STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

Bulletin No. 73

EVAPORATION FROM WATER SURFACES IN CALIFORNIA

EDMUND G. BROWN
Governor

HARVEY O. BANKS
Director of Water Resources

OCTOBER, 1959

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UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION RESEARCH DIVISION
P. O. BOX 750
FT. COLLINS, COLORADO

Western Soil and Water Management
Research Branch

May 1, 1959

Mr. Harvey O. Banks, Director
Department of Water Resources
State of California
Sacramento 5, California

Dear Mr. Banks:

There is submitted herewith a report entitled "Evaporation from Water Surfaces in California." It includes the records from 1881 to 1954 published by the State Division of Water Resources in Bulletins Nos. 54, 54-A and 54-B entitled "Evaporation from Water Surfaces in California" and records for the period 1954 to 1958.

The investigations on which this report is based were supported by and the report was prepared under cooperative agreement between the Department of Water Resources of the State of California and the Agricultural Research Service of the United States Department of Agriculture.

Respectfully submitted,

Omer J. Kelley
Chief of Branch

O R G A N I Z A T I O N

UNITED STATES DEPARTMENT OF AGRICULTURE

Agricultural Research Service
Byron T. Shaw, Administrator

Soil and Water Conservation Research Division
Cecil H. Wadleigh, Director

Western Soil and Water Management Research Branch
Omer J. Kelley, Chief

This bulletin was prepared by:

Harry F. Blaney, Irrigation Engineer

and

Dean C. Muckel, Irrigation Engineer

ORGANIZATION

DEPARTMENT OF WATER RESOURCES

HARVEY O. BANKS	Director of Water Resources
RALPH M. BRODY	Deputy Director
JAMES F. WRIGHT	Deputy Director
WILLIAM L. BERRY	Chief, Division of Resources Planning

Liaison with the

United States Department of Agriculture

Agricultural Research Service

has been the responsibility of

CARL B. MEYER	Chief, Special Activities Branch

- - - - - - 0 - - - - - -

PAUL L. BARNES	Chief, Division of Administration
PORTER A. TOWNER	Chief Counsel
ISABEL C. NESSLER	Coordinator of Reports

ACKNOWLEDGMENT

The assistance of engineers and water organizations throughout California is gratefully acknowledged. The inclusion of evaporation records and corresponding data in this bulletin represents a direct contribution from the many individuals and groups interested in the conservation of water. Assistance and advice given in preparing the many tabulations is especially appreciated.

FOREWORD

For many years, the State Department of Water Resources, and its predecessor agencies, have cooperated with the United States Department of Agriculture in study and research on the subject of evaporation from water surfaces in California.

The results of this research have been published in a series of bulletins. The first of these bulletins contains general explanatory textual matter. The latter two contain extensive tables of evaporation, wind, and temperature data for various stations located in California and adjacent states. The bulletins previously published are:

Division of Water Resources Bulletin No. 54, "Evaporation From Water Surfaces in California, A Summary of Pan Records and Coefficients, 1881 to 1946", 1947.

Division of Water Resources Bulletin No. 54-A, "Evaporation From Water Surfaces in California, Basic Data", 1948.

Division of Water Resources Bulletin No. 54-B, "Evaporation From Water Surfaces in California, 1946 to 1954", 1955.

The present publication, Department of Water Resources Bulletin No. 73, includes most of the text of the original Bulletin No. 54. Minor editorial changes have been made in order to include recent material and to simplify the identification of subdivisions of the various agencies involved. Since the original bulletin is out of print, this will provide a means of preserving and effecting wider dissemination of the valuable background material. Appendix B of the present publication presents the results of a recent special study of evaporation in the San Francisco Bay and Sacramento-San Joaquin Delta regions.

Appendix A of Bulletin No. 73 will be published as quickly as available data can be collected and checked, and will include basic data for evaporation stations throughout California. Since Bulletin 54-B is no longer available, the tabular data will cover the period since 1946, preserving the continuity of records previously published. Future bulletins in the 73-series will be published from time to time and will include data collected in the interim between dates of publication, together with complete records of stations not previously published.

CHAPTER I

INTRODUCTION

Much of the irrigated agriculture of the west has been made possible by the impounding of flood waters. Storage dams conserve a water supply that otherwise might be wasted, help to prevent floods, and make possible the production of power. Reservoirs replenished by snow-fed streams flowing out of high mountains receive a more uniform water supply than those located in lower areas where snowfall is small and run-off is deficient. Reservoir replenishment in the higher areas occurs during late spring and early summer. Along the secondary streams of the lower mountains run-off quickly approaches a peak and as rapidly diminishes into periods of minimum stream flow. In such areas reservoirs must be designed for a carry-over supply from wet years for use during years of water deficiency. Under such conditions an extensive system of storage reservoirs may be the only means of maintaining an adequate water supply.

Both conditions prevail in California, water being plentiful in the north and generally deficient in the southern portion of the State. Wherever water is scarce, losses are closely scrutinized. For this reason, evaporation from water surfaces is a subject that has been given considerable attention. Experimental studies have been conducted by the United States Department of Agriculture in cooperation with the California Department of Water Resources and its predecessors. Evaporation measurements have been recorded at many places by state and private organizations and by departments of the Federal Government including the Forest Service, Bureau of Reclamation, Bureau of Plant Industry, and the Agricultural Research Service.

Evaporation is the natural process of changing water into vapor. Dry air has a greater capacity for absorbing moisture than moist air; hence, evaporation increases under conditions of low humidity. It increases with high temperatures and decreases with low temperatures. Wind increases evaporation from small water surfaces by replacing moist air over the water with drier air moving in from a distance. From large water areas dry winds increase evaporation for limited distances from the windward shore, but for the central area and toward the leeward shore evaporation remains fairly constant because the moving air has little additional capacity for moisture. In general, relatively low evaporation occurs in coastal areas and at high elevations, and high evaporation occurs in places where high temperature, low humidity, or strong winds prevail. Evaporation varies from day to day and from year to year according to the weather conditions at each locality. Differences in evaporation up to 50 or 100 per cent have been determined for localities separated by only a few miles. Evaporation measurements, therefore, should be made at each reservoir where records are desired. Attempts to use records obtained elsewhere may lead to error.

Studies of evaporation from storage reservoirs indicate that for long periods of deficient stream-flow, reservoirs may yield, for useful purposes, as little as 50 per cent of the total water supply, the balance being lost by evaporation through years of carry-over storage. This being so, reservoirs are not always designed for the maximum quantity of water a stream will deliver over a period of years, as smaller reservoirs having less evaporating surface and smaller losses may yield in a similar period as much water as could have been obtained from the larger storage. On streams of more uniform flow a reservoir will be more completely replenished each year

and evaporation will be limited to a smaller percentage of the total water supply. In some places replenishment occurs only during winter and spring months, whereas evaporation continues throughout the year. Under such conditions annual evaporation sometimes exceeds annual replenishment.

The topography of the State, with its high mountains and narrow valleys, encourages the construction of storage dams which now number over 800 of all types. The aggregate storage capacity is nearly 12 million acre-feet. One hundred of these have individual capacities of 10,000 acre-feet or more. An estimate of evaporation from reservoirs is difficult to obtain, as the aggregate surface area is unknown. Reservoir evaporation in California varies according to location from three to five feet in depth annually, which when applied to the total surface area of all reservoirs, undoubtedly amounts to an impressive total.

Evaporation losses are of importance as an element affecting the net water supply available for irrigation of crops, for production of power, and for municipal and industrial uses. Except in unusual instances they cannot be measured directly because of unknown elements of supply and loss of water entering or leaving the reservoir. Thus, recourse is necessary to research studies for determination of the relationships existing between evaporation from small containers, which is measurable, and from large bodies of water for which direct measurements are impossible.

Of the items in the hydrologic equation, precipitation is measured over a wide network of stations throughout the Nation, streamflow is recorded, and both sets of data are set forth in government publications. Evaporation records are less extensive and few are made available by publications. For the most part government agencies

have confined evaporation measurements to pan investigations and the collection of data has been left principally to private organizations that are interested in the conservation and use of water. It is the purpose of this report to overcome the lack of published evaporation records in California through compilation of such existing data as are obtainable from publications and private and public files. Search has disclosed many records not heretofore available for public use. The total of some 250 evaporation records throughout the State will be helpful in designing new reservoirs and estimating evaporation losses from others.

In the northern portion of the State water is more plentiful than in the south and less interest has been shown in collection of evaporation records, particularly in the northeastern counties and along the coast as far south as Santa Barbara County. Very few records exist in these areas. In the Sacramento and San Joaquin Valleys evaporation measurements have been made in various localities by government and private agencies. The first such measurement to be recorded was by the State Engineer at Kingsburg from 1881 to 1885. (18), (31).[1] In mountain areas tributary to the Central Valley some records are available but they are not as numerous as might be expected. With the advent of the Central Valley Project and the construction of Shasta and Friant Dams, the lack of adequate evaporation data has been recognized and plans have been made by the Bureau of Reclamation for installation of a network of evaporation stations throughout the area. A considerable percentage of all evaporation measurements within the State has been made in Los Angeles County where great sums have been spent for importation of water from outside sources, and in San Diego County, where a small water supply

[1] Numbers in parenthesis refer to literature cited

and a large population growth have required construction of an extensive reservoir system.

Because of the size of the State and the differences in altitude and climate, depths of evaporation vary greatly in different localities. The greatest differences occur in the south where evaporation in the Mojave and Colorado desert regions may be two to three times the depth that occurs along the coast. This difference in evaporation is caused by differences in temperature and humidity. The desert effect is noted at borderline stations where winds alternately blow from the desert and from the coast. At Beaumont, in San Gorgonio Pass, dry fall winds from the desert sometimes increase evaporation to twice that occurring in a nearby area not so affected.

Evaporation has been defined as "the process by which water passes from a liquid or a solid state to a vapor" (2). Usually, evaporation is recorded from small evaporation pans by hook-gage measurement, although occasionally volumetric measurements are used. Allowance is made for rain falling in the pan which is treated in computations as so much water added, the net result being the actual depth of evaporation for the period of measurement. Evaporation from large water areas may be computed by applying the proper coefficient to pan records. It also may be computed as the residual factor in the summation of the items of inflow and outflow including bank storage, rain on the water area, and changes in the elevation of the water surface. This total is sometimes referred to as "gross" evaporation, as it is the actual loss from lake or reservoir. Gross evaporation minus the rainfall is called "net" evaporation, a term intended to indicate the net loss in storage resulting from evaporation losses and precipitation gains. Net evaporation may be a minus quantity. Gross evaporation is always positive.

An evaporation coefficient is defined as the ratio for conversion of evaporation from a given volume of water to equivalent evaporation from another volume of water, differing in depth or area. It is useful for the conversion of known evaporation from a small water area, such as an evaporation pan, to equivalent evaporation from a larger area, as a lake or reservoir. It may be used for the reduction of a normally high rate of evaporation from a small pan to equivalent evaporation from a large pan or from one type of pan to another of different characteristics. Later in this report a tabulation shows all known coefficients for the principal evaporation pans as determined by experiments of the former Research Division of Irrigation and Water Conservation, Soil Conservation Service (now Agricultural Research Service), U. S. Department of Agriculture.

CHAPTER II

TYPES OF EVAPORATION PANS

The importance of evaporation has been recognized by engineers as an item in the water supply of a region, but there has been no organized effort to obtain widespread records from a single standard type evaporation pan. Neither has there been planned coverage of a region by evaporation stations to obtain a comparable group of records that would show the extent of evaporation losses from water surfaces under different conditions of topography, climate, altitude or latitude. Consequently, a haphazard group of records has been accumulated by various organizations throughout the western states that have only relative values to each other since different types and sizes of evaporation pans were used in obtaining them. The principal pans used in obtaining these records are the Weather Bureau Class A pan, the Bureau of Plant Industry pan, a square floating pan sometimes called the United States Geological Survey pan, and a corresponding land pan of the same size sometimes designated as the Colorado pan. These are used under many conditions in several states. In Los Angeles County there also is a group of about 25 ground pans used by the Los Angeles County Flood Control District, for which records of 10 to 15 years are available representing both valley and mountain areas. Ground pans of various diameters have been used in experimental studies and their records are valuable in showing the effect of size of pan on the depth of evaporation loss. Since 1936 the Department of Agriculture has experimented with a screen covered pan designed to reduce the evaporation approximately to the depth of loss from a larger body of water.

The Weather Bureau Pan

The Weather Bureau pan first came into use in the western states about 1916 and its records are the most numerous of any single type of pan now used. As a result they are valuable for comparative study. Because of the extent of the water requirements and the need for water storage in most sections of the state, the Weather Bureau pan has been used extensively in California and about 50 of its records have been collected from publications and public and private files for tabulation in this report. The Weather Bureau pan is four feet in diameter, 10 inches deep, made of 22-gage galvanized iron, and set on 2 x 4-inch timbers that permit circulation of air beneath the pan. A stilling well in the pan permits measurement, by hook gage, of water evaporated. Depth of water in the pan should not be less than seven inches nor more than eight inches (36) although these limitations often are difficult to meet and many times water surfaces have been too high or too low. Since it is exposed above ground and receives the full effect of sun and wind, water in the Weather Bureau pan warms up rapidly in the morning and cools rapidly after sundown. During the daytime it has a high rate of loss that exceeds that of any other evaporation pan in common use. Although it is set above ground where it is relatively free from drifting sand or rolling weeds it is not easy to keep the water clean. At certain temperatures growths of algae accumulate to form a scum on the water surface. Copper sulphate kills the algae but it should not be used, as the copper replaces the galvanizing and forms rust spots that eventually become leaks. A more satisfactory method is to use any one of a number of bleaching liquids containing a small percentage of sodium-hypochlorite. These liquids may be obtained at any grocery store. Within a few minutes the chlorine kills the algae and clarifies

the water. Experience has demonstrated that it is harmless to the galvanized surface. Infrequently the Weather Bureau pan has been placed on a raft floating on the surface of a lake or reservoir or used as a floating pan partly submerged in water. Few Weather Bureau pan records are published regularly, but a small group are included in the monthly U. S. Weather Bureau Climatological Data (41). Usually air temperature and rainfall records may be obtained from the same publication so that fairly complete meteorologic data are often available for use with the evaporation records.

The Bureau of Plant Industry Pan

This pan has been used by the Bureau of Plant Industry, United States Department of Agriculture, at its numerous plant experiment stations throughout the West. The first records were made about 1907. Records for a majority of the stations prior to 1934 have been published in issues of the Monthly Weather Review (21) (22). As compared with the 50 Weather Bureau pans in California only five Bureau of Plant Industry pans appear to have been used at one time or another in the State. These were located at the Biggs Rice Station, Butte County; U. S. Cotton Field Station at Shafter, Kern County; the U. S. Date Garden, Indio, Riverside County; the U. S. Yuma Field Station, near Bard, Imperial County, all being operated by the Bureau of Plant Industry. An experimental pan of the same type was at the Division of Irrigation Experiment Station, Fullerton, Orange County. These pans were made of 22-gage galvanized iron six feet in diameter, 24 inches deep, set 20 inches in the ground with the water surface in the pan at ground level (36). Changes in water level in such pans should approximate one inch. Measurement is made with a hookgage in an outside stilling well. A rain gage, anemometer,

maximum and minimum thermometers in a shelter, and a psychrometer are standard equipment at each Bureau of Plant Industry Station. Because this pan is set in the ground and contains a greater volume of water than the Weather Bureau pan, its water temperatures are cooler during the day and warmer during the night. Consequently, evaporation is lower than from the more exposed pan.

The Square Ground Pan

The square ground pan, sometimes called the Colorado pan, was first used at the Colorado Agricultural Experiment Station about 1890 and with a few exceptions has since been in continuous use. It appears to have the longest record of any evaporation pan known. This pan is made of 18-gage galvanized iron, three feet square, usually 18 inches deep, and set 14 inches in the ground with the water surface held at ground level. Water surface fluctuation should not exceed one inch. Measurements are made by hook gage in a stilling well on the inside wall of the pan (36). The evaporation loss is less than from the Weather Bureau pan because it is protected by surrounding soil but more than from the Bureau of Plant Industry six-foot pan because of its smaller size. About 37 of these pans have been used in California.

The Square Floating Pan

This is sometimes known as the United States Geological Survey pan, but according to a letter to Rohwer (36) from the former Chief Hydraulic Engineer of the U. S. Geological Survey, the survey has no official floating pan. It is the same type and size as the square ground pan. This pan is made of 18-gage galvanized iron and is sometimes supported by two metal cylinders so placed that the

surface of the water in the pan coincides with the surface of the reservoir. Diagonal perforated diaphragms, extending from corner to corner, reduce surge, although many of the floating pans used in California reservoirs do not have them. The pans are partly protected from wave action by surrounding rafts that may be either square or triangular and they may be attached to rafts either flexibly by chains or fastened solidly to the raft timbers. I the pan is thus supported the metal cylinders are unnecessary.

Depth of evaporation is determined by cup measurement to bring the water level up to a fixed index point in the center of the pan. Advantages of the floating pan are that because it is partly submerged, temperatures of the water in the pan and in the reservoir are almost identical; they change slowly and are more uniform than temperatures in the Weather Bureau pan. As the pan is located offshore, it is subject to the same conditions of wind, humidity and temperature that control reservoir evaporation. The main disadvantage of the floating pan is loss of record by splashing of water into or out of the pan in time of storm. It is not always possible to know when this occurs, and there is little doubt that many evaporation records for floating pans are erroneous.

The Los Angeles County Flood Control District Pan

The pan commonly used by the Los Angeles County Flood Control District is two feet in diameter, three feet deep, and set in the ground with three inches of the rim exposed. A brass rod pointed at the upper end and set in a block of concrete on the bottom of the pan is the index point for the water level which normally is at the level of the ground surface. Depth of water evaporated is computed from cup measurements which restore the water level to the height

of the index point. Prior to September, 1937, the index point in the Flood Control pan at the Baldwin Park Station, near Los Angeles, was at a level about one inch above ground; after this date it was lowered to the level of the ground surface. Because of the change the Flood Control pan record is divided in two periods of approximately equal length, showing 10 inches greater annual evaporation for the period of higher water surface. The reasc s for the higher evaporation are readily apparent: First, the water surface is closer to the top of the pan where it has greater exposure to wind; second, with the water surface higher than the surrounding ground, the heat of the sun shining on the exposed side of the pan between the ground and the water surface is transmitted to the water within, with resultant increased evaporation. This example emphasizes the value of maintaining water levels in ground pans at or below the level of the ground surface.

The Screened Pan

The screened pan has been used experimentally by the Department of Agriculture at the Fullerton Evaporation Station and elsewhere in order to study the effect on evaporation of shading the water surface (49). The pan was of the same size as the Flood Control pan, two feet in diameter by three feet deep, set in the ground 2.75 feet. Water levels were maintained at ground level and measurements of water evaporated were made with a hook gage in an outside stilling well. The screen was made of galvanized hardware cloth with one-fourth inch mesh and suspended horizontally in the pan midway between the rim and the water surface. Tests were also made with a screen of six meshes per inch, but the annual evaporation resulting from use of the finer mesh was only slightly less than from the

more open screen. Experiments with the screened pan were undertaken for the purpose of finding one that would have the same annual evaporation as a larger water surface. If evaporation could be reduced to an amount equivalent to that from a lake or reservoir no reduction factor would be necessary for estimating reservoir evaporation from pan measurements. Experiments with the screened pan under different climatic conditions in Southern California indicat ithat a coefficient of nearly unity could be obtained. Following these experiments, the Los Angeles County Flood Control District adopted the one-forth inch screen for use with all Flood Control District pans. This could be accomplished without difficulty as both sets of pans were of the same dimensions.

Meteorologic Equipment

Since evaporation varies with the atmospheric changes there should be at each major evaporation station a set of instruments for recording meteorologic data including wind movement, maximum and minimum air and water temperatures, humidity, and precipitation. The anemometer for recording wind movement should be set at the northwest corner of the 2 x 4's supporting the Weather Bureau pan where it will not throw shadows on the water. The anemometer cups should be six inches above the rim of the pan. It is best to employ a standard height for the cups as the velocity of the wind increases with distance above ground. At a number of stations in Southern California, the anemometer is placed about seven feet above ground, thereby setting up a different standard of wind velocity than that obtained from the lower instruments.

Thermometers of the recording maximum and minimum Weather Bureau type should be kept in a standard thermometer shelter about

five feet above ground, with the opening on the north side to prevent the sun from shining on the instruments when the door is open. Floating maximum and minimum thermometers supported by corks or by stoppered test tubes are suitable for registering water temperatures in evaporation pans. Mean temperatures, both for air and for water, are taken as the average of the maximum and minimum recordings. Air temperatures are sometimes recorded on the chart of a seven-day thermograph but they are less accurate than thermometer readings. In this case the mean temperatures may be taken as the average of the sum of the temperatures shown for each of the two-hour periods throughout the 24 hours. It also may be determined by means of a planimeter but the two-hour average method is simpler.

Humidity may be determined from the temperatures of the wet and dry bulbs of either the sling or whirling type of psychrometer, or from the recording charts of a hygrothermograph or a hair hygrometer. The psychrometer gives the most accurate results. If either of the recording instruments is used it should be kept in the shelter with the thermometers.

The standard eight-inch Weather Bureau type rain gage should be installed at all stations where evaporation is measured, as the depth of rain falling in the pan must be known in computing the true depth of evaporation. The station should be enclosed in a tight mesh wire fence for protection of equipment and to keep out intruders. A gate in the fence should be kept locked. Reference is made to Circular L, Instrument Division of the Weather Bureau (24) for instructions as to size of fence necessary for enclosure of the station equipment and its location within the fence. (The 12-inch x 15-foot area shown in Circular L is the minimum size that will hold the necessary equipment.) It is the opinion of the author

that the close proximity of the 4 x 4-inch fence posts to the evaporation pan permits undesirable shadows to pass over the water surface. They also create wind eddies over the pan and at the anemometer. As few posts as possible should be used and they should be kept as far as is feasible from the pan. Four posts of boiler tubing or two-inch pipe set 16 feet apart at the corners, with horizontal tubular bracing at the level of the top strand of wire, make a strong and satisfactory fence that throws few shadows and creates a minimum of wind disturbance.

Wherever possible the evaporation station should be located on open, level ground, free from shade and obstructions to wind. In the preparation of the tabulations in this report there have come to light some records obtained from evaporation pans located in the vicinity of shrubs or trees which, while small in the beginning, grew each year until in the course of time the grown shrubbery shaded the water in the pan or blanketed it from the wind, resulting in a gradual reduction of the evaporation. The future growth of vegetation or the possibility of future building construction that will have an influence on the evaporation should be considered in selecting the site of an evaporation station.

CHAPTER III

EVAPORATION INVESTIGATIONS

In order to make use of existing evaporation records and obtain the greatest benefit from them, the relationship between evaporation from various small standard pans and from larger bodies of water has long been of interest to engineers. In Bulletin 54-A and in this bulletin there are tabulated a large number of evaporation data recorded by various water organizations throughout the State. In the present chapter are brief descriptions of evaporation experiments carried on, not only in California but in other areas where different climatic conditions prevail. To a considerable degree the experimental studies have been made for the purpose of arriving at factors or coefficients showing the monthly and annual relationships existing between evaporation from small artificial water surfaces contained in metal tanks or pans and the larger water areas such as those of large tanks or lakes and reservoirs. In most cases the accuracy of coefficients obtained by investigation has had little opportunity for proof, but where such opportunity has occurred there has been good correlation.

It is generally assumed that agreement is reasonably good under all conditions of water storage. The principal error in this assumption lies in the favorable conditions under which the coefficient is determined as related to the less favorable conditions where pan evaporation is measured at the lake or reservoir. Usually an experimental station is in an open, level location where there are no immediate obstructions to divert the wind from the pan or create wind eddies over its water surface. Because of rough topography at many reservoirs the evaporation pan is sometimes placed

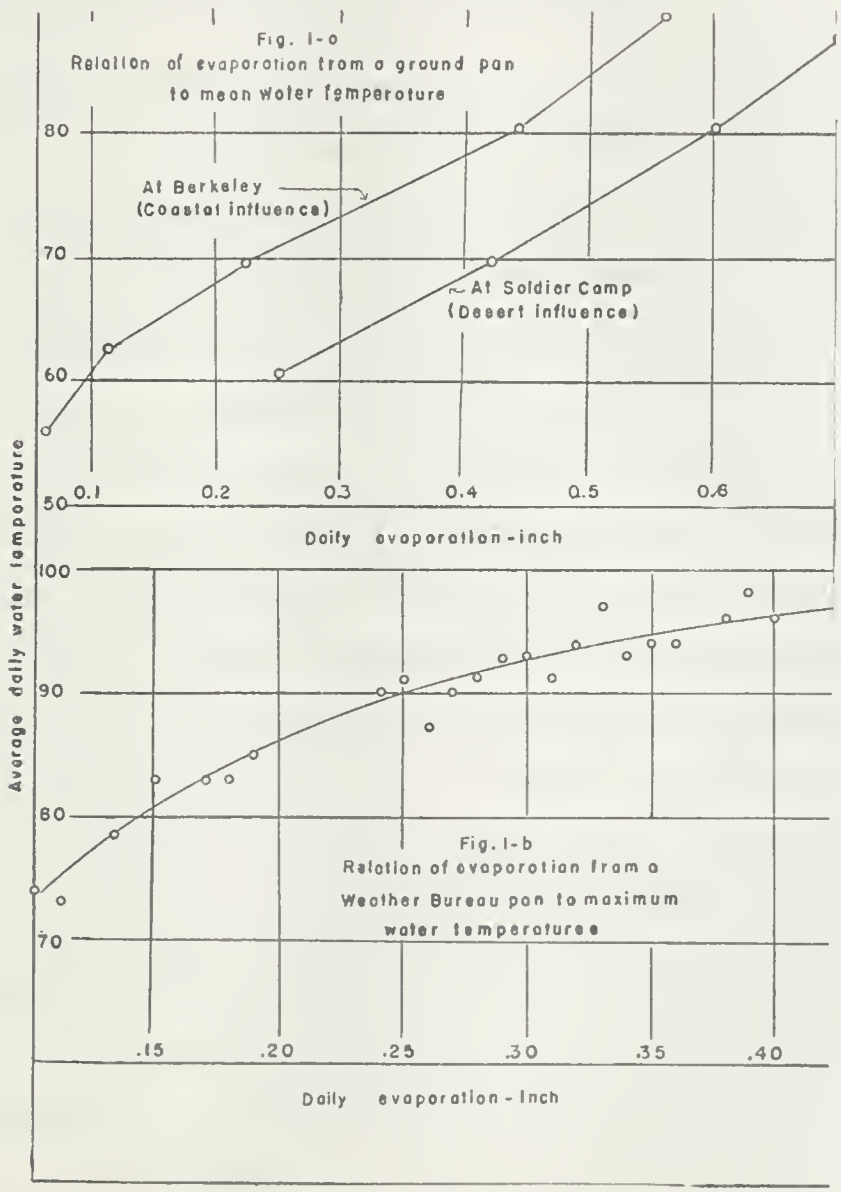
on top of the dam and thus above the reservoir surface which fluctuates widely with the season, or at some distance from it at either a higher or a lower level. Its location is determined by topography or the convenience of the operator.

Evaporation from a pan situated in an area where hillside slopes, brush and tall trees offer obstruction to winds cannot be expected to agree with evaporation from a similar pan located on a float at the water surface, or on an island where wind movement over the water surface is uninterrupted. Moreover, greater humidity exists close to the water surface in a reservoir than at a distance or at another elevation. For these reasons, land pans at reservoirs frequently are not in the best locations for estimating reservoir evaporation. In theory, floating pans, partly submerged, would have evaporation losses more nearly commensurate with actual reservoir evaporation were it not for their unreliability caused by water splashing into or out of the pan during times of storm. A number of floating pans are used in California, they would be more numerous but for this tendency toward unreliability.

Relation of Water Temperature to Evaporation

At various times in the past 40 years evaporation studies have been carried on by the Agricultural Research Service or its predecessors. All but two of these studies were in cooperation with the State of California. The first was in connection with investigations of evaporation in irrigation and water requirements of crops in the years 1903-05 (14). Among other studies, the relation of temperature of the water to evaporation was established by means of heated water in evaporation pans. Average daily water temperatures were obtained at four stations during the summers of 1904-05 for

comparison with average daily evaporation. The results indicated in Fig. 1-a, show that evaporation increases with water temperatures, but as other factors were involved it may be expected that for the same average water temperature evaporation varies for different localities. Thus, in Fig. 1-a, the line representing Berkeley conditions shows less evaporation for the same average temperature because of the higher humidity of the coastal area than that shown for Soldiers Camp near Lone Pine, which is removed from the coastal influence.



A different form of curve was obtained during studies at Baldwin Park, Los Angeles County, through plotting maximum daily water temperatures against daily evaporation from a Weather Bureau pan (46). The points on the curve, shown in Figure 1-b, are weighted averages of many observations, so that the diffusion of points is confined to a narrow range. The curved line is fitted to the points by observation. The tendency of the curve to approach the horizontal at its upper limits is an indication of heat dissipation resulting from the process of evaporation.

The Relation of Air Temperature to Evaporation

Although temperature is one of the principal factors causing evaporation, it is not the only one. The differences between air and water temperatures, wind, and humidity, together with the length of the day (which differs with the seasons), all combine to control the evaporation rate. The relation of evaporation to air temperature plots as a temperature-loop instead of a straight line. The longer the period of record the greater is the opportunity for securing a smooth curve with all points falling in regular order. The temperature-loop in Figure 2 shows the relation between monthly evaporation from a 12-foot diameter ground pan and mean monthly air temperature at the evaporation station near Fullerton. Not all points fall directly on the curve, as other factors are involved. The temperature-loop plots in two parts, each representative of a different period of the year. For the same mean monthly air temperature, evaporation from a shallow pan is greater in the first half of the year than during later months. For example, for a mean monthly temperature of 65 degrees the average monthly evaporation in Figure 2 is approximately 6.3 inches in early summer as compared

with 4.3 inches for the same length of time in the September-October period. For a deep lake or reservoir the temperature-loop is reversed, since the heat stored at depth in the water returns to the surface in the late summer or fall, where it causes increased evaporation.

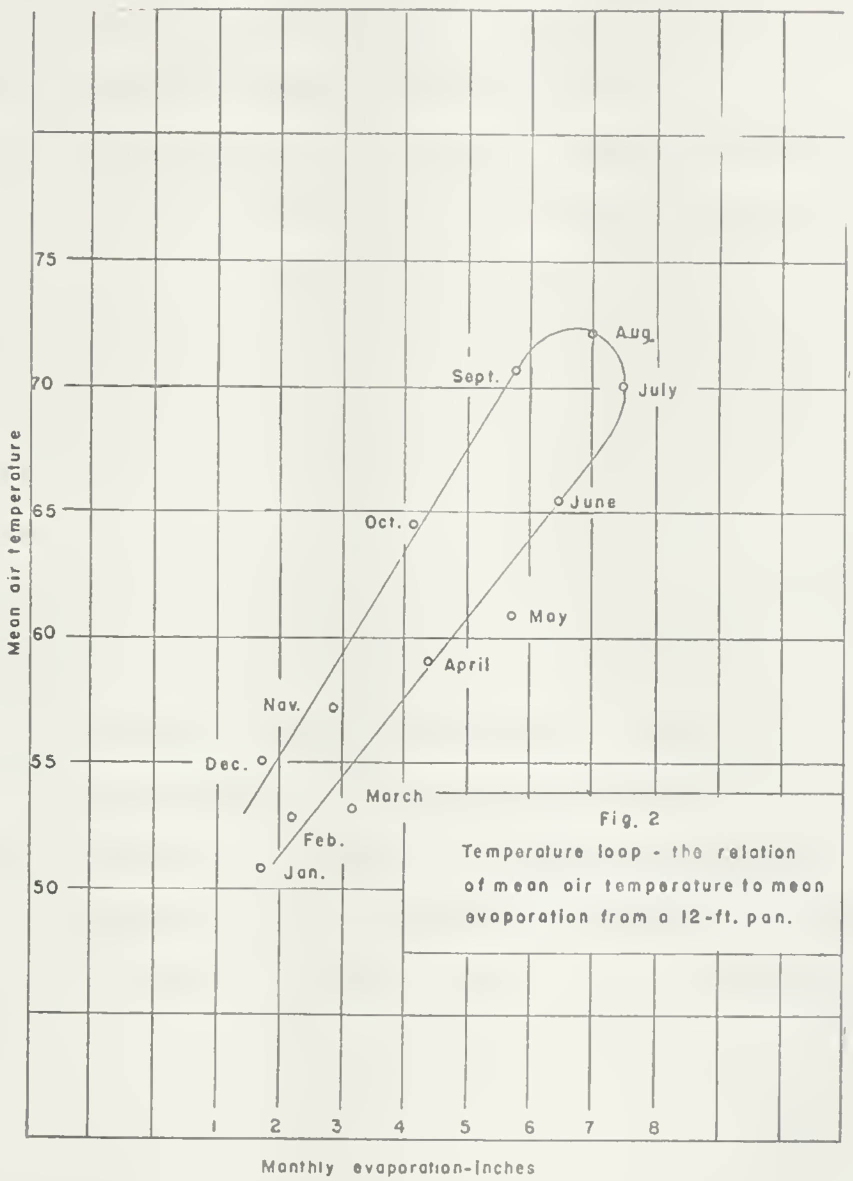


Fig. 2
Temperature loop - the relation of mean air temperature to mean evaporation from a 12-ft. pan.

The Relation of Altitude to Evaporation

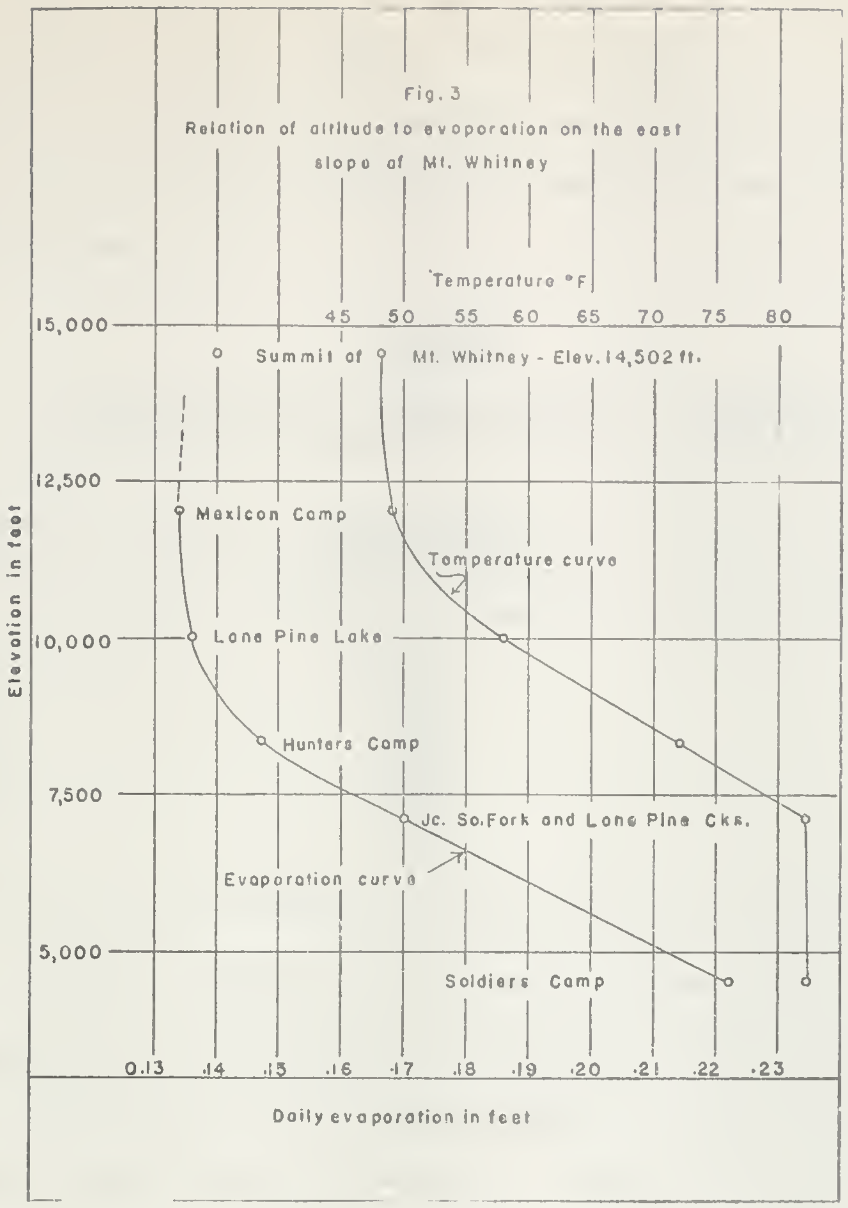
With other conditions unchanged, evaporation would increase with elevation as the rarefied atmosphere at higher levels offers less obstruction to the water molecules that escape from a freely-exposed

water surface. Higher elevations, however, are characterized by lower temperatures and changes in other climatic factors that more than offset the effect of decrease in barometric pressure. The net result is a decrease in evaporation that is more or less proportional to the decrease in temperature. Few attempts have been made to determine this relationship; the Mt. Whitney study is the only one known to have been undertaken in California.

Mt. Whitney Study. An early attempt was made in 1905 by Frank Adams, then of the Office of Experiment Stations, U. S. Department of Agriculture, in cooperation with the State of California (14) to determine the effect of altitude on evaporation from a water surface by measuring the depth of water vaporized from a series of pans set in the ground at different elevations on the eastern slope of Mt. Whitney. Each pan was 22 inches in diameter. Besides the evaporation pans the equipment at each station consisted of a rain gage, maximum and minimum thermometers, hook gage and sling psychrometer. The period of measurement was limited to 20 days. The positions of the stations, located between Lone Pine and Mt. Whitney, were selected with care but did not possess altogether uniform conditions as regards the surrounding topography and ground cover.

Observations were conducted at the following places between elevations 4,515 and the top of Mt. Whitney at 14,502 feet:

Station	Elev., feet
Soldiers Camp	4,515
Junction South Fork and Lone Pine Creeks	7,125
Hunters Camp	8,370
Lone Pine Lake	10,000
Mexican Camp	12,000
Summit Mt. Whitney	14,502



From examination of the Mt. Whitney topographic map it appears the evaporation stations probably followed Lone Pine Creek approximately. The lower station at Soldiers Camp appears to have been in the moderately rough country three to four miles west of Lone Pine. The junction of South Fork and Lone Pine Creeks probably was in steep country rising sharply above the creek on both north and south slopes, and from there on to the top of the mountain the slopes appear to be rough and steep. Under such conditions it is probable that pan exposure varied with respect to sun, wind, and temperature.

Copies of the original data are unavailable, but from a chart of the results prepared by Carl Rohwer, Table 1 and Figure 3 have been prepared showing probable daily evaporation and temperatures that are in conformity with curves plotted at earlier times when the data must have been at hand.

TABLE 1

Evaporation and Temperatures at Locations on the East Slope of Mt. Whitney, California

Elevation, feet	Mean daily evaporation, foot	Mean daily temperature, °F.
4,515	0.223	82
7,125	.170	82
8,370	.147	74
10,000	.136	58
12,000	.134	49
14,502	.140	48

Plotted evaporation and temperatures show a close relationship to each other. The curves are nearly parallel except at elevations 4,515 and 7,125 feet where there was little or no change in temperature regardless of altitude. Evaporation decreased uniformly from elevation 4,515 to 8,370 feet and more rapidly from there on up to 12,000 feet. The evaporation pan on the summit of Mt. Whitney, in contrast with those on the eastern slope, was exposed to winds from all directions and shows a slightly higher rate of evaporation than that from the two pans below. It is doubtful if the curve should pass through the summit point, and for this reason the dotted line misses it at the left. Above 7,000 feet the temperature decreases at a nearly uniform rate up to 10,000 feet, more rapidly to 12,000 feet, and from this point to the summit the temperature

difference appears to be only one degree. This study was made for the purpose of determining the effect of altitude on evaporation, but the results are inconclusive as they show a decrease in evaporation to be more closely related to change in temperature than to change in barometric pressure. Under certain conditions, however, evaporation may increase at higher elevations. This relationship is best shown from records of the Los Angeles County Flood Control District pans obtained from sea level to elevations of 3,000 to 4,000 feet in the San Gabriel Mountains. The Flood Control pans are all of the same size, so that a direct comparison is possible. Although other factors than elevation affect the evaporation, it has been found in Los Angeles and San Diego Counties that evaporation increases with elevation. Also evaporation increases with distance from the ocean, as the higher mountain areas are the farthest from the coast. In the areas involved, the lower altitudes, being closer to the ocean, have higher humidities than those at a distance or at greater elevations. In the lower levels fogs are not uncommon. They may be dense local ground fogs or high fogs; in either case they obscure the sun and cool the atmosphere. Thus, evaporation is lowered. The higher elevations, being at some distance from the ocean, are less affected and usually are entirely above the fog belt; thus evaporation is increased. In some instances, particularly for stations situated in summit areas between the ocean and desert regions, dry winds from the desert contribute further to increase the evaporation. The relationship of evaporation to altitude in Los Angeles County is shown roughly in Figure 4-a. The same data have been used in Figure 4-b to show the general relationship between evaporation and distance of the evaporation pans from the Pacific Ocean. Both charts show higher evaporation as both elevation

and distance from the ocean increase. Cuyamaca Reservoir in San Diego County, at elevation 4,600 feet near the summit between San Diego and the Imperial Valley, is thus affected. Evaporation at Cuyamaca Reservoir is greater than at several other reservoirs located at lower elevations nearer the ocean.

The Salton Sea Investigation

Prior to 1907 there had been little interest in evaporation investigations made wholly for the purpose of studying evaporation laws and developing formulas applicable to western arid and semiarid conditions. In 1907 the U. S. Weather Bureau undertook some preliminary studies at Reno, Nevada (3) in order to determine the means of approach and the type of equipment necessary for further studies then contemplated in the Salton Sea desert area of Southern California. In 1908 preliminary studies were undertaken in the area surrounding Salton Sea, and in 1909-10 the Salton Sea investigation was in progress. The purpose of the investigation was the study of natural laws affecting evaporation from water surfaces and the development of a general formula embracing all the conditions involved. As far as can be determined, however, the results were inconclusive and published reports on the investigation are fragmentary.

The program included study of air and water temperatures, wind movement at different levels, vapor pressure, evaporation from pans of different sizes and at different elevations with regard to the surface level. The main portion of the study was undertaken at Salt Creek Bridge over an arm of Salton Sea, but supplementary studies were carried on concurrently at Indio and Mecca in the Coachella Valley to the north of Salton Sea, at Brawley in the

Imperial Valley, and at Mammoth in the desert area southeast of the sea.

Salt Creek Bridge was on the Southern Pacific Railroad on the eastern shore at Salton Sea. This large body of water, which had an area of approximately 425 square miles at the time of the investigation, lies below sea level in a desert region of extremely high summer temperatures. The water surface fluctuated according to inflow from the few streams in the vicinity, principally New and Alamo Rivers, which carried surplus water from the Imperial Valley; also from rainfall on the water area and by loss of water from evaporation. San Felipe Creek and Whitewater River flow into the sea following storms, but published records for the period of investigation are not available. Being below sea level there was no outflow, and since the bottom of the sea is presumed to be composed of tight materials, seepage losses may be considered negligible.

Evaporation was measured from pans located at towers erected on land and offshore. Tower No. 1 was 1,500 feet inland from Salt Creek Bridge, on a mesa 30 to 40 feet above the sea. Five two-foot diameter pans each about 10 inches deep were observed. Pan No. 1 was at the bottom of the tower and four similar pans were at 10-foot intervals on staging to a height of 40 feet. Anemometers accompanied each pan, but the records of wind movement at all levels do not appear to be available. Tower No. 2 was 500 feet offshore in 25 feet of water. Pans at this tower were four feet in diameter with Pan No. 1 suspended above the water as close as the waves would permit, with other pans at 10-foot intervals to a height of 45 feet. Tower No. 3 was offshore and was used for special experiments which are not here discussed. Tower No. 4 was about 7,500 feet offshore in 5 feet of water with four-foot circular pans placed as at Tower

No. 2. In addition, several land pans were located in line between the sea and Tower No. 1 to determine the effect of distance from a water surface on the evaporation. Data for these pans are not available.

At each of the four supplementary stations six-foot pans were placed on boards at the ground level and two-foot pans on towers 10 feet above ground. There appears to have been no effort to have all pans exactly true to dimensions of diameter and depth. Nominally, the pans were described as two, four and six feet in diameter and 10 inches deep. Actually these dimensions were not maintained in construction as apparently it was not understood by the investigators that uniformity in size was of any importance. At the beginning of the investigation it apparently was believed that evaporation would be the same from pans similarily exposed regardless of size. During the course of the work it developed that such an assumption was in error. Diameters of the two-foot pans varied from 23 to 26 inches, which was sufficient to affect evaporation rates slightly. Diameters of the four-foot pans were more uniform, but their depths differed from 9.4 to 10.4 inches, a variation that probably would have less influence on evaporation loss than variations in diameter. The six-foot pans varied in diameter from 70.0 to 73.9 inches and in depth from 9.1 to 9.4 inches instead of the prescribed 10 inches. No corrections appear to have been made in any of the evaporation records on account of discrepancies in size.

Some of the results of the study at Salt Creek Bridge during parts of 1909 and 1910 are presented in Table 2. Mean temperatures are shown in Table 3. Only data for pans at the top and the bottom of the towers are shown, and these are not for a complete 12-month period. There is, however, a complete set of evaporation data

TABLE 2

Evaporation at Salt Creek Bridge, Salton Sea
Riverside County, California
Elevation 205 feet below sea-level (4), Lat. 33° 25' N., Long. 115° 50' W.

Year and month	Evaporation in inches					
	Tower No. 1[a] 1,500 feet inland		Tower No. 2[b] 500 feet offshore		Tower No. 4[c] 7,500 feet offshore	
	Pan No. 1	Pan No. 5	Pan No. 1	Pan No. 5	Pan No. 1	Pan No. 5
1909						
July	22.15	24.96	14.77	18.63	14.03	17.98
August	18.50	21.21	12.53	15.03	12.19	15.33
September	15.50	19.47	12.40	15.18	12.08	15.40
October	13.19	17.20	9.20	12.21	9.24	13.02
November	7.49	10.05	6.21	8.13	5.96	7.48
December	6.42	9.55	4.67	6.97	5.25	6.97
6-month total	83.25	102.44	59.78	76.15	58.75	76.18
1910						
January	5.08	7.05	3.61	5.14	3.41	4.69
February	7.42	9.45	5.01	7.17	5.09	7.40
March	11.00	13.56				
April	14.78	18.54				
May	19.00	24.11				

[a]Pan No. 1, diameter 26.8 inches, depth 9.3 inches, at ground level
Pan No. 5, diameter 24.2 inches, depth 9.4 inches, on tower 41.0 feet above ground

[b]Pan No. 1, diameter 48.2 inches, depth 10.2 inches, suspended from tower 4 feet above Salton Sea
Pan No. 5, diameter 48.2 inches, depth 9.4 inches, on tower 45 feet above Salton Sea

[c]Pan No. 1, diameter 48.2 inches, depth 10.3 inches, suspended from tower 4 feet above Salton Sea
Pan No. 5, diameter 48.1 inches, depth 10.4 inches, on tower 45 feet above Salton Sea

for the top and bottom of the three towers for the last six months of 1909 (4) and from them certain conclusions can be drawn: In all cases, evaporation is considerably higher at the top of the towers than at lower levels regardless of whether the pans were over land or water. This resulted from greater wind movement and lower humidity in vertical sections. Evaporation at Towers 2 and 4 was nearly identical for each elevation above the water surface, indicating probable uniform moisture conditions of the air at these levels regardless of distance from the shore. This could be expected, since prevailing winds passed over several miles of water surface before it reached the towers.

TABLE 3

Temperature at Salt Creek Bridge
(Tower No. 1, Salton Sea Investigation),
Riverside County, California

Month	Mean air temperature degrees F.[1]	Month	Mean air temperature degrees F.[1]
1909		1910	
June	88	January	43
July	92	February	56
August	90	March	66
September	85	April	74
October	72	May	82
November	60		
December	52		

[1]Records obtained from original notes of the investigation

Differences in evaporation at Towers 1 and 2 are attributed to two factors: Tower 1, at which the higher evaporation occurred, was 1,500 feet inland, in the desert, where temperatures were higher than over the water, and the drier air had a greater capacity for moisture. Also, these pans were smaller than at Tower 2. Both factors indicate increased evaporation at the land station.

The evaporation station at Indio was in an alfalfa patch which was irrigated and cut as necessary. The effect of the tall grass surrounding the pan was to decrease wind movement at the water surface and have a lowering effect on the evaporation. However, the yearly total amounted to 119 inches from a 6-foot diameter pan (Table 4), which is a reflection of the high temperatures and long evaporating season in the Indio region. Evaporation from the 2-foot pan at the top of the 10-foot tower totaled 200 inches, an increase that should be expected because of the opportunity for greater wind travel and because of the smaller size of the pan. Evaporation measured at Mecca, Brawley and Mammoth during a 12-month period is shown in Tables 5 to 7. The data were taken directly from the United States Weather Bureau Abstract of Data No. 4 (4) in which the year was not specified. There is some reason to believe that the tabulation was made up of broken records obtained during 1909-10. The high rates of evaporation indicated for these localities show the effect of desert temperature and humidity.

Estimates of Probable Evaporation From Salton Sea. Salton Sea was formed in 1905 as a result of a break in the banks of the Colorado River which poured into the Salton Basin for a period of nearly two years, eventually forming a body of water some 15 miles wide by 45 miles long. From this area there is no outlet, as the bottom of the Salton Sea lies at a depth of 273.5 feet below sea level. Into it drain the flood waters of a large mountain and desert region through the channels of Whitewater River, San Felipe Creek and Mammoth Wash. Surplus water from the Imperial Irrigation District flows into the sea through Alamo and New Rivers. Flood waters enter unmeasured, but for many years the irrigation district has kept records of drainage inflow. Rainfall records are maintained

TABLE 4

Evaporation at Indio, Riverside County, California

Station
  Location . . . . At U. S. Date Farm about 1 3/4 miles west of Indio. Lat. 33°44' N., Long. 116°16' W.
  Elevation . . . . . . 20 feet
Evaporation pan
  Description
    Pan No. 1 . . . . Diameter 72 inches, depth 9.2 inches, at ground level at foot of tower in alfalfa field
    Pan No. 2 . . . . Diameter 24 inches, depth 9.3 inches, at top of 10-foot tower in alfalfa field
Authority for data . . U. S. Weather Bureau
Publication reference . Abstract of Data No. 4 (4)
Meteorologic data. . . None

Month[1]	Evaporation in inches		Month[1]	Evaporation in inches	
	Pan No. 1	Pan No. 2		Pan No. 1	Pan No. 2
January	3.18	5.52	July	16.34	27.24
February	5.08	8.83	August	13.78	23.05
March	7.50	12.09	September	12.37	21.13
April	12.05	19.17	October	8.91	16.85
May	15.84	25.13	November	5.17	9.44
June	16.11	26.69	December	3.00	5.25
			Totals	119.33	200.39

[1] The year of record is not entirely clear, but it appears that the January to June data were recorded in 1910 and the July to December data in 1909.

TABLE 5

Evaporation at Mecca, Riverside County, California

Station
  Location. . . . . In Coachella Valley, north of Salton Sea. Lat. 33°31' N., Long. 116°02' W.
  Elevation . . . . 189 feet below sea level
Evaporation pan
  Description
    Pan No. 1 . . . . . . Diameter 73.9 inches, depth 9.1 inches, on ground at foot of tower
    Pan No. 2 . . . . . . Diameter 23.0 inches, depth 9.5 inches, at top of 10-foot tower
Authority for data. . . U. S. Weather Bureau
Publication reference . Abstract of Data No. 4 (4)
Meteorologic data . . . None

Month[1]	Evaporation in inches		Month[1]	Evaporation in inches	
	Pan No. 1	Pan No. 2		Pan No. 1	Pan No. 2
January	2.92	5.46	July	15.21	22.59
February	5.00	8.75	August	13.22	20.41
March	8.07	11.87	September	10.29	16.86
April	10.87	16.96	October	8.17	12.43
May	12.72	21.26	November	4.13	7.15
June	14.23	21.56	December	2.98	4.65
			Totals	107.81	169.95

[1] The year of record is not entirely clear but it appears that the January to June data were recorded in 1910 and the July to December data in 1909.

TABLE 6

Evaporation at Brawley, Imperial County, California

Station
- Location . . . . .In Imperial Valley, south of Salton Sea. Lat. 32°58' N., Long. 115°32' W.
- Elevation . . . . . . .110 feet below sea level

Evaporation pan
- Description
  - Pan No. 1 . . . . .Diameter 70.5 inches, depth 9.2 inches, on ground at foot of tower
  - Pan No. 2 . . . . .Diameter 24 inches, depth 9.5 inches, at top of 10-foot tower

Authority for data . . .U. S. Weather Bureau
Publication reference. .Abstract of Data No. 4 (4)
Meteorologic data. . . .None

Month[1]	Evaporation in inches		Month[1]	Evaporation in inches	
	Pan No. 1	Pan No. 2		Pan No. 1	Pan No. 2
January	3.05	5.32	July	14.14	20.96
February	5.00	8.00	August	11.26	21.18
March	8.00	11.00	September	10.15	16.30
April	10.74	16.04	October	6.99	11.58
May	13.79	21.57	November	4.09	7.01
June	13.68	20.21	December	2.66	4.57
			Totals	103.55	163.74

1 The year of record is not entirely clear but it appears that the January to June data were recorded in 1910 and the July to December data in 1909.

TABLE 7

Evaporation at Mammoth,[1] Imperial County, California

Station
  Location . . . . On the main line of the Southern Pacific Railroad, southeast of Salton Sea. Lat 33°05' N., Long. 115°13' W.
  Elevation. . . . . . . 245 feet above sea level
Evaporation pan
  Description
    Pan No. 1 . . . . . Diameter 70.0 inches, depth 9.4 inches, on ground at foot of tower
    Pan No. 2 . . . . . Diameter 23.0 inches, depth 9.4 inches, at top of 10-foot tower
Authority for data . . U. S. Weather Bureau
Publication reference . Abstract of Data No. 4 (4)
Meteorologic data. . . None

Month[2]	Evaporation in inches		Month[2]	Evaporation in inches	
	Pan No. 1	Pan No. 2		Pan No. 1	Pan No. 2
January	4.24	6.47	July	18.00	25.68
February	5.67	8.89	August	13.73	18.15
March	8.99	11.65	September	12.16	17.04
April	12.02	17.13	October	9.49	14.72
May	15.52	22.00	November	5.26	8.08
June	16.75	24.17	December	3.70	5.12
			Totals	125.53	179.10

1 The Southern Pacific Railroad station of Mammoth is no longer on the map. It appears to have been east of Calipatria in the vicinity of Tortuga or Amos.

2 The year of record is not entirely clear but it appears that the January to June data were recorded in 1910 and the July to December data in 1909.

at several stations north and south of the sea from which it is possible to estimate the depth of rain falling on the water surface. Stage heights also are recorded by the Imperial Irrigation District. Data are available from which estimates of water surface areas may be computed for different water stages. With these records it becomes possible to estimate roughly the probable evaporation from Salton Sea for periods of moderate to normal precipitation and of low flow in unmeasured streams. In other years there probably would be sufficient contribution to the sea to affect the accuracy of the estimated evaporation. These years should not be included in evaporation tabulations.

Using such data a few engineers have estimated evaporation for Salton Sea, the results being in general agreement. Unpublished figures prepared by the Salton Sea investigators show computed evaporation for the 10-year period 1909-10 to 1918-19 to be 68.76 inches annually as shown in Table 8. In estimating these values the inflow from Alamo and New Rivers was arbitrarily taken as 277,000 acre-feet annually. The records do not show that any inflow was considered from such streams as San Felipe Creek, Whitewater River or the numerous flood washes that enter from the east.

Robson (34) estimated total evaporation for the six-year period April 1, 1907 to April 1, 1913, to be 65.84 inches, on basis of the following data:

Loss in elevation of Salton Sea	26.10 feet
Total rainfall on lake surface	1.38 feet
Total run-off into Salton Sea	1.25 feet
Discharge from Alamo and New Rivers (estimated)	4.19 feet
Total	32.92 feet
Yearly average	65.84 inches

Since the discharge from Alamo and New Rivers had to be estimated and there was no record of inflow from Whitewater River and San Felipe Creek it is probable that the total and average are too low.

TABLE 8

Average Computed (Lake) Evaporation From Salton Sea, California, 1909-10 to 1918-19

(Source: Unpublished estimates by Salton Sea investigators, U.S. Weather Bureau)

Year	Evaporation in inches	Year	Evaporation in inches
1909-10	72.76	1914-15	84.69
1910-11	66.57	1915-16	65.23
1911-12	64.22	1916-17	53.17
1912-13	65.99	1917-18	69.73
1913-14	68.27	1918-19	76.96
		Average	68.76

Probable evaporation shown in Table 9 was computed by Grunsky for 1907-08 (16) in the same manner. This table appears to be subject to some adjustment, possibly because of the effect of wind in changing water surface elevations for some months.

In recent years the rising water level in Salton Sea has resulted in encroachment on adjoining lands, causing some concern to the owners. The flat lands at the southern end of the sea are most affected as a small rise in the sea level here covers a wide expanse. In addition, the outlets of drainage channels are being submerged by rising waters.

Investigations of Evaporation From Small Water Areas

Evaporation studies have been carried on for a number of years at Denver and Fort Collins, Colorado, and at Fullerton and other

Southern California localities. The results obtained have been of general benefit to engineers through discussion of evaporation fundamentals, the development of evaporation formulas, and in establishing the values of evaporation coefficients for the reduction of pan evaporation to equivalent evaporation from larger water areas. The difficulty of direct determination of evaporation from large water areas results from the general impossibility of obtaining a complete inventory of all the waters entering and leaving the reservoir. In isolated instances where the only change in water levels is through dissipation of moisture into the atmosphere, evaporation may be measured directly with staff gages. Occasionally, opportunities exist for computing evaporation from records of inflow, outflow, bank storage, precipitation on the water surface, and changes in water surface levels. In such cases evaporation is the residual item in the water supply. Both conditions are predicated on the assumption that seepage from the bottom of the reservoir is negligible.

TABLE 9

Computed (Lake) Evaporation From
Salton Sea, California, 1907-08 (16)

Year and month	Evaporation in inches	Year and month	Evaporation in inches
1907		1907-continued	
April	5.16	October	6.84
May	8.52	November	6.48
June	8.88	December	4.20
July	8.28		
August	6.36	1908	
September	11.16	January	2.16
		February	2.64
		March	3.00
		Total	73.68

Usually evaporation is measured from small water surfaces in standard evaporation pans. Such measurements may be reduced to lake or reservoir equivalents through use of conversion factors or coefficients derived experimentally for the type and size of pan from which the records at the reservoirs are obtained. In actual practice a number of types and sizes of evaporation pans are in common use. The Weather Bureau pan is set above the ground surface where it is exposed to the sun's rays and the sweep of the wind, both of which increase the evaporation. Both circular and square pans set in the ground with only a few inches of rim exposed are partly insulated by the surrounding soil so that there is a tendency toward a more uniform water temperature and a lower evaporation than in the exposed Weather Bureau pan. The ratio of the wetted perimeter of the pan to the water area is likewise a factor in increasing the evaporation, as water evaporates at a more rapid rate when in contact with the warm metal that forms the boundary of the water surface. The rim effect varies inversely according to the diameter of the pan, the greatest relative effect being on pans having the smallest diameters. The ratio of pan circumference to area of the water surface is $\frac{4}{d}$ which is equal to a value of four for a one-foot diameter pan as compared with a value of 0.333 for the 12-foot pan. Thus, the rim effect is 12 times greater per unit area for the small pan than for the larger one. The capillary rise of moisture on the inside of the pan, increased by a slight wave action, creates a wetted area from which evaporation occurs at a higher rate than from the horizontal water surface.

Denver, Colorado, Investigations. Determination of evaporation coefficients for a variety of pans has been one of the long time objectives of the Department of Agriculture. The first of these

studies was undertaken at Denver, Colorado, where an outdoor evaporation laboratory was established in 1915 for studying, from an engineering point of view, problems connected with the utilization of water in irrigation. A general lack of information regarding specific conclusions that would be useful to the engineering profession prompted the investigators to undertake the following studies:

(a) Variation in the amount of evaporation from pans of varying sizes;

(b) Variation in the amount of evaporation from pans of varying depths;

(c) Comparison of the amount of evaporation from flowing and still water;

(d) Comparison of the results obtained from different types of so-called standard evaporation pans;

(e) Comparison of the evaporation amounts from round pans and square pans of small size;

(f) An extension of the results of experimental pans to larger water areas.

Measurements were made during 1916 and 1917 from a series of circular ground pans of diameters from 1 to 12 feet, each three feet deep, set in the ground 2.75 feet. Other types included a Bureau of Plant Industry pan, a Colorado type square pan, a Weather Bureau pan and a floating pan. Coefficients were determined as a relation of the evaporation from the various pans to evaporation from the 12-foot diameter pan. Because of climatic conditions resulting from the high altitude at Denver it was not possible to carry on evaporation measurements during winter months and the coefficients are necessarily based on approximately eight months of record.

On completion of the season of 1916 a progress report presented a partial list of evaporation coefficients for the principal pans studied (37). During the following year, 1917, measurements

were continued and a summary of the coefficients obtained during the investigation was published (38).

Fort Collins, Colorado, Investigations. A second investigation was undertaken at the Colorado Agricultural Experiment Station, in which the objectives were "determination of factors causing the derivation of the general law under which these factors operate and the evaluation of the relation between evaporation as it takes place from various types of standard evaporation tanks and as it is found to occur from a larger water surface." Evaporation from a Weather Bureau pan, a three-foot square ground pan and a three-foot square floating pan was compared with the loss from an 85-foot diameter reservoir seven feet in depth. Measurements were begun in September, 1926, and continued through the open-water season of 1927 and 1928. This study was also limited to a period of approximately eight months each season. Although determination of an evaporation formula was the principal objective, the data permitted establishment of coefficients relative to evaporation from the 85-foot reservoir. Descriptions of the experiment and conclusions arrived at were published in 1931 (35).

Southern California Investigation. This investigation dealt with evaporation losses from various types of evaporation pans in a coastal region where freezing was not a factor and measurements were possible throughout the year. It established relationships of such losses for monthly and annual periods continuously from 1935 to 1939, inclusive, at a central evaporation station at Fullerton, Orange County, about 10 miles from the coast, and from 1939 to 1941 at Lake Elsinore, Riverside County, about 25 miles inland.

Fullerton Evaporation Station. At this station the mean annual temperature during the period of investigation was 60 degrees and the relative humidity was 68 per cent, with high thin fogs a

common occurrence during summer months. Wind velocity, 20 inches above ground, averaged 2.8 miles per hour. Rainfall, varying from 11 to 23 inches annually during the periods November to April, averaged 15.75 inches per season.

The principal study was determination of pan coefficients relative to evaporation from a 12-foot diameter pan, three feet deep, set 2.75 feet in the ground, with the water surface coincident with the ground surface. Previous experiences with a 12-foot pan and an 85-foot diameter reservoir by Sleight (37) and Rohwer (35) had led to the general conclusion that for diameters greater than 12 feet the size of the pan had little effect on evaporation. It is believed, however, as a result of the author's studies, that evaporation from a 12-foot pan is not the absolute minimum that would be obtained from a larger pan, but that the difference is immaterial in view of other discrepancies often appearing in evaporation measurements.

For comparison with evaporation from the 12-foot pan measurements were made from a series of circular ground pans of similar depth, with diameters of from one to six feet. In addition there was a Weather Bureau pan, a square ground pan of the Colorado type, a Bureau of Plant Industry pan, screened pan and an insulated pan, from all of which evaporation measurements were obtained continuously for periods of from two to five years. Also, there was a series of small pans from which tests were made to determine the effect of color of pans and the effect of different concentrations of salt solution on evaporation losses. Summaries of evaporation from the principal pans at the Fullerton Station are shown later in this report.

<u>Lake Elsinore Evaporation Station</u>. Lake Elsinore, with an area of about 5,500 acres, is an excellent outdoor evaporation laboratory. Its water supply comes from the San Jacinto River which

flows only during the winter and spring months; this flow is measured by the U. S. Geological Survey a short distance above the lake. There has been no outflow since 1916. All the evidence points toward a tight lake bottom that prevents seepage losses of any importance. Evaporation studies were undertaken for the purpose of checking some of the Fullerton station coefficients. Evaporation was measured from a Weather Bureau pan and from a screened pan and was computed for the lake from records of inflow, rainfall on the lake surface, and changes in lake levels. A considerable degree of accuracy was possible in arriving at lake evaporation throughout the long dry summer months when the only change in water surface was through evaporation.

Meteorologic conditions at the lake were similar to those at the Fullerton station. During the period of measurement the average temperature was 64 degrees; wind movement averaged 2.0 miles per hour, alternating between land and ocean breezes. Rainfall varied from 10.96 to 24.45 inches annually.

CHAPTER IV

EVAPORATION COEFFICIENTS

The usefulness of evaporation coefficients is better understood when it is recognized that evaporation from small artificial water surfaces is greater than the loss for larger areas. Ground pans of equal depth but of different diameters, installed under identical conditions of temperature, wind, humidity and rainfall, have different rates of evaporation, the smaller pans having the higher losses. The relation of evaporation from a given size or type of pan to evaporation from a different pan or from a larger body of water is designated as a coefficient and is a ratio. It is variable according to the integrated effect of the meteorologic factors on different pans, and is usually higher in summer than in winter. Annual coefficients are less variable than monthly coefficients. Coefficients are useful for the reduction of evaporation from a small pan to that from a larger pan or from one pan to another of different characteristics. It is the common method of estimating reservoir evaporation from pan records.

In general, it may be presumed that coefficients obtained as a result of the investigations in Colorado are applicable to the region of the inter-mountain states where winter temperatures are below freezing. Coefficients obtained in Southern California would appear to be applicable to the lower areas of the southwestern states where winters are short and mild. In California the Colorado coefficients probably apply to the higher mountain regions, while the Southern California coefficients are more suitable for the lower elevations of coastal and interior valleys.

The Weather Bureau Pan Coefficient

A summary of evaporation records at the Fullerton station is presented later in this report. The ratio of evaporation from the 12-foot diameter pan to evaporation from the smaller pans gives the value of the coefficients that are for use under similar conditions of exposure and weather conditions. The Weather Bureau pan coefficients were consistent throughout the five-year period of investigation, the average annual value being 0.77 with variations from 0.76 to 0.78. During the three-year test at Lake Elsinore the average annual coefficient for the Weather Bureau pan, based on computed evaporation from the lake, was identical with that at the Fullerton stations, but major differences occurred in the monthly coefficients as shown in Table 10. The excellent agreement obtained through the use, as basic evaporation areas, of such dissimilar water areas as a 12-foot pan and a 5,500-acre lake is proof that the 12-foot pan is as large as is necessary for the computation of satisfactory evaporation coefficients.

Differences in coefficients as regards pans and reservoirs are due to the capacity for heat storage in the different water volumes. In the pans much of the heat recieved from the sun during the day is lost at night. In the larger volumes of water a portion of the heat received during the spring and early summer is used in evaporating the surface water and another portion is absorbed in warming the water to a considerable depth. Later in the season the heat in storage gradually returns to the surface where it becomes available for increasing the evaporation during the cooler fall months when pan evaporation is approaching a minimum. During the early part of the season pan evaporation exceeds lake evaporation, but in the fall and winter months evaporation from the deeper body of water may

TABLE 10

Mean Monthly Evaporation and Reduction Coefficients for a Screened Pan and a Weather Bureau Pan at the Fullerton and Lake Elsinore Evaporation Stations

Month	Fullerton, California 1936-39 inclusive					Lake Elsinore, California 1939-41 inclusive				
	Evaporation, in inches			Coefficients		Evaporation, in inches			Coefficients	
	Pan numbers						Pan numbers			
	1	2[a]	3	Screened pan	Weather Bureau pan	Lake Elsinore	4[a]	5	Screened pan	Weather Bureau pan
January	1.82	2.11	2.80	0.83	0.65	1.96	2.05	2.38	0.96	0.82
February	2.20	2.34	3.06	.93	.77	2.00	2.59	3.15	.77	.63
March	3.30	3.12	4.35	1.06	.76	3.24	3.53	4.78	.92	.68
April	4.44	4.30	5.58	1.03	.80	4.20	4.82	6.34	.87	.66
May	5.81	5.73	7.21	1.02	.81	5.92	6.54	8.72	.90	.68
June	6.74	6.62	8.26	1.02	.82	7.04	7.15	9.15	.99	.77
July	7.41	7.35	9.14	1.01	.81	7.96	8.36	10.74	.95	.74
August	7.00	7.07	8.67	.99	.81	7.44	7.31	9.60	1.02	.78
September	5.85	6.12	7.67	.96	.76	6.32	5.72	7.27	1.10	.87
October	4.05	4.47	5.28	.91	.75	4.96	4.42	5.31	1.12	.93
November	3.09	3.59	4.30	.86	.72	3.16	2.83	3.25	1.12	.97
December	1.81	2.08	2.73	.87	.66	2.04	1.98	2.14	1.03	.95
Year	53.52	54.90	69.16	0.975	0.77	56.24	57.30	72.83	0.98	0.77

Description of pans:
- Pan No. 1 (sunken pan), diameter 12 feet, depth 2.75 feet
- Pan No. 2 (sunken pan), diameter 2 feet, depth 3 feet
- Pan No. 3 (Weather Bureau pan), diameter 4 feet, depth 10 inches
- Pan No. 4 (sunken pan), diameter 2 feet, depth 3 feet
- Pan No. 5 (Weather Bureau pan), diameter 4 feet, depth 10 inches

[a] The screened pans were covered with a quarter-inch mesh galvanized hardware screen stretched on a wire ring and suspended within the pan midway between the rim and the water surface.

[b] Area of Lake Elsinore is 5,500 acres

equal or exceed pan evaporation. The length of this excess period depends on the depth of the lake, the amount of heat stored in the water and the time required for its return to the surface. Thus it may be expected that monthly evaporation from a deep lake or reservoir will differ from the computed values that are based on pan records and predetermined monthly evaporation coefficients. Regardless of such monthly differences the annual heat energy received at the reservoir and pan should be about the same; hence, the annual evaporation from the reservoir should be nearly identical with the value computed by means of annual coefficients.

The Six-foot Diameter Ground Pan Coefficient

Comparison was made of evaporation from two six-foot diameter pans at the Fullerton station, one being three feet in depth with a three-inch rim above ground, the other a standard Bureau of Plant Industry pan which was two feet in depth with a four-inch rim. Evaporation from the Bureau of Plant Industry pan was consistently less than that from the deeper pan, but only by a small amount each month. Since the pans were of the same diameter and received the same heat energy, the differences in evaporation must be attributed to some special pan characteristics such as depth of water or height of rim above the water surface. The coefficient for the deeper pan, based on five years of measurement, averaged 0.91 as compared with 0.94 for the Bureau of Plant Industry pan in a two-year period. Few of the six-foot pans are used in California.

The Square Ground Pan Coefficient

The square pan, 3 x 3 feet, 18 inches deep, is used in some areas both as land and floating types. The land pan usually is set

14 or 15 inches in the ground. Both land and floating pans are frequently painted black inside and outside, a condition that increases the evaporation. The annual coefficient for conversion of evaporation from the unpainted square ground pan to that from the 12-foot pan at the Fullerton station averaged 0.89 for the five-year period 1935 to 1939, inclusive, with annual values ranging from 0.87 to 0.90 (49). This coefficient is not in agreement with the Colorado values for this pan, which according to Sleight (38) and Rohwer (35) was 0.79. A comparison of the records shows different rim heights for the two pans. Sleight (38) described the square ground pan at Denver, as three feet deep, set 2.75 feet in the ground with the water surface approximately at ground level. Rohwer's (35) pan at Fort Collins, was 18 inches deep, set in the ground with its top edge 1 3/4 inches above the ground level. Allowance for variation in the water surface in Rohwer's pan was one inch and the maximum distance below the rim was two inches. The square pan at the Fullerton station was 18 inches deep, set in the ground 14 inches so that there was a four-inch rim as compared with a three-inch rim at Denver and a 1 3/4 - inch rim at Fort Collins. Experiments have shown a rapid decrease in evaporation when water stands at progressively greater depths below the top of the pan. A lower rim at the Fullerton station should result in more evaporation and a lower coefficient that would more nearly approach those derived through the Colorado studies. The monthly coefficients were quite uniform, showing a range of values from 0.87 to 0.93. This narrow range, similar to that found for the Bureau of Plant Industry pan, fails to show the seasonal trend in coefficients that has been disclosed for pans other sizes. For example, monthly coefficients for various circular ground pans are high in summer and low in winter. They follow the seasonal range of

temperature. Likewise, coefficients for the Weather Bureau pan are highest during the hottest months when comparison is made with the 12-foot pan, but when evaporation from a Weather Bureau pan is compared with that from Lake Elsinore, the highest coefficients are seen to occur in the fall and the lowest in early spring (47). This is the direct result of heat storage in the lake.

The Square Floating Pan Coefficient

The square floating pan in California is used primarily in San Diego County, although its use is by no means confined to that area. The longest period of record was 23 years at Henshaw Reservoir where a land pan of the same size was also in use for the same period. The floating pan is used for estimating reservoir evaporation by approximating reservoir conditions as to water temperatures and exposure to wind. Although it is partly protected from waves by a surrounding float there often is uncertainty as to the exact depth of evaporation during storms when water splashes into or out of the pan. If water splashes in, too little evaporation is indicated; if it splashes out, the evaporation recorded is too high. When records from the floating pan are uncertain, measurements from a square ground pan may be substituted with a reasonable degree of accuracy. To obtain the best results, water inside the land and floating pans should be kept at the same depth as the outside surface. Paint should not be applied, as it changes the rate of evaporation. It does, however, delay rusting and prolongs the life of the metal. In practice, the floating pan is subject to more wind than the land pan, with the probability that the wind movement increases the evaporation. Other differences occur because of splash. Examination of records of 19 pairs of land and floating square pans, as indicated

in Table 11, shows a few great differences in mean annual evaporation. The mean ratio of evaporation from the floating pan to the ground pan for the 19 stations is 0.95, as compared with an experimental value of 1.03 obtained as one of the results of Rohwer's studies (35). The length of the record and the number of places of observation scattered throughout the State indicate average figures that might ordinarily be expected in practice. Most of the stations are at reservoirs or lakes where water in storage has opportunity to warm up by standing in the sun. The floating pans at Independence and at Kingsburg were in running water which is colder, especially at Independence where the Owens River flows out of the high mountains. This condition could readily account for the low evaporation from the floating pan as compared with the ground pan.

The coefficient for converting evaporation from the three-foot square floating pan to evaporation from a 12-foot diameter pan at Denver, as recorded by Sleight (38) was 0.89 in 1915 to 1917. This is higher than Rohwer's value (35) of 0.77 obtained by comparison with evaporation from an 85-foot diameter reservoir. No studies to determine the values of coefficients for the floating pan have been made in California although the generally accepted value in practice appears to range from 0.79 to 0.83. This is in agreement with results obtained by experiment and by reservoir practice. A comparison of coefficients for square pans as determined by experiment, with those recommended in a Final Report of Subcommittee on Evaporation of the Special Committee on Irrigation Hydraulics (1) and others suggested by Hall (17) are presented in Table 12. As a result of this tabulation it appears that an average value of 0.80 may be accepted by engineers for computing reservoir evaporation from a three-foot square land or floating pan. Exceptions to these values are

TABLE 11

Comparison of Evaporation from Square Ground and Floating Pans at Various Lakes and Reservoirs in California

Station	County	Length of record	Mean annual evaporation: Ground pan square 3x3 ft., 18 ins. deep	Mean annual evaporation: Floating pan square 3x3 ft., 18 ins. deep	Ratio of evaporation from floating pan to evaporation from ground pan
		Years	Inches	Inches	Ratio
Bouquet Canyon Reservoir	Los Angeles	10	86.90	71.25	0.82
Buena Vista Lake	Kern	1	67.84	81.11	1.20
Clear Lake	Lake	5	41.32	36.48	.88
Cuyamaca Reservoir	San Diego	7	69.72	68.30	.98
El Capitan Reservoir	San Diego	10	73.17	69.38	.95
Henshaw Reservoir	San Diego	23	63.77	[1]70.06	1.10
Independence	Inyo	3	[2]83.57	[2]65.62	.78
Kingsburg	Fresno	4	59.76	46.23	.77
Lake Hodges	San Diego	12	[3]58.57	55.06	.94
Lower Otay Reservoir	San Diego	19	57.03	57.44	1.01
Morena Reservoir	San Diego	11	74.80	65.29	.87
Pardee Reservoir	Calaveras	14	54.37	58.89	1.08
San Pablo Reservoir	Contra Costa	15	53.83	39.00	.72
San Pablo Reservoir	Contra Costa	8	44.30	47.84	1.05
San Pablo Reservoir	Contra Costa	8	45.36	48.23	1.06
San Vicente Reservoir	San Diego	2	60.30	64.42	1.07
Sweetwater Reservoir	San Diego	4	59.64	53.23	.89
Tinemaha Reservoir	Inyo	9	90.00	74.23	.82
Upper San Leandro Reservoir	Alameda	14	42.79	47.18	1.10
	Total	179		Mean	0.95

1 Monthly records incomplete
2 Pans were 10 inches deep
3 Square concrete basin with four-inch walls

coefficients determined by Sleight (38) for a floating pan and by the author (49) for a land pan. Sleight's floating pan was 3,400 feet from the laboratory where his other records were obtained and the different location or the higher humidity at the lake, could account for the higher evaporation ratio. The high coefficient for the land pan at the Fullerton station has previously been explained as the result of a higher pan rim than those reported at other evaporation stations. For square land pans similarly installed a coefficient of 0.89 is applicable for Southern California.

TABLE 12

Comparison of Evaporation Coefficients for 3x3 Foot Square Land and Floating Pans for Reducing Pan Evaporation to Equivalent Evaporation From Larger Water Areas

Investigator	Reference	Evaporation coefficients for 3 x 3 ft. pans	
		Land	Floating
Sleight	(38)	0.79	0.89
Rohwer	(35)	.79	.77
Subcommittee	(1)	.78	.80
Hall	(17)	.81	.80
Young	(49)	[1].89	

[1] Higher coefficient is a result of a four-inch rim above the ground surface.

The Screened Pan Coefficient

The most efficient pan is the one for which the coefficient approaches unity; that is, the evaporation from the pan closely approximates evaporation from a larger body of water. Attempts by the Department of Agriculture to produce a pan having this characteristic resulted in a screened pan designed and tested at the Fullerton station during a four-year period. This pan was two feet in diameter, three feet deep, set in the ground 2.75 feet. At this point a new

principle in evaporation studies was introduced in the form of a ¼-inch galvanized mesh screen suspended horizontally midway between the top of the pan and the average water surface. The screen reduced the interception of heat energy at the water surface during the day, reduced back radiation at night and lessened the wind effect over the water. Average annual evaporation was less than that for any other type of small pan and closely approximated the evaporation from a 12-foot ground pan.

The average annual coefficient for reducing evaporation from the screened pan to equivalent evaporation from the 12-foot pan was 0.98. Monthly coefficients varied considerably, being slightly above unity from March through July and tapering off to values as low as 0.81 during the colder months. At Lake Elsinore a three-year test produced identical annual coefficients (47) but with significant differences in the monthly coefficients. Because of the greater capacity of the lake, heat stored in the water at depth earlier in the year moved upward as the surface water turned colder and sank. Thus, the surface of the lake continued warm for many weeks after the air temperatures began to cool and lake evaporation during fall months exceeded the loss from the evaporation pan. In consequence, the monthly coefficients were less than unity during the early part of the year and greater than unity during the later months. Results of the screened pan tests at both stations have been shown in Table 10.

For a more general application, Table 13 shows evaporation coefficients for a majority of evaporation pans in common use as determined by similar investigations at Denver and Fort Collins, Colorado, Milford, Utah, and Fullerton, California. The agreement for the several locations was generally good although some tendency existed toward higher values at the Fullerton Station. For the

Weather Bureau pan at the Fullerton coefficient was 0.77 as compared with an average of 0.70 obtained through the Colorado studies. For the Colorado-type square ground pan the coefficient was found to be 0.89 at the Fullerton station (49) as compared with 0.79 obtained at both Colorado investigations. This has been explained as being caused by the difference in rim heights at the different stations.

TABLE 13

Evaporation Coefficients as Determined by Various Investigations in Western States

Location	Period	Authority	Evaporation coefficients: Weather Bureau pan	Screen (Young) pan	Bureau Plant Industry pan	Square floating pan U.S.G.S.	12-ft. diameter pan
Elsinore, Calif.	Annual	Young	0.77	0.98			
Fullerton, Calif.	Annual	Young	.77[1]	.98	0.91		1.00
Silver Lake, Calif.	Annual	Young & Blaney	.61[2]				
East Park Reservoir, Calif.	--	Rohwer	.69				
Denver, Colo.	Apr-Nov.	Sleight	.66		.90	0.91	.99
Denver, Colo.	Apr-Nov.	Sleight	.70[1]				
Denver, Colo.	Apr-Nov.	Blaney	.69[1]		.91		1.00
Ft. Collins, Colo.	Apr-Nov.	Rohwer	.70			.77	1.00
Lake Hefner, Okla.	Annual	Kohler	.69	.91	.91		
Milford, Utah	Mar-Oct.	White	.67[1]				1.00
General	--	A.S.C.E.	.70			.80	

1 Based on 12-foot pan.
2 Mojave Desert, Calif.

CHAPTER V

EVAPORATION FROM LARGE WATER AREAS

The number of evaporation records and coefficients available permit estimation of lake evaporation that is fairly dependable and the probable evaporation from most lakes and reservoirs is computed by this means. The most accurate data are obtained directly from staff gage measurements from closed lakes during the dry season when there is neither inflow nor outflow. A tight lake bottom is a prerequisite for this condition. Such opportunities are few. During the rainy season when streams are flowing, evaporation is computed from records of inflow, outflow, rainfall on the lake surface and change in water levels. A few such records of monthly evaporation for California and Nevada are shown in Table 14. Mean annual evaporation is shown in Table 15.

Buena Vista Lake is a shallow reservoir of fluctuating size covering several thousand acres about 20 miles southwest of Bakersfield. The data representing this reservoir are summarized for the period 1937 to 1945 from records of inflow, outflow, rainfall on the lake surface and lake fluctuations by Walter Ruppel, office of Harry L. Haehl, consulting engineer, San Francisco. The lake records were obtained by the Buena Vista Water Storage District. Rainfall was averaged from Weather Bureau stations at Bakersfield, Buttonwillow and Maricopa.

Evaporation from Tulare Lake has been estimated by Harding (20) for a period prior to 1916 when there was no inflow, and with the exceptions of periods of rainfall the evaporation could be measured directly from changes in lake levels as shown on staff gages. Seepage was considered to be negligible. Rainfall was taken from the Hanford records. Computed records for Buena Vista and Tulare Lakes, although

TABLE 14

Evaporation Computed for a Few Lakes in California and Nevada

(Evaporation in inches)

Month	California				Nevada	
	Buena Vista Lake, Kern County, Elevation 290 ft.	Tulare Lake, Kings County, Elevation 200 ft. (20)	Lake Elsinore, Riverside County, Elevation 1,260 ft.	Eagle Lake, Lassen County, Elevation 5,100 ft. (20)	Walker Lake, Mineral County, Elevation 4,030 ft. (20)	Pyramid Lake, Washoe County, Elevation 3,830 ft. (20)
January	1.2	1.4	1.8	1.8[1]	2.4	3.0
February	1.8	1.6	1.6	1.8[1]	1.8	3.0
March	2.9	3.0	2.9	2.4[1]	2.4	3.6
April	4.3	3.6	4.4	3.0[1]	2.4	3.6
May	6.0	6.0	5.8	3.6	3.0	4.2
June	6.2	8.4	6.7	4.8	4.8	4.8
July	8.5	9.6	7.8	6.0	6.0	4.8
August	10.2	7.2	7.9	5.4	6.6	4.8
September	7.8	7.2	6.6	5.4	7.8	5.4
October	4.6	3.6	5.2	3.6	5.4	4.8
November	2.5	2.4	3.2	2.4	4.8	4.2
December	1.7	1.2	2.3	1.8	3.0	3.6
Annual	57.7	55.2	56.2	42.0	50.4	49.8

1 Estimated

prepared independently and for different series of years, are in harmony with each other, each showing a mean evaporation of 55 to 58 inches annually.

TABLE 15

Computed Mean Annual Evaporation for Several Lakes in California

Location		Elevation, in feet	Period, in years	Evaporation, in inches	Authority
Name	County				
Buena Vista	Kern	290	1937-45	57.7	Harry L. Haehl
Eagle Lake	Lassen	5100	1927-34	42.0	S. T. Harding
Lake Elsinore	Riverside	1260	1916-41	56.2	Arthur A. Young
Salton Sea	Imperial	-238	1948-53	73.0	Harry F. Blaney
Silver Lake	San Bernardino	900	1938	79.0	Harry F. Blaney
Tulare Lake	Kings	200	-- --	55.2	S. T. Harding

Lake Elsinore, Riverside County, California, is fed by the San Jacinto River. It overflows at long intervals and at times is nearly dry. The computed mean evaporation from the lake for the 26-year period 1916 to 1941 is 56.2 inches or 4.7 feet annually.

Eagle Lake is in Lassen County, California, at elevation 5,100 feet. Some seepage from the lake occurs and some unmeasured inflow enters it during the early part of the year. At its highest stages Eagle Lake covered an area of some 30,000 acres. This area was large enough so that small discrepancies in water supply did not materially affect the accuracy of the computed evaporation, which was only for the period of minor stream flow. Since Eagle Lake is at a relatively high elevation, evaporation is low, averaging 3.5 feet or 42.0 inches per year.

Gage heights at Walker Lake, in western Nevada, available for the years 1929 to 1934, inclusive, indicate an annual lake evaporation of 50.4 inches. Elevation of the lake was about 4,030 feet

and its area about 90 square miles. Rainfall and most stream flow were unmeasured at the north end of the lake. Some local unmeasured flow occurred, but in years of low rainfall it was insufficient to affect the computed depth of evaporation measurably.

Pyramid Lake, also in western Nevada, at the time of record had an area of about 200 square miles at altitude 3,830 feet. It received the measured flow of Truckee River and gage heights and rainfall records were available. Annual evaporation for the 7-year period 1927 to 1934, inclusive, amounted to 49.8 inches, which is practically identical with the computed evaporation from Walker Lake.

CHAPTER VI

SUMMARY

Additions to the irrigated acreage in the West since the first of the century, and the widespread demand for power, have resulted in the development of many reservoirs from which losses by evaporation are becoming increasingly important as a factor in the water supply. Construction programs for the future call for more and larger reservoirs and for further economy in water use. In early years when the supply was plentiful no attention was given to water losses, but as the demand increased attention became focused on them. This interest is expected to continue as water requirements are extended and the value of water increases. This report has been prepared as a foundation for estimating evaporation from present and future reservoirs throughout California.

The depth of evaporation varies throughout the State from a maximum in the hot desert regions to a minimum in the snowclad mountains. Along the coast it is held to a medium loss by moderate temperatures and the presence of haze or fog which often partially obscures the sun. At the lower elevations evaporation is recorded throughout the year, but in the mountains freezing prevents measurement during the winter months. Pan records vary also according to type of evaporation pan from which they are obtained. Pans exposed above the ground surface have the highest loss. Of the pans set in the ground the greatest depth of evaporation occurs from the smallest and the least depth from the largest pan. The four-foot diameter Weather Bureau pan is a favorite in many places. Evaporation from this pan has been recorded as high as 156 inches a year on the Colorado Desert, and as low as 58 inches annually along the coast.

Desert winds at pans located on summit areas between coast and desert increase the normally low evaporation. An example is the record at Fern Canyon, at elevation 5,100 feet in the San Gabriel Mountains, where the recorded evaporation averages 76 inches annually or 18 inches higher than at sea level and approximately the same latitude. Fern Canyon is above the fog belt.

Evaporation usually is measured from small metal pans and translated to equivalent evaporation for large water areas through use of reduction coefficients that must first be determined by experiment. Evaporation recorded from pans is the true evaporation, with rain falling in the pan accounted for as water added. This is the common method of calculating pan evaporation. In some cases evaporation from reservoirs is designated as "gross" or "net" evaporation. Gross reservoir evaporation is the actual depth of water lost to the atmosphere. Net evaporation is the gross evaporation minus the depth of rain falling on the water surface. Gross evaporation is always positive but net evaporation is negative in months when the true evaporation is less than the rainfall. The terms "gross" and "net" are used in connection with estimating reservoir losses but not in connection with pan evaporation.

Different types and sizes of evaporation pans are in common use. The standard Weather Bureau pan is the most popular one and has the most extensive list of records, but it also has a rate of annual evaporation that is at least 30 per cent higher than evaporation from a large water surface. The Bureau of Plant Industry pan, six feet in diameter, is set in the ground. Its rate of loss is considerably less than that from the more exposed Weather Bureau pan. Ground and floating pans, each three feet square, are used in many places for estimating reservoir evaporation. Evaporation records from

these pans are not identical but are close enough so that when a floating pan record is lost through wave action a substitute record may be obtained from the ground pan. The Los Angeles County Flood Control District observes some 25 evaporation pans forming a county network throughout valley and mountain areas. Records usually have been continuous for the past 15 years. The screened pan was designed to reduce evaporation to an amount approximately equal to the loss for a large water area. Its principal use has been experimental, but the Los Angeles County Flood Control District, beginning about the first of 1946, adopted it as a standard pan.

Theoretically, at the higher elevations, evaporation should increase as a result of the decreasing barometric pressures, but practically it decreases as a result of the lower temperatures. This was demonstrated by the Mt. Whitney study by Frank Adams in 1905.

The Salton Sea investigations by the U. S. Weather Bureau in 1909-10 demonstrated the difference in evaporation over land and water areas. Evaporation was greater over a land area than over a water area. On a water area as large as Salton Sea evaporation close to the windward shore is greater than at a distance offshore. As the air moving over the water absorbs moisture, evaporation decreases until it becomes nearly constant. Air moving from the water to dry land loses some of the moisture absorbed in its passage. For both land and water locations evaporation increased in vertical sections.

Investigations by the Department of Agriculture at Fullerton demonstrated that different rates of evaporation occurred from different types and sizes of evaporation pans. Evaporation coefficients were determined that are applicable in estimating evaporation from large water areas from records of pans similarly located.

Coefficients used should be those developed under climatic conditions closely similar to those existing where they are to be applied. Coefficients obtained by experiment in Colorado should be useful in mountain areas where winter conditions prevent evaporation from water surfaces during winter months. California coefficients were determined at a low elevation and should be applicable for valley and mountain areas where winter conditions prevent evaporation from water surfaces during winter months.

Coefficients for a majority of evaporation pans have been derived through comparison with evaporation from a 12-foot diameter pan similarly situated. At Fort Collins, Colorado, comparison was made with evaporation from an 85-foot diameter shallow reservoir. The results show little difference in the coefficients regardless of the size of the base pan. Coefficients determined in California agree generally with those obtained in Colorado with the exception of the coefficient for the Weather Bureau pan, which was 10 per cent higher at the California station. Coefficients vary from month to month, usually being higher in summer than in winter. Annual coefficients are the mean values of all the monthly coefficients. Monthly evaporation from shallow pans differs from evaporation from deep bodies of water. The difference is due to amount of heat storage in the different volumes of water. Shallow pans hold but little heat in the water. Deep reservoirs absorb heat during the early months of the year and return it to the surface in the fall when the air is cooler. This increases the temperature of the water surface and the depth of evaporation at a time of year when pan evaporation is decreasing. Because of this it is not likely that monthly evaporation computed by means of coefficients will agree with actual monthly reservoir evaporation. Annual evaporation should be

approximately the same in either case, as both pan and reservoir are exposed to the same total amount of heat from the sun.

Pan coefficients vary according to the size and exposure of the evaporation pan. The Weather Bureau pan is the least efficient as it has the highest rate of loss and the lowest coefficient. For pans set in the ground the largest are the most efficient and have the highest coefficients. In experimental studies, coefficients for all other pans are based on evaporation from the 12-foot pan, or as in the Fort Collins study, on evaporation from the 85-foot diameter shallow reservoir. A coefficient of 1.00 has been adopted for both the 12-foot pan and the 85-foot reservoirs and all other coefficients are ratios based on this value.

Evaporation from large water areas may be computed directly from records of inflow, outflow, rainfall on the water surface, and change in water levels. Such computations give results that are more or less approximate, as usually all items entering into the equation cannot be evaluated. In most cases, however, where such computations have been attempted the results have been sufficiently accurate to provide valuable data.

A large number of evaporation records are presented in the appendixes to this report. They include pan measurements obtained because of the interest of many organizations in many.portions of the State. Records are most numerous where there is a scarcity of water and many areas where water is plentiful or is in small demand have not found it necessary to observe evaporation losses. For years evaporation has been recorded at many of the larger reservoirs storing water for irrigation, municipal use, or power. Where stream flow is unreliable as a result of dry years, carry-over storage is

a necessity. Under such conditions evaporation may become a higher percentage of the total replenishment than on streams where the flow is more regular.

The long-term mean evaporation for a small group of Weather Bureau pans located at various places in Southern California is shown in Table 16. The base station for this tabulation is the Riverside Citrus Station, which has a record of 21 years of measurement. The table shows the annual index of evaporation for each station and sets up a comparison of the mean evaporation with the 21-year calculated mean. A similar tabulation was computed for Weather Bureau pans at stations in the Central Valley based on a 19-year record of evaporation at the College of Agriculture at Davis, as shown in Table 17. In general, the tabulations show only small differences between the mean of record and the calculated long-term mean.

TABLE 16

ANNUAL EVAPORATION FROM A GROUP OF WEATHER BUREAU PANS IN THE SOUTH COASTAL BASIN WITH EVAPORATION INDICES BASED ON A 21-YEAR PERIOD OF RECORD AT THE RIVERSIDE CITRUS STATION

Year	Riverside Citrus Station, Riverside County (Base station) elevation 1,040 feet		Lower San Fernando Reservoir, Los Angeles County, elevation 1,140 feet		Jameson Reservoir, Santa Barbara County, elevation 2,230 feet		Encino Reservoir, Los Angeles County, elevation 1,020 feet		Gibraltar Reservoir, Santa Barbara County, elevation 1,210 feet		Baldwin Park Evaporation Station, Los Angeles County, elevation 87 feet		Tujunga Spreading Ground, Los Angeles County, elevation 815 feet	
	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent
1925	70.09	109	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---
1926	68.66	107	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---
1927	64.36	100	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---
1928	68.47	107	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---
1929	69.09	108	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---
1930	63.08	98	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---
1931	67.76	106	105.76	116	-----	---	-----	---	-----	---	-----	---	-----	---
1932	*64.22	100	99.14	109	-----	---	-----	---	68.65	109	-----	---	-----	---
1933	62.25	97	103.50	114	56.40	105	85.01	111	66.55	105	64.42	103	82.88	109
1934	67.20	105	89.66	99	58.06	108	78.07	101	66.56	105	64.27	103	76.88	101
1935	60.31	94	82.89	91	54.62	101	73.60	96	60.49	96	62.11	99	66.81	88
1936	62.35	97	89.77	99	58.83	109	81.64	106	66.53	105	64.86	104	77.30	101
1937	59.51	93	83.52	92	59.02	110	73.81	96	63.96	101	61.03	97	71.55	94
1938	63.40	99	85.99	95	51.43	96	74.60	97	58.09	92	62.50	100	81.55	107
1939	64.56	100	93.73	103	53.29	99	76.21	99	62.09	98	63.32	101	78.46	103
1940	70.41	110	84.97	94	54.06	100	72.40	94	63.96	101	60.26	96	79.69	105
1941	59.34	92	76.77	85	47.28	88	64.52	84	53.41	84	57.02	91	68.53	90
1942	64.26	100	88.21	97	46.71	87	76.16	99	58.94	93	*61.37	98	72.88	96
1943	62.72	98	85.80	95	45.24	84	78.24	102	61.43	97	60.90	97	74.16	97
1944	59.74	93	80.79	89	48.40	90	72.71	94	-----	---	55.93	89	65.84	86
1945	59.62	93	83.30	92	52.50	98	73.42	95	-----	---	-----	--	-----	---
Years of record	21		15		13		13		12		12		12	
Mean of record	64.22	100	88.92	99	52.75	98	75.41	98	62.56	99	61.37	98	74.66	98
21-year mean	64.22		90.73		53.83		76.95		63.19		62.62		76.18	

* One month record estimated.

TABLE 17

ANNUAL EVAPORATION FROM A GROUP OF WEATHER BUREAU PANS
IN THE SAN JOAQUIN AND SACRAMENTO VALLEYS
WITH EVAPORATION INDICES BASED ON A 19-YEAR PERIOD
OF RECORD AT THE COLLEGE OF AGRICULTURE AT DAVIS, CALIFORNIA

Year	Davis College of Agriculture, Yolo County, elevation 51 feet (Base Station)		Alvarado, Alameda County, elevation 3 feet		Lodi, San Joaquin County, elevation 50 feet		Lake Curry, Napa County, elevation 248 feet		Pardee Reservoir, Calaveras County, elevation 670 feet		Oakdale, Stanislaus County, elevation 215 feet		Friant Government Camp, Fresno County, elevation 400 feet	
	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent	Evaporation, inches	Index, per cent
1927	62.45	93	52.79	100	-----	---	-----	---	-----	---	79.06	103	-----	---
1928	63.89	95	49.76	94	-----	---	-----	---	-----	---	81.48	106	-----	---
1929	65.62	98	53.75	101	-----	---	-----	---	-----	---	81.38	106	-----	---
1930	61.49	91	54.35	102	-----	---	-----	---	-----	---	*80.88	106	-----	---
1931	73.48	109	54.84	103	73.97	108	73.33	117	70.07	112	82.67	108	-----	---
1932	74.65	111	53.65	101	73.21	107	69.17	110	69.70	112	79.16	103	-----	---
1933	74.03	110	52.29	99	75.29	110	68.81	110	75.12	120	75.97	99	-----	---
1934	66.51	99	53.26	100	71.76	105	65.73	105	71.99	115	79.05	103	-----	---
1935	63.18	94	51.82	98	*66.82	98	60.31	96	57.40	92	73.43	96	-----	---
1936	71.06	106	52.77	100	71.46	104	63.34	101	63.17	101	75.47	99	-----	---
1937	66.54	99	52.39	99	70.65	103	60.36	96	61.85	99	72.25	94	-----	---
1938	67.48	100	52.14	98	*65.63	96	59.32	94	60.55	97	72.00	94	-----	---
1939	75.54	112	54.58	103	78.61	115	70.41	112	64.45	103	76.20	100	-----	---
1940	62.70	93	53.63	101	67.97	99	60.57	96	64.14	103	-----	---	-----	---
1941	61.54	92	52.78	100	62.87	92	56.38	90	59.58	95	-----	---	78.31	93
1942	63.32	94	-----	---	62.36	91	59.59	95	58.88	94	-----	---	86.13	102
1943	67.89	101	-----	---	67.67	99	62.37	99	57.93	93	-----	---	83.11	99
1944	65.28	97	-----	---	67.33	98	*61.32	98	58.09	93	-----	---	83.21	99
1945	71.51	106	-----	---	67.13	98	65.40	104	57.89	93	-----	---	81.90	97
Years of record	19		15		15		15		15		13		5	
Mean of record	67.24	100	52.99	100	69.52	101.5	63.76	101.5	63.39	101.5	77.62	101.3	82.53	98
19-year mean	67.24		52.99		68.49		62.82		62.45		76.62		84.22	

* Partly estimated.

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APPENDIX B

Evaporation in the San Francisco Bay and Sacramento-San Joaquin Delta Areas

by

Dean C. Muckel
Agricultural Research Service
United States Department of Agriculture

APPENDIX B

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TABLES

PLATES

EVAPORATION IN THE SAN FRANCISCO BAY AND SACRAMENTO-SAN JOAQUIN DELTA AREAS

By Dean C. Muckel, Irrigation Engineer, United States Department of Agriculture, Agricultural Research Service, Berkeley, California

During 1953 and 1954 the California State Engineer made an investigation into the feasibility of barriers across the San Francisco Bay to create fresh water pools or lakes. As a part of this investigation, the State entered into a contract with the U. S. Agricultural Research Service, Soil and Water Conservation Research Division to determine the evaporation losses which might occur from any fresh water pools so formed. At the conclusion of the investigation by the State, the U. S. Army Engineer District, San Francisco, Corps of Engineers, started a comprehensive investigation of the entire San Francisco Bay system and requested that the evaporation studies be continued for a five-year period under a cooperative agreement beginning in 1955. The area covered included South San Francisco Bay, San Pablo Bay, Suisun Bay, and the Sacramento-San Joaquin Delta. This report presents evaporation data collected during the period 1953 to date.

A survey of data existing in 1953 revealed that evaporation measurements were being made from United States Weather Bureau type pans (four feet in diameter and ten inches deep) at 15 locations in the San Francisco Bay and Sacramento-San Joaquin Delta areas (see figure 1). A concentration of these records was found along the southern shores of South San Francisco Bay. Two

records were found on the northern shore of San Pablo Bay, two on the south edge of Suisun Bay, and others in outlying areas as the upper fringe of the delta. Slightly inland, two evaporation records were found near Berkeley and San Leandro.

In order to obtain better coverage, three additional evaporation stations were installed in 1953. One station was located at the University of California Richmond Field Station in the City of Richmond. This station was well exposed to the prevailing winds off the bay and was believed to represent conditions along the waterfront on the eastern side of San Pablo Bay. Another station was installed on the northern edge of San Pablo Bay about one mile north of Sears Point Road and midway between Napa River and Sonoma Creek on the southern levee of South Slough. This location represents conditions along the northerly edge of San Pablo Bay. A third station was installed on Joice Island near Volanti Slough in the middle of a large water consuming area.

In 1955 in cooperation with the Corps of Engineers, additional stations were installed. Three were in the Sacramento-San Joaquin Delta, one at Walnut Grove, one on Mandeville Island, and one near Stockton Mowry Bridge. Other stations were located at Hamilton Air Force Base and the Burlingame City Sewerage Plant. The California Department of Water Resources cooperated in the installation of the three delta stations.

Table 1 is a list of the evaporation station pans in the San Francisco Bay region and shows the period of record and average annual gross evaporation for the period of record.

TABLE 1.--LIST OF EVAPORATION STATIONS IN THE SAN FRANCISCO BAY REGION

Station	Location number on figure 1	Period of record	Average annual gross evaporation from Weather Bureau type pans for period of record
San Francisco Bay			
Alvarado (WB)	3	1924-1941	52.85
Newark (WB)	15	1942-date	58.20
Plant No. 1 (Leslie Salt Co.)	16	1944-date	56.36
Plant No. 2 (Leslie Salt Co.)	17	1944-date	58.26
Baumberg (Leslie Salt Co.)	6	1941-date	56.83
Alviso (Leslie Salt Co.)	4	1941-date	48.90
Redwood City (Leslie Salt Co.)	18	1951-date	64.30
Richmond 1/	19	1953-date	52.66
Burlingame 2/	7	1955-date	56.54
Hamilton Field 2/	9	1955-date	71.15
San Pablo Bay			
Sears Point Road 1/	21	1953-1955	65.32
A-14 (Leslie Salt Co.)	1	1952-date	58.64
A-20 (Dutton's Landing) 3/	2	1953-date	62.33
Suisun Bay			
Antioch (U. S. Bureau of Reclam.)	5	1948-date	75.59
Martinez (U. S. Bureau of Reclam.)	12	1953-date	77.07
Joice Island 1/	10	1953-date	62.57
Sacramento-San Joaquin Delta			
Davis (WB)	8	1926-date	67.22
Lodi (WB)	11	1931-date	69.19
Tracy (U. S. Bureau of Reclam.)	22	1950-1953	71.07
Tracy Pumping Plant (U. S. Bureau of Recl.)	25	1955-date	104.83
Walnut Grove 2/	24	1955-date	66.36
Mandeville Island 2/	13	1955-date	78.00
Mowry Bridge 2/	14	1955-date	66.56
Stations adjacent to area			
San Pablo Reservoir (EBMUD)	20	1951-date	56.61
Upper San Leandro Reservoir (EBMUD)	23	1951-date	54.86

1/ Installed by California State Division of Water Resources. Responsibility assumed by Corps of Engineers, November, 1954.

2/ Station established in cooperation with the Corps of Engineers.

3/ Evaporation pan and raingage installed by Leslie Salt Company. Atmometer, hygrothermograph, and thermometers installed for this investigation. Observations by Leslie Salt Company.

In connection with the Corps of Engineers comprehensive investigation of the San Francisco Bay, it was required that evaporation be determined for the period October, 1922, to September, 1955, inclusive. Only two records were of sufficient length to cover this period, one at Davis and one at Newark. The Newark station was originally at Alvarado and the two records (Alvarado and Newark) are sometimes combined to form a continuous record. Studies during this investigation showed that the two records differed and that an adjustment should be made of the Alvarado record in order to extrapolate the Newark record. This was done by accumulating the Alvarado-Newark record in reverse chronological order and plotting. A distinct break in the plotted line occurred at the time when the station was moved from Alvarado to Newark. Calculations showed that the Alvarado records should be multiplied by 1.056 to extend the Newark record properly.

From the records of the two base stations (Davis and Newark extended) monthly percentages of the means were calculated and the short-time records at various other stations extrapolated on this basis. Table 2 shows the mean monthly evaporation at Davis with the per cent variation from mean for each month. Table 3 presents similar data for the Newark station. The annual evaporation at Davis varied from 89 to 115 per cent of the 33-year average and the annual evaporation at Newark varied from 93 to 108 per cent of the 33-year average. Somewhat greater departures from the 33-year average will be found for individual months.

In Table 4, the computed 33-year average monthly evaporation at several stations within the San Francisco Bay and Sacramento-San Joaquin Delta areas are shown.

TABLE 2.--MONTHLY EVAPORATION AND PER CENT OF MONTHLY MEAN FOR THE PERIOD
OCTOBER 1922 THROUGH SEPTEMBER 1955 AT DAVIS, CALIFORNIA

(Evaporation in inches)

Year	October		November		December		January		February		March		April		May		June		July		August		September		Annual	
	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent
1922-23	4.97	98	2.18	91	1.18	99	1.11	93	1.96	98	3.89	107	5.48	96	8.17	98	9.19	93	10.89	98	9.67	98	7.95	101	66.64	99
-24	4.91	96	2.50	104	1.10	93	1.09	91	2.11	106	3.60	95	5.66	99	8.46	102	9.77	99	10.71	97	9.52	96	7.75	98	67.18	98
-25	4.73	93	2.20	92	1.03	87	1.19	98	2.03	102	3.78	100	5.51	96	8.01	96	9.85	100	11.23	101	9.58	97	7.33	93	66.47	97
1925-26	4.88	96	2.28	95	1.19	100	1.07	89	2.04	102	4.18	110	5.91	103	7.76	93	10.17	103	11.29	102	9.99	101	7.86	100	68.62	100
-27	4.35	85	1.94	81	1.45	122	.93	78	1.04	52	3.03	80	5.29	92	8.17	98	9.32	94	10.68	96	8.66	89	7.78	99	62.64	92
-28	4.82	95	1.34	56	1.39	118	.89	74	1.82	91	1.94	52	4.80	84	8.46	102	10.79	109	10.27	93	9.87	100	7.62	96	64.01	93
-29	4.99	98	1.79	75	.65	55	.61	51	2.11	106	3.88	102	5.07	88	9.03	108	8.57	87	10.47	94	9.63	98	6.84	87	63.64	93
-30	5.21	102	3.41	143	.79	67	.83	69	2.09	104	3.24	85	4.14	72	6.39	77	9.54	96	10.25	92	10.30	104	6.10	78	62.29	91
1930-31	4.66	91	2.45	102	1.50	126	.80	67	1.78	89	4.64	122	7.06	123	9.42	113	9.76	99	12.08	109	11.16	114	8.30	105	73.61	107
-32	4.93	97	2.86	120	.69	58	1.39	116	2.13	106	4.61	121	6.00	115	8.16	98	10.28	104	11.78	106	10.85	110	7.76	98	71.44	104
-33	6.30	124	3.83	160	1.56	131	1.00	88	2.90	145	4.71	111	7.26	126	7.53	90	9.77	99	12.42	112	11.09	113	7.87	100	75.74	111
-34	5.98	117	3.30	138	.70	59	1.39	116	1.36	68	3.48	92	5.47	95	7.43	89	9.06	92	11.44	103	9.90	100	8.64	110	68.15	109
-35	4.93	97	1.85	77	1.56	131	.87	73	1.52	76	3.75	99	4.49	78	8.27	99	9.62	97	10.00	90	9.37	95	6.90	87	63.13	92
1935-36	5.01	98	2.16	90	1.22	103	1.46	122	1.28	64	5.14	135	5.80	101	9.25	111	8.39	85	11.10	100	10.22	104	8.61	109	69.64	102
-37	5.54	109	2.75	115	1.52	128	1.08	90	2.07	104	3.22	85	6.67	116	9.07	109	8.85	90	10.50	95	9.85	100	7.55	96	68.67	100
-38	4.62	90	2.02	84	1.04	88	1.02	85	1.82	91	2.99	79	4.96	87	8.80	106	10.27	104	10.90	98	9.91	100	7.79	99	66.14	97
-39	4.19	82	3.66	153	1.17	98	1.55	129	3.29	165	3.85	101	7.66	134	9.23	111	11.34	115	11.53	104	10.27	104	7.58	96	75.32	110
-40	5.18	102	2.70	113	1.36	114	1.11	93	1.99	100	3.68	97	5.44	95	7.98	96	9.43	95	9.64	87	8.43	95	6.68	85	63.62	93
1940-41	4.22	83	2.19	91	1.91	161	1.09	91	1.08	54	3.76	99	5.01	87	7.11	86	8.70	88	9.30	84	8.30	85	8.54	108	61.21	89
-42	5.65	111	1.73	92	1.27	108	.76	63	2.00	100	4.01	106	3.86	67	6.84	82	10.30	104	10.95	99	9.40	95	7.58	96	64.35	94
-43	4.97	98	1.84	77	.81	68	1.61	134	1.54	77	2.55	67	5.24	91	9.89	119	9.66	98	10.99	99	9.84	100	7.73	98	66.67	97
-44	4.93	97	2.22	93	1.69	142	1.20	100	2.48	124	4.39	116	4.24	74	8.42	101	8.88	90	9.89	89	9.81	99	8.78	111	66.93	98
-45	4.87	96	1.68	70	.64	54	.97	81	2.42	121	2.80	74	7.67	134	7.30	88	11.14	113	11.31	102	9.99	101	9.83	124	70.62	103
1945-46	5.58	110	1.78	74	.72	61	1.58	132	1.59	80	3.61	95	5.62	98	7.93	95	10.35	105	11.47	103	10.50	106	8.72	111	69.45	101
-47	5.69	112	3.26	136	.70	59	1.35	112	1.33	66	3.50	92	6.91	121	9.87	118	11.27	114	11.89	107	10.13	101	9.30	118	75.20	110
-48	4.12	81	2.97	124	1.45	122	1.94	162	2.70	135	3.96	104	3.92	68	6.47	78	9.00	91	11.25	101	9.42	97	6.95	88	64.15	94
-49	4.89	96	3.32	139	.98	83	2.29	191	1.73	86	3.35	88	7.21	126	8.67	104	11.82	120	12.37	112	9.92	101	8.52	108	75.07	110
-50	6.69	131	2.54	106	1.32	111	1.77	148	2.69	135	3.76	99	7.48	130	9.72	117	9.84	99	12.37	112	10.32	92	7.84	99	76.34	115
1950-51	4.65	92	2.35	98	.79	67	.69	58	1.33	66	5.33	134	5.92	103	8.50	102	11.17	113	11.21	101	10.02	102	8.04	102	70.00	102
-52	5.34	105	1.99	83	1.49	126	1.32	110	1.71	86	4.32	114	6.19	106	9.35	112	8.80	89	10.59	95	9.74	99	7.44	94	68.28	100
-53	4.45	87	2.67	112	1.27	107	1.11	93	3.37	169	4.04	106	5.46	95	6.69	80	9.45	96	11.26	101	9.24	94	7.56	96	66.57	97
-54	5.79	114	1.58	66	2.01	170	1.30	108	1.66	83	3.30	87	6.01	105	9.19	110	10.68	108	12.80	115	9.71	98	8.17	104	72.20	105
-55	5.96	117	1.67	70	1.01	85	1.14	95	2.97	149	5.71	151	5.30	93	9.31	112	11.01	111	11.46	103	10.93	112	8.35	106	74.82	109
Computed 33-year mean	5.09	100	2.39	100	1.19	100	1.20	100	2.00	100	3.80	100	5.72	100	8.33	100	9.88	100	11.10	100	9.86	100	7.89	100	68.45	100

Quantities for period October, 1922, through April, 1926, computed by formula E = k(t x p).

TABLE 3.--MONTHLY EVAPORATION AND PER CENT OF MONTHLY MEAN FOR THE PERIOD OCTOBER 1922 THROUGH SEPTEMBER 1955 AT NEWARK, CALIFORNIA

(Evaporation in inches)

Year	October		November		December		January		February		March		April		May		June		July		August		September		Annual	
	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent	Evapo-ration	Per cent
1922-23	4.19	102	1.99	91	1.34	93	1.44	95	1.80	84	3.51	93	4.82	94	6.70	94	7.45	94	8.50	100	7.60	102	6.49	108	55.83	98
-24	4.26	104	2.26	103	1.29	90	1.48	98	2.00	93	3.36	89	5.03	98	7.16	101	8.05	101	8.48	99	7.01	94	6.37	106	56.75	99
-25	4.08	100	3.12	144	2.36	163	2.23	148	2.38	111	4.44	116	5.18	101	6.43	91	8.68	109	8.92	104	7.63	103	6.40	106	61.85	108
1925-26	4.41	108	2.44	111	1.94	134	1.48	98	2.34	109	5.12	134	5.26	102	7.67	108	7.71	97	8.29	97	7.01	94	6.29	104	59.96	105
-27	3.67	90	2.89	132	2.31	159	1.06	70	3.05	142	3.71	98	5.45	106	7.40	104	7.31	92	8.02	94	6.77	91	5.73	95	57.37	100
-28	3.92	96	1.95	89	1.37	96	1.38	92	2.61	121	3.40	90	5.42	105	6.42	90	8.05	101	7.30	86	7.18	97	5.07	84	54.07	94
-29	3.81	93	1.93	88	1.03	72	1.16	77	2.79	130	4.20	111	5.15	100	7.12	100	7.53	95	8.53	100	7.29	98	5.11	85	55.65	97
-30	4.23	103	2.29	104	1.35	94	1.54	102	2.40	112	4.41	116	5.94	116	6.98	98	8.02	101	8.18	96	7.22	97	5.48	91	58.04	101
1930-31	3.68	90	2.24	102	1.28	89	1.49	98	2.18	101	4.16	110	5.71	111	7.61	107	8.19	103	8.74	103	6.97	94	5.71	95	57.96	101
-32	3.80	93	2.22	101	1.12	78	1.75	116	2.28	106	4.00	116	5.58	108	6.58	93	7.85	99	8.05	94	7.49	101	5.44	91	56.16	98
-33	3.98	97	2.34	107	1.32	92	1.57	104	2.32	108	3.98	105	5.55	108	6.80	96	7.49	94	7.78	91	6.92	108	5.64	94	55.69	97
-34	3.47	85	2.15	98	1.53	105	1.14	75	2.02	94	3.40	90	5.85	114	7.37	104	7.73	97	8.44	99	7.33	99	5.55	92	55.98	98
-35	3.86	94	2.07	94	1.48	103	1.30	86	1.93	90	3.67	97	4.65	90	7.38	104	8.32	105	8.42	99	7.11	96	4.92	82	55.11	96
1935-36	4.03	98	1.91	87	1.08	75	1.37	91	1.84	86	4.04	107	5.34	104	7.94	112	7.28	92	8.19	96	7.17	97	5.60	93	55.79	97
-37	3.72	91	1.69	78	1.54	106	1.31	87	2.10	98	3.26	86	5.02	98	7.32	103	7.61	96	8.17	96	7.28	98	5.81	97	54.83	96
-38	3.54	86	2.34	107	1.56	107	1.58	104	2.24	104	4.35	114	4.68	91	6.70	94	7.48	94	7.53	88	8.13	96	5.32	88	55.45	97
-39	3.60	88	2.36	108	1.09	76	1.56	103	3.03	141	3.32	88	5.44	106	7.24	102	8.12	102	8.20	96	7.25	98	6.07	101	57.28	100
-40	4.15	101	1.91	87	1.33	92	1.60	106	2.22	103	3.65	96	5.32	104	7.02	98	7.84	99	8.37	98	7.28	98	5.48	91	56.17	98
1940-41	3.81	93	1.86	85	2.18	150	1.71	113	2.06	96	4.61	122	4.65	90	7.16	101	7.63	96	8.13	95	7.12	96	6.09	101	57.01	99
-42	3.92	96	1.44	67	1.21	84	1.34	89	2.41	112	4.13	109	4.10	80	6.82	96	9.00	113	9.33	110	7.78	105	5.88	98	57.36	100
-43	4.22	103	2.07	94	1.09	76	1.44	95	1.88	88	2.62	69	4.44	86	8.35	117	8.22	103	8.77	103	8.05	108	6.76	112	57.91	101
-44	4.42	108	2.16	98	1.85	127	1.29	85	2.24	104	4.35	114	4.75	92	7.65	108	7.08	89	8.38	98	7.85	105	6.24	104	58.26	102
-45	3.81	93	2.23	102	.80	56	.88	58	2.06	96	2.94	78	6.06	118	6.50	92	8.69	109	11.33	133	7.44	100	6.93	115	59.67	104
1945-46	3.66	89	1.65	76	1.24	86	1.64	108	1.45	68	3.37	89	5.16	100	6.75	95	8.51	107	8.63	101	7.76	104	7.19	119	57.01	100
-47	5.24	128	2.52	116	1.01	70	.99	65	1.42	66	3.14	80	5.45	106	8.07	114	8.58	108	8.99	105	8.04	108	7.08	118	60.53	106
-48	4.46	109	2.50	114	1.51	105	1.92	127	2.31	107	4.08	108	4.42	86	6.21	88	7.78	98	8.32	97	7.17	97	6.15	102	56.83	99
-49	4.32	105	3.31	152	1.35	94	2.17	144	1.76	82	3.79	100	6.03	118	7.17	101	8.86	112	8.49	99	7.24	97	6.63	110	61.12	106
-50	5.12	125	1.88	86	1.45	101	1.92	127	2.20	102	3.56	94	5.10	99	6.92	97	7.12	90	9.14	107	8.83	118	6.35	106	59.59	104
1950-51	4.35	106	2.41	110	1.28	89	1.11	74	1.77	82	3.60	95	4.02	78	6.70	94	7.72	97	8.09	95	7.39	99	5.71	95	54.15	93
-52	4.68	114	2.07	94	1.30	90	2.37	157	1.60	74	3.83	101	4.72	92	7.39	104	7.80	98	8.18	96	7.54	102	6.11	102	57.59	100
-53	3.25	79	2.32	106	1.98	137	1.23	81	2.36	110	3.89	103	5.27	102	7.15	100	8.41	106	9.20	108	7.17	97	5.99	100	58.22	102
-54	4.66	114	2.00	91	1.80	124	2.20	145	2.01	93	2.72	72	5.19	101	7.17	101	8.12	102	9.76	114	7.47	101	6.82	113	59.92	104
-55	4.90	119	1.69	78	1.26	87	1.27	82	1.88	87	4.22	110	4.87	96	6.61	93	8.04	101	8.79	103	7.55	102	6.13	102	57.21	100
Computed 33-year mean	4.10	100	2.19	100	1.44	100	1.51	100	2.15	100	3.78	100	5.14	100	7.10	100	7.95	100	8.53	100	7.42	100	6.02	100	57.34	100

Quantities for the period October 1922 through July 1924 computed by formula E = k(t x p).

Quantities for the period August 1924 through March 1942 represent recorded evaporation at Alvarado increased by 1.056 per cent.

TABLE 4.--CALCULATED MEAN EVAPORATION IN INCHES
FROM A WEATHER BUREAU TYPE PAN FOR PERIOD
OCTOBER 1922 THROUGH SEPTEMBER 1955

(in inches)

Station	Month												Annual Total
	October	November	December	January	February	March	April	May	June	July	August	September	
Newark	4.10	2.19	1.44	1.51	2.15	3.78	5.14	7.10	7.95	8.53	7.42	6.02	57.33
Burlingame	4.16	2.02	1.27	.80	2.42	4.21	6.65	8.14	7.90	8.47	7.34	5.72	59.10
Richmond	3.37	1.91	1.47	1.44	2.25	3.64	4.64	7.22	7.31	7.34	6.42	5.38	52.39
Hamilton Air Force Base	5.87	3.12	2.83	1.93	2.83	4.75	7.35	9.28	10.10	10.41	8.54	7.22	74.23
Dutton's Landing	4.63	2.14	1.70	1.05	2.52	4.10	5.02	8.00	8.92	8.97	8.35	6.64	62.04
Joice Island	4.34	1.77	.88	1.22	1.78	3.48	5.16	7.51	8.13	9.30	8.23	7.25	59.05
Martinez	5.51	2.91	1.54	1.71	2.20	4.02	5.82	8.54	10.53	11.76	9.90	8.66	73.10
Mandeville Island	5.41	2.35	1.52	1.64	2.26	4.07	6.65	9.31	10.63	12.05	10.29	8.36	74.54
Stockton Mowry Bridge	3.56	1.44	.69	1.02	.94	3.42	4.96	8.34	10.66	11.00	7.91	6.16	60.10
Walnut Grove	3.75	1.28	.85	2.54	1.98	3.70	5.53	7.69	9.42	10.48	7.68	6.61	61.51
Davis	5.09	2.39	1.19	1.20	2.00	3.80	5.72	8.33	9.88	11.10	9.86	7.89	68.45

Experimental work by the Agricultural Research Service at Lake Elsinore and Fullerton (Bulletin 54, California Department of Public Works, 1947) indicated that evaporation as measured in a Weather Bureau type pan should be multiplied by 0.77 to convert it to lake evaporation. In Weather Bureau Research Paper No. 38 entitled "Evaporation from Pans and Lakes" by Kohler, Nordenson, and Fox dated May, 1955, evaporation data from Lake Hefner and elsewhere are discussed. According to this paper, an annual reduction coefficient of 0.70 (as commonly used throughout the United States) is correct provided the average water temperature in the pan is equal to the average air temperature. In the pans operated within the San Francisco Bay region, the water temperatures average from three to five degrees above the air temperatures. The consistency of this temperature differential is immediately apparent from Table 5. Applying adjustments from these temperature differences in the equation contained in Research Paper No. 38 indicated that the annual reduction coefficient for the San Francisco Bay region should be increased to about 0.76.

The equation as given and solved graphically in Research Paper No. 38 is:

Lake evaporation = $0.70 \, [\text{pan evaporation} + 0.00051 \, P_{xp} (0.37 + 0.0041_{vp})(T_a - T_o)^{0.88}]$ where

P = atmospheric pressure

xp = proportion of advected energy (Class A pan) used for evaporation

vp = daily wind movement at Class A pan (6 inches above rim)

TABLE 5.--AVERAGE TEMPERATURE OF AIR AND WATER IN UNITED STATES WEATHER BUREAU TYPE PAN AT SEVEN STATIONS IN SAN FRANCISCO BAY AND SACRAMENTO-SAN JOAQUIN DELTA AREAS
(In degrees Fahrenheit)

Month	Burlingame		Hamilton AF Base		Dutton's Landing		Richmond Field Station		Joice Island		Mandeville Island		Stockton Mowry Bridge	
	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water
1956														
February	47.2	*52.4	46.2	*49.4	----	----	48.3	----	47.4	----	45.7	----	46.5	----
March	50.9	55.8	50.5	55.6	50.3	54.8	52.1	*58.3	53.3	*60.4	52.6	*60.0	53.6	*63.6
April	54.6	58.2	54.8	58.1	53.5	58.7	54.2	60.1	56.3	*61.0	56.7	61.1	58.8	65.6
May	59.0	65.6	50.9	64.3	59.3	64.3	58.8	65.6	60.5	*68.8	62.7	66.8	64.6	59.5
June	61.3	67.1	63.0	68.9	64.1	68.1	61.0	*68.2	67.3	*72.4	68.5	72.5	71.3	73.6
July	61.9	69.3	62.5	69.4	----	67.9	58.8	67.5	67.2	*73.1	68.0	72.9	73.5	76.2
August	62.2	68.5	62.9	70.0	63.3	67.5	60.6	67.7	67.5	*73.4	68.3	73.3	71.9	75.0
September	63.0	67.5	63.8	67.7	----	*65.4	63.4	*67.5	67.8	----	68.3	71.0	----	*73.0
October	57.6	61.0	57.7	60.8	57.6	58.9	59.3	62.5	59.9	----	58.9	62.7	61.0	62.5
November	53.3	52.1	52.0	52.4	----	52.4	56.8	*56.3	53.3	*55.8	51.9	54.1	52.1	50.7
December	47.8	47.6	44.4	46.2	45.6	*48.2	49.7	*51.9	44.4	*50.0	45.0	46.2	45.6	44.3
1957														
January	45.2	47.0	43.6	45.3	42.3	43.9	46.5	*50.3	43.0	*49.2	43.4	45.6	43.2	42.6
February	52.3	54.9	50.8	53.6	51.2	52.5	52.7	*55.7	51.4	*58.5	51.2	53.2	51.5	51.5
March	53.6	58.3	53.0	57.2	----	56.5	54.1	*58.3	54.5	*64.6	54.4	59.7	55.1	59.1
April	57.0	62.5	57.1	62.0	56.1	60.7	58.4	62.1	58.6	*70.8	60.1	64.5	60.2	64.2
May	59.4	66.1	59.2	66.1	57.9	62.7	58.9	65.3	60.8	*75.5	61.8	65.4	64.5	68.1
June	63.5	69.0	66.3	70.8	----	68.2	62.5	69.7	69.5	*79.4	72.9	70.8	74.7	74.8
July	63.6	69.1	65.4	71.2	65.9	69.2	61.3	68.4	70.3	*78.9	71.8	72.6	75.5	77.0
August	61.8	67.4	63.3	68.8	65.1	69.2	62.2	*68.4	----	*77.7	68.5	71.5	71.9	74.2
September	64.6	68.2	64.8	68.8	65.0	67.0	64.4	*68.8	68.2	*75.2	68.4	70.6	71.0	72.6
October	60.1	63.2	59.2	61.8	59.8	61.7	61.9	*63.7	----	*68.4	61.0	62.6	61.2	63.3
November	53.0	54.2	59.9	52.8	----	51.8	54.1	----	51.3	*57.6	52.3	52.4	51.8	50.2
December	49.1	50.0	46.8	47.9	----	47.3	49.4	----	45.2	*52.2	46.4	46.8	46.3	46.8
1958														
January	49.8	51.0	47.3	48.9	45.9	47.4	50.2	----	46.0	*48.2	45.7	47.2	46.8	47.2
February	55.1	57.4	53.7	56.0	52.9	54.7	55.1	----	53.1	*60.3	53.7	55.2	54.6	54.8
March	50.9	55.6	49.2	54.0	----	54.4	51.7	*56.8	50.1	*57.8	50.5	54.9	51.2	54.4
April	55.6	61.1	55.8	63.4	56.3	60.9	57.5	*62.3	58.1	----	58.8	61.9	60.3	64.3
May	61.1	66.8	60.4	68.0	60.8	66.4	60.3	----	63.9	*74.3	63.8	67.7	67.8	68.7
June	63.7	70.6	65.0	70.7	*65.2	70.5	64.4	----	67.4	*77.7	68.8	72.8	70.7	72.3

* Less than 20 days recorded.

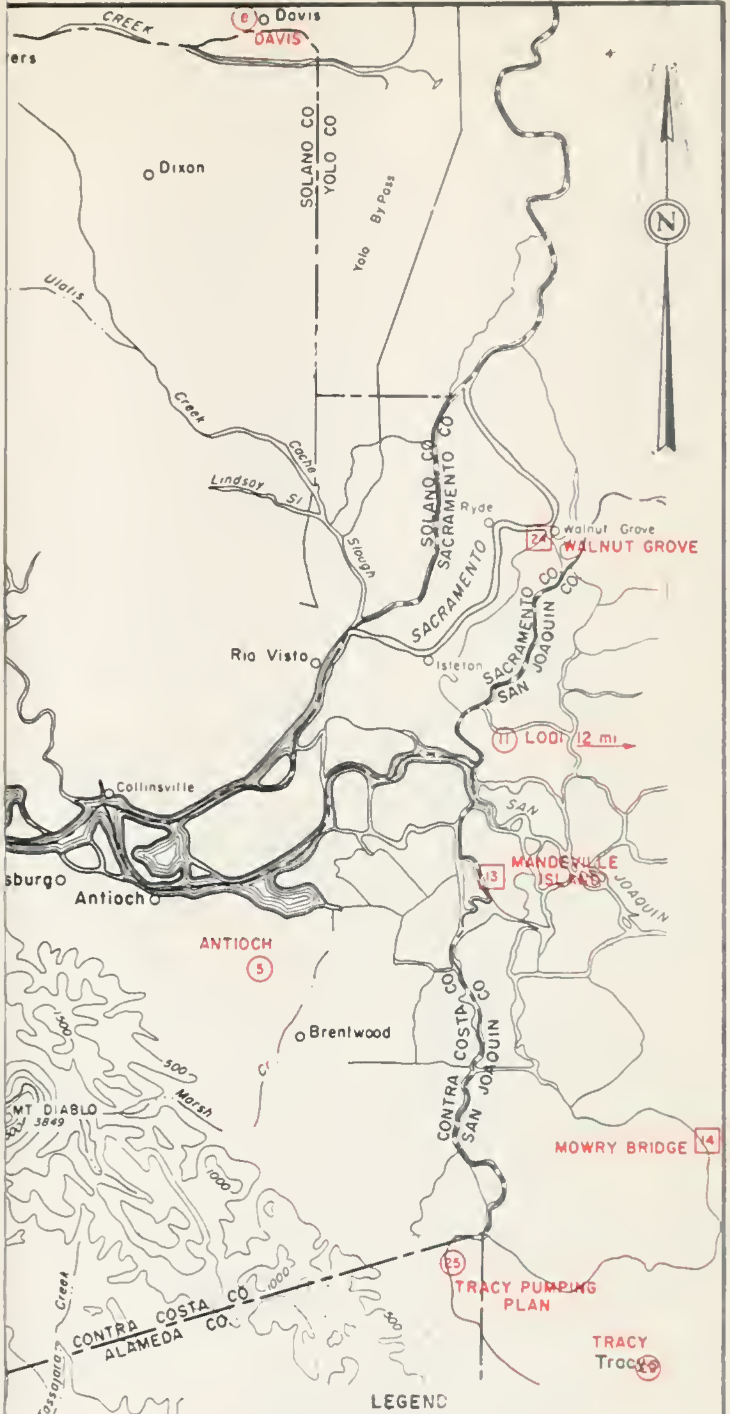
T_o = water surface temperature, in degrees Fahrenheit

T_a = air temperature, in degrees Fahrenheit

The coefficients now being used for the San Francisco Bay area are given in Table 6.

TABLE 6.--MONTHLY COEFFICIENTS FOR REDUCTION OF EVAPORATION AS MEASURED IN A WEATHER BUREAU TYPE PAN TO EVAPORATION FROM A LAKE SURFACE, SAN FRANCISCO BAY REGION

Month	Coefficient	Month	Coefficient
January	0.60	July	0.80
February	.70	August	.80
March	.70	September	.75
April	.75	October	.75
May	.75	November	.70
June	.80	December	.65



LEGEND

9 STATIONS OPERATED FOR THIS INVESTIGATION

5 STATIONS OPERATED BY OTHERS

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
BERKELEY, CALIFORNIA

EVAPORATION IN THE SAN FRANCISCO BAY
AND
SACRAMENTO-SAN JOAQUIN DELTA AREAS

EVAPORATION STATIONS EQUIPPED WITH WEATHER BUREAU TYPE EVAPORATION PANS

SCALE OF MILES

4 0 4 8 12

Pleasanton

Calaveras Res

Milpitas


UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
BERKELEY, CALIFORNIA
EVAPORATION IN THE SAN FRANCISCO BAY
AND
SACRAMENTO-SAN JOAQUIN DELTA AREAS
EVAPORATION STATIONS EQUIPPED
WITH WEATHER BUREAU TYPE
EVAPORATION PANS
SCALE OF MILES
4 0 4 8 12
LEGEND
STATIONS OPERATED FOR THIS INVESTIGATION
STATIONS OPERATED BY OTHERS
N
DAVIS
Davis
Winters
PUTAH CREEK
St Helena
Conn Res
NAPA CO
SONOMA CO
Kenwood
Dixon
SOLANO CO
YOLO CO
Yolo By Pass
Curry Lake
Vacaville
Ulatis
Creek
NAPA CO
SOLANO CO
Napa
Sonoma
Fairfield
Lindsay Sl
Cache
Slough
SOLANO CO
SACRAMENTO CO
Ryde
Walnut Grove
WALNUT GROVE
Petaluma
Creek
DUTTON'S LANDING
A-14
Cordelia
JOICE ISLAND
SACRAMENTO
Rio Vista
SACRAMENTO CO
SAN JOAQUIN CO
Isleton
SEARS POINT ROAD
SOLANO CO
SONOMA CO
Lake Chabot
Novato
Vallejo
LODI 12 mi
HAMILTON FIELD
Ignacio
San Pablo Bay
Benicio
Collinsville
MARIN CO
CONTRA COSTA CO
Martinez
MARTINEZ
Pittsburg
Antioch
MANDEVILLE ISLAND
SAN JOAQUIN
San Rafael
Concord
ANTIOCH
SAN PABLO RES.
San Pablo Res
RICHMOND
Brentwood
RICHMOND FIELD STATION
Walnut Creek
Walnut Creek
MT DIABLO 3849
Marsh Cr
BERKELEY
Sausalito
CONTRA COSTA CO
SAN JOAQUIN CO
MOWRY BRIDGE
SAN FRANCISCO CO
ALAMEDA CO
UPPER SAN LEANDRO RES.
Danville
OAKLAND
Upper San Leandro Res
TRACY PUMPING PLAN
SAN FRANCISCO
Alameda
CONTRA COSTA CO
ALAMEDA CO
Tassajara Creek
TRACY
Tracy
Lower San Leandro Res
San Lorenzo
Hayward
Pleasanton
San Francisco Bay
BAUMBERG
ALAMEDA CO
SAN MATEO CO
San Andreas Res
BURLINGAME
ALVARADO
Alameda Creek
San Mateo
Niles
PLANT NO. 1
PLANT NO 2
NEWARK
Irvington
Crystal Springs Res
REDWOOD CITY
Redwood City
Half Moon Bay
Palo Alto
Calaveras Res
ALVISO
Alviso
Milpitas