Water-Loss Investigations: Lake Mead Studies

GEOLOGICAL SURVEY PROFESSIONAL PAPER 298

Prepared in collaboration with the U. S. Department of the Navy, Bureau of Ships and Navy Electronics Laboratory; U. S. Department of the Interior, Bureau of Reclamation; and U. S. Department of Commerce, Weather Bureau

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By G. EARL HARBECK, JR., MAX A. KOHLER, GORDON E. KOBERG, *and* OTHERS

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PREFACE

This report is the third and final one of the series on water-loss investigations conducted jointly by several Federal agencies during the years 1950–53. Previous reports are water-loss investigations: Lake Hefner studies, technical report (Geological Survey Professional Paper 269 and also Navy Electronics Laboratory Report 327, San Diego 52, Calif.) and water-loss investigations: Lake Hefner studies, base data report (Geological Survey Professional Paper 270 and also Navy Electronics Laboratory Report 328, San Diego 52, Calif.).

The report, which describes the investigation of evaporation from Lake Mead, was assembled for publication in the Water Resources Division of the U. S. Geological Survey, C. G. Paulsen, Chief Hydraulic Engineer, under the administrative supervision of R. W. Davenport, Chief, Technical Coordination Branch, and under the technical supervision of W. B. Langbein, Hydraulic Engineer.

The report was prepared by U. S. Geological Survey, U. S. Weather Bureau, and U. S. Bureau of Reclamation personnel as shown in the table of contents. The complete report was reviewed by the technical staffs of the cooperating agencies.

R. D. Russell, E. R. Anderson, L. J. Anderson, and J. J. Marciano, of the U. S. Navy Electronics Laboratory, acted as consultants throughout the project. They actively participated in planning the studies and offered much helpful advice and assistance during the period of field observations. Their comprehensive review of the report is gratefully acknowledged.

SYMBOLS AND DIMENSIONS

[The numbers in parentheses refer to the equations where the symbol first appears or where additional clarification may be obtained. There is some duplication of symbols because of the desire to preserve the notation used in the original papers]

Symbol	*Dimensions*	*Description*
c	$L^2T^{-2}\Theta^{-1}$	Specific heat of water (2).
c		Empirical constant (7).
d	L	Zero-point displacement of the wind profile (9).
e	$ML^{-1}T^{-2}$	Vapor pressure (numerical subscript indicates height in meters) (14).
e_a	$ML^{-1}T^{-2}$	Vapor pressure of the air (3).
e_z	$ML^{-1}T^{-2}$	Vapor pressure of the air at height z (4).
e_0	$ML^{-1}T^{-2}$	Vapor pressure of saturated air at the temperature of the water surface (3).
e_0	$ML^{-1}T^{-2}$	Vapor pressure of saturated air at the assumed temperature of the water surface (fig. 38).
k_0		Von Kármán's constant (4).
q'		Empirical constant (10).
t	T	Time (24).
u	LT^{-1}	Average wind speed in x-direction (numerical subscript indicates height in meters) (6).
u_p	LT^{-1}	Average wind speed over evaporation pan (23).
u_z	LT^{-1}	Average wind speed at height z (8).
u_*	LT^{-1}	Friction velocity (4).
x	L	Distance along horizontal coordinate axis (11).
x_0	L	Distance from origin of horizontal coordinate axis (12).
z	L	Distance along vertical coordinate axis (4).
z_0	L	Roughness parameter (4).
D	L^2T^{-1}	Molecular vapor diffusivity (4).
E	L^3	Volume of evaporated water (2) or
M	$ML^{-2}T^{-1}$	Mass of evaporated water from unit area in unit time (4).
E_a	LT^{-1}	Computed pan evaporation (22), assuming $T_0=T_a$.
E_L	LT^{-1}	Lake evaporation (22).
E_p	LT^{-1}	Pan evaporation (23).
I		Denotes Pearson's function $I(X,p)$ (11).
K_0	Θ	Temperature of water surface in °K (fig. 38).
K_0	Θ	Assumed temperature of water surface in °K (fig. 38).
L	L^2T^{-2}	Latent heat of vaporization (2).
M		Auxiliary variable (11).
N		Empirical constant (14).
P	$ML^{-1}T^{-2}$	Atmospheric pressure (3).
Q_a	ML^2T^{-2}	Atmospheric radiation (1).
Q_{ar}	ML^2T^{-2}	Reflected atmospheric radiation (1).
Q_{bs}	ML^2T^{-2}	Long-wave radiation emitted by the body of water (1).
Q_e	ML^2T^{-2}	Energy utilized by evaporation (1).
Q_h	ML^2T^{-2}	Energy conducted from the body of water to the atmosphere as sensible heat (1).
Q_n	LT^{-1}	Net radiation expressed in same units as evaporation (22).
Q_r	ML^2T^{-2}	Reflected solar radiation (1).
Q_s	ML^2T^{-2}	Solar radiation incident to the water surface (1).
Q_v	ML^2T^{-2}	Net energy advected into the body of water by all water volumes entering or leaving the body of water, except that volume leaving as evaporated water (1).
Q'_v	ML^2T^{-2}	Net energy advected into the body of water by all volumes entering or leaving the body of water (table 23).
Q_w	ML^2T^{-2}	Energy advected out of the body of water by the mass of evaporated water (1).
Q_ϑ	ML^2T^{-2}	The increase in energy stored in the body of water (1).
R		Bowen ratio or ratio of Q_h to Q_e (2).
S	$L^{-2}T^2\Theta$	Stability parameter (17).
T	Θ	Temperature (numerical subscript indicates height in meters) (17).
T_a	Θ	Temperature of the air (3).
T_b	Θ	Arbitrary base temperature (2).
T_e	Θ	Temperature of evaporated water (2).

Symbol	Dimensions	Description
T_0	Θ	Water-surface temperature (3).
T_0^*	Θ	Assumed water-surface temperature (fig. 38).
α		An empirical constant (10).
α		Portion of advected energy into a lake utilized for evaporation (fig. 38).
α_p		Portion of energy transfer through pan walls utilized in (or not available for) evaporation (23).
γ		An empirical constant (3) (22)
γ_p		An empirical constant (fig. 37).
δ_l	L	Thickness of the laminar film (4).
ν	L^2T^{-1}	Kinematic viscosity of the air (4).
ρ	ML^{-3}	Density of the air (4).
ρ_e	ML^{-3}	Density of evaporated water (2).
Γ		The gamma function (12).
Δ		Slope of saturation vapor pressure versus temperature curve (22).
χ	ML^{-3}	Vapor concentration per unit volume (11).
χ_0	ML^{-3}	Saturation vapor concentration (11).

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WATER-LOSS INVESTIGATIONS: LAKE MEAD STUDIES

By G. Earl Harbeck, Jr., Max A. Kohler, Gordon E. Koberg, and others

ABSTRACT

A comprehensive study to determine the evaporation loss from Lake Mead was made during the period March 1952 to September 1953. Techniques of measuring evaporation tested during the course of an interagency cooperative investigation conducted at Lake Hefner, Okla., were used.

Evaporation from Lake Mead during the 1953 water year as determined from this investigation was found to be 875,000 acre-feet, equivalent to a depth of slightly more than 7 feet over the lake surface. Techniques were developed for the continuing determination of monthly evaporation from the reservoir.

INTRODUCTION

By G. Earl Harbeck, Jr., U. S. Geological Survey

Storage began in Lake Mead in 1935, and since then hydrologists and hydraulic engineers have speculated on the quantity of water lost by evaporation from the reservoir. The usual method of evaporation measurement had been through the use of evaporation pans, of which the widely accepted Weather Bureau class A pan is one example. Differences in pan design, the difficulty of obtaining for comparative purposes a precise water budget for a large reservoir, and the scarcity of records from regions as arid as the location of Lake Mead—all supported the desirability of obtaining an independent evaluation of Lake Mead evaporation for comparison with the large evaporation losses that were observed at the Weather Bureau class A pans at Boulder City, Nev., and in the vicinity of Lake Mead.

The determination of evaporation loss as a residual quantity, using the well-known technique of measuring inflow and outflow and accounting for changes in reservoir storage, was soon found to be impracticable because of the overshadowing effect of even small percentage errors in measuring the relatively large volumes of inflow and outflow. Unmeasured inflow, although not large in comparison with evaporation, is sufficiently great that errors in estimating it cast further doubt on the validity of the evaporation figures thus determined. Moreover, it was realized that "bank" storage in the reservoir, or ground-water storage in the voids in the gravel, sand, and other rock material that underlie the reservoir, which is unaccounted for by a hydrographic survey, was of considerable magnitude. Bank storage may add a substantial volume of storage to the commonly used figure of capacity indicated by a hydrographic survey, but a direct measurement of bank storage is not practicable and it must be determined by other means.

Since the magnitude of possible errors in estimating unmeasured inflow and changes in bank storage indicated that accurate determinations of evaporation by measuring the inflow, outflow, and change in storage were not possible, better techniques for the measurement of evaporation were sought. Not only was an accurate evaluation of the evaporation loss considered desirable, but it was believed that when such data were available one of the unknowns in the water budget would be removed and the problem of estimating unmeasured inflow and bank storage could be attacked with more hope of success.

HISTORICAL REVIEW

A historical review of developments leading to the present study of evaporation from Lake Mead was prepared by Russell (U. S. Geol. Survey, 1954a, p. 1–2) in the interagency report describing the Lake Hefner studies. Both the Lake Mead and Lake Hefner studies were outgrowths of studies conducted at Lake Mead by representatives of the Navy and Interior Departments in 1947–49. The possibility of applying certain recently developed techniques for the determination of evaporation from Lake Mead was recognized, and preliminary estimates of monthly evaporation from Lake Mead were made by Anderson and Pritchard (1951) on the basis of scant limnological and meteorological data obtained during the early studies in connection with their report on the physical limnology of the lake.

The need for additional data with which to subject these techniques to a rigorous test was immediately apparent. At a conference of the collaborating agencies held in Boulder City in December 1948, it was decided (1) to investigate the mass-transfer and energy-budget techniques for the determination of evaporation and ultimately to apply one or both of them, if suitable, to a determination of evaporation from Lake Mead, and (2) if possible to develop techniques for the determination of evaporation from existing and proposed reservoirs on the basis of climatological and limnological data. A report was later prepared by Anderson, Anderson, and Marciano (1950) that reviewed current evaporation theory and described the instrumentation developed for the proposed investigation.

The Weather Bureau had long recognized that additional information was needed concerning the areal and seasonal variation in the pan coefficient, which is the ratio between pan and lake evaporation. Studies by the Weather Bureau of evaporation from its standard class A pan and from other types of pans were included in the proposed program.

Because of its hydrologic complexity and the possible effect of the rugged terrain on meteorological factors, Lake Mead was considered unsuitable for the purpose of testing the techniques. Although data were lacking, it was believed that the terrain surrounding Lake Mead has a considerable effect on wind patterns over the lake. In order that information might be available on which to base a decision as to the proper location of meteorological instruments when the study was eventually made at Lake Mead, it was deemed essential that a study be made of wind patterns in Boulder Basin. That study, which was made by the Weather Bureau and the Bureau of Reclamation during the period August 1950 to October 1951, is described in this report.

Lake Hefner at Oklahoma City was chosen for the tests of the energy-budget and mass-transfer techniques, after an exhaustive study of the suitability of lakes and reservoirs in western United States (Harbeck, 1951). At Lake Hefner accurate determination of evaporation by the water-budget method was possible, thus providing a control for the evaluation of results obtained by the energy-budget and mass-transfer techniques.

The Lake Hefner studies (U. S. Geol. Survey, 1954a) showed the energy-budget technique to be rigorous and dependable for the determination of evaporation from most reservoirs for periods of a week or longer. Two of the mass-transfer equations tested at Lake Hefner gave satisfactory results, as did a quasi-empirical equation developed from the Lake Hefner data. The studies made by the Weather Bureau indicated that previous values of annual pan-to-lake coefficients were reasonably consistent with those found at Lake Hefner. A pronounced seasonal variation was observed.

PROBLEM AT LAKE MEAD

The primary problem at Lake Mead was to determine evaporation from the reservoir. It was decided (1) to use as a control the energy-budget method, which was supported on rigorous principles and had been proved by the Lake Hefner studies to give satisfactory results; (2) to test further the two mass-transfer equations that had given satisfactory results at Lake Hefner; (3) to test the quasi-empirical equation, in order to determine whether the constant in this equation that had been determined for Lake Hefner was also applicable to Lake Mead; (4) to test further the Cummings radiation integrator (CRI), which offered considerable promise as a substitute for the expensive radiation-measuring equipment that had been used at Lake Hefner (Harbeck, 1954); and (5) to investigate the areal variation in net radiation received at Lake Mead, to determine whether records obtained at one station in Boulder Basin could be considered representative of the entire lake.

Further investigations of pan-to-lake coefficients were considered advisable in order to obtain more information as to their areal and seasonal variation. Although the energy-budget results at Lake Mead were not expected to be as accurate as the water-budget control at Lake Hefner, annual figures were expected to be adequate for another check of the annual coefficient determined at Lake Hefner. The monthly results were expected to be of adequate accuracy to indicate whether the seasonal variation at Lake Mead corresponds to that at Lake Hefner.

Equipment was moved from Lake Hefner to Lake Mead in the autumn of 1951. Most of the next winter was spent in installing equipment at Lake Mead. Observations were begun on March 1, 1952, and were continued until September 30, 1953, the end of the 1953 water year.

PERSONNEL

GENERAL SUPERVISION

Geological Survey.—R. W. Davenport, chief, Technical Coordination Branch, Water Resources Division, assisted by W. B. Langbein, gave general supervision to the work of the Survey. G. E. Harbeck, Jr., was responsible for field operations and liaison and for the preparation of this report, in which he was assisted by G. E. Koberg. J. H. Gardiner, district engineer, Surface Water Branch, Tucson, Ariz., exercised administrative supervision over Geological Survey personnel stationed at Boulder City. The engineer-in-charge of the Boulder City office of the Surface Water Branch has been assigned the responsibility for the continuing computations of evaporation from Lake Mead.

Bureau of Reclamation.—J. R. Riter, chief development engineer, Project Investigation Division, was in general charge of the work for this Division of the Bureau, with consultation provided by W. U. Garstka, head, River Regulation Section. C. P. Vetter, chief, Office of River Control, Region III, succeeded by J. W. Stanley, regional river control engineer, was in general charge for the Bureau at Boulder City, with R. P.

Leatham responsible for technical aspects of the work. R. B. Spearman, chief, Civil Engineering Branch, Engineering Division, was the technical representative for Boulder Canyon Project, which will continue to obtain basic data for the evaporation determinations as part of the normal project activities.

Weather Bureau.—W. E. Hiatt, chief, Hydrologic Services Division, was in general charge for the Bureau, with technical direction by M. A. Kohler, chief research hydrologist. V. W. Rupp, western area engineer, was responsible for general field liaison, and C. A. Carpenter, meteorologist in charge of the Las Vegas station, for local liaison. M. A. Kohler, T. J. Nordenson, and W. E. Fox prepared that part of the report describing the studies made by the Weather Bureau.

Bureau of Ships.—E. L. Schwab, Jr., Cdr., USN, head, Sonar Design Branch, Electronics Division, was responsible for the Bureau's participation, with technical direction and liaison by B. K. Couper, oceanographer, Sonar Design Branch. G. B. Cummings, then civilian assistant, Sonar Branch, represented the Bureau during the time that the project was being planned.

Navy Electronics Laboratory.—R. Dana Russell, senior consultant (geophysics), was in general charge for the Laboratory, with E. R. Anderson acting as technical consultant for the energy-budget studies, J. J. Marciano for the mass-transfer studies, and L. J. Anderson for instrumentation.

FIELD AND OFFICE PERSONNEL

C. P. Vetter, succeeded in April 1953 by J. W. Stanley, acted as technical coordinator for Bureau of Reclamation, Geological Survey, and Navy personnel at Lake Mead.

Installation of most of the equipment at Lake Mead was made by Bureau of Reclamation, Geological Survey, and Navy personnel working together. The Weather Bureau class A pan station on Boulder Island was installed by H. N. Schwartz of the Weather Bureau office at Phoenix.

Until their detachment on May 1, 1953, C. C. McCall, Lt., USN, assisted by J. D. M. Freitas, MNC, USN, and H. E. Knudsen, MNC, USN, who were assigned to the project by the Bureau of Ships, operated the meteorological equipment on the Boulder Basin barge, on Boulder Island, and on the raft in Boulder Wash. They also made the thermal surveys of the lake.

The operation and maintenance of the CRI station at Boulder Island, Overton Arm, and Bonelli Landing, and the raft stations at Overton Arm and Temple Bar, were under the direct supervision of H. O. Wires, U. S. Geological Survey, with assistants furnished by the Bureau of Reclamation. After the detachment of Navy personnel, Wires also assumed responsibility for the operation and maintenance of all equipment at Lake Mead, including the making of the thermal surveys. He was then assisted by C. W. McCuin of the Bureau of Reclamation, and for a short time by F. W. Kennon of the Geological Survey.

Operation of the gaging stations—Virgin River near Littlefield and Colorado River below Hoover Dam (under the immediate supervision of F. S. Anderson) and Colorado River near Grand Canyon and Bright Angel Creek near Grand Canyon (under the immediate supervision of A. G. Hely)—and the furnishing of resulting discharge records were the responsibility of the Tucson District of the Geological Survey, J. H. Gardiner, district engineer.

Processing of the data and computation of results at Boulder City was under the immediate supervision of G. E. Koberg of the Geological Survey, assisted by Mildred K. Hunter and E. A. Massa of the Bureau of Reclamation. Analysis of the mass-transfer data was made by G. E. Harbeck, Jr., assisted by G. E. Koberg.

Processing of data for the Weather Bureau section of the report was performed in the Hydrologic Investigations Section, Hydrologic Services Division, by J. T. Riedel, assisted by J. W. Miller, Margaret R. Langston, and Madeline B. Triplett.

Photographs of all field installations were made by the Bureau of Reclamation; some are used as illustrations in this report.

GENERAL DESCRIPTION OF LAKE MEAD

By G. Earl Harbeck, Jr., U. S. Geological Survey

RESERVOIR AREA AND THE DAM

Lake Mead, the largest reservoir in the United States, is located on Colorado River, which in this area is the boundary between Nevada and Arizona. The lake is formed by Hoover Dam, a concrete arch-gravity structure that has a maximum structural height of 726.4 feet. Although the dam was completed in 1936, storage began during the previous year. A complete description of the dam and reservoir has been prepared by the Bureau of Reclamation (1941). The physical limnology of the lake has been described by Anderson and Pritchard (1951).

A hydrographic survey of Lake Mead was made by agencies of the Department of the Interior and the Department of the Navy in 1948–49. A report describing the studies was prepared by Smith, Vetter, Cummings, and others (in preparation) and summarized by Thomas (1954). At the time of the survey the total capacity at maximum water-surface elevation (1,221.4 ft), exclusive of surcharge, and with gates in a raised position, was 29,827,000 acre-feet, of which 2,620,000

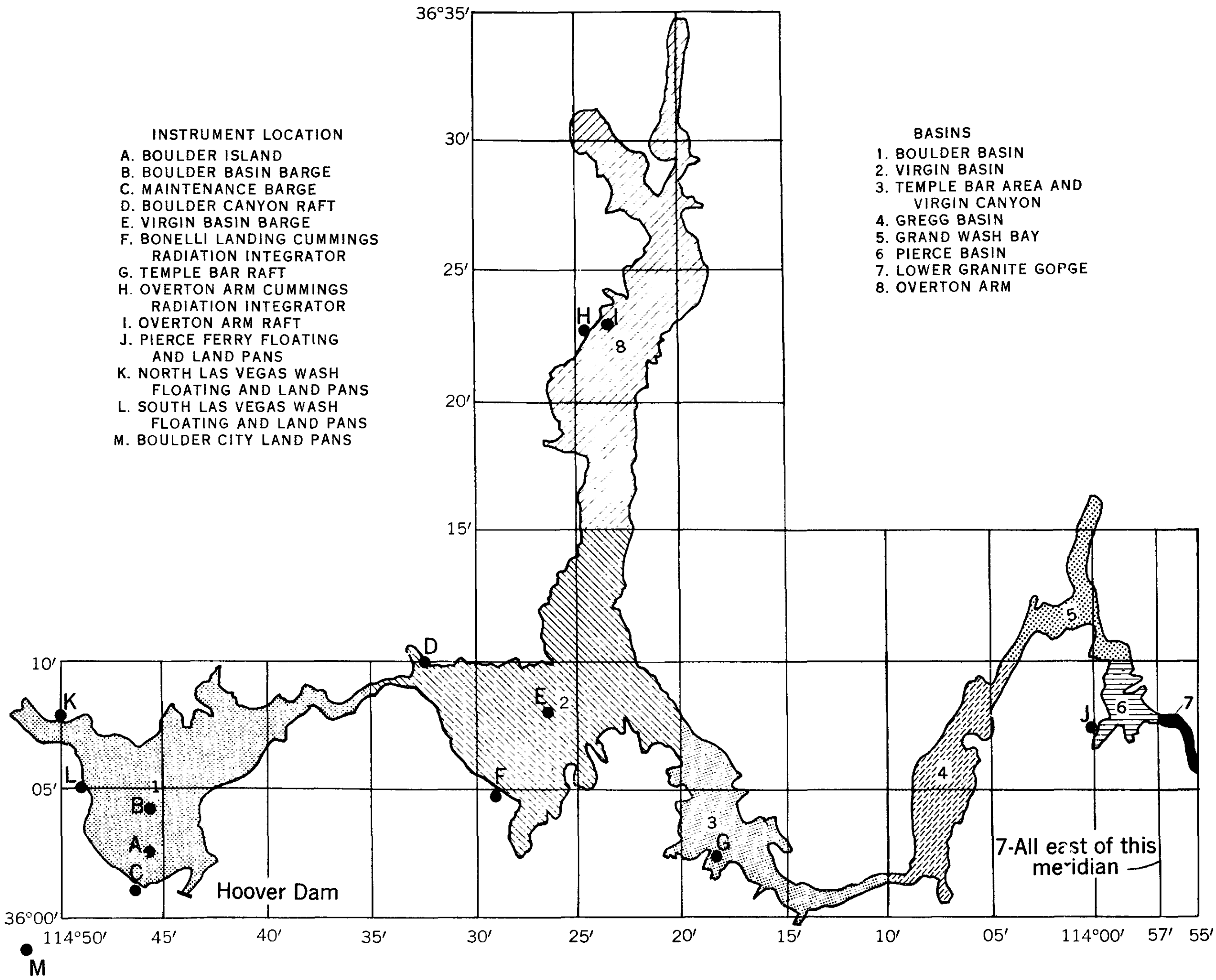

FIGURE 1.—Map of Lake Mead showing location of instruments.

acre-feet was dead storage below the sill of the lowest outlet. For flood-control operation, total capacity, including surcharge, was 31,047,000 acre-feet. The water-surface area at maximum controlled water-surface elevation was 158,000 acres. As these are the latest figures available, they are used as a basis for computations in this report. The lake is extremely irregular in shape. Boulder and Virgin Basins (numbered 1 and 2 on fig. 1) contain about 60 percent of the total storage in the reservoir.

During the period covered by this report, March 1, 1952, to September 30, 1953, reservoir elevation varied from 1,133.2 feet in April 1952 to 1,201.1 feet in July 1952. Correspondingly, surface area varied between 108,000 and 146,000 acres, and total content, between 18,231,000 and 26,743,000 acre-feet (see fig. 2). Inflow during the 1952 water year was considerably greater than in 1953 (see fig. 3), and the maximum elevation attained in 1953 was 1,166.5 feet, approximately 35 feet lower than in 1952.

CLIMATOLOGY

The climate at Lake Mead is arid. Mean annual temperature at Las Vegas is 66°F (19°C) and annual precipitation is less than 5 inches, according to Weather Bureau records. Maximum temperatures of 110°F (43°C) are not uncommon in July and August. Average minimum temperature in January is 30°F (−1°C). Winds are generally light.

Figure 4 illustrates the relation between water-surface temperature at Lake Mead and air temperature at Lake Mead and Las Vegas. It will be noted that water-surface temperatures lag about 1 month behind air temperatures. A lag of about one-half month was observed at Lake Hefner, Okla., a much smaller lake. Winds at Lake Hefner were much stronger, however,

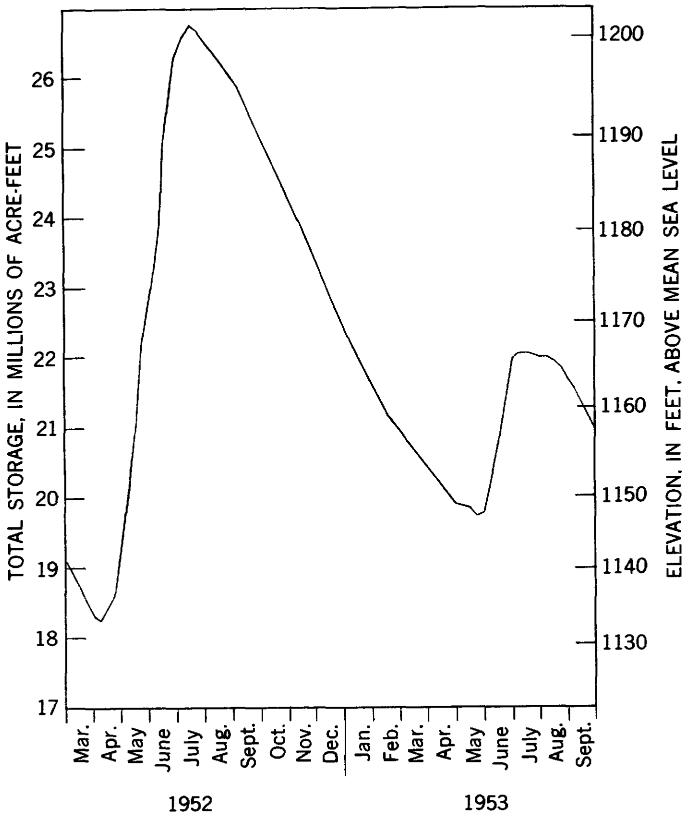

FIGURE 2.—Monthly variation in total contents of Lake Mead.

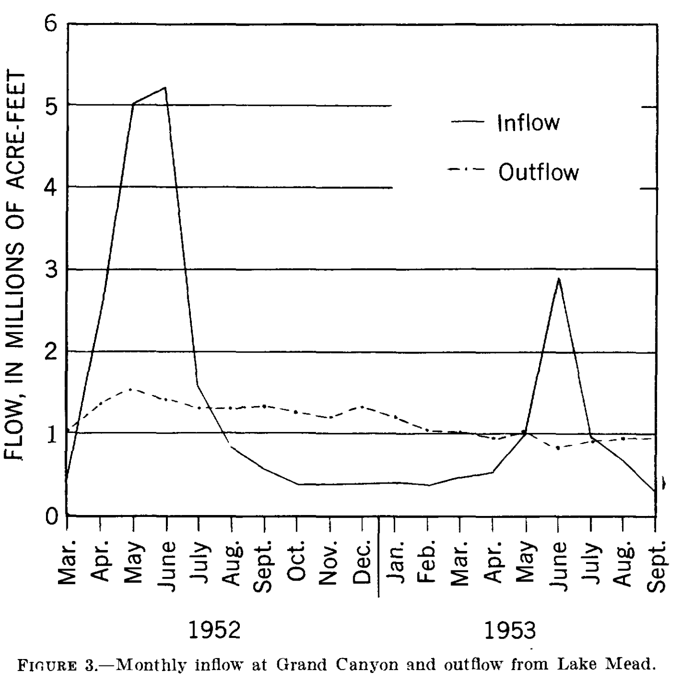

FIGURE 3.—Monthly inflow at Grand Canyon and outflow from Lake Mead.

and thermal stratification was almost entirely absent. For the period July 1, 1952, to June 30, 1953, average air temperature at the 8-meter level at the barge in Boulder Basin was 20.9°C, and at Las Vegas airport 19.0°C. Average water-surface temperature for the

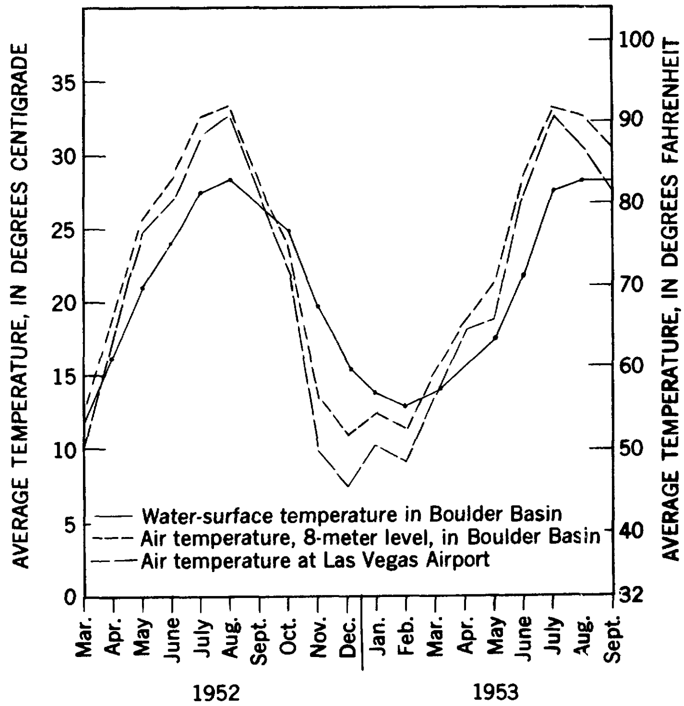

FIGURE 4.—Variation in monthly average air temperature at Lake Mead and at Las Vegas, Nev., and in water-surface temperature at Lake Mead.

same period was 19.8°C. Nearly all of the difference in air temperatures is attributable to the fact that the altitude of Las Vegas airport is about 1,000 feet higher than Lake Mead.

The relation between wind speed at the 8-meter level at the barge in Boulder Basin and wind speed at the Las Vegas airport is shown in figure 5. Wind speeds over the lake are in general higher than at the airport. The anemometer at the airport is almost exactly 8 meters above the ground so that the records are comparable in this respect. During much of the year the circulation is thermally induced rather than the result of large-scale cyclonic activity, and the local terrain has a great influence on both wind speed and direction (see section on wind patterns over Boulder Basin). It is not surprising, therefore, that the correlation between wind speeds at the two locations is no better than fair.

The correlation between vapor pressure at Lake Mead and at Las Vegas is shown in figure 6. If the vapor pressure at Las Vegas can be considered representative of unmodified air in this region, it is apparent that the air over Lake Mead is substantially modified during its passage over the lake. It is also apparent that the vapor blanket extends above the 8-meter level at midlake. In general the vapor pressure difference between the 2- and 8-meter levels is less than the difference between Las Vegas and the 8-meter level. It should be noted that the correlation between vapor

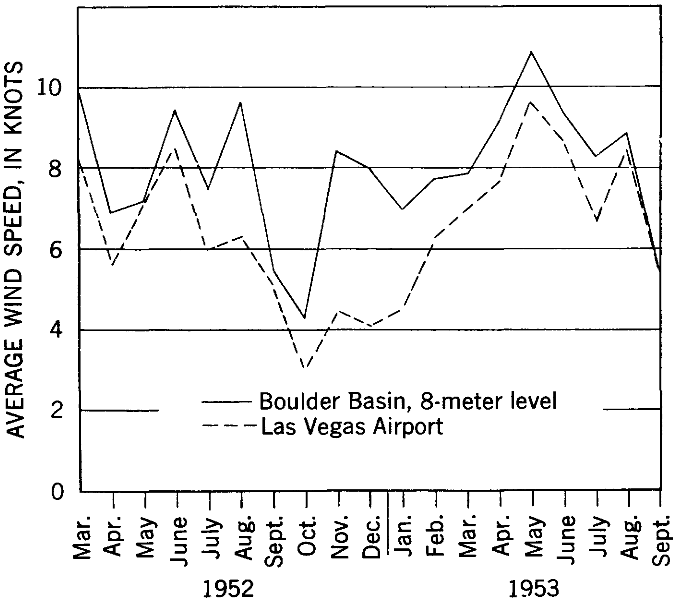

FIGURE 5.—Variation in monthly average wind speed at Lake Mead and at Las Vegas, Nev.

pressures at Lake Mead and Las Vegas is much better than between wind speeds at these two locations.

Figure 7 was prepared to indicate the extent to which conditions during the period March 1952 to September 1953 were near normal. As past records for comparison purposes were lacking at Lake Mead, the only recourse was to base the comparisons on records obtained at the Weather Bureau station at the Las Vegas airport. The site of the station was changed during the period 1937–52 and the locations of certain instruments were also changed, but it is believed that the usefulness of the record for general comparative purposes has not been affected thereby. Studies made by the Weather Bureau, which are described in a subsequent chapter, indicate that the change was significant with respect to dewpoint. Records of evaporation from a class A pan at Boulder City are also shown in figure 7.

Pan evaporation was somewhat below normal during the 19-month period. During the water year ending September 30, 1953, pan evaporation was 4 percent below the 1936–53 average. Percentage of both sunshine and air temperature were slightly above normal. Humidity was below normal. Precipitation during the 1953 water year was above normal at the Las Vegas airport; but, on the basis of other precipitation records at stations at Lake Mead, precipitation on the lake was apparently below normal during this period, which is quite possible in view of the areal variability of desert rainfall. On the basis of the preceding comparisons, it must be concluded that, generally speaking, weather conditions were not greatly different from normal.

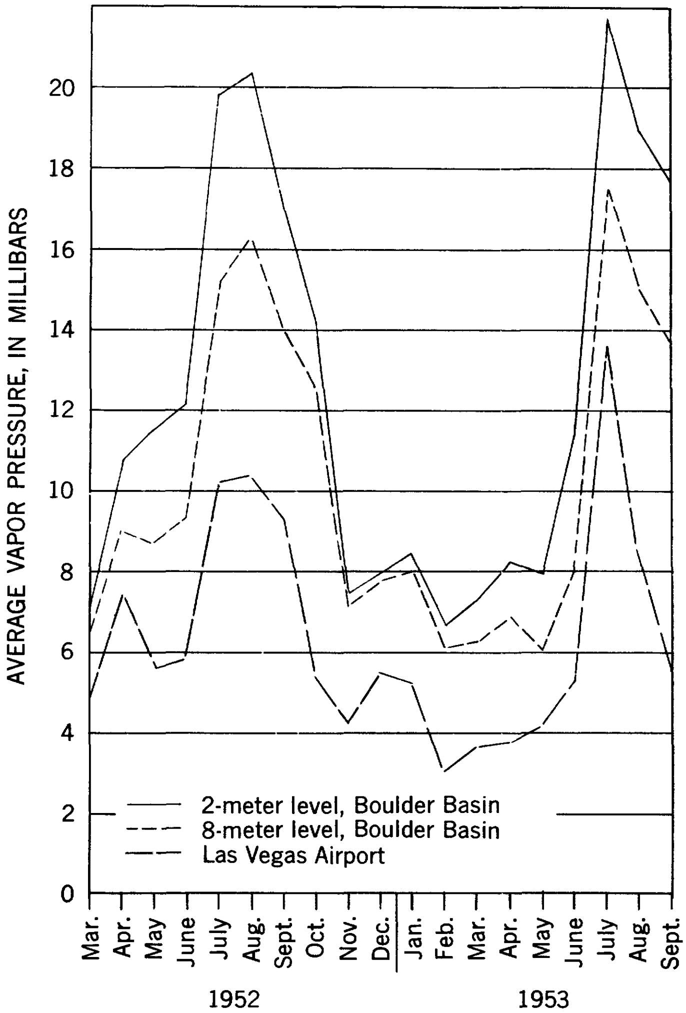

FIGURE 6.—Variation in monthly average vapor pressure at Lake Mead and at Las Vegas, Nev.

WIND PATTERNS OVER BOULDER BASIN

By MAX A. KOHLER, U. S. Weather Bureau

Because of the cost of instrumentation and collection and analysis of the data, particularly for the turbulent transport approach, it was evident that planned observations at Lake Mead would, of necessity, be limited to a rather small segment of the reservoir. To make the most of such a limited program, a knowledge of the wind pattern over the reservoir was deemed necessary in order that the most nearly representative sites could be selected for the observational equipment. It is this phase of the program (determination of flow patterns) for which the wind analyses reported herein were conducted.[1] (U. S. Weather Bureau, 1953).

[1] This phase of the Lake Mead study is presented in greater detail in the cited report. Because the work was an integral part of Lake Mead studies, however a summary is included herein.

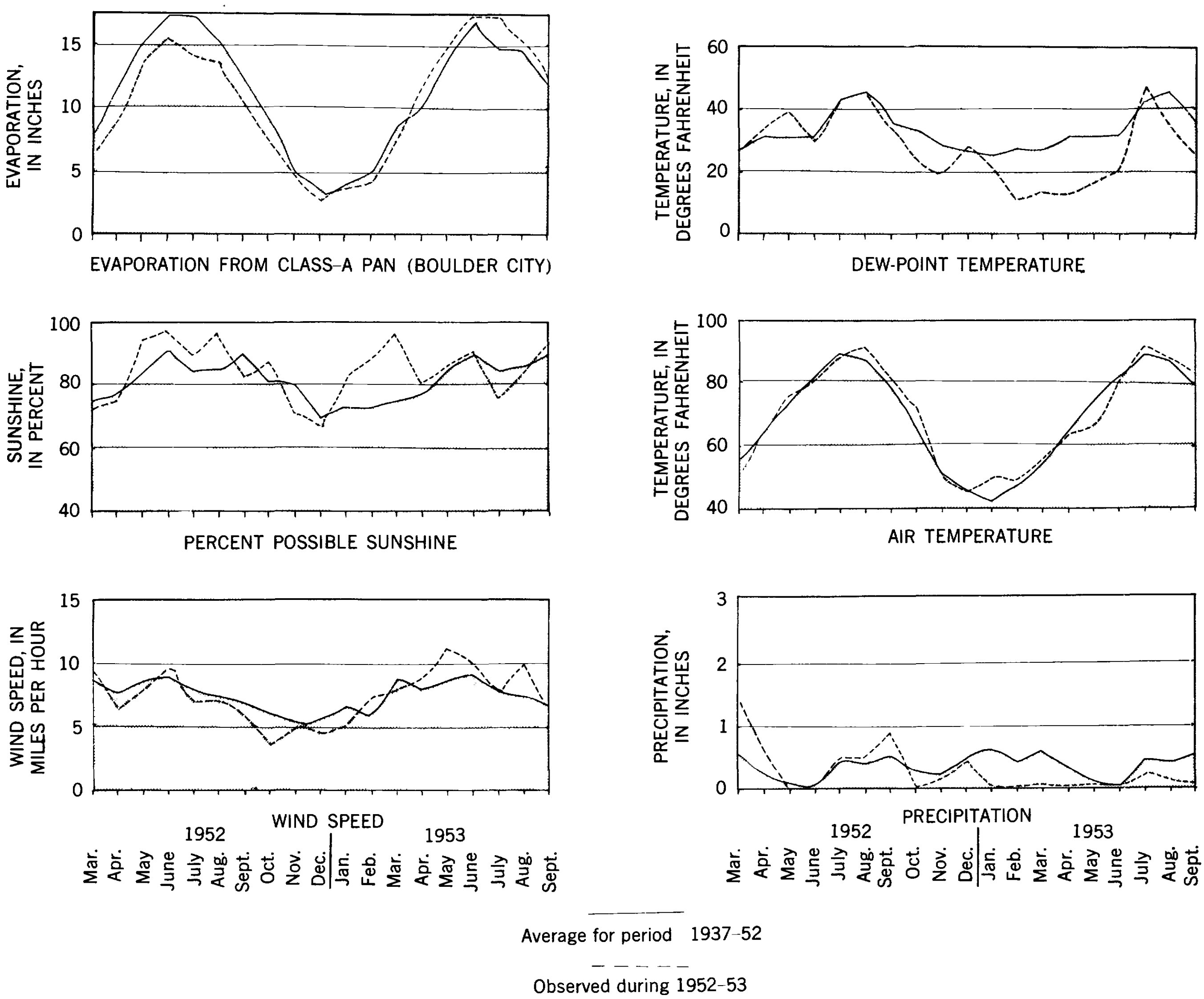

FIGURE 7.—Comparison between meteorological data at Las Vegas, Nev., during 1952-53 and averages for 1937-52.

At a conference of the cooperating agencies held in Oklahoma City in April 1950, it was agreed that initial mass-transfer studies at Lake Mead would be confined to the lower part—the Boulder Basin. It was further agreed that a network of recording wind stations should be established in this area as soon as feasible and operated for a period of at least 1 year, to determine the local flow patterns. The Weather Bureau was to furnish the necessary instruments and analyze the records, and the Office of River Control of the Bureau of Reclamation was to undertake installation and maintenance of the equipment.

At a subsequent conference in Boulder City in April 1950, representatives of the Bureau of Reclamation, the Navy, and the Weather Bureau discussed detailed arrangements relative to instrumentation, installation, and operation of the network and made an inspection of Boulder Basin to select sites for the wind stations. Nine sites were selected (see fig. 8), consideration being given to their accessibility, the time required for servicing of equipment, height above water level, and availability of suitable equipment.

There was some delay in shipment of the instruments and in construction of the masts and shelters, consequently the network was not placed in operation until June 15, 1950. Because of instrumental difficulties, the records collected prior to the first of August were not suitable for analysis. The 9 stations were closed October 31, 1951, providing 15 months of data for analysis.

On March 27, 1951, one additional wind station was established at Pierce Ferry (fig. 8), in the Colorado arm of Lake Mead, to provide information required by the Bureau of Reclamation. Although there are about 7 months of record for this station concurrent with that

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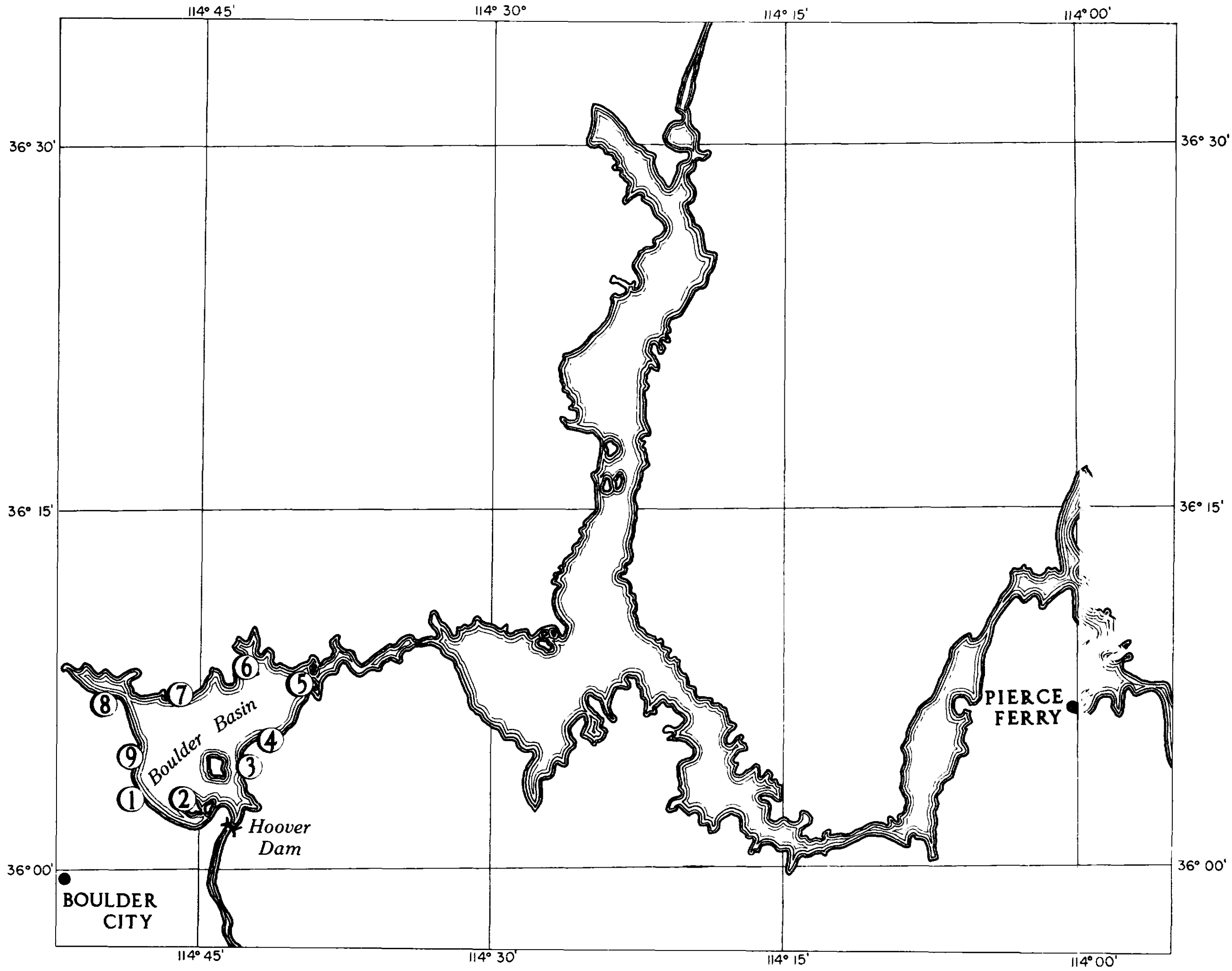

FIGURE 8.—Map of Lake Mead showing location of stations used in study of wind patterns.

from the original network, it has been excluded from the wind rose charts principally because of its rather remote location. The data for this station are summarized elsewhere (U. S. Weather Bureau, 1953).

DESCRIPTION OF NETWORK

The locations of the 10 stations (including that at Pierce Ferry) are shown on the map of figure 8. Although an effort was made to select sites within a relatively narrow elevation range, other considerations resulted in the selection of locations ranging in elevation from 1,211 to 1,296 feet, as follows:

Station	Elev (ft)	Station	Elev (ft)	Station	Elev (ft)
1	1, 296	4	1, 237	7	1, 257
2	1, 260	5	1. 234	8	1, 216
3	1, 211	6	1, 235	9	1,265

The Pierce Ferry station was installed adjacent to the existing class A evaporation station at an elevation of approximately 1,370 feet.

The anemometers were mounted with the cups about 8 feet above the ground surface, and the vanes were about 2 feet higher (fig. 9). It should be pointed out that the height of the instruments above the water surface varied considerably during the observational period because of seasonal fluctuations in contents of the reservoir. Variations in reservoir level are shown graphically in figure 10.

ANALYSIS AND RESULTS

Wind roses and other types of wind frequency data are customarily presented in terms of percent of time, primarily because observations of wind direction are normally taken as a time series. The recorders used in this study provided an observation of wind direction each time the anemometer indicated an accumulated wind movement of 2 miles, and thus the data are in a form directly suitable for computation of percent of wind movement from each direction. Inasmuch as

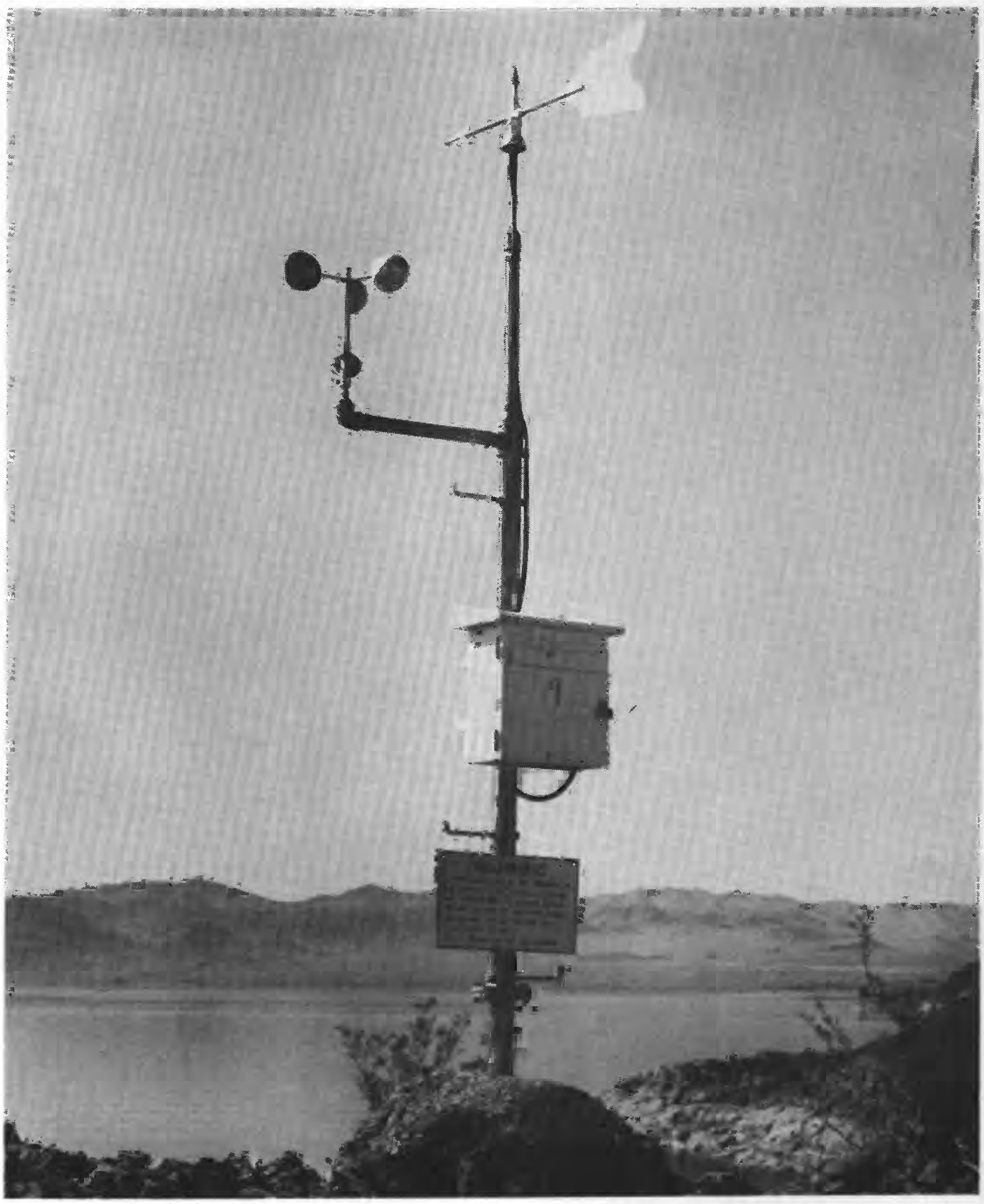

FIGURE 9.—Anemometer and vane at station 9. Photograph by Bureau of Reclamation.

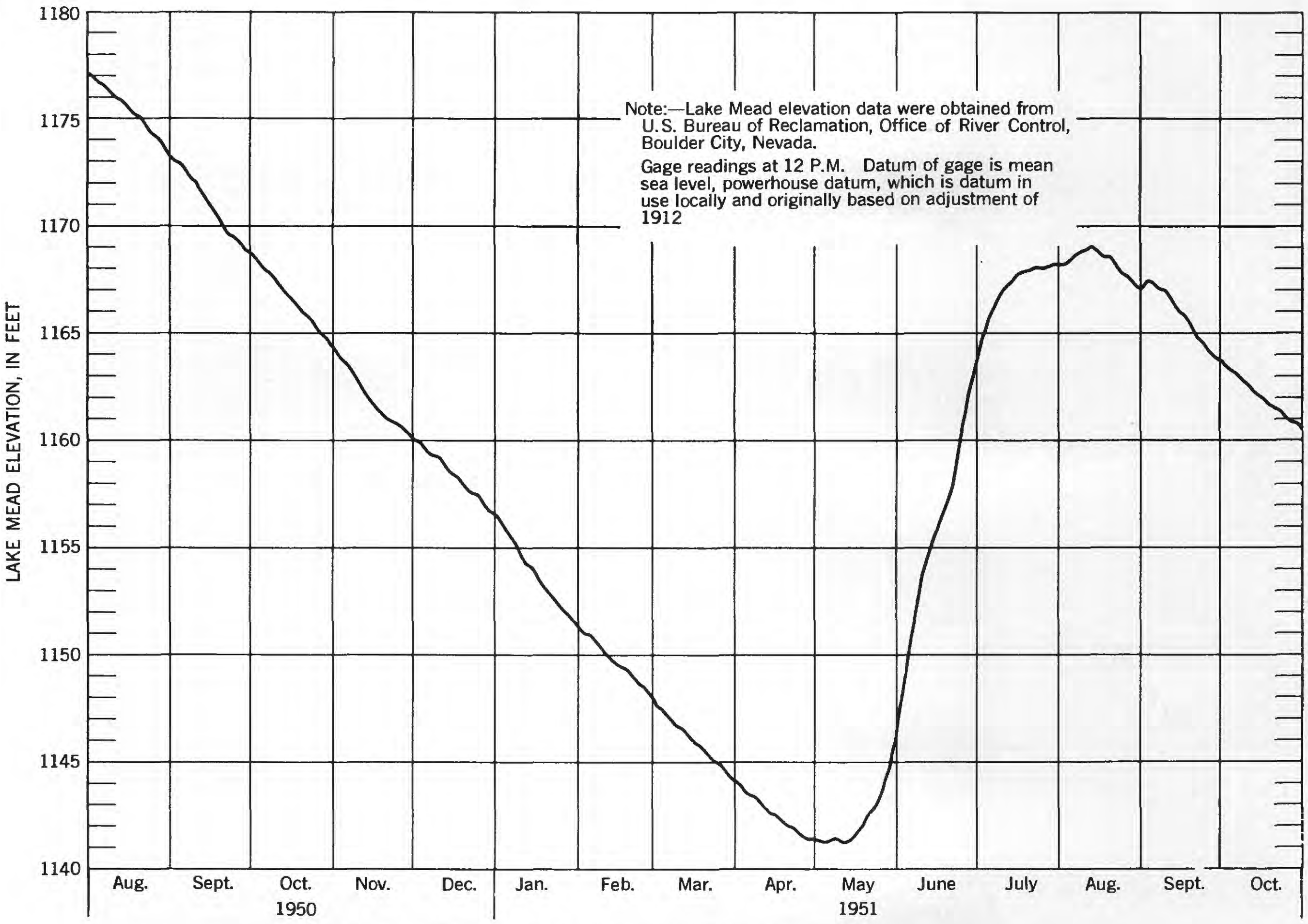

FIGURE 10.—Elevation of Lake Mead surface during the period of wind observations.

data in this form would fully serve the purpose of the study, all frequency analyses presented here are in terms of percent of wind movement.

To define adequately diurnal and seasonal variations in the wind pattern, the data were analyzed by 4-hour periods throughout the days of each month of record, and the results for the six 4-hour periods were in turn summarized to obtain daily values.

Frequency data derived from records of four selected months are presented as wind roses on plate 1. The daily wind rose for each station is encircled by the six 4-hour wind roses, and the average hourly wind speed is shown at the center of each rose.

The most striking feature of the wind pattern over the Boulder Basin is its pronounced diurnal fluctuation, brought about by the topographic configuration (mountain–valley and canyon breezes), and by the temperature differences between land and water areas (land–sea breeze).

The winds at station 8 display a very prominent seasonal variation as compared with those at most other stations. This can be explained by canyon effects, and by the fact that movement resulting from temperature contrasts between land and water are more nearly in phase with the prevailing winds. The greatest temperature contrasts occur in about January and June—the water being colder than the air in summer and warmer in winter—and the prevailing wind in the lower levels is northeasterly in winter and southerly in summer. Close examination of winds for other stations reveals similar effects that result from topography and land-water temperature contrasts.

Resultant wind and average wind speed at each of the nine stations for the last full year of record are summarized in table 1. The wind at most stations tends to shift approximately 180° diurnally, which accounts for the pronounced difference between average and resultant wind speeds. For example, the wind at station 8 is either northwest or southeast most of the time, and the movement from each direction is about the same. The west-southwest direction of the resultant wind at this station results primarily from the fact that the southwest nocturnal wind has no diurnal counterpart from the north and east.

TABLE 1.—*Average resultant wind speed and direction and average wind speed at Lake Mead, November 1950 to October 1951*

Station	Resultant wind		Average wind speed (mph)
	Direction	Speed (mph)	
1	S	1.7	8.0
2	SSE	3.1	8.8
3	SE	3.2	10.2
4	S	3.0	7.7
5	S	2.4	7.9
6	SSE	1.7	6.3
7	S	2.4	10.8
8	WSW	1.0	8.6
9	SSE	2.3	8.9

INSTRUMENTATION AND METHODS

By GORDON E. KOBERG, U. S. Geological Survey

WATER-BUDGET INSTRUMENTATION

Although evaporation from Lake Mead was not determined by the water-budget method as at Lake Hefner, a water budget without the stringent accuracy required at Lake Hefner had to be obtained to evaluate advection and storage terms of the energy budget, and as an approximate check to guard against gross errors in the computed figures of evaporation. Instruments at installations existing at the time of the study were utilized for this purpose.

INFLOW

The Colorado River is the main source of surface inflow into Lake Mead. The nearest stream-gaging station, which is near Grand Canyon, Ariz., is 190 river miles above the convergence (at usual reservoir levels), which is defined as the boundary between the muddy Colorado River water and the clear Lake Mead water. The only Colorado River tributary below the Grand Canyon gaging station whose flow is measured is Bright Angel Creek, which enters the main stream a quarter of a mile below the Grand Canyon gaging station. Standard stream-gaging techniques, as described by Corbett (1943), are used. All other tributaries between Bright Angel Creek and the convergence are unmeasured. It was considered impractical to attempt to measure these minor tributaries, although they may have considerable flow at times. The two stream-flow records are classified as excellent, which means that in general the error in daily records is believed to be less than 5 percent. Over a period of a month the error is probably less.

It was also necessary to adjust measured flows at Grand Canyon for the time of travel between that point and the head of the reservoir, which on the basis of hydrologic studies was estimated to be from 2 to 3 days, depending on the flow. Using the method described by Corbett (1943, p. 156–157), adjustments were also made for channel storage between the two points, which was significant only during periods of high runoff. These adjustments were minor, however, for the periods of about 1 month used in the computations.

Virgin River is the only other major tributary to Lake Mead whose flow is measured. The discharge records obtained at the gaging station near Littlefield, Ariz., are considered to be slightly less accurate on a percentage basis than the Grand Canyon record, but this is of little consequence, as the average flow of Virgin River is less than 1.5 percent of the flow at Grand Canyon.

Unmeasured inflow includes the runoff entering Colorado River between the mouth of Bright Angel Creek and the head of the reservoir, and flow of all streams except Virgin River that discharge directly into Lake Mead. The area from which this runoff is derived has topographic and climatic characteristics not greatly different from those of the Virgin River basin. Unmeasured runoff was therefore considered to be proportional to Virgin River flow. A large error in the estimated proportionality factor would have little consequence, however, since unmeasured inflow is such a small item that it is substantially less than the possible error in the Grand Canyon record, even though that record is considered to be of excellent accuracy.

OUTFLOW

Reservoir releases are the major surface outflow from Lake Mead. Outflow is measured at a stream-gaging station located 1 mile below Hoover Dam, and the records thus obtained are checked against figures obtained from power plant records. These records are rated as excellent. Pumping from Lake Mead for domestic and industrial uses is less than one-tenth of one percent of the outflow and was disregarded.

CHANGE IN RESERVOIR CONTENTS

An accurate area-capacity curve is available which was prepared on the basis of a hydrographic survey of the lake made in 1948–49 (Smith, Vetter, Cummings, and others, in preparation). Between 1948 and 1952 the capacity of the reservoir was slightly reduced because of the addition of sediment to the lake. The slight change in capacity was of little consequence in the present study because the sediment was deposited at the bottom of the lake, where the temperature of the water remains almost constant throughout the year. Thus, the small capacity change has no effect on computed figures of change in energy storage.

Changes in lake stage are recorded on a Stevens remote-registering gage with the actuating element mounted over a stilling well built into Hoover Dam. The gage-indicator dial and a Stevens water-stage recorder are located in the powerhouse. Bureau of Reclamation employees make midnight observations of lake stage by observing the gage-indicator dial. These midnight observations of lake stage were used throughout the computations.

RAINFALL ON THE LAKE SURFACE

Rainfall on the lake surface is a small item in the water budget, averaging less than one-half of one percent of the inflow. Four tipping-bucket recording rain gages were used to measure rainfall; they were located on Boulder Island in Boulder Basin, on the barge in Boulder Basin, at Bonelli Landing, and at Overton Arm. The rainfall recorded at each station was assumed to be representative of the rainfall on the basin or basins in which the gage was located, except that records from the two tipping-bucket recording rain gages in Boulder Basin were averaged to obtain the rainfall on Boulder Basin. Monthly rainfall at all four stations at Lake Mead and at the Weather Bureau station at the Las Vegas airport is shown in figure 11.

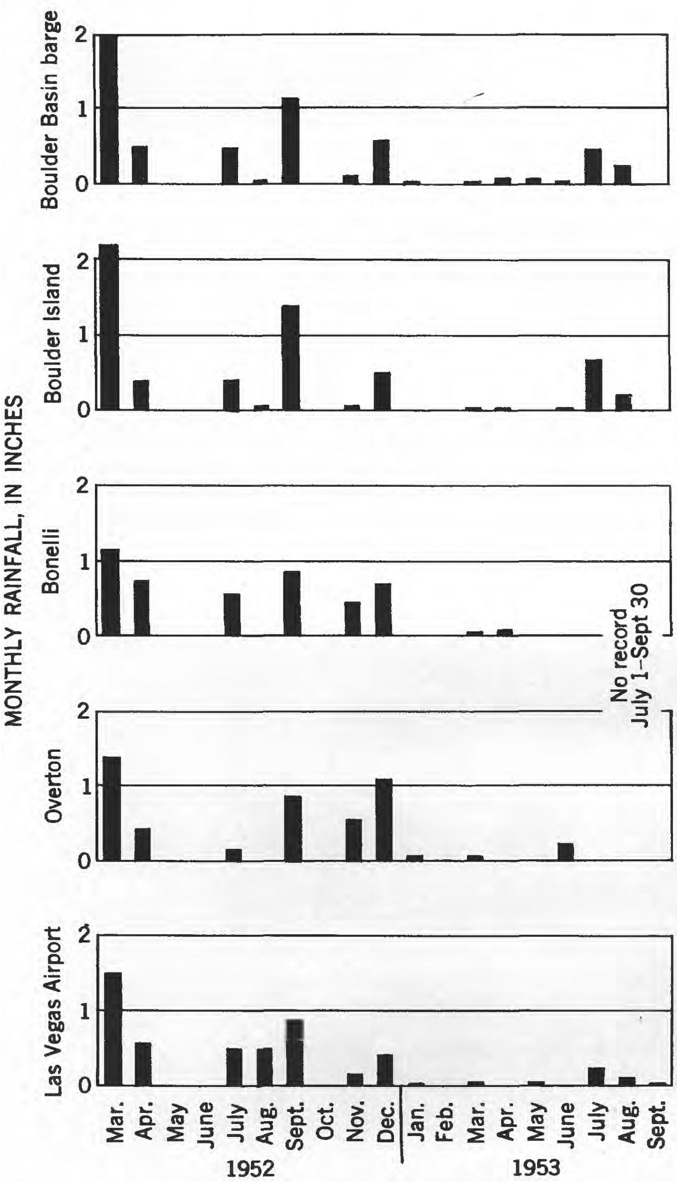

FIGURE 11.—Monthly rainfall in Lake Mead area and at Las Vegas, Nev.

All four rain gages were in operation by March 1, 1952. In July 1953 the two rain gages at Bonelli Landing and Overton Arm were discontinued, after which the average of the two rain gages at Boulder Island and Boulder Basin barge was assumed to be representative of the entire lake.

ENERGY-BUDGET INSTRUMENTATION

Incoming atmospheric and solar radiation at Lake Mead were measured with a Gier and Dunkle flat-plate radiometer and an Eppley pyrheliometer, located on Boulder Island (see fig. 1). The Cummings radiation integrator (CRI), a heavily insulated pan of water, was also used to measure net incoming radiation, both atmospheric and solar. Records obtained during the Lake Hefner studies, according to Harbeck (1954, p. 126) indicated that the CRI offered considerable promise as a replacement for the conventional radiation equipment, but that additional data were needed. Three CRI's were therefore used at Lake Mead, one for direct comparison with the radiation equipment and the other two to determine the areal variation in radiation over Lake Mead.

It was considered unnecessary to measure solar radiation reflected from the water surface. Studies by E. R. Anderson (1954, p. 78–88) indicated that it could be computed from climatological records with sufficient accuracy for use in the determination of evaporation.

RADIATION MEASUREMENT

Solar radiation was measured by the Eppley pyrheliometer. The pyrheliometer is a flat circular plate mounted horizontally inside a lime glass bulb. The plate is divided into a central white spot, a black ring, and an outer white ring. A 10-junction thermopile measures the temperature difference between the black and white areas, which is proportional to the radiation flux penetrating the glass bulb.

Total incoming radiation was measured by the Gier and Dunkle flat-plate radiometer (Dunkle and others, 1949). The radiometer consists of a flat 2-inch-square plate mounted horizontally in the blast of a small blower. The plate is a sandwich with a blackened aluminum upper surface and a polished aluminum lower surface; between is a thermopile measuring the vertical temperature gradient across an insulating sheet forming the center layer of the sandwich. The thermopile voltage is thus proportional to the heat flow down through the plate, which in turn is proportional to energy received at the blackened surface after deduction of the black-body radiation. To obtain the latter correction, a separate thermocouple is used to measure the black-surface temperature. The function of the blower blast is to eliminate unequal convection from the upper and lower sides of the plate.

Pyrheliometer and radiometer voltages were recorded using an amplifying and recording system similar to the one used for temperature and humidity as described by Anderson, Anderson, and Marciano (1950, p. 50–54).

Figure 12 shows the radiation equipment installed on Boulder Island. On top of the small platform and to the left is the flat-plate radiometer and to the right is the Eppley pyrheliometer. As it was considered unnecessary to obtain a direct measurement of reflected solar radiation using downward-facing Eppley pyrheliometers, it was possible to locate the equipment on Boulder Island instead of the barge, thus reducing operational difficulties.

The radiation equipment was started in operation on February 20, 1952, and continued through September 30, 1953. The equipment performed exceptionally well with little lost record. Table 2 shows the percentage of usable data for the pyrheliometer and flat-plate radiometer.

In the spring of 1953 there was an apparent disagreement between solar radiation recorded at the Las Vegas airport and Boulder Island. On July 17, 1953, in order to check the calibration of the pyrheliometer on Boulder Island, a new calibrated pyrheliometer was mounted on top of the maintenance barge moored on the south shore of Boulder Basin and a continuous record of solar radiation was obtained. The calibration check was continued until September 7, 1953, when it was decided that there had been no discernible change in calibration of the Boulder Island pyrheliometer.

The manufacturer's calibration of the Eppley pyrheliometer was used, which is based on the Smithsonian scale of 1913. According to MacDonald and Foster (1954), instruments calibrated to the 1913 scale give results that may be 2.5 percent too high. No corrections were applied to observed values.

TABLE 2.—*Percentage of usable data for radiation equipment, by energy-budget periods*

Period	Pyrheliometer	Flat-plate radiometer	Cummings radiation integrators (usable temperature data only)		
			Boulder Island	Bonelli Landing	Overton Arm
1952					
Mar. 12–Apr. 14	99	98	100	59	97
Apr. 15–May 11	100	98	100	79	74
May 12–June 11	98	93	89	79	60
June 12–July 8	95	91	100	63	40
July 9–Aug. 5	99	97	90	78	100
Aug. 6–Sept. 3	98	97	93	70	97
Sept. 4–Oct. 2	97	94	87	76	88
Oct. 3–Nov. 5	95	90	84	76	89
Nov. 6–Dec. 2	100	100	94	59	88
1952–1953					
Dec. 3–Jan 8	99	99	98	84	57
1953					
Jan. 9–Feb. 2	99	96	100	95	32
Feb. 3–Mar. 2	97	93	97	77	79
Mar. 3–31	94	87	92	99	32
Apr. 1–Apr. 27	98	98	78	99	76
Apr. 28–May 27	97	95	93	88	76
May 28–June 29	99	97	94	75	70
June 30–July 29	95	91	95	----------	----------
July 30–Aug. 26	89	83	87	----------	----------
Aug. 27–Sept. 28	97	94	89	----------	----------

FIGURE 12.—Gier and Dunkle flat-plate radiometer and Eppley pyrheliometer on Boulder Island in Lake Mead. Photograph by Bureau of Reclamation.

One minor change was made in the monthly accuracy checks of the input impedance of the radiation amplifier to prevent inaccuracies resulting from the external radiation circuits. The regular monthly check had been accomplished by substituting a fixed 500-ohm resistor for the radiation circuit and adjusting the mechanical zero of the galvanometer until zero input voltage was indicated on the recorder. After a period of operation, the mechanical zero of the galvanometer was usually slightly off, but not enough to cause any serious error providing the resistance of the radiation circuit was substantially less than the resistance of the reference circuit. However, the resistance of the flat-plate radiometer is 250 ohms, and any small error in the mechanical zero of the galvanometer could cause serious error in the flat-plate radiometer record and yet not cause appreciable error in the pyrheliometer record because the resistance of the pyrheliometer is only 10 ohms.

In order to have a continuous check of the mechanical zero of the galvanometer, an additional reference circuit of 500 ohms was added to the 15-point switch in October 1952, which was used as an indication of zero output from the flat-plate radiometer, pyrheliometer, and flat-plate radiometer thermocouple. The mechanical zero was adjusted whenever there was a noticeable difference between the zero values indicated by the 500-ohm reference circuit and a direct-short reference circuit.

The maintenance of the radiation equipment required occasional dusting of the pyrheliometer bulb and polishing the reflecting surface of the underside of the radiometer. A coat of flat-black enamel was given to the radiometer plate periodically. The enamel used was the same brand as that used by the manufacturer.

CUMMINGS RADIATION INTEGRATORS (CRI)

The areal distribution of incoming radiation was determined by installing two CRI's in remote areas accessible by automobile, one in the Overton Arm area and the other at Bonelli Landing. A third CRI was installed on Boulder Island for comparison with the conventional radiation equipment.

The Boulder Island CRI was placed in operation on February 20, 1952, and continued in operation until February 25, 1953, when the overhanging rim was removed in order to determine if it was fullfilling its purpose of maintaining the area of the water surface exposed to solar radiation nearly constant. On March 2, 1953, the Boulder Island CRI was again placed in operation, but without the rim.

A thermocouple psychrometer was installed on Boulder Island on July 27, 1952, after it had been determined that the recorded air temperatures and humidities at the Boulder Basin barge were not representative of Boulder Island. The temperature of rainfall and the temperature of the overhanging rim of the CRI were replaced in the recording sequence by dry- and wet-bulb temperatures.

The Bonelli Landing CRI was constructed and operated exactly as the Boulder Island CRI except that the area of the overhanging rim was 10 percent less than that of the Boulder Island CRI. It was installed on February 15, 1952, and was operated until July 8, 1953. A thermocouple psychrometer was installed on June 19, 1952, after it had become apparent that the recorded air temperatures and humidities at Boulder Wash raft were not representative of conditions at the Bonelli CRI.

The Overton Arm CRI (see fig. 13) was constructed about 5½ miles south of the Overton boat anchorage and was identical with the Bonelli CRI. It was installed on February 15, 1952, and was operated until July 8, 1953. On June 19, 1952, a thermocouple psychrometer was installed.

The CRI's were serviced at weekly intervals using the technique developed at Lake Hefner (Harbeck, 1954, p. 121–122). The Overton and Bonelli CRI's, which were visited about once a week, had less usable temperature data than the Boulder Island CRI, which was checked daily. Table 2 shows the amount of usable temperature data for each CRI by energy-budget periods.

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

TEMPERATURE PROFILES OF LAKE

Temperature profiles were obtained with a surface-bucket thermometer and a 450-foot bathythermograph (Spilhaus, 1938), using the technique described by Anderson and Pritchard (1951), in which the surface-bucket thermometer is used to calibrate the bathythermograph each time a profile is obtained. The bathythermograph (BT) provides a continuous record of temperature versus depth. A stylus, attached to a Bourdon tube, records the temperature on a smoked-glass slide. The slide is held in a frame attached to a pressure bellows, and hence the frame and slide move relative to the arc of the stylus as the depth changes. The BT gives relative temperature to an accuracy of 0.1°–0.3°F. Observed surface temperatures are used to calibrate the bathythermograph record.

During the Lake Mead water-loss investigation, it was necessary to use four different BT's because some became inoperative. The first BT was used only for the thermal survey made in March 1952. The second BT was used for the surveys made in April 1952 through

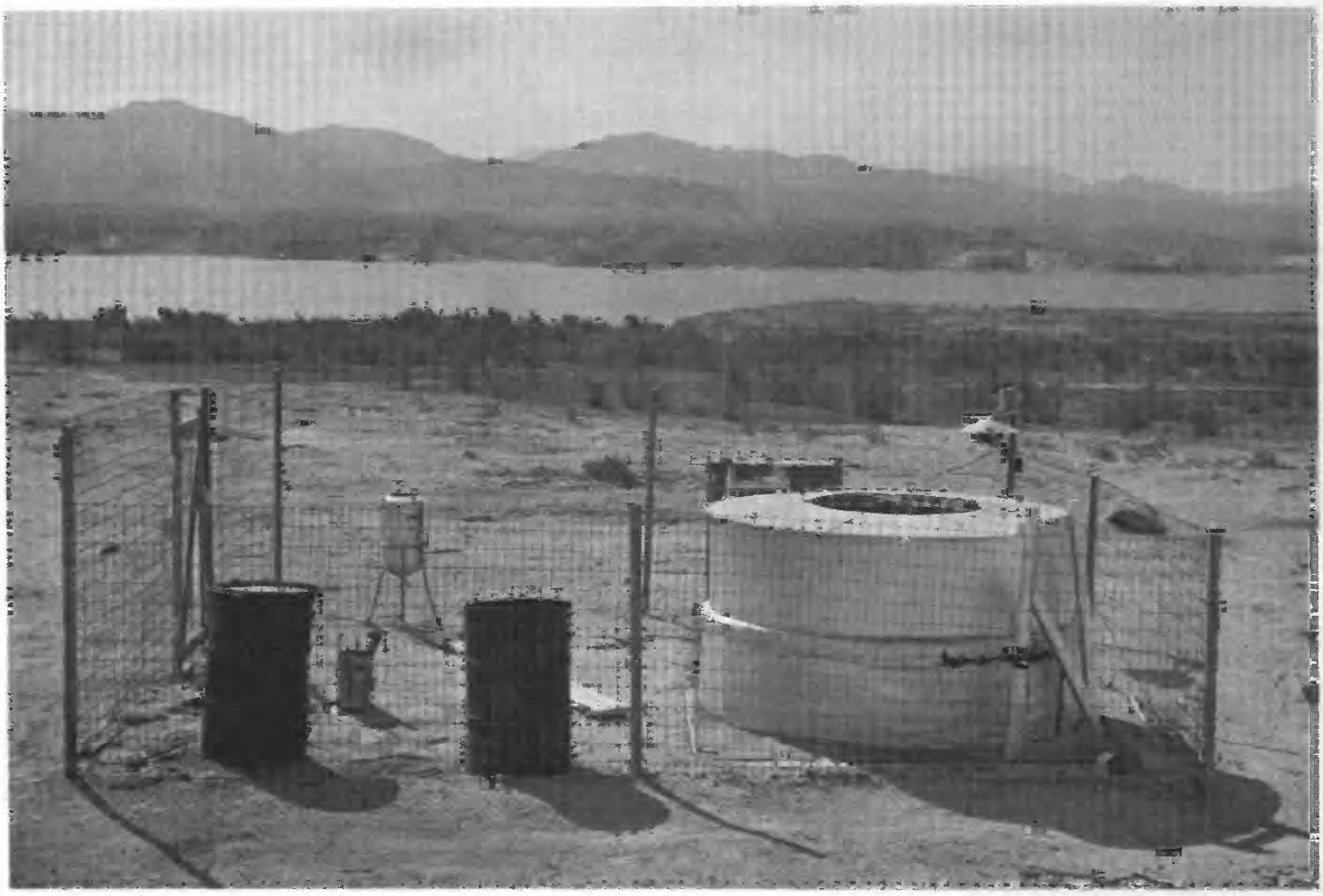

FIGURE 13.—Cummings Radiation Integrator installation at Overton Arm. Note thermocouple "hat" at right rear corner of fence. Photograph by H. O. Wires.

September 1952. The third BT was used for the October 1952 survey, and the fourth was used in all subsequent surveys.

During the period January 1953 through May 1953, the third and fourth BT's were tied together and lowered simultaneously at all stations for each thermal survey. The third BT indicated a more rapid decrease of temperature with depth than the fourth BT, to a depth of 100 feet below the lake surface. At greater depths the difference was about 1.0°F. For each thermal survey, all temperature profiles recorded by the same BT were averaged to obtain the mean profile of the lake. During the comparison period the difference between mean profiles that were obtained using the third and fourth BT's remained fairly constant.

In the original program for the Lake Mead studies the temperature profile recorder (TPR) (Anderson and Burke, 1951) was to be used to determine temperature profiles. Because the TPR was designed for the Lake Hefner study, certain modifications were needed before it could be used at Lake Mead, owing to the much greater depth of water in Lake Mead. These modifications were completed about 6 months after the project started. In an equipment test at Lake Mead, the TPR gave erratic results, mostly attributable to the difficulty in maintaining watertight connections under the extreme pressures met at great depths. After careful study it was decided that further modification was necessary, but this was not completed until the end of the project.

CONTINUOUS TEMPERATURE PROFILES

In order to obtain further information as to the thermal structure of the lake, a series of thermocouples, located at depths of ¼, ½, 1, 2, 4, 8, 16, 32, and 64 meters below the lake surface, was installed at the Boulder Basin barge on September 30, 1952. The temperatures indicated by these thermocouples were recorded sequentially. On January 23, 1953, the series of thermocouples was modified and additional thermocouples added, the new depths being ¼, 1, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 46, 52, 58, 64, 70, 76, and 82 meters. This series remained in operation until October 1, 1953, except for the period May 20, 1953, to July 10, 1953, when the amplifier was being repaired. The Virgin Basin barge also had a string of thermocouples similar to the one at the Boulder Basin barge, at depths of 1, 4, 8, 12, 16, 24, 32, 40, 48, 56, 64, 72, 80, and 88 meters.

MASS-TRANSFER INSTRUMENTATION

The location of the barge mass-transfer station in Boulder Basin was selected on the basis of a study of wind patterns in Boulder Basin that was made during 1950–51 by the Weather Bureau (1953), using data furnished by the Bureau of Reclamation. Later in the investigations another mass-transfer station was installed on a barge in the Virgin Basin. The location of the stations is shown in figure 1.

The mass-transfer instrumentation at Lake Mead was essentially the same as that used at Lake Hefner (L. J. Anderson, 1954) but on a considerably reduced scale. Copper-constantan thermocouples were used for all temperature measurements. The low-power amplifier developed especially for the Lake Hefner study was used to amplify the thermocouple voltages. The amplifier was of a negative-feedback-galvanometer type with a power consumption of 4 watts. A complete description of the amplifier and the thermocouple psychrometer may be obtained by referring to Anderson, Anderson, and Marciano (1950), Bellaire and Anderson (1951), and Denton (1951). The amplified thermocouple voltages were recorded on a 1 ma Esterline-Angus recorder with a spring-wound-clock chart drive. A 20-point rotary switch was used for sequential temperature measurements.

Wind speed was measured with a standard 3-cup Robinson-type contact anemometer. Rainfall was measured with a tipping-bucket rain gage. The method of recording depended on the number of items to be recorded. If three items or more were to be recorded, the Esterline-Angus operation recorder with a spring-wound chart drive was used. If two items or less were to be recorded, an auxiliary chronograph pen was attached to the 1 ma recorder for each item. Capacitor-discharge circuits were used for operating the recorder relays.

Figure 14 shows the barge anchored in Boulder

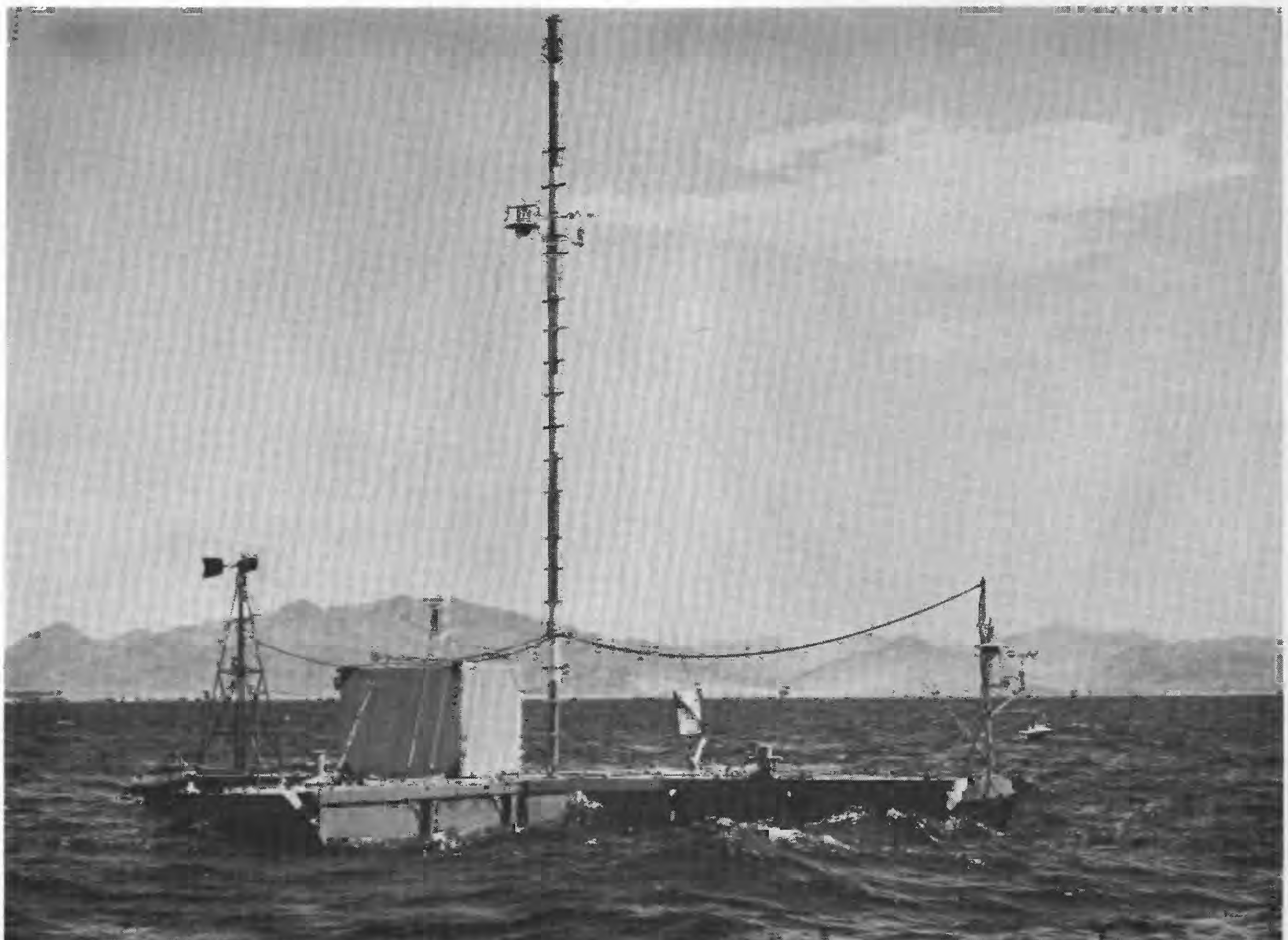

FIGURE 14.—Barge anchored in Boulder Basin of Lake Mead, with anemometers and thermocouple psychrometers at 2- and 8-meter levels. Photograph by Bureau of Reclamation.

Basin. Dry- and wet-bulb temperatures were measured at 2 and 8 meters above the water surface. Water-surface temperatures were also recorded. Wind speeds at 2- and 8-meter levels and amounts of rainfall were recorded on an Esterline-Angus operation recorder. The barge was operated during the period February 22, 1952, to October 1, 1953.

At a conference held in Boulder City, December 8–12, 1952, it was recommended that a barge similar to the barge in Boulder Basin be installed in the Virgin Basin to determine whether there is a significant difference between wind speed, humidity, and water-surface temperatures in the two basins. It was placed in operation May 5, 1953. Wet- and dry-bulb temperatures at the 2- and 8-meter levels and water-surface temperatures were recorded, as were water temperatures at various depths. Wind speed was measured at 2¾- and 8¾-meter levels and was registered on the 1 ma recorders by the addition of a chronograph pen for each anemometer.

The areal distribution of meteorological and limnological elements over the lake was determined by the use of three small raft stations. One raft was located 5½ miles south of the Overton boat anchorage, another in Boulder Wash at the west end of the Virgin Basin, and the third near the Temple Bar boat anchorage.

The rafts were identical in construction and instrumentation. In the original instrumentation program water-surface temperature, dry- and wet-bulb temperatures measured at ½, 1, and 2 meters above the water surface were recorded at each raft. After a few months of operation, measurements at the ½- and 1-meter levels were discontinued when it was decided that there was no further need for them.

Because the rafts were small the amplifier did not operate satisfactorily in heavy seas, and for this reason the rafts were located in sheltered coves. Deep coves were selected to assure representative water-surface temperatures. The wind speed recorded at each raft was not believed to be representative of conditions over the open lake and was recorded simply because the equipment was available.

The Overton Arm raft was placed in operation on February 19, 1952, at a site well protected from a northerly wind, but unprotected from a southerly wind. When southerly winds of 10 knots or greater occurred the amplifier became inoperative, and all temperature records were unusable. The raft was operated at this location until a strong southerly wind caused it to break loose from its anchor on June 14, 1952. The raft was reanchored on June 24, 1952, in a well-protected cove 1 mile west of the previous location, and was operated at this site until July 6, 1953.

The Boulder Wash raft, which was placed in operation on February 19, 1952, was anchored in a narrow canyon with high rock walls on three sides. It was soon apparent that the recorded temperatures of water surface and ambient air were affected by radiation reflected from the canyon walls. A survey was made to obtain a new location for the station, but all available sites were unprotected from the wind, and the raft station was finally discontinued on December 8, 1952.

The Temple Bar raft (see fig. 15) was installed on February 22, 1952, and remained in operation until April 16, 1953, when it broke loose from its anchor. On April 27, 1953, the raft was temporarily moored near the shore west of the previous location. On May 7, 1953, the raft was anchored in the original location and it remained there until July 8, 1953.

PERFORMANCE AND MAINTENANCE OF EQUIPMENT

ACCURACY INSPECTION

Periodic inspection of the equipment in the field was made to maintain prescribed accuracy requirements. The temperature and humidity data were checked weekly at all stations with a calibrated sling psychrometer. Daily inspection was made at Boulder Island during the summer of 1953. Daytime air temperatures obtained from sling-psychrometer readings were as much as 2.0°C higher than the recorded values although the wet-bulb depression was usually within 0.5°C. This discrepancy occurred most frequently on Boulder Island, where radiation from the rugged terrain apparently influenced the sling-psychrometer readings. When sling-psychrometer readings were made near the U. S. Weather Bureau instrument shelter, they agreed better with the thermocouple-psychrometer record when the wind was from the south than from the north. Insufficient shielding of the sling psychrometer from the sun was also partly responsible for these discrepancies. At nearly all times the depression measured with the sling psychrometer was less than the recorded depression, which is considered good evidence of the reliability of the thermocouple psychrometer. Because the humidity was usually very low, it was difficult to obtain the correct wet-bulb depression with a sling psychrometer before the wick dried.

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

The thermocouple reference bath at each station was contained in a 1-gallon Dewar flask. It was of course essential that a temperature of 0°C be maintained at all times. At the stations that were visited only once a week, reference temperatures were in summer occasionally found to be above 0°C, because most of the

FIGURE 15.—Raft moored near Temple Bar, at Lake Mead, with thermocouple psychrometers at ½-, 1-, and 2-meter levels. Triangular float supports water-surface thermocouple. Photograph by Bureau of Reclamation.

ice had melted. Whenever this occurred the Dewar flask was exchanged for one that had better insulating properties.

USABLE DATA

The stations in Boulder Basin were visited daily. Usually the remote CRI and raft stations were visited weekly but occasionally were visited twice a week to correct malfunctioning of the equipment. Table 3 shows the percentage of usable data by energy-budget periods.

The stations visited weekly had a yield of usable data about the same as that obtained at Lake Hefner. The stations visited daily had an exceptionally high yield of usable data, reflecting the wealth of experience the maintenance crew had gained at Lake Hefner.

MAINTENANCE PROBLEMS

The thermocouple amplifier, the heart of each station, performed well. Each amplifier was taken from the station and overhauled. At each overhaul the amplifier's optical system was realined and the tubes and exciter lamp replaced. Most amplifier malfunctioning was caused by tube or exciter lamp failures. In fairly rough seas the amplifier would not operate satisfactorily on the small rafts and in extremely rough seas would not operate on the barge. A gimbal system for the amplifier was tried at all floating stations but little improvement was noted.

The Esterline-Angus recorders had a spring-wound chart drive. Most loss of record resulted from stopping of the chart drive or jamming of the paper on the drive sprockets.

The wet-bulb reservoirs for the thermocouples in Boulder Basin were filled about twice a week. Auxiliary reservoirs were installed at the outlying stations to keep the wet-bulb reservoirs from going dry between weekly visits. Very few data were lost owing to dry reservoirs, and none because of frozen reservoirs. During the first few months of operation several of the wet-bulb wicks were observed to be encrusted with salt. This was soon remedied by obtaining distilled water of better quality. Each time the reservoir was filled, the accumulated dust was removed from the wet thermocouple wick, and it was examined closely for any signs of salt crust. Wicks were frequently replaced.

TABLE 3.—*Percentage of usable data for meteorological equipment, by energy-budget periods*

Period	Usable temperature data				Usable wind data	
	Boulder Basin barge	Virgin Basin barge	Overton Arm raft	Temple Bar raft	Boulder Basin barge	Virgin Basin barge
1952						
Mar. 12–Apr. 14	84	----------	67	97	100	----------
Apr. 15–May 11	88	----------	74	96	88	----------
May 12–June 11	96	----------	51	73	100	----------
June 12–July 8	85	----------	78	86	100	----------
July 9–Aug. 5	100	----------	96	100	94	----------
Aug. 6–Sept. 3	100	----------	100	89	98	----------
Sept. 4–Oct. 2	96	----------	93	63	94	----------
Oct. 3–Nov. 5	94	----------	100	100	100	----------
Nov. 6–Dec. 2	100	----------	100	82	98	----------
1952–53						
Dec. 3–Jan. 8	90	----------	85	92	100	----------
1953						
Jan. 9–Feb. 2	100	----------	60	100	91	----------
Feb. 3–Mar. 2	97	----------	70	83	100	----------
Mar. 3–31	95	----------	75	76	100	----------
Apr. 1–27	97	----------	85	52	89	----------
Apr. 28–May 27	87	37	90	66	100	19
May 28–June 29	85	64	79	62	99	30
June 30–July 29	72	74	----------	----------	93	80
July 30–Aug. 26	86	96	----------	----------	100	88
Aug. 27–Sept. 28	70	90	----------	----------	97	72

The insect screens installed at Lake Hefner were removed for better ventilation. Close examination of the trace recorded during periods of very light wind indicated that the wet-bulb wick was not ventilated sufficiently, and the recorded wet-bulb temperature was in error. Insufficient ventilation occurred for periods of only a few hours and at infrequent intervals.

No trouble was encountered with the lake-surface thermocouple assembly. The only maintenance required was to remove algae from the thermocouple.

SUMMARY OF INSTRUMENTATION AND METHODS

In the original instrumentation program for Lake Mead, all requirements could not be anticipated. As the investigation proceeded, unnecessary instrumentation was discontinued and other instrumentation added when certain meteorological and limnological data were deemed important in the computations.

The equipment performed exceptionally well in the dry climate at Lake Mead, but most of the credit should go to the maintenance crew. The climate also introduced new maintenance problems, but these were soon solved with a minimum loss of record.

It was unfortunately necessary during the first 8 months of operation to change frequently the bathythermographs used in making temperature profiles. Other than this, the bathythermograph apparently provided water-temperature data of the accuracy expected.

Discrepancies between temperatures measured with the thermocouple psychrometer and the sling psychrometer were greater than those observed at Lake Hefner. This was especially true of the observations made on Boulder Island, owing in part to low humidity and inadequate shielding. The thermocouple psychrometer usually indicated a depression the same as or greater than the sling psychrometer. Because a wet-bulb depression that is too large cannot easily be explained, the thermocouple psychrometer was believed to be more accurate in general than the sling psychrometer.

The check calibration of the pyrheliometer after 3 years of use indicated no noticeable change in calibration. The calibration of the flat-plate radiometer was not checked, but comparisons with the CRI at Lake Hefner and Lake Mead indicated no noticeable change with time.

ENERGY-BUDGET STUDIES

By GORDON E. KOBERG, U. S. Geological Survey

The energy budget for a reservoir may be expressed as follows:

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

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_e = energy utilized by evaporation
Q_h = energy conducted from the body of water as sensible heat
Q_v = net energy advected into the body of water
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 an excellent 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:

$$Q_e=\rho_e EL;\ Q_h=RQ_e;\ \text{and}\ Q_w=\rho_e c\ E\ (T_e-T_b)$$

in which 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 the 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. For computational purposes each of the items is expressed on a unit-area, unit-time basis.

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

SOLAR RADIATION

The data on solar radiation (Q_s) were processed by drawing a smooth curve connecting the intermittent periods of record resulting from the sequential system of recording. During periods of broken cloud cover, when solar radiation is extremely variable, the interpolated portions of the record are subject to error, but the errors are believed to be random and, for periods of a month, insignificant in amount. A comparison with a continuous record, obtained on the shore of Lake Mead for a short period, indicates this to be true.

Periods of missing data were estimated on the basis of data recorded previous to and succeeding the missing period, and on records obtained at the Las Vegas airport. The amount of missing data seldom exceeded 5 percent (see table 2) in any one energy-budget period (the period between thermal surveys of the lake), and the error so introduced is small for any such period.

Mean values of solar radiation were computed for hourly periods and totaled to obtain figures of daily solar radiation from February 23, 1952, through September 30, 1953.

REFLECTED SOLAR RADIATION

Reflected solar radiation (Q_r) was determined indirectly from the measured solar radiation. Empirical reflectivity curves, which give the ratio of reflected to incident solar radiation as a function of sun altitude for various conditions of cloud cover, were developed by E. R. Anderson during the Lake Hefner studies.

Hourly observations of type and amount of cloud cover were furnished by the U. S. Weather Bureau at the Las Vegas airport. Cloud conditions at the Las Vegas airport are believed to be representative of the Lake Mead area also, at least for periods of 30 days or so. Sun altitude was computed for each hour by means of an ephemeris.

Reflectivity was computed for each hourly period and then multiplied by mean hourly solar radiation to obtain reflected solar radiation.

ATMOSPHERIC RADIATION

Long-wave radiation from the atmosphere (Q_a) was measured directly during the night using the Gier and Dunkle flat-plate radiometer. Theoretically, during the day it could be evaluated indirectly, using the radiometer for measuring both the solar and atmospheric radiation and the Eppley pyrheliometer for measuring only the solar radiation, the difference between the two being the atmospheric radiation. However, as at Lake Hefner, where the same instruments and computational procedure were used, it was noted that atmospheric radiation at Lake Mead apparently began to decrease at sunrise, reached a minimum about solar noon, and increased again until sunset. Because this appeared improbable, the daytime values were again interpolated between the nighttime values. In the absence of information to the contrary, instrumental deficiencies of this type of instrument are considered to be responsible for the indicated decrease in daytime atmospheric radiation. The reflectivity of the black paint on the radiometer may not be the same for all wave lengths, and it may not be completely independent of sun altitude.

The data were processed by drawing a smooth curve through the intermittent record. Daytime mean values were computed for each hourly period. During the night, mean values were computed for the approximate periods sunset to midnight and midnight to sunrise.

For periods of missing data an estimate was made on the basis of data recorded before and after the missing period and partly on the basis of air temperatures during the missing period. The amount of missing data seldom exceeded 10 percent in any one energy-budget period (see table 2). For this reason and also because the day-to-day variation in atmospheric radiation is small, the error introduced is believed to be of little consequence.

Daytime interpolated values and mean nighttime values were used in the total daily atmospheric radiation computations for the period February 23, 1952, through September 30, 1953.

REFLECTED ATMOSPHERIC RADIATION

The reflectivity of a water surface for atmospheric radiation is about 0.030 for source temperatures between 0°C and 30°C as shown by measurements made by Gier and Dunkle (U. S. Geol. Survey, 1954a, p. 96–98). Reflected atmospheric radiation (Q_{ar}) was computed by multiplying atmospheric radiation by this reflectivity.

Daily values of reflected solar radiation were computed from February 23, 1952, through September 30, 1953.

RADIATION FROM THE LAKE

Long-wave radiation emitted from the lake (Q_{bs}) was computed according to the Stefan-Boltzman law for black-body radiation, with an emissivity factor of 0.970 for water as determined by Gier and Dunkle (U. S. Geol. Survey, 1954a, p. 96–98).

Daily computations of long-wave radiation emitted from the lake were not made. An average value for the energy-budget period was obtained by using an average water-surface temperature of the lake for that period. The variation of long-wave radiation with temperature is nearly linear over the range in water-surface temperatures experienced in any one period.

The average lake-surface temperature used in computing radiation from the lake was obtained by weighting the surface temperatures recorded at Boulder Basin and Virgin Basin barges, and Overton Arm and Temple Bar rafts, according to the area represented. For the period March 12, 1952, through April 27, 1953, the Boulder Basin barge represented both the Boulder and Virgin Basins (basins 1 and 2, fig. 1); for the same period the Overton Arm raft represented the Overton Arm area (basin 8), and Temple Bar raft represented the upper basins (basins 3–7). From April 28, 1953, through June 29, 1953, the Boulder Basin barge represented only the Boulder Basin, the Virgin Basin barge represented the Virgin Basin, and Overton Arm and Temple Bar rafts represented the same basins as before. For the period June 29, 1953, through September 28, 1953, the average lake-surface temperature was obtained by averaging Boulder Basin and Virgin Basin barge records.

For each energy-budget period comparison was made of the differences between the average weighted water-surface temperature of the lake and the various average water-surface temperatures recorded at the barge and raft stations. The greatest difference was only 1.3°C. The greatest difference between temperature at the Boulder Basin barge and the weighted mean temperature of the lake was 0.6°C, which is not particularly surprising in view of the fact that the Boulder Basin temperature was perforce weighted rather heavily in determining the mean temperature for the lake. Observations at the Virgin Basin barge and the two raft stations indicate that the areal temperature variation is not great and that a single measurement in Boulder Basin should give a reasonable figure for the entire lake, at least for periods of a month in length.

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:

$$R=\gamma \frac{(T_0-T_a)\,P}{(e_0-e_a)\,1{,}000} \qquad (3)$$

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.

Computing Bowen ratios for Lake Mead, T_2 and e_2 were used for T_a and e_a, respectively. For each raft or barge station the variables were averaged by periods and were weighted by area to obtain an average T_2, T_0, and e_2 for the lake.

The term e_0 was obtained from the average T_0 for the lake. This method introduces a slight error because the relation between temperature and saturation vapor pressure is not linear. A study of selected periods indicated that the error was always less than 0.5 millibar and generally about 0.2 millibar, which is equivalent to an error of less than 2 percent in the average vapor-pressure difference.

For each period Bowen ratios were computed for each barge and raft station and compared with the ratio used for the lake. The maximum deviation from the Bowen ratio for the entire lake was 0.079 (equivalent to approximately 8 percent in computed evaporation), which indicates that the variation in the Bowen ratio from one basin to another is not great.

It has long been a moot question as to the place and height at which air temperature and humidity measurements for the Bowen ratio should be made. To investigate the effect on evaporation of the choice of place and height at which these variables are measured, a study was made using air temperature and humidity measured as follows: (1) At the 2-meter level over Lake Mead (R_2); (2) At the 8-meter level over Lake Mead (R_8); (3) At the Weather Bureau station at the Las Vegas airport (R_v).

Temperature and humidity measured at Las Vegas are assumed to be representative of unmodified air in the Lake Mead area. It was necessary to adjust the observed air temperatures at Las Vegas for the difference in elevation between the airport and Lake Mead, which is about 1,000 feet. The average difference between air temperature at Lake Mead and at the Las Vegas airport is 1.9°C, which agrees closely with the temperature lapse rate of 0.65°C per 100 meters of the U. S. Standard Atmosphere. Observed air temperatures at Las Vegas were therefore adjusted by adding 1.9°C. The change in vapor pressure with elevation was considered negligible.

Evaporation from Lake Mead was computed for all energy-budget periods using equation 2, using the same data for all variables except R. The results are given in table 4, which shows that for the entire 19 periods evaporation computed using R_v is 0.6 percent less than, and evaporation computed using R_8 is 1.6 percent greater than, evaporation computed using R_2. Computed figures of evaporation for individual periods also agree well, the maximum difference being approximately 7 percent. Figures obtained using R_8 are generally slightly greater than those obtained using R_2, for no apparent reason, but the deviations between figures obtained using R_v and R_2 appear to be random. No seasonal variation is apparent.

Although the finding that it makes little difference where air temperature and humidity are measured, insofar as the effect on evaporation is concerned, is of considerable practical value, the theoretical implications should not go unnoticed. The quantity 0.61 $(T_0-T_a)/(e_0-e_a)$ in the expression for the Bowen ratio must therefore be invariant with height. The limiting values of the coefficient 0.61 as given by Bowen are 0.58 and 0.66, but he does not suggest that its value varies with height. If the coefficient 0.61 is assumed to be constant, it must follow that the variation of both temperature and humidity with height is the same. It is not implied that this relation holds for short periods of time, but for periods of about a month the foregoing analysis indicates that it is valid.

TABLE 4.—*Effect on computed evaporation from Lake Mead of using Bowen ratios based on measurements at different heights over the lake and at Las Vegas*

Period	Evaporation, in inches, using indicated temperature and humidity data for computing Bowen ratio		
	2-meter level Lake Mead (R_2)	Las Vegas Airport (R_v)	8-meter level Lake Mead (R_8)
1952			
Mar. 12–Apr. 14	6. 22	6. 32	6. 34
Apr. 15–May 11	4. 34	4. 41	4. 45
May 12–June 11	9. 80	9. 74	9. 92
June 12–July 8	9. 95	9. 25	9. 81
July 9–Aug 5	8. 72	8. 68	8. 85
Aug. 6–Sept. 3	9. 84	9. 84	10. 07
Sept. 4–Oct. 2	6. 72	6. 78	6. 82
Oct. 3–Nov. 5	6. 33	6. 45	6. 40
Nov. 6–Dec. 2	8. 89	8. 72	8. 89
1952–1953			
Dec. 3–Jan. 8	6. 09	6. 09	6. 13
1953			
Jan. 9–Feb. 2	3. 25	3. 46	3. 33
Feb. 3–Mar. 2	5. 48	5. 68	5. 57
Mar. 3–Mar. 31	4. 88	4. 93	5. 11
Apr. 1–Apr. 27	4. 48	4. 29	4. 66
Apr. 28–May 27	8. 74	8. 36	8. 81
May 28–June 29	9. 17	8. 91	9. 33
June 30–July 29	8. 12	8. 24	8. 39
July 30–Aug. 26	8. 43	8. 42	8. 65
Aug. 27–Sept. 28	10. 68	10. 67	10. 84
Total	140. 13	139. 24	142. 37

ADVECTED ENERGY

Advected energy (Q_v) is defined as the net energy gained by a body of water as a result of volumes of water entering or leaving the lake. It includes surface and subsurface inflow and outflow, and rainfall on the lake surface. The main problem in computing energy advected into or out of Lake Mead is that little is known concerning the volume or temperature of bank storage losses or gains for short periods of time. Unmeasured surface inflow can be estimated with good accuracy.

The inflow–outflow–change-in-storage, or water-budget equation, for Lake Mead contains three unknowns: evaporation, unmeasured surface inflow, and changes in bank storage or unmeasured ground-water inflow. If changes in bank storage and unmeasured surface inflow are combined and called unmeasured inflow, we have but two unknowns. Similarly, in equation 1, all items can be measured except Q_e, Q_h and Q_w, and the portion of Q_v attributable to unmeasured inflow. Both the temperature and volume of the energy advected by unmeasured inflow are unknown. Q_e, Q_h, and Q_w can be computed if the volume of evaporation is known; and if the temperature of the unmeasured inflow can be determined, two equations can be written (the energy-budget equation and the water-budget equation), each of which has only two unknowns. The system is therefore solvable, depending only on a determination of the temperature of the unmeasured inflow, which includes both surface inflow and changes in bank storage.

With little error, the temperature of the unmeasured surface inflow can be considered to be the same as that of the measured surface inflow. The temperature of water going into bank storage is not known but is considered to be about equal to the inflow temperature, as it is believed that most large increases in bank storage result from the flooding of peripheral sediment deposits, in which case the assumption appears reasonable. This usually occurs in late spring and summer, which is the period of high inflow. Water is withdrawn from bank storage during the fall, winter, and early spring, the period of low inflow. During the time the water remains in bank storage it is presumably cooled and its energy is gradually released to the reservoir, where its effect is taken into account by the thermal surveys. The assumption that the temperature of water released from bank storage is also equal to the inflow temperature is probably not greatly in error, for, at the time the water is being released, inflow temperatures are considerably lower than during the period of high inflow. The procedure is admittedly subject to error, but on an annual basis the average change in bank storage is estimated to be less than 3 percent of the inflow (though a substantially greater proportion of the average annual change in water storage), and the entire advected energy term is not a major item in the annual energy budget.

Although direct solution of the two simultaneous equations (energy and water budget) is possible, it is much simpler to use a successive approximation technique. A preliminary estimate of evaporation was used in the water-budget equation to compute the unmeasured inflow. This, in conjunction with figures of measured inflow and outflow, was used to determine Q_v in the energy-budget equation. Evaporation was then computed using the energy-budget equation, and the entire process repeated if necessary. Usually little difficulty was experienced in obtaining a rapid convergence.

A rough check of the computed value of total unmeasured inflow was available, for the unmeasured surface inflow could be estimated quite reliably, as explained in the section on inflow. It might thereby be concluded that it would be possible to determine changes in bank storage for monthly periods. Such is not the case, however, for the indicated changes in bank storage are generally not large compared with other items in the water budget. Moreover, with this method of computation all errors in measured inflow, outflow, and change in reservoir storage are thrown into the estimate of unmeasured inflow; any further computations based thereon are not reliable.

The various methods of determining inflow, outflow, change in storage, and rainfall are described in the section on instrumentation. The temperatures of these various items were computed in the following manner. The temperature of total inflow was assumed to equal the temperature observed daily at the Grand Canyon gaging station, plus a correction based on monthly observations of inflow temperature at the convergence. The temperature observed at the convergence was compared with the temperature observed at the Grand Canyon gaging station, with the time lag taken into account. The correction varied from 0°F during periods of high inflow in the spring to a maximum of 7°F during periods of low inflow in the winter. Observations of outflow temperatures were made daily in the tailrace by Bureau of Reclamation employees. A constant correction of −2°F was applied to all daily observations as found by Anderson and Pritchard (1951, p. 39). 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). Figure 16 shows the monthly average inflow temperatures at the convergence, and, the outflow temperatures below Hoover Dam. The gates at elevation 900 feet were used for all reservoir releases except during the period June to November 1952, when the gates at elevation 1,050 feet were used.

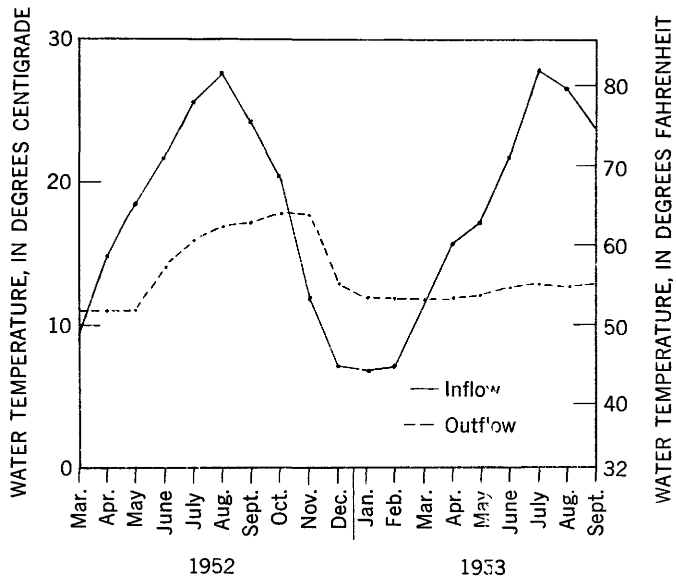

FIGURE 16.—Monthly average inflow temperature at the convergence of muddy Colorado River and Lake Mead waters, and average outflow temperature below Hoover Dam at Lake Mead.

Advected energy was computed for weekly periods and for the periods between thermal surveys. Density and specific heat were assumed constant for all computations. Figure 17 shows the variation in advected energy at Lake Mead.

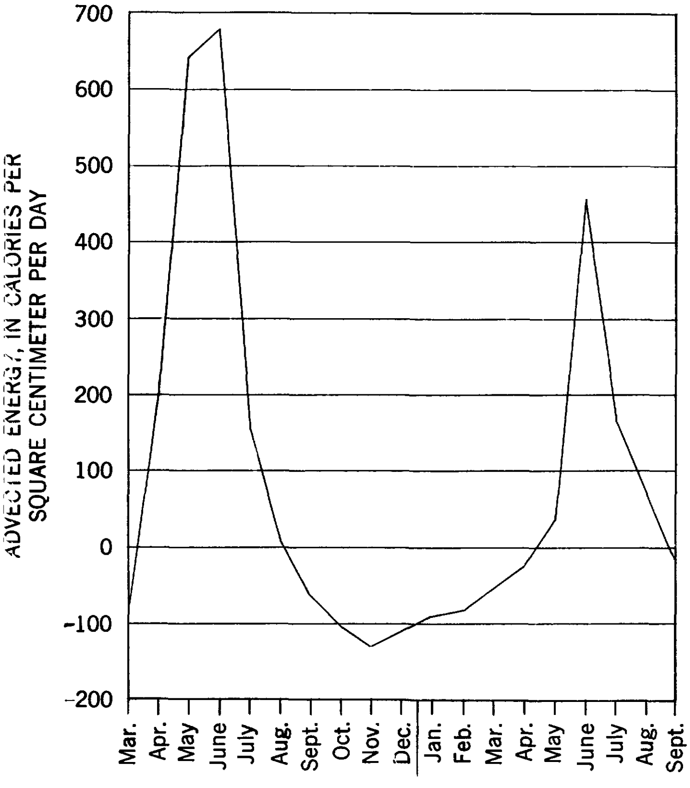

FIGURE 17.—Variation in advected energy at Lake Mead. Base temperature is 0°C.

ENERGY STORAGE

Energy storage (Q_θ) in Lake Mead was computed from thermal profiles of the lake taken once each month at 30 stations located throughout the area of the lake. The location of the stations was selected on the basis of the previous study by Anderson and Pritchard (1951).

During the spring, summer, and fall, the thermal surveys were made during the early morning hours, when the surface temperature was most nearly constant. For navigational purposes, the preferred time for these observations was during a full phase of the moon. In winter the diurnal variation in surface temperature was insignificant, and observations were made during the day.

The lake-temperature profiles, recorded on smoked slides, were replotted on graph paper. The observed lake-surface temperature at the time the profile was taken was used to calibrate the profile at the surface. Below the surface the temperature profile was divided into 5-meter layers and mean temperatures computed

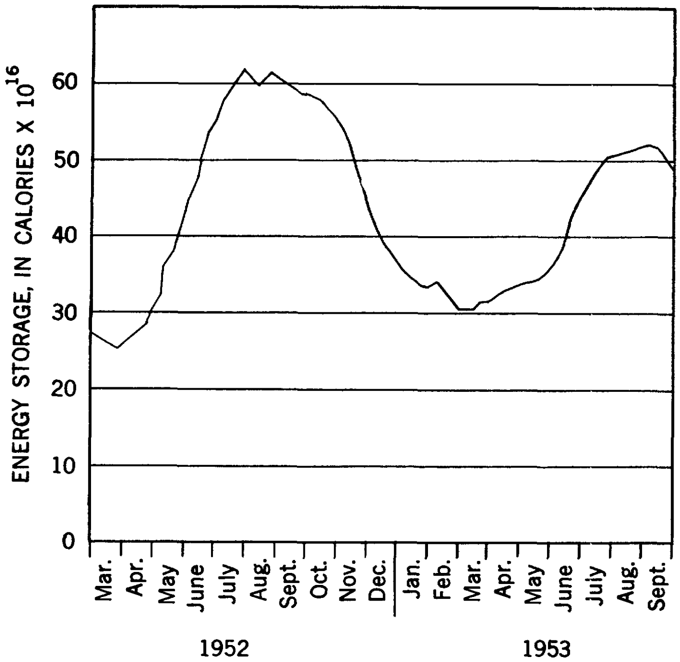

FIGURE 18.—Variation in energy storage in Lake Mead. Base temperature is 0°C.

for each layer. For each thermal survey the computed temperatures in the same layer were averaged to obtain the mean. The energy content in each layer was computed, using the mean temperature and area for each 5-meter layer, and all were summed to obtain the total energy content above an arbitary base temperature of 0°C. Because the change in energy storage, rather than the energy storage itself, is used in computing evaporation, the choice of base temperature was immaterial. Density and specific heat were considered constant. Figure 18 shows the variation in energy storage by energy-budget periods.

Weekly temperature profiles were taken at two representative thermal survey stations. Evaporation was computed on a weekly basis using these two profiles for computing changes in energy storage. During the period when BT 8117 and BT 7309A were tied together and lowered simultaneously, energy storage for the lake was computed from the profile given by each BT and evaporation computed from the indicated change in energy storage. Table 5 shows a comparison of the results; all parameters are the same except change in energy storage. The weekly results vary considerably at times, and for this reason determinations of evaporation for weekly periods by the energy-budget method are not too reliable, at least at Lake Mead, because of the relatively great importance of the change-in-energy-storage item. However, the effect of the use of two different BT's is significant for the regular energy-budget periods of approximately a month in length for which changes in energy storage were computed from the 30-station surveys, as shown in table 6, which indicates that the two bathythermographs gave consistent results. The discrepancy between the weekly results shown in table 4 is presumably due to the fact that only two stations were used, and that transitory small-scale anomalies in thermally induced circulation patterns were responsible.

TABLE 5.—*Evaporation from Lake Mead for indicated periods of about one week, with changes in energy storage as determined from temperature profiles using different bathythermographs*

Period	Bathythermograph	
	No. 8117 (inches)	No. 7309A (inches)
1953		
Jan. 9–Jan. 14	0. 34	1. 25
Jan. 15–Jan. 21	1. 22	1. 05
Jan. 22–Jan. 28	1. 08	1. 26
Jan. 29–Feb. 2	. 28	. 04
Feb. 3–Feb. 12	2. 08	1. 39
Feb. 13–Feb. 19	. 82	1. 32
Feb. 20–Feb. 24	−. 05	−. 08
Feb. 25–Mar. 2	2. 75	2. 88
Mar. 3–Mar. 11	1. 46	1. 83
Mar. 12–Mar. 18	. 62	. 20
Mar. 19–Mar. 25	1. 79	1. 71
Mar. 26–Mar. 31	1. 37	1. 09
Apr. 1–Apr. 8	2. 42	2. 33
Apr. 9–Apr. 15	. 65	1. 03
Apr. 16–Apr. 22	1. 80	1. 34
Apr. 23–Apr. 27	1. 13	1. 00
Apr. 28–May 13	4. 55	5. 13
May 14–May 21	1. 73	. 88
May 22–May 27	3. 13	3. 26

TABLE 6.—*Evaporation from Lake Mead for indicated periods of approximately one month, with changes in energy storage as determined from temperature profiles using different bathythermographs*

Period	Bathythermograph	
	No. 8117 (inches)	No. 7309A (inches)
1953		
January 9–February 2	3. 02	3. 25
February 3–March 2	5. 47	5. 48
March 3–March 31	5. 39	4. 88
April 1–April 27	4. 57	4. 48
April 28–May 27	8. 62	8. 74

Daily changes in energy storage were computed, using the continuous records of the variation of temperature with depth obtained at the two barges. The daily figures also proved to be unreliable and inconsistent and were therefore discarded.

PERFORMANCE OF CUMMINGS RADIATION INTEGRATORS

As described in the section on instrumentation, three CRI's were installed at Lake Mead. One was placed on Boulder Island, to obtain a direct comparison

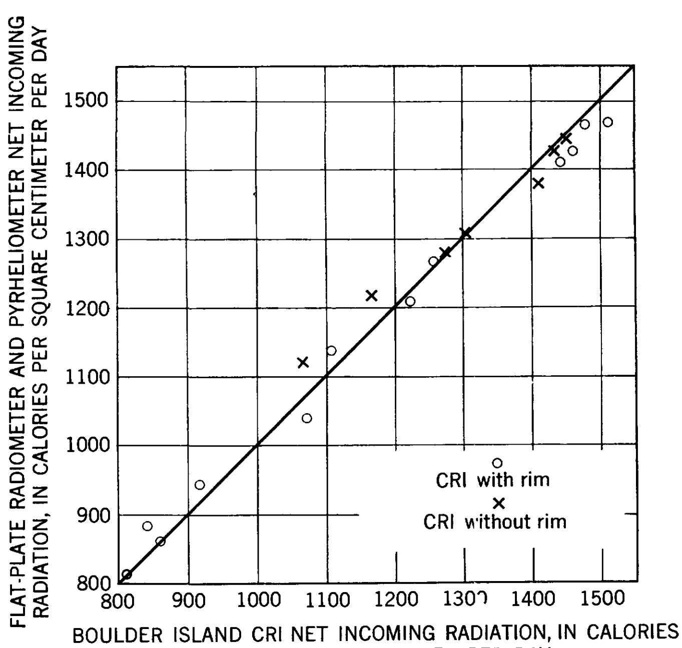

FIGURE 19.—Comparison between net incoming radiation for energy-budget periods as measured by the Boulder Island Cummings radiation integrator and by the flat-plate radiometer and pyrheliometer.

between net incoming radiation as measured with the CRI and as measured with the Gier and Dunkle flat-plate radiometer and the Eppley pyrheliometer. Two other CRI's were located at Overton Arm and at Bonelli Landing to determine the areal variation, if any, in radiation in the Lake Mead area.

The comparison between net radiation as measured at Boulder Island using the conventional radiation instruments and using the CRI is shown in figure 19. The correlation is excellent, the maximum deviation being approximately 5 percent, but a slight seasonal bias is evident. The CRI apparently gives results that are consistently a little too great in the summer and a little too small in the winter. No logical reason for this discrepancy could be found, but it was considered likely that it resulted in part from the exchange in energy between the water surface and the overhanging rim of the CRI, in part from the seasonal variation in the amount of water-surface area exposed to the direct rays of the sun, and in part from the limitations of the flat-plate radiometer.

The overhanging rim was originally designed to minimize the seasonal variation in water-surface area exposed to direct solar radiation. The problem of rim-water energy exchange was soon recognized. Using measurements of rim and water-surface temperatures, it was possible to compute the energy interchange, but the results were known to be subject to error because of uncertainties as to the emissivity of the underside of the rim and as to the accuracy of a determination of rim temperature from measurement at only one point.

In an attempt to determine the effect of the overhanging rim, it was removed from the Boulder Island CRI on February 25, 1953. Results obtained during the remainder of the project, as shown in figure 19, indicate that the removal of the rim had little effect, if any, during the summer months but may have a pronounced effect during the rest of the year, if the trend indicated by the two lowest measurements is borne out by data that may be obtained in the future.

It would appear preferable to design a CRI in which the water surface is at the same level as the rim, thus completely avoiding the rim-water energy exchange and the seasonal variation in the area of water surface exposed to solar radiation. There is also no theoretical reason why the CRI need be so large. The practical problems connected with the complete elimination of the overhanging rim, such as the prevention of overflow as a result of precipitation, the maintenance of a constant water level, and the prevention of "splash out" from wind, have not yet been solved but do not appear insurmountable.

The absence of areal variation in net incoming radiation is illustrated in figures 20 and 21, which show the relation between radiation as measured by the Boulder Island CRI and the Overton Arm and Bonelli Landing CRI's. For comparative purposes, data obtained from the Boulder Island CRI were used in preference to those from the pyrheliometer and radiometer at the same station, in order to eliminate the possible obscuration of areal variation by differences in instrumentation. During the summer months the Bonelli and Overton CRI data agree better with data from the conventional radiation equipment at Boulder Island than do the Boulder Island CRI data.

During the period March 12, 1952, to March 2, 1953, records from all these CRI's and the radiation equipment are available for comparison. Records obtained after that date were not used, in order to eliminate any possible bias resulting from the removal of the rim on the Boulder Island CRI in late February 1953. For that period average daily net incoming radiation measured by the four sets of equipment was as follows:

	Calories per sq cm per day
Boulder Island radiation equipment	1,155
Boulder Island CRI	1,160
Bonelli Landing CRI	1,133
Overton Arm CRI	1,134

Since the Bonelli and Overton results differ by only 2 percent from the mean Boulder Island data, there appears to be no basis to conclude that there is a significant areal variation in radiation over the Lake Mead area.

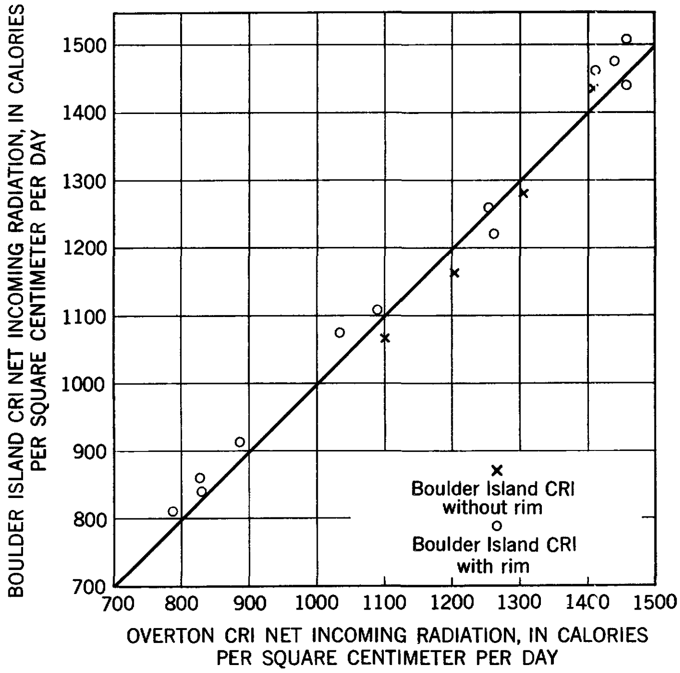

FIGURE 20.—Comparison between net incoming radiation for energy-budget periods as measured by the Ovrton and the Boulder Island Cummings radiation integrators.

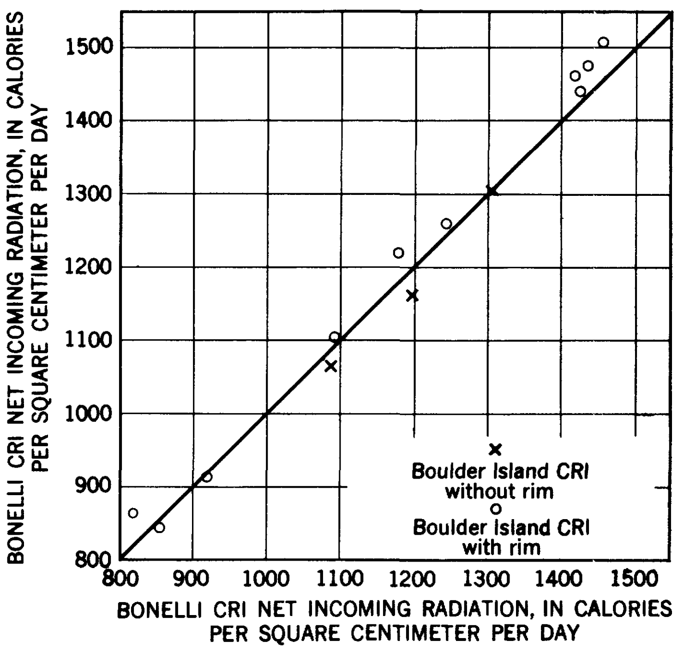

FIGURE 21.—Comparison between net incoming radiation for energy-budget periods as measured by the Bonelli and the Boulder Island Cummings radiation integrators.

SUMMARY OF MEASUREMENTS OF ENERGY-BUDGET TERMS

The method of measuring or computing each term in the energy-budget equation has been discussed in the preceding sections. Little has been said, however, of their relative magnitudes, the seasonal variation therein, or of the effects of errors in individual terms upon the resultant computed figures of evaporation.

Of the terms in the energy-budget equation, solar and atmospheric radiation and the reflected portions thereof, are almost completely independent of the physical characteristics of a reservoir. Radiation from the water surface, advected energy, and change in energy storage depend to some extent on certain hydrologic characteristics of a reservoir, including its thermal structure, the relation between inflow, outflow, and capacity, and its operating regimen. The remaining terms, which are the quantities of energy utilized for evaporation, conducted to the atmosphere, and carried away by the evaporated water, depend on both net incoming radiation and reservoir characteristics.

In table 7 are shown average values of each term for energy-budget periods of approximately one month in length. The magnitudes of the radiation terms Q_s, Q_r, Q_a, and Q_{ar}, are representative of the arid region in which Lake Mead is located. When more is known of the areal variation in Q_a, the atmospheric radiation, perhaps reasonable advance estimates can be made of the sum of these four items at any proposed reservoir site.

Average daily values of each of the items given in table 6 were computed for the period July 9, 1952, to June 29, 1953, which is approximately a year, and are given with comparable values for Lake Hefner in table 8. For all items except advected energy and change in energy storage, the variation between the two lakes is about as might be expected as a result of the difference in climate. Advected energy, Q_v, and change in energy storage, Q_ϑ, for Lake Hefner are representative of average annual values, but for Lake Mead are not. For a period of many years the average annual change in water storage in Lake Mead would be zero. The average annual change in energy storage would also be zero, since there is no reason to anticipate a change in the average annual water temperature. The figure of −4 calories per square centimeter per day for Q_v indicates a net loss of energy from the lake, which is impossible over a long period, as inflow volumes exceed outflow volumes and inflow temperatures exceed outflow temperatures. The term $Q_v - Q_\vartheta$ is, however, fairly independent of annual operations and should be representative of an average year. The figure of 52 calories

TABLE 7.—*Average values, by periods, for terms in the energy budget, for Lake Mead*

[In calories per square centimeter per day]

Period	Q_s	Q_r	Q_a	Q_{ar}	Q_{bs}	Q_v	Q_e	Q_h	Q_w	Q_ϑ
1952										
Mar. 12–Apr. 14	560	40	633	15	769	−26	273	−34	6	98
Apr. 15–May 11	627	41	699	20	823	471	239	−36	7	703
May 12–June 11	735	47	749	24	871	636	468	−63	18	755
June 12–July 8	724	45	817	29	894	542	545	−86	23	633
July 9–Aug. 5	695	43	842	29	943	103	459	−50	23	193
Aug. 6–Sept. 3	635	42	864	29	946	4	500	−56	25	17
Sept. 4–Oct. 2	502	36	769	26	923	−67	342	−8	16	−131
Oct. 3–Nov. 5	420	35	674	17	893	−106	275	+14	12	−258
Nov. 6–Dec. 2	283	28	623	14	830	−135	490	+129	16	−736
1952–1953										
Dec. 3–Jan. 8	237	26	618	14	788	−106	245	+68	6	−398
1953										
Jan. 9–Feb. 2	304	30	621	14	770	−86	194	+23	4	−196
Feb. 3–Mar. 2	398	34	596	14	760	−83	293	+37	6	−233
Mar. 3–Mar. 31	533	39	643	16	770	−51	251	−29	6	72
Apr. 1–Apr. 27	597	39	680	19	797	−26	247	−34	7	176
Apr. 28–May 27	719	44	648	16	813	15	434	−69	13	131
May 28–June 29	762	46	731	24	861	446	412	−86	15	667
June 30–July 29	650	38	858	28	930	161	400	−61	19	315
July 30–Aug. 26	612	38	832	27	942	74	444	−43	22	88
Aug. 27–Sept. 28	587	42	761	26	930	−19	477	−19	23	−150

TABLE 8.—*Average daily values of terms in energy-budget equation, Lake Mead and Lake Hefner*

[In calories per square centimeter per day]

	Q_s	Q_r	Q_a	Q_{ar}	Q_{bs}	Q_v	Q_e	Q_h	Q_w	Q_ϑ	$Q_v - Q_\vartheta$
Lake Mead	506	37	692	20	842	−4	344	−5	12	−56	52
Lake Hefner	420	26	638	19	781	2	222	8	6	−2	4

per square centimeter per day for Lake Mead compared with 4 for Lake Hefner is quite significant. For Lake Hefner, as for most lakes, it indicates a general balance between heat imported, exported, and stored in water. For Lake Mead it indicates a general excess of heat imports, which contributes to increased evaporation from the reservoir.

EFFECT OF ERRORS IN EVALUATING ENERGY-BUDGET ITEMS

The accuracy with which each term in the energy-budget equation can be evaluated depends on the inherent accuracy of the measuring equipment and the completeness of the record. Some items, such as solar radiation, are measured with an instrument whose output can be made to provide a record of the quantity sought. Other items, such as advected energy, must be computed from measurements of other parameters.

A simple calibration is all that is needed to determine the accuracy of certain measuring and recording instruments. Many other types of measurements cannot be checked by direct calibration procedures, and it may be necessary to estimate their accuracy on the basis of previous experimental verifications of the techniques used, as with the measurements of inflow and outflow.

Loss of record also affects the accuracy of the determination of the average value of any item for a specified period of time. In many instances it was necessary to make interpolations or estimates for short periods of missing record, which obviously affects the accuracy of the average for the entire period.

Table 9 was prepared to indicate the limits of error of the measurement of each term in the energy-budget equation, and the effect on computed evaporation. The estimated maximum likely errors shown include both calibration errors and those resulting from missing record.

Statistically, if the indicated errors are combined by adding the individual variances, the estimated maximum error of computed monthly evaporation is about 10 percent in summer and 13 percent in winter. It should be remembered that these are estimated to be the maximum likely error, and the error in most monthly figures is believed to be substantially less. On an annual basis the error should be considerably less than 10 percent because the percentage of error in evaluating the change in energy in the reservoir decreases markedly as the length of period increases.

On the basis of the figures shown in table 9 it is evident that for the purpose of determining evaporation, certain measurements must be made with as great accuracy as possible, but others need not be. For example, at Lake Mead, water temperatures must be measured quite accurately and many profiles taken in order to ensure that the average temperature of the lake is determined within 0.1°C, which is equivalent to an error of 10 percent of the evaporation during winter months. On the other hand, to determine reflected solar energy within 10 percent, which is equivalent to an error of only 1 percent in evaporation, no instrumentation was necessary other than that required for the measurement of solar energy itself. When the preliminary plans for any contemplated evaporation study are made, it is most desirable that estimates be made of the magnitudes of the various quantities involved and the probable errors of measurement in order that a rational and economical program of instrumentation may be devised.

TABLE 9.—*Estimated maximum error in each energy-budget term and the resultant error in computed monthly evaporation from Lake Mead*

Term	Estimated maximum error	Percent error in computed evaporation	
		Summer month	Winter month
Q_s	2 percent	4	2
Q_r	Less than 10 percent	1	1
Q_a	2 percent	4	4
Q_{ar}	Less than 10 percent	1	1
Q_{bs}	1.0°C in average lake-surface temperature.	3	4
Q_v	5 percent in inflow and outflow volumes and 1.0°C in inflow and outflow temperatures.	4	2
Q_h	20 percent in average Bowen ratio for entire lake.	5	4
Q_w	1.0°C in average lake-surface temperature.	0	0
Q_ϑ	0.1°C in average temperature of lake.	5	10

MASS-TRANSFER STUDIES

By G. EARL HARBECK, JR., U. S. Geological Survey

The results of the Lake Hefner studies indicated that of the various mass-transfer equations tested, those of Sutton and Sverdrup (the 1937 form) were suitable for use with available field instruments. A new quasi-empirical equation was found to give good results for Lake Hefner, but there was no assurance that it was applicable to other lakes. It was further found that at Lake Hefner the effect of atmospheric stability was unimportant, at least for periods of one day or longer.

SVERDRUP'S EQUATIONS

For comparative purposes two of the equations proposed by Sverdrup may be expressed as follows:

Sverdrup (1937): $$E=\frac{0.623\rho k_0 u_*(e_0-e_z)}{P\left[\ln\left(\frac{z+z_0}{\delta_l+z_0}\right)+\frac{k_0\delta_l u_*}{D}\right]} \quad (4)$$

Sverdrup (1946): $$E=\frac{0.623\rho k_0 u_*(e_0-e_z)}{P\left[\ln\left(\frac{z+z_0}{z_0}\right)\right]} \quad (5)$$

In equation 4 Sverdrup used $\delta_l=27.5\nu/u_*$, and in both equations he used the following equation to express the variation of wind with height:

$$u=\frac{u_*}{k_0}\ln\left(\frac{z+z_0}{z_0}\right) \quad (6)$$

The difference between the equations 4 and 5 lies wholly in the denominator. Using Sverdrup's value for $\delta_l=27.5\nu/u_*$ or the value $30\nu/u_*$ that was used in the Lake Hefner report, evaporation computed using equation 5 is approximately twice that obtained using equation 4.

Sverdrup's 1937 equation gave reasonably good results at Lake Hefner, but this is believed to be at least partly coincidental. In both equations Sverdrup assumed that the variation of moisture with height followed a logarithmic law, which is believed to be a satisfactory approximation. In his 1937 work he used the expression:

$$e_z=e_0-c\ln\left(\frac{z+z_0}{z_0}\right) \quad (7)$$

in which the value of c was empirically determined.

Rearranging equation 7 and using two levels, z_1 and z_2, we obtain

$$\frac{e_0-e_{z_2}}{e_0-e_{z_1}}=\frac{\ln\left(\frac{z_2+z_0}{z_0}\right)}{\ln\left(\frac{z_1+z_0}{z_0}\right)} \quad (8a)$$

Similarly using equation 6 we may write

$$\frac{u_{z_2}}{u_{z_1}}=\frac{\ln\left(\frac{z_2+z_0}{z_0}\right)}{\ln\left(\frac{z_1+z_0}{z_0}\right)} \quad (8b)$$

Although Sverdrup stated that z_0 should be determined from the wind profile, equations 8a and 8b indicate that we can determine z_0 from either the wind or humidity profile. However, both the Lake Hefner and Lake Mead data indicate that the values of z_0 computed from the wind profile differ considerably from those computed from the humidity profile. In general the humidity ratio $(e_0-e_{z_2})/(e_0-e_{z_1})$ is considerably less than the wind ratio u_{z_2}/u_{z_1}, hence z_0 computed from the humidity ratio is very much less than z_0 computed from the wind ratio.

Sverdrup's 1946 equation was used for computing evaporation from Lake Hefner with z_0 determined from the wind profile, and the results were far too large. If this equation were used for Lake Mead, the results would be far too small because of the much smaller value of z_0. His 1937 equation gave much better results at Lake Hefner; it appears preferable because it is based upon the existence of a laminar sublayer below the turbulent layer, whereas the 1946 equation is based on the assumption that the turbulent layer extends down to the water surface. It cannot be accepted on theoretical grounds, however, because of the implication that it makes no difference whether z_0 is determined from the wind or humidity profile. However, if z_0 for Lake Mead is determined from the wind profile, the resulting figures of evaporation based on the 1937 equation are too small.

From the Lake Hefner daily averages of meteorological data (U. S. Geol. Survey, 1954b) and from the Lake Mead data, certain information is available to substantiate the statement concerning the method used to determine z_0. Admittedly, daily data are not as desirable as short-period observations for defining wind and humidity profiles, but it is believed that they are adequate to illustrate this particular point. From the data for both reservoirs, ratios of the wind speeds and vapor-pressure differences were determined for the 8- and 2-meter levels for those days on which the average air-water temperature difference (T_8-T_0) was between $-0.9°C$ and $+0.9°C$, as shown in table 10.

TABLE 10.—*Ratios of a average wind speed and vapor-pressure difference for Lake Hefner and Lake Mead, based on daily average data*

	Number of days	$\frac{u_8}{u_2}$	u_8 (knots)	$\frac{e_0-e_8}{e_0-e_2}$	T_8-T_0 (°C)
Lake Hefner	45	1. 237	10. 5	1. 135	0. 01
Lake Mead	58	1. 145	6. 8	1. 105	0. 08

For Lake Hefner, $z_0=0.57$ cm on the basis of the wind ratio and $z_0=0.0067$ cm on the basis of the humidity ratio. For Lake Mead similar values of z_0 are 0.014 cm and 0.0004 cm. It should be noted that the wind ratio for Lake Hefner given in table 10 does not agree precisely with those given in table 3 of the Lake Hefner report (U. S. Geol. Survey, 1954, p. 49). Those in the earlier report are based upon many more data, and the variation in wind ratio with wind speed was taken into account. This was not done in the present study, but the results for the two lakes are believed to be comparable because similar data were used.

SUTTON'S EQUATION

Sutton's equation (1934) for evaporation from a smooth surface was modified by Marciano and Harbeck (1954), to give evaporation from a rough surface on the basis of Sutton's (1949) expression for macroviscosity. The modified equation, when tested with the Lake Hefner data, gave as good or better results than any of the theoretical equations tested. For Lake Mead it was soon apparent that results obtained, using the modified equation, were only approximately half those determined from the energy budget. It may have been that the simple modification performed to make Sutton's smooth-surface equation applicable to rough surfaces was inadequate, and the results obtained with the Lake Hefner data were to a large extent coincidental. On the other hand, the value of the wind-profile exponent, which takes atmospheric stability into account in Sutton's equation, was considerably different for Lake Mead. Sutton (1953, p. 308) pointed out that his equation was applicable only to a hydrodynamically smooth surface.

CALDER'S EQUATION

According to Sutton (1953, p. 309), Calder (1949) has obtained expressions for evaporation from both rough and smooth surfaces. For a rough surface the logarithmic wind law used by Calder was

$$\frac{u}{u_*}=\frac{1}{k_0}\ln\left(\frac{z-d}{z_0}\right) \tag{9}$$

in which d=zero-point displacement. Calder does not state whether a zero-point displacement occurs over a water surface. The Lake Hefner wind observations at 2, 4, and 8 meters above the water surface indicated no significant departure from the ordinary logarithmic law, and it is therefore assumed that $d=0$ for a water surface.

Because of mathematical difficulties, Calder replaced the more exact logarithmic law, equation 9, by a power law of the type

$$\frac{u}{u_*}=q'\left(\frac{z}{z_0}\right)^{\alpha} \tag{10}$$

in which the values of q' and α depend on the range of z/z_0 within which equation 10 is to agree with equation 9.

Based on a mathematical treatment of the problem of the turbulent diffusion from a continuously emitting line source of infinite length, at surface level and perpendicular to the surface wind, Calder expressed the variation of humidity with height and with distance downwind as follows:

$$\chi(x,z)=\chi_0\left\{1-I\left[\frac{z^{2\alpha+1}}{M(2\alpha+1)^2x},\frac{-(\alpha+1)}{(2\alpha+1)}\right]\right\} \tag{11}$$

in which $\chi(x,z)$=vapor concentration in gm cm^{-3} at the point (x,z)

χ_0=saturation vapor concentration in gm cm^{-3}

I denotes Pearson's function, $I(X,p)$, values of which have been tabulated by Pearson (1922).

M is defined by Calder as follows:

$$M=\frac{{z_0}^{2\alpha}}{\alpha(q')^2}$$

in which z_0, α, and q' are determined from equation 9 and equation 10.

Calder's expression for evaporation from a rough rectangular surface of unit width and length x_0 is as follows:

$$E(x_0)=\left(\frac{2\alpha+1}{\alpha+1}\right)\frac{\chi_0}{\pi}\sin\left\{\frac{(\alpha+1)\pi}{2\alpha+1}\right\}(2\alpha+1)^{\frac{1}{2\alpha+1}}M^{\frac{\alpha+1}{2\alpha+1}}\Gamma\left(\frac{\alpha+1}{2\alpha+1}\right)u_z\,z^{-\alpha}\,x_0^{\frac{\alpha+1}{2\alpha+1}} \tag{12}$$

Observations of wind, temperature, and humidity were made at barges moored one each in midlake at Lake Hefner and Boulder Basin of Lake Mead. Equation 11 was therefore rearranged to give $(\chi_0-\chi)$ in terms of χ_0, with $x=x_0/2$, and the result substituted in equation 12, which was also divided by x_0 to give average point evaporation over the length x_0. The resulting equation is as follows:

$$E=\frac{(2\alpha+1)\sin\left\{\frac{(\alpha+1)\pi}{(2\alpha+1)}\right\}(2\alpha+1)^{\frac{1}{2\alpha+1}}M^{\frac{\alpha+1}{2\alpha+1}}\Gamma\left(\frac{\alpha+1}{2\alpha+1}\right)u_z\,z^{-\alpha}\,x_0^{\frac{-\alpha}{2\alpha+1}}(\chi_0-\chi)}{(\alpha+1)\,\pi\left\{I\left[\frac{z^{2\alpha+1}}{M(2\alpha+1)^2(x_0/2)},\frac{-(\alpha+1)}{(2\alpha+1)}\right]\right\}} \tag{13}$$

For the selected values of α, z, and x_0 it is possible to compute the coefficient N in an equation of the form

$$E=Nu_8\ (e_0-e_8) \quad (14)$$

in which E is in cm/(3 hours), u_8 in knots, and (e_0-e_8) in millibars.

Unfortunately the difficulty in interpolating in Pearson's tables makes it inadvisable to preselect values of α. It is easier to choose values of the ratio $(\alpha+1)/(2\alpha+1)$ that appear in the tables, as for example 0.95, 0.90, and 0.85. These three values were used with an x_0 of 3.45×10^5 cm for Lake Hefner and an x_0 of 1.135×10^6 cm for Boulder Basin of Lake Mead. The results are listed in table 11.

TABLE 11.—*Values of N obtained by use of Calder's equation*

$\frac{\alpha+1}{2\alpha+1}$	α	u_8/u_2	N Lake Mead	N Lake Hefner
0.95	0.0556	1.080	1.92×10^{-4}	1.93×10^{-4}
.90	.1250	1.189	9.10×10^{-4}	9.22×10^{-4}
.85	.2143	1.346	2.43×10^{-3}	2.45×10^{-3}

It was not readily apparent whether there was a significant difference in the values of N for Lake Mead and Lake Hefner for the preselected values of $(\alpha+1)/(2\alpha+1)$ or whether the apparent differences resulted from small errors in the computations. In any event, for computational purposes the differences are negligible, and Calder's equation indicates that for a given value of α, N is independent of the size of the lake, at least over the selected range of values of α and x_0. It cannot be concluded, however, that α is independent of the size of the lake. Instead, α should decrease with distance downwind, with an initial value at the upwind edge representative of the upwind terrain and approaching zero at an infinite distance downwind, if steady-state conditions are assumed.

The relation between an average value of N and the wind ratio u_8/u_2 is shown in figure 22. Table 10 shows that for Lake Hefner the average value of u_8/u_2 was approximately 1.237, for which α is 0.154. From figure 27, the value of N corresponding to this wind ratio is 1.3×10^{-3}, which is slightly more than twice the value of N found to best fit the observed data. In other words, if evaporation from Lake Hefner had been computed using a value of 1.3×10^{-3} for N, the results would have been approximately twice as great as the measured evaporation. For Lake Mead the value of N corresponding to a wind ratio of 1.145 (for which α is 0.098), would be 5.7×10^{-4}. This is not greatly different from the empirical value of 6.25×10^{-4} determined for Lake Hefner and tested at Lake Mead, but in the absence of other corroborative information must perforce be questioned as possibly only coincidental.

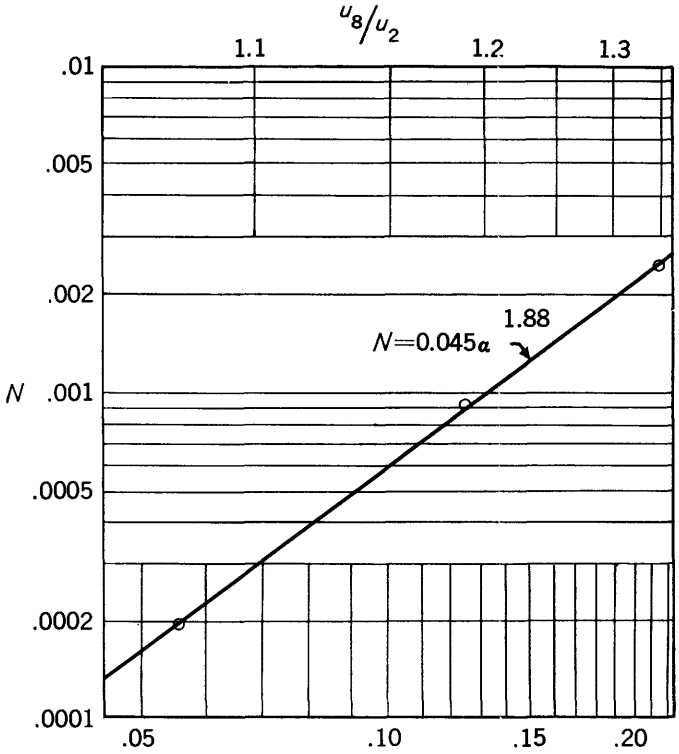

FIGURE 22.—Relation between "N" and "α" in Calder's equation.

Figure 22 indicates that Calder's equation is extremely sensitive to changes in α. A change of 0.01 in α at $\alpha=0.10$ results in a change of approximately 19 percent in computed evaporation. Although there is good evidence that changes in the value of α are rapid and often of considerable magnitude, the results of both the Lake Hefner and Lake Mead studies suggest that evaporation is affected to a much lesser degree than is indicated by Calder's evaporation equation.

It is apparent from figure 22 that the relation between N and α can be closely approximated by a power function, as follows:

$$N=0.045\alpha^{1.88} \quad (15)$$

The maximum error in N is approximately 2 percent for values of α between 0.05 and 0.20.

Because the value of the constant N obtained from Calder's equation gives figures of evaporation that differ considerably from observed evaporation, and because of the apparent tendency for the equation to overcorrect greatly for the effect of atmospheric stability, Calder's equation was discarded. In its present form, at least, the results obtained cannot be considered reliable.

LAKE HEFNER QUASI-EMPIRICAL EQUATION

The equation determined as best fitting the Lake Hefner data was

$$E=6.25\times10^{-4}u_8(e_0-e_8) \quad (16)$$

in which E is in cm/(3 hours), u_8 in knots, and (e_0-e_8) in millibars. At Lake Hefner, Marciano and Harbeck (1954, p. 64) found that the effect of atmospheric stability was not significant at least for figures of daily evaporation. It could not be assumed that this was true at Lake Mead, however, and any test of the validity of equation 16 must also include a study of the effect of atmospheric stability.

In order to investigate whether the constant 6.25×10^{-4} was applicable to Lake Mead, a period of approximately 1 year in length (12 energy-budget periods) was selected for study. This period, July 9, 1952 to June 29, 1953, was selected because the data were considered to be of good quality. During the first few months of operation there was a larger percentage of missing record than occurred later, as might be expected. During the last few months, the observational program was not as comprehensive; records of water temperature and wet- and dry-bulb temperatures at the outlying raft stations were discontinued.

For this 356-day period, computed evaporation obtained by the energy-budget technique was 5 percent less than that obtained by equation 16 (see table 12). Although on an annual basis the agreement was satisfactory, deviations of considerable magnitude were noted for individual energy-budget periods of approximately 1 month in length.[2] An examination of the deviations revealed that they had a definite seasonal trend and were significantly correlated with a number of parameters, including wind shear (as expressed by the ratio u_8/u_2), atmospheric stability (as expressed by S, the stability parameter, which is proportional to the Richardson number), and the humidity profile (as expressed by the ratio $(e_0-e_8)/(e_0-e_2)$. The stability parameter S was defined as follows:

$$S=\frac{(T_8-T_0)}{u_8^2} \tag{17}$$

in which T_8 and T_0 are in degrees centigrade and u_8 in knots.

The effect of atmospheric stability is illustrated in figure 23. Computed energy-budget evaporation for each period was divided by the summation of the products of wind speed and vapor pressure difference (8-meter data) for that period, to eliminate the effects of those two variables, and the ratio plotted

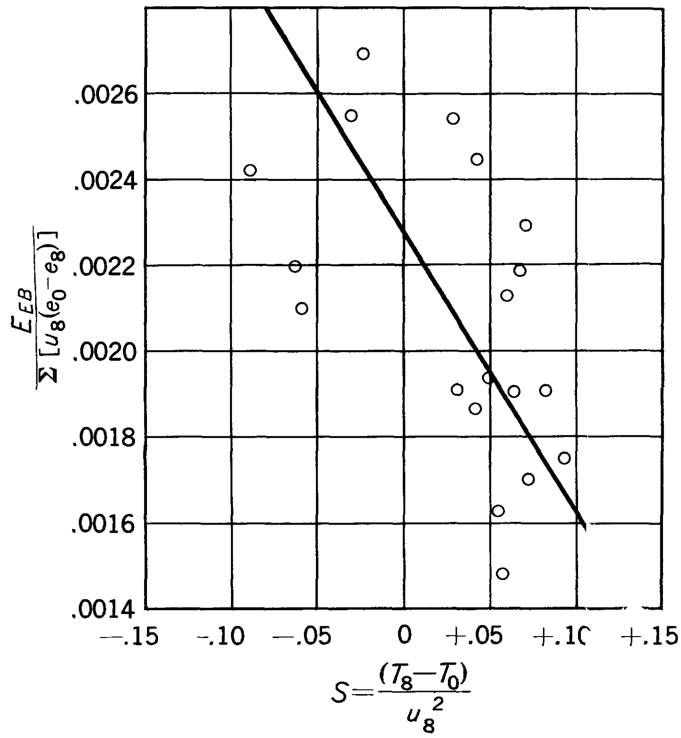

FIGURE 23.—Relation between the stability parameter (S) and the ratio of the energy budget to the summation of the product $u_8(e_0-e_8)$.

against S, the stability parameter. A poor but significant correlation is evident in figure 23. A similar analysis using the 2-meter data is illustrated in figure 24; no apparent correlation exists.

The preceding analysis indicated that if wind and humidity data for the 2-meter level at the barge station were used in equation 16, the effect of atmospheric stability would be negligible. Unfortunately equation 16 could not be used with the 2-meter data for the computation of evaporation because the constant, 6.25×10^{-4}, would not be applicable .

That the use of the 2-meter data would minimize the effects of stability might seem surprising. Many wind and humidity profiles derived from the Lake Hefner data for the 2-, 4-, 8-, and 16-meter levels were plotted on semilogarithmic graph paper. At Lake Mead measurements were made at only the 2- and 8-meter levels, so that similar graphs for Lake Mead could not be made. Within the limits of observational error, the Lake Hefner wind data plotted as a straight line, at least between 2 and 8 meters, regardless of stability. This would probably not have been true if short-period observations had been used, but the use of 3-hour averages presumably smoothed out the curvature. The slopes of the lines were highly correlated with stability, however; large wind ratios were associated with stable conditions and small wind ratios with unstable conditions. Thus the effect of change in slope due to stability

[2] The possibility that the energy-budget results were subject to seasonal bias was investigated. It was not considered possible that incoming radiation data were seriously in error because of the fact that these items were measured by the pyrheliometer and flat-plate radiometer as well as the CRI. Other items such as change in energy storage and advected energy showed no correlation whatever with the deviations between energy-budget and 8-meter mass-transfer results.

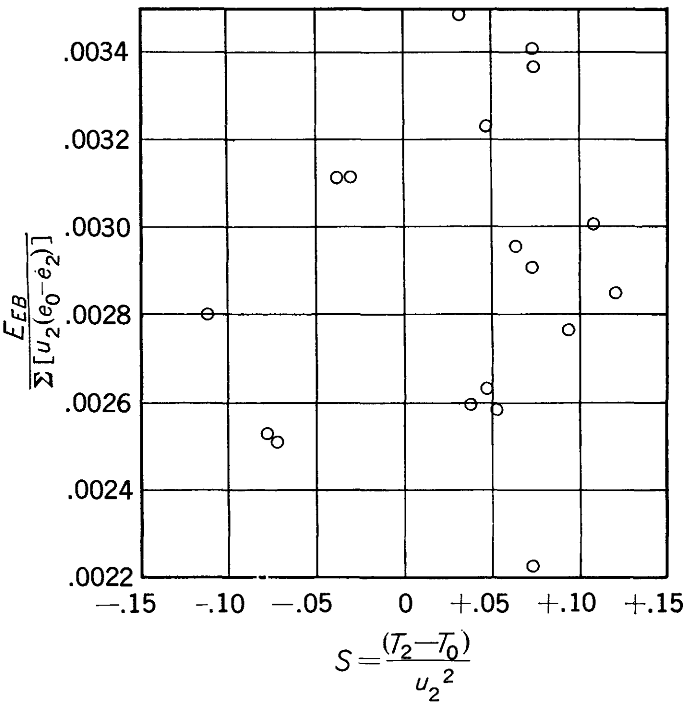

FIGURE 24.—Relation between the stability parameter (S) and the ratio of the energy budget to the summation of the product $u_2(e_0-e_2)$.

is much less at the 2-meter level than at the 8-meter level, insofar as absolute values of wind speed and humidity are concerned.

It should be noted that if Sverdrup's equation is used, measurements can be made at any height above the water surface provided they are made within the vapor blanket (U. S. Geol. Survey, 1954, p. 51). This is in contrast with the requirements for an equation of the type proposed by Sutton, which are that measurements of humidity be made in unmodified air above the vapor blanket. The quasi-empirical equation 16 is used to determine evaporation at a single point in the reservoir and is therefore similar to Sverdrup's equation rather than Sutton's, and measurements at any height within the vapor blanket may be used.

To minimize the effects of stability, it might be argued that it would be best to make observations as close to the water surface as possible, but certain practical considerations dictate a compromise. As the observational level approaches the surface, wind, humidity, and temperature differences decrease, and the effects of errors of measurement increase. At both Lake Mead and Lake Hefner the 2-meter data are not considered to be as reliable as the 8-meter data because cup-type anemometers were used, and the 2-meter wind probably reached the anemometer stalling speed more frequently than did the 8-meter wind.

Since the deviations between the energy-budget and 8-meter mass-transfer results were observed to be correlated with both the wind ratio and humidity-difference ratio, a multiple correlation was made using as the dependent variable $\Sigma u_8(e_0-e_8)$ for each monthly period, in which u is in knots and e in millibars. The independent variables were $\Sigma u_2(e_0-e_2)$ and S for the same periods. The resulting regression equation was

$$u_8(e_0-e_8)=1.346u_2(e_0-e_2)+75.7\ S \quad (18)$$

For neutral stability, for which $S=0$

$$u_8(e_0-e_8)=1.346u_2(e_0-e_2) \quad (19)$$

Since figure 24 indicates that the effect of stability is insignificant at the 2-meter level, equation 19 may be used to convert equation 16 for use with data obtained at the 2-meter level, as follows:

$$E=2.65\times10^{-3}u_2(e_0-e_2) \quad (20)$$

in which E is now given in inches per day and u and e are in the same units hitherto used.

The foregoing development was made using data for the barge station in Boulder Basin. It was realized that wind speeds measured in the approximate center of Boulder Basin were not necessarily representative of the entire lake. The variability in both wind speed and direction in Boulder Basin has already been noted. Because of the configuration of the reservoir and the ruggedness of the surrounding terrain, there is every reason to suppose that the same conditions prevail in other basins of the lake. Measurements were not made, however, because additional stations for measuring wind speeds in the other basins would necessarily have been placed on shore or in sheltered locations, for it was not deemed practical to construct additional barges substantial enough to withstand the buffeting by waves in exposed locations. During the last few months of the project a barge was operated in the Virgin Basin, but the period of record was so short that it was of little value for the purpose of estimating the variation in wind speed over the entire reservoir. Wind speeds recorded at the barge station in Boulder Basin were therefore considered to be representative of the entire lake.

Raft stations, as described in the chapter on instrumentation, were installed in Overton Arm and near Temple Bar. The locations were so selected that water depths at the rafts were roughly the same as the average water depths in that part of the lake, in the hope that water-surface temperatures recorded at the selected sites would be representative of water-surface temperatures in their areas. Records of wet- and dry-bulb temperatures at the 2-meter level were also obtained at the raft stations, in order that the humidity difference, (e_0-e_2), could be computed.

In general, water temperatures at the raft stations were slightly higher than at the barge in Boulder Basin, as might be expected because the water was shallower. Differences in humidity were not of any considerable magnitude, but the humidity gradient, as expressed by (e_0-e_2), was in general greater than at the Boulder Basin barge. Evaporation computed by means of equation 20 was therefore adjusted, using humidity differences measured at the raft stations as representative of the shallower areas of the lake, and a weighted average was obtained.

RESULTS OF ENERGY-BUDGET AND MASS-TRANSFER COMPUTATIONS

By G. Earl Harbeck, Jr., U. S. Geological Survey

EVAPORATION BY ENERGY-BUDGET PERIODS

Evaporation from Lake Mead by energy-budget periods from March 12, 1952, to September 28, 1953, has been computed from the 8-meter and 2-meter data by means of equations 16 and 20, and is shown in table 12 with figures of energy-budget evaporation. Mass-transfer evaporation from Lake Mead, as computed by substituting the 8-meter data in the equation developed for Lake Hefner, is generally much greater than energy-budget evaporation during late spring and summer (periods 4–7 and 15–18 inclusive), which is indicative of the previously mentioned stability effects. During the winter the reverse is true, as may be seen by comparing the results for periods 9–12, inclusive. It should be noted, however, that computation of evaporation on an annual basis by means of equation 16, which was derived for Lake Hefner, gave good results at Lake Mead. Evaporation so computed for periods 5–16 (approximately a year) totaled 86.87 inches, as compared with the energy-budget evaporation figure of 82.59 inches, a difference of only 5 percent. Such close agreement is particularly surprising in view of the fact that Lake Mead differs from Lake Hefner in many respects, such as size, shape, orographic setting, and climate. However, the marked effect of the difference in size of the two lakes upon wind and humidity profiles is readily apparent (see preceding section).

Table 12.—*Evaporation from Lake Mead for energy-budget periods, March 12, 1952, to September 28, 1953*

[In inches]

Number	Period	Number of days in period	Computed evaporation: Energy-budget	Mass-transfer 8-meter data [1]	Mass-transfer 2-meter data [2]	Energy budget minus mass-transfer 2-meter data	Average of energy-budget and mass-transfer	Mass-transfer Las Vegas and Boulder Basin data [3]
	1952							
1	Mar. 12–Apr. 14	34	6. 22	5. 02	4. 94	+1. 28	5. 58	5. 08
2	Apr. 15–May 11	27	4. 34	4. 05	3. 68	+. 66	4. 01	3. 51
3	May 12–June 11	31	9. 80	9. 53	8. 87	+. 93	9. 34	8. 02
4	June 12–July 8	27	9. 95	10. 60	9. 38	+. 57	9. 66	10. 10
5	July 9–Aug. 5	28	8. 72	9. 53	8. 16	+. 56	8. 44	8. 49
6	Aug. 6–Sept. 3	29	9. 84	13. 07	11. 46	−1. 62	10. 65	11. 56
7	Sept. 4–Oct. 2	29	6. 72	7. 57	7. 50	−. 78	7. 11	6. 05
8	Oct. 3–Nov. 5	34	6. 33	6. 36	7. 17	−. 84	6. 75	6. 25
9	Nov. 6–Dec. 2	27	8. 89	7. 29	8. 52	+. 37	8. 71	9. 44
	1952–1953							
10	Dec. 3–Jan. 8	37	6. 09	5. 43	6. 36	−. 27	6. 22	7. 01
	1953							
11	Jan. 9–Feb. 2	25	3. 25	2. 59	2. 84	+. 41	3. 04	2. 79
12	Feb. 3–Mar. 2	28	5. 48	4. 19	4. 65	+. 83	5. 07	4. 98
13	Mar. 3–Mar. 31	29	4. 88	4. 46	4. 42	+. 46	4. 65	4. 09
14	Apr. 1–Apr. 27	27	4. 48	5. 35	5. 21	−. 73	4. 84	5. 47
15	Apr. 28–May 27	30	8. 74	9. 62	9. 12	−. 38	8. 93	8. 71
16	May 28–June 29	33	9. 17	11. 41	9. 73	−. 56	9. 45	9. 01
17	June 30–July 29	30	8. 12	9. 20	7. 62	+. 50	7. 87	8. 62
18	July 30–Aug. 26	28	8. 43	10. 77	9. 67	−1. 24	9. 05	11. 43
19	Aug. 27–Sept. 28	33	10. 68	10. 29	9. 99	+. 69	10. 34	10. 11
	1952–1953							
5–16	July 9–June 29	356	82. 59	86. 87	85. 14	−2. 73	83. 86	83. 85
1–19	Mar. 12–Sept. 28	566	140. 13	146. 33	139. 29	+0. 69	139. 71	140. 72

[1] Computed using equation 16, adjusted to entire lake. [2] Computed using equation 20, adjusted to entire lake. [3] Computed using equation 24.

A comparison between the evaporation values computed from the 2-meter data and the energy-budget results is given in figure 25. Table 12 shows that the 2-meter mass-transfer results agree much better with the energy-budget figures than do the 8-meter mass-transfer results. For the two mass-transfer computations there is little difference in the annual total, as might be expected, but the 2-meter results for 14 of the 19 periods agree more closely with the energy-budget values. For the 19 periods the average difference, without regard to sign, between the energy-budget and the 2-meter mass-transfer results was 0.72 inch, or 10 percent of the average evaporation per period of average 1-month length.

It may appear that the deviations between the energy-budget results and the 2-meter mass-transfer results, as shown in table 12, are not random. The first 5 deviations are positive and the next 3 are negative. Farther down the column, a run of 3 positive deviations is followed by a run of 3 negative deviations. It should be remembered that only the data for periods 5–16 inclusive were used in the correlation analysis that resulted in the 2-meter equation. From the fact that the first 5 deviations are alike in sign, one might question the general reliability of the correlation analysis. Accordingly a test was made to determine if the algebraic signs of the deviations constitute a random series. From the tables prepared by Swed and Eisenhart (1943), it was found that there is no reason to doubt the randomness of the series as far as this particular test is concerned.

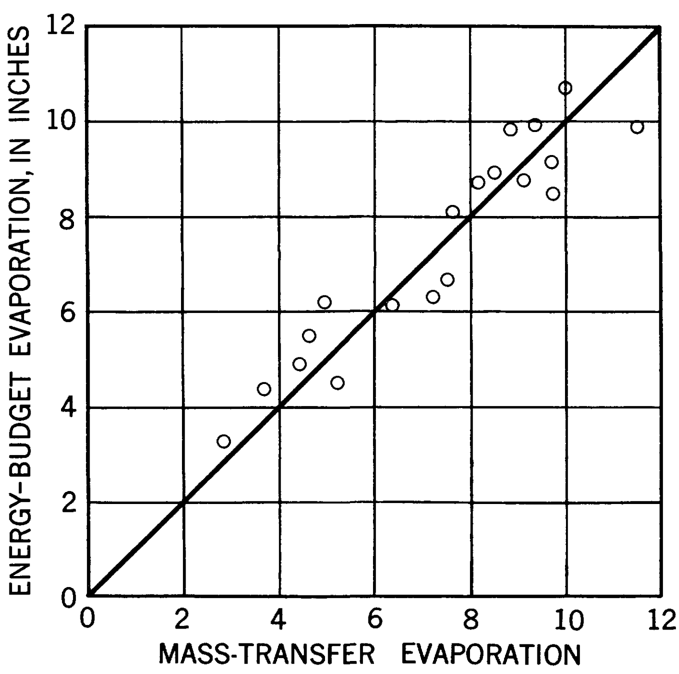

FIGURE 25.—Comparison between computed figures of evaporation from Lake Mead for energy-budget periods, using the energy-budget and mass-transfer methods.

It should be noted that for practical purposes the energy-budget and the mass-transfer techniques are independent. Certain few data, of which the water-surface temperature is the most important, are used in both methods. An error in measurement of water-surface temperature does not affect both results to the same extent, however. Vapor pressure of the ambient air is another parameter common to both methods. An error in measuring this item is of utmost importance in the mass-transfer method, but is of relatively minor significance in the energy-budget method because it is used only in the Bowen ratio.

By previous agreement of representatives of the cooperating agencies, the results based upon the energy-budget method were accepted as the control in the study, and the mass-transfer results were compared to them. Because of the close agreement in the results obtained by the two methods, and because of the relative independence of the two methods, the average of the two may well be expected to be closer to the true value than either of them. These results, shown in table 12, may be considered to be the best estimate of evaporation from Lake Mead during the period covered by the study.

EVAPORATION BY CALENDAR MONTHS

The computation of the mass-transfer results on a calendar-month basis was straightforward, requiring only the summing of daily values. Computation of energy-budget evaporation on a calendar-month basis was somewhat more difficult. It was not considered practical to compute evaporation directly by the energy-budget technique, because of the possible error in determining changes in energy storage for each calendar month. For reasons mentioned (p. 25), thermal surveys were not made exactly at monthly intervals, and interpolated month-end figures of energy storage may be questionable. The first energy-budget period was March 12 to April 14, 1952. Energy-budget evaporation for the period April 1–14 was computed as follows:

E_{EB} (Apr. 1–14) =

$$\frac{E_{MT}\ (\text{Apr. 1–14})}{E_{MT}\ (\text{Mar. 12–Apr. 14})} E_{EB}\ (\text{Mar. 12–Apr. 14}) \qquad (21)$$

in which E_{EB} is energy-budget evaporation and E_{MT} is mass-transfer evaporation. Energy-budget evaporation was computed for other periods in a similar fashion and the results totaled to obtain monthly figures. Energy-budget evaporation for the periods March 1–11, 1952, and September 29 and 30, 1953 (prior to the first, and subsequent to the last, thermal surveys), was assumed to be equal to the mass-transfer evaporation.

A comparison of the energy-budget and mass-transfer results by calendar months is shown in table 13, as is the average of the two results, again considered to be the best estimate of evaporation from Lake Mead. The monthly variation in evaporation is shown in figure 26. The existence of a double wave, as postulated by Neumann (1954) for shallow lakes, is neither confirmed or disproved. Evaporation during April 1952 may have been less than at some time during the preceding winter, but no secondary minimum was observed during the spring of 1953. Evaporation during November 1952 confirmed Neumann's hypothesis of a secondary maximum during that year. Preliminary computations indicate that a similar but much smaller secondary maximum occurred in December 1953. Perhaps for a lake as deep as Lake Mead it might be speculated that the double wave will be observed during some years but not in others, depending on the variation in weather conditions.

Evaporation in acre-feet (see table 13) was computed by multiplying the evaporation in inches by the average surface area for the month. A computation to indicate the magnitude of the possible error thereby introduced was made for June 1952, the month having the greatest change in stage during the entire period of observation. For this month, evaporation in acre-feet was computed as the sum of the daily mass-transfer figures, each of the daily figures being the product of the daily evaporation in inches and the daily surface area. The difference between this figure and the figure obtained from using the average area for the month was 0.5 percent, which was considered negligible.

TABLE 13.—*Monthly evaporation from Lake Mead, March 1, 1952, to September 30, 1953*

Month	Evaporation from Lake Mead			
	Energy-budget method (inches)	Mass-transfer method (inches)	Average of two methods (inches)	Average of two methods (thousands of acre-feet)
1952				
March	5.74	4.90	5.32	48.8
April	4.48	3.81	4.14	37.7
May	7.86	6.92	7.39	73.7
June	11.98	11.00	11.49	130.3
July	9.07	8.48	8.78	106.2
August	10.94	12.48	11.71	140.2
September	7.08	7.93	7.50	87.9
October	5.26	6.07	5.66	64.5
November	9.56	9.32	9.44	104.1
December	5.62	5.81	5.72	60.7
1953				
January	4.21	3.83	4.02	41.3
February	5.08	4.33	4.70	47.1
March	5.44	4.79	5.12	50.3
April	5.45	6.22	5.84	56.4
May	8.76	9.25	9.00	85.8
June	8.38	8.88	8.63	85.3
July	8.59	8.12	8.36	86.0
August	10.33	11.31	10.82	110.8
September	8.47	8.01	8.24	82.9
Total, water year 1953	85.15	85.94	85.55	875.2
Total, 19-month period	142.30	141.46	141.88	1500.0

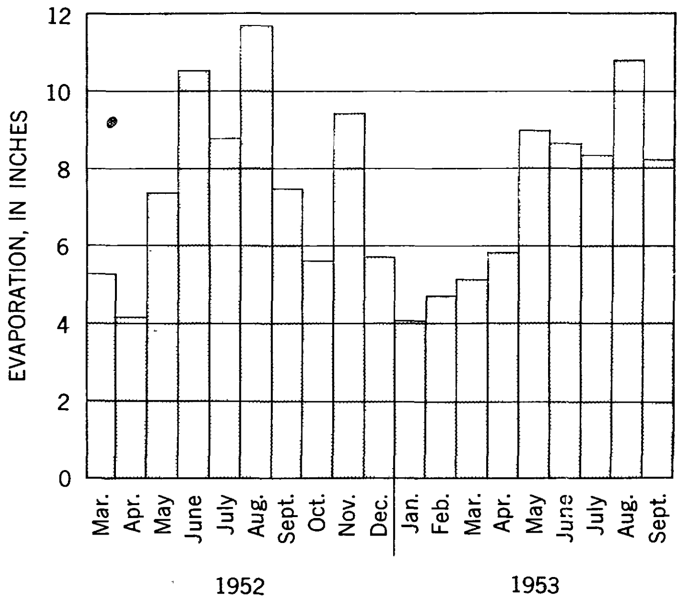

FIGURE 26.—Monthly evaporation from Lake Mead (average of mass-transfer and energy-budget results).

Evaporation from Lake Mead during the 1953 water year, computed as the average of the energy-budget and mass-transfer results, was 85.52 inches, or 875,000 acre-feet. Immediately the question arises as to whether evaporation during that year was above or below normal. Evaporation expressed as a volume is computed as the product of evaporation expressed in units of depth times the area of the reservoir, and either of these may vary from year to year.

Graphs showing the relation between meteorological parameters measured at Las Vegas during the period covered by this study and during the entire period of record at the Weather Bureau station were presented in the section on climatology (fig. 7). The average percentage of sunshine and air temperatures during the study period was slightly above normal, which could be taken as an indication that evaporation from Lake Mead was also above normal. Wind speeds were not greatly different from normal, thus permitting no conclusion on this basis. Humidity was substantially below normal, from which it might be concluded that evaporation was above normal. No information is available as to whether water-surface temperatures were above or below normal. Evaporation from the class A land pan at Boulder City was below normal during the study period.

Because of the conflicting conclusions that might be drawn from the data and the absence of any information as to normal water-surface temperatures, it would appear unreasonable to state, on the basis of a cursory examination of climatological records alone, that evaporation from Lake Mead during the period March 1952 to September 1953 was either markedly above or below normal. This point will be discussed further in a later chapter.

SURFACE-WATER WITHDRAWAL: THEORETICAL CONSIDERATIONS

The suggestion has been advanced that a substantial saving in evaporation might be effected by releasing warm water from the surface of Lake Mead instead of the relatively cold water at the elevation of the intake tower gates. It might appear that the amount of water saved might be computed by simply assuming that all of the additional energy thus removed would have been used for evaporation. Such an assumption is invalid, for it ignores the effect of the surface withdrawal on the water-surface temperature of the lake. If withdrawals are made at the surface, the temperature of the water surface will be decreased, thereby decreasing the amount of energy dissipated by radiation from the water surface and increasing the amount of energy conducted to the water surface from the atmosphere. Both of these result in more energy being available for evaporation, so that the net saving is actually considerably less than would be computed under the simple assumption that the energy can be removed in outflow without any counterbalancing effects.

The period July 9, 1952, to June 29, 1953, for which average radiation data are shown in table 8, was selected for study. It was assumed that withdrawals were made at the surface temperature, which is not the measured surface temperature but the temperature that would be attained after such withdrawals had been made for a sufficiently long time to establish equilibrium conditions. The average temperature eventually to be attained was unknown but could be determined by a successive-approximation technique, because the saving in evaporation as computed by use of the energy budget (equation 2) had to be the same as that computed according to mass-transfer theory. Any of the mass-transfer equations could be used, for it was assumed that the only effect of withdrawing surface water was to change the temperature of the surface, thus affecting only the vapor-pressure-difference term.

During the period selected for study, average water-surface temperature of Lake Mead was 19.9°C. If surface withdrawals had been made, the water-surface temperature would have been 19.2°C, thus effectively decreasing the amount of energy returned to the atmosphere by radiation from the water surface and increasing the amount of energy conducted from the atmosphere to the lake. The computed decrease in evaporation was 8 percent. Under the erroneous assumption that all of the additional energy removed from the lake by surface withdrawals would have been used for evaporation, the computed saving in evaporation would have been almost twice as great.

Although the computations indicate that a saving of 8 percent in evaporation from Lake Mead might be obtained by surface withdrawals, this figure must be considered a theoretical maximum. For a saving of this amount to be obtained, the water removed must be at the temperature of the surface, whereas the surface isothermal layer in Lake Mead is often nonexistent or quite thin. On calm summer days temperature decreases sharply with depth near the surface, and the theoretical saving would be reduced if the cooler water below the surface were withdrawn.

The possibility that evaporation from a reservoir could be substantially reduced by withdrawing warm water from the surface instead of cool water at some depth is quite attractive. It should of course be recognized that evaporation from the river surface below the dam will be increased thereby, and the possible saving previously computed is not a net gain. The engineering practicability of the proposal is beyond the scope of this discussion; it is presented elsewhere in this report in the chapter on withdrawal of water from Lake Mead.

PAN AND LAKE EVAPORATION

By Max A. Kohler, Tor J. Nordenson, and William E. Fox, U. S. Weather Bureau

The prime objective of the water-loss investigations, March 1952 to September 1953, was the determination of evaporation from Lake Mead. It is of extreme importance to the operation of this arid-region reservoir—the largest of existing artificial lakes. With experience gained at Lake Hefner (U. S. Geol. Survey, 1954a), it was believed that reliable estimates of evaporation from Lake Mead could be made by each of several techniques, and an observational program was planned to provide the required data.

The Bureau of Reclamation had maintained a rather extensive network of pan stations around the lake for a number of years and little added instrumentation was required for the present study. In order to restrict costs it was decided to forego installation of additional types of land pans, such as the BPI, Colorado, and screened pans that had been used at the Lake Hefner project.

The only station added to the existing network was installed on Boulder Island in Boulder Basin. It was believed that data collected from a point well out in the lake would prove of value for special studies and regular visits to this site were required for other purposes. The site is not representative in the sense that shore pans are; data obtained there were not expected to be equivalent.

Because no attempt was to be made to determine evaporation by the water-budget method, which can not be applied to Lake Mead with reasonable assurance as to success, there is no forthright basis for comparing results of the several methods; each must be appraised in the light of results obtained by the others. Fortunately, computations of annual evaporation at Lake Mead by the mass-transfer, energy-budget, and modified pan procedures show remarkable agreement; there is little reason for concern as to which "answer" is correct. Computations presented in this chapter show rather conclusively that differences between the several methods are well within the range of error to be expected in estimates of normal annual evaporation that are based on a few years of record.

Appreciable differences in the observed pan evaporation values at the various sites around Lake Mead had been recognized for some time and they had been pointed to as evidence of the inconsistencies to be expected in the application of pan data. Accordingly, every attempt has been made to determine the causes of these differences and their effect on estimated lake evaporation.

INSTRUMENTATION AND OBSERVATIONAL PROCEDURE

The long-established network of the Bureau of Reclamation consisted of four pan stations, to which one was added for the duration of the study period. Those in the original group (fig. 1) were Boulder City, North Las Vegas Wash, South Las Vegas Wash, and Pierce Ferry, and the additional station was installed on Boulder Island in Boulder Basin.

Boulder City station.—The site of this station is 4 miles southwest of Lake Mead and on the northwest edge of Boulder City proper, as can be seen in figures 27 and 28. In addition to instruments normally found

FIGURE 27.—Boulder City station, facing south toward city and developed area. Photograph by Bureau of Reclamation.

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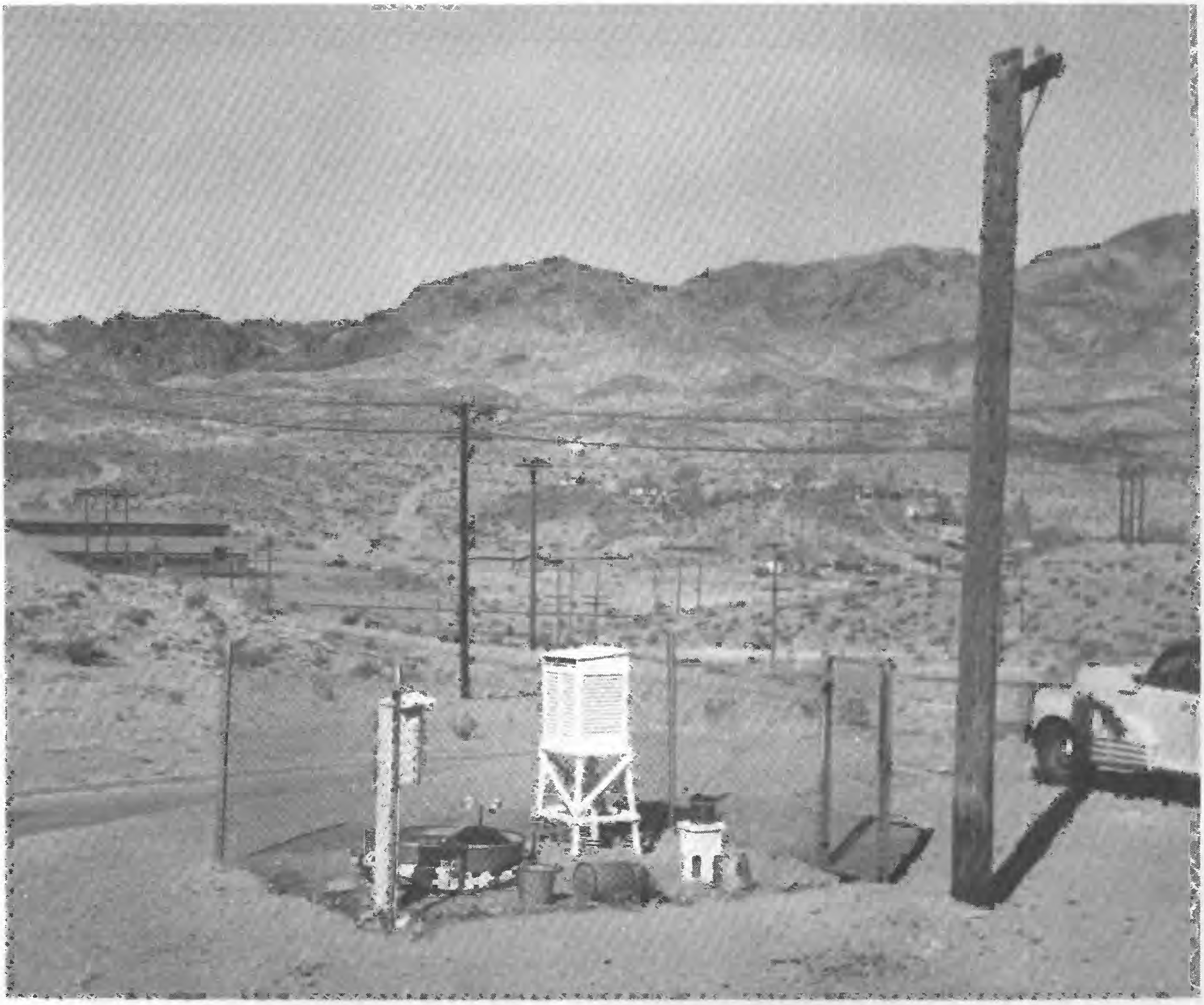

FIGURE 28.—Boulder City station class A pan, looking northwest from city. Photograph by Bureau of Reclamation.

at class A installations (pan, rain gage, anemometer, and maximum and minimum thermometers), the station equipment includes psychrometer, hygrothermograph and water-temperature thermograph. No special equipment was added for the study period. The station elevation is 2,522 feet above mean sea level, and observations have been maintained continuously since August 1935.

Pierce Ferry station.—The site of this station is in Pierce Basin (fig. 1), approximately 60 miles east-northeast of Boulder City at an elevation of 1,368 feet above mean sea level. The land pan and related equipment were located approximately one-half mile south of the lake shore and a floating pan (figs. 29, 30) was anchored about 300 feet offshore. The Pierce Ferry station, established in April 1936, was closed at the end of June 1952 because of the withdrawal of all resident personnel from the area. Unfortunately, therefore, records are available for only 4 of the 19 months of the study period. Before the study period, the station equipment included a psychrometer and all items normally found at a class A station except an anemometer. In February 1952 an anemometer was installed, and also a Six maximum-minimum thermometer for pan-water observations of temperature.

Las Vegas Wash stations.—The North and South Las Vegas Wash land stations, with installed floating pans, were located north and south of Las Vegas Bay, northwest of Boulder Basin (fig. 1). The stations (see figs. 31–34) were established in August 1935 and discontinued on September 30, 1953.[3] Daily attendance was

[3] Prior to July 1939, the north and south stations were known as Nevada and Arizona pans, respectively. The Arizona pan was located 6 miles southeast of the present site. The Nevada pan was merely renamed.

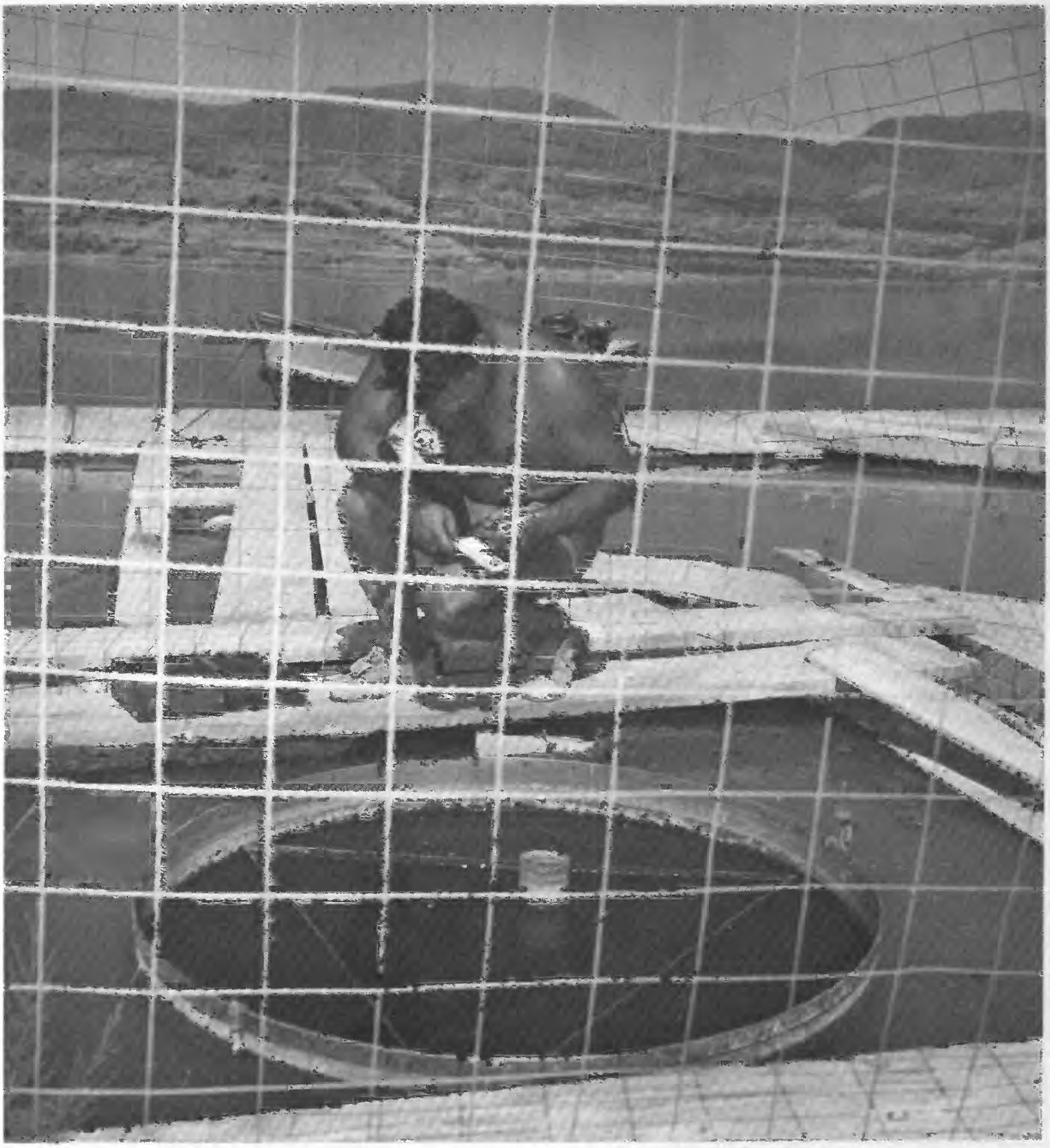

FIGURE 29.—Pierce Ferry station floating pan, closeup. Photograph by Bureau of Reclamation.

impractical in this remote area; the pans were serviced only twice weekly during the winter season and three times weekly during the summer. Only evaporation and precipitation were observed before March 1952, when anemometers were installed at the two land pans (figs. 31, 33).

The land stations were operated in a unique "mobile" manner. The equipment (pans and enclosures) was moved up and down the slope with fluctuating lake levels so that the pans were always exposed near the water's edge and at an altitude corresponding approximately to the lake level.

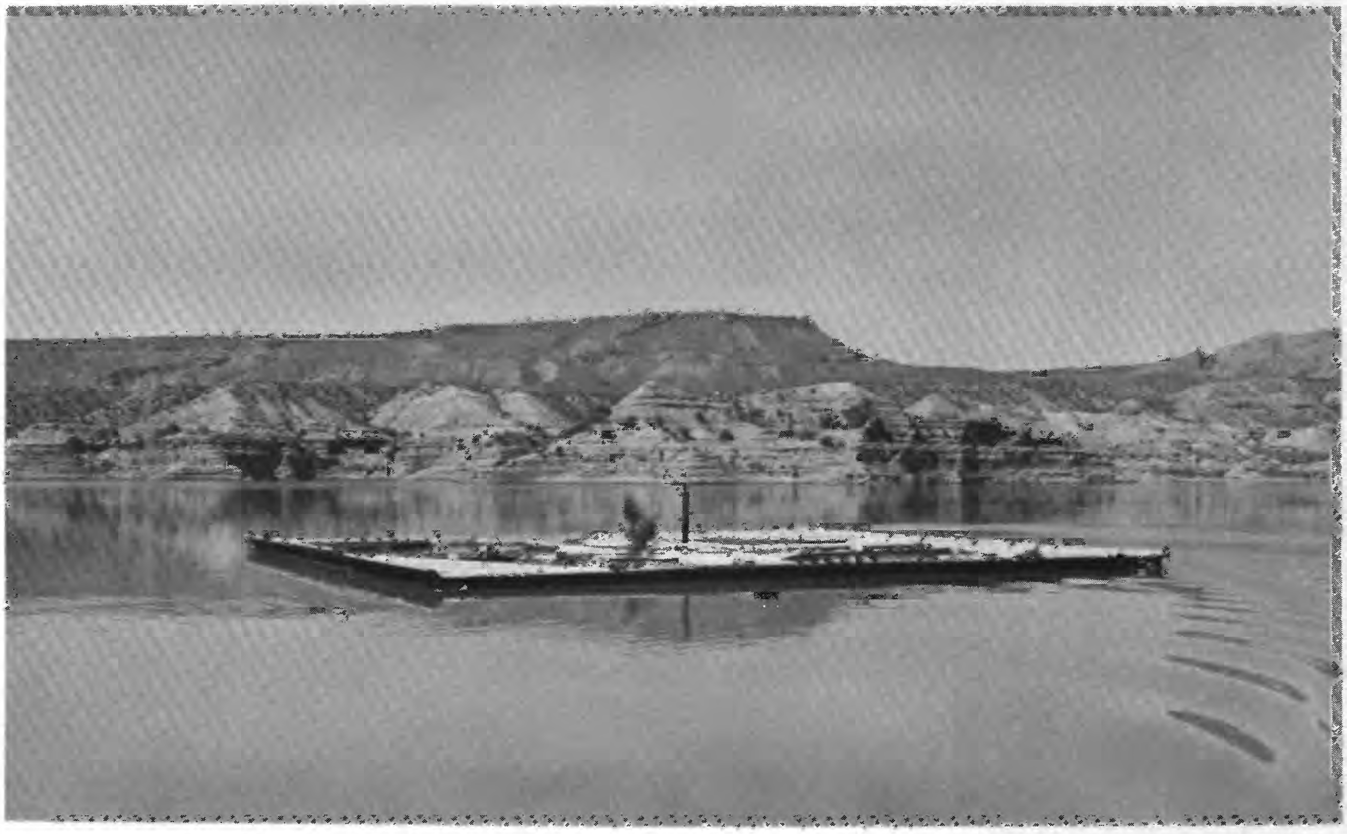

FIGURE 30.—Pierce Ferry station floating pan, general view. Photograph by Bureau of Reclamation

Boulder Island station.—The site of this station was on the main ridge line (northwest-southeast) of the island at an elevation of 1,260 feet above mean sea level. The surface slopes rather steeply all the way from the ridge to the water's edge (fig. 35), and no site could be considered as representative in the usual sense Nevertheless, the equipment was installed in the hope that the data collected would be of assistance in special analyses, and daily observations were made from March 1, 1952 to September 30, 1953.

Initially, the pan station was equipped with psychrometer, Six maximum-minimum thermometer, and hygrothermograph, in addition to standard layout. Also, on the island, and immediately adjacent (see figs. 35, 36), were humidity, wind, and radiation equipment required for mass-transfer and energy-budget computations. Operation of the hygrothermograph was discontinued on January 28, 1953, when it was decided that records obtained with wet and dry thermocouples would be reasonably applicable to the Class A pan. In August 1953 a second anemometer was installed on the pan support (opposite corner) for purposes of comparison, as discussed in a subsequent section.

Las Vegas Weather Bureau Airport Station (WBAS)—The Weather Bureau maintains a first-order station at McCarran Field, which is located 6 miles south of Las Vegas and 25 miles west-northwest of Hoover Dam. The site is at an elevation of 2,162 feet above mean sea level. The station is not equipped with an evaporation pan, but all other pertinent meteorological observations are made, including solar radiation.

ANALYSIS AND INTERPRETATION OF DATA

Terrain in the vicinity of Lake Mead is quite rugged, with elevations ranging from 1,133 feet, lowest lake level during the analysis period, to over 5,000 feet, only 7 miles east of Hoover Dam. This and other factors, such as extreme changes in lake level, land-lake effects, and local irrigation, make the region ideal for microclimatological studies. Conversely, it can be said that the area is not well suited for evaporation experiments directed toward the estimation of reservoir evaporation from climatological and pan observations Station-to-station variations in observed data must be carefully scrutinized to assure proper interpretation and, under such circumstances, erroneous and non-representative observations can multiply the uncertainties.

FIGURE 31.—North Las Vegas Wash station class A evaporation pan. Photograph by Bureau of Reclamation.

AIR TEMPERATURE

Monthly averages of daily maximum, minimum, and mean air temperatures pertinent to this chapter are listed in table 14. Examination of mean annual temperature data for many stations in the tristate area surrounding Lake Mead shows an average change of about 4°F per thousand feet of elevation. When this elevation effect is taken into account, the 19-month average temperatures for the three land stations shown in table 14 will be found to be consistent within about 1°F. From January 1, 1951 through June 30, 1952, the average temperature at Pierce Ferry was 67.2°F as compared to 63.8°F at Boulder City, a difference of 3.4°F for a range of 1,154 feet in elevation. Thus, it would appear that any temperature variations ascribable to exposure are relatively minor, at least for extended periods.

It will be noted that the 2-meter temperature at the barge in Boulder Basin averages somewhat lower than that on Boulder Island. This results primarily from the fact that the Island observations are taken 60 to 130 feet above the water surface, where temperature is less subject to the influence of the relatively cooler water.

DEWPOINT TEMPERATURE

Dewpoint temperature data for Las Vegas WBAS, the Boulder Basin barge, and the pan stations are tabulated in table 15. Variation in dewpoint with station elevation is much less than that of air temperature, hence notable differences in table 15 (p. 46) undoubtedly result from other causes, such as (1) lake, irrigation, and other localized effects, (2) variation in height above the surface, and (3) instrumental or observational deficiencies.

The Las Vegas Airport Station is located in an open, undeveloped area; the dewpoint data are believed to be essentially free of local effects. There is good reason to believe the data are representative of upwind conditions at the lake, except for the difference in elevation.

TABLE 14.—*Monthly mean air temperature*

[In degrees Fahrenheit]

Period	Land pans									Las Vegas (WBAS)			Mean 2-meter dry-bulb temperature, Boulder Basin barge [2]
	Boulder City			Boulder Island			Pierce Ferry [1]						
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	
1952													
March	58.8	40.4	49.6	[3] 65.6	[3] 46.3	[3] 56.0	65.2	41.1	53.2	61.6	39.2	50.4	53.4
April	74.1	54.0	64.1	81.3	58.5	69.9	82.1	53.4	67.8	77.0	51.2	64.1	65.1
May	88.2	63.8	76.0	94.0	68.5	81.2	94.2	64.1	79.2	91.0	61.4	76.2	76.6
June	92.2	65.1	78.7	96.2	73.2	84.7	100.6	70.0	85.3	96.0	64.5	80.3	81.9
July	99.8	74.7	87.3	105.1	80.5	92.8	------	------	------	103.5	72.8	88.2	88.9
August	101.5	76.7	89.1	[3] 105.0	[3] 84.1	[3] 94.6	------	------	------	105.5	76.1	90.8	90.3
September	94.0	68.4	81.2	[3] 98.0	[3] 74.3	[3] 86.2	------	------	------	95.4	65.9	80.7	82.4
October	86.2	61.5	73.9	90.6	66.1	78.4	------	------	------	88.8	54.9	71.9	75.2
November	60.4	43.0	51.7	69.8	50.9	60.4	------	------	------	61.6	37.3	49.5	56.8
December	54.1	38.5	46.3	[3] 62.3	[3] 45.9	[3] 54.1	------	------	------	56.3	34.5	45.4	52.3
1953													
January	60.7	42.3	51.5	[3] 66.2	[3] 47.3	[3] 56.8	------	------	------	63.2	37.5	50.4	54.5
February	60.5	40.9	50.7	66.0	44.1	55.0	------	------	------	62.6	34.8	48.7	52.5
March	69.4	47.6	58.5	75.2	[3] 50.3	[3] 62.8	------	------	------	71.5	41.3	56.4	58.6
April	75.3	52.7	64.0	81.1	[3] 56.0	[3] 68.6	------	------	------	78.3	49.5	63.9	64.6
May	77.5	54.4	66.0	[3] 83.7	[3] 58.4	[3] 71.0	------	------	------	79.6	52.8	66.2	68.9
June	94.2	67.4	80.8	[3] 98.7	[3] 72.9	[3] 85.8	------	------	------	97.9	65.5	81.7	81.5
July	100.2	76.8	88.5	[3] 106.7	[3] 81.5	[3] 94.1	------	------	------	104.4	76.7	90.6	89.8
August	98.1	73.2	85.7	[3] 103.5	[3] 79.7	[3] 91.6	------	------	------	102.1	72.1	87.1	89.2
September	96.5	70.3	83.4	[3] 102.9	[3] 71.3	[3] 87.1	------	------	------	98.8	64.7	81.8	86.0
Average, March–June 1952	78.3	55.8	67.1	84.3	61.6	73.0	85.5	57.2	71.5	81.4	54.1	67.8	69.2
Average, March 1952–February 1953	77.5	55.8	66.7	83.3	61.7	72.5	------	------	------	80.2	52.5	66.4	69.2
Average, October 1952–September 1953	77.8	55.7	66.8	83.9	60.4	72.1	------	------	------	80.4	51.8	66.1	69.2

[1] Station closed June 30, 1952.

[2] Average elevation during period, approximately 1167 ft. above mean sea level.

[3] Partly estimated.

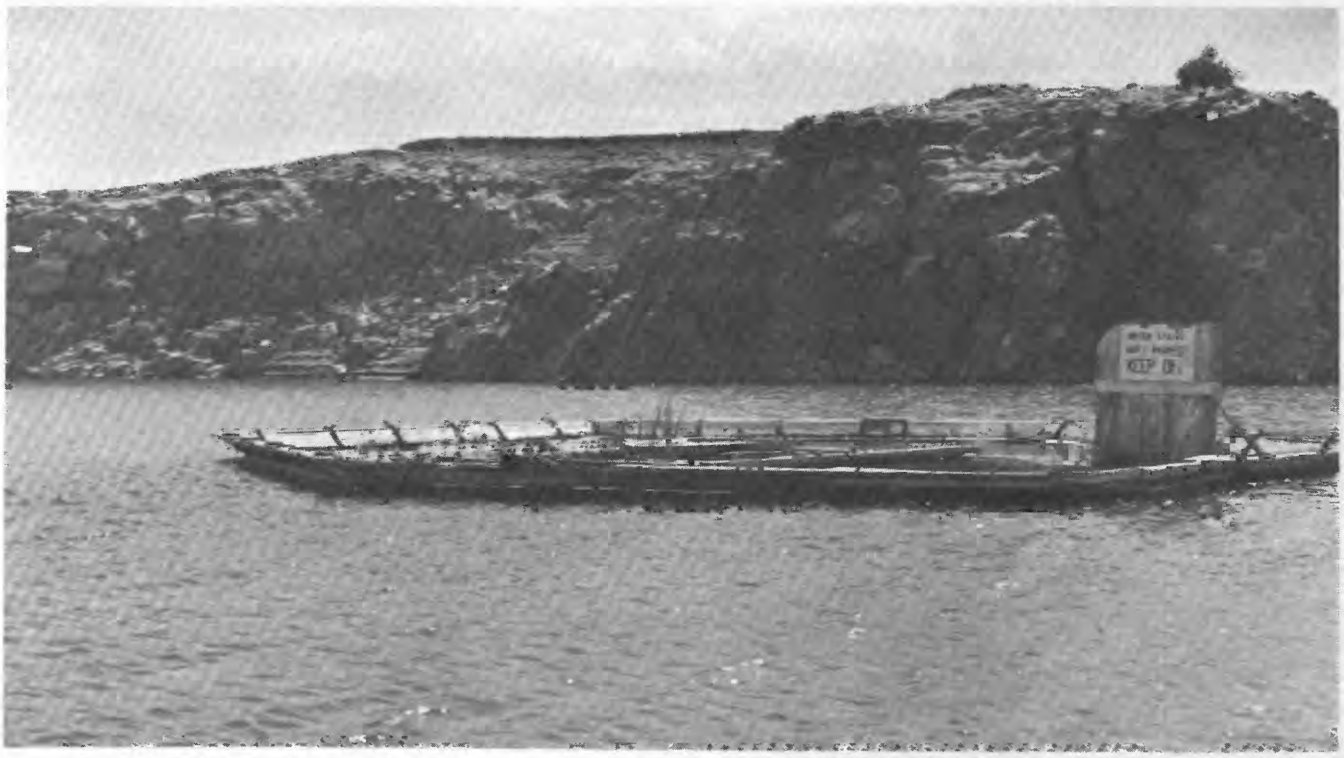

FIGURE 32.—North Las Vegas Wash station floating evaporation pan (northerly direction). Photograph by Bureau of Reclamation.

FIGURE 33.—South Las Vegas Wash station class A evaporation pan (southerly direction). Photograph by Bureau of Reclamation.

Although Boulder City data were derived from hygrothermograph charts, they are supported by frequent psychrometric observations. In arid regions, where the wet-bulb depression is large, rapid drying of the wick can result in wet-bulb readings which are too high if the observer is not extremely careful. Such bias may account for part of the difference between Las Vegas and Boulder City dewpoints, but it is believed that evapotranspiration and watering of lawns in the local area are primarily responsible, possibly augmented to some extent by the nearness of Lake Mead. The fact that Boulder City data fit the generalized pan relation (as discussed later in this section) lends some support to this belief.

The data shown in table 15 for the Pierce Ferry station are based on once-daily psychrometric readings taken at time of the regular observation. The data are almost certainly erroneous; it is inconceivable that the dewpoint at this station could average several degrees higher than at 2 meters over the Boulder Basin barge. Although solar radiation received at Pierce Ferry may well exceed that at Boulder Island, entering the generalized pan relation (subsequently discussed) with observed Pierce Ferry data yields computed radiation one-third greater than that observed in the Boulder Basin. This difference is also unrealistic.

The dewpoint data shown for the Boulder Basin barge are considered reliable and representative of conditions over the lake. Considering the pronounced vertical gradient observed at the barge and the sharp relief (fig. 35), appreciable variations might be expected from point to point on the island. Even so, it is questioned that the observed difference (August to November 1952) between dewpoints derived from the thermocouples and hydrothermograph are real rather than erroneous.

TABLE 15.—*Monthly mean dewpoint temperature*

[In degrees Fahrenheit]

Period	Las Vegas (WBAS)	Boulder City	Boulder Island		Boulder Basin barge		Pierce Ferry [2,3]
			2-meter thermocouple [1]	Hygrothermograph	2 meters [1]	8 meters [1]	
1952							
March	24	27	----------	32	36	34	43
April	31	41	----------	43	46	42	47
May	24	31	----------	46	48	41	50
June	23	29	----------	----------	50	43	55
July	36	45	----------	62	63	56	----------
August	41	46	57	65	64	58	----------
September	23	41	53	60	59	54	----------
October	24	40	50	56	54	51	----------
November	20	29	36	40	37	36	----------
December	28	31	37	39	38	38	----------
1953							
January	25	32	39	38	40	39	----------
February	12	23	32	----------	34	32	----------
March	15	28	33	----------	36	33	----------
April	14	32	33	----------	39	35	----------
May	18	36	32	----------	38	32	----------
June	21	40	36	----------	49	38	----------
July	47	54	59	----------	66	60	----------
August	34	50	54	----------	62	55	----------
September	26	44	49	----------	60	53	----------
Average (March 1952–February 1953)	26	35	----------	----------	47	44	----------
Average (October 1952–September 1953)	24	37	41	----------	46	42	----------

[1] From average monthly values of vapor pressure.
[2] Station closed June 30, 1952.
[3] Pierce Ferry dewpoints appear to be erroneous, or may not be representative for average values, as they are based on only one reading each day.

WIND MOVEMENT

Monthly totals of wind movement are listed in table 16 (p. 50). Attention is called to the fact that nonstandard pintle supports were inadvertently supplied for Pierce Ferry, Boulder Island and Las Vegas Wash (north and south) stations and, as a result, the cups were exposed at a level of about 12 inches above the pan rim, whereas standard exposure is 6 inches. Therefore, observed data for these stations are probably several percent high with respect to a standard installation.

Since all required data were available for computing Boulder Island pan evaporation, it was deemed important that standard wind observations be made. Accordingly, a second anemometer, mounted on the opposite corner of the pan support at standard height, was observed during the final month of the program. While the newly-installed anemometer recorded almost 20 percent less wind during September 1953, this cannot be taken as the effect of lowering the cups by 6 inches with respect to the pan. The site of the first anemometer was on a corner of the pan support projecting outward from the sloping ground surface so that the height of the cups above the surface was actually over a foot more than was the case for the second anemometer.

Correlation between stations of monthly wind movement is not as high as might be expected, but the data for the two Las Vegas Wash stations display what is perhaps the most glaring inconsistency. While 38 percent more wind movement was recorded at the north station during the period March 1952 through January 1953, almost 4 percent more movement was recorded at the south station during the last 8 months. As indicated earlier, these two stations are moved up and down the slope with changing lake level and such moves may have affected the observed wind movement. While exposure at the north station presented no problem, it became increasingly difficult to avoid relatively dense vegetation at the south station as the lake filled. An attempt was made to clear a reasonable distance from the pan location; however, comparison between lake contents (see fig. 2) and monthly wind records indicates that the exposure was affected. The pan evaporation data at the two sites also lend support to this conclusion.

SOLAR RADIATION

Solar radiation data pertinent to this chapter are summarized in table 17 (p. 50). The data listed for Las Vegas are from the permanent installation at the Weather Bureau Airport station. These data were not used in any phase of the analysis, but are included to call attention to the discrepancy between the two sets of observations. The Las Vegas equipment was inspected on June 25, 1953, at which time it was found to be recording about 18 percent too high.

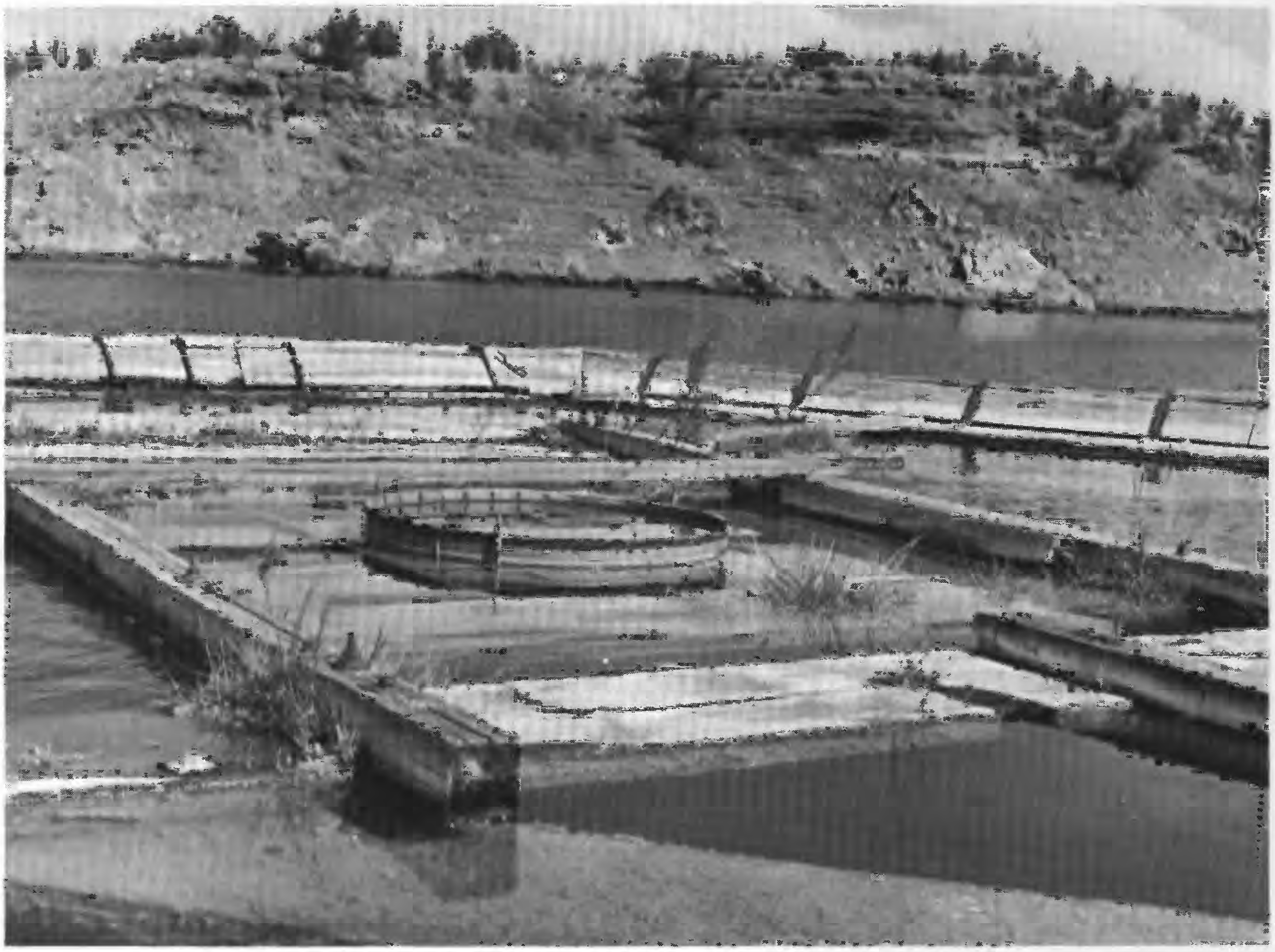

FIGURE 34.—South Las Vegas Wash station floating evaporation pan. Photograph by Bureau of Reclamation

FIGURE 35.—General view of Boulder Island equipment showing setting in lake. Photograph by Bureau of Reclamation.

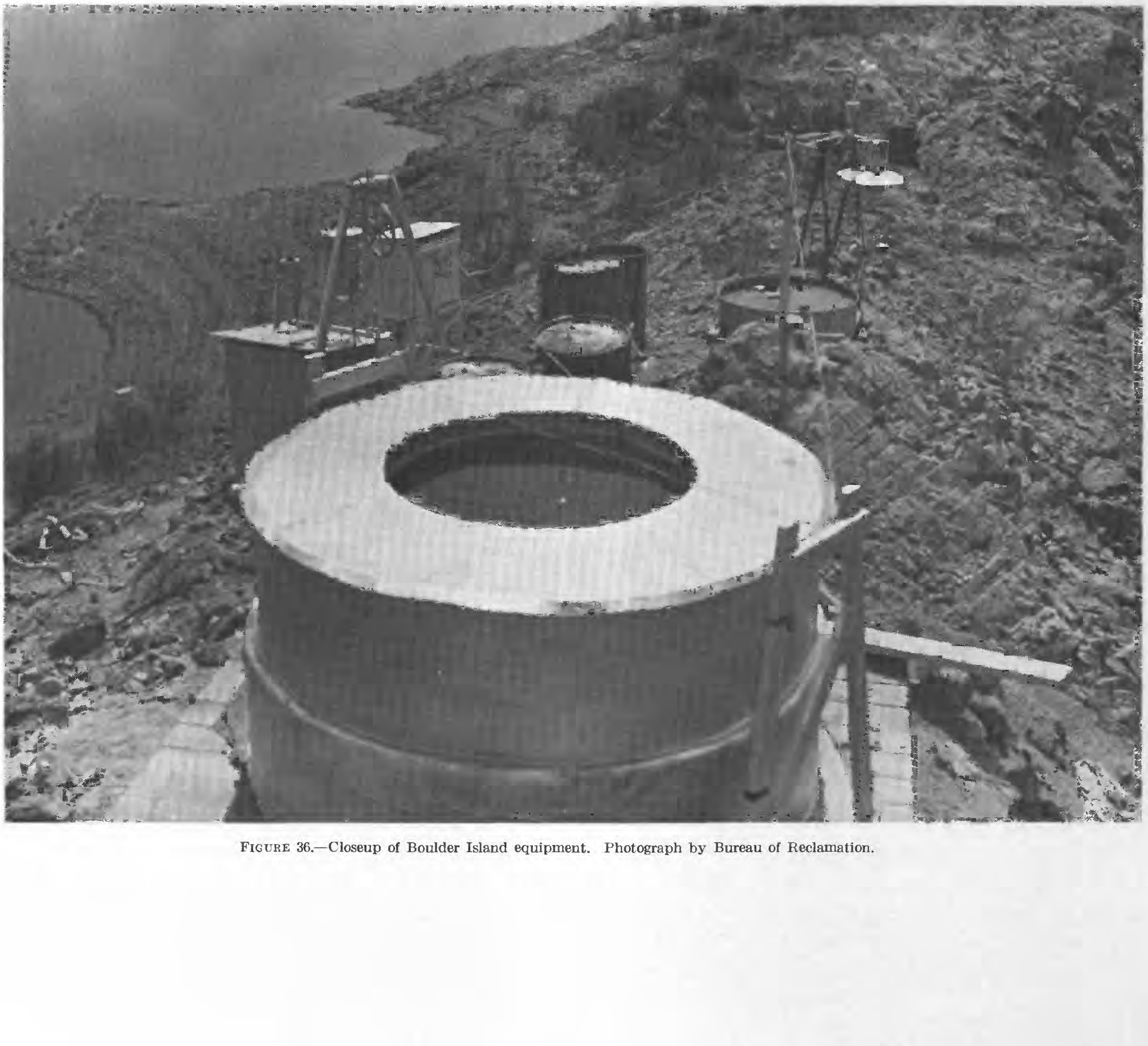

FIGURE 36.—Closeup of Boulder Island equipment. Photograph by Bureau of Reclamation.

TABLE 16.—*Monthly wind movement*

[In miles]

Period	Land pans					Boulder Basin barge		
	Boulder City	Boulder Island	North Las Vegas Wash [1]	South Las Vegas Wash [1]	Pierce Ferry [2]	2-meter data	8-meter data	Estimated 4-meter values[3]
1952								
March	3, 857	[4] 6, 568	4, 597	3, 943	1, 998	7, 165	8, 471	7, 818
April	2, 585	4, 230	2, 978	2, 583	1, 793	4, 744	5, 706	5, 225
May	2, 531	4, 573	2, 968	2, 577	1, 868	4, 949	6, 161	5, 555
June	2, 573	5, 425	2, 661	1, 747	2, 107	6, 299	7, 831	7, 065
July	1, 534	3, 933	1, 970	1, 017		5, 006	6, 429	5, 718
August	1, 565	4, 514	1, 994	1, 012		6, 534	8, 243	7, 388
September	1, 491	2, 738	1, 572	585		3, 875	4, 568	4, 222
October	976	1, 964	1, 779	742		3, 273	3, 639	3, 456
November	2, 278	5, 837	3, 302	2, 844		6, 183	6, 971	6, 577
December	2, 097	4, 633	2, 631	1, 998		6, 071	6, 847	6, 459
1953								
January	2, 363	4, 291	2, 904	2, 274		5, 166	5, 974	5, 570
February	2, 699	4, 891	2, 954	3, 176		5, 214	5, 944	5, 579
March	3, 235	4, 781	3, 120	3, 095		5, 574	6, 727	6, 150
April	3, 317	5, 189	3, 396	3, 443		6, 202	7, 525	6, 864
May	4, 162	7, 029	4, 096	4, 456		7, 549	9, 291	8, 420
June	3, 032	5, 248	3, 030	3, 436		6, 078	7, 772	6, 925
July	2, 292	4, 507	2, 849	3, 069		5, 594	7, 116	6, 355
August	2, 397	4, 720	3, 092	3, 118		6, 191	7, 570	6, 880
September	1, 367	[5] 2, 397	2, 272	1, 954		3, 797	4, 498	4, 148
Average, March–June 1952	2, 886	5, 199	3, 301	2, 712	1, 942	5, 789	7, 042	6, 416
Average, March 1952–February 1953	2, 212	4, 466	2, 692	2, 042		5, 373	6, 399	5, 886
Average, October 1952–September 1953	2, 518	4, 624	2, 952	2, 800		5, 574	6, 656	6, 115

[1] Observations taken only two or three times weekly. Monthly values estimated by proportioning totals.
[2] Station closed June 30, 1952.
[3] Estimated wind movement 4 meters above the lake is the average of the 2-meter and 8-meter values (assuming wind varies with log of height).
[4] Wind movement estimated March 1–3, 1952.
[5] Wind movement at anemometer 2 on opposite side of pan from main anemometer (and at standard height) recorded 1,950 miles of wind movement in September 1953.

WATER TEMPERATURE

The monthly average of daily maximum, minimum, and mean water temperatures of land and floating pans and of water-surface temperatures of the lake at the Boulder Basin barge are shown in table 18.

Attention is directed to the fact that the Las Vegas Wash stations were attended only two or three times weekly and the monthly data were accordingly derived from maximum and minimum temperatures occurring between observations.

PAN EVAPORATION

Table 19 summarizes evaporation from the 5 land and 3 floating pans. As might be expected, annual evaporation from the floating pans is appreciably less than from the class A pans, station by station. Monthly ratios display a pronounced seasonal variation, however, and it will be noted that evaporation from the floating pans actually exceeds that from the land pans during the period October to January.

There has been considerable discussion among those acquainted with the project concerning possible effects on pan evaporation of nonstandard exposure and observational practices, particularly at the Boulder City station. Since comparative observations during the course of the program were not feasible, conclusions can only be based on data collected at other locations. The relation between pan evaporation and meteorological factors presented in the Lake Hefner report (Kohler, 1954, fig. 96) has subsequently been revised through consideration of data collected at additional stations (Kohler, Nordenson, and Fox, 1955). The revised relation is presented in figure 37 of this report.

TABLE 17.—*Monthly mean solar radiation*

[In langleys per day]

Period	Boulder Island	Las Vegas [1]	Period	Boulder Island	Las Vegas [1]
1952			*1953*		
March	463	442	January	281	316
April	586	540	February	394	438
May	728	694	March	527	589
June	756	744	April	608	668
July	677	684	May	722	791
August	646	670	June	765	865
September	513	541	July	629	644
October	437	468	August	634	672
November	295	322	September	573	590
December	242	257			

[1] Prior to June 26, 1953, the pyrheliometer at Las Vegas was not operating properly and the readings are questionable. On July 29, 1952 the instrument was reading about 6 percent low and was recalibrated accordingly. A check was again made on June 25, 1953, when the pyrheliometer was found to be reading 18 percent high.

TABLE 18.—*Monthly mean water-surface temperature*

[In degrees Fahrenheit]

Month	Land pans															Floating pans									Boulder basin barge
	Boulder City			Boulder Island			N. Las Vegas Wash [1]			S. Las Vegas Wash [1]			Pierce Ferry [2]			N. Las Vegas Wash [1]			S. Las Vegas Wash [1]			Pierce Ferry [2]			
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Mean
1952																									
March	61.9	40.1	51.2	-----	-----	-----	67.6	38.8	53.2	67.5	41.8	54.6	63.3	44.0	53.6	65.8	44.0	54.9	66.0	45.2	55.6	76.8	42.6	59.7	53.2
April	77.5	50.1	63.8	-----	-----	-----	87.5	51.3	69.4	86.0	53.8	69.9	73.4	53.5	63.4	78.1	52.8	65.4	82.6	53.0	67.8	92.4	71.0	81.7	61.0
May	88.5	58.3	73.4	89.1	62.2	75.6	97.0	55.4	76.2	96.0	58.4	77.2	-----	55.6	-----	87.3	59.4	73.4	89.7	59.9	74.8	98.8	66.9	82.8	69.6
June	89.9	59.0	74.4	89.8	63.8	76.8	97.9	60.6	79.2	98.8	61.3	80.0	-----	58.9	-----	90.8	67.0	78.9	94.3	68.7	81.5	85.9	62.6	74.2	75.2
July	95.9	67.0	81.4	96.5	74.3	85.4	104.7	68.1	86.4	102.5	68.8	85.6	-----	-----	-----	99.1	73.9	86.5	100.5	75.0	87.8	-----	-----	-----	81.5
August	94.3	69.0	81.6	95.5	74.4	85.0	104.5	70.0	87.2	103.4	72.0	87.7	-----	-----	-----	97.3	75.0	86.2	101.0	79.5	90.2	-----	-----	-----	83.1
September	86.2	62.7	74.4	90.4	68.4	79.4	97.1	63.8	80.4	95.6	68.5	82.0	-----	-----	-----	90.1	70.3	80.2	99.7	72.0	85.8	-----	-----	-----	80.2
October	77.6	54.9	66.2	84.2	60.9	72.6	85.3	53.3	69.3	83.6	58.3	71.0	-----	-----	-----	81.7	62.7	72.2	92.1	73.0	82.6	-----	-----	-----	77.0
November	57.8	41.0	49.4	61.2	46.3	55.2	64.0	39.0	51.5	65.9	42.4	54.2	-----	-----	-----	69.1	51.3	60.2	65.8	55.3	60.6	-----	-----	-----	67.5
December	52.5	38.2	45.4	59.6	44.8	52.2	58.4	36.9	47.6	57.4	39.2	48.3	-----	-----	-----	62.4	47.2	54.8	63.1	50.7	56.9	-----	-----	-----	60.3
1953																									
January	56.8	40.6	48.7	[3]63.7	[3]45.9	54.8	61.4	38.7	50.2	60.9	41.3	51.1	-----	-----	-----	61.7	46.6	54.2	63.0	49.5	56.2	-----	-----	-----	56.8
February	57.3	37.8	47.6	64.5	43.2	53.8	64.3	36.4	50.4	64.3	38.9	51.6	-----	-----	-----	63.1	43.9	53.5	66.1	47.0	56.6	-----	-----	-----	55.2
March	68.2	43.2	55.7	73.6	48.6	61.1	75.9	40.9	58.4	73.3	44.4	58.8	-----	-----	-----	71.1	46.6	58.8	71.5	48.4	60.0	-----	-----	-----	56.1
April	75.9	47.5	61.6	79.8	52.4	66.1	90.0	36.0	63.0	85.0	39.0	62.0	-----	-----	-----	79.0	45.0	62.0	81.0	48.0	64.5	-----	-----	-----	60.1
May	78.0	47.4	62.7	[3]81.5	[3]54.1	67.8	94.0	44.0	69.0	91.0	46.0	68.5	-----	-----	-----	84.0	63.0	73.5	84.0	61.0	72.5	-----	-----	-----	63.3
June	87.8	56.6	72.2	[3]88.4	[3]63.3	75.8	98.2	57.2	77.7	98.6	59.8	79.2	-----	-----	-----	88.2	63.3	75.8	90.7	62.8	76.8	-----	-----	-----	71.1
July	93.6	69.4	81.5	[3]93.6	[3]73.9	83.8	103.3	69.5	86.4	105.3	70.0	87.6	-----	-----	-----	98.0	76.0	87.0	95.5	75.9	85.7	-----	-----	-----	81.7
August	91.1	64.7	77.9	[3]92.0	[3]69.7	80.8	99.5	63.9	81.7	100.0	80.0?	90.0?	-----	-----	-----	94.5	70.8	82.6	94.6	73.7	84.2	-----	-----	-----	82.9
September	87.2	60.4	73.8	[3]87.6	[3]65.6	76.6	94.7	58.1	76.4	96.2	58.8	77.5	-----	-----	-----	91.0	66.3	78.6	90.1	72.6	81.4	-----	-----	-----	82.9
Average March-June 1952	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	80.5	55.8	68.2	83.2	56.7	69.9	88.5	60.8	74.6	64.8
Average March 1952-February 1953	74.7	51.6	63.1	-----	-----	-----	82.5	51.0	66.8	81.8	53.7	67.8	-----	-----	-----	78.9	57.8	68.4	82.0	60.7	71.4	-----	-----	-----	68.4
Average October 1952-September 1953	73.6	50.1	61.9	77.7	55.7	66.7	82.4	47.8	65.1	81.8	51.5?	66.7?	-----	-----	-----	78.6	56.9	67.8	79.8	59.8	69.8	-----	-----	-----	67.9

[1] Based on readings taken two or three times a week.
[2] Station closed June 30, 1952.
[3] Partly estimated.

TABLE 19.—*Monthly pan evaporation*

[In inches]

Period	Land pans					Floating pans		
	Boulder City	Boulder Island	North Las Vegas Wash	South Las Vegas Wash	Pierce Ferry [1]	North Las Vegas Wash	South Las Vegas Wash	Pierce Ferry [1]
1952								
March	6.36	[2] 8.36	7.96	6.71	5.86	5.07	5.14	3.79
April	8.85	[3] 9.68	10.34	10.08	9.08	7.62	6.05	5.88
May	13.75	16.34	14.75	14.55	15.81	12.23	10.17	9.71
June	15.55	19.84	14.75	15.17	18.46	14.35	12.71	10.45
July	14.22	[3] 17.45	14.46	14.02		13.06	11.72	
August	13.55	[4] 20.08	15.42	14.54		13.83	13.96	
September	10.51	[5] 11.93	10.59	8.54		8.50	9.86	
October	7.28	7.60	7.80	5.10		9.57	6.72	
November	4.45	6.21	5.52	4.33		6.25	6.80	
December	2.65	3.41	3.03	2.54		3.70	3.56	
1953								
January	4.12	4.39	3.93	3.69		3.98	3.73	
February	5.03	5.52	5.31	5.28		4.95	4.93	
March	8.60	9.84	9.12	9.30		6.75	6.57	
April	10.14	12.85	11.38	11.21		9.14	8.03	
May	13.97	[3] 16.69	15.23	13.75		12.15	10.08	
June	16.63	20.30	17.49	18.10		13.93	12.61	
July	14.16	20.03	15.60	16.64		13.38	11.94	
August	14.66	20.30	17.28	17.19		15.70	14.08	
September	10.72	16.98	13.72	11.86		12.63	9.88	
Total, March–June 1952	44.51	54.22	47.80	46.51	49.21	39.27	34.07	29.83
Total, March 1952–February 1953	106.32	130.81	113.86	104.55		103.11	95.35	
Total, October 1952–September 1953	112.41	144.12	125.41	118.99		112.13	98.93	
Total, March 1952–September 1953	195.20	247.80	213.68	202.60		186.79	168.54	

[1] Station closed June 30, 1952.
[2] Evaporation estimated for 5 days.
[3] Evaporation estimated for 1 day.
[4] Evaporation estimated for 3 days.
[5] Evaporation estimated for 2 days.

Of the stations in the Lake Mead area, all data required for direct application of figure 37 are available only at Boulder Island. It is believed the radiation observations on the island are also representative of conditions at Boulder City, however, and so computations have been made for both stations (table 20). Although the empirical derivation of figure 37 was based in part on the records for Boulder City, the results shown in the table certainly lend no support to the existence of bias resulting from nonstandard practices. Computations for Boulder Island are based on dewpoint derived from the thermocouple wet- and dry-bulb readings. While the computed values for the period as a whole are about 4 percent too high, there is an appreciable seasonal variation in the bias. There is doubt as to whether the wind and dewpoint data used are representative and the seasonal shift in the wind direction, as discussed in a previous chapter, may be significant.

Also included in table 20 are computed values of pan evaporation believed to be most representative of the Boulder Basin under conditions prevailing prior to construction of Hoover Dam (that is, representative of upwind conditions).

To assist in appraising the normality of the 19-month concentrated observational period, annual evaporation from each pan (including the "representative" pan) for the entire period of record is summarized in table 21, and monthly evaporation from the Boulder City pan only are listed in table 22.

ESTIMATION OF ANNUAL LAKE EVAPORATION

The practice of converting class A pan evaporation to estimated lake evaporation by application of the 0.70 coefficient is of long standing. Although the propriety of assumed fixed proportionality is frequently questioned on theoretical grounds, such data as are available indicate that derived values of the coefficient (from annual data) are reasonably consistent. On the premise that stability of the coefficient approaches that necessary for requisite accuracy, it follows that analyzing possible causes of variations might lead the way to improved results through empirical adjustments.

To illustrate, let it be assumed that the 0.70 coefficient is applicable under the following idealized conditions:

1. Temperature, dewpoint, wind and solar radiation

TABLE 20.—*Observed and computed class A pan evaporation at Boulder City, Boulder Island, and a "representative" station.*

[In inches]

Period	Boulder City		Boulder Island		Representative Station
	Observed	Computed	Observed	Computed [1]	Computed [2]
1952					
March	6. 36	6. 44	8. 36	6. 42	7. 85
April	8. 85	8. 61	9. 68	10. 94	10. 40
May	13. 75	14. 35	16. 34	17. 18	15. 92
June	15. 55	15. 67	19. 84	19. 15	16. 80
July	14. 22	14. 21	17. 45	17. 93	15. 85
August	13. 55	14. 09	20. 08	18. 98	16. 10
September	10. 51	10. 39	11. 93	12. 44	11. 72
October	7. 28	7. 82	7. 60	9. 19	8. 90
November	4. 45	4. 33	6. 21	8. 32	5. 11
December	2. 65	2. 81	3. 41	5. 34	3. 85
1953					
January	4. 12	4. 10	4. 39	5. 61	5. 18
February	5. 03	5. 24	5. 52	6. 90	6. 30
March	8. 60	8. 46	9. 84	10. 66	9. 86
April	10. 14	10. 26	12. 85	13. 71	12. 70
May	13. 97	13. 05	16. 69	18. 51	16. 51
June	16. 63	15. 89	20. 30	21. 26	18. 40
July	14. 16	14. 38	20. 03	19. 08	16. 50
August	14. 66	14. 08	[3] 20. 30	18. 76	16. 51
September	10. 72	11. 28	16. 98	13. 59	12. 81
Total	195. 20	195. 46	247. 80	253. 97	227. 27
Total, March 1952–February 1953	106. 32	108. 06	130. 81	138. 40	123. 98
Total, October 1952–September 1953	112. 41	111. 70	144. 12	150. 93	132. 63

[1] Dewpoint from daily psychrometric readings assumed to be average for day from March through July 1952. Recording thermocouple data used from July 1952 through September 1953.
[2] This is the evaporation estimated to occur from a class A pan exposed at the elevation of Lake Mead, but where the air has not been affected by the reservoir. The assumption is made that the vapor pressure and the temperature of the air at Las Vegas (when corrected to the elevation of Lake Mead) will be representative of the air upwind from Lake Mead. A study of air temperatures at various elevations in the Grand Canyon area shows an increase of 4°F per 1,000 ft. decrease in elevation and the Las Vegas WBAS temperatures were increased accordingly. Dewpoints at Las Vegas WBAS were increased 1°F per 1,000 ft. in accordance with the change with elevation (pressure) under dry adiabatic conditions. Boulder City pan wind movement and Boulder Island solar radiation were used in the computations.
[3] Evaporation estimated for 4 days owing to questionable hook gage readings.

at the pan are representative of conditions at the windward edge of the reservoir.

2. There is no net flow of heat through the pan walls during the period; that is, mean air and water temperatures are equal.

3. There is no outflow from the reservoir other than as evaporation.

4. Net advected energy for the lake (energy content of inflow less that of evaporated water) is balanced by a change in energy content over the period.

5. The lake is circular and of some specified diameter.

6. The pan and lake are at some specified latitude. Other specifications may further enhance stability of the coefficient, but this list includes all of the more important items. Since all idealized conditions specified in items 1 through 6 are never encountered, the problem can be visualized as one of delineating the effect of variations so that required adjustments can be made. This is the approach discussed in a Weather Bureau research paper (Kohler, Nordenson, and Fox, 1955), the essential features of which are described in the following paragraphs:

Considering the above specifications in the order listed, the requirement that the index pan be exposed to the same meteorological conditions as the lake is self evident. This may require adjustment for air and dewpoint temperatures if there is appreciable difference in elevation at the pan and reservoir sites. Further adjustment of pan evaporation may be required for dewpoint if air reaching the pan is appreciably modified by the lake, or if local effects, such as irrigation, result in consistent differences between the air approaching the pan and the lake. How to determine when pan wind is representative of the lake is another problem. Wind movement observed 6 inches above the rim of the pan at Lake Hefner was about one-half that observed at 4 meters over the lake, but computations show that this ratio can vary appreciably without materially affecting the results.

Two approaches are presented in the research paper to account for heat transfer through the wall of the pan—one based on a modification in the relation of figure 37, and the second utilizing observations of air and pan-water temperatures. The relation of figure 37 yields estimates of evaporation from the class A pan with its consequent boundary losses—that is, $\gamma_p=0.025$ as derived empirically—in effect adjusts for sensible heat transfer through the pan. If, then, the theoretical value, γ, is substituted into the relation, computed values of evaporation should correspond to those observed in a "hypothetical" or "theoretical" pan which has the radiation characteristics of the class A pan, but which permits no sensible heat transfer through the walls of the pan. On the basis of data now available, it is evident that the annual coefficient for this "hypothetical" pan is near 0.70, and is essentially independent of climatic variations. Thus, annual lake evaporation can be estimated from the following equation (using daily or monthly averages and accumulating):

$$E_L=0.70\left(\frac{Q_n\Delta+E_a\gamma}{\Delta+\gamma}\right) \quad (22)$$

where E_L is the average daily lake evaporation in inches (assuming any advection to be balanced by a change in energy storage), $Q_n\Delta$ and E_a are as determined in figure 37, and $\gamma=0.000367\ P$ (units of degrees Fahrenheit and inches of mercury).

TABLE 21.—*Annual (water year) pan evaporation*

[In inches]

Water year	Class A land pans					Floating pans		
	Boulder City	North Las Vegas Wash	South Las Vegas Wash[1]	Pierce Ferry	Representative station[2]	North Las Vegas Wash	South Las Vegas Wash[1]	Pierce Ferry
1936	137. 27							
1937	129. 08	134. 99	128. 24	94. 98	----------	98. 18	107. 21	93. 89
1938	123. 02	122. 43	117. 19	116. 38	----------	111. 28	10[illegible]. 95	115. 20
1939	117. 72	128. 89	120. 19	126. 30	----------	105. 54	102. 13	107. 66
1940	124. 37	145. 37	141. 44	125. 49	----------	107. 21	103. 42	94. 73
1941	104. 96	116. 78	113. 50	104. 06	122. 52	102. 17	94. 25	80. 25
1942	118. 26	124. 57	122. 93	----------	137. 25	111. 88	9[illegible]. 89	----------
1943	123. 73	128. 81	124. 61	126. 75	133. 48	110. 40	8[illegible]. 43	91. 60
1944	119. 94	119. 00	114. 87	131. 79	135. 10	109. 41	91. 38	87. 03
1945	111. 44	114. 64	111. 08	109. 65	129. 64	100. 42	84. 75	77. 69
1946	114. 04	127. 30	128. 66	----------	130. 10	107. 05	9[illegible]. 13	----------
1947	113. 82	117. 31	123. 95	----------	132. 68	104. 55	94. 27	----------
1948	116. 81	113. 37	110. 85	128. 45	139. 44	112. 10	101. 59	116. 15
1949	110. 79	111. 27	98. 52	118. 46	126. 23	101. 05	9[illegible]. 28	80. 17
1950	114. 94	125. 60	120. 74	129. 49	135. 40	104. 22	100. 73	89. 21
1951	112. 12	----------	----------	130. 02	129. 32	----------	----------	81. 42
1952	105. 02	117. 14	109. 95	----------	122. 24	103. 60	95. 40	----------
1953	112. 41	125. 41	118. 99	----------	132. 63	112. 13	9[illegible]. 93	----------

[1] This station was moved to its present location in July 1939.
[2] See footnote 2 to Table 20. Las Vegas WBAS solar radiation (observed or computed from percent sunshine) was used for the period prior to March 1952.

TABLE 22.—*Monthly pan evaporation at Boulder City, Nev.*

[In inches]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1936	10. 22	5. 48	3. 75	4. 56	4. 73	9. 46	13. 24	17. 82	20. 04	18. 37	15. 62	13. 98	137. 27
1937	8. 06	5. 93	3. 53	3. 30	4. 30	6. 84	11. 98	17. 36	18. 22	17. 73	18. 43	13. 40	129. 08
1938	9. 83	5. 47	4. 35	4. 59	4. 42	6. 91	11. 96	13. 39	17. 11	17. 40	15. 50	12. 11	123. 02
1939	7. 85	5. 47	3. 46	3. 43	4. 02	7. 37	10. 93	15. 08	19. 01	18. 39	14. 18	8. 53	117. 72
1940	8. 23	3. 67	3. 47	2. 70	4. 83	9. 10	10. 60	15. 70	17. 31	19. 85	17. 72	11. 19	124. 37
1941	7. 65	5. 05	2. 29	2. 35	2. 89	6. 03	8. 30	14. 19	16. 25	15. 37	13. 03	11. 56	104. 96
1942	6. 43	4. 11	2. 65	3. 71	4. 71	7. 86	11. 13	14. 77	18. 75	17. 41	14. 14	12. 59	118. 26
1943	8. 17	5. 71	3. 63	4. 09	4. 66	7. 32	9. 08	15. 80	17. 52	16. 96	14. 48	12. 18	119. 60
1944	8. 01	4. 93	3. 04	3. 24	3. 21	7. 94	9. 78	13. 94	16. 68	18. 63	17. 64	12. 90	119. 94
1945	8. 60	4. 47	3. 58	2. 66	4. 79	6. 45	10. 78	15. 10	15. 72	14. 64	12. 71	11. 94	111. 44
1946	6. 72	4. 82	2. 39	4. 28	4. 61	8. 15	11. 06	14. 66	17. 96	14. 65	13. 76	10. 98	114. 04
1947	6. 25	3. 31	3. 11	3. 36	4. 41	7. 83	10. 77	13. 87	16. 37	16. 67	14. 42	13. 45	113. 82
1948	7. 53	4. 66	2. 74	4. 18	4. 07	7. 06	10. 90	14. 92	15. 52	17. 88	15. 17	12. 18	116. 81
1949	8. 04	5. 08	3. 28	2. 59	2. 80	6. 93	10. 17	12. 18	16. 38	17. 36	13. 89	12. 09	110. 79
1950	7. 52	4. 62	2. 97	3. 43	4. 41	7. 92	12. 55	13. 86	16. 72	15. 28	14. 05	11. 61	114. 94
1951	8. 54	5. 28	4. 08	3. 43	4. 19	8. 21	9. 59	13. 38	15. 42	16. 22	12. 46	11. 32	112. 12
1952	7. 38	4. 12	3. 26	2. 53	4. 94	6. 36	8. 85	13. 75	15. 55	14. 22	13. 55	10. 51	105. 02
1953	7. 28	4. 45	2. 65	4. 12	5. 03	8. 60	10. 14	13. 97	16. 63	14. 16	14. 66	10. 72	112. 41
Total	142. 31	86. 63	58. 23	62. 55	77. 02	136. 34	191. 81	263. 74	307. 16	301. 19	265. 41	213. 24	2, 105. 61
Average	7. 91	4. 81	3. 24	3. 48	4. 28	7. 57	10. 66	14. 65	17. 06	16. 73	14. 74	11. 85	116. 98

A second and possibly more obvious approach involves the direct computation of transfer through the pan and the determination of what portion was utilized in (or not available for) the evaporation process. From the Bowen ratio concept and the derived relation between pan evaporation, water temperature, dewpoint, and wind, the following equation was developed:

$$E_L=0.70[E_p+0.00051\ P\alpha_p(0.37+0.0041\ u_p)(T_0-T_a)^{0.88}] \qquad (23)$$

where E_L and E_p are average daily lake and pan evaporation, respectively; α_p is the proportion of energy transfer through pan walls utilized in (or not available for) evaporation process; P is normal station pressure in inches of mercury; u_p is pan wind in miles per day; and T_a and T_0 are air and pan-water temperatures in degrees Fahrenheit, respectively.

Items 3 and 4 of the listed specifications jointly require that no heat be supplied to the lake from external sources other than those acting upon the pan. Assuming that reasonable estimates of heat storage and

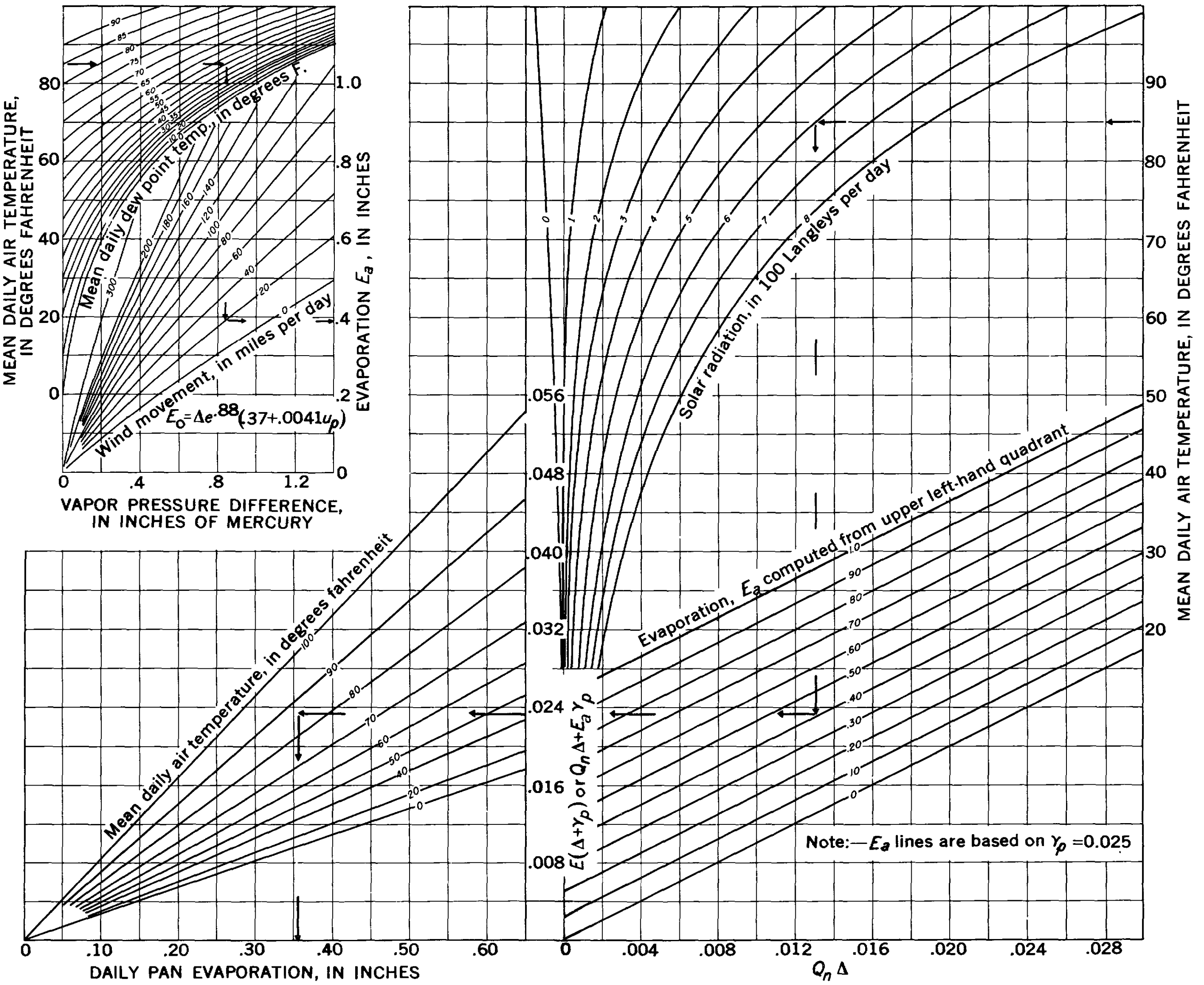

FIGURE 37.—Revised relation of pan-evaporation and meteorological factors for class A pans, using energy-balance approach. Based on data from Vicksburg, Miss., Silver Hill Md., Boulder City, Nev., and Lake Hefner, Okla After Kohler, 1954, and Kohler, Nordenson, and Fox, 1955.

advection to and from the lake are available, it was shown that the proportion of such energy affecting the evaporation process could be approximated by the relation shown in figure 38. Similarly, it was shown by Kohler, Nordenson, and Fox (1955) that the proportion of energy transfer through the pan walls that is utilized in the evaporation process could be approximated from figure 39.

With respect to specifications 5 and 6, relative to latitude and lake size, it can only be stated that at present empirical analysis indicates that neither factor is of particular importance. The discussion of size effect presented by Kohler (1954, p. 142) has, in a sense, been substantiated by observations at Lake Mead. Although it might be expected that angle of the sun would affect pan evaporation owing to variation in the radiant energy intercepted by the pan walls, the generalized relation of figure 37 seems to give equally reliable results from Texas to Alaska.

LAKE MEAD COMPUTATIONS

It is indeed unfortunate that none of the pan stations operated throughout the 19-month period are "representative" in the sense required for application of equation 23—a development subsequent to instrumentation of the project. The accuracy with which Boulder City pan data can be estimated from the generalized relation of figure 37, however, indicates that evaporation computed for the "representative" site should be quite reliable. It follows then that equation 22, solved with "representative" data, should provide reasonably accurate estimates of annual lake evaporation. Such computations have been made, using the data described in footnote 2 of table 20, and the results are given in

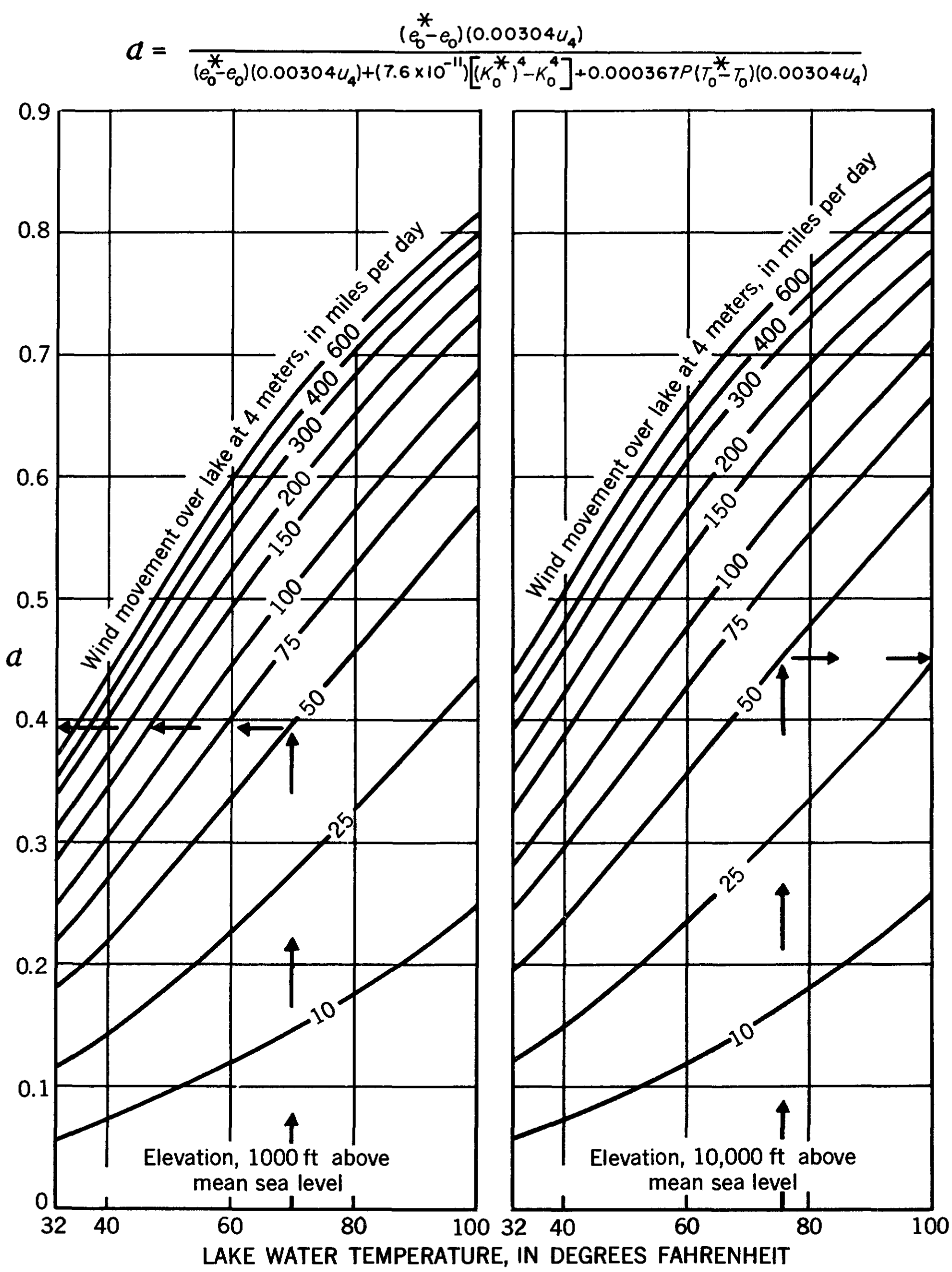

FIGURE 38.—Proportion of advected energy (into a lake) utilized for evaporation.

table 23. For comparative purposes, energy-budget evaporation and that computed using the Lake Hefner empirical mass-transfer equation (Kohler, 1954, table 27, second equation) are also given in the table. Although the divergence for individual periods is as much as 25 percent, differences between the three methods for the beginning and ending annual periods (partially overlapping) are only a few percent. Basic data and computations for advection adjustments given in table 23 are listed in table 24.

The close agreement of the computations shown in table 23 goes far to instill confidence for the reliability of each approach and prompts speculation as to the feasibility of estimating Lake Mead evaporation for previous years. This was done using equation 22, the only approach of the three for which data are available, and the results are shown in table 25. Temperature profiles for the lake are available since October 1940; however, inflow and outflow temperature observations began in 1944.

To be wholly consistent with table 23, all computations for table 25 should also have been made on a monthly basis. This would have required analysis of approximately 140 temperature profiles and much addi-

$$\alpha_p=\frac{\left[(e_0^*-e_a)^{0.88}-(e_0-e_a)^{0.88}\right](0.37+0.0041\,u_p)}{\left[(e_0^*-e_a)^{0.88}-(e_0-e_a)^{0.88}\right](0.37+0.0041\,u_p)+(7.6\cdot10^{-11})\left[(K_0^*)^4-K_0^4\right]+0.000367\,P\left[(T_0^*-T_a)^{0.88}-(T_0-T_a)^{0.88}\right](0.37+0.0041\,u_p)}$$

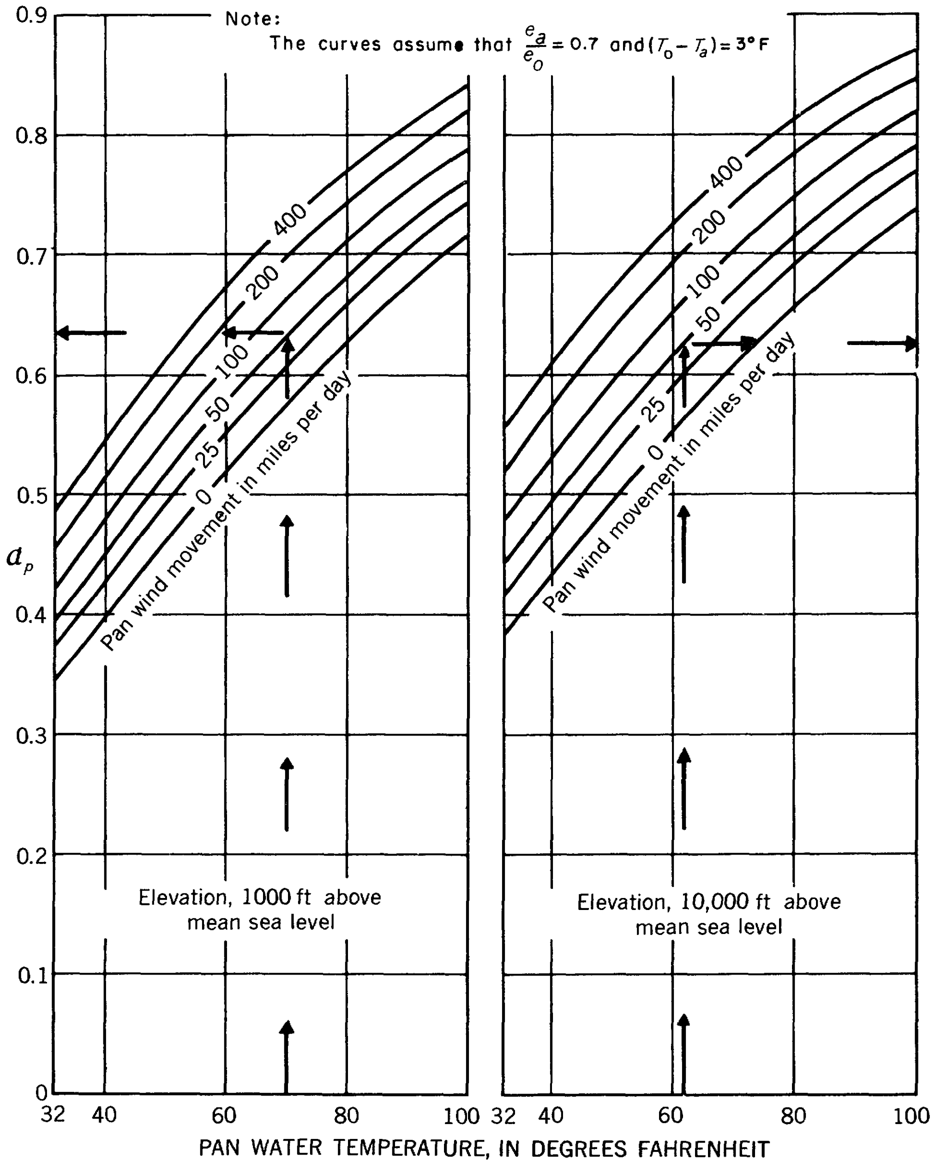

FIGURE 39.—Proportion of advected energy (into class A pan) utilized for evaporation.

tional computational effort. Energy advection and E_L were derived by accumulating computed monthly values. Conversion to an evaporation adjustment was based on annual data using a weighted annual value of α. This value of α, which was derived from the first and last full year of the 19-month period, is given by $\alpha_n\Sigma[Q'_v-Q_\vartheta]_i=\Sigma\alpha_i[Q'_v-Q_\vartheta]_i$ in which the subscript i denotes a monthly value, the subscript n an annual value, and $[Q'_v-Q_\vartheta]$ is the advection-storage difference. Conversion of the adjustment from acre-feet to depth in inches required a further approximation, as surface area varies throughout the year.

Values in the last two columns of table 25 represent computed pan coefficients for the Boulder City pan and for the "representative" pan. The first is shown to illustrate the reliability of observed pan evaporation as an index—in this specific case—and the second shows both the magnitude and variability of the pan coefficient at the Lake Mead site under idealized conditions.

Examination of column 4 in table 25 indicates that advection of energy during the past 13 years has increased evaporation from Lake Mead by an average of about 5 inches per year. Since this added loss results from the fact that temperature of the water

TABLE 23.—*Comparison of Lake Mead evaporation as computed from equation 22, the energy budget, and an empirical mass-transfer equation*

Period	(a) Air temp. (°F)	(b) Dewpt temp. (°F)	(c) Pan wind (miles per day)	(d) Solar radiation (langleys per day)	(e) $\alpha(Q'_v-Q_\theta)$ (in. of evap.)	Computed lake evaporation (inches): (f) Empirical mass transfer	Computed lake evaporation (inches): Energy budget	Computed lake evaporation (inches): Equation 22 plus $\alpha(Q_v-Q_\theta)$	Difference (cols. 7 and 9)	Difference (cols. 8 and 9)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1952										
Mar. 12–Apr. 14	61. 4	24. 0	119	560	−1. 5	5. 0	6. 2	5. 9	−0. 9	0. 3
Apr. 15–May 11	72. 3	34. 2	68	627	−2. 4	3. 7	4. 3	4. 3	−. 6	0
May 12–June 11	82. 2	26. 4	86	735	−1. 8	8. 9	9. 8	8. 9	0	. 9
June 12–July 8	86. 7	25. 4	78	724	−1. 3	9. 8	10. 0	8. 1	1. 7	1. 9
July 9–Aug. 5	93. 2	38. 5	49	695	−1. 3	8. 4	8. 7	8. 1	. 3	. 6
Aug. 6–Sept. 3	94. 5	42. 4	51	635	−. 5	11. 2	9. 8	8. 6	2. 6	1. 2
Sept. 4–Oct. 2	83. 5	35. 7	50	502	. 6	7. 3	6. 7	7. 2	. 1	−. 5
Oct. 3–Nov. 5	73. 9	25. 3	40	420	1. 9	7. 2	6. 3	7. 7	−. 5	−1. 4
Nov. 6–Dec. 2	50. 9	19. 7	73	283	6. 1	8. 5	8. 9	8. 5	0	. 4
1952–1953										
Dec. 3–Jan. 8	50. 2	29. 8	67	237	3. 7	6. 6	6. 1	6. 3	. 3	−. 2
1953										
Jan 9–Feb 2	55. 2	23. 0	77	304	. 9	2. 9	3. 2	3. 5	−. 6	−. 3
Feb 3–Mar. 2	52. 1	12. 9	106	398	1. 3	4. 7	5. 5	5. 2	−. 5	. 3
Mar. 3–Mar. 31	61. 4	15. 9	100	533	−1. 2	4. 2	4. 9	4. 8	−. 6	. 1
Apr. 1–Apr. 27	68. 1	15. 6	102	596	−2. 0	4. 9	4. 5	4. 0	. 9	. 5
Apr. 28–May 27	69. 8	16. 7	144	719	−1. 5	9. 0	8. 7	8. 4	. 6	. 3
May 28–June 29	83. 5	22. 5	102	762	−3. 1	9. 8	9. 2	9. 2	. 6	
June 30–July 29	94. 9	46. 4	72	650	−2. 3	8. 4	8. 1	7. 7	. 7	. 4
July 30–Aug. 26	92. 3	35. 7	78	613	−. 5	10. 7	8. 4	8. 4	2. 3	0
Aug. 27–Sept. 28	85. 9	27. 9	52	587	1. 5	10. 3	10. 7	10. 5	−. 2	. 2
Total	--------	--------	--------	--------	--------	141. 5	140. 0	135. 3	--------	--------

a, Las Vegas WBAS air temperature plus 4°F (adjusting to Lake Mead elevation).
b, Las Vegas WBAS dewpoint temperature plus 1°F (adjusting to Lake Mead elevation).
c, Wind movement at Boulder City pan.
d, Solar radiation from Boulder Island installation.
e, Adjustment for change in energy storage and net advection of energy as shown in table 24.
f, Computed from equation 2, table 27, of Lake Hefner report (Kohler, 1954) using data from Boulder Basin barge.

discharged at the dam averages several degrees colder than the water entering at the head of the reservoir, it follows that evaporation could theoretically be reduced if it were practical to withdraw only the warmer, surface water. The engineering aspects of this possibility have been analyzed by engineers of the Bureau of Reclamation, and the results of their studies are presented in the section entitled "Withdrawal of water from Lake Mead."

ESTIMATION OF MONTHLY LAKE EVAPORATION

In an attempt to derive a means of estimating monthly lake evaporation from pan data, it was shown by Kohler (1954) that the monthly pan coefficient is approximately proportional to the ratio of vapor pressure difference (water to air) for the lake and pan. Thus, monthly lake evaporation can be computed from pan evaporation, dewpoint, and pan-water and lake-surface-water temperatures. In reality, this maneuver simply substitutes pan wind for wind over the lake in the empirical mass-transfer equation, and results would most likely be inferior to those obtained with the mass-transfer equation, if reliable lake-wind data were available.

Although one might expect that application of equation 22 would yield computed values of lake evaporation displaying a pronounced seasonal bias with respect to actual evaporation, this in not borne out by the data in table 23. Differences between energy-budget computations and those using equation 22 are not particularly correlated with season, and the average difference per period is only one-half inch. The larger differences are highly correlated with departures from a mean curve relating Boulder City and lake winds, strongly indicating that at least part of the discrepancy results from the fact that Boulder City wind is not always representative of conditions at the lake, particularly for shorter periods. Apparently, seasonal variation in back radiation (pan relative to lake) and other factors which come to mind have only minor effect on the pan coefficient, under the idealized specifications set forth in the previous section.

TABLE 24.—*Computation of adjustments for advection and change in energy storage*

Period	Average elevation of Lake Mead (ft above msl)	(a) Q_v		(b) Q_w		(c) Q_ϑ		(d) 4-Meter wind at Boulder Basin barge (miles per day)	Average water temp. of lake surface (°F)	(e) α	(f) $-\alpha Q_\vartheta$ in. of evap	(g) $\alpha Q_v'$ in. of evap.
		Cal per cm²	In. of evap.	Cal per cm²	In. of evap.	(Cal.×10⁻¹⁶)	In. of evap.					
1952												
Mar. 12–Apr. 14	1, 136	−884	−0. 6	−204	−0. 1	1. 470	2. 2	214	55. 9	0. 50	−1. 1	−0. 4
Apr. 15–May 11	1, 142	12, 717	8. 5	−189	−. 1	8. 578	12. 7	168	64. 4	. 54	−6. 9	4. 5
May 12–June 11	1, 168	19, 716	13. 3	−558	−. 4	11. 856	15. 9	203	72. 3	. 61	−9. 7	7. 9
June 12–July 8	1, 193	14, 634	9. 9	−621	−. 4	9. 774	11. 6	225	76. 8	. 64	−7. 4	6. 1
July 9–Aug. 5	1, 200	2, 884	2. 0	−644	−. 4	3. 179	3. 7	182	82. 8	. 66	−2. 4	1. 1
Aug. 6–Sept. 3	1, 197	116	. 1	−725	−. 5	. 281	. 3	237	82. 8	. 69	−. 2	−. 3
Sept. 4–Oct. 2	1, 192	−1, 943	−1. 3	−464	−. 3	−2. 157	−2. 6	139	79. 7	. 60	1. 6	−1. 0
Oct. 3–Nov. 5	1, 186	−3, 604	−2. 4	−408	−. 3	−4. 830	−5. 9	124	76. 1	. 57	3. 4	−1. 5
Nov. 6–Dec. 2	1, 179	−3, 645	−2. 4	−432	−. 3	−10. 589	−13. 3	232	66. 2	. 58	7. 7	−1. 6
1952–1953												
Dec. 3–Jan. 8	1, 172	−3, 922	−2. 6	−222	−. 1	−7. 546	−9. 8	208	59. 5	. 52	5. 1	−1. 4
1953												
Jan. 9–Feb. 2	1, 165	−2, 150	−1. 4	−100	−. 1	−2. 431	−3. 3	159	56. 5	. 47	1. 6	−. 7
Feb. 3–Mar. 2	1, 160	−2, 324	−1. 6	−168	−. 1	−3. 172	−4. 3	214	55. 0	. 49	2. 1	−. 8
Mar. 3–Mar. 31	1, 155	−1, 479	−1. 0	−174	−. 1	0. 989	1. 4	191	56. 1	. 49	−. 7	−. 5
Apr. 1–Apr. 27	1, 150	−702	−. 5	−189	−. 1	2. 225	3. 2	219	59. 9	. 53	−1. 7	−. 3
Apr. 28–May 27	1, 147	450	. 3	−390	−. 3	1. 823	2. 7	280	63. 1	. 57	−1. 5	0
May 28–June 29	1, 155	14, 718	9. 9	−495	−. 3	10. 498	14. 8	234	70. 2	. 61	−9. 0	5. 9
June 30–July 29	1, 166	4, 830	3. 3	−570	−. 4	4. 723	6. 4	195	81. 3	. 66	−4. 2	1. 9
July 30–Aug. 26	1, 165	2, 072	1. 4	−616	−. 4	1. 221	1. 7	223	83. 3	. 68	−1. 2	. 7
Aug. 27–Sept. 28	1, 162	−627	−. 4	−759	−. 5	−2. 418	−3. 3	158	82. 8	. 65	2. 1	−. 6

Base temperature of 0°C. used throughout computations.

a, Net energy advected into the body of water by all volumes entering or leaving the body of water, except that volume leaving as evaporated water.
b, Energy advected out of the body of water by the mass of evaporated water.
c, The change in energy stored in the body of water.
d, Wind at 4 meters computed as average of wind movement at 2 and 8 meters above lake level.
e, Values obtained from figure 35.
f, Computed adjustment to Lake Mead evaporation for change in energy storage.
g, Computed adjustment to Lake Mead evaporation for net advection of energy.

TABLE 25.—*Computation of Lake Mead evaporation and pan coefficients, 1941–53*

Water year	E_L from Eq. 22 (inches) [a]	Q_v' (equiv. acre-ft of evap.) [b]	Q_ϑ (equiv. acre-ft of evap.) [d]	$\alpha(Q_v'-Q_\vartheta)$ (acre-ft of evap.) [e]	Average Lake Mead Area (1,000 acres)	$\alpha(Q_v'-Q_\vartheta)$ (in. of evap.) [f]	Lake evap. (inches) (E_L plus col. 7)	Ratio of E_L to E_p for Boulder City class A pan	Ratio of E_L to E_p for representative class A pan
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1941	74. 5	[c] 294, 000	170, 000	62, 000	138. 6	5. 4	79. 9	0. 71	0. 61
1942	82. 3	[c] 97, 000	−16, 000	56, 500	144. 2	4. 7	87. 0	. 70	. 60
1943	79. 5	[c] 75, 000	−24, 000	49, 500	140. 6	4. 2	83. 7	. 66	. 60
1944	81. 3	97, 000	−48, 000	72, 500	134. 8	6. 5	87. 8	. 68	. 60
1945	78. 2	68, 000	−62, 000	65, 000	128. 8	6. 1	84. 3	. 70	. 60
1946	76. 4	32, 000	−79, 000	55, 500	124. 7	5. 3	81. 7	. 67	. 59
1947	77. 1	212, 000	140, 000	36, 000	122. 4	3. 5	80. 6	. 68	. 58
1948	82. 7	89, 000	−64, 000	76, 500	131. 8	7. 0	89. 7	. 71	. 59
1949	76. 7	191, 000	43, 000	74, 000	129. 7	6. 8	83. 5	. 69	. 61
1950	81. 8	46, 000	−59, 000	52, 500	125. 0	5. 0	86. 8	. 71	. 60
1951	78. 1	110, 000	−7, 000	58, 500	118. 8	5. 9	84. 0	. 70	. 60
1952	75. 5	237, 000	130, 000	53, 500	122. 9	5. 2	80. 7	. 72	. 62
1953	80. 8	−30, 000	−151, 000	60, 500	122. 5	5. 9	86. 7	. 72	. 61
Total	1, 024. 9	1, 518, 000	−27, 000	772, 500	1, 684. 8	71. 5	1, 096. 4	9. 05	7. 81
Average	78. 8	116, 800	−2, 100	59, 400	129. 6	5. 5	84. 3	. 70	. 60

[a] Based on Boulder City wind; radiation observed at Boulder Island March 1952–Sept. 1953 and Las Vegas May 1950–Feb. 1952, and computed from Las Vegas per cent sunshine prior to May 1950; and Las Vegas air and dewpoint temperatures adjusted to Lake Mead elevation. Comparative studies showed Las Vegas dewpoints prior to move in December 1948 required a correction of −6°F to be comparable with recent observations.

[b] The net advected energy (Q_v') was computed from monthly data using the following:

(1) Inflow = outflow + estimated evaporation + change in storage.

(2) Inflow Temp. $=(T+2.6°C)-(0.04T)-(2.1\times10^{-5}\times q)$ where T and q are Grand Canyon water temperature in °C and mean flow in cfs, respectively. When computed inflow temperature is less than T, then T is used.

(3) Outflow water temp. = Hoover Dam tailrace water temp. − 1.1°C.

(4) Heat of vaporization assumed to be 585 cal/cm³.

[c] Computed from well-defined relation between energy advection and change in storage.

[d] Computed from temperature profiles at the intake towers.

[e] A weighted annual value of 0.50 was used for α (see text).

[f] Based on average annual area; may differ from accumulation of monthly values.

SUMMARY OF EVAPORATION STUDIES

It is believed computations presented in this chapter demonstrate that annual evaporation from Lake Mead (assuming no advection or change in energy storage) can be reliably estimated, either by applying a coefficient of 0.70 to the observed Boulder City pan evaporation (column 9, table 25) or by application of equation 22 to "representative" meteorological data. With respect to the 19-month test period, it can be said that differences between evaporation as computed by these two techniques (corrected for Lake Mead energy advection and change in energy storage) and that obtained by the energy-budget or mass-transfer approaches are well within the probable error of those approaches.

Studies involving data from a number of experiments under differing climatic regimes substantiate the conclusion that transfer of heat through the class A pan causes moderate variation in the pan coefficient. Under the climatic regime at Lake Mead there is a net flow of heat into the pan such that a coefficient of about 0.60 (column 10, table 25) should be observed for a representative pan (assuming that the net advected energy for the lake is balanced by a corresponding change in energy storage). The fact that the generally accepted coefficient of 0.70 is applicable for the Boulder City pan is coincidental; it so happens that the effects brought about by increased elevation (Boulder City with respect to Lake Mead) and local watering of lawns compensate for the heat transfer through the pan.

It also appears that, on the average, actual monthly lake evaporation can be estimated from equation 22 to within 10 percent, provided the energy advection and storage terms can be evaluated within reasonable limits. Judging from the 19-month test period, it may be possible to reduce the more extreme errors materially by using wind data which are more representative than those observed at the Boulder City pan station.

Since equation 22 provided results consistent with the mass-transfer and energy-budget techniques for the 19-month period, it was applied for the period 1941–53 when sufficient data were available. This analysis yielded an average annual lake evaporation of about 84 inches. Averaging lake evaporation for the first and last full years of the 19-month study period (column 9, table 23) also gives a value of approximately 84 inches, indicating that the study period was reasonably representative.

The close agreement between results obtained from equation 22 and from the energy-budget and mass-transfer approaches lends considerable added support to the conclusion expressed in the Lake Hefner report (Kohler, 1954, p. 148) relative to size effect. Equation 22 is based on the assumption that the rate of lake evaporation (depth per unit of time) is independent of water-surface area, and the fact that it is found to apply for a reservoir as large as Lake Mead and also for a 12-foot sunken pan goes far to invalidate conclusions to the contrary. Reliability of data and computations are not such that it can be conclusively stated that size has no effect on evaporation but, on the other hand, any such effect must be minor compared to that derived on theoretical grounds. Apparently variations in wind and water temperature over the surface of the lake cannot be neglected, as has been done by a number of previous investigators.

The necessity to adjust meteorological observations to obtain representative data at this relatively "well instrumented" project points up the extent to which each reservoir must be considered an entity in itself. Even so, such adjustments are usually of only moderate magnitude and probably can often be neglected.

FUTURE PROGRAM AT LAKE MEAD

By G. Earl Harbeck, Jr., U. S. Geological Survey and Max A. Kohler, U. S. Weather Bureau

The possibility of maintaining indefinitely the full observational program designed for the studies covered by this report was given no consideration by the cooperating agencies because of the man-power requirements and the cost involved. Moreover, the determination of daily or weekly evaporation was believed unnecessary for operational purposes.

The need for continuing measurements of evaporation from Lake Mead may not be readily apparent. The evaporation loss during the 1953 water year was 875,000 acre-feet. To some readers this figure may have little physical significance because of its magnitude. The loss might be likened to the complete and sudden disappearance at some point in its course of a river 100 feet wide, 6 feet deep, flowing at 2 feet per second. Evaporation from Lake Mead is the largest hitherto unmeasured diversion, if it may be called that, from the Colorado River. In the light of present knowledge little if anything can be done to decrease the loss, so that it may be considered a relatively fixed charge against the storage system. But accepted accounting principles require a knowledge of the magnitude of fixed charges even though nothing can be done to decrease them, and the efficient design and operation of one storage reservoir or a system of them requires that the magnitude of present and planned diversions from the system be known.

For the determination of evaporation on a continuing basis, it was desired that instrumentation and field and office work be minimized, consistent with the need for figures of monthly evaporation from Lake Mead. Accordingly, it was deemed desirable that fullest possible use be made of the records obtained at the first-order Weather Bureau station at the Las Vegas airport.

Studies were made to determine the correlation between certain meteorological parameters as measured at the Las Vegas airport and at Lake Mead. Figures 4 and 6 indicate that correlation between air temperatures and vapor pressures measured at the two places is excellent. On the other hand, figure 5 shows that the relation between wind speeds measured at the Las Vegas airport and wind speeds measured in Boulder Basin is not nearly as well defined. The relation between water-surface temperature and air temperature, as shown in figure 4, appears to be well enough defined so that with an allowance for time lag, water-surface temperature could be estimated with a fair degree of accuracy. It was not believed wise to attempt this, however, for water-surface temperature could conceivably be affected by variables that would not have a corresponding effect on air temperature, such as advected energy. During a year of extremely high or extremely low inflow the estimated water-surface temperature might be subject to large error.

The mass-transfer equation finally decided upon requires measurements of wind speed at Boulder Island, water-surface temperature in Boulder Basin, and air temperature and humidity at the Weather Bureau station at the Las Vegas airport. The best-fitting empirical equation for computing evaporation for periods of about one month in length is as follows:

$$E=0.001813\ u\ (e_0-e_a)t[1-0.03(T_a-T_0)] \quad (24)$$

in which

E=evaporation in inches for period
u=average wind speed at Boulder Island in knots
e_0=saturation vapor pressure in millibars at the average temperature of the water surface, T_0
e_a=average vapor pressure of the air in millibars determined by averaging 4:30 a. m. and 4:30 p. m. observations of vapor pressure at the Las Vegas airport
t=number of days in period
T_a=average air temperature in degrees centigrade at Las Vegas airport+1.9°C
T_0=average water-surface temperature in degrees centigrade.

The constant 0.001813 necessarily includes conversion of units, proportionality constants, and the height above ground at which the wind, temperature, and humidity are measured. The constant correction of 1.9°C to be applied to observed Las Vegas temperatures is the average difference between Las Vegas temperature and the 8-meter air temperature in Boulder Basin. The Las Vegas airport is at an elevation approximately 1,000 feet higher than Lake Mead. Both the International Standard Atmosphere and the U. S. Standard Atmosphere are based on a temperature lapse rate of 0.65°C per 100 meters. Using this lapse rate the indicated temperature difference should be 1.98°C, which agrees with the observed difference very closely.

Theoretically it can be argued that the stability correction term $[1-0.03\ (T_a-T_0)]$ is not correct in form. Many investigators have agreed that the Richardson number, which is a measure of the balance between buoyant and dynamic forces, is a good stability parameter, but there is little agreement as to the manner in which this parameter should be used. The denominator of the expression for the Richardson number includes the square of the wind speed. On a monthly basis at least, variation in wind speed at Lake Mead was not great, and no significant improvement in the correlation resulted from its inclusion. Since there was no advantage to including a nonsignificant term in an empirical equation, it was omitted.

Because the anemometer on Boulder Island is at a fixed elevation, its height above the lake surface is variable. The foregoing analysis was based upon data obtained when the average water-surface elevation was 1,156 feet. A correction factor was computed using equation 8b with z_0=0.014 cm (from wind ratio data in table 10). The correction to be applied to observed Boulder Island wind speeds ranges from 0.95 for a lake elevation of 1,070 feet to 1.05 for an elevation of 1,200 feet.

Computed figures of evaporation for energy-budget periods based on equation 24 are shown in table 12. A comparison between evaporation computed using equation 24 and the average of the energy-budget and mass-transfer results is shown in figure 40. Energy-budget periods instead of calendar months were used in the regression analysis in order to eliminate the possible error inherent in the distribution of energy-budget evaporation on a calendar month basis. In comparison with the average of the energy-budget and 2-meter mass-transfer results, the average error, without regard to sign, using equation 24, was 0.9 inch, or 9 percent of the average evaporation per period. Since the periods average about 1 month in length, it is believed that monthly evaporation from Lake Mead can be determined using equation 24 with an average error of 10 percent or less. The apparent close agreement between the totals for periods 5–16 is meaningless, for the total of 83.86 inches (the average of the energy-budget and mass-transfer) was used in determining the constants

TABLE 26.—*Computation of Lake Mead evaporation from equation 22, using data to be available under continuing program*

Period	(a) Air temp. (°F)	(b) Dew point (°F)	(c) Pan wind (miles per day)	(d) Solar radiation (langleys per day)	Lake area (1,000 acres)	(e) (Q'_v in. of evap.)	(e) Q_ϑ (in. of evap.)	(f) α	(g) $\alpha(Q'_v - Q_\vartheta)$	Computed lake evaporation in inches: (h) Avg., mass transfer and energy budget	E_L plus col. 10	Difference cols. 11 and 12
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1952												
Mar. 27–Apr. 29	68	30	89	584	109. 1	2. 9	6. 6	0. 50	−1. 8	4. 5	6. 0	−1. 5
Apr. 30–May 26	79	28	81	723	118. 3	12. 1	18. 2	. 56	−3. 4	5. 8	5. 3	+. 5
May 27–June 26	85	24	86	752	133. 5	13. 8	13. 4	. 64	. 3	11. 7	11. 5	+. 2
June 27–Aug. 4	92	36	50	691	144. 9	4. 0	7. 0	. 65	−2. 0	11. 4	10. 9	+. 5
Aug. 5–Aug. 28	95	44	53	634	143. 6	−. 4	1. 4	. 69	−1. 2	9. 8	6. 3	+3. 5
Aug. 29–Sept. 29	86	37	50	526	140. 8	−1. 5	−2. 6	. 61	. 7	8. 0	8. 5	−. 5
Sept. 30–Oct. 29	77	25	32	444	137. 0	−2. 3	−5. 1	. 57	1. 6	5. 5	7. 1	−1. 6
Oct. 30–Nov. 25	57	22	76	300	132. 8	−2. 5	−12. 4	. 59	5. 8	8. 3	8. 6	−. 3
Nov. 26–Dec. 29	49	27	66	249	127. 9	−2. 9	−9. 7	. 53	3. 6	6. 7	5. 9	+. 8
1952–1953												
Dec. 30–Feb. 3	54	25	72	286	123. 3	−2. 3	−6. 0	. 51	1. 9	4. 6	5. 1	−. 5
1953												
Feb. 4–Mar. 2	52	13	109	400	120. 2	−1. 5	−3. 6	. 49	1. 0	5. 0	4. 6	+. 4
Mar. 3–Mar. 30	62	16	101	530	117. 8	−1. 0	1. 0	. 49	−1. 0	4. 6	4. 7	−. 1
Mar. 31–Apr. 28	68	15	104	602	115. 9	−. 6	1. 6	. 52	−1. 1	5. 3	6. 3	−1. 0
Apr. 29–July 7	80	21	116	736	117. 1	9. 9	17. 8	. 60	−4. 7	20. 3	20. 1	+. 2
July 8–Aug. 2	94	52	74	613	123. 6	1. 6	5. 4	. 67	−2. 5	7. 2	5. 6	+1. 6
Aug. 3–Aug. 31	91	34	77	635	122. 8	. 7	1. 0	. 67	−. 2	10. 0	9. 1	+. 9
Sept. 1–Sept. 29	86	27	46	575	120. 8	−1. 0	−1. 7	. 62	. 4	8. 0	8. 2	−. 2
Total (disregarding signs)										136. 7	133. 8	14. 3

a, Las Vegas (Airport) air temperature plus 4°F (adjusting to Lake Mead elevation).
b, Las Vegas (Airport) dewpoint temperature plus 1°F (adjusting to Lake Mead elevation).
c, Wind movement at Boulder City pan.
d, Solar radiation from Boulder Island installation.
e, Net advection of energy (Q'_v) and change in energy storage (Q_ϑ) were computed as explained in footnote b of table 25.
f, Computed from fig. 35.
g, Correction to lake evaporation, as computed from eq. 22, for net advection of energy and change in energy storage.
h, Computed in same manner as data shown in table 12.

in equation 24. It is estimated that the average error of computed annual evaporation using equation 24 will be 5 percent or less.

In the section of this report entitled "Pan and lake evaporation" it was shown that monthly lake evaporation could be reliably estimated using a modified pan approach as given by equation 22. The average difference between evaporation computed in this manner (table 23) and that of the energy budget is only one-half inch per month. To attain this indicated degree of reliability under the future program, however, would require that the energy advection and storage terms be evaluated with the same precision as during the 19-month study period.

In planning the future, or continuing, program, it was decided that evaluation of the energy advection and storage terms would necessarily be based on a single temperature profile taken at the intake towers, temperature of the inflow at the Grand Canyon gaging station, and outflow temperature as observed at the tailrace. The computations summarized in table 26 were made to illustrate the reliability which might be expected when these observations are used in the future.

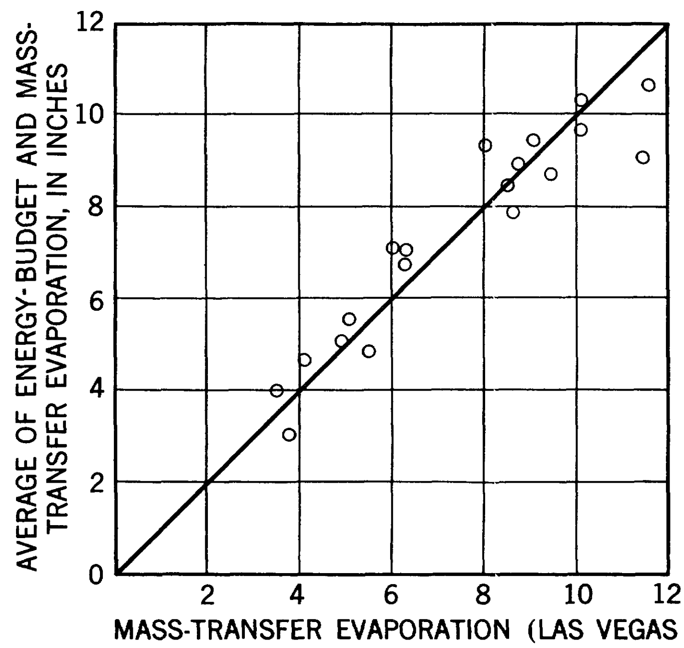

FIGURE 40.—Comparison, for energy-budget periods, between the average of the mass-transfer and energy-budget results with the results obtained using Las Vegas and Boulder Basin data.

Comparing the results in this table and in table 23 show that the average error is increased materially when using the single profile and inflow temperature observation, but that the overall evaporation for the 19-month period is essentially unchanged. In other words, annual evaporation computed on the basis shown in table 26 should be reliable.

The relative invariance of the coefficient shown in column 6 of table 25 indicates that the Boulder City pan can be used to provide still a third check on annual evaporation from Lake Mead. The extreme variation from the mean annual coefficient is only about 5 percent.

WITHDRAWAL OF WATER FROM LAKE MEAD

By Walter U. Garstka, H. Boyd Phillips, Ira E. Allen, and Donald J. Hebert, U. S. Bureau of Reclamation

In the section entitled "Surface-water withdrawal: theoretical considerations," it was concluded that a saving of approximately 8 percent in evaporation would be realized if it were possible to withdraw water from the surface of Lake Mead. The assumptions and methods of computation will not be repeated here, but for the period chosen for study, July 9, 1952, to June 29, 1953, evaporation from Lake Mead was approximately 900,000 acre-feet. The saving of 8 percent, therefore, would amount to 72,000 acre-feet. During the period selected for study, the average surface area of the lake was 128,000 acres, which corresponds to an elevation of 1,174 feet. From the time storage was begun at Lake Mead, the average active content has been about 16,300,000 acre-feet, corresponding to an elevation of approximately 1,139 feet. At elevations below 1,174 feet, the saving would be reduced during an otherwise comparable period. Moreover, to obtain the maximum possible saving, the water removed must be at the temperature of the surface, and in Lake Mead the decrease in temperature with depth is sometimes quite rapid.

HYDRODYNAMICS OF WITHDRAWALS FROM A RESERVOIR

To help visualize what takes place when water is withdrawn from a reservoir, several electric-analogy studies were performed. Two 2-dimensional models and one 3-dimensional model were studied. For all three models, the depth of reservoir was taken to be 400 feet and the "surface" layer was taken to be one-twelfth of the total depth. Discharge for all three models was 19,200 cfs, which was the average discharge from Lake Mead for the period July 1952 through June 1953.

A weir near the surface and a slot at middepth of the reservoir were used as the 2-dimensional models, and a single morning-glory spillway was used as the 3-dimensional model. The 3-dimensional model consisted of a 7½-degree sector of the reservoir around the morning-glory spillway. All three models had crest lengths of 500 feet.

The following conditions, necessary for the application of the electric-analogy technique, based upon a solution of Laplace's equation, were assumed for all three models: a homogeneous fluid possessing the same temperature, density, salinity, sediment content, and viscosity at all points. Furthermore, it was assumed that the reservoir remained at the same level and that the momentum of inflows did not carry through perceptibly to the point of discharge.

The results of this study are given in figures 41, 42, and 43. Streamlines of the flows have been drawn dividing the discharge into 12 equal increments. At some remote distance from the point of discharge the stream lines become parallel and divide the reservoir vertically into 12 equal tubes. As the reservoir depth decreases with distance upstream from the dam these tubes would remain 12 in number, but they would reduce proportionately in thickness as long as stillwater conditions prevailed in the reservoir.

Figures 41, 42, and 43 show lines of equal time distance of particles of water from the point of discharge. Analyses of these isochronic lines show how long it would take, after the start of discharge, for flow to come equally from all depths in the prototype. For the weir this elapsed time would be approximately 2½ hours. For the submerged slot at middepth of the reservoir this would be approximately 1½ hours. In the 3-dimensional model of the morning-glory spillway, the increments between isochronic lines are not equal and are indicated by relative values on figure 43. For the prototype dimensions and discharge used in this study, analyses show that about 8 hours would be required to establish equal flow from each depth in this morning-glory spillway.

The results of this electric-analogy study show that, except in the vicinity immediately adjacent to the spillway, the flow is essentially parallel and uniform in each of the three cases, with each of the stream tubes furnishing an equal volume of water regardless of its depth in the reservoir. The proportion of so-called surface layer of water to the total withdrawal from the reservoir would depend on the ratio of the depth of the surface layer to the total depth. Thus, in this electric-analogy model of Lake Mead, because the surface layer was taken to be one-twelfth of the total depth, this surface layer accounted for 8⅓ percent of the total discharge in each of the three models.

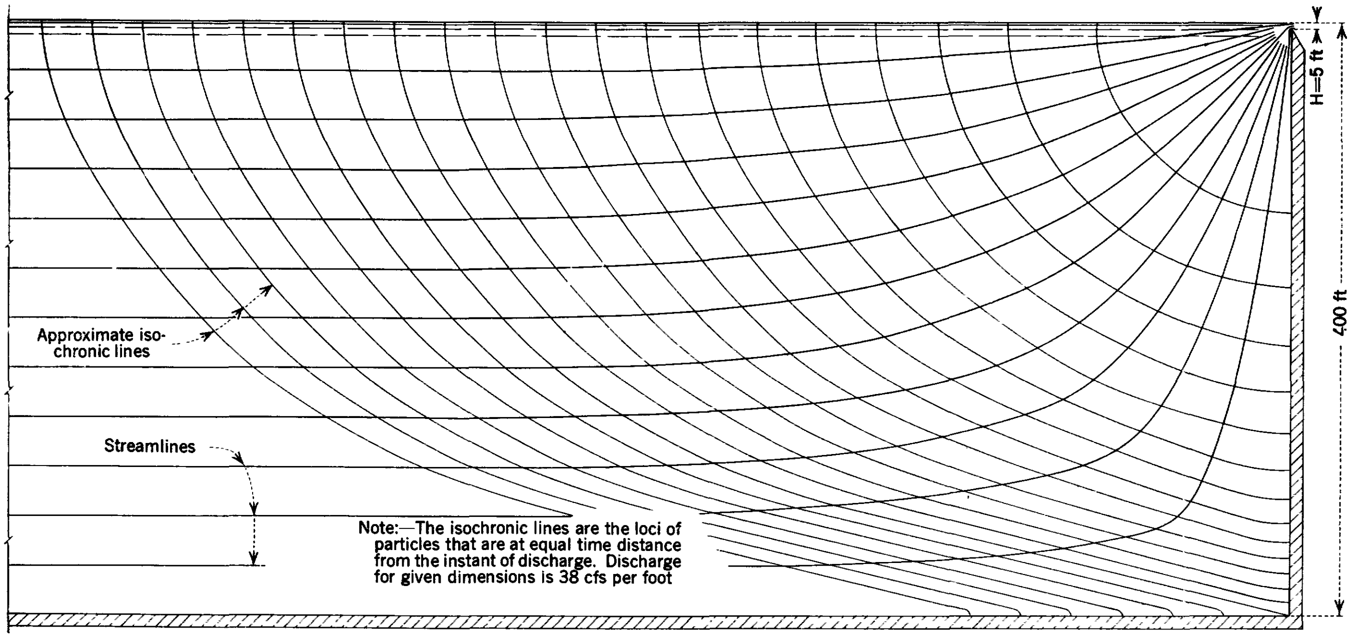

FIGURE 41.—Electric analogy tray study, two-dimensional flow diagram—discharge over a sharp-crested weir near the surface of a reservoir.

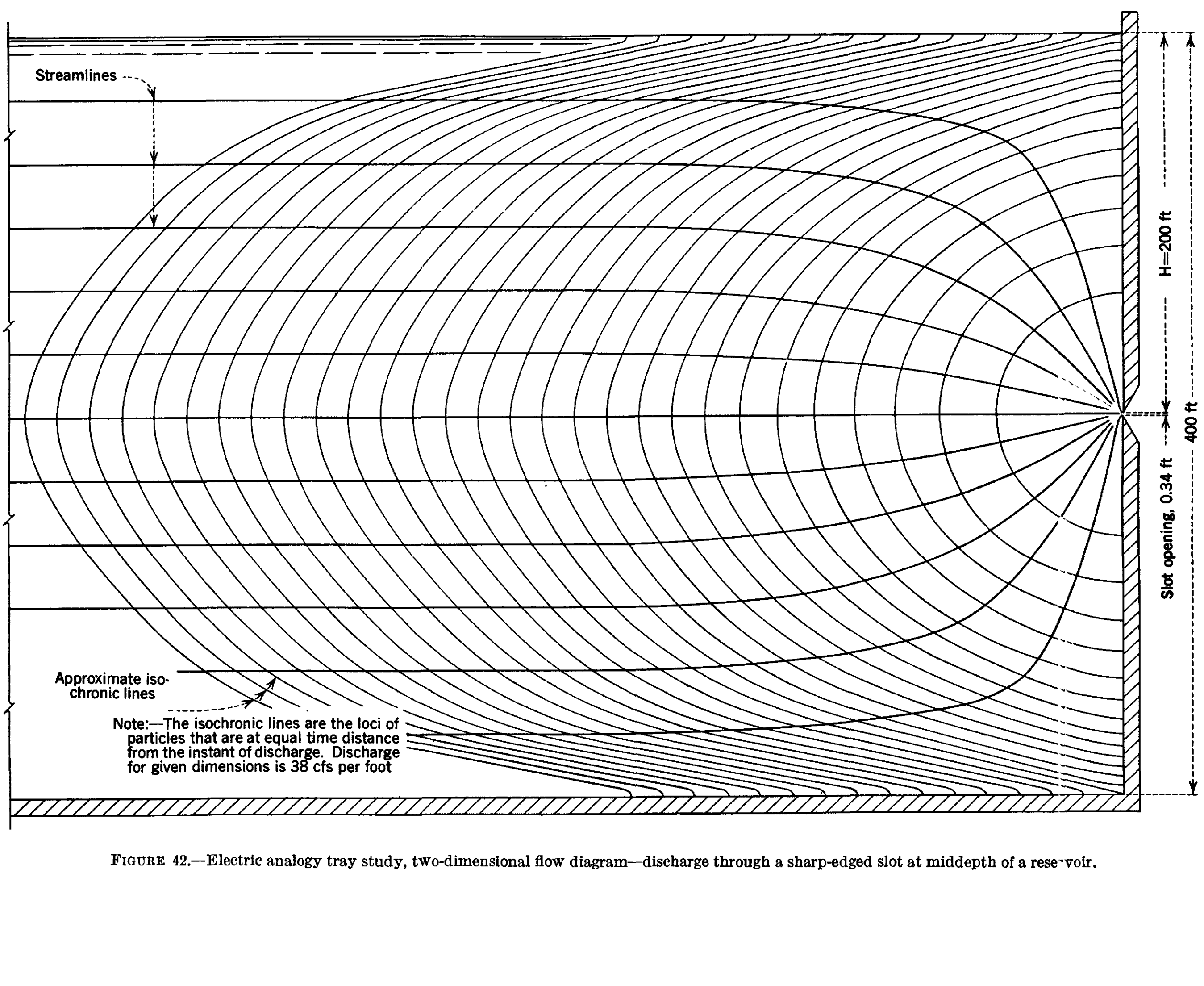

FIGURE 42.—Electric analogy tray study, two-dimensional flow diagram—discharge through a sharp-edged slot at middepth of a reservoir.

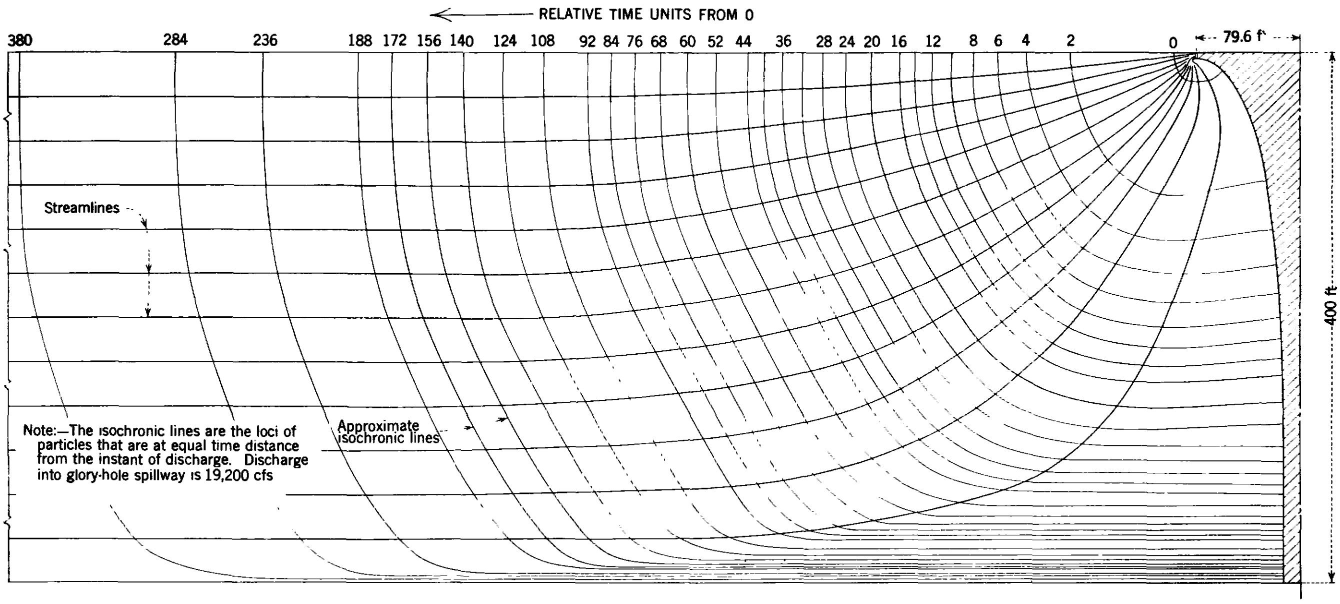

FIGURE 43.—Electric analogy tray study, radial flow pattern—discharge into a morning-glory spillway near the surface of a reservoir.

The three electric-analogy studies showed what would take place under the idealized conditions necessary for the application of that technique. It should be realized that the chances of all of the conditions being met, for any length of time, in an actual reservoir are somewhat remote. Differences with depth in density and viscosity are known to occur in reservoirs. Density differences may be due to temperature, salinity, or suspended load (turbidity).

In irrigation and water-supply reservoirs, density differences due to salinity vary with the seasons. Density differences due to turbidity are evanescent and, over long periods of time, can be considered to be minor. In reservoirs, differences in density are due predominantly to differences in temperature. Data from Lake Mead show how small these density differences are. For example, the average density profile, based on water temperatures at Lake Mead for the period July 9, 1952, to June 23, 1953, showed a variation of less than 0.15 percent from the surface to the bottom at approximately 400 feet, expressed relative to density at 4°C. Representation of such minute variations was not practicable in this electric-analogy study.

Viscosity differences, which are proportional to water-temperature differences would vary at Lake Mead by 21 percent from the surface to the bottom at about a 400-foot depth. Higher densities and higher viscosities would naturally be associated with the lower temperatures, usually found at greater depths. For the 1-year study period Lake Mead water temperatures averaged 68.4°F at the surface and 52.2° F at the bottom.

Anderson and Pritchard (1951) present a series of graphs of Lake Mead temperature and salinity distribution in relation to depth. These graphs show that temperatures are essentially isothermal (the range being less than 10°F) for the period about mid-December through mid-April, and that dissolved salt content shows but little variation with depth for the period mid-January through mid-May, at Hoover Dam and for Boulder Basin. Thus, insofar as density stratification is concerned, Lake Mead is essentially homogeneous during winter and early spring seasons, and the flow patterns as they were delineated in the electric analogy studies should be applicable.

During other portions of the year, Lake Mead departs from the severe conditions imposed for direct prototype interpretation of electric analogy models. During late spring, summer, and early autumn, changing air temperatures and the spring flood season inflow, with changing water temperatures, salinities and turbidities, result in density currents, which produce at times a very complicated density structure of the lake.

A distinction should be kept in mind between density stratification of still water and density currents. Bell (1942) has defined a density current as a gravity flow of a liquid or a gas through, over, or under a fluid of approximately equal density. A general discussion of density currents, including descriptions of specific observations of density currents is given by Lane and Carlson (1954), and Gould (in Smith, Vetter, Cummings and others, in preparation) has given a detailed discussion of density currents in Lake Mead.

Although under special conditions a current's density may be due only to its suspended load, as a rule its characteristic density is the result of a combination of turbidity, salinity, and temperature.

Most of the turbidity currents that were observed to reach the western part of Lake Mead occurred during the first 7 years of the life of the reservoir, when the original channel of the Colorado River was still well defined under the waters of the reservoir. Sediment deposits in this channel have caused the density currents to spread out into thinner layers. The increased area of the interface has resulted in reduced velocities and increased opportunities for desilting and diffusion so that, as the reservoir matures, density currents become less and less capable of reaching Hoover Dam. Lane and Carlson refer to a similar progression at Elephant Butte Reservoir, in which density currents were observed first in 1917.

This subject was investigated in detail by the Subcommittee on Lake Mead of the Interdivisional Committee on Density Currents of the National Research Council. Figures 87 to 92 of volume 2 of their report (Natl. Research Council, 1949) show density-current flows through Lake Mead. The first three of these figures show inflows that have densities greater than those of the lake, moving along the bottom. Figures 90, 91, and 92, for the periods June 20–28, 1935, April 30–May 5, 1940, and May 21–June 7, 1940, respectively, show inflows of densities less than those of the lake, moving at the surface. Pages 899 to 904 of volume 3 show that beginning with 1941 the rate of flow of density currents became so slow as to be below the limit of measurement downstream from mile 335, Boulder Canyon. At mile 354.7, between the intake towers at Hoover Dam, the differences in density observed as the inflows moved toward the dam have been reduced greatly. Three of the flows (for the periods April 21–May 1, 1942, February 19–28, 1945, and March 18–23, 1946, shown on pages 900, 903, and 904, respectively) resulted in an almost homogeneous condition at mile 354.7.

Anderson and Pritchard (1951, page 53) state that—

> Virgin Basin acts as a large "mixing bowl" in which the large seasonal variations in salinity of the inflowing Colorado River waters are smoothed to nearly their mean value. Below Virgin Basin the water is nearly uniform with respect to salinity.

This information leads to the conclusion that Boulder Basin of Lake Mead is characterized chiefly by density stratification rather than by density currents, and that the lake as a whole, as described by Anderson and Pritchard, exhibits certain broad circulation patterns characteristic of various parts of the lake for various reasons, insofar as can be determined with the currently available techniques. Furthermore, it is concluded that, during part of the year at least, the density stratification of Boulder Basin is due chiefly to temperature rather than salinity or turbidity.

Returning to the results of the electric-analogy studies, figure 42 showed that all the reservoir contributed to the sharp-edged slot at middepth. It will be recalled that the electric analogy assumed a homogeneous reservoir. Would the flow pattern of figure 42 develop in a reservoir possessing a density stratification? In regard to this question, the Cooperative Hydraulics Laboratory, U. S. Soil Conservation Service, and the California Institute of Technology produced a film—No. Aa–1–II–D, dated 1947—entitled "A Laboratory Demonstration of Density Currents." Several sequences in this film show a release from a glass-walled model of a reservoir in which a density stratification had been established. There is to be seen clearly a convergence from both above and below of strata having densities different from that of the stratum at the level of the orifice through which the drawdown was taking place.

It can be reasoned that, in the presence of density stratification, there could be expected a difference in the response and in the proportionate contribution of density layers. The heavier layers near the bottom of the reservoir would require a greater lifting force than would be the case in a homogeneous reservoir. As the amount of drag exerted between two layers is related to their viscosities, the resistance to uplift or convergence exhibited by a reservoir that is stratified by densities primarily due to temperature would be influenced also by the viscosities corresponding to those water temperatures.

Our search for an understanding of the withdrawal of water from a reservoir is affected by still another complicating factor: the rate of change of water temperature in relation to rate of flow within the reservoir, both horizontally and vertically. Figure 41 of the electric-analogy studies shows a division of the stream tubes by the isochronic lines, such that the areas of all divisions are equal. The shape of the isochronic lines shows that the distances to be traversed by a unit quantity of water from lower depths are shorter than at the surface, which means that rate of flow of unit quantities at greater depths is lower than at the surface. As the unit quantities from lower lying layers rise slowly toward the surface, they attain levels that are characterized during most of the year at Lake Mead, by higher temperatures. As mentioned previously, a rise in temperature is accompanied by a decrease in viscosity, which results in lessening the difference between surface and lower layers.

The velocities of unit quantities impelled by the withdrawal are not the only velocities which that unit quantity may possess, as it may be subjected at various times to velocities, possibly possessing an opposite algebraic sign, that are due to the general seasonal circulation pattern of the reservoir, and, if near the surface, to wind effects. Whatever all other velocities may be, it is clear that there must be an average net velocity of the reservoir sufficient to supply the volumes of water demanded by the rate of withdrawal.

A transect was drawn on a topographic map of Boulder Basin on a bearing of N. 60° E. and passing through the point, latitude 36° 04′, longitude 114° 45′. The length of this transect at water surface elevation 1,174 feet was about 5.5 miles, by no means the greatest distance across Boulder Basin. The cross-sectional area of the water, above the sediment deposit as determined by the Comprehensive survey of sedimentation in Lake Mead 1948–1949, (Smith, Vetter, Cummings and others, in preparation) was determined below elevation 1,174, the average Lake Mead elevation for the period of the study. In order to supply the 19,200 cubic feet per second being withdrawn, the average velocity of the flow at that transect would be 0.002 foot per second. This rate of flow should be taken into account in relation to the rate of heating of the unit quantities as they converge to the point of discharge.

An assumption used in this electric-analogy study was that the approach channel to the weir and to the submerged slot was straight and rectangular in cross section. Both of these assumed characteristics are approximated at Hoover Dam by Black Canyon, which is immediately upstream from the dam. The morning-glory spillway was assumed to be in the center of a circular basin.

In the weir and in the submerged slot, convergence of flows was assumed to take place only vertically. In the morning-glory spillway, both lateral and vertical convergence would take place. However, in order to sustain the rate of discharge, 19,200 cfs, there would have to be both lateral and vertical convergence within Boulder Basin to supply flows to Black Canyon and thence to Hoover Dam.

In view of the complexity of the system, it is doubtful that that a conception anywhere near the truth is attained by attempts to infer what the sources within the reservoir are that make up the withdrawal, using temperature of the waters as the single index of their sources. If a radioactive-tracer technique were to be developed and applied to a large reservoir, it might be possible to ascertain the makeup of reservoir withdrawals.

Muskat (1946) develops the general relations for the classical hydrodynamics of flow, wherein pressure gradients, external body force, and internal resistive forces of the fluid are all considered. He concludes his discussion with the following statement (p. 127):

> . . . Even a cursory inspection of treatises on hydrodynamics will disclose that except for certain cases of relatively simple geometry the mathematical difficulties in the solution of the classical equations are quite unsurmountable . . .

However, some qualitative idea of the nature of the interactions in a reservoir possessing a stratification in both density and viscosity might be attained through carefully designed model investigations, without attempting immediately the ultimate in rigorous mathematical solutions. Model-prototype comparisons of the results of such studies would be informative.

In summary, field experience, practical observation, and all of the very limited literature, computations, and model studies available to us up to the time of writing indicate that, once a steady state is established, the withdrawals of water from a reservoir consist of contributions from the whole of the reservoir, yet it appears reasonable to infer that, in a reservoir possessing density stratification and a circulation pattern, there would be some unknown departure in the proportionate contribution of the various layers as compared with the equal contributions from all layers under homogeneous reservoir conditions, and that the contribution of the topmost layer would be far greater than indicated for the homogeneous condition for weir discharges and less than indicated for submerged slots.

ENGINEERING ASPECTS OF WITHDRAWALS FROM THE SURFACE OF A RESERVOIR

Assuming that density stratification might favor an increased proportional contribution from the surface layers, it seems reasonable to suppose that an increase in length of weir and a reduction in the head on the weir would yield an outflow containing more of the surface waters.

One way of increasing the length of a weir is to use a morning-glory spillway which does not depend upon the dimensions of the dam or upon topography at the dam site for allowable crest length. The use of a number of morning-glory spillways would make it possible to reduce the time of travel of surface waters to the points of outflow, thus tending to reduce the rise of temperatures of the surface waters. As shown in figure 43, the ever-expanding hemisphere supplying the volume of flow results in a reduction of velocities of unit quantities, so that at some distance the outflow velocities of surface waters become imperceptible.

The pursuit of this concept leads to the consideration of a system of morning-glory spillways, each of which would be, in effect, a hydrodynamic sink. The effect of adjoining sinks is to change the equal potential surfaces from hemispheres to oblate spheroids, then to disks, as the vertical distance from the sink is increased. The change in isochronic lines may be obtained from figure 43 by rotating the pattern 90 degrees counterclockwise. After rotation, the water surface of the drawing becomes the vertical axis of the sink, and the reservoir bottom becomes the vertical line of symmetry between adjacent sinks, which would need to be 800 feet apart. Such a system of sinks would result in increasing the ratio of waters from the top 25 feet to total withdrawal from about 8 to about 10 percent, in a homogeneous reservoir.

As the practical problems involved in the accomplishment of such a system of morning-glory spillways, adjustable over an operating range of 100 feet or more and connected by a system of insulated conduits to supply the penstocks, are fantastic in relation to the very small gain in theoretical effectiveness, the remoteness of economic feasibility of such an approach becomes evident.

It should be recalled that the withdrawal over a weir would, under homogeneous reservoir conditions, discharge only part of the surface layer in the outflow. As discussed previously, it is reasonable to expect that in a density-stratified reservoir, the actual contribution of the surface layer might be greater. In the absence of techniques capable of yielding a quantitative answer as to the temperature of the water which would remain in the lake if all withdrawals were made with weirs at the surface, and in view of the fact that the relation of water temperature to evaporation is nonlinear, no attempt is made to express just what fraction of the theoretical saving might be attained in actual practice.

For a reservoir in the design stage, it might be feasible to consider construction of several types of discharge structures for withdrawal near the surface. A series of intake towers might be built with provision through numerous gates for withdrawal at any desired reservoir level, from the maximum reservoir surface elevation downwards.

A series of drum gates, or some similar type, could be installed to perform as a series of weirs. Such gates or systems of gates would need to span the operating range of elevations of the reservoir, and there would have to be a collection system to convey the overflow of the weir system to the outlet works or to the powerplant. There would have to be provision for the collection of surface floating debris to provide for the protection of turbines and other structures, a problem that is simplified by installation of subsurface intakes.

During those times of the year when the reservoir would be homogeneous with respect to temperature, no appreciable reduction of evaporation loss can be expected to result from withdrawals over a surface weir, in contrast to withdrawals from lower depths.

Whatever saving is attained at one reservoir would not be a net saving. If surface waters from a reservoir were to be discharged into the downstream reaches, evaporation in those reaches (including any reservoirs) would be increased because of higher water temperatures.

WITHDRAWALS FROM LAKE MEAD

Discharges from Lake Mead are usually made through four towers which take the water to the powerplant and to a series of valves. Except during unusual floods, nearly all outflow from Lake Mead goes through the powerplant. Each of the four intake towers has two gates for withdrawing water. The plan for operation of the outlet gates at Hoover Dam, which has been followed, provided for releasing all water through the upper gates in the intake towers (sill elevation 1,045 feet) when the surface of Lake Mead was above elevation 1,175 feet, and for the use of the lower gates (sill elevation 895 feet) only whenever the surface of Lake Mead was below elevation 1,175 feet. The fourth and last of the lower intake tower gates was scheduled for modification in the fall of 1955 to permit operation of the lower gates under full reservoir pressure. When this has been accomplished, it is contemplated that all future releases of water for power will be made through the lower gate openings.

Considerations influencing the adoption of the plan to make future water releases through the lower gates include the following:

1. The water used for cooling the generator and transformer equipment at Hoover Dam is drawn from the tailrace and penstocks. Experience gained when the upper gates have been in use indicates that the warmer water (at about 64°F as compared with about 54°F when the lower gates are in use) caused a noticeable reduction in cooling efficiency. If water in the penstocks were to be drawn from the surface of the lake, supplemental cooling equipment would be required in some instances where present cooling equipment cannot accommodate a larger quantity of cooling water, to avoid reduction of the electrical capacity of the generators and transformers. An alternative arrangement would be to provide a separate source of cooling water from lower levels of the lake.

2. Experience gained in 1949 and in 1952, when only the upper gates were used for extended periods, indicates that sediment is deposited around the lower gates and in the seats of the lower bulkhead gates in sufficient quantity to cause difficulty in the seating of bulkhead gates. It is therefore believed likely that

the lower gates might be rendered inoperative if they were not used for an extended period.

3. Many complaints have been received from personnel of the Fish and Game Commission of Nevada and other sportsmen's groups, and from fishermen interested in the Colorado River downstream from Hoover Dam, after the change in use of the lower to the upper gates was made, because of alleged injurious effects upon trout below Hoover Dam. That change resulted in an increase in the water temperature below Hoover Dam of 8° to 10°F. Prolonged release of warm water could conceivably result in elimination of trout from the upper reaches of Lake Mohave. Additional evidence of the effect on fish life of change in water temperature downstream from dams is the fact that release of water from Shasta Lake, on the Sacramento River in California, at much lower temperatures than those which prevailed before the dam was built, has resulted in a substantial increase in the salmon run.

The results of the Lake Hefner studies (U. S. Geol. Survey, 1954a) and of the Lake Mead water-loss investigation, which is described in this report, all indicate very clearly that most efficient storage, insofar as evaporational loss is concerned, is in reservoirs having a minimum of exposed surface area in relation to volume of water in storage. Project planners, although recognizing that this is but one element to be considered in the over-all project plan, strive to select those reservoir sites which will give the largest volume of storage coupled with the smallest exposed surface area.

However, practically no freedom of action is available to the Bureau of Reclamation to reduce appreciably by reservoir operation the magnitude of evaporation losses from Lake Mead, owing to the nature of the reservoir and the facilities available at Hoover Dam, and owing to the multiple-purpose demands upon the waters discharged from this reservoir. The suggestion might be made to draw the reservoir down at an accelerated rate during low-temperature periods in order to have a lower level with a smaller exposed area during the hottest part of the year. Such an operation would be in direct conflict with the cyclic-carryover storage concept upon which the reservoir was built, as the capacity of Lake Mead exceeds twice the available annual inflow of the Colorado River during recent years.

Anderson and Pritchard (1951, Appendix F, p. 101–153) present temperature and salinity data for 12 cruises. Their report includes a detailed description of the circulation in Lake Mead for each of the cruises. Howard (in Smith, Vetter, Cummings, and others, in preparation) gives the salinity data for the Colorado River below Hoover Dam for 8 of those cruises. Water-temperature data for the Colorado River below Hoover Dam are available in the Bureau of Reclamation's operational records of the Boulder Canyon Project. Data pertaining to only 4 of the cruises—III, VI, VIII, and X—were found to be sufficiently complete for use in an analysis aimed at finding the source of waters being withdrawn from Lake Mead. Only the data at Hoover Dam, identified as cruise station 1, about 300 feet upstream from the dam, were used.

Anderson and Pritchard's temperature data, obtained in depth from one lowering, in general are given by 25-foot intervals for the first 100-foot depth and by 50-foot intervals below 100 feet. Their salinity data, expressed as parts per million (ppm), are given usually for six depths not corresponding, in most cases, to the depths of the temperature data. For this analysis, as the maximum depths of the data were around 440 feet, the reservoir was considered as being made up of 11 layers, each 40 feet deep. Anderson and Pritchard's data were plotted on figure 44, the curves of which were used to yield interpolated data at the middepth of each of the 11 layers, on the assumption that the middepth value would best express the characteristic of each layer. Anderson and Pritchard's data and the interpolated value for temperature and salinity are given in table 27.

The assumptions underlying this analysis are the same as those used in the electric analogy study, principally that the reservoir is homogeneous and that withdrawal is from still water at constant level. Under such conditions the flow pattern, neglecting lateral convergence to the point of discharge, should be that shown in the electric analogy figure 42 for the submerged slot. In that case, the outflow should be the average of 11 layers, all of which, in a rectangular section, would be making equal contributions to the outflow.

The results given in table 27 are discussed by cruises:

Cruise III, April 28, 1948. Transitional winter-to-spring lake condition. Lower intakes.—The average of the interpolated salinites was 682 ppm, assuming that all layers contributed equally to the outflow. The salinity value corresponding to the depth of the point of withdrawal was interpolated as being 689 ppm. However, the observed salinity of the outflow was 666 ppm, a value that is less than any of the samples taken above Hoover Dam, thus rendering this result inconclusive. The computed average temperature was 53.2°F, the observed outflow temperature was 53°F. Temperature corresponding to depth of withdrawal was 51.7°F. This would indicate mixing of contributions from various layers, with shallower depths contributing more than their expected proportion.

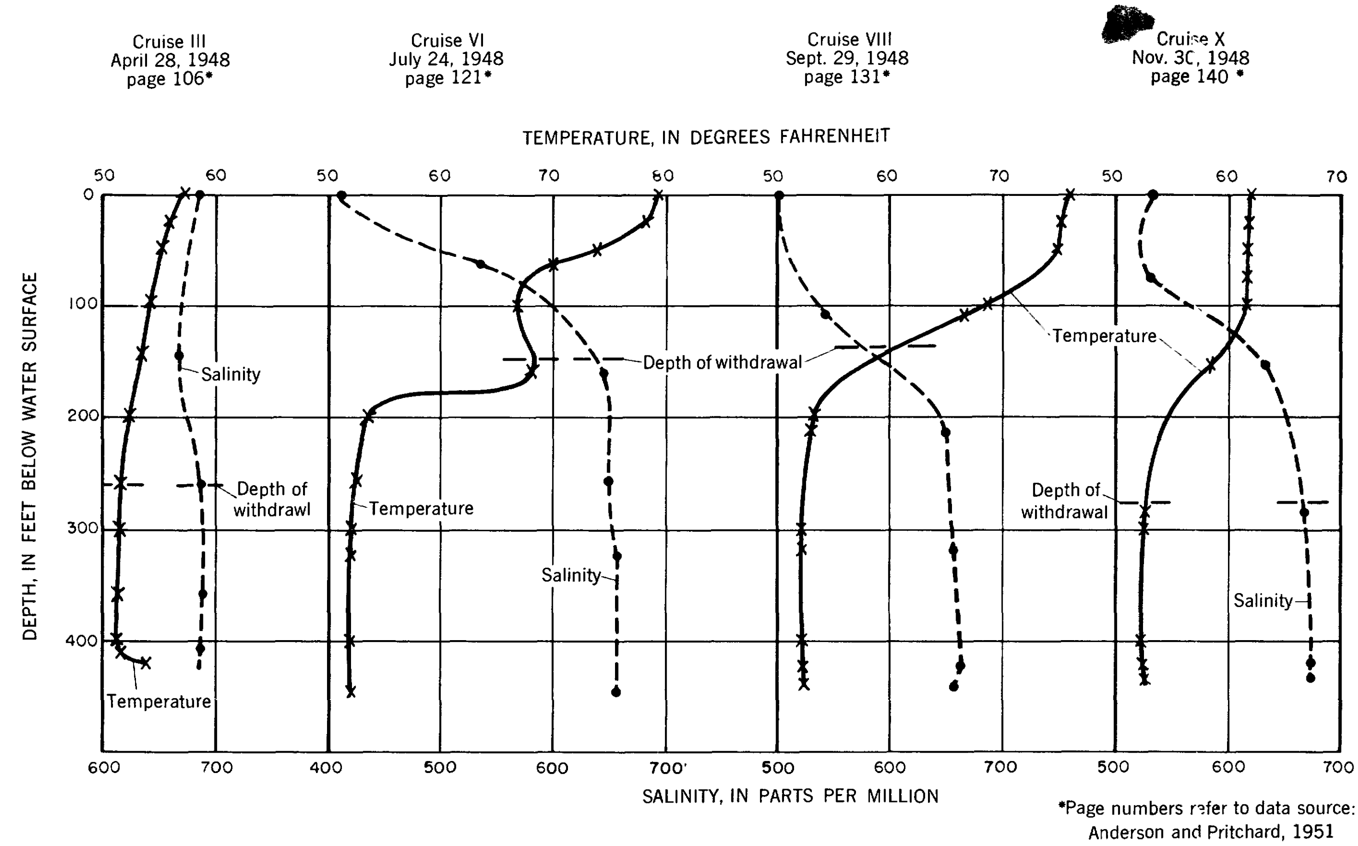

FIGURE 44.—Temperature and salinity, Lake Mead, at station 1, Hoover Dam.

Cruise VI, July 24, 1948. Transitional spring-to-summer lake condition. Upper intakes. The average of the interpolated salinities was 614 ppm. The observed outflow salinity was 646 ppm, and the salinity interpolated at level of discharge was 637 ppm. The average of the interpolated temperatures was 59.6°F, the observed temperature was 61°F, and the temperature at depth of withdrawal was 68°F. This cruise would indicate a greater proportionate contribution from the layers of higher salinity, and almost equal contribution from all layers insofar as temperature might be an index.

Cruise VIII, September 29, 1948. Summer lake condition. Upper intakes. The interpolated average salinity, 611 ppm, and the observed salinity, 612 ppm, are about equal, although the close agreement is no doubt coincidental. As the interpolated salinity at the level of withdrawal was 577 ppm, this would indicate that all levels from the reservoir are contributing equally to the outflow. The average of the interpolated temperatures is 58.9°F, observed outflow was 64°F, and temperature at level of withdrawal was 61°F. This could mean that the surface layers were contributing more than their proportionate share of the outflow.

Cruise X, November 30, 1948. Fall lake condition. Lower intakes. The observed outflow salinity was 678 ppm, whereas the average of interpolated salinities was 625 ppm and that of level of withdrawal was 665 ppm. This would indicate a greater-than-average contribution from the lower lying, more saline layers of the lake. The average of interpolated temperatures was 56°F; observed outflow temperature was 52°F, and that of level of withdrawal was 52.7°F. This would indicate the same trend as the salinity contributions for this cruise—that lower layers are giving a little more than their expected share.

The change of temperature of about 9 degrees when discharges are changed from one level to the other at the intake towers appears to depend, in the analysis of these four cruises, upon the temperature profiles of the lake. However, it has been observed that a change of temperature takes place with changes of intake level even when the reservoir temperature profile is changing very slowly. No exact explanation can be given for this now, though it indicates that contributions to the outflow are not exactly in accordance with hydrodynamic concepts, the denser layers near the bottom contributing more than their expected share.

TABLE 27.—*Salinity and temperature characteristics of withdrawals from Lake Mead in 1948, at station 1, Hoover Dam*

Analysis of data

[Observational data from Anderson and Pritchard, 1951, appendix F]

Nominal depth below water surface (feet)	Cruise III, April 28						Cruise VI, July 24						Cruise VIII, September 29						Cruise X, November 30					
	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated
	Depth (feet)	Salinity (ppm)	Salinity (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Salinity (ppm)	Salinity (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Salinity (ppm)	Salinity (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Salinity (ppm)	Salinity (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)
0	0	687		0	57.3		0	411		0	79.3		0	502		0	76.0		0	532		0	61.9	
20			684	25	56.1	56.3			432	225	78.2	78.5			503	25	75.3	75.4			522	25	61.8	61.8
60			677	50	55.6	55.2	62.5	534	530	50	73.7	70.7			515	50	75.1	74.3			524	50	61.6	61.6
100			672	100	54.4	54.4			597	62.5	70.0	66.9	108.5	544	538	100	68.7	68.7	75	530	565	75	61.6	61.5
140	146	669	669	146	53.8	53.9	160	645	634	100	66.9	68.0			582	108.5	66.8	60.0	154	632	620	100	61.5	59.5
180			672			52.8			647	160	68.1	57.5			632	200	53.4	54.4			644	154	58.4	55.9
220			682	200	52.5	52.2			648	200	53.5	53.2	213.5	652	652	213.5	53.2	53.0			655	200	54.6	53.7
260	261	689	689	261	51.7	51.7	256	649	649	256	52.6	52.6			655	300	52.2	52.5			663	285	52.5	52.9
300			690	300	51.6	51.6			653	300	52.2	52.2	318	658	657	318	52.4	52.4	285	667	668	300	52.4	52.4
340			690	359	51.5	51.5	321.5	656	656	321.5	52.2	52.1			660	400	52.3	52.2			671	400	52.2	52.3
				400	51.3																			
380	359	690	688	408	51.5	51.3			656	400	51.9	52.0	423	665	663	423	52.3	52.2	420	674	673	420	52.4	52.2
420	408	687	686	421	53.9	53.9	446	655	655	446	51.9	51.9	439.5	658	665	439.5	52.4	52.3	433	674	674	433	52.4	52.4

Evaluation of results

[Salinity observations from Smith, Vetter, Cummings and others, (in preparation); temperature observations from U. S. Bureau of Reclamation reports]

	Cruise III April 28		Cruise VI July 24		Cruise VIII September 29		Cruise X November 30		Averages			
									Cruises III and X (lower intakes)		Cruises VI and VIII (upper intakes)	
	Salinity (ppm)	Temperature (°F)	Salinity (ppm)	Temperature (°F)	Salinity (ppm)	Temperature (°F)	Salinity (ppm)	Temperature (°F)	Salinity (ppm)	Temperature (°F)	Salinity (ppm)	Temperature (°F)
Average of interpolated data, assuming equal contribution from all layers in reservoir	682	53.2	614	59.6	611	58.9	625	56.0	654	54.6	612	59.2
Observed data at outflow below Hoover Dam	666	53	646	61	612	64	678	52	672	52.5	629	62.5
Observed elevation of Lake Mead surface feet	1158.3		1191.45		1181.03		1171.05					
Depth of water at point of withdrawal, over active intake tower sill feet	263.23		146.45		136.03		276.05		269.64		141.24	
Interpolated value at point of withdrawal	689	51.7	637	68.0	577	61	665	52.7	677	52.2	607	64.5

A comparison of the averages of temperatures for cruises III and X when the lower intakes were in use, and cruises VI and VIII when upper intakes were in use, shows no great differences, though the average head of water for the operation of the lower intakes was 270 feet as compared with the head on the upper intakes of 141 feet. From the temperature data, one could draw two conclusions: (1) that all levels contributed almost equally, or (2) that all withdrawals come from only one layer at the level of withdrawal. In the light of the discussion of hydrodynamics presented previously in this chapter and the model studies performed at the California Institute of Technology, the second conclusion seems hardly tenable. The averages of salinity for the two groups are of no help in indicating a trend.

There is a possibility that the data gathered at Hoover Dam might not be indicative of the pattern of the outflow from the reservoir because of the proximity of the points of sampling to the outflow structures. To investigate this, temperature data for station 2, at the upstream end of Black Canyon, for cruises III, VI, VIII, and X were analyzed in the manner of the data for station 1, described in detail in the preceding paragraphs. Station 2 data are plotted on figure 45, and the analyses are given in table 28. The results are about the same as for station 1, with the exception of cruise VI, for which there was a considerable temperature difference with depth in the upper 200 feet of the reservoir. This difference apparently was due to a local circulation pattern, rather than to convergence of streamlines.

The reports on the Lake Mead density currents investigations present voluminous data on temperatures in Lake Mead. Table 29 gives analyses for 5 samplings in 1943 and 1944, when Lake Mead was full, at elevations of about 1,200 feet. Three of the samplings were made at Hoover Dam, mile 354.7, in 1943; 2 samplings were made at mile 353.5, about 1 mile upstream from the dam in 1944. Concurrent data are not available for both of these sampling stations. Temperature and bicarbonate content data, where available, are plotted on figure 46. The results of these analyses are on the same order as were those of the cruises. Again there is no difference between the meaning of the analyses at mile 354.7 and those at mile 353.5.

TABLE 28.—*Temperature characteristics of withdrawals from Lake Mead, in 1948, at station 2, Black Canyon*

Analysis of data
[Observational data from Anderson and Pritchard, 1951, appendix F]

Nominal depth below water surface (feet)	Cruise III, April 28			Cruise VI, July 24			Cruise VIII, September 29			Cruise X, November 30		
	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated
	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Temperature (°F)	Temperature (°F)
0	0	57.3		0	80.6		0	76.6		0	62.0	
20	25	56.3	56.6	25	78.7	79.0	25	75.1	75.4	25	61.5	61.6
60	50	54.6	54.4	50	76.8	74.4	50	74.8	73.6	50	61.5	61.5
100	100	54.1	54.1	100	67.1	67.1	100	68.4	68.4	100	61.5	61.5
140			53.5			61.0			62.5			58.6
180	200	52.9	53.0	200	53.6	55.9	200	53.5	56.5	200	54.3	55.8
220			52.5			53.1			53.2			54.0
260			51.9			52.6			52.7			53.2
300	300	51.4	51.4	300	52.2	52.2	300	52.0	52.0	300	52.5	52.5
340			51.3			52.0			51.9			52.3
380	400	51.2	51.2	400	51.9	51.9	400	51.7	51.7	400	52.0	52.1
420	429	51.2	51.2	450	51.9	51.9	442	51.7	51.7	427	52.0	52.0

Evaluation of results
[Additional data from U. S. Bur. Reclamation reports]

	Cruise III, April 28	Cruise VI, July 24	Cruise VIII, September 29	Cruise X, November 30	Averages: Cruises III and X (lower intakes)	Averages: Cruises VI and VIII (upper intakes)
Average of interpolated data, assuming equal contribution from all layers in reservoir °F	52.8	59.2	59.0	55.9	54.4	59.1
Observed data at outflow below Hoover Dam °F	53	61	64	52	52.5	62.5
Observed elevation of Lake Mead surface feet	1,158.23	1,191.45	1,181.03	1,171.05		
Depth of water at point of withdrawal, over active intake tower sill feet	264	146	136	276	269.64	141.24
Interpolated value at point of withdrawal °F	51.9	60.3	63	53	52.4	61.6

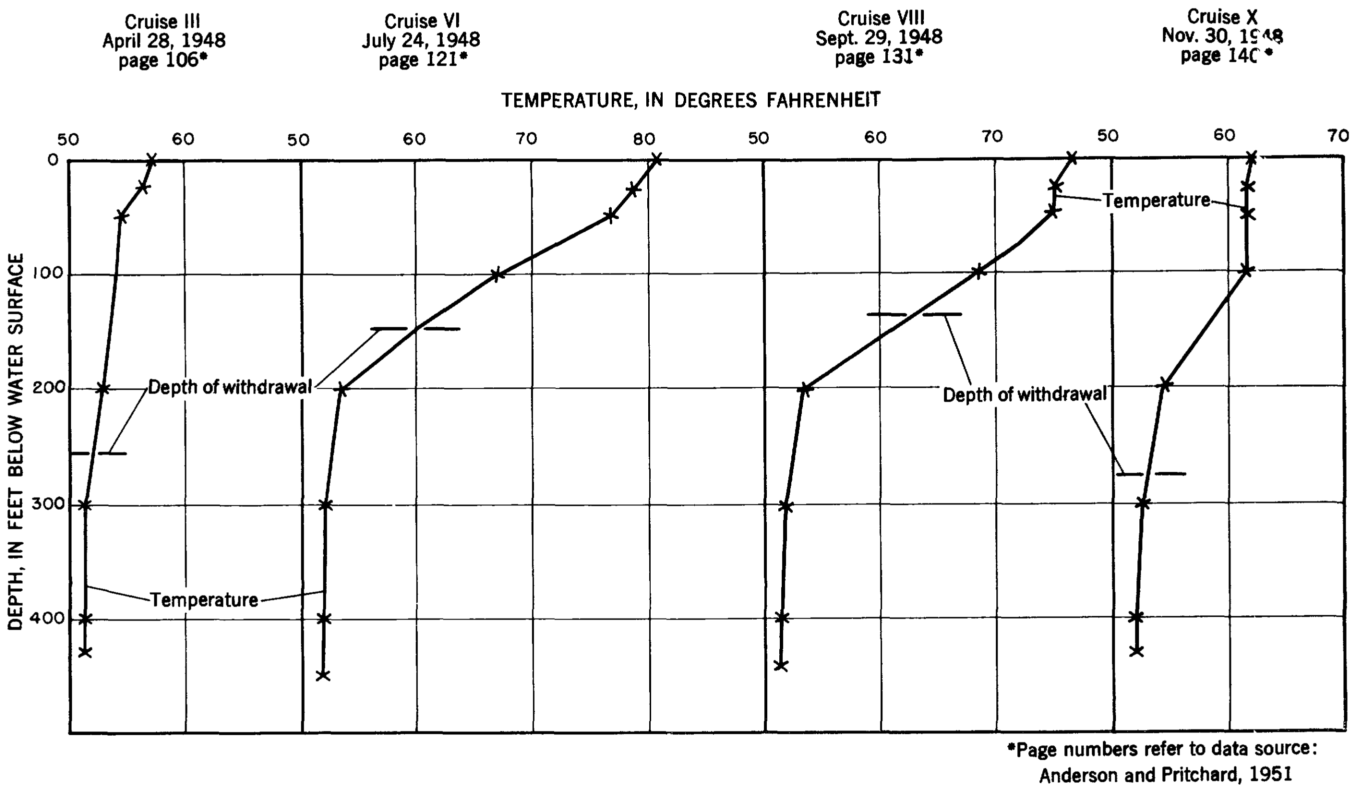

FIGURE 45.—Temperature and salinity, Lake Mead, at station 2, Black Canyon.

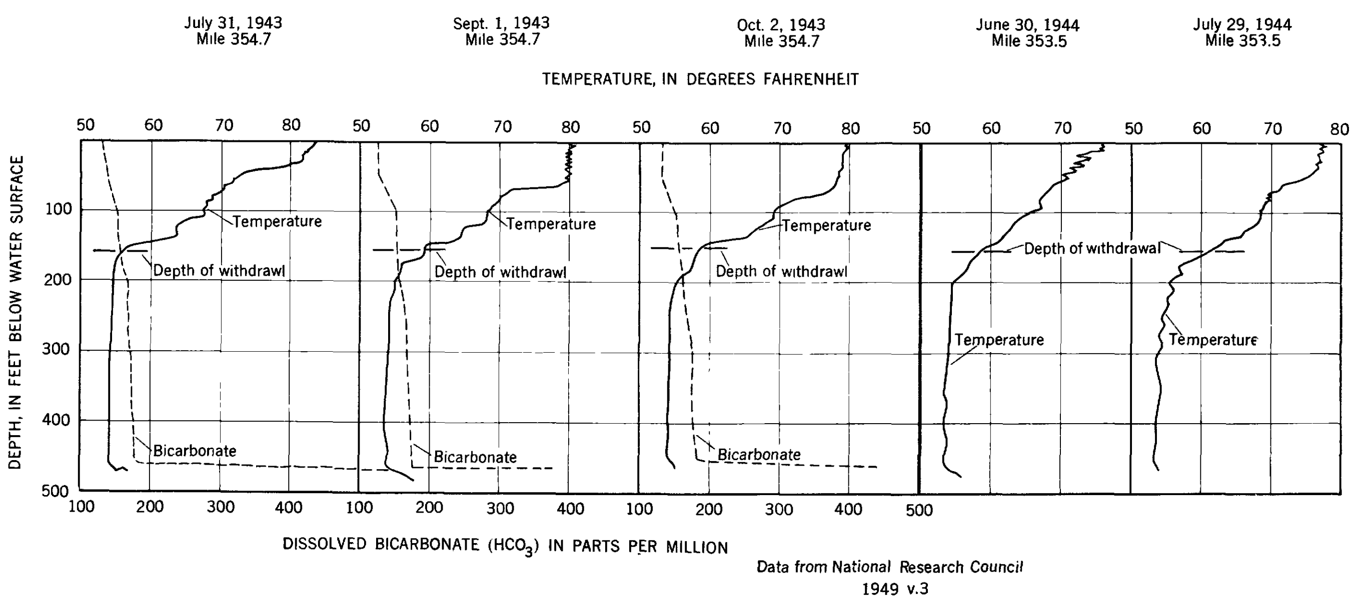

FIGURE 46.—Temperature and dissolved bicarbonate, Lake Mead, at mile 354.7, Hoover Dam, and mile 353.5, Black Canyon.

TABLE 29.—*Temperature and dissolved bicarbonate characteristics of withdrawals from Lake Mead in 1943 and 1944, at mile 354.7, Hoover Dam, and mile 353.5, Black Canyon*

Analysis of data

[Observations of temperature, taken from National Research Council, 1949, Lake Mead density currents investigations, V. 3; of bicarbonate composition, from U. S. Geological Survey Water Supply Paper 970 or 1022]

Nominal depth below water surface (feet)	Mile 354.7																		Mile 353.5					
	July 31, 1943						September 1, 1943						October 2, 1943						June 30, 1944			July 29, 1944		
	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated	Observed		Interpolated
	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Bicarbonate (ppm)	Bicarbonate (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Bicarbonate (ppm)	Bicarbonate (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Bicarbonate (ppm)	Bicarbonate (ppm)	Depth (feet)	Temperature (°F)	Temperature (°F)	Depth (feet)	Temperature (°F)	Temperature (°F)
0	0	83.6	-----	5	132	-----	0	80.2	-----	5	126	-----	0	79.3	-----	5	133	0	0	75.8	-----	0	76.8	-----
20	20	81.7	81.7	-----	-----	134	20	79.6	79.6	-----	-----	126	20	79.1	79.1	-----	-----	133	20	74.2	74.2	20	76.8	76.8
60	60	71.7	71.7	50	139	140	60	78.8	78.8	50	127	132	60	77.9	77.9	50	133	135	60	69.0	69.0	60	71.7	71.7
100	100	67.6	67.6	100	152	152	100	68.1	68.1	100	151	151	100	69.2	69.2	100	151	151	100	65.1	65.1	100	68.5	68.5
140	137	63.8	61.5	150	155	154	133	64.6	63.8	150	155	153	150	58.7	62.5	150	159	156	137	61.8	61.2	140	63.2	63.2
180	175	55.2	54.9	-----	-----	160	175	56.0	56.0	-----	-----	156	175	57.7	57.7	-----	-----	160	170	56.6	56.3	175	56.9	57.1
220	225	54.5	54.5	200	166	167	225	54.6	54.7	200	159	162	225	54.6	54.6	200	162	164	225	54.2	54.2	225	55.0	55.4
260	250	54.3	54.3	250	168	169	263	54.3	54.3	250	166	167	250	54.4	54.3	250	169	168	263	53.9	54.0	275	54.0	54.2
300	300	54.2	54.2	300	172	172	300	54.3	54.3	-----	-----	169	300	54.3	54.3	300	177	177	300	54.0	54.0	300	54.1	54.1
340	350	54.2	54.2	350	174	173	337	54.2	54.2	-----	-----	170	350	54.2	54.2	350	174	174	338	53.9	53.9	350	54.2	54.0
380	375	54.2	54.2	400	176	175	375	54.1	54.1	-----	-----	173	375	54.2	54.2	-----	-----	176	375	53.8	53.8	375	53.6	53.8
420	425	54.1	54.1	450	178	176	425	53.9	53.9	465	178	175	425	54.1	54.1	400	178	178	425	53.8	53.6	425	53.6	53.6

Evaluation of results

[Observations below Hoover Dam, of temperature, taken from National Research Council, 1949, Lake Mead density currents investigations V. 3; of bicarbonate composition, from U. S. Geol. Survey Water-Supply Paper 970 or 1022]

	Mile 354.7						Mile 353.5		Averages by stations			Average of both stations
	July 31, 1943		September 1, 1943		October 2, 1943		June 30, 1944	July 29, 1944	Mile 354.7		Mile 353.5	
	Temperature (°F)	Bicarbonate (ppm)	Temperature (°F)	Bicarbonate (ppm)	Temperature (°F)	Bicarbonate (ppm)	Temperature (°F)	Temperature (°F)	Temperature (°F)	Bicarbonate (ppm)	Temperature (°F)	Temperature (°F)
Average of interpolated data, assuming equal contribution from all layers in reservoir	60.3	161	61.1	158	61.1	161	59.0	60.2	60.8	160	59.6	60.3
Observed data at outflow below Hoover Dam	59	159	59	160	60	156	60	62	59.3	158	61.0	60
Observed elevation of Lake Mead surface feet	1201.55		1199.54		1195.37		1194.84	1199.67				
Depth of water at point of withdrawal over active upper intake tower sill feet	157		155		150		150	155	154		152	153
Interpolated value at depth of active upper intake tower sill	56.2	156	59.2	153	58.7	158	58.8	61.2	58.0	156	60.0	58.8

It is concluded from these analyses that withdrawals from a reservoir possessing density stratification, the density increasing with depth, would contain some undetermined greater proportion from the layers nearer the surface than is to be expected under idealized hydrodynamic conditions when withdrawals are made from the upper portions of the reservoir. Also, under the condition of density stratification, there is withdrawal of a greater proportion of the denser layers nearer the bottom of the reservoir than is to be expected under idealized hydrodynamic conditions, when withdrawals are made from the lower parts of the reservoir. An inspection of the tables shows without exception that an assumption that withdrawals might consist only of those density strata lying above the level of the outlet structure is untenable; otherwise, the outflows would have been at temperatures much higher than those which have been observed.

SUMMARY OF WATER WITHDRAWAL

Field experience, practical observation, and all of the very limited literature, computations, and model studies available to date indicate that, once a steady state is attained, the withdrawals of water from a reservoir consist of contributions from the whole of the reservoir. Under idealized conditions each unit depth of the reservoir would contribute equally to the total withdrawal. It cannot be stated, based upon knowledge available at time of writing, exactly what influence density currents and density stratification would have upon changing the proportionate contribution of each unit depth. In a stratified reservoir density differences due to temperature also possess different viscosities, and density currents, whether due to temperature, salinity, or turbidity, or some combination of all three, have a momentum. It can be reasoned on general grounds that withdrawals from a reservoir possessing density stratification, the density increasing with depth, (1) would contain some undetermined greater proportion from the layers nearer the surface than is to be expected under idealized hydrodynamic conditions, when withdrawals are from the upper portions of the reservoir, and (2) would contain some greater proportion of the denser layers nearer the bottom of the reservoir than is to be expected under idealized hydrodynamic conditions when withdrawals are made from the lower portions of the reservoir.

Although the theoretical saving which might be attained in evaporation loss through withdrawing of only surface waters has been demonstrated hypothetically, the attempt, beyond that of providing a weir, to increase the proportion of surface water to be withdrawn would require structures so fantastically intricate and expensive as to preclude any consideration of such an installation at a reservoir the size of Lake Mead. The economic justification for withdrawals over a weir at the surface would require careful study for multiple-purpose applicability to a specific project.

Even assuming that it were hydrodynamically and economically feasible to withdraw only the warm surface water from a reservoir, other considerations would tend to mitigate the advantages of such a system in over-all project operation. Encroachment of sediment deposits near the face of the dam could result in impairment of outlet works. The discharge of warm surface waters from a reservoir would result in higher river temperatures downsteam from the reservoir, resulting in unfavorable conditions for certain species of fish and wildlife. The reduction of evaporation losses from a reservoir due to withdrawal only of surface waters would be compensated to some extent by increased evaporation losses from downstream parts of the river system, including any reservoirs receiving the warmer releases.

As our understanding of the hydrodynamics of withdrawals from reservoirs possessing density stratification and exhibiting density currents is far from complete, further investigations of this subject are recommended. A hydraulic model investigation of the hydrodynamics of withdrawals from reservoirs is being conducted by the Bureau of Reclamation.

CONCLUSIONS

By G. Earl Harbeck, Jr., U. S. Geological Survey, and Max A. Kohler, U. S. Weather Bureau

Evaporation from Lake Mead was determined by both the energy-budget and mass-transfer techniques for the period March 1952 to September 1953. An adaptation of Sutton's equation and Sverdrup's 1937 equation, both of which gave good results at Lake Hefner, were found to be unsuitable for use at Lake Mead. Calder's equation for evaporation from a rough surface was tested using both the Lake Hefner and Lake Mead data, but the results were not encouraging.

The quasi-empirical equation found to be applicable to Lake Hefner was further tested at Lake Mead. On an annual basis, the agreement between the energy-budget results and the results obtained with this mass-transfer equation was excellent. It should be emphasized that the two methods are, for all practical purposes, independent. Mass-transfer results as first computed from data obtained at the 8-meter level showed a pronounced seasonal variation, however, presumably owing to the effect of atmospheric stability. It was found that this could be made negligible by the use of data obtained at the 2-meter level instead of the 8-meter level employed at Lake Hefner.

Evaporation from Lake Mead during the water year ending September 30, 1953, was 85.6 inches, equivalent to a volume of 875,000 acre-feet. During the entire 19-month period of observations, maximum monthly evaporation of 11.7 inches occurred in August 1952, and the minimum of 4.0 inches occurred in January 1953. Evaporation computed by the methods described in this report is gross evaporation. The net loss attributable to the construction of the reservoir is considerably less, of course, because substantial losses occurred in this reach of the river before the reservoir was built.

Tests of the CRI, which were begun at Lake Hefner, were continued at Lake Mead. The agreement between the net sum of certain radiation items as measured using the Eppley pyrheliometer and the Gier and Dunkle flat-plate radiometer and using the CRI was found to be excellent. The variation in these radiation items was found to be small over an area the size of Lake Mead, as shown by the good agreement between records obtained at Boulder Island, Overton Arm, and Bonelli Landing.

Analysis of wind and humidity profiles obtained at Lake Mead confirmed an earlier finding from the Lake Hefner data that these two parameters do not vary with height in the same manner, although commonly assumed to do so by many research workers in the field.

Studies of evaporation from pans indicate that reliable estimates of annual evaporation from Lake Mead can be made by applying a coefficient of 0.70 to the observed evaporation from the Boulder City class A pan, provided adjustments are made for energy advected into the reservoir and for changes in energy storage. A second technique, suitable for the determination of monthly evaporation also, requires measurements of solar radiation, air temperature, humidity, and wind speed. A graphical method was devised to simplify the necessary computations.

Prior to the Lake Mead investigation, the value of about 0.70 as the annual pan coefficient had been verified at Lake Hefner, Oklahoma City, Okla., where the climate is such that annual air and pan-water temperatures are equal and where adjustment for energy advection and storage in the lake was not appreciable. The Lake Mead investigation also yielded an average value of 0.70 for the annual pan coefficient for the class A Weather Bureau pan at Boulder City, Nev., but this was due to a combination of circumstances. The climate in the vicinity of Lake Mead results in pan-water temperatures which average lower than corresponding air temperatures and thus would imply a relatively low pan coefficient. This effect is offset by the fact that the Boulder City pan is at an elevation appreciably higher than the lake and is also in an area where the humidity is affected by local watering of lawns. The chapter on pan and lake evaporation describes adjustments made to pan observations to allow for these variations in exposure and environment. Differences between annual evaporation computed for Lake Mead by the pan techniques and that obtained by the energy budget or mass-transfer approaches are well within the probable error of these approaches. Therefore, this investigation confirmed the usage in both the planning and operation of irrigation projects of annual evaporation estimates and computations based upon utilization of class A evaporation-pan data.

Two methods for the determination of monthly evaporation from Lake Mead on a continuing basis were developed. One, an empirical mass-transfer formula, requires measurements of water-surface temperature in Boulder Basin, wind speed at Boulder Island, and records of air temperature and humidity obtained at the Weather Bureau station at the Las Vegas airport. The other, a modified pan approach, requires records of solar radiation, air and dewpoint temperature at Las Vegas, inflow and outflow volumes and temperatures from records obtained at the Grand Canyon gaging station and at Hoover Dam, thermal surveys at the Hoover Dam intake towers, and wind speed at the Boulder City pan. Of all the data required for the two methods, only measurements of water-surface temperature in Boulder Basin and wind speed at Boulder Island were not already being obtained as a part of the network of hydrologic and climatologic observations in the Lake Mead area.

The two methods are relatively independent. The only two items common to both are air temperature and humidity, which are to be obtained from the Weather Bureau records at the Las Vegas airport station. The manner in which these data are used in the two methods is quite different, and a possible measurement error would not have the same effect on the two results.

Because of the relative independence of the two methods, the close agreement between computed and observed results during the period of the Lake Mead study, and the absence of any significant seasonal bias for either method, it is concluded that the two methods should give figures of monthly evaporation from Lake Mead that are of acceptable accuracy.

It can be demonstrated that evaporation losses might be substantially reduced if it were possible to withdraw only the warmer water from the surface of a reservoir. Studies of the theoretical aspects of withdrawing water from Lake Mead indicate that if the reservoir were homogeneous, the outflow would consist of equal contributions from all depths, regardless of whether the water was withdrawn at the surface, at middepth, or through a morning-glory spillway. Lake Mead as a whole is not homogeneous, however, and stratification could cause surface withdrawals to contain some undetermined larger contribution from the layers near the surface. Laboratory studies to determine the effect of stratification on withdrawals are recommended.

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APPENDIX

TABLE 30.—*Daily mean solar radiation*

[In calories per square centimeter per day. *Indicates questionable or missing data]

Day	1952										1953								
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	316	598	714	743	763	720	637	517	368	267	286	376	475	623	698	665	800	495	640
2	434	611	721	632	770	721	616	511	316	301	266	382	*	630	743	809	800	742	642
3	497	638	560	575	752	710	610	482	364	285	284	350	514	620	766	799	715	751	637
4	457	649	742	733	532	709	545	484	376	306	311	379	510	637	757	734	344	745	644
5	478	640	751	753	646	610	543	*	340	137	289	295	526	603	760	580	705	752	621
6	369	617	731	773	646	605	518	498	368	286	77	382	*	589	713	646	689	691	631
7	185	656	688	754	676	655	497	*	153	194	158	*	*	677	782	785	726	644	554
8	*	668	752	809	215	675	623	469	280	280	182	213	521	587	756	800	551	541	535
9	*	658	749	778	647	632	491	486	377	284	*	342	508	677	665	794	631	595	571
10	178	336	752	790	772	690	594	485	364	288	*	406	545	646	744	823	737	611	592
11	451	529	750	785	779	703	595	472	332	289	265	398	538	707	609	777	710	656	608
12	489	628	706	802	770	701	573	470	275	283	280	401	514	652	773	670	707	560	593
13	506	650	766	791	780	668	599	473	292	289	163	420	543	293	761	814	733	546	574
14	541	673	751	784	781	680	592	470	223	280	288	414	572	691	517	822	461	570	575
15	225	701	676	*	755	677	586	469	89	284	313	360	530	695	676	806	709	527	562
16	455	686	653	*	751	643	490	341	188	125	296	437	565	643	743	710	301	665	559
17	544	659	755	*	742	663	557	314	328	88	250	458	523	658	753	758	283	703	529
18	316	620	665	793	757	513	546	434	331	100	231	220	*	690	*	640	688	706	559
19	565	660	722	801	743	624	75	422	333	163	238	452	419	*	491	776	710	676	566
20	498	457	739	780	716	644	*	398	325	86	218	472	554	457	703	791	691	659	549
21	598	623	766	772	725	650	457	418	271	278	332	482	522	443	797	802	682	682	550
22	595	679	781	742	717	652	528	428	325	293	341	483	*	349	785	798	677	681	563
23	529	688	734	466	637	656	526	433	115	301	340	295	613	690	595	808	691	658	576
24	503	512	787	757	454	647	517	422	331	161	298	344	548	711	815	814	722	659	*
25	588	622	716	775	636	482	526	292	325	254	326	472	349	673	823	828	717	612	563
26	595	595	720	732	599	537	405	416	319	295	335	482	608	640	740	785	706	305	521
27	614	181	734	766	704	653	519	424	321	275	374	492	607	185	822	820	695	594	534
28	581	349	705	773	613	559	515	418	316	254	355	454	442	746	641	810	680	680	524
29	592	310	796	778	529	*	509	379	268	271	355	------	574	748	774	726	484	658	522
30	560	686	776	775	705	638	513	336	232	221	314	------	614	644	*	760	358	653	516
31	599	------	719	------	686	626	------	385	------	271	359	------	623	------	748	------	382	648	------

TABLE 31.—*Daily atmospheric radiation*

[In calories per square centimeter per day. *Indicates questionable or missing data]

Day	1952										1953								
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	619	651	704	736	800	820	784	685	685	642	590	605	601	677	590	716	741	883	720
2	599	615	736	782	822	825	814	676	662	590	605	605	568	698	598	641	749	778	741
3	571	660	736	793	869	845	861	691	663	576	597	635	568	697	604	665	835	741	758
4	649	662	698	806	904	864	857	691	670	570	584	620	590	683	628	716	835	726	779
5	628	661	686	842	907	890	838	712	664	647	605	649	597	734	657	754	792	*	788
6	638	706	729	806	892	901	850	698	663	654	648	670	619	727	698	739	827	*	788
7	693	712	747	779	878	899	850	723	698	662	668	641	619	620	672	712	850	*	808
8	*	684	670	763	892	908	843	700	712	640	722	627	641	604	649	719	899	*	*
9	604	650	707	735	848	901	823	763	590	613	648	597	633	607	605	712	878	*	836
10	637	689	677	763	792	843	776	743	584	599	628	576	640	635	638	715	857	*	776
11	613	701	699	769	792	813	742	743	620	584	613	591	633	611	605	762	899	868	757
12	589	696	731	749	792	835	755	692	663	592	656	577	640	614	635	778	864	872	780
13	575	674	760	793	792	864	755	677	671	642	683	599	619	681	663	740	914	870	800
14	601	633	744	768	785	871	794	663	668	634	621	613	590	605	741	742	886	830	763
15	658	634	671	*	806	872	808	678	628	620	576	597	605	625	674	716	850	838	780
16	674	654	659	*	817	864	820	670	661	669	591	591	634	664	661	770	871	790	782
17	575	699	649	*	807	878	836	699	611	677	656	590	662	670	749	778	850	779	779
18	609	703	694	778	824	878	823	692	627	655	649	566	628	648	735	727	*	785	790
19	598	717	725	778	812	893	767	677	619	656	640	542	683	704	699	734	*	825	771
20	583	724	787	809	841	899	*	663	619	683	655	539	676	740	663	758	878	880	767
21	554	728	712	821	853	878	729	655	649	569	617	525	640	778	620	773	869	855	770
22	536	715	689	806	856	878	747	619	643	576	599	518	634	712	677	793	878	800	697
23	533	685	733	812	927	856	755	627	633	586	598	597	640	698	658	792	871	839	662
24	607	704	718	800	939	865	769	640	548	593	613	671	691	715	577	763	893	833	*
25	619	740	749	805	925	878	763	620	569	606	663	568	706	720	611	772	885	872	*
26	608	714	736	828	911	893	720	620	554	562	626	576	683	728	632	754	892	848	740
27	613	694	758	804	*	899	706	643	547	587	576	619	705	776	611	707	893	831	699
28	595	557	787	821	*	883	721	626	547	584	581	619	712	653	634	734	907	752	742
29	647	726	791	806	842	830	706	*	620	576	590	------	683	620	668	745	913	772	689
30	691	694	778	801	827	810	691	*	647	628	623	------	633	634	691	784	911	724	772
31	670	------	774	------	827	795	------	650	------	619	605	------	640	------	718	------	885	721	------

TABLE 32.—*Mean water temperatures of 5-meter layers for each monthly thermal survey*

[In degrees centigrade, at time indicated]

Depth of layer (meters)	1952										1953									
	Mar. 12 0315	Apr. 15 0300	May 12 1015	June 12 0200	July 9 0830	Aug. 5 1315	Sept. 4 1100	Oct. 2 2400	Nov. 5 2200	Dec. 2 2400	Jan. 9 0600	Feb. 2 2400	Mar. 2 1005	Mar. 31 1230	Apr. 28 0600	May 27 2400	June 29 2200	July 29 2400	Aug. 27 0200	Sept. 29 0300
0–5	11. 4	15. 0	20. 1	22. 3	26. 2	29. 3	28. 9	26. 3	22. 3	16. 9	14. 1	13. 5	12. 3	14. 7	17. 0	17. 7	23. 8	29. 1	27. 6	25. 6
5–10	11. 4	14. 7	18. 6	21. 8	24. 2	27. 7	28. 3	26. 0	22. 2	17. 0	14. 0	13. 4	12. 2	14. 1	16. 7	17. 7	23. 4	28. 3	27. 5	25. 5
10–15	11. 4	13. 9	17. 5	20. 7	22. 5	24. 6	27. 0	25. 7	22. 2	17. 0	13. 9	13. 3	12. 2	13. 7	16. 0	17. 6	22. 4	25. 8	27. 1	25. 4
15–20	11. 4	12. 5	16. 1	19. 5	21. 6	22. 2	24. 1	25. 1	22. 2	17. 0	13. 9	13. 3	12. 3	13. 2	15. 4	17. 4	21. 1	22. 5	25. 2	24. 9
20–25	11. 4	11. 8	14. 8	18. 7	20. 8	21. 2	21. 8	23. 4	22. 2	17. 0	13. 9	13. 3	12. 3	12. 9	14. 5	16. 8	19. 7	20. 5	22. 1	22. 7
25–30	11. 3	11. 4	13. 8	17. 7	19. 9	20. 3	20. 9	21. 9	22. 2	17. 0	13. 9	13. 3	12. 3	12. 8	13. 9	16. 1	18. 6	19. 1	20. 4	20. 8
30–35	11. 2	11. 2	13. 1	16. 9	18. 9	19. 2	19. 8	20. 8	21. 8	17. 1	13. 9	13. 3	12. 3	12. 6	13. 5	14. 9	17. 4	18. 0	19. 1	19. 5
35–40	11. 2	11. 1	12. 6	15. 8	17. 7	18. 0	18. 4	19. 4	21. 0	17. 0	13. 9	13. 2	12. 2	12. 5	13. 2	14. 0	16. 3	17. 0	18. 0	18. 3
40–45	11. 2	11. 0	12. 2	14. 3	16. 4	16. 9	17. 0	17. 7	19. 5	16. 9	13. 9	13. 1	12. 2	12. 4	12. 9	13. 3	15. 1	16. 0	17. 0	17. 2
45–50	11. 1	11. 0	11. 9	13. 2	14. 9	15. 1	15. 5	15. 7	17. 8	16. 4	13. 9	13. 1	12. 1	12. 3	12. 7	13. 0	14. 1	15. 0	16. 1	16. 3
50–55	11. 1	10. 9	11. 5	12. 3	13. 6	13. 9	14. 2	14. 1	15. 9	15. 3	13. 7	13. 0	12. 1	12. 3	12. 5	12. 8	13. 4	14. 1	15. 3	15. 5
55–60	11. 0	10. 8	11. 4	11. 9	12. 6	13. 0	12. 9	12. 9	14. 2	14. 0	13. 2	12. 8	12. 1	12. 2	12. 4	12. 6	13. 0	13. 5	14. 5	14. 8
60–65	10. 9	10. 7	11. 4	11. 6	12. 0	12. 4	12. 3	12. 2	13. 2	13. 2	13. 1	12. 6	12. 1	12. 0	12. 2	12. 4	12. 7	13. 1	13. 8	14. 0
65–70	10. 9	10. 7	11. 0	11. 4	11. 6	12. 0	11. 9	11. 8	12. 6	12. 7	12. 8	12. 4	12. 1	12. 0	12. 1	12. 2	12. 5	12. 8	13. 3	13. 5
70–75	10. 8	10. 6	11. 0	11. 2	11. 4	11. 7	11. 7	11. 6	12. 3	12. 3	12. 6	12. 2	12. 0	11. 9	12. 0	12. 2	12. 3	12. 6	13. 0	13. 0
75–80	10. 7	10. 6	10. 8	11. 1	11. 2	11. 6	11. 5	11. 5	12. 0	12. 0	12. 4	12. 0	11. 9	11. 8	12. 0	12. 1	12. 2	12. 4	12. 8	12. 7
80–85	10. 7	10. 6	10. 8	11. 0	11. 1	11. 4	11. 4	11. 3	11. 9	11. 9	12. 2	11. 9	11. 9	11. 7	11. 9	12. 0	12. 0	12. 3	12. 6	12. 5
85–90	10. 6	10. 6	10. 8	10. 9	11. 0	11. 3	11. 3	11. 2	11. 8	11. 8	12. 2	11. 8	11. 9	11. 6	11. 9	12. 0	11. 9	12. 2	12. 5	12. 3
90–95	10. 6	10. 6	10. 7	10. 9	11. 0	11. 2	11. 2	11. 2	11. 7	11. 7	12. 0	11. 6	11. 7	11. 5	11. 8	11. 9	11. 8	12. 1	12. 4	12. 2
95–100	10. 7	10. 5	10. 7	10. 8	10. 9	11. 2	11. 2	11. 1	11. 6	11. 7	11. 8	11. 6	11. 6	11. 5	11. 8	11. 9	11. 7	12. 1	12. 4	12. 1
100–105	10. 6	10. 5	10. 6	10. 8	10. 8	11. 2	11. 2	11. 1	11. 6	11. 6	11. 7	11. 4	11. 5	11. 4	11. 8	11. 9	11. 7	12. 1	12. 3	12. 0
105–110	10. 6	10. 5	10. 6	10. 8	10. 8	11. 1	11. 1	11. 0	11. 6	11. 5	11. 6	11. 3	11. 4	11. 3	11. 8	11. 9	11. 7	12. 0	12. 2	11. 9
110–115	10. 7	10. 4	10. 6	10. 7	10. 7	11. 1	11. 1	10. 9	11. 6	11. 5	11. 5	11. 2	11. 3	11. 2	11. 8	11. 9	11. 7	12. 0	12. 2	11. 8
115–120	10. 7	10. 4	10. 5	10. 7	10. 7	11. 1	11. 1	10. 9	11. 5	11. 5	11. 5	11. 1	11. 1	11. 2	11. 7	11. 8	11. 7	12. 0	12. 2	11. 8
120–125	10. 7		10. 5	10. 6	10. 6	11. 1	11. 1	10. 8	11. 5	11. 5	11. 5	11. 1	11. 1	11. 1	11. 8	11. 8	11. 7	11. 9	12. 1	11. 7
125–130			10. 5	10. 5	10. 6	11. 1	11. 1	10. 9	11. 4	11. 5	11. 6	11. 1	11. 1	11. 1			11. 7	11. 9	11. 9	11. 7
130–135				10. 4	10. 6	11. 1	11. 1	10. 9	11. 4	11. 5										
135–140				10. 2	10. 5	11. 1	11. 1	11. 0												

TABLE 33.—*Daily averages of air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*

Date	Average air temperature (°C) at indicated height														Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft		Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters											
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb						2 meters	8 meters	2¾ meters	8¾ meters	
March 1952																								
1	11.2	8.0	10.9	7.4	-----	-----	-----	-----	12.1	7.9	-----	-----	11.8	7.8	11.3	-----	11.8	-----	11.3	14.3	16.9	-----	-----	-----
2	-----	-----	-----	-----	-----	-----	-----	-----	9.0	4.0	-----	-----	8.3	4.1	11.1	-----	11.8	-----	11.0	11.1	12.7	-----	-----	-----
3	-----	-----	-----	-----	-----	-----	-----	-----	8.4	3.8	-----	-----	8.8	4.2	11.2	-----	11.5	-----	11.7	7.2	7.9	-----	-----	-----
4	11.4	6.4	11.5	5.9	-----	-----	-----	-----	11.0	6.0	-----	-----	11.4	6.1	11.7	-----	12.0	-----	11.9	4.6	5.4	-----	-----	-----
5	12.2	7.2	12.6	6.4	-----	-----	-----	-----	13.4	7.1	-----	-----	13.3	7.5	11.9	-----	12.5	-----	12.0	5.4	6.5	-----	-----	-----
6	-----	-----	-----	-----	-----	-----	-----	-----	14.3	7.0	-----	-----	15.0	7.9	12.1	-----	12.3	-----	12.5	9.6	11.5	-----	-----	-----
7	-----	-----	-----	-----	-----	-----	-----	-----	14.5	7.1	-----	-----	15.0	7.8	11.4	-----	11.8	-----	11.9	8.1	9.7	-----	-----	-----
8	6.6	5.5	6.4	5.4	-----	-----	-----	-----	7.4	6.1	-----	-----	8.8	6.6	11.1	-----	10.9	-----	11.7	3.7	4.0	-----	-----	-----
9	10.0	7.8	9.8	7.4	-----	-----	-----	-----	9.5	7.4	-----	-----	10.0	7.9	11.6	-----	11.4	-----	12.0	9.2	10.6	-----	-----	-----
10	10.8	7.9	11.0	7.7	-----	-----	-----	-----	-----	-----	-----	-----	12.7	8.5	11.8	-----	-----	-----	12.1	17.3	20.4	-----	-----	-----
11	10.3	5.3	10.0	5.1	-----	-----	-----	-----	-----	-----	9.0	5.0	-----	-----	11.3	-----	-----	11.4	-----	9.2	10.5	-----	-----	-----
12	10.0	5.8	10.1	5.2	-----	-----	-----	-----	-----	-----	9.1	6.0	-----	-----	11.5	-----	-----	11.6	-----	10.6	12.3	-----	-----	-----
13	10.2	4.9	9.6	4.6	-----	-----	-----	-----	10.8	5.0	10.2	6.4	9.8	4.9	11.3	-----	11.8	11.8	11.4	8.3	9.8	-----	-----	-----
14	-----	-----	-----	-----	-----	-----	-----	-----	9.1	5.0	-----	-----	10.0	5.8	11.2	-----	11.5	-----	11.9	6.9	7.9	-----	-----	-----
15	-----	-----	-----	-----	-----	-----	-----	-----	11.8	7.6	-----	-----	11.8	8.0	-----	-----	12.0	11.8	11.7	5.3	6.4	-----	-----	-----
16	-----	-----	-----	-----	-----	-----	-----	-----	11.2	6.9	-----	-----	10.8	7.5	-----	-----	11.9	-----	11.2	11.4	13.3	-----	-----	-----
17	12.6	8.5	-----	-----	-----	-----	-----	-----	10.6	6.9	-----	-----	10.6	7.7	-----	-----	11.8	-----	12.3	5.0	5.8	-----	-----	-----
18	12.7	8.2	12.7	7.7	-----	-----	-----	-----	13.2	7.8	13.2	9.5	13.5	8.9	11.5	-----	12.2	11.8	12.4	14.8	17.7	-----	-----	-----
19	13.5	7.4	13.7	7.1	-----	-----	-----	-----	14.0	7.2	13.0	8.1	14.3	8.4	11.6	-----	12.1	12.5	11.6	12.8	15.4	-----	-----	-----
20	10.4	4.2	10.2	3.6	-----	-----	-----	-----	10.4	3.4	-----	-----	11.4	4.4	11.4	-----	11.4	-----	11.6	12.1	14.1	-----	-----	-----
21	8.6	3.2	8.4	2.6	-----	-----	-----	-----	8.8	2.2	-----	-----	9.4	3.3	11.5	-----	10.8	-----	11.6	14.9	17.3	-----	-----	-----
22	9.1	3.0	8.9	2.5	-----	-----	-----	-----	8.5	1.8	-----	-----	9.2	3.1	11.6	-----	10.7	-----	11.7	12.8	14.8	-----	-----	-----
23	8.7	3.4	8.7	2.8	-----	-----	-----	-----	7.9	2.7	-----	-----	8.7	3.7	11.5	-----	10.6	-----	11.4	5.6	5.9	-----	-----	-----
24	12.4	7.8	12.5	7.3	-----	-----	-----	-----	12.0	6.2	-----	-----	12.0	6.8	11.5	-----	11.4	-----	12.3	5.5	6.6	-----	-----	-----
25	15.4	9.8	16.0	8.9	-----	-----	-----	-----	16.0	8.8	16.4	10.5	15.6	9.5	11.9	-----	11.5	13.6	12.1	5.2	6.5	-----	-----	-----
26	15.2	10.1	15.8	9.4	-----	-----	-----	-----	15.0	9.1	15.2	9.9	15.6	9.3	12.3	-----	12.8	12.4	12.6	5.5	7.0	-----	-----	-----
27	16.9	9.3	16.8	8.4	-----	-----	-----	-----	16.4	8.7	15.4	8.8	15.8	8.8	12.9	-----	12.2	10.8	12.3	3.6	4.6	-----	-----	-----
28	14.9	10.0	15.2	8.9	-----	-----	-----	-----	15.0	9.0	14.2	8.6	15.0	8.8	13.0	-----	13.5	12.8	13.9	2.7	3.1	-----	-----	-----
29	16.7	11.4	17.3	10.9	-----	-----	-----	-----	17.0	10.6	15.0	10.0	17.3	10.0	13.8	-----	14.2	13.8	14.2	5.5	7.2	-----	-----	-----
30	18.9	12.1	20.2	11.5	-----	-----	-----	-----	19.9	11.8	16.1	11.2	19.6	11.1	13.0	-----	14.4	14.1	13.7	7.8	10.4	-----	-----	-----
31	16.7	11.3	18.1	10.6	-----	-----	-----	-----	18.0	11.0	-----	-----	19.5	11.1	13.3	-----	15.7	-----	13.7	3.2	4.1	-----	-----	-----

TABLE 33.—*Daily averages of air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*—Continued

Date	Average air temperature (°C) at indicated height														Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft		Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters							2 meters	8 meters	2¾ meters	8¾ meters	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb										
April 1952																								
1	18.0	10.7	18.7	9.5	------	------	------	------	17.1	10.1	19.6	10.9	16.4	9.3	14.9	------	14.7	14.7	15.4	3.6	4.5	------	------	------
2	17.4	11.4	17.9	10.3	------	------	------	------	17.2	10.2	17.8	10.6	18.0	10.0	15.3	------	15.4	14.8	15.8	3.0	3.6	------	------	------
3	19.2	10.8	20.0	10.0	------	------	------	------	20.6	10.7	20.0	11.8	19.6	10.5	14.9	------	14.0	12.8	14.7	4.0	5.1	------	------	------
4	20.6	12.0	21.2	10.9	------	------	------	------	20.8	11.8	20.5	12.9	19.0	11.0	15.2	------	14.8	12.9	15.0	3.9	4.8	------	------	------
5	19.5	13.0	20.2	12.0	------	------	------	------	19.9	12.8	20.8	13.4	20.0	11.4	15.7	------	16.8	15.4	16.7	2.6	3.2	------	------	------
6	20.7	13.3	21.7	12.8	------	------	------	------	22.1	13.6	------	------	22.2	10.6	15.9	------	16.1	15.1	16.9	6.2	8.3	------	------	------
7	20.1	11.7	20.8	11.1	------	------	------	------	22.3	12.8	------	------	22.1	11.9	14.4	------	15.7	------	14.9	10.4	12.8	------	------	------
8	17.3	11.0	17.8	10.2	------	------	------	------	17.2	10.9	18.8	12.4	18.3	11.1	14.8	------	14.0	15.0	16.0	6.2	7.6	------	------	------
9	16.8	9.2	17.2	8.3	------	------	------	------	15.9	8.7	16.4	9.8	16.9	8.1	15.0	------	13.8	13.9	16.8	5.5	6.5	------	------	------
10	15.4	10.2	15.4	9.8	------	------	------	------	15.8	10.0	16.3	12.4	16.3	9.6	14.4	------	14.1	15.8	15.4	8.6	9.7	------	------	------
11	15.2	10.5	15.8	9.5	------	------	------	------	15.0	10.7	15.8	13.2	16.3	10.1	14.2	------	14.3	16.0	15.8	5.6	7.0	------	------	------
12	------	------	------	------	------	------	------	------	15.9	11.5	17.1	13.7	17.2	11.0	------	------	15.8	16.8	17.2	2.9	3.3	------	------	------
13	------	------	------	------	------	------	------	------	20.0	12.7	17.0	13.0	20.7	11.7	------	------	16.1	16.0	16.9	9.5	11.8	------	------	------
14	17.9	10.1	18.5	9.3	------	------	------	------	18.9	10.5	18.2	12.7	19.0	9.6	15.3	------	15.9	16.2	15.7	8.1	9.8	------	------	------
15	17.5	10.2	18.2	8.6	------	------	------	------	18.1	10.2	18.3	12.4	18.4	9.1	15.9	------	14.8	16.2	16.7	4.7	5.6	------	------	------
16	20.1	11.6	20.9	10.2	------	------	------	------	22.0	12.6	20.8	14.0	20.6	11.2	16.0	------	15.4	15.0	16.5	4.6	5.6	------	------	------
17	21.8	12.8	22.6	11.6	------	------	------	------	23.1	13.8	22.3	15.6	21.5	12.3	17.1	------	16.1	15.3	16.7	4.3	5.2	------	------	------
18	21.3	14.2	21.7	12.5	------	------	------	------	20.8	13.3	20.8	15.8	20.8	12.0	18.2	------	17.4	16.7	17.8	2.9	3.7	------	------	------
19	------	------	------	------	------	------	------	------	20.1	13.0	18.1	14.5	20.4	12.6	------	------	16.5	16.1	17.1	10.0	12.3	------	------	------
20	------	------	------	------	------	------	------	------	16.6	12.6	15.2	14.5	16.6	13.0	------	------	16.0	16.2	16.4	8.4	9.9	------	------	------
21	------	------	------	------	------	------	------	------	18.0	12.9	17.7	------	18.7	12.9	------	------	16.8	17.0	16.8	6.8	------	------	------	------
22	19.1	14.7	19.1	13.1	------	------	------	------	------	------	18.6	------	20.4	13.4	16.7	------	------	18.1	18.2	5.1	------	------	------	------
23	20.4	15.0	20.9	13.4	------	------	------	------	------	------	20.1	------	21.5	13.9	17.4	------	------	18.9	19.2	2.8	------	------	------	------
24	19.8	15.1	20.3	13.9	------	------	------	------	21.0	15.2	20.0	------	20.7	13.9	17.6	------	18.9	18.2	18.7	4.2	------	------	------	------
25	19.7	14.3	20.2	13.8	------	------	------	------	21.4	14.6	19.8	------	22.0	14.7	17.2	------	18.9	17.9	18.3	7.6	------	------	------	------
26	18.6	12.7	18.8	11.8	------	------	------	------	20.4	12.6	19.8	------	20.2	12.9	17.5	------	18.7	18.9	18.0	3.8	------	------	------	------
27	17.4	13.9	17.4	13.6	------	------	------	------	16.4	12.8	16.8	------	16.2	12.8	17.4	------	16.5	17.1	17.9	8.1	------	------	------	------
28	14.2	11.4	14.1	11.2	------	------	------	------	14.3	10.6	15.1	------	14.9	------	16.2	------	16.9	17.7	17.7	6.5	7.4	------	------	------
29	15.9	13.3	15.9	13.0	------	------	------	------	15.4	12.8	14.9	------	15.7	------	16.0	------	16.6	17.0	17.3	9.2	10.5	------	------	------
30	17.2	14.2	17.1	13.4	------	------	------	------	16.8	13.6	16.8	------	17.6	------	16.8	------	17.5	18.2	18.7	------	3.0	------	------	------
May 1952																								
1	20.5	16.3	20.9	15.9	------	------	------	------	20.3	15.1	20.1	------	21.5	15.0	18.0	------	19.2	19.8	20.9	1.6	2.6	------	------	------
2	23.1	16.6	24.1	15.3	------	------	------	------	23.4	16.2	20.0	------	24.2	16.4	19.4	------	21.1	20.5	21.7	3.3	4.5	------	------	------
3	23.9	15.7	25.2	14.8	------	------	------	------	26.0	15.4	21.1	------	26.6	16.2	18.9	------	20.8	20.6	21.5	4.4	5.8	------	------	------
4	24.2	14.4	25.0	12.9	------	------	------	------	25.3	14.7	21.7	------	24.8	13.9	19.1	------	20.9	20.4	19.7	4.2	5.3	------	------	------
5	24.1	15.1	25.1	13.7	------	------	------	------	------	------	21.0	------	24.6	13.4	20.0	------	------	19.5	19.1	5.4	6.5	------	------	------
6	24.7	14.3	25.8	12.9	------	------	------	------	------	------	23.4	------	25.8	13.2	19.9	------	------	21.9	19.6	6.0	7.6	------	------	------
7	25.5	16.0	26.0	15.2	------	------	------	------	------	------	23.9	------	27.9	14.4	19.2	------	------	20.8	18.5	12.7	16.0	------	------	------
8	21.4	12.8	22.0	11.2	------	------	------	------	------	------	22.7	------	22.1	11.9	18.8	------	------	20.6	17.2	6.9	8.5	------	------	------
9	22.3	13.8	22.9	11.8	------	------	------	------	25.8	------	23.4	------	22.6	11.9	19.2	------	20.6	20.7	18.0	4.0	4.8	------	------	------
10	23.6	14.7	24.1	12.6	------	------	------	------	24.4	------	23.8	------	22.9	12.4	20.6	------	20.4	21.3	20.0	3.0	3.6	------	------	------
11	23.9	15.1	24.5	14.0	------	------	------	------	24.0	------	23.8	------	24.4	13.1	20.8	------	21.8	22.5	21.8	4.7	5.9	------	------	------
12	26.0	15.1	26.9	14.1	------	------	------	------	26.4	------	25.4	------	26.8	14.1	21.2	------	21.8	22.5	22.9	4.4	5.4	------	------	------
13	28.2	14.9	29.0	14.0	------	------	------	------	29.3	------	27.9	18.0	28.3	14.1	21.1	------	22.1	23.1	20.0	7.2	9.1	------	------	------
14	25.9	16.1	26.8	14.1	------	------	------	------	26.1	------	------	------	26.6	14.0	21.1	------	21.0	------	20.4	6.6	8.6	------	------	------

15	22.9	14.0	23.2	12.9	----	----	----	----	23.8	----	----	----	22.8	11.7	20.4	----	19.9	----	19.5	9.1	10.9	----	----	----
16	19.1	10.9	19.1	10.7	----	----	----	----	19.8	----	----	----	19.0	11.0	20.2	----	19.4	----	18.5	7.7	9.2	----	----	----
17	21.6	13.6	22.0	12.4	----	----	----	----	22.7	----	----	----	21.9	12.8	20.1	----	20.0	----	19.2	9.3	11.1	----	----	----
18	23.0	----	23.7	12.3	----	----	----	----	23.4	----	----	----	23.0	12.6	20.3	----	19.1	----	20.3	5.2	6.4	----	----	----
19	24.2	----	25.3	14.5	----	----	----	----	22.6	----	----	----	24.9	13.8	20.9	----	20.0	----	21.5	3.2	4.0	----	----	----
20	28.0	----	28.9	15.7	----	----	----	----	30.0	----	27.0	17.0	29.2	15.9	21.6	----	21.7	23.0	21.8	9.5	12.0	----	----	----
21	24.1	14.8	24.6	13.4	----	----	----	----	24.6	----	23.5	15.0	24.0	13.8	21.4	----	20.0	21.2	19.7	5.2	5.8	----	----	----
22	23.4	13.8	23.7	13.0	----	----	----	----	23.9	----	----	----	23.3	12.7	21.3	----	20.9	----	20.0	7.8	9.5	----	----	----
23	24.4	15.6	25.2	14.0	----	----	----	----	26.3	----	----	----	25.1	14.0	21.6	----	21.2	----	20.4	4.9	5.8	----	----	----
24	26.1	17.4	26.4	15.6	----	----	----	----	26.2	----	----	----	26.4	14.8	22.5	----	23.5	----	23.0	2.8	3.0	----	----	----
25	26.3	17.8	27.5	16.0	----	----	----	----	28.1	----	----	----	28.2	15.4	22.8	----	23.8	----	24.0	3.6	4.7	----	----	----
26	27.4	17.8	28.6	15.8	----	----	----	----	29.0	----	----	----	30.8	16.6	23.4	----	23.9	----	25.7	3.2	3.9	----	----	----
27	29.3	17.2	30.2	15.0	----	----	----	----	30.8	----	30.0	16.4	30.1	16.4	23.8	----	25.2	24.9	25.7	3.0	3.9	----	----	----
28	28.4	----	29.7	16.1	----	----	----	----	31.0	----	27.8	17.5	30.8	16.0	24.1	----	25.8	23.3	25.3	5.7	7.0	----	----	----
29	28.8	----	31.4	14.5	----	----	----	----	31.8	----	26.3	17.3	31.0	14.0	23.2	----	24.9	23.9	23.1	6.4	8.5	----	----	----
30	27.6	----	28.8	15.5	----	----	----	----	30.7	----	27.0	17.0	----	----	22.8	----	24.9	24.0	----	9.2	11.8	----	----	----
31	26.7	----	27.8	14.6	----	----	----	----	29.9	----	27.8	17.8	----	----	21.6	----	24.0	24.1	----	8.7	11.2	----	----	----

June 1952

1	25.8	14.8	26.5	13.1	----	----	----	----	27.2	----	25.8	16.2	----	----	21.8	----	23.5	23.9	----	6.8	8.6	----	----	----
2	23.8	16.0	23.9	14.7	----	----	----	----	25.4	----	----	----	----	----	23.0	----	23.4	----	----	6.2	7.3	----	----	----
3	23.6	17.5	23.9	17.0	----	----	----	----	24.3	----	26.0	17.0	----	----	21.4	----	23.9	23.9	----	10.4	12.7	----	----	----
4	26.9	19.7	27.5	18.6	----	----	----	----	25.9	----	26.7	19.2	----	----	24.0	----	24.8	24.2	----	2.8	3.4	----	----	----
5	29.4	18.3	30.8	16.4	----	----	----	----	31.4	----	26.4	18.4	31.9	----	24.4	----	26.7	25.0	25.4	6.9	9.1	----	----	----
6	28.8	18.0	29.7	16.9	----	----	----	----	31.3	15.9	----	----	30.8	----	24.0	----	25.2	----	24.2	8.0	10.3	----	----	----
7	27.7	17.2	29.0	15.4	----	----	----	----	29.0	15.1	29.4	19.0	28.7	----	24.4	----	25.0	25.8	23.8	4.4	5.8	----	----	----
8	28.5	17.1	28.9	15.8	----	----	----	----	29.7	15.8	----	----	29.7	----	24.9	----	25.9	----	25.0	5.1	6.4	----	----	----
9	27.0	16.6	27.4	16.1	----	----	----	----	29.3	15.4	----	----	30.0	----	24.2	----	25.1	----	24.7	11.2	13.5	----	----	----
10	25.5	14.3	25.6	13.2	----	----	----	----	25.9	13.8	29.1	17.2	27.0	----	23.7	----	23.3	26.0	23.2	5.7	6.8	----	----	----
11	27.6	16.3	28.0	15.9	----	----	----	----	----	----	28.0	17.0	29.5	----	23.1	----	----	25.7	23.4	13.0	16.4	----	----	----
12	25.6	14.2	26.3	12.9	----	----	----	----	28.0	14.3	27.6	17.0	27.3	14.1	22.9	----	23.1	25.6	21.0	8.3	10.0	----	----	----
13	27.1	15.6	28.0	14.4	----	----	----	----	29.1	15.8	28.7	18.2	28.8	14.7	23.2	----	23.3	25.8	22.0	8.2	10.7	----	----	----
14	----	----	----	----	----	----	----	----	30.6	17.0	27.4	17.8	29.6	15.2	23.3	----	23.8	25.6	21.9	7.2	9.2	----	----	----
15	----	----	----	----	----	----	----	----	30.6	16.6	26.8	13.1	27.4	14.8	----	----	23.9	24.9	21.7	5.1	6.2	----	----	----
16	28.4	16.2	29.2	14.5	----	----	----	----	30.3	16.3	26.7	12.9	28.8	15.7	24.6	----	24.0	24.0	22.7	4.6	5.6	----	----	----
17	26.4	17.3	28.2	15.8	----	----	----	----	29.7	17.4	25.0	14.0	28.7	16.0	25.2	----	25.7	24.5	24.0	4.7	6.0	----	----	----
18	----	----	----	----	----	----	----	----	33.1	17.8	----	----	31.8	17.3	----	----	25.6	----	23.5	7.3	9.3	----	----	----
19	30.9	16.7	----	----	----	----	----	----	32.8	16.7	----	----	31.2	14.9	24.7	----	25.6	----	22.5	9.4	12.1	----	----	----
20	29.0	17.0	29.0	15.6	----	----	----	----	29.8	17.5	----	----	34.5	15.0	25.3	----	24.2	----	22.9	4.8	6.1	----	----	----
21	30.6	18.2	31.3	16.5	----	----	----	----	32.3	17.9	----	----	31.9	16.1	25.0	----	25.8	----	23.3	9.2	11.7	----	----	----
22	29.8	18.4	30.6	16.9	----	----	----	----	31.8	18.3	----	----	30.9	----	24.9	----	25.2	----	22.1	8.2	10.0	----	----	----
23	28.1	18.2	29.3	17.1	----	----	----	----	29.0	17.4	----	----	29.0	----	24.5	----	24.0	----	21.0	10.6	13.1	----	----	----
24	27.9	17.4	28.2	16.5	----	----	----	----	28.9	16.5	27.4	17.3	28.3	----	23.9	----	24.0	24.5	21.6	9.4	11.4	----	----	----
25	27.6	16.2	27.9	14.8	----	----	----	----	26.1	14.8	27.2	16.6	----	----	23.9	----	22.7	24.1	----	9.9	12.1	----	----	----
26	26.2	16.0	26.2	15.1	----	----	----	----	25.8	15.1	26.0	16.3	26.5	----	24.2	----	22.9	24.0	21.0	10.2	12.0	----	----	----
27	26.7	16.3	27.1	15.1	----	----	----	----	27.0	15.9	25.8	17.0	26.9	----	23.9	----	23.6	24.0	21.8	8.1	10.0	----	----	----
28	27.7	17.2	28.2	16.1	----	----	----	----	28.8	17.3	28.1	17.6	28.8	----	23.9	----	23.8	24.4	21.7	10.0	12.3	----	----	----
29	28.0	17.2	28.7	16.0	----	----	----	----	30.3	16.4	28.0	18.3	29.1	----	23.7	----	23.7	24.1	21.3	7.4	9.3	----	----	----
30	28.4	17.8	29.0	15.8	----	----	----	----	28.0	16.0	27.5	16.2	27.8	----	24.7	----	24.8	25.0	23.0	4.6	6.0	----	----	----

TABLE 33.—*Daily averages of air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*—Continued

Date	Average air temperature (°C) at indicated height														Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft		Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters											
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb						2 meters	8 meters	2¾ meters	8¾ meters	
July 1952																								
1	30.0	18.8	30.6	17.2	-----	-----	-----	-----	30.2	17.8	29.4	18.0	30.1	-----	25.4	-----	27.2	26.9	24.9	5.2	6.3	-----	-----	-----
2	30.5	20.1	31.7	16.8	-----	-----	-----	-----	31.3	17.8	29.8	17.9	30.8	-----	26.4	-----	28.4	27.0	26.8	3.7	4.6	-----	-----	-----
3	31.7	20.8	32.8	18.4	-----	-----	-----	-----	32.8	18.7	31.3	19.1	32.6	19.0	26.7	-----	29.4	28.2	28.0	5.7	7.6	-----	-----	-----
4	32.5	21.9	34.4	19.5	-----	-----	-----	-----	34.8	20.0	31.8	22.0	34.0	21.5	26.0	-----	30.0	27.7	27.4	6.3	8.7	-----	-----	-----
5	31.9	22.5	33.8	20.5	-----	-----	-----	-----	33.6	21.6	32.2	22.0	33.4	22.3	25.6	-----	29.1	26.9	25.5	7.1	9.8	-----	-----	-----
6	32.3	23.5	32.8	21.2	-----	-----	-----	-----	32.4	20.9	32.0	21.0	30.6	21.8	26.6	-----	29.2	27.0	25.0	4.8	6.2	-----	-----	-----
7	32.2	22.0	33.6	19.3	-----	-----	-----	-----	31.7	18.8	31.0	20.7	31.8	21.2	27.5	-----	28.1	28.2	26.0	5.6	7.3	-----	-----	-----
8	31.4	21.9	32.2	20.5	-----	-----	-----	-----	33.2	20.2	29.7	20.4	32.0	21.9	26.4	-----	27.9	27.0	24.7	8.7	11.1	-----	-----	-----
9	29.8	22.5	31.1	20.8	-----	-----	-----	-----	31.2	21.1	30.0	21.0	30.0	20.9	26.7	-----	28.2	27.1	24.7	3.3	4.3	-----	-----	-----
10	31.5	20.2	32.7	18.4	-----	-----	-----	-----	32.7	19.7	30.0	20.0	31.5	20.1	27.3	-----	28.6	27.9	26.8	4.9	6.1	-----	-----	-----
11	32.1	19.4	33.0	17.0	-----	-----	-----	-----	34.2	17.9	31.0	20.3	33.1	20.1	26.9	-----	27.8	28.0	26.8	6.4	8.2	-----	-----	-----
12	31.3	19.0	32.0	16.8	-----	-----	-----	-----	32.1	17.6	29.9	19.8	32.3	19.4	26.9	-----	27.7	28.0	26.5	5.8	7.3	-----	-----	-----
13	29.8	18.8	30.4	16.1	-----	-----	-----	-----	31.7	17.6	29.1	17.4	30.6	19.4	27.4	-----	28.6	28.5	27.0	4.2	5.0	-----	-----	-----
14	30.3	19.5	31.2	16.9	-----	-----	-----	-----	-----	-----	30.0	18.4	30.9	19.3	28.1	-----	-----	28.7	28.8	3.3	3.7	-----	-----	-----
15	32.2	21.5	33.4	18.6	-----	-----	-----	-----	31.6	18.8	31.0	20.0	31.3	20.0	28.6	-----	28.5	28.4	28.5	4.2	5.1	-----	-----	-----
16	32.5	19.6	33.5	18.0	-----	-----	-----	-----	36.0	17.9	32.0	20.9	33.0	22.0	27.9	-----	29.0	28.9	29.7	6.2	7.7	-----	-----	-----
17	32.8	20.9	34.2	18.0	-----	-----	-----	-----	33.7	18.9	32.7	21.1	33.4	20.4	28.5	-----	30.3	30.1	29.6	4.1	5.0	-----	-----	-----
18	32.8	20.7	34.0	18.8	-----	-----	-----	-----	35.8	19.1	32.3	21.9	34.5	20.1	28.3	-----	29.5	29.7	29.9	6.4	8.2	-----	-----	-----
19	34.7	20.2	36.0	18.5	-----	-----	-----	-----	36.0	19.6	34.5	20.2	36.0	20.5	27.9	-----	29.9	29.8	29.8	6.8	8.8	-----	-----	-----
20	33.5	23.5	34.4	22.3	-----	-----	-----	-----	35.4	21.8	32.0	23.7	35.4	22.5	27.3	-----	29.0	28.0	27.9	13.5	17.1	-----	-----	-----
21	33.4	23.0	35.0	21.4	-----	-----	-----	-----	35.8	20.8	32.3	23.7	36.1	24.5	27.3	-----	28.0	28.0	28.2	9.8	12.8	-----	-----	-----
22	33.9	22.2	35.4	20.7	-----	-----	-----	-----	36.0	21.0	33.4	24.3	37.0	26.2	27.7	-----	29.1	28.8	29.1	6.8	9.4	-----	-----	-----
23	33.3	22.9	34.6	21.2	-----	-----	-----	-----	35.1	21.8	34.8	23.9	34.6	26.0	28.2	-----	30.1	29.9	28.9	5.8	7.1	-----	-----	-----
24	30.4	23.7	30.7	22.8	-----	-----	-----	-----	31.6	22.0	30.8	24.1	31.7	23.3	27.4	-----	28.4	28.8	27.7	8.6	10.8	-----	-----	-----
25	31.2	24.5	31.9	22.9	-----	-----	-----	-----	33.0	22.5	32.8	24.6	33.8	23.0	28.3	-----	28.8	29.8	28.6	5.0	6.5	-----	-----	-----
26	32.0	25.0	32.9	23.5	-----	-----	-----	-----	33.3	22.7	32.6	23.9	33.8	23.1	29.3	-----	29.1	30.0	28.9	-----	6.0	-----	-----	-----
27	31.3	24.1	32.2	22.0	-----	-----	-----	-----	33.0	21.7	31.7	24.0	33.7	23.0	28.6	-----	30.0	30.0	28.6	-----	7.4	-----	-----	-----
28	30.7	23.2	31.2	21.8	-----	-----	-----	-----	31.9	22.0	31.0	23.4	32.4	23.9	28.2	-----	30.0	29.1	28.9	-----	10.0	-----	-----	-----
29	27.8	23.0	27.7	22.2	-----	-----	-----	-----	28.9	22.3	28.8	23.0	29.0	23.6	27.6	-----	29.2	29.0	28.1	4.4	5.1	-----	-----	-----
30	28.8	22.8	29.2	22.1	-----	-----	-----	-----	28.8	22.4	29.3	22.5	29.5	23.7	28.1	-----	29.0	29.4	28.7	4.2	4.8	-----	-----	-----
31	30.9	23.6	31.5	22.0	-----	-----	-----	-----	29.7	22.0	31.1	22.2	31.6	23.0	29.1	-----	31.1	30.0	29.4	3.8	4.6	-----	-----	-----
August 1952																								
1	31.7	22.5	32.2	20.6	-----	-----	-----	-----	33.1	20.4	31.5	21.1	32.3	20.9	29.9	-----	30.8	30.6	29.7	3.3	4.0	-----	-----	-----
2	32.4	22.7	33.6	20.2	-----	-----	-----	-----	33.7	20.0	31.7	20.4	32.5	21.2	30.2	-----	30.7	30.5	30.2	2.8	3.3	-----	-----	-----
3	33.7	23.0	35.0	20.3	-----	-----	-----	-----	35.0	21.1	32.9	20.7	35.4	21.5	30.5	-----	31.4	31.4	31.4	4.2	5.4	-----	-----	-----
4	34.3	22.2	35.5	20.8	-----	-----	-----	-----	37.3	21.0	-----	-----	36.2	21.8	29.6	-----	32.1	-----	30.8	8.0	10.1	-----	-----	-----
5	33.1	24.1	34.6	22.3	-----	-----	-----	-----	36.0	22.2	35.0	24.0	35.3	21.2	28.6	-----	31.0	30.9	29.6	10.3	13.1	-----	-----	-----
6	33.0	24.2	34.5	22.5	-----	-----	-----	-----	35.9	22.1	33.4	24.5	34.8	22.2	28.6	-----	31.4	30.0	29.5	5.2	7.0	-----	-----	-----
7	33.8	23.8	35.2	22.0	-----	-----	-----	-----	36.4	22.0	34.2	22.9	36.1	22.0	29.1	-----	31.0	30.5	30.0	6.1	8.2	-----	-----	-----
8	34.6	23.0	35.8	21.6	-----	-----	-----	-----	37.7	21.8	34.4	24.6	36.8	21.3	29.1	-----	30.8	30.7	29.3	9.6	12.4	-----	-----	-----
9	33.7	22.7	34.5	21.6	-----	-----	-----	-----	35.7	21.7	33.3	24.0	35.4	20.8	28.5	-----	29.9	30.1	28.0	13.1	16.2	-----	-----	-----
10	33.2	21.2	34.6	19.0	-----	-----	-----	-----	36.0	20.3	33.7	23.0	36.0	-----	27.8	-----	29.5	30.0	28.2	9.1	11.6	-----	-----	-----
11	32.5	20.3	33.5	17.7	-----	-----	-----	-----	35.3	19.0	32.4	21.8	35.0	-----	27.9	-----	29.2	29.7	29.1	9.2	12.3	-----	-----	-----
12	31.2	20.8	32.0	18.8	-----	-----	-----	-----	34.3	19.5	32.3	21.0	33.8	-----	27.8	-----	29.0	29.9	29.2	7.6	9.6	-----	-----	-----
13	31.9	22.5	32.4	21.1	-----	-----	-----	-----	32.0	22.1	32.0	22.5	33.0	-----	28.2	-----	29.2	30.0	28.8	6.5	8.1	-----	-----	-----

14	32.9	23.1	33.5	20.9	----	----	----	----	33.9	21.0	31.9	23.9	34.2	21.3	28.3	----	29.5	29.8	28.5	11.5	14.5	----	----	----
15	32.7	23.8	33.7	22.0	----	----	----	----	34.1	21.9	32.1	24.1	35.0	21.9	28.5	----	29.0	29.3	28.8	12.8	15.9	----	----	----
16	31.1	23.4	31.7	21.7	----	----	----	----	32.2	21.8	31.0	23.8	32.9	22.0	28.0	----	29.0	29.0	28.5	11.4	14.1	----	----	----
17	31.1	22.9	32.5	21.9	----	----	----	----	32.3	22.1	31.8	23.2	33.2	22.2	28.2	----	29.6	29.9	29.0	4.5	6.0	----	----	----
18	32.8	23.2	33.8	22.5	----	----	----	----	34.4	22.5	32.1	24.1	34.7	23.0	28.6	----	31.1	30.0	30.0	5.6	7.3	----	----	----
19	33.8	22.4	34.7	21.9	----	----	----	----	34.9	21.0	33.0	23.2	34.9	22.0	28.2	----	30.3	29.4	29.2	9.8	12.3	----	----	----
20	33.1	22.6	33.5	21.0	----	----	----	----	31.7	21.2	32.6	23.0	33.1	22.4	28.2	----	29.8	29.6	27.7	9.6	12.1	----	----	----
21	32.6	22.6	33.6	20.8	----	----	----	----	----	----	32.4	21.5	32.9	22.2	28.1	----	----	30.0	28.5	5.5	7.2	----	----	----
22	32.6	22.2	33.3	20.8	----	----	----	----	----	----	32.9	22.0	34.0	21.2	28.6	----	----	30.6	30.0	3.5	4.8	----	----	----
23	33.2	20.5	34.4	19.0	----	----	----	----	----	----	33.1	21.2	32.5	20.7	28.5	----	----	30.4	30.2	6.0	7.6	----	----	----
24	32.3	21.3	33.2	19.6	----	----	----	----	----	----	32.7	23.7	34.6	21.8	28.2	----	----	30.0	28.6	12.5	15.5	----	----	----
25	31.1	22.4	31.5	21.3	----	----	----	----	32.0	21.4	31.7	22.8	32.6	22.0	27.6	----	30.0	29.1	28.2	9.4	----	----	----	----
26	30.8	22.0	31.4	21.0	----	----	----	----	31.9	21.0	31.0	22.3	32.1	21.2	27.5	----	29.2	29.2	28.2	11.4	----	----	----	----
27	31.5	21.3	31.7	20.7	----	----	----	----	32.3	20.2	31.1	22.1	33.0	21.0	27.2	----	29.0	29.1	27.8	9.9	12.4	----	----	----
28	30.4	22.1	31.1	20.6	----	----	----	----	31.8	20.4	31.0	21.1	32.8	21.4	27.2	----	29.2	29.2	27.9	5.4	6.9	----	----	----
29	30.6	21.5	31.3	19.9	----	----	----	----	----	----	31.1	20.0	31.8	----	27.6	----	----	29.4	28.1	5.4	6.6	----	----	----
30	32.1	21.5	33.4	18.6	----	----	----	----	----	----	32.9	20.3	33.3	----	28.0	----	----	29.6	29.1	3.9	4.8	----	----	----
31	31.0	20.7	32.1	19.2	----	----	----	----	----	----	30.0	18.1	32.6	----	28.4	----	----	29.8	29.9	3.0	3.6	----	----	----

September 1952

1	31.2	21.5	31.3	19.0	----	----	----	----	31.5	18.4	30.0	17.4	32.3	----	28.5	----	29.7	29.5	30.6	2.9	3.3	----	----	----
2	31.4	21.4	31.9	20.3	----	----	----	----	31.7	19.2	31.0	19.8	32.2	----	28.7	----	30.0	30.0	30.5	3.1	3.8	----	----	----
3	33.0	21.7	34.0	19.9	----	----	----	----	34.7	19.2	32.1	20.8	34.5	----	28.5	----	29.6	29.7	30.3	6.2	7.8	----	----	----
4	33.2	21.6	34.3	19.4	----	----	----	----	35.0	20.0	33.0	22.0	34.7	----	28.2	----	32.0	29.2	29.6	5.9	7.6	----	----	----
5	31.8	22.5	32.5	20.6	----	----	----	----	----	----	31.9	21.4	33.3	----	28.3	----	----	29.7	29.7	2.8	3.3	----	----	----
6	31.9	22.3	33.3	19.6	----	----	----	----	----	----	32.3	21.2	34.3	----	28.2	----	----	29.6	30.0	6.1	7.6	----	----	----
7	31.1	21.4	32.3	20.1	----	----	----	----	----	----	31.6	21.2	33.9	----	28.1	----	----	29.0	29.9	5.6	7.1	----	----	----
8	32.1	20.2	33.0	19.0	----	----	----	----	32.4	18.2	31.9	21.9	32.8	----	28.2	----	30.1	28.9	29.7	5.6	7.0	----	----	----
9	31.4	17.4	31.9	15.8	----	----	----	----	31.8	15.6	31.2	18.3	----	----	27.7	----	30.8	29.1	----	9.1	11.3	----	----	----
10	27.6	15.0	27.7	13.9	----	----	----	----	29.7	14.5	29.3	14.9	----	----	26.6	----	27.6	28.3	----	11.1	14.4	----	----	----
11	22.2	11.8	21.9	11.0	----	----	----	----	22.8	11.4	22.2	11.7	23.1	12.5	26.2	----	25.2	27.5	27.0	6.0	6.3	----	----	----
12	23.9	13.0	23.8	12.4	----	----	----	----	23.7	12.7	23.1	12.1	23.7	13.6	26.0	----	25.0	27.7	27.0	4.8	5.2	----	----	----
13	25.0	15.4	24.9	13.2	----	----	----	----	24.9	15.0	24.5	13.1	24.8	14.1	26.0	----	25.8	27.4	26.7	5.4	5.8	----	----	----
14	28.0	17.1	28.3	15.1	----	----	----	----	27.8	16.2	28.1	15.0	27.0	15.8	26.0	----	26.1	27.8	27.5	4.8	5.4	----	----	----
15	27.5	17.3	27.7	16.2	----	----	----	----	28.0	16.4	26.8	15.2	----	----	26.3	----	25.8	28.0	----	4.6	5.5	----	----	----
16	28.6	19.2	29.5	17.8	----	----	----	----	28.4	16.8	29.0	17.4	----	----	26.4	----	26.9	27.8	----	3.9	4.3	----	----	----
17	30.6	21.1	31.3	18.6	----	----	----	----	----	----	31.0	17.9	----	----	26.8	----	----	27.9	----	3.6	4.4	----	----	----
18	29.3	21.0	30.0	19.3	----	----	----	----	27.5	18.8	28.8	18.6	30.0	20.2	27.0	----	26.7	28.4	28.0	2.9	3.4	----	----	----
19	25.6	19.8	25.9	19.2	----	----	----	----	----	----	25.0	19.0	26.2	20.0	26.0	----	----	27.0	26.9	8.0	9.2	----	----	----
20	20.8	18.8	20.1	18.6	----	----	----	----	----	----	21.5	19.4	22.0	20.0	25.0	----	----	25.8	26.0	4.2	----	----	----	----
21	23.5	19.3	23.0	19.1	----	----	----	----	----	----	----	----	----	----	25.2	----	----	----	----	3.2	----	----	----	----
22	25.4	20.5	25.2	19.6	----	----	----	----	----	----	----	----	----	----	25.4	----	----	----	----	3.9	4.2	----	----	----
23	26.2	20.6	26.6	19.4	----	----	----	----	----	----	27.0	19.0	----	----	25.8	----	26.5	27.3	----	3.5	3.9	----	----	----
24	26.8	19.7	27.4	18.6	----	----	----	----	28.1	18.1	27.8	17.4	----	----	26.0	----	26.8	26.7	----	4.2	5.2	----	----	----
25	26.8	20.7	27.2	19.0	----	----	----	----	27.9	17.5	27.5	17.5	28.5	18.0	26.1	----	26.6	27.1	26.9	3.1	3.4	----	----	----
26	26.4	19.4	26.1	18.7	----	----	----	----	26.4	17.9	26.7	17.0	26.8	18.1	26.0	----	26.6	25.8	27.0	2.8	3.1	----	----	----
27	27.1	19.6	27.2	19.0	----	----	----	----	27.7	17.2	25.4	18.0	27.7	18.0	26.3	----	26.8	26.6	26.7	2.8	3.1	----	----	----
28	26.5	19.5	26.5	18.1	----	----	----	----	26.0	17.6	25.9	16.7	27.5	17.4	26.5	----	26.0	26.6	27.0	3.2	3.4	----	----	----
29	26.8	19.7	26.8	18.7	----	----	----	----	26.3	17.7	26.6	17.4	27.1	18.0	26.3	----	26.1	26.8	27.0	----	----	----	----	----
30	27.7	19.7	28.0	17.5	----	----	----	----	28.8	17.1	28.7	16.0	27.5	17.6	26.3	----	26.0	26.6	26.8	3.4	3.8	----	----	----

TABLE 33.—*Daily averages of air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*—Continued

Date	Average air temperature (°C) at indicated height																Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft				Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters									2 meters	8 meters	2¾ meters	8¾ meters	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb												

Date	BB 2 m Dry	BB 2 m Wet	BB 8 m Dry	BB 8 m Wet	VB 2 m Dry	VB 2 m Wet	VB 8 m Dry	VB 8 m Wet	BW Dry	BW Wet	OA Dry	OA Wet	TB Dry	TB Wet	Water BB barge	Water VB barge	Water BW raft	Water OA raft	Water TB raft	Wind BB 2 m	Wind BB 8 m	Wind VB 2¾ m	Wind VB 8¾ m	Wind Boulder Island
October 1952																								
1	27.4	20.0	27.3	18.2	------	------	------	------	28.0	16.9	28.0	16.2	27.0	16.7	26.4	------	26.9	26.0	26.8	2.7	3.0	------	------	------
2	26.5	19.2	26.4	17.9	------	------	------	------	26.4	16.7	25.8	15.0	27.3	16.6	26.3	------	26.0	26.5	27.0	3.3	3.6	------	------	------
3	27.0	19.6	26.8	18.4	------	------	------	------	26.5	17.8	25.5	16.4	27.0	17.0	26.5	------	26.0	26.7	27.3	2.8	3.0	------	------	------
4	26.8	19.4	26.6	18.4	------	------	------	------	26.2	17.2	25.7	16.1	27.3	17.5	26.4	------	26.4	26.5	27.4	2.8	3.1	------	------	------
5	27.1	19.7	27.0	18.0	------	------	------	------	25.7	16.5	25.5	15.9	26.3	16.6	26.5	------	25.9	26.0	27.5	2.6	2.9	------	------	------
6	26.8	18.6	27.1	16.6	------	------	------	------	25.6	15.7	25.0	15.2	26.6	15.6	26.3	------	25.7	26.0	26.8	3.6	4.0	------	------	------
7	26.0	18.6	26.0	16.1	------	------	------	------	24.8	15.5	25.0	15.0	25.6	14.6	26.2	------	25.3	25.8	26.6	4.6	5.1	------	------	------
8	25.9	17.0	25.7	15.8	------	------	------	------	24.0	15.3	23.7	14.1	24.5	15.5	25.7	------	25.1	25.8	26.0	4.6	5.2	------	------	------
9	25.7	17.1	25.8	16.0	------	------	------	------	26.0	16.0	24.1	15.3	26.2	16.1	25.4	------	25.2	25.6	26.2	5.3	6.2	------	------	------
10	25.0	16.7	25.2	15.8	------	------	------	------	25.7	15.9	23.8	15.1	26.1	16.1	25.2	------	25.1	25.7	25.8	5.1	6.0	------	------	------
11	25.5	17.9	25.1	------	------	------	------	------	24.7	15.1	24.2	14.7	25.4	15.8	25.6	------	25.0	25.5	26.0	3.5	3.7	------	------	------
12	25.4	18.1	25.4	------	------	------	------	------	24.1	15.2	23.7	14.3	24.0	15.3	26.1	------	25.0	25.2	26.0	3.6	3.9	------	------	------
13	25.1	17.3	24.7	16.3	------	------	------	------	23.6	14.7	22.4	13.7	23.8	14.5	25.9	------	25.0	25.0	25.8	3.2	3.6	------	------	------
14	26.0	16.9	25.9	15.7	------	------	------	------	25.0	14.7	24.7	12.5	24.3	14.4	25.8	------	24.6	24.9	25.2	5.1	5.8	------	------	------
15	23.6	14.6	23.8	14.1	------	------	------	------	23.8	12.7	22.4	11.7	22.8	12.9	25.2	------	24.1	24.2	25.1	4.6	5.0	------	------	------
16	22.4	14.5	22.1	14.2	------	------	------	------	22.0	13.0	20.9	11.1	21.8	12.6	24.9	------	24.0	24.1	25.0	4.1	4.3	------	------	------
17	22.0	15.0	21.8	14.8	------	------	------	------	22.0	13.6	21.3	13.0	21.9	13.7	24.6	------	23.6	24.0	24.9	3.6	3.6	------	------	------
18	24.5	15.9	24.8	15.3	------	------	------	------	24.8	15.1	22.9	14.2	24.0	14.6	24.7	------	24.8	24.2	25.0	5.0	5.9	------	------	------
19	24.3	16.3	24.2	15.4	------	------	------	------	24.0	15.0	22.7	14.5	24.8	15.4	24.5	------	23.6	24.0	24.9	3.2	3.3	------	------	------
20	23.4	16.3	23.3	15.3	------	------	------	------	22.6	14.7	22.0	13.8	22.3	14.8	24.6	------	23.6	24.0	24.7	3.4	3.8	------	------	------
21	22.6	15.8	22.5	14.8	------	------	------	------	22.0	14.2	21.9	13.0	21.9	14.1	24.6	------	23.5	23.7	24.9	3.7	4.2	------	------	------
22	22.6	16.0	22.8	15.4	------	------	------	------	21.8	14.1	21.9	13.0	22.1	14.5	24.5	------	23.2	23.7	24.7	3.2	3.3	------	------	------
23	22.6	15.8	22.4	15.5	------	------	------	------	21.6	14.1	21.7	12.9	21.7	13.6	24.2	------	23.4	23.5	24.5	3.5	4.0	------	------	------
24	22.1	15.6	21.7	15.2	------	------	------	------	------	------	20.7	12.0	20.9	13.0	24.2	------	------	23.4	24.2	3.4	3.8	------	------	------
25	21.0	14.2	20.7	14.2	------	------	------	------	------	------	19.3	11.0	19.8	12.4	23.8	------	------	23.0	23.8	3.7	4.0	------	------	------
26	20.6	14.2	20.4	14.0	------	------	------	------	------	------	20.0	11.0	20.0	12.2	23.9	------	------	23.0	23.8	3.8	4.2	------	------	------
27	20.8	14.3	20.7	14.0	------	------	------	------	------	------	19.3	11.1	20.0	12.5	23.7	------	------	22.9	23.8	3.8	4.4	------	------	------
28	20.9	13.6	20.8	13.2	------	------	------	------	------	------	19.6	11.9	20.5	13.1	23.4	------	------	23.1	24.0	3.8	4.1	------	------	------
29	20.4	14.0	20.1	13.5	------	------	------	------	------	------	19.1	10.9	20.2	13.1	23.2	------	------	22.7	23.5	3.7	3.9	------	------	------
30	21.2	15.1	21.2	14.8	------	------	------	------	------	------	20.0	12.1	21.6	14.9	23.0	------	------	22.7	23.6	3.0	3.1	------	------	------
31	22.3	15.4	22.4	14.9	------	------	------	------	------	------	21.5	13.6	22.4	14.3	23.1	------	------	22.7	23.5	6.3	7.4	------	------	------
November 1952																								
1	21.2	14.4	21.1	14.2	------	------	------	------	21.4	13.6	20.3	13.2	21.9	14.3	22.7	------	22.7	22.6	23.1	4.2	4.6	------	------	------
2	21.2	12.2	20.9	------	------	------	------	------	21.0	11.0	20.7	10.4	22.0	13.8	22.8	------	22.5	22.0	23.0	8.2	9.2	------	------	------
3	20.6	12.4	20.8	------	------	------	------	------	------	------	20.8	10.7	22.0	13.8	22.3	------	------	21.5	23.0	8.3	9.6	------	------	------
4	19.6	13.1	19.6	------	------	------	------	------	------	------	18.5	11.4	20.2	13.0	21.9	------	------	21.0	22.5	5.8	6.4	------	------	------
5	18.0	11.9	17.9	------	------	------	------	------	18.2	11.7	16.9	10.0	18.8	11.6	21.7	------	22.0	21.3	22.1	4.5	4.8	------	------	------
6	18.0	11.9	17.8	------	------	------	------	------	18.1	11.7	17.1	9.9	18.8	11.6	21.6	------	21.5	21.3	22.2	4.0	4.3	------	------	------
7	17.6	11.1	17.2	------	------	------	------	------	17.6	11.2	16.3	9.0	17.3	10.8	21.2	------	21.4	21.1	22.0	5.0	5.2	------	------	------
8	17.2	12.1	17.1	------	------	------	------	------	18.0	11.8	16.8	11.0	17.7	12.3	21.4	------	21.7	21.0	21.4	7.3	8.2	------	------	------
9	17.1	8.7	16.9	------	------	------	------	------	17.6	6.6	16.6	7.0	------	------	21.3	------	21.1	20.7	------	------	11.4	------	------	------
10	14.1	7.6	13.8	7.4	------	------	------	------	14.6	7.0	12.7	5.5	------	------	20.8	------	21.0	20.6	------	5.3	6.0	------	------	------
11	14.5	7.7	14.3	------	------	------	------	------	14.8	7.7	13.6	6.0	------	------	20.5	------	20.9	20.7	------	5.2	5.8	------	------	------

12	17.0	9.6	16.9	9.5	---	---	---	---	17.8	9.1	17.4	8.9	---	---	20.5	---	20.3	20.4	---	9.9	11.4	---	---	---
13	16.8	10.1	17.0	9.9	---	---	---	---	16.9	9.8	15.2	8.5	18.9	11.0	20.1	---	20.3	20.0	21.0	7.8	8.7	---	---	---
14	15.9	10.4	15.6	9.8	---	---	---	---	17.0	10.0	17.0	11.1	19.1	11.7	20.2	---	20.4	20.0	20.9	14.6	16.9	---	---	---
15	11.6	7.8	11.2	7.2	---	---	---	---	12.2	7.8	13.2	8.0	12.7	8.1	19.7	---	20.0	19.6	20.7	11.8	13.7	---	---	---
16	9.9	7.3	9.6	7.0	---	---	---	---	10.0	7.9	8.7	7.0	9.7	7.2	19.1	---	19.7	18.9	19.5	6.6	7.2	---	---	---
17	11.1	6.9	10.8	6.8	---	---	---	---	10.7	7.3	10.0	7.2	10.5	7.6	19.0	---	19.1	18.4	19.8	5.2	5.7	---	---	---
18	12.4	7.0	12.3	6.8	---	---	---	---	12.9	6.6	11.6	7.2	12.8	8.2	19.1	---	19.0	18.6	19.7	8.5	9.7	---	---	---
19	13.6	7.8	13.6	7.5	---	---	---	---	14.2	7.2	13.0	7.8	13.0	8.1	19.0	---	18.9	18.8	19.6	7.8	8.8	---	---	---
20	13.2	8.0	13.0	7.6	---	---	---	---	12.6	7.8	12.3	8.0	12.3	7.9	18.7	---	18.9	18.6	19.6	6.3	7.3	---	---	---
21	12.8	8.2	12.6	7.9	---	---	---	---	12.6	8.1	11.3	7.1	13.6	8.6	18.6	---	18.6	18.5	19.7	6.8	8.2	---	---	---
22	10.3	4.6	10.2	4.2	---	---	---	---	11.0	4.5	10.0	4.3	11.5	6.4	18.4	---	18.8	17.8	19.6	8.8	9.9	---	---	---
23	8.9	4.2	8.5	3.6	---	---	---	---	9.1	3.4	8.9	3.7	9.7	5.1	18.3	---	18.7	17.7	18.8	11.4	13.0	---	---	---
24	9.4	3.7	9.2	3.1	---	---	---	---	9.4	3.2	8.5	3.0	8.8	4.4	17.8	---	18.2	17.3	18.6	8.9	10.0	---	---	---
25	9.0	4.5	8.7	4.2	---	---	---	---	8.8	4.0	7.4	3.0	8.0	4.0	17.7	---	17.8	17.0	18.2	5.3	6.3	---	---	---
26	8.5	3.8	8.2	3.1	---	---	---	---	7.8	3.7	8.0	2.6	8.6	4.0	17.5	---	17.8	17.0	18.2	8.4	9.4	---	---	---
27	7.1	2.0	6.7	1.4	---	---	---	---	7.0	2.0	6.3	1.7	7.4	3.1	17.2	---	17.5	16.8	18.2	7.1	7.5	---	---	---
28	7.2	3.0	7.0	2.6	---	---	---	---	7.0	2.5	6.3	1.8	6.7	2.5	17.1	---	17.0	16.5	17.9	7.2	7.9	---	---	---
29	8.4	4.0	8.1	3.1	---	---	---	---	8.3	3.4	7.9	2.8	7.8	3.4	16.8	---	17.0	16.3	17.9	7.4	8.1	---	---	---
30	10.2	5.5	10.1	5.3	---	---	---	---	10.3	6.0	10.0	5.3	9.8	5.9	16.8	---	17.0	15.9	17.7	6.3	7.0	---	---	---

December 1952

1	9.4	5.9	9.1	---	---	---	---	---	---	---	8.8	5.7	9.2	6.2	16.9	---	---	15.8	17.4	9.8	10.7	---	---	---
2	11.9	7.2	11.7	7.1	---	---	---	---	---	---	11.9	7.6	---	---	16.8	---	---	16.2	---	9.6	10.9	---	---	---
3	10.6	5.2	10.5	5.1	---	---	---	---	---	---	9.5	5.1	---	---	16.4	---	---	15.7	---	7.3	8.2	---	---	---
4	9.2	5.0	9.0	4.8	---	---	---	---	---	---	7.7	3.4	---	---	---	---	---	15.6	---	7.0	7.7	---	---	---
5	7.6	4.8	7.7	4.7	---	---	---	---	---	---	6.7	3.3	7.0	5.0	---	---	---	15.1	17.0	8.7	9.8	---	---	---
6	---	---	---	---	---	---	---	---	---	---	9.0	5.5	11.7	7.0	---	---	---	15.1	17.0	6.9	11.0	---	---	---
7	---	---	---	---	---	---	---	---	---	---	12.3	7.7	14.2	8.9	---	---	---	15.2	17.1	19.6	22.8	---	---	---
8	---	---	---	---	---	---	---	---	---	---	12.6	8.2	14.1	9.2	---	---	---	15.2	17.0	8.9	10.4	---	---	---
9	12.3	7.1	12.1	6.9	---	---	---	---	---	---	11.2	6.6	11.1	7.3	16.0	---	---	15.0	16.8	5.8	6.6	---	---	---
10	11.6	7.1	11.2	6.8	---	---	---	---	---	---	11.2	6.7	10.1	6.4	16.0	---	---	---	16.8	5.1	5.9	---	---	---
11	11.7	7.3	11.4	---	---	---	---	---	---	---	---	---	10.0	6.5	15.9	---	---	---	16.6	4.8	5.4	---	---	---
12	13.4	9.3	13.1	8.9	---	---	---	---	---	---	---	---	11.2	7.2	15.8	---	---	---	16.5	4.4	4.8	---	---	---
13	16.4	10.3	16.4	9.8	---	---	---	---	---	---	---	---	12.8	8.3	15.9	---	---	---	16.0	6.2	7.1	---	---	---
14	15.0	10.9	14.9	10.6	---	---	---	---	---	---	---	---	13.0	8.7	15.8	---	---	---	16.3	5.3	5.8	---	---	---
15	13.6	10.0	13.1	---	---	---	---	---	---	---	---	---	12.7	8.9	15.6	---	---	---	16.0	3.0	3.4	---	---	---
16	13.4	9.8	13.2	9.8	---	---	---	---	---	---	12.8	8.5	12.8	9.3	15.4	---	---	---	15.6	3.4	4.2	---	---	---
17	13.7	10.8	13.4	---	---	---	---	---	---	---	13.1	10.9	12.6	11.0	15.6	---	---	14.8	15.6	6.5	7.3	---	---	---
18	12.9	11.0	12.2	---	---	---	---	---	---	---	12.7	11.2	12.5	11.0	15.2	---	---	14.8	15.6	4.4	5.3	---	---	---
19	13.9	11.1	13.7	---	---	---	---	---	---	---	14.0	11.1	14.3	11.0	15.7	---	---	15.0	16.2	11.2	12.4	---	---	---
20	12.6	9.6	12.7	---	---	---	---	---	---	---	12.6	9.7	13.1	9.8	15.7	---	---	14.2	15.9	10.0	11.4	---	---	---
21	11.8	7.0	11.4	6.9	---	---	---	---	---	---	11.2	7.3	---	---	15.1	---	---	14.3	---	6.3	7.1	---	---	---
22	12.6	8.3	9.6	5.7	---	---	---	---	---	---	8.0	4.8	8.9	5.6	15.2	---	---	14.0	15.8	6.6	7.2	---	---	---
23	10.2	4.8	8.9	---	---	---	---	---	---	---	8.7	4.0	9.8	5.0	15.7	---	---	14.4	15.8	10.1	11.4	---	---	---
24	7.0	2.9	7.0	---	---	---	---	---	---	---	6.0	2.3	6.4	3.5	15.0	---	---	14.0	15.7	5.5	6.1	---	---	---
25	8.0	4.5	7.8	---	---	---	---	---	---	---	7.1	4.2	7.3	4.4	15.0	---	---	14.0	15.0	5.2	5.7	---	---	---
26	8.3	5.1	8.0	---	---	---	---	---	---	---	6.3	3.6	6.8	4.0	15.0	---	---	14.5	15.0	6.2	6.8	---	---	---
27	8.6	5.7	8.2	---	---	---	---	---	---	---	7.2	4.4	7.2	4.7	14.8	---	---	14.0	15.0	4.5	5.0	---	---	---
28	9.4	6.1	9.2	---	---	---	---	---	---	---	7.7	4.8	7.8	5.0	14.9	---	---	13.8	15.0	5.8	6.3	---	---	---
29	9.0	5.9	8.9	---	---	---	---	---	---	---	7.0	4.7	7.2	4.7	14.9	---	---	13.8	14.9	4.6	5.2	---	---	---
30	10.6	6.6	10.4	6.6	---	---	---	---	---	---	7.8	4.9	7.0	5.2	15.0	---	---	13.6	14.4	8.2	9.3	---	---	---
31	10.6	7.2	10.4	7.2	---	---	---	---	---	---	9.5	6.8	9.5	6.1	15.1	---	---	13.8	14.5	8.9	10.1	---	---	---

TABLE 33.—*Daily averages of air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*—Continued

Date	Average air temperature (°C) at indicated height														Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft		Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters											
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb						2 meters	8 meters	2¾ meters	8¾ meters	
January 1953																								
1	10.4	7.4	9.9	----	----	----	----	----	----	----	8.4	6.3	8.4	6.1	14.6	----	----	13.7	14.7	3.8	4.3	----	----	----
2	10.3	7.4	10.0	----	----	----	----	----	----	----	8.4	6.3	8.9	6.4	14.5	----	----	13.6	14.8	5.2	5.8	----	----	----
3	11.0	8.2	10.2	----	----	----	----	----	----	----	9.0	7.0	8.7	6.9	14.5	----	----	13.7	14.7	4.3	4.7	----	----	----
4	11.4	7.9	11.0	----	----	----	----	----	----	----	8.8	6.4	8.9	6.0	14.4	----	----	13.5	14.8	4.8	5.2	----	----	----
5	10.3	7.1	10.0	----	----	----	----	----	----	----	8.1	5.4	8.8	6.3	14.2	----	----	13.1	14.8	3.7	4.1	----	----	----
6	13.8	8.9	13.8	8.8	----	----	----	----	----	----	11.6	7.4	12.6	7.7	14.5	----	----	12.9	14.6	16.0	18.3	----	----	----
7	14.6	10.0	14.7	10.0	----	----	----	----	----	----	14.0	10.8	15.0	10.3	14.5	----	----	12.9	13.9	16.5	19.5	----	----	----
8	14.8	12.3	14.8	12.2	----	----	----	----	----	----	13.2	11.0	15.3	12.1	14.1	----	----	12.8	14.2	5.8	7.9	----	----	----
9	13.8	12.1	13.4	11.8	----	----	----	----	----	----	13.2	11.1	13.1	11.0	14.1	----	----	13.0	14.4	3.7	4.3	----	----	----
10	13.3	11.4	12.9	11.2	----	----	----	----	----	----	12.5	10.0	12.2	10.0	14.1	----	----	13.6	14.8	3.3	3.7	----	----	----
11	12.8	10.8	12.2	10.7	----	----	----	----	----	----	11.3	9.1	11.6	9.5	14.2	----	----	13.1	14.5	2.9	3.1	----	----	----
12	12.9	10.6	13.0	10.2	----	----	----	----	----	----	11.9	9.4	12.4	9.8	14.1	----	----	13.4	14.3	2.8	3.0	----	----	----
13	14.0	10.7	14.0	10.5	----	----	----	----	----	----	12.2	9.4	13.7	10.0	14.0	----	----	13.2	14.8	8.4	9.9	----	----	----
14	14.2	7.7	14.0	7.1	----	----	----	----	----	----	12.6	6.9	13.2	7.1	14.0	----	----	13.0	14.0	10.6	12.3	----	----	----
15	12.9	7.1	12.6	6.5	----	----	----	----	----	----	12.5	6.3	12.7	6.5	13.9	----	----	13.0	13.9	10.6	12.3	----	----	14.0
16	10.6	5.4	10.3	5.0	----	----	----	----	----	----	9.1	4.5	9.0	4.5	13.8	----	----	12.9	13.8	6.4	7.0	----	----	7.0
17	10.4	6.0	10.0	5.8	----	----	----	----	----	----	9.0	4.8	8.5	4.6	13.5	----	----	12.8	13.8	3.5	4.3	----	----	2.5
18	10.9	7.0	10.7	6.7	----	----	----	----	----	----	9.7	5.7	9.7	5.6	13.5	----	----	12.7	13.8	2.9	3.6	----	----	2.2
19	11.8	7.8	11.4	7.5	----	----	----	----	----	----	9.4	5.6	10.0	6.1	13.3	----	----	12.5	13.7	3.4	3.6	----	----	2.1
20	12.6	8.2	12.6	8.0	----	----	----	----	----	----	9.9	6.3	10.5	7.0	13.4	----	----	12.3	13.6	6.7	7.8	----	----	6.7
21	14.5	8.2	14.3	7.6	----	----	----	----	----	----	13.4	7.0	13.5	7.5	13.6	----	----	12.6	13.5	----	12.3	----	----	12.8
22	12.3	6.4	12.4	6.0	----	----	----	----	----	----	11.4	5.3	11.5	6.0	13.4	----	----	12.1	13.6	----	8.0	----	----	6.8
23	12.1	7.8	12.0	7.3	----	----	----	----	----	----	11.0	6.0	10.2	5.9	13.4	----	----	12.8	13.7	----	4.6	----	----	2.9
24	11.7	8.2	11.8	7.8	----	----	----	----	----	----	----	----	10.7	7.0	13.3	----	----	----	13.7	----	3.6	----	----	2.1
25	13.7	9.6	13.8	9.0	----	----	----	----	----	----	----	----	14.4	8.9	13.3	----	----	----	13.9	----	9.8	----	----	9.8
26	14.7	9.6	14.9	9.0	----	----	----	----	----	----	----	----	14.0	8.4	13.3	----	----	----	13.9	5.4	6.4	----	----	5.0
27	13.1	6.8	13.0	6.0	----	----	----	----	----	----	----	----	11.5	6.0	13.4	----	----	----	13.3	5.7	6.5	----	----	4.3
28	10.0	5.4	9.8	4.8	----	----	----	----	----	----	----	----	9.0	4.8	13.3	----	----	----	13.7	3.8	4.1	----	----	2.9
29	11.3	7.0	11.1	6.5	----	----	----	----	----	----	----	----	10.5	6.5	13.3	----	----	----	13.8	3.4	3.7	----	----	2.2
30	13.2	7.8	13.6	7.4	----	----	----	----	----	----	----	----	11.0	7.0	13.1	----	----	----	13.7	5.3	6.4	----	----	5.4
31	14.0	7.9	14.3	7.1	----	----	----	----	----	----	----	----	12.0	7.0	13.1	----	----	----	13.9	5.4	6.2	----	----	5.5
February 1953																								
1	11.0	7.1	10.7	6.8	----	----	----	----	----	----	----	----	10.0	4.9	13.2	----	----	----	13.6	3.6	3.9	----	----	2.3
2	11.5	7.5	11.3	6.5	----	----	----	----	----	----	----	----	10.6	6.7	13.3	----	----	----	13.8	3.2	3.4	----	----	2.2
3	11.7	7.9	11.8	7.5	----	----	----	----	----	----	----	----	11.0	7.0	13.4	----	----	----	13.8	2.6	2.9	----	----	2.2
4	12.3	8.5	12.4	7.8	----	----	----	----	----	----	----	----	11.8	7.4	13.3	----	----	----	13.7	3.0	3.2	----	----	2.5
5	13.3	8.2	13.5	7.9	----	----	----	----	----	----	----	----	12.5	8.0	13.3	----	----	----	13.9	2.6	2.9	----	----	3.0
6	15.2	10.8	15.6	9.6	----	----	----	----	----	----	----	----	13.5	9.1	13.4	----	----	----	14.1	3.2	3.9	----	----	2.5
7	15.2	10.4	15.6	9.7	----	----	----	----	----	----	----	----	14.5	9.1	13.8	----	----	----	14.8	3.5	4.1	----	----	3.2
8	14.8	8.4	14.9	7.8	----	----	----	----	----	----	----	----	15.0	7.9	13.3	----	----	----	13.6	13.4	16.2	----	----	17.9
9	12.0	6.4	11.6	5.6	----	----	----	----	----	----	----	----	11.6	5.9	13.3	----	----	----	12.9	13.3	14.8	----	----	15.4
10	10.9	5.0	10.6	4.7	----	----	----	----	----	----	----	----	10.8	5.2	13.0	----	----	----	13.3	8.2	9.2	----	----	8.8
11	9.4	4.8	9.0	4.7	----	----	----	----	----	----	8.9	3.9	8.9	4.2	13.0	----	----	12.0	12.9	4.2	4.6	----	----	2.9

12	12.0	6.6	12.0	6.2	-----	-----	-----	-----	-----	-----	11.3	5.0	11.1	5.8	13.2	-----	-----	12.1	13.0	12.6	14.7	-----	-----	15.3
13	11.9	6.4	11.9	6.2	-----	-----	-----	-----	-----	-----	11.4	5.5	11.3	5.9	12.9	-----	-----	11.7	12.9	6.0	6.8	-----	-----	5.5
14	11.4	6.9	11.7	6.5	-----	-----	-----	-----	-----	-----	10.6	5.8	10.6	5.9	12.8	-----	-----	12.1	13.3	3.6	4.0	-----	-----	2.7
15	12.9	7.4	13.0	6.9	-----	-----	-----	-----	-----	-----	11.0	6.2	12.1	6.5	12.8	-----	-----	12.1	12.9	4.1	4.6	-----	-----	3.7
16	12.4	6.8	12.4	6.3	-----	-----	-----	-----	-----	-----	11.0	5.0	10.9	5.5	12.8	-----	-----	11.9	12.9	4.1	4.6	-----	-----	3.3
17	11.1	6.6	11.2	5.8	-----	-----	-----	-----	-----	-----	10.2	5.8	10.4	5.1	13.0	-----	-----	12.2	13.2	3.7	4.0	-----	-----	2.9
18	11.6	5.2	11.4	4.9	-----	-----	-----	-----	-----	-----	9.6	3.1	10.9	4.9	12.5	-----	-----	11.5	12.9	11.7	13.6	-----	-----	14.1
19	8.6	3.9	8.1	3.2	-----	-----	-----	-----	-----	-----	7.7	1.4	8.4	-----	12.8	-----	-----	10.7	12.3	15.2	17.7	-----	-----	15.7
20	7.5	2.1	7.2	1.6	-----	-----	-----	-----	-----	-----	6.1	0.5	7.2	-----	12.4	-----	-----	10.5	12.4	9.7	10.9	-----	-----	10.2
21	8.6	2.7	7.9	2.3	-----	-----	-----	-----	-----	-----	7.8	2.7	7.9	-----	12.3	-----	-----	10.6	12.3	11.2	12.8	-----	-----	14.3
22	8.3	2.3	8.5	2.2	-----	-----	-----	-----	-----	-----	7.4	3.3	6.5	-----	12.4	-----	-----	10.7	12.7	4.5	4.8	-----	-----	3.8
23	9.1	3.6	8.9	3.2	-----	-----	-----	-----	-----	-----	-----	-----	7.6	-----	12.0	-----	-----	11.1	12.5	5.3	5.8	-----	-----	3.6
24	10.1	6.7	9.8	6.3	-----	-----	-----	-----	-----	-----	8.8	5.0	11.4	-----	12.5	-----	-----	11.3	12.4	14.0	16.2	-----	-----	15.8
25	9.8	6.4	9.6	6.3	-----	-----	-----	-----	-----	-----	9.3	5.3	-----	-----	12.4	-----	-----	11.2	-----	4.4	4.8	-----	-----	-----
26	10.7	6.3	10.9	5.7	-----	-----	-----	-----	-----	-----	9.9	4.9	-----	-----	12.5	-----	-----	11.8	-----	4.0	4.4	-----	-----	-----
27	11.8	6.8	12.6	6.6	-----	-----	-----	-----	-----	-----	10.2	5.2	11.8	6.6	12.7	-----	-----	12.0	13.3	3.6	4.1	-----	-----	-----
28	12.6	8.0	12.9	7.6	-----	-----	-----	-----	-----	-----	11.1	6.8	13.4	7.7	12.4	-----	-----	11.6	12.8	10.2	12.1	-----	-----	-----

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1	10.2	5.1	10.4	4.9	-----	-----	-----	-----	-----	-----	10.5	5.1	-----	-----	12.3	-----	-----	11.0	-----	15.9	18.0	-----	-----	-----
2	7.8	4.0	8.4	4.0	-----	-----	-----	-----	-----	-----	6.5	3.0	7.0	3.9	12.2	-----	-----	10.8	11.7	5.0	5.5	-----	-----	-----
3	10.2	4.6	10.4	4.2	-----	-----	-----	-----	-----	-----	8.3	3.1	9.5	3.5	12.2	-----	-----	10.8	11.9	8.4	9.6	-----	-----	9.4
4	10.8	5.7	11.1	5.4	-----	-----	-----	-----	-----	-----	9.2	4.3	10.0	4.5	12.2	-----	-----	11.1	12.2	5.6	6.4	-----	-----	4.3
5	13.7	7.9	14.1	7.6	-----	-----	-----	-----	-----	-----	12.8	6.7	13.0	5.7	12.6	-----	-----	11.7	13.0	5.0	5.8	-----	-----	4.0
6	13.6	7.6	13.4	7.2	-----	-----	-----	-----	-----	-----	-----	-----	14.0	7.0	13.0	-----	-----	-----	13.6	3.6	4.0	-----	-----	2.5
7	16.8	9.1	17.7	8.5	-----	-----	-----	-----	-----	-----	-----	-----	16.1	8.2	13.0	-----	-----	-----	13.3	4.6	5.7	-----	-----	5.4
8	14.5	9.8	15.0	9.1	-----	-----	-----	-----	-----	-----	-----	-----	16.2	9.3	13.5	-----	-----	-----	14.3	2.6	3.0	-----	-----	2.4
9	15.2	9.3	15.7	9.1	-----	-----	-----	-----	-----	-----	-----	-----	16.7	9.8	13.4	-----	-----	-----	14.1	6.0	7.8	-----	-----	5.7
10	16.0	9.2	16.6	8.6	-----	-----	-----	-----	-----	-----	-----	-----	16.8	8.8	13.0	-----	-----	-----	13.1	8.9	10.9	-----	-----	10.8
11	13.9	8.6	14.1	-----	-----	-----	-----	-----	-----	-----	-----	-----	14.7	7.7	13.0	-----	-----	-----	12.9	4.5	5.6	-----	-----	5.1
12	15.5	8.9	16.0	-----	-----	-----	-----	-----	-----	-----	14.4	7.8	16.8	8.9	12.4	-----	-----	12.7	13.8	12.7	15.5	-----	-----	15.8
13	13.2	8.0	13.6	-----	-----	-----	-----	-----	-----	-----	13.2	6.8	13.9	6.8	12.7	-----	-----	12.1	12.9	5.2	6.3	-----	-----	6.1
14	12.7	6.8	12.8	-----	-----	-----	-----	-----	-----	-----	12.1	4.8	12.9	5.7	12.9	-----	-----	11.7	12.8	5.1	5.8	-----	-----	5.7
15	12.0	6.9	12.2	-----	-----	-----	-----	-----	-----	-----	11.8	4.9	12.3	5.9	13.4	-----	-----	12.8	13.8	3.5	3.8	-----	-----	2.3
16	15.0	8.4	15.6	-----	-----	-----	-----	-----	-----	-----	13.5	-----	15.1	7.3	13.8	-----	-----	13.3	14.0	5.4	6.9	-----	-----	6.0
17	17.4	9.4	18.5	8.6	-----	-----	-----	-----	-----	-----	16.2	-----	18.7	9.4	13.4	-----	-----	14.3	13.8	5.6	7.1	-----	-----	-----
18	16.7	8.9	16.8	8.3	-----	-----	-----	-----	-----	-----	15.3	7.7	17.8	8.9	13.7	-----	-----	13.4	14.0	6.0	7.5	-----	-----	-----
19	19.4	9.8	19.7	9.7	-----	-----	-----	-----	-----	-----	18.7	10.4	20.8	9.8	13.1	-----	-----	13.4	13.8	14.3	17.9	-----	-----	16.6
20	16.4	8.2	16.6	7.7	-----	-----	-----	-----	-----	-----	15.8	7.4	16.8	7.9	12.6	-----	-----	12.3	12.7	13.3	16.1	-----	-----	16.7
21	14.3	7.7	15.0	7.1	-----	-----	-----	-----	-----	-----	13.7	7.4	15.5	7.1	12.6	-----	-----	12.7	12.8	6.4	7.7	-----	-----	8.1
22	14.8	8.5	15.1	7.0	-----	-----	-----	-----	-----	-----	13.9	7.3	15.6	7.1	13.7	-----	-----	12.7	13.7	4.6	5.5	-----	-----	-----
23	14.9	9.4	15.9	8.8	-----	-----	-----	-----	-----	-----	15.7	-----	16.6	7.9	14.6	-----	-----	13.4	15.0	2.8	3.1	-----	-----	-----
24	17.2	10.6	18.6	9.7	-----	-----	-----	-----	-----	-----	17.4	-----	18.0	9.8	15.0	-----	-----	14.9	16.4	3.5	4.5	-----	-----	3.4
25	19.2	11.1	20.5	10.1	-----	-----	-----	-----	-----	-----	17.3	10.7	-----	-----	13.7	-----	-----	14.5	-----	6.3	8.6	-----	-----	8.8
26	16.5	9.7	18.9	9.6	-----	-----	-----	-----	-----	-----	17.9	9.6	-----	-----	14.6	-----	-----	15.9	-----	6.0	8.0	-----	-----	-----
27	17.8	10.7	19.0	10.4	-----	-----	-----	-----	-----	-----	18.1	10.0	-----	-----	14.2	-----	-----	17.4	-----	5.2	6.6	-----	-----	-----
28	19.2	11.1	20.3	11.3	-----	-----	-----	-----	-----	-----	19.8	11.2	-----	-----	13.6	-----	-----	16.2	-----	8.7	10.3	-----	-----	10.4
29	14.3	9.4	14.3	9.2	-----	-----	-----	-----	-----	-----	15.7	8.6	-----	-----	13.4	-----	-----	14.7	-----	9.6	11.3	-----	-----	10.6
30	14.4	10.6	14.4	10.4	-----	-----	-----	-----	-----	-----	15.2	9.5	-----	-----	14.6	-----	-----	15.1	-----	3.7	4.4	-----	-----	4.0
31	15.8	10.4	16.2	9.8	-----	-----	-----	-----	-----	-----	16.0	11.0	-----	-----	15.7	-----	-----	16.1	-----	3.5	4.3	-----	-----	3.0

TABLE 33.—*Daily averages of air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*—Continued

Date	Average air temperature (°C) at indicated height														Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft		Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters							2 meters	8 meters	2¾ meters	8¾ meters	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb										
April 1953																								
1	17.6	10.3	18.5	10.0							18.0	10.5			15.5			17.0		5.6	7.2			
2	19.7	11.7	20.5	10.6							20.0	12.0			15.8			17.8		4.7	6.1			
3	19.4	11.9	20.7	10.8							20.0	12.0			16.8			17.7		4.6	5.9			
4	20.0	12.0	21.4	11.3											17.5					4.2	5.2			
5	20.0	12.2	20.4	11.3											16.6					10.3	12.9			12.5
6	17.3	11.7	17.5	11.3											13.3					16.8	20.5			21.0
7	13.0	5.8	13.1	5.7											13.5									14.5
8	11.9	4.8	11.9	4.4							12.1	4.9			13.7			14.0						12.8
9	12.5	5.2	12.7	5.0							11.2	4.6			14.0			14.7						6.9
10	13.7	5.8	13.8	5.5							14.1	6.4	16.2	7.3	13.7			14.2	15.1	8.4	9.6			10.3
11	12.5	5.3	12.6	4.8							12.4	5.0	13.8	6.0	13.6			14.2	15.0	6.5	7.3			7.4
12	13.6	6.4	13.8	5.8							12.8	6.3	15.0	6.7	13.6			15.0	15.7	6.2	6.9			
13	14.3	8.1	15.0	7.3							14.1	7.7	17.4	9.5	13.4			14.8	15.2	4.9	6.0			
14	15.7	9.3	16.2	8.6							15.9	8.4	17.2	8.7	14.2			16.2	16.6	3.2	3.7			2.3
15	17.0	9.4	17.7	8.4							17.1	8.6	19.0	8.9	15.7			17.0	17.7	3.1	3.7			3.2
16	16.5	10.4	16.6	9.9							19.7	9.4	21.7	10.8	15.2			16.4	17.3	9.2	11.4			10.4
17	18.9	9.9	19.2	9.2							21.3	10.2	22.0	11.7	14.7			15.9	15.7	6.4	7.7			
18	19.6	10.4	19.8	9.6							20.0	9.8	21.3	11.0	16.2			16.1	15.8	4.2	5.0			
19	19.6	12.3	19.7	11.6							20.9	11.9			16.3			17.5		6.1	7.7			
20											21.7	12.8			16.0			18.8		3.4	4.3			
21	22.0	12.5									21.4	12.9			16.7			17.6		5.1	6.8			6.9
22	19.2	14.3	19.7	13.4							18.7	13.0			16.6			16.8		7.5	9.4			
23	20.5	14.3	21.3	13.8							20.0	13.6	22.9	13.7	16.3			16.8	17.0	10.1	12.1			
24	21.5	14.6	23.0	13.2							23.2	12.9	23.4	13.4	16.9			19.7	19.0	4.0	5.6			
25	23.6	15.7	24.3	14.1							24.8	13.8	25.7	13.8	18.1			19.8	20.8	4.9	6.8			5.3
26	24.4	14.1	25.0	13.4							25.0	15.0	28.0	14.4	17.4			20.0	21.2	9.4	12.8			14.5
27	21.7	14.1	22.4	13.6							21.8	14.1	23.6	13.7	15.9			18.4	18.0	14.6	18.2			17.3
28	19.3	10.9	19.6	9.9							19.0	10.0	19.8	9.7	16.7			17.5	16.0	10.8	13.0			12.5
29	18.9	10.5	19.1	9.7							18.8	9.4	19.8	10.0	16.7			17.7	17.7	10.5	12.4			11.0
30	18.2	9.9	18.2	9.2							17.4	8.5	17.0	9.0	16.0			17.0	16.5	10.2	12.1			
May 1953																								
1	17.5	9.4	17.5	8.5							16.1	7.9	17.5	8.6	16.8				17.2	8.6	10.0			11.0
2	17.8	9.4	17.8	8.8							17.0	8.2	18.0	8.7	16.6				17.3	10.9	12.9			13.4
3	19.3	9.9	20.0	8.9							19.7	9.0	20.0	9.4	17.1				17.2	7.5	9.1			9.1
4	20.4	11.2	21.5	10.3							21.6	10.3	21.3	10.9					17.5	6.0	7.7			7.8
5											22.9	11.3	22.3	10.8					18.6	3.4	4.1			3.2
6					21.5	13.1	23.0	11.8			21.1	12.2	24.0	11.6		18.8			19.6	5.2	6.9			6.8
7					22.1	11.7	23.2	10.6			23.2	11.6	24.4	11.6		17.5			17.8	10.5	13.1			13.5
8	19.6	9.8	20.0	9.0	19.8	10.2	20.1	9.1			20.8	10.0			16.5					13.7	16.4			15.9
9	17.3	8.9	17.4	8.1	17.5	9.0	17.6	8.0			17.7	8.5			16.4					9.3	10.9			12.1
10	17.6	9.3	17.7	8.0	17.2	8.5	17.4	7.6			17.0	7.7			16.9					7.6	9.0			9.5
11	17.0	8.9	17.1	7.7	16.8	8.2	17.1	7.8			17.2	8.7			16.5			17.4		7.8	9.2			9.8
12	18.7	10.6	19.4	9.1	18.1	10.3	18.6	8.8			18.9	9.8			17.1			18.3		5.3	6.3			4.9

13	19.9	11.0	20.9	10.2	-----	-----	-----	-----	-----	-----	19.7	10.7	-----	-----	17.8	-----	-----	19.5	-----	4.5	5.6	-----	-----	5.3
14	22.1	12.0	23.0	10.7	21.9	12.1	22.8	10.7	-----	-----	21.9	11.7	-----	-----	17.0	18.0	-----	19.0	-----	9.4	12.1	-----	-----	11.8
15	17.6	10.9	17.6	10.2	18.1	10.9	18.1	10.2	-----	-----	19.5	11.0	19.9	11.0	16.5	-----	-----	18.8	17.4	8.6	10.4	11.0	-----	9.9
16	18.2	11.2	18.4	10.5	-----	-----	-----	-----	-----	-----	17.7	11.7	19.5	10.9	16.8	-----	-----	17.6	17.9	8.3	10.0	5.9	-----	9.5
17	21.6	13.8	22.9	12.4	21.6	13.6	22.6	12.1	-----	-----	22.4	13.4	24.2	13.0	17.7	-----	-----	18.8	19.3	8.5	10.9	6.8	-----	11.6
18	23.9	14.5	25.7	13.0	-----	-----	-----	-----	-----	-----	24.1	15.0	26.4	14.4	18.8	-----	-----	20.8	20.4	8.8	11.6	6.7	-----	12.5
19	25.4	14.7	27.0	13.8	25.0	15.5	25.8	14.8	-----	-----	26.2	14.8	27.8	-----	17.7	17.4	-----	19.8	18.9	13.0	16.6	13.0	-----	17.0
20	24.2	15.0	25.8	14.3	-----	-----	-----	-----	-----	-----	25.1	15.0	26.7	-----	18.2	-----	-----	19.1	19.0	9.8	12.7	-----	-----	12.3
21	25.1	13.8	26.6	13.1	-----	-----	-----	-----	-----	-----	26.7	13.8	27.4	-----	17.7	-----	-----	18.0	17.6	13.9	17.4	-----	-----	16.2
22	24.8	14.4	26.3	13.4	24.3	14.5	26.0	13.8	-----	-----	25.7	14.9	28.1	-----	18.1	18.1	-----	18.9	17.9	9.9	12.7	-----	-----	12.8
23	22.9	12.7	24.1	11.9	23.1	14.1	24.5	13.3	-----	-----	25.4	14.8	26.2	13.8	17.2	17.1	-----	18.8	17.6	15.2	18.8	-----	21.0	-----
24	19.5	9.7	19.7	8.7	19.3	10.5	19.8	9.6	-----	-----	20.2	10.8	21.2	10.1	17.4	17.1	-----	18.8	17.7	8.7	10.3	-----	10.5	-----
25	20.9	10.8	21.3	10.0	-----	-----	-----	-----	-----	-----	23.3	12.9	23.2	11.9	17.2	-----	-----	18.6	17.8	12.8	15.3	-----	15.3	-----
26	19.2	9.8	19.7	8.8	-----	-----	-----	-----	-----	-----	20.2	11.3	-----	-----	17.4	-----	-----	18.1	-----	6.6	7.9	-----	9.6	-----
27	19.3	9.6	19.2	9.0	18.8	10.2	19.2	9.3	-----	-----	19.7	10.6	-----	-----	17.8	-----	-----	19.0	-----	7.8	9.0	-----	13.4	8.2
28	17.0	10.0	16.8	9.3	17.0	9.8	17.0	9.0	-----	-----	17.3	10.0	17.8	9.7	17.3	-----	-----	18.4	17.4	11.4	13.3	-----	13.7	12.2
29	19.4	11.7	19.8	10.8	-----	-----	-----	-----	-----	-----	18.2	11.2	20.1	11.6	17.4	-----	-----	19.0	18.3	6.5	8.0	-----	7.1	8.2
30	21.6	12.8	22.6	11.5	-----	-----	-----	-----	-----	-----	21.7	13.0	23.5	13.1	18.3	-----	-----	20.2	20.0	6.4	8.1	-----	6.4	6.9
31	23.4	13.2	24.8	12.3	22.6	13.2	24.3	12.0	-----	-----	24.7	13.5	26.3	14.8	18.0	-----	-----	20.7	19.5	7.4	9.6	-----	11.6	10.8

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1	21.9	12.5	22.5	11.5	22.6	12.9	23.3	12.1	-----	-----	24.4	12.9	24.9	-----	18.2	-----	-----	19.9	18.8	8.1	9.9	-----	13.5	9.2
2	20.3	12.7	20.8	11.0	20.7	12.9	21.0	12.4	-----	-----	21.4	12.3	21.8	-----	19.3	-----	-----	20.9	19.9	3.8	4.3	-----	3.5	4.0
3	23.3	13.9	24.5	12.6	-----	-----	-----	-----	-----	-----	22.9	13.6	23.7	-----	20.5	-----	-----	21.6	21.5	3.3	4.0	-----	-----	3.3
4	25.6	15.3	26.5	14.0	-----	-----	-----	-----	-----	-----	25.3	15.5	26.7	-----	21.0	-----	-----	22.5	22.0	5.3	6.8	-----	-----	6.5
5	25.6	15.3	27.0	14.0	24.8	14.6	26.4	13.9	-----	-----	25.9	16.9	29.0	17.3	20.1	19.4	-----	21.9	20.6	7.4	9.8	8.0	10.4	9.9
6	24.5	15.3	25.0	14.8	23.9	15.6	24.9	14.9	-----	-----	24.8	16.9	27.0	17.8	19.0	18.9	-----	21.0	19.9	11.1	13.9	10.2	12.8	14.0
7	23.7	15.0	24.4	14.6	23.1	15.9	24.3	-----	-----	-----	24.3	16.7	25.7	17.4	18.9	18.9	-----	20.9	19.8	10.4	13.0	10.1	12.9	13.0
8	24.9	14.6	26.1	13.9	24.7	14.5	25.7	-----	-----	-----	25.7	15.7	26.9	16.4	19.0	19.3	-----	20.5	19.2	11.6	14.5	12.8	16.4	12.8
9	25.2	14.5	26.4	14.2	-----	-----	-----	-----	-----	-----	27.0	15.7	26.3	-----	19.1	-----	-----	20.0	19.0	9.0	11.6	-----	-----	12.2
10	26.1	14.8	27.7	14.0	-----	-----	-----	-----	-----	-----	27.8	15.9	-----	-----	19.9	-----	-----	21.4	-----	7.5	8.8	-----	-----	8.6
11	27.3	16.5	28.3	15.3	26.1	17.1	28.3	15.8	-----	-----	28.6	17.2	-----	-----	21.0	21.1	-----	23.1	-----	5.5	7.5	5.8	-----	6.2
12	28.6	16.9	30.9	16.5	26.9	17.3	29.8	16.4	-----	-----	29.2	19.0	31.0	17.5	20.8	20.6	-----	23.0	21.4	7.2	9.3	7.9	-----	10.4
13	28.5	16.2	29.5	14.6	27.2	16.4	28.5	14.4	-----	-----	30.2	17.4	30.1	15.8	22.3	22.1	-----	24.6	22.1	4.4	5.7	5.0	-----	5.3
14	31.0	17.3	32.1	15.0	27.8	16.2	30.4	14.3	-----	-----	30.9	17.6	30.8	15.3	23.1	22.6	-----	26.0	23.0	5.9	7.7	5.4	-----	6.5
15	30.2	17.4	31.7	14.6	28.9	16.4	29.5	15.2	-----	-----	30.1	17.7	31.4	16.0	23.4	22.9	-----	23.8	23.4	7.1	9.0	8.4	-----	-----
16	29.2	17.1	30.6	15.7	-----	-----	-----	-----	-----	-----	31.2	17.9	31.4	17.0	21.3	21.4	-----	23.5	22.3	10.8	13.8	-----	-----	14.0
17	27.1	17.4	28.6	15.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	22.4	22.1	-----	-----	-----	5.1	6.6	-----	-----	6.8
18	25.6	16.1	26.1	14.4	25.4	15.6	25.7	14.7	-----	-----	-----	-----	-----	-----	22.3	22.5	-----	-----	-----	8.0	10.0	-----	-----	9.8
19	26.1	17.0	27.2	-----	25.9	16.4	26.9	15.8	-----	-----	-----	-----	28.3	15.8	20.7	22.2	-----	-----	21.2	14.1	17.6	-----	-----	18.4
20	28.3	18.0	30.2	-----	27.0	17.8	29.1	15.9	-----	-----	-----	-----	29.0	16.4	22.0	23.0	-----	-----	21.8	8.0	10.8	-----	-----	10.3
21	29.0	-----	30.8	-----	28.3	17.9	30.6	16.0	-----	-----	-----	-----	30.9	16.8	23.3	23.8	-----	-----	24.0	5.2	7.3	-----	-----	6.0
22	30.8	-----	32.5	-----	29.2	18.5	31.3	17.0	-----	-----	-----	-----	32.7	17.8	24.2	24.2	-----	-----	25.3	5.4	7.4	-----	-----	8.0
23	32.1	-----	33.1	-----	31.0	18.7	33.6	17.7	-----	-----	-----	-----	-----	-----	23.7	24.8	-----	-----	-----	7.9	10.7	-----	-----	-----
24	31.2	-----	32.9	-----	-----	-----	-----	-----	-----	-----	32.5	17.9	-----	-----	25.1	-----	-----	26.8	-----	3.6	4.6	-----	-----	-----
25	31.0	17.8	32.2	-----	30.3	17.4	32.1	15.5	-----	-----	31.8	16.9	-----	-----	25.2	25.1	-----	25.0	-----	9.0	11.4	-----	-----	11.9
26	30.8	16.3	32.4	-----	30.8	17.2	32.0	16.0	-----	-----	31.8	17.6	-----	-----	21.9	24.6	-----	24.4	-----	10.1	12.9	-----	-----	12.9
27	27.5	17.3	29.5	-----	27.9	16.7	29.0	14.5	-----	-----	28.4	16.6	-----	-----	23.6	25.1	-----	25.2	-----	3.7	4.7	-----	-----	4.2
28	29.5	16.8	31.0	-----	28.9	16.4	29.8	15.0	-----	-----	29.0	17.8	-----	-----	23.2	24.3	-----	25.0	-----	9.4	12.1	-----	-----	11.5
29	29.3	17.9	30.8	-----	28.4	17.4	30.2	15.6	-----	-----	29.7	18.1	-----	-----	22.9	24.2	-----	25.6	-----	7.5	9.7	-----	-----	9.0
30	30.6	19.0	31.8	-----	29.8	18.6	32.0	17.0	-----	-----	31.6	19.3	-----	-----	23.9	24.5	-----	26.0	-----	4.6	5.8	-----	-----	5.9

TABLE 33.—*Daily averages and air and water temperatures and wind speeds, March 1952–September 1953, at Lake Mead*—Continued

Date	Average air temperature (°C) at indicated height														Average water-surface temperature (°C)					Average wind speed (knots) at indicated height				
	Boulder Basin barge				Virgin Basin barge				Boulder Wash raft		Overton Arm raft		Temple Bar raft		Boulder Basin barge	Virgin Basin barge	Boulder Wash raft	Overton Arm raft	Temple Bar raft	Boulder Basin barge		Virgin Basin barge		Boulder Island
	2 meters		8 meters		2 meters		8 meters		2 meters		2 meters		2 meters											
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb						2 meters	8 meters	2¾ meters	8¾ meters	
July 1953																								
1	31.7	18.7	33.3	17.2	30.4	18.7	32.1	16.2	------	------	------	------	------	------	24.7	25.5	------	------	------	4.6	6.0	5.4	5.9	5.7
2	30.7	18.3	31.6	16.8	30.1	18.4	31.8	16.5	------	------	------	------	------	------	25.2	26.4	------	------	------	4.4	5.5	4.3	5.5	4.4
3	32.8	19.8	34.6	17.9	31.5	20.2	33.6	18.1	------	------	------	------	------	------	25.4	27.0	------	------	------	4.8	6.5	5.3	6.9	6.2
4	32.7	20.4	34.0	19.1	31.1	20.5	33.1	19.1	------	------	------	------	------	------	24.5	25.6	------	------	------	8.9	11.9	8.2	10.7	12.4
5	31.0	21.6	33.4	19.8	31.2	21.2	33.6	19.2	------	------	------	------	------	------	25.3	26.3	------	------	------	4.2	5.6	3.8	4.8	5.1
6	31.9	20.9	33.7	19.5	------	------	------	------	------	------	------	------	------	------	25.4	------	------	------	------	8.9	11.9	------	------	------
7	31.6	21.3	34.0	20.5	------	------	------	------	------	------	------	------	------	------	24.3	------	------	------	------	11.4	15.0	------	------	14.8
8	31.2	21.3	33.9	20.3	------	------	------	------	------	------	------	------	------	------	24.2	------	------	------	------	7.9	10.8	------	------	11.1
9	------	------	------	------	29.8	22.9	31.2	21.6	------	------	------	------	------	------	------	26.7	------	------	------	5.6	7.5	5.3	6.7	------
10	------	------	------	------	31.0	22.6	32.6	21.1	------	------	------	------	------	------	26.5	27.4	------	------	------	5.3	7.0	4.8	5.9	7.0
11	------	------	------	------	32.4	23.0	33.9	21.3	------	------	------	------	------	------	------	28.0	------	------	------	3.9	5.0	4.2	5.5	------
12	------	------	------	------	32.2	22.6	32.6	21.8	------	------	------	------	------	------	------	28.4	------	------	------	5.7	7.2	5.7	7.1	------
13	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	6.0	7.4	5.7	6.9	------
14	29.2	23.2	------	------	29.1	23.2	29.5	22.6	------	------	------	------	------	------	26.9	27.6	------	------	------	6.8	8.4	6.5	7.8	9.4
15	30.4	24.1	30.4	23.2	29.5	23.3	29.9	23.0	------	------	------	------	------	------	28.1	28.4	------	------	------	4.9	6.0	4.3	5.7	6.0
16	29.6	24.2	29.9	23.0	29.0	22.6	29.5	21.6	------	------	------	------	------	------	28.2	27.4	------	------	------	4.0	4.5	6.2	7.4	3.7
17	29.4	23.6	29.7	22.4	28.4	22.5	29.0	21.8	------	------	------	------	------	------	28.0	27.5	------	------	------	4.9	5.8	4.7	5.7	5.8
18	30.5	23.6	31.0	21.8	29.2	22.6	30.0	21.8	------	------	------	------	------	------	28.6	28.4	------	------	------	6.8	8.2	6.1	7.2	7.7
19	32.7	24.2	33.6	21.4	31.2	22.3	32.3	21.5	------	------	------	------	------	------	29.6	29.2	------	------	------	3.6	4.4	4.1	5.2	4.0
20	33.8	24.7	34.9	21.9	32.3	23.2	33.8	21.1	------	------	------	------	------	------	29.6	29.5	------	------	------	5.6	7.2	6.4	7.8	6.5
21	33.7	24.4	35.1	21.8	------	------	------	------	------	------	------	------	------	------	29.7	------	------	------	------	4.1	5.2	3.8	4.9	5.3
22	34.7	24.6	36.2	21.7	------	------	------	------	------	------	------	------	------	------	30.3	------	------	------	------	3.8	4.9	3.8	4.7	5.1
23	36.3	23.8	37.7	21.8	------	------	------	------	------	------	------	------	------	------	30.2	------	------	------	------	7.4	9.7	7.0	8.8	9.5
24	34.8	23.9	35.6	22.7	34.4	22.8	35.4	21.8	------	------	------	------	------	------	28.9	28.6	------	------	------	------	------	12.2	15.1	17.2
25	34.4	24.2	35.3	22.8	32.7	23.2	33.6	22.3	------	------	------	------	------	------	29.0	28.8	------	------	------	------	------	9.4	11.7	13.3
26	------	------	------	------	32.2	23.0	33.5	21.4	------	------	------	------	------	------	------	29.5	------	------	------	7.6	9.9	5.0	6.2	11.0
27	------	------	------	------	32.8	22.7	33.9	20.8	------	------	------	------	------	------	29.3	30.0	------	------	------	7.5	9.7	6.6	8.3	11.1
28	------	------	------	------	31.6	23.2	33.0	21.7	------	------	------	------	------	------	30.0	29.3	------	------	------	3.5	4.5	5.1	6.2	5.8
29	34.1	24.8	34.8	22.4	32.1	23.1	32.9	22.2	------	------	------	------	------	------	30.2	29.4	------	------	------	6.6	8.3	6.2	7.7	------
30	31.3	23.6	31.3	21.8	------	------	------	------	------	------	------	------	------	------	28.8	------	------	------	------	12.7	15.2	10.8	12.7	------
31	30.8	23.8	31.6	21.8	30.1	22.3	30.8	21.0	------	------	------	------	------	------	27.9	28.1	------	------	------	8.3	10.3	6.1	7.5	------
August 1953																								
1	31.5	22.8	32.1	21.0	29.8	21.2	30.1	20.0	------	------	------	------	------	------	27.9	28.2	------	------	------	8.9	10.8	5.2	6.1	------
2	32.6	20.0	33.3	18.2	30.9	19.5	31.6	18.0	------	------	------	------	------	------	28.0	28.0	------	------	------	9.0	11.1	9.5	11.8	------
3	31.9	19.9	32.5	17.2	30.4	18.5	30.8	17.1	------	------	------	------	------	------	28.0	27.6	------	------	------	7.5	9.1	9.6	11.8	------
4	30.4	20.0	30.9	17.6	29.6	18.6	30.3	16.9	------	------	------	------	------	------	28.2	27.4	------	------	------	6.6	8.0	7.6	8.8	6.4
5	30.8	------	31.9	17.0	29.4	18.1	30.3	16.4	------	------	------	------	------	------	28.2	27.8	------	------	------	5.0	6.0	5.7	6.5	4.9
6	31.4	20.3	32.3	18.8	29.9	19.4	31.1	17.4	------	------	------	------	------	------	28.3	28.0	------	------	------	6.2	7.8	5.6	6.9	6.5
7	33.1	21.9	34.4	21.5	32.1	21.9	33.8	19.4	------	------	------	------	------	------	28.1	28.0	------	------	------	6.2	7.9	5.8	7.5	7.2
8	33.3	23.2	35.3	22.0	32.5	22.2	34.0	20.2	------	------	------	------	------	------	28.5	28.6	------	------	------	5.8	7.6	5.8	7.1	6.8
9	32.4	23.7	33.4	22.0	30.5	22.4	31.5	20.6	------	------	------	------	------	------	28.5	28.5	------	------	------	7.8	9.7	6.0	7.3	10.7
10	33.3	24.0	34.2	22.1	30.7	23.0	32.1	20.6	------	------	------	------	------	------	29.2	28.8	------	------	------	6.6	8.3	5.8	7.0	8.8
11	33.7	23.7	34.5	21.6	31.5	22.7	32.2	21.2	------	------	------	------	------	------	29.9	29.4	------	------	------	3.2	4.0	3.3	3.9	4.0
12	33.0	24.4	34.1	21.4	32.0	21.5	32.7	19.9	------	------	------	------	------	------	29.6	28.8	------	------	------	4.4	5.6	5.1	6.4	4.6
13	33.0	23.9	33.9	21.0	30.6	22.4	31.9	20.3	------	------	------	------	------	------	29.4	28.5	------	------	------	6.5	8.3	5.2	6.5	9.2

14	32. 2	22. 7	33. 2	20. 8	30. 6	21. 4	31. 6	20. 3	----	----	----	----	----	----	29. 0	28. 9	----	----	----	4. 3	5. 3	4. 5	5. 4	4. 3
15	31. 9	22. 3	32. 7	20. 8	30. 5	21. 0	30. 9	20. 0	----	----	----	----	----	----	28. 9	28. 7	----	----	----	6. 3	6. 9	5. 7	6. 4	6. 5
16	31. 9	21. 8	32. 8	20. 8	30. 5	21. 1	31. 2	20. 0	----	----	----	----	----	----	28. 6	29. 2	----	----	----	4. 9	6. 1	3. 6	3. 9	4. 3
17	32. 6	20. 3	33. 5	19. 1	31. 3	20. 8	32. 1	18. 9	----	----	----	----	----	----	28. 4	29. 1	----	----	----	5. 6	7. 0	6. 6	7. 8	6. 0
18	32. 5	20. 4	34. 0	18. 5	31. 2	19. 7	32. 0	18. 6	----	----	----	----	----	----	29. 0	29. 0	----	----	----	4. 1	5. 0	5. 8	6. 7	4. 5
19	33. 1	21. 0	34. 3	19. 8	31. 2	21. 0	32. 0	19. 5	----	----	----	----	----	----	28. 5	29. 1	----	----	----	7. 2	9. 0	7. 0	8. 1	8. 0
20	35. 2	22. 9	36. 4	21. 8	33. 3	22. 6	34. 6	21. 2	----	----	----	----	----	----	28. 3	28. 6	----	----	----	9. 8	12. 5	10. 2	----	12. 4
21	34. 5	22. 3	35. 3	20. 8	31. 6	21. 9	32. 6	21. 0	----	----	----	----	----	----	28. 2	28. 0	----	----	----	10. 0	12. 3	9. 2	----	12. 3
22	31. 7	----	32. 8	18. 1	30. 1	20. 8	30. 9	19. 1	----	----	----	----	----	----	28. 7	28. 5	----	----	----	4. 0	5. 0	5. 3	----	4. 5
23	----	----	----	----	31. 0	21. 7	32. 0	20. 2	----	----	----	----	----	----	----	28. 3	----	----	----	9. 9	12. 2	7. 6	----	11. 6
24	33. 4	----	34. 3	20. 2	32. 0	21. 1	33. 2	19. 8	----	----	----	----	----	----	28. 3	28. 0	----	----	----	9. 8	12. 2	10. 7	----	11. 3
25	31. 8	----	32. 3	21. 3	31. 0	22. 1	31. 6	21. 3	----	----	----	----	----	----	28. 1	27. 5	----	----	----	12. 6	15. 4	11. 4	----	15. 7
26	28. 4	----	28. 3	22. 4	26. 8	21. 7	27. 0	21. 4	----	----	----	----	----	----	27. 6	27. 0	----	----	----	9. 6	11. 2	10. 9	----	10. 9
27	29. 0	----	29. 3	22. 3	27. 4	22. 4	28. 2	21. 4	----	----	----	----	----	----	27. 5	27. 4	----	----	----	6. 4	7. 8	4. 2	----	7. 3
28	30. 9	----	31. 2	17. 0	29. 1	20. 2	29. 8	19. 3	----	----	----	----	----	----	27. 3	27. 0	----	----	----	9. 4	11. 2	12. 5	----	9. 7
29	28. 9	----	29. 0	17. 1	27. 7	18. 3	28. 2	17. 4	----	----	----	----	----	----	27. 1	26. 4	----	----	----	12. 6	14. 8	11. 9	----	13. 1
30	27. 4	----	27. 4	15. 8	26. 6	16. 0	26. 8	15. 2	----	----	----	----	----	----	26. 5	26. 0	----	----	----	8. 6	9. 9	11. 4	----	10. 2
31	27. 1	----	27. 1	15. 5	26. 2	16. 1	26. 3	14. 7	----	----	----	----	----	----	26. 5	26. 2	----	----	----	5. 4	6. 0	6. 9	----	5. 6

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1	27. 7	----	27. 7	16. 5	26. 4	17. 0	26. 6	16. 1	----	----	----	----	----	----	26. 9	26. 3	----	----	----	3. 4	3. 8	4. 5	----	3. 3
2	----	----	----	----	26. 9	17. 3	27. 4	15. 8	----	----	----	----	----	----	----	26. 6	----	----	----	3. 1	3. 7	3. 6	----	2. 8
3	29. 9	20. 2	30. 5	18. 0	28. 5	19. 5	29. 4	17. 4	----	----	----	----	----	----	28. 0	26. 6	----	----	----	3. 3	3. 8	4. 1	----	2. 7
4	30. 2	21. 2	31. 1	19. 7	28. 8	20. 1	29. 9	17. 9	----	----	----	----	----	----	28. 2	27. 1	----	----	----	3. 6	4. 4	3. 6	----	3. 4
5	31. 3	20. 9	32. 5	19. 8	29. 1	19. 8	30. 6	17. 6	----	----	----	----	----	----	27. 9	26. 7	----	----	----	5. 4	6. 9	5. 9	----	5. 7
6	30. 8	20. 1	31. 6	19. 0	29. 8	19. 3	30. 8	17. 3	----	----	----	----	----	----	27. 7	27. 2	----	----	----	4. 6	5. 7	4. 6	----	4. 9
7	30. 6	21. 1	31. 7	19. 4	29. 4	19. 7	30. 4	18. 2	----	----	----	----	----	----	27. 9	27. 3	----	----	----	----	----	4. 3	----	3. 0
8	30. 3	20. 8	31. 4	19. 9	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3. 5	4. 1	4. 3	----	3. 1
9	31. 1	21. 0	32. 0	19. 8	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	5. 5	7. 2	6. 3	----	5. 2
10	30. 7	20. 9	31. 7	19. 9	29. 2	18. 9	30. 4	18. 1	----	----	----	----	----	----	28. 2	27. 4	----	----	----	4. 7	5. 4	3. 0	----	4. 2
11	29. 9	20. 5	30. 7	18. 9	28. 8	19. 6	29. 8	17. 9	----	----	----	----	----	----	28. 4	27. 6	----	----	----	3. 7	4. 3	3. 3	4. 0	2. 8
12	----	----	----	----	29. 2	19. 1	30. 2	18. 2	----	----	----	----	----	----	----	27. 9	----	----	----	3. 4	4. 0	3. 6	3. 9	2. 8
13	----	----	----	----	29. 7	19. 7	30. 5	17. 8	----	----	----	----	----	----	----	28. 0	----	----	----	2. 9	3. 3	3. 4	4. 0	2. 5
14	31. 3	----	32. 7	----	29. 5	19. 7	30. 0	18. 0	----	----	----	----	----	----	30. 4	28. 1	----	----	----	2. 7	3. 0	4. 2	4. 8	2. 4
15	32. 0	21. 8	32. 6	----	29. 4	19. 6	30. 3	17. 9	----	----	----	----	----	----	30. 2	27. 8	----	----	----	3. 4	4. 0	3. 9	4. 5	2. 4
16	31. 8	21. 4	32. 4	----	29. 5	18. 6	28. 8	17. 6	----	----	----	----	----	----	30. 0	27. 9	----	----	----	3. 7	4. 4	3. 8	4. 1	3. 1
17	31. 9	21. 6	32. 5	----	29. 4	19. 3	30. 2	17. 4	----	----	----	----	----	----	29. 5	27. 7	----	----	----	4. 4	5. 4	6. 3	7. 2	5. 0
18	32. 0	21. 6	32. 9	19. 5	29. 6	18. 4	30. 4	17. 1	----	----	----	----	----	----	29. 1	27. 7	----	----	----	6. 1	7. 5	7. 6	8. 4	6. 9
19	31. 1	21. 8	31. 7	----	28. 0	18. 8	29. 4	17. 0	----	----	----	----	----	----	29. 2	27. 5	----	----	----	3. 7	4. 5	5. 4	6. 1	3. 5
20	30. 7	21. 2	31. 0	----	28. 2	18. 2	28. 8	16. 9	----	----	----	----	----	----	29. 2	27. 4	----	----	----	4. 6	5. 3	5. 5	6. 5	4. 3
21	31. 1	21. 2	31. 1	----	27. 8	18. 1	28. 5	17. 4	----	----	----	----	----	----	28. 7	26. 9	----	----	----	8. 0	9. 6	7. 5	9. 0	9. 0
22	29. 9	19. 8	30. 3	----	27. 9	16. 8	28. 6	15. 6	----	----	----	----	----	----	28. 1	26. 3	----	----	----	8. 6	10. 1	8. 8	10. 2	8. 5
23	27. 8	18. 9	28. 2	17. 0	25. 1	15. 0	25. 3	14. 6	----	----	----	----	----	----	28. 2	26. 5	----	----	----	3. 5	3. 9	5. 0	----	2. 8
24	26. 5	17. 4	----	----	24. 7	15. 4	24. 8	14. 4	----	----	----	----	----	----	27. 3	26. 3	----	----	----	3. 3	3. 5	4. 8	----	2. 1
25	29. 9	19. 1	30. 4	17. 4	25. 8	16. 0	26. 0	14. 9	----	----	----	----	----	----	28. 1	26. 5	----	----	----	5. 5	6. 6	3. 8	----	----
26	29. 5	17. 9	29. 5	17. 8	26. 6	17. 1	27. 1	15. 8	----	----	----	----	----	----	27. 6	26. 1	----	----	----	7. 7	9. 2	7. 8	9. 0	8. 4
27	29. 0	18. 8	29. 1	16. 1	26. 5	15. 2	26. 9	14. 1	----	----	----	----	----	----	27. 3	25. 8	----	----	----	6. 3	7. 2	10. 5	11. 5	7. 1
28	28. 0	20. 5	28. 2	16. 9	24. 7	15. 7	25. 2	14. 0	----	----	----	----	----	----	27. 0	25. 0	----	----	----	8. 6	10. 1	8. 0	8. 8	11. 6
29	27. 2	20. 8	27. 2	18. 0	24. 8	16. 7	25. 4	15. 3	----	----	----	----	----	----	27. 2	25. 3	----	----	----	3. 8	4. 2	5. 0	----	2. 2
30	28. 4	20. 8	29. 1	17. 8	25. 6	16. 8	26. 6	15. 9	----	----	----	----	----	----	27. 3	25. 5	----	----	----	3. 5	4. 2	4. 3	----	3. 2

TABLE 34.—*Daily evaporation from class A pan at Boulder City, Nev.*

[In inches]

Day of month	1952										1953								
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.14	0.34	0.25	0.56	0.53	0.39	0.38	0.40	0.19	0.05	0.10	0.12	0.27	0.30	[1] 0.37	0.42	0.64	0.35	0.39
2	.15	.27	.32	.30	.52	.56	.30	.34	.23	.09	.03	.13	.14	.32	.56	.41	.58	.66	.33
3	.15	.45	.42	.27	.47	.55	.53	.27	.39	.12	.11	.15	.18	.29	.39	.38	.59	.48	.35
4	.14	.40	.47	.33	.53	.46	.40	.29	.22	.10	.06	.15	.17	.40	.44	.48	.66	.47	.34
5	.15	.37	.35	.50	.45	.45	.38	.28	.17	.05	.09	.20	.25	.34	.44	.47	.33	.47	.35
6	.20	.44	.43	.55	.39	.34	.41	.30	.13	.10	.12	.26	.25	.38	.37	.48	.48	.47	.35
7	.20	.40	.54	.68	.51	.36	.35	.27	.13	.13	.09	.21	.38	.43	.58	.60	.50	.53	.40
8	.04	.31	.51	.53	.43	.51	.40	.23	.11	.09	.04	.28	.31	.35	.54	.50	.37	.61	.30
9	.01	.33	.41	.57	.31	.61	.55	.28	.28	.09	.08	.31	.21	.22	.59	.61	.62	.33	.42
10	.01	.31	.53	.54	.54	.54	.62	.25	.11	.10	.10	.21	.28	.31	.46	.58	.36	.40	.51
11	.24	.17	.32	.45	.61	.38	.41	.24	.12	.10	.08	.11	.28	.35	.37	.52	.52	.40	.36
12	.19	.23	.33	.54	.51	.50	.27	.20	.16	.11	.09	.26	.21	.27	.35	.54	.62	.46	.39
13	.11	.34	.54	.49	.51	.44	.37	.31	.16	.19	.08	.19	.31	.14	.34	.74	.34	.45	.32
14	.18	.34	.50	.57	.35	.43	.36	.32	.11	.16	.18	.17	.29	.32	.33	.56	.27	.41	.35
15	.20	.42	.44	.71	.45	.46	.27	.35	.12	.12	.21	.17	.23	.30	.40	.56	.15	.41	.26
16	.23	.40	.40	.47	.54	.46	.43	.19	.06	.11	.22	.16	.19	.35	.31	.67	.28	.32	.49
17	.10	.43	.43	.47	.47	.27	.33	.19	.09	.03	.10	.17	.30	.49	.35	.52	.32	.54	.37
18	.23	.36	.46	.62	.47	.41	.56	.23	.13	.01	.08	.17	.28	.46	.30	.37	.32	.50	.37
19	.24	.40	.31	.70	.54	.32	.30	.20	.14	.03	.09	.23	.43	.34	.63	.49	.41	.57	.32
20	.35	.15	.59	.46	.52	.55	.10	.21	.11	.09	.10	.19	.38	.28	.42	.62	.44	.53	.33
21	.30	.18	.61	.55	.49	.30	.11	.18	.07	.10	.23	.18	.29	.26	.69	.54	.47	.61	.37
22	.31	.26	.38	.64	.56	.40	.24	.19	.17	.10	.25	.16	.33	.18	.61	.51	.43	.53	.43
23	.19	.29	.39	.47	.54	.43	.23	.19	.15	.13	.14	.12	.24	.26	.63	.62	.56	.45	.42
24	.14	.33	.36	.46	.33	.47	.40	.18	.14	.06	.14	.13	.28	.36	.51	.71	.62	.56	.28
25	.32	.27	.46	.56	.40	.38	.41	.17	.07	.04	.17	.08	.33	.47	.54	.59	.62	.55	.32
26	.26	.31	.47	.49	.36	.38	.24	.16	.07	.08	.16	.17	.30	.53	.49	.82	.57	(2)	.41
27	.38	.10	.55	.43	.44	.39	.27	.16	.14	.04	.22	.17	.38	.26	.41	.69	.54	.80	.44
28	.26	.06	.50	.44	.43	.33	.26	.17	.29	.04	.18	.18	.39	.37	.36	.55	.47	.57	.23
29	.34	.05	.44	.65	.31	.32	.23	.18	.12	.05	.12	------	.32	.45	.27	.58	.44	.45	.25
30	.38	.14	.57	.55	.34	.53	.40	.17	.07	.13	.18	------	.18	[1] .36	.57	.50	.38	.53	.27
31	.22	------	.47	------	.37	.63	------	.18	------	.01	.28	------	.22	------	.35	------	.26	.25	------
Total	6.36	8.85	13.75	15.55	14.22	13.55	10.51	7.28	4.45	2.65	4.12	5.03	8.60	10.14	13.97	16.63	14.16	14.66	10.72

[1] Estimated value obtained by distributing 2-day total for April 30–May 1. [2] Included in next observation.

TABLE 35.—*Daily evaporation from class A pan at Boulder Island, Lake Mead, Nev.*

[In inches]

Day of month	1952 Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1953 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	[1] 0.30	0.30	0.19	0.88	0.55	0.44	0.35	0.28	0.36	0.19	(2)	0.12	0.40	0.26	0.39	0.58	0.74	0.50	0.84
2	[1] .25	.22	.31	.50	.66	.44	.43	.28	.25	.06	.15	.15	.20	.45	.42	.54	.72	1.04	.25
3	[1] .26	.34	.44	.48	.51	.46	.49	.25	.39	.12	.09	.11	.24	.36	.53	.36	.61	.78	1.02
4	.23	.41	.54	.41	.71	.61	.72	.29	.33	.25	.04	.12	.22	.38	.49	.57	(2)	.68	.48
5	.25	.26	.45	.48	.68	.88	.50	.25	.17	.14	.07	.10	.19	.51	(2)	.51	1.10	.56	.59
6	.20	.27	.58	.78	.22	.63	.43	.28	.17	.06	.14	.14	.19	.57	1.07	.91	.55	.60	.66
7	.47	.68	.79	.69	.64	.57	[1] .56	(2)	.18	(2)	.25	.17	.28	.75	(2)	(2)	.99	.61	(2)
8	(2)	.54	.83	.52	.68	.73	[1] .56	.55	.10	.55	.16	.32	.22	.35	1.02	1.16	1.32	.62	.92
9	.13	[1] .49	.43	.62	.42	1.02	.78	.30	.29	.11	.03	.29	.19	.34	.68	.70	.69	(2)	.49
10	.36	[1] .20	.39	.92	.34	.75	.67	.39	.30	.12	.10	.36	.35	.27	.56	.67	.49	1.27	.59
11	.10	[1] .35	.35	.49	.67	.67	.72	.34	.16	.06	.06	.14	.40	.35	.48	.66	.54	.68	.46
12	.30	.18	.52	.94	.78	.81	.45	.27	.13	.10	.07	.29	.29	.38	.22	.57	(2)	.43	(2)
13	.23	.42	.63	.61	.61	.72	.35	.31	.31	.12	.04	.27	.42	.24	.36	.69	.93	.56	(2)
14	.17	.43	.66	.86	.49	.66	.36	.21	.38	.17	.26	.13	.18	.19	.43	.68	.87	.51	1.31
15	.22	.37	.53	.55	.45	.87	.37	.45	.21	.04	.36	.17	.25	.29	.56	.72	.03	.45	.49
16	[1] .15	.31	.61	.65	.57	.71	.41	.26	.06	.07	.23	.15	.21	.22	.22	.76	.75	(2)	.52
17	[1] .25	.22	.41	.54	.74	.70	.38	.21	.07	0	.09	.16	.41	.71	(2)	.75	.29	1.11	.46
18	.37	.31	.54	.59	.56	.56	.40	.11	.18	0	.10	.22	.24	.46	1.12	.67	(2)	.64	.70
19	.18	[1] .50	.33	.84	.80	.58	.45	.24	.22	.12	.05	.42	.47	.29	.75	(2)	1.25	.55	.79
20	.40	[1] .30	.44	.68	.76	[1] .75	.17	.36	.20	.13	.08	.22	.59	.48	[1] .65	1.43	1.03	.97	.49
21	.40	.28	.87	.82	[1] .65	.62	.03	.16	.12	0	.26	.24	.41	.22	.71	.68	.69	.89	.48
22	.37	.35	.56	.64	.51	.60	.18	.18	.23	.14	.29	.39	.41	.38	.67	.49	.78	.69	.78
23	.34	.31	.48	.86	.66	.50	.27	.27	.26	.13	.13	.10	.21	.42	.89	1.05	.75	[1] .65	.80
24	.14	.34	.37	.63	.65	[1] .72	.27	.21	.23	.19	.06	.12	.21	.42	.70	.86	(2)	[1] .66	.37
25	.28	.34	.42	.68	.46	[1] .71	.21	.22	.14	(2)	.13	.21	.34	.41	.57	.43	1.10	.88	.38
26	.24	.47	.42	.67	.52	.60	.36	.13	.13	.17	.31	.12	.39	.74	.69	1.00	.63	.83	(2)
27	.39	[1] .20	.47	.60	.58	.61	.24	.17	.19	.06	.16	.18	.43	.74	.45	.81	.76	(2)	(2)
28	.25	.04	.41	.69	.57	.71	.23	.16	.22	.08	.19	.11	.47	.55	.58	(2)	.66	1.11	2.18
29	.31	.26	.76	.57	.42	.47	.29	.20	.14	.05	.10	------	.60	.35	.37	1.40	.56	.71	.68
30	.37	.01	.74	.65	.23	.55	.30	.11	.09	.06	.11	------	.24	.77	.44	.65	.62	1.32	.25
31	.45	------	.87	------	.36	.43	------	.16	------	.12	.28	------	.19	------	.67	------	.58	------	------
Total	8.36	9.68	16.34	19.84	17.45	20.08	11.93	7.60	6.21	3.41	4.39	5.52	9.84	12.85	16.69	20.30	20.03	20.30	16.98

[1] Estimated from pan-evaporation relation. [2] Included in next observation.

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