	24. 6	----------	----------	6. 8	26. 1	30. 0	555
5	22. 9	15. 6	24. 3	----------	----------	3. 3	26. 1	30. 0	555
6	24. 4	15. 7	26. 0	27. 2	26. 7	----------	25. 6	29. 4	555
7	25. 8	16. 4	26. 4	----------	----------	1. 9	25. 6	29. 4	555
8	26. 6	17. 0	26. 5	27. 5	27. 5	3. 9	25. 6	30. 0	555
9	27. 0	18. 2	25. 8	----------	27. 0	4. 9	25. 6	30. 0	555
10	26. 0	20. 0	26. 0	----------	----------	8. 2	26. 1	30. 6	555
11	22. 9	16. 0	25. 4	----------	----------	9. 0	25. 6	28. 9	555
12	23. 3	18. 1	25. 2	27. 2	27. 0	4. 6	25. 6	29. 4	555
13	25. 1	18. 2	25. 1	26. 1	25. 6	6. 6	25. 0	30. 0	555
14	26. 6	19. 4	25. 6	----------	26. 4	6. 7	25. 6	30. 6	555
15	26. 8	19. 8	25. 0	26. 7	26. 1	5. 8	25. 6	30. 6	555
16	27. 7	20. 2	25. 8	27. 5	26. 4	7. 4	25. 6	30. 0	555
17	27. 4	20. 6	25. 7	26. 7	25. 8	7. 9	25. 6	30. 0	555
18	28. 5	21. 0	25. 8	26. 7	26. 1	6. 7	25. 6	28. 3	555
19	27. 2	19. 7	25. 5	27. 0	26. 1	4. 5	25. 6	30. 6	555
20	26. 6	18. 8	24. 7	27. 2	26. 1	10. 2	25. 6	30. 0	555
21	28. 2	21. 8	25. 0	----------	----------	5. 1	25. 6	31. 1	555
22	24. 2	20. 6	24. 9	26. 4	27. 0	6. 8	25. 6	30. 0	555
23	23. 7	20. 2	25. 0	26. 1	27. 0	8. 8	25. 6	30. 0	555
24	22. 7	20. 1	24. 8	----------	----------	6. 8	25. 6	28. 9	555
25	23. 7	20. 5	24. 7	----------	----------	6. 7	25. 6	28. 3	555
26	21. 0	18. 2	24. 8	----------	----------	9. 1	25. 0	28. 9	512
27	26. 2	21. 0	25. 0	26. 7	25. 3	6. 4	25. 0	28. 9	512
28	26. 6	20. 8	25. 3	26. 7	25. 6	3. 9	25. 6	30. 6	512
29	27. 8	21. 3	25. 4	27. 2	26. 1	7. 7	25. 6	31. 1	512
30	27. 8	20. 6	25. 5	----------	----------	4. 7	26. 1	30. 6	512
October 1955									
1	22. 8	19. 8	26. 0	----------	----------	7. 2	26. 1	30. 0	512
2	23. 0	20. 0	25. 2	26. 4	25. 8	7. 0	25. 6	28. 3	512
3	22. 7	19. 4	24. 8	26. 1	25. 8	6. 0	25. 0	28. 9	512
4	23. 6	19. 8	24. 6	26. 4	25. 6	9. 1	25. 0	28. 3	512
5	24. 7	19. 5	24. 9	27. 0	26. 1	9. 1	25. 0	28. 9	512
6	20. 7	15. 5	24. 6	26. 4	25. 6	13. 2	25. 0	28. 9	512
7	16. 2	9. 2	24. 4	----------	----------	3. 8	23. 9	27. 2	555
8	17. 0	9. 2	23. 6	----------	----------	4. 8	23. 3	26. 7	555
9	17. 4	10. 0	23. 2	24. 4	24. 2	4. 5	22. 8	25. 6	512
10	19. 9	11. 9	22. 2	24. 2	23. 1	5. 9	22. 2	25. 6	512
11	24. 0	17. 2	22. 5	24. 4	23. 6	8. 0	22. 8	26. 1	512
12	19. 6	14. 5	22. 2	23. 9	23. 3	9. 3	22. 8	26. 1	512
13	16. 9	10. 1	21. 8	23. 9	22. 8	4. 3	21. 7	25. 0	512
14	19. 4	11. 7	22. 6	24. 2	23. 3	3. 4	21. 1	25. 0	512
15	22. 6	11. 6	21. 8	24. 4	23. 6	6. 8	21. 7	25. 0	512
16	19. 4	11. 3	21. 4	22. 5	21. 7	9. 7	21. 7	25. 0	512
17	16. 1	9. 6	20. 8	21. 9	21. 1	6. 1	21. 1	22. 2	512
18	18. 7	10. 8	22. 0	23. 6	23. 1	2. 8	20. 6	24. 4	512
19	22. 3	12. 1	21. 0	----------	----------	6. 5	20. 1	23. 9	555
20	22. 9	12. 8	20. 6	----------	----------	6. 1	21. 1	25. 0	555
21	21. 6	13. 4	20. 6	23. 3	22. 8	4. 4	20. 6	26. 7	328
22	21. 7	14. 5	20. 4	21. 7	21. 4	6. 5	20. 6	26. 1	328
23	19. 8	13. 2	20. 4	22. 2	21. 7	10. 8	20. 6	24. 4	328
24	10. 9	5. 2	19. 4	20. 6	19. 7	6. 0	19. 4	26. 1	328
25	14. 1	5. 6	19. 3	21. 1	19. 4	4. 3	19. 4	25. 6	328
26	19. 8	10. 1	19. 0	20. 8	19. 7	6. 4	19. 4	25. 6	328
27	22. 1	12. 8	18. 7	----------	----------	14. 0	18. 9	25. 6	328
28	14. 0	6. 8	17. 8	----------	----------	14. 0	18. 3	23. 9	328
29	12. 6	5. 3	17. 2	----------	----------	8. 8	17. 8	22. 8	328
30	12. 6	5. 8	16. 8	----------	----------	----------	17. 2	21. 1	328

TABLE 10.—*Mean water temperatures for 3-foot layers for each thermal survey, in °C, for time shown*

Depth of layers (feet)	1954															1955						
	July 21 12:00 m.	July 30 12·15 p. m.	Aug. 9 12:30 p. m.	Aug. 19 12:10 p. m.	Sept. 1 11:15 a. m.	Sept. 13 12:15 p. m.	Sept. 23 12:15 p. m.	Oct. 4 12:15 p. m.	Oct. 15 10:15 a. m.	Oct. 26 10:00 a. m.	Nov. 5 10:50 a. m.	Nov. 16 11:50 a. m.	Nov. 26 10:25 a. m.	Dec. 6 11:10 a. m.	Dec. 21 10:40 a. m.	Jan. 3 11:10 a. m.	Jan. 13 11:30 a. m.	Jan. 24 2:20 p. m.	Feb. 4 9:40 a. m.	Feb. 14 11:05 a. m.	Mar. 1 10:50 a. m.	Mar. 11 9:00 a. m.
0–3	28.8	29.2	28.0	27.4	28.3	26.1	24.5	25.1	21.5	19.4	14.1	15.1	13.2	12.5	9.5	9.4	8.2	7.4	9.6	8.8	11.7	13.7
3–6	28.7	29.0	27.9	27.3	27.3	25.9	24.4	24.8	21.4	19.3	13.8	15.0	13.2	12.5	9.4	9.4	8.2	7.4	9.6	8.5	11.3	13.6
6–9	28.6	28.7	27.8	27.2	27.2	25.8	24.2	24.6	21.4	19.3	13.6	14.9	13.2	12.5	9.2	9.3	8.2	7.3	9.6	8.4	11.3	13.6
9–12	28.5	28.4	27.7	27.1	27.1	25.8	24.1	24.5	21.4	19.3	13.6	14.8	13.2	12.4	9.1	9.2	8.2	7.3	9.6	8.4	11.2	13.5
12–15	28.4	28.4	27.7	27.2	27.1	25.8	24.0	24.4	21.4	19.4	13.8	14.7	13.3	12.3	9.0	9.1	8.3	7.2	9.6	8.5	11.0	13.5
15–18	28.4	28.3	27.6	27.1	27.0	25.8	24.0	24.4	21.4	19.5	14.0	14.7	13.4	12.4	9.0	9.1	8.5	7.5	9.8	8.6	11.0	13.5
18–21	28.3	28.1	27.6	27.1	26.9	25.7	24.1	24.4	21.6	19.6	14.2	14.6	13.5	12.4	9.0	9.2	8.5	7.6	9.8	8.7	10.8	13.4
21–24	28.2	28.1	27.6	27.2	26.8	25.7	24.2	24.3	21.8	19.8	14.4	14.6	13.5	12.7	9.4	9.2	8.9	7.5	9.8	8.8	10.8	13.5
24–27	28.0	28.0	27.7	27.3	26.7	26.0	24.4	24.2	22.1	20.1	14.6	14.6	13.6	12.7	9.3	9.1	8.7	8.0	9.9	8.8	10.6	13.5
27–30	27.6	27.8	27.7	27.3	26.6	26.0	24.4	24.1	22.2	20.1	14.5	14.5	13.6	12.9	9.2	8.7	8.7	7.9	9.9	8.8	10.4	13.4
30–33	27.7	27.4	27.5	27.2	26.4	26.1	24.4	24.1	22.3	20.1	14.7	14.4	13.6	12.9	9.0	8.9	8.6	7.7	9.9	9.0	10.3	13.4
33–36	25.4	25.9	27.1	27.1	26.3	26.0	24.5	24.0	22.3	20.1	15.0	14.3	13.7	12.8	9.2	8.8	8.6	7.6	------	9.0	10.3	13.3
36–39	24.3	24.1	26.5	26.9	26.2	26.0	24.4	23.8	22.2	20.1	15.0	14.1	13.7	12.8	9.4	8.9	8.7	7.4	------	9.1	10.1	13.1
39–42	23.5	23.1	25.1	26.6	26.2	26.1	24.4	23.6	22.1	20.1	15.2	14.1	------	13.1	9.5	8.8	8.6	7.5	------	9.1	10.0	12.8
42–45	23.5	22.4	23.6	25.7	26.0	26.0	24.4	23.6	21.7	20.0	15.5	14.1	------	13.1	9.5	------	8.0	------	------	9.0	9.8	12.7
45–48	23.1	22.1	22.6	24.6	------	26.1	------	------	21.7	------	15.5	13.9	------	------	------	------	------	------	------	------	------	------
48–52	22.5	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

Depth of layers (feet)	1955																					
	Mar. 23 9:05 a. m.	Apr. 4 9:05 a. m.	Apr. 15 10:15 a. m.	Apr. 25 10:50 a. m.	May 5 11:05 a. m.	May 16 1:40 p. m.	May 26 4:30 p. m.	June 6 2:15 p. m.	June 17 11:00 a. m.	June 27 11:10 a. m.	July 7 11:05 a. m.	July 19 11:30 a. m.	July 29 9:10 a. m.	Aug. 8 12:55 p. m.	Aug. 19 11:30 a. m.	Aug. 29 11:45 a. m.	Sept. 8 10:55 a. m.	Sept. 19 10:40 a. m.	Sept. 29 11:45 a. m.	Oct. 10 10:45 a. m.	Oct. 20 11:10 a. m.	Oct. 31 10:35 a. m.
0–3	13.2	13.1	15.2	18.6	22.6	24.6	23.0	25.4	24.6	26.5	26.6	26.7	27.5	30.3	27.6	28.5	26.8	25.6	25.8	22.2	20.7	16.5
3–6	13.2	13.0	15.1	18.6	22.3	24.4	23.0	24.8	24.5	26.5	26.6	26.6	27.4	29.0	27.5	27.8	26.2	25.6	25.6	22.2	20.6	16.5
6–9	13.2	13.0	15.1	18.6	22.0	24.2	22.9	24.3	24.5	26.4	26.6	26.6	27.4	28.5	27.3	27.6	26.0	25.5	25.5	22.1	20.6	16.5
9–12	13.1	13.0	15.0	18.4	21.7	23.9	22.9	23.9	24.4	26.3	26.5	26.5	27.2	28.1	27.2	27.5	25.5	25.4	25.4	22.1	20.6	16.4
12–15	13.2	12.9	15.0	18.2	21.5	23.7	22.9	23.8	24.3	26.2	26.5	26.5	27.0	27.9	27.2	27.4	25.2	25.4	25.4	22.1	20.6	16.5
15–18	13.4	12.9	15.1	18.0	21.4	23.3	22.9	23.7	24.3	26.2	26.5	26.5	26.7	27.7	27.1	27.3	25.9	25.4	25.3	22.1	20.6	16.7
18–21	13.4	12.9	15.1	18.0	21.4	22.8	22.8	23.6	24.2	26.0	26.5	26.4	26.7	27.7	27.1	27.2	24.9	25.4	25.2	22.0	20.5	16.7
21–24	13.6	13.0	15.1	17.9	21.3	22.0	22.8	23.5	24.0	25.8	26.5	26.6	26.6	27.5	27.1	27.1	25.2	25.4	25.2	22.2	20.6	16.7
24–27	13.7	13.0	14.8	17.9	21.1	21.4	22.8	23.5	23.8	25.6	26.4	26.5	26.8	27.4	27.0	27.0	25.2	25.4	25.0	22.3	20.7	16.9
27–30	13.6	12.9	14.6	17.6	21.1	20.9	22.5	23.5	23.6	25.1	26.3	26.5	26.7	27.0	26.9	26.8	25.1	25.4	24.8	22.4	20.7	17.0
30–33	13.5	12.8	14.6	17.6	21.0	20.5	22.6	23.5	23.3	24.5	26.1	26.3	26.7	26.8	26.8	26.6	25.1	25.4	24.8	22.5	20.6	17.3
33–36	13.8	12.9	14.6	17.6	20.8	20.1	22.4	23.4	23.0	24.2	26.0	26.2	26.4	26.4	26.7	26.3	25.1	25.4	24.8	22.8	20.7	17.3
36–39	13.7	12.9	14.7	17.5	21.0	19.9	22.2	23.4	22.9	24.0	25.8	25.8	26.2	26.1	26.5	26.2	25.3	25.2	24.8	23.0	20.7	17.3
39–42	13.8	12.9	14.7	17.5	20.8	19.9	21.8	23.3	22.8	23.6	25.5	25.6	26.0	------	26.4	26.1	25.3	25.2	24.8	22.8	20.7	17.4
42–45	13.8	------	14.7	17.4	20.8	20.0	21.4	23.3	22.8	23.5	25.2	25.5	25.8	------	26.2	------	25.2	------	24.8	22.6	20.7	17.3
45–48	------	------	------	------	------	------	21.6	------	22.8	------	------	------	------	------	------	------	------	------	------	------	20.7	17.2
48–52	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

TABLE 11.—*Lake Colorado City class A evaporation pan data, from July 21, 1954, to October 30, 1955*

Date	July 1954				August 1954				September 1954				October 1954			
	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)
1					0.43			85	0.41			49	0.33			80
2					.49			10	.51			67	.32			97
3					.58			90	.59			92	.41			75
4					.60			100	.53			85	.39			77
5					.66			40	.46			79	.23			145
6					.57			55	.46			77	.17			157
7					.58			65	.25			45	.27			109
8					.42			45	.43			74	.20			66
9					.48			55	.44			80	.30			102
10					.56			35	.52			94	.36			108
11					.61			51	.49			62	.43			89
12					.43			73	.52			80	.34			59
13					.62			104	.45			70	.45			141
14					.72			80	.41			68	.39			124
15					.54			95	.46			84	.01			57
16					.56			105	.47			61	.38			41
17					.58			122	.30			66	.43			69
18					.54			123	.40			72	.31			73
19					.50			99	.48			97	.36			110
20					46			118	.52			102	.35			99
21	0.62			85	.42			129	.59			114	.22			39
22	.58			77	.44			41	.42			.67	.25			99
23	.55			49	.43			67	.47			73	.16			45
24	.51			21	.50			98	.40			68	.19			114
25	.55			20	.35			109	.33			42	.18			116
26	.55			19	.55			95	.42			62	.29			143
27	.60			54	.52			94	.40			80	.12			83
28	.43			44	.43			69	.49			131	.24			89
29	.51			43	.47			83	.23			93	.16			81
30	.53			40	.27			26	.20			114	.22			57
31	.26			45	.38			64					.22			88

Date	November 1954				December 1954				January 1955				February 1955			
	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Min	Wind (miles per day)
1	0.21			113	0.14			63	0.11			64	0.15	67	41	54
2	.13			110	.10			47	.05			43	.12	56	34	108
3	.19			128	.18			44	.06	67		86	.16	68	36	162
4	.20			80	.38			165	.02	64	59	84	.13	50	46	106
5	.20			65	.18			94	.06	60	49	115	.05	54	37	36
6	.18			35	.20			104	.17	50	32	72	.07	50	38	128
7	.19			55	.19			101	.07	47	33	57	.12	49	31	61
8	.16			64	.23			102	.06	47	35	87	.21	61	31	96
9	.12			70	.16			71			34	105	.29	66	32	164
10	.09			32	.08			152	[1].01			66			35	151
11	.13			38	.18			125	.02			33				67
12	.18			60	.12			100	.05			51	[1].48			83
13	.27			98	.05			94	.02	47		111	.17			147
14	.07			78	.24			92	.10	55	32	111	.16	68		73
15	.13			48	.23			128	.05	43	42	77	.20	69	35	63
16	.22			75	.18			128	.10	61	35	67	.21	64	40	73
17	.26			121	.23			192	.10	64	38	126	.18	62	36	122
18	.10			78	.15			82			36	108	.08	63	36	128
19	.14			41	.07			67	[1].23			115			39	147
20	.19			45	.21			28	.16			144				64
21	.20			95	.03			34	.06			116				65
22	.06			46	.21			29				97				85
23	.22			67	.06			30	[1].30			69				139
24	.13			45	.12			82	.07			60	[1].69			88
25	.13			71	.20			125	.21			118	.14			115
26	.29			110	.21			73	.11	53		81	.23	72		59
27	.29			143				94	.14	58	31	73	.21	75	48	59
28	.27			79				29	.23		32	111	.30	73	48	75
29	.18			170				113	.09			57				
30	.21			120	[1].21			62	.19	65		79				
31									.23	61	33	161				

[1] Accumulated evaporation since last observation.

TABLE 11.—*Lake Colorado City class A evaporation pan data, from July 21, 1954, to October 30, 1955*—Continued

Date	March 1955				April 1955				May 1955				June 1955			
	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)
1	0.27	75	45	45	0.44	70	42	123	0.48	89	--------	102	0.41	91	68	70
2	.22	79	45	98	.23	71	43	93	.60	89	62	147	.45	91	67	132
3	.31	82	46	68	.14	76	50	59	.24	90	63	34	.25	91	61	100
4	.36	81	54	86	.11	79	47	54	.54	93	59	83	.50	93	68	107
5	.26	62	53	151	.31	76	50	171	.30	91	63	53	.35	89	62	62
6	.15	53	40	96	.45	64	48	136	.44	93	65	59	.40	90	64	105
7	.23	66	32	61	.26	70	42	101	.42	74	63	58	.41	96	65	90
8	.31	70	33	114	.31	70	43	126	.40	88	63	83	.15	93	70	148
9	.36	75	35	114	.22	66	47	69	.28	81	65	145	.23	70	59	132
10	.44	75	48	114	.10	83	54	24	.06	78	63	65	.40	79	54	110
11	.42	78	53	70	.39	78	55	193	.17	75	61	53	.35	87	56	52
12	.17	62	53	62	.52	72	49	268	.19	89	61	35	.48	90	60	100
13	.26	80	47	87	.46	73	44	82	.72	92	61	69	.51	91	64	91
14	.36	84	41	104	.31	82	46	78	.40	92	62	76	.48	94	64	92
15	.42	78	61	168	.44	81	49	100	.36	90	63	75	.49	94	66	78
16	.24	56	43	142	.51	87	55	50	.38	93	65	119	.37	95	63	120
17	.14	68	43	106	.35	83	55	80	.30	87	60	125	.46	95	69	108
18	.08	55	46	63	.31	79	59	108	.34	87	60	113	.51	93	69	82
19	.27	77	45	80	.54	84	64	74	.27	77	60	111	.40	88	69	187
20	.26	76	46	150	.34	81	52	43	.16	78	57	136	.34	94	65	49
21	.21	54	35	103	.46	84	54	54	.35	90	59	109	.43	93	67	61
22	.31	65	32	171	.52	89	54	146	.53	83	62	64	.45	95	66	37
23	.35	73	33	69	.45	69	56	148	.31	86	60	54	.52	97	65	81
24	.19	77	39	178	.52	83	50	56	.56	92	63	95	.63	94	67	99
25	--------	--------	43	149	.34	83	56	109	.76	88	63	125	.63	96	68	92
26	--------	--------	--------	162	.36	88	59	107	.45	83	59	94	.37	95	70	88
27	--------	--------	--------	143	.51	85	65	98	.58	86	57	142	.76	92	69	97
28	--------	--------	--------	14	.49	82	52	136	.48	81	67	60	.51	95	72	128
29	[1].93	74	--------	92	.49	84	53	156	.69	85	54	127	.47	92	68	134
30	.38	77	44	184	.41	--------	63	102	.24	87	59	98	.64	--------	69	120
31	.44	85	48	258	--------	--------	--------	--------	.52	91	63	128	--------	--------	--------	--------

Date	July 1955				August 1955				September 1955				October 1955			
	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)	Evaporation (inches)	Water temperature (°F) Max	Water temperature (°F) Min	Wind (miles per day)
1	0.48	97	--------	134	0.48	92	71	74	0.31	88	55	41	0.54	87	70	59
2	.57	89	70	93	.42	93	69	50	.40	91	59	40	.17	87	69	83
3	.56	91	69	106	.42	95	69	49	.47	90	62	77	.12	77	64	67
4	.49	93	71	93	.32	91	70	73	.52	90	61	46	.23	81	67	102
5	.80	95	70	97	.38	90	71	64	.19	84	63	47	.31	87	69	66
6	.31	95	71	91	.45	93	70	57	.36	92	61	18	.33	80	66	123
7	.58	94	70	118	.45	95	69	40	.33	92	65	36	.19	77	50	37
8	.64	94	71	114	.44	96	70	42	.41	92	65	40	.14	73	51	33
9	.59	94	71	100	.48	99	70	68	.37	88	65	71	.28	76	48	54
10	.45	88	68	96	.37	90	73	47	.50	94	68	107	.22	77	50	58
11	.51	92	69	55	.49	90	71	85	.31	81	66	23	.06	84	52	65
12	.46	99	69	47	.40	91	65	67	.28	92	65	41	.46	75	63	61
13	.46	99	72	70	.38	93	66	52	.35	90	65	68	.16	77	50	34
14	.53	92	72	48	.47	92	65	54	.31	90	65	60	.20	81	50	56
15	.14	96	70	54	.41	90	64	50	.40	91	67	86	.27	80	52	64
16	.31	91	69	53	.43	94	61	34	.38	92	67	87	.34	75	54	91
17	.21	83	69	45	.51	97	65	32	.28	85	66	86	.23	71	50	42
18	.13	81	69	72	.21	93	68	79	.38	89	71	59	.20	80	48	50
19	.26	91	70	68	.30	93	68	72	.50	92	68	72	.25	79	52	47
20	.37	91	71	80	.19	85	66	69	--------	--------	66	--------	.26	79	52	55
21	.32	93	69	75	.28	87	70	66	[1].54	--------	--------	--------	.23	80	54	55
22	.71	95	71	62	.37	96	70	47	.21	80	--------	62	.22	80	54	33
23	.26	98	70	71	.44	93	71	53	.21	89	68	92	.30	81	57	70
24	.33	90	71	66	.46	95	69	57	.14	88	70	64	.15	67	41	33
25	.49	92	70	81	.51	94	69	96	--------	--------	71	--------	.22	70	35	103
26	.45	94	70	87	.48	96	70	62	[1].84	--------	--------	--------	.27	75	38	132
27	.16	87	68	64	.43	90	64	43	.24	87	--------	67	.40	73	48	67
28	.34	95	70	55	.39	94	65	40	.29	88	68	77	.26	66	49	72
29	.50	99	71	63	.42	97	69	67	.32	91	69	87	.20	69	42	51
30	.44	97	68	36	.39	82	69	87	.33	93	68	68	.20	65	35	65
31	.51	--------	74	62	.39	83	63	61	--------	--------	--------	--------	--------	--------	--------	--------

[1] Accumulated evaporation since last observation.

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