AN ANALYSIS TO DETERMINE THE SAFE YIELD OF THE WATER RESOURCES OF SAN DIEGO COUNTY, CALIFORNIA

Thesis by Munson W. Dowd, In Partial Fulfilment of the Requirements for the Degree of Master of Science, California Institute of Technology, Pasadena, California, 1946

Table of Contents

Index for Tables

Introduction

As is indicated in the following report, the safe yield of the water resources of San Diego County is definitely limited. Proposals for future expansion indicate increased yield, but they are expensive and their benefits limited. The City of San Diego has thus of necessity turned to an outside source, the Colorado River, as an adequate supply for the future. A pipeline is at present under construction from the Metropolitan Aqueduct to supplement the present system.

This study is based principally on data and figures found in the various reports enumerated in the bibliography. The subject is a very large one, which to be adequately covered would require voluminous amounts of data and much more time than is available. However, a general survey of the conditions prevailing in San Diego County and the approximate safe yields of all major rivers is included. It is suggested that any further investigations be made for yields of single rivers in order that thorough analyses can be conducted.

A. General Physiography of San Diego County.

In general, San Diego County is divided into two major drainage areas, the east and the west. The rainfall on the eastern one-third flows into the Imperial Valley and the Gulf of Lower California. The runoff from the western two-thirds of the County, with which this report is concerned, constitutes the major portion of the total and natural drainage channels carry it into the ocean.

The western part of the county is divided again into two regions, the narrow coastal belt and the mountainous highland. This upper area slopes up gradually from the coastal belt to the summit of the mountains, dropping off rather steeply on the east to form the other drainage area already mentioned. This highland area which extends far down into Mexico appears to be a huge block of the earth's crust which has been broken and lifted on its eastern side. In many ways it resembles the Sierra Nevada mountains to the north but the amount of uplift and tilting has been much less.

The coastal belt consists principally of a series of relatively high, flat topped benches or terraces through which the various streams cut on their way from the highlands to the ocean. These terraces, formed by the sea during numerous geological eras, terminate at the Pacific Ocean in a line of cliffs. The cliffs are characteristic of the entire coastline except for the area in the immediate vicinity of San Diego Bay. As a result of the Spanish influence, the series of terraces are called "mesas", some having received individual names as Otay Mesa which lies between the Tia Juana and Otay Rivers, and Linda Vista Mesa which extends from the San Diego River to the Los Penasquitos River.

The major streams which intersect these mesas are wide, flat bottomed and are bounded by steep slopes which vary to several hundred feet in height. Major streams are so called because they carry most of the water and head in the highland area. Minor streams which arise on the mesas themselves are geologically young and their channels are short narrow gashes which terminate in either a major stream valley or the ocean.

Since these major valleys play a large part in this analysis, a further discussion of them should be well worthwhile. Explicitly the valleys are those occupied by the (starting from the north) Santa Margarita, San Luis Rey, San Dieguito, San Diego, Sweetwater, Otay, and Tia Juana Rivers.

Santa Margarita Valley, which as a valley starts halfway between Home Ranch and Deluz Station where the River leaves its rock gorge, is about one half mile wide and ten miles long. Its average gradient is roughly ten feet per mile. About three miles east of the San Luis Rey Mission, the River of the same name leaves its gorge in the highland area and enters a flat bottomed valley about three hundred feet below the terraces. It is eight miles long with an average gradient of eleven feet per mile. The San Dieguito River Valley runs from a point six miles from the River's mouth to the ocean. It has a grade of only seven feet per mile and a width of half a mile. Mission Valley, along the San Diego River, extends from the gorge west of Cowles Mountain westward to Mission Bay, a distance of eight miles. It varies in width from one-third to three-fifths of a mile and has a slope of eleven feet per mile. Sweetwater Valley has the same characteristics as the others with steep clifflike walls one hundred to three hundred feet high, a length of eight miles and a width of one-fourth to one-half mile. It ends in San Diego Bay. Otay Valley also ends in San Diego Bay, extending due west from the base of Otay Mountain. It is very steep with a slope of twenty five feet per mile and does not have the characteristic flat bottom of the other valleys but slopes steeply from the base of the bluffs on each side of the stream channel. Tia Juana Valley is again very much like the others but differs in that some of it is in Mexico. It crosses the international boundary at Tia Juana and extends westward six miles to the ocean. It is bordered by cliffs four hundred feet high during part of its length but these diminish to low slopes of only twenty five feet. In general the valley floor is flat with a width of one mile and a slope toward the ocean of eight feet per mile.

These various features of the stream valleys are due to the characteristics of the arid region and to the alternate rising and sinking of the land. In an arid country such as this, the streams which rise in the mountains sometimes carry large volumes of water which rush to the ocean eroding the valley walls. For other periods, however, there are a number of dry years when very little flow reaches the ocean, the majority sinking into the river bed. The fact that this coastal region is lower than it was at some past time also affects the physical characteristics of the valleys since they were eroded much deeper than they are at present and have since filled in. This tends to make the walls very steep and forms a basin for storage of water.

The highland area lies east of the coastal belt, extending eastward from the highest mesas to the boundary of the area covered in this analysis. Like the coastal belt, this region has been subjected to repeated raising and lowering but has not actually been below sea level since early geologic time.

The mountains of the highland area belong to what is known as the "Peninsular" Range since it forms the backbone of the peninsula of Lower California. In its northern extremities, the Peninsular Range intersects the San Jacinto and San Bernardino Ranges. There is little regularity in the distribution of the high peaks, that is, they don't lie in ranges. In the northeastern part of the watershed included in this study, elevations of six thousand feet are not uncommon and the general elevation in the eastern half is over three thousand feet above sea level. However, the western half varies from five hundred to fifteen hundred feet above sea level with only a few peaks around three thousand feet.

The southern slopes of the mountains are ordinarily nearly barren of vegetation but the northern slopes are covered by various types of brush and trees such as chaparral, live oak, pine, etc. In many of the mountain slopes and valleys grazing is excellent.

Highland Basins.

It is believed that at one time this highland area had been eroded to a peneplane but subsequent uplift brought on additional stream erosion which caused the present geographical features. There was also a large amount of faulting which took place, lifting some blocks of the earth's crust above others and thus forming the mountains. Also, faulting fractured rocks in many places making them more easily worn away by streams.

Many square miles of the highland area are covered by large flat tracts which are referred to as highland basins. Of these, El Cajon Valley, Santa Maria Valley, and Warner's Valley are typical examples. El Cajon Valley, which is about halfway from the head of the San Diego River to the sea, forms a nearly square basin extending six miles in a direction perpendicular to the River and Five miles along it. The River valley above and below is less than one-fourth mile wide. The floors of the valleys are comparitively smooth, sloping gently toward the stream. In general, the alluvial cover is thin near the stream but may be thirty or more feet in thickness at the borders of the basin. The underlying granite is thoroughly disintegrated at the surface but becomes firmer with depth until it is solid at depths of from fifty to one hundred feet. In places the granite outcrops at the surface.

These highland basins are divided into three belts in accordance with their geographical distribution. The first or lower belt includes Fallbrook Plain, El Cajon, and several other valleys. The intermediate basins include Bear Valley and Santa Maria Valley, and the third belt or higher basins includes Warner's and San Felipe Valleys.

B. Precipitation and Runoff.

All waters in the County are derived of course from the precipitation on the included ground area. Part of the water which falls as rain or snow is lost by evaporation. Another part percolates into the soil to ultimately reach the water table or be lost in transpiration from plants, and the remainder joins the surface runoff of which a part reaches the ocean. During the past years, particularly the last thirty, a series of dams have been constructed on most of the major rivers to act as a source of water supply for the County and for the city of San Diego. This impounding of water, often for long periods, presents surfaces to the atmosphere from which fifty to seventy five inches of water evaporate per year. The large quantities involved will be discussed later.

Most of the precipitation occurring in San Diego County is due to cyclonic storms or "lows" from the North Pacific Ocean that appear off the coasts of Alaska, British Columbia, and the northern United States. These lows have a general easterly movement as they reach the continent but many are deflected southward. The frequency and intensity of the rains occurring in the County depend upon the number of lows deflected south and the degree of deflection. If a large percentage of the lows are deflected to the south, a wet season ensues. If only a few lows arrive, the season is dry. Thus the rainfall is largely controlled by the general movement of these storms which bring about ninety per cent of San Diego County's rainfall.

Another type of storm comes upon San Diego from the southwest.

This type moves slowly, sometimes remaining stationary over southern California and Arizona for several days. During most winters, however, only one or two of these storms yield any precipitation over San Diego County.

In addition to these two types of storms, local thunder showers occur over the higher mountains in July and August. These seldom reach the coast and their duration is very limited. Thus they have very little effect on the total annual precipitation.

The fourth type of storm is known as a "sonora" since it reverses the ordinary storm movement and traverses from Sonora, Mexico, accompanied by northerly and northeasterly winds. This storm which is cyclonic in character extends over large areas and occurs chiefly in the summer. It is of infrequent occurrence, however, and has little influence on the total precipitation. Most of the contributions of the "sonoras" percolate into the ground.

Very little of the precipitation occurs as snow, although some usually falls in the higher mountain areas during every winter. However, only on the most protected slopes of the highest mountains does the snow remain for more than a few days.

Records of precipitation for several stations in San Diego County are available for over sixty years, but the detailed records presented in this report on pages A-32 to A-34 include only the period from nineteen hundred to the present. The data was obtained from statistics of the United States' Weather Bureau.

Since the precipitation in San Diego County is extremely irregular, being subject to wide deviations, the mean has very little significance for any particular year or station, making short term averages of small value. As shown by the curve on page A-35, in which comparisons of rainfall with the sixty five year average are shown, it is concluded that the average of a twenty five year record differed only 4.6% from that of the longer period. This curve was made by dividing the period of record at San Diego into subdivisions of three, five, ten, etc. to sixty years each. The average annual precipitation for each of the periods was calculated and again averages found for periods of equal length. A plot was then made of per cent variation from the sixty five year average v.s. duration of the record in years. From the curve it can be seen that the average of a record of only five years can be expected to vary 16% from the sixty five year average.

The distribution of precipitation by days, months, and years affects materially the available water supply in San Diego County. In this report, since only the more general phases of ground and surface water are considered, the annual precipitation and runoff only are presented.

Of interest however, are the bar charts presented on page A-2 which show the percentage of annual rainfall occuring during each month for six stations in the County. It will be noted that in all cases most of the rainfall occurs during the winter months of December, January, February, and March. June is without exception the month of low rainfall with the other summer months only slightly better. In the mountain areas, particularly Campo, local thunder storms occur during the summer.

Variations in annual precipitation are diagrammed by means of a bar graph on page A-3 for nine important stations. The records are of varying length depending upon the data available. The years are plotted horizontally and the departures from the average, either plus or minus, are shown by the vertical scale. The two most striking facts indicated by these charts are (1) there is a pronounced irregularity of rainfall, only a few years being near average, and (2) there is a tendency for wet or dry years to occur in cycles. Of these two observations the second is the more important in considerations of the safe yield of underground and reservoir water supplies. For example, as will be discussed later, the safe yield of Sweetwater Reservoir is determined by a drouth period extending from 1898 to 1905. Since then the drouth periods have been of shorter duration and thus safe yields have been much larger.

A knowledge of geographic distribution of precipitation is important in connection with studies of both ground and surface waters. Ground water supply as well as that in reservoirs is replenished annually by rainfall on and above the area considered.

The horizontal distribution of rainfall in San Diego County is typical for regions in which a mountain range parallels the ocean from which cyclonic storms approach. The slope leading up to the crest of the range elevates the whole body of moisture-laden air during its movements, inducing more rapid condensation of moisture as a result of the cooling and expansion which occurs. As soon as the air reaches the crest and starts down the opposite slope, condensation of moisture stops as a result of compression and increased temperature. This same phenomenon occurs on the west slope of the Sierra Nevada mountains but the rainfall zone is from 3,000 to 6,500 feet above sea level, the amount decreasing at a higher level. Since San Diego County mountains reach an altitude of only 6000 feet, the maximum rainfall occurs at the peaks.

This altitude variation is shown in striking fashion by the curve of average annual rainfall v.s. altitude presented on page A-4. For the stations which have a rainfall which is inconsistent with the curve shown, there is usually an explanation possible by consideration of local conditions. As also indicated by this curve, the stations located to the east of the first range have a precipitation which is less than that at a comparable altitude on the west. This is readily explainable by consideration of the fact that storms approach from the west. The diagrams on page A-5 which were taken from the United States Geological Survey Water Supply paper 446 indicate the close relationship between ground slope and precipitation. In general, rainfall varies from ten inches on the coast to forty inches in the mountains.

A further characteristic of rainfall study well worth mentioning is the relationship between the variations of runoff and precipitation. The diagram on page A-7 showing annual variation of runoff when compared to that of rainfall, page A-6, indicates that runoff follows the same pattern as rainfall but is subject to wider seasonal fluctuations, the maximum rate being two and one-half to three times the normal and the minimum being zero or thereabouts. From the rainfall curves it can be seen that the maximum is about 150% and the minimum about 40% of normal.

The relation between daily runoff and precipitation is very interesting. In general, although precipitation of some magnitude begins in November, it is almost January before a flood runoff occurs, after about one-fifth to one-fourth of the average season's rainfall has occurred. This lag in runoff is due to the lack of moisture in the ground when the rains begin. The rainfall is so small during the summer and autumn that the ground becomes very dry and can absorb a large quantity of water before any runoff occurs. This is of course true of the alluvium in the valleys as well as the thin but widespread surface materials in other parts of the drainage areas. After sufficient rain has fallen to saturate or partially saturate the surface materials, any additional runs off. The converse of this phenomenon occurs in the spring and part of the summer after the rains when the streams continue to flow, fed by groundwater. It is very difficult to obtain a figure relating the amount of rainfall necessary to cause runoff since so many factors enter the picture such as amount of rainfall during the preceeding year and intensity of the early rains. Although some work has been done on this subject, the detailed analysis will add nothing to this report. The typical example of the San Diego River at the diverting dam as related in Water Supply Paper 446 indicates the trends in all cases considered.

The average depth of precipitation, in inches, required to produce runoff the first year after a year with less than 90% of average rainfall, or second year after one with 70% or less, is 8.5 inches. This drops to 6.3 inches for a year following one with 90 to 110 % of average precipitation. After a year with over 110% of average rainfall, only 3.1 inches of rain are required to produce runoff. The exact figures vary depending on the type of material the water traverses but as mentioned, trends are the same.

The percent of precipitation appearing as runoff varies considerably in the areas included in this report. The table on page A-8 presents summaries of this data for a few points on the various watersheds. The principal value of this table as far as determination of safe yield is concerned is purely negative in that it indicates what cannot be done. In view of the large amount of variation in runoff as compared to precipitation, from zero to 23%, calculation of runoff by the product of rainfall, area, and a runoff coefficient is not justifiable. The error would probably be several hundred percent either way depending upon many complex factors.

In summary, the annual precipitation in San Diego County varies from about ten inches near the coast to forty five inches in the mountains. The increase is about 0.55 inches for each 100 feet of increase in altitude. East of the first high range of mountains, the rainfall decreases as indicated by the curve on page A-4 until it is eighteen to twenty inches in the mountain valleys and second range of mountains.

C. Evaporation.

At several places in San Diego County records have been kept of evaporation from the surfaces of large bodies of water. The earliest records were those taken on Sweetwater Reservoir in 1889. Data was recorded from this reservoir until 1895 after which nothing was done until the period from 1915 to 1921. Other data has been taken at La Mesa Reservoir, Cuyamaca Reservoir, and several others. Table A-9 presents the mean evaporation values as obtained by the floating pan method. Some data was taken at Sweetwater by means of a Piche Evaporometer located in a lattice house fifteen feet above ground and forty feet above the lake surface. These results indicated a magnitude of about 48/57 of that recorded by the surface pans which were probably more nearly correct. Evaporations reported were the gross values, corrections being made for rainfall entering the pans.

The monthly variation of evaporation is of interest although of more detail than is necessary for this report. The values as presented in the curve on page A-9 show that as would be expected the bulk of evaporation takes place during the warm summer months. There is a possibility that the depth of water lost from a floating pan during the summer may be greater than that from a reservoir, since the small quantity of water in the pan would attain a higher temperature than a lake. However, experiments and observations indicate that very little difference exists since water temperatures in the pan exceed those in the lake by only one or two degrees F. during the heat of the day.

Thus the evaporation from a reservoir surface varies from about fifty five inches near the coast to seventy six inches in the high and dry valleys. Variations in annual evaporation appear to be small but during each year monthly records show that the warm months are responsible for most of the evaporation. In the discussion of losses from reservoirs, annual losses due to evaporation are assumed, but are based on a comparison with records available.

Of equal interest is the evaporation or water loss from the soil. The relation between losses from water surfaces and soil is not direct, however, since many factors affect the latter. Loss from soil depends upon the depth to the zone of saturation, the capillary rise of the soil, and the kind and quantity of plants growing on the soil. Capillary forces bring water to the surface from depths of from four to nine feet depending upon the character of the soil. If the water table is below nine feet, no water is lost by this means, but transpiration by plants is nevertheless effective. If the soil is permanently saturated, the loss by evaporation is approximately that found for an open water surface.

In Water Supply Paper 446, the average annual absorption of the fill in San Luis Rey Valley is stated as being 14,450 acre feet. The total land from which losses can occur is 6,640 acres, the remainder having a water table too low to be affected by capillarity. Since the annual absorption is equal to the average annual loss, the average absorption was divided by the land area, and an average depth of water lost was determined to be 2.19 feet per year from ground water surfaces. This value of 2.19 feet is approximately correct for all of the major valleys of San Diego County.

D. Ground aters.

It is convenient to divide San Diego County into seven areas for discussion of ground waters. They are (1) Major valleys of six largest streams, (2) minor valleys of the coastal belt, (3) minor valleys of the highland area, (4) Nestor and Chula Vista sea terraces adjacent to San Diego Bay, (5) interstream areas underlain by Tertiary formations, (6) highland areas underlain by crystalline rocks not covered by residuum, and (7) highland areas in gently sloping and level parts in which crystalline rocks are overlain by water-borne materials.

Although the first group constitutes only a small part of the area of the County, it is by far the most important as a source of water. The other areas possess a larger quantity of stored ground water but are not capable of yielding large quantities at any one point, although small but reliable supplies are obtained. Since the major valleys are the principal source of ground water, net safe yield calculations will be limited to them.

The major valleys have previously been discussed in connection with the physiography. They are the narrow, flat-bottomed valleys extending from the coast twenty to twenty five miles inland bordering the principal streams of San Diego County. The streams traversing the major valleys are (from north to south), Santa Margarita, San Luis Rey, San Dieguito, San Diego, Sweetwater, and Tia Juana Rivers. The valleys trend in general northeast to southwest and are from three to fifteen miles apart. These valleys head in the highland area, traverse the mesas and open onto the ocean. It is the unconsolidated alluvial material that underlies the floors of these valleys which contains the ground water.

Although as mentioned, these major valleys are comparatively small in area, they are among the most valuable assets of San Diego County, since without their water the mesas and thickly populated parts of the County would be lacking an important source of water supply. Although water stored in reservoirs constitutes a major part of the water supply of San Diego City, for example, ground water is used continuously and can be heavily drawn upon in cases of emergency.

The major stream valleys consist of two separate groups, as previously mentioned, the coastal valleys and the highland valleys which are inland. The coastal valleys are Santa Margarita Valley below Deluz station, San Luis Rey Valley below Guajome Ranch, San Dieguito Valley, Mission Valley (on the San Diego River), Sweetwater Valley below Sweetwater Dam, and Tia Juana Valley. The aggregate area of all of these valleys is 17,500 acres. The highland valleys lying along the major streams are the Upper San Luis Rey between the east boundary of the Pala Indian Reservation and Bonsall, the upper San Diego Valley on the San Diego River from El Cajon to Old

Mission Dam, and the Delsea and Jamacho Valleys on the Sweetwater River. The total aggregate area of these valleys is 10,540 acres.

The soils of all of the valleys are composed of sand and silt derived mainly from the granitic rocks of the highland area and the Tertiary formations of the coastal belt. Before they were settled these valleys supported growths of willow, cottonwood, and underbrush. The surface of the coastal area is gently undulating with underlying formations consisting largely of gravel and sand interbedded with clay. During the rainy weather little but grass grows.

The water in these valleys is stored much as in surface reservoirs since the surrounding rocks are practically impervious. The rocks of the highland area are dense and contain only a little water in the fissures. However, well logs show that the impervious formations underlie the valleys at depths nowhere exceeding 215 feet. Above this impervious base is the alluvial fill, composed of silt, sand, and gravel which is very porous. The water for this fill is derived by absorption of surface runoff and rainfall. Water escapes from these basins by seeping into the stream channels, by underflow through the fill into lower basins, by evaporation from the surface, or by transpiration from plants. Thus water is stored in the underground basins much as in surface reservoirs, with the water level or water table rising or falling depending upon the rate of use v.s. the rate of replenishment.

As a necessary prerequisite to the investigation of safe yield is a more thorough discussion of each of the valleys concerned, the porosity of its fill, the depth to which the water table can be lowered, etc.

The following is a table showing the basic quantities required for determination of the safe yield of ground water in the major valleys. The values given were taken from Water Supply Paper 446 published by the United States Geological Survey.

Underground Water in Major Valleys

Valley	Area underlain by valley fill	Effect. area of valley fill	Assumed max. water table could be lowered ft.	% volume that could be drained	Acre ft. available	Total from each river
Santa Margarita	3,640	1,820	50	15	13,700	13,700
San Luis Rey (Upper)	4,376	3,060	30	25	23,000	35,300 35,300
San Luis Rey (Lower)	3,270	1,635	50	15	12,300	35,300
San Pasqual	1,880	1,320	40	25	13,200	20,500
San Dieguito	2,210	1,220	30	20	7,300	
Lakeside	3,120	2,180	30	25	16,400	25,200
Mission	2,470	1,480	30	20	8,880	
Sweetwater (Upper)	1,065	750	30	25	5,620	11,120
Sweetwater (Lower)	1,532	920	30	20	5,500	
Tia Juana	4,380	2,630	45	20	23,700	23,700
Totals	27,943	17,015			129,600A.F.	

The principal error in this table is probably in the percent volume that could be drained. This is a function of porosity and percent of the pore water is available. It would take many samples of the soils from all depths to ascertain this quantity at all accurately. The studies made by the U.S.G.S. in this connection were not too complete.

Thus roughly 130,000 acre feet of water are available in San Diego County from underground sources in the major valleys. By installation of a sufficient quantity of pumps, this amount could probably be used in one year. Or, it might be maintained to be used only in periods of emergency. The safe yield of this source then depends upon the rate with which replenishment will take place.

Before dams were constructed on the major rivers, it was simple to determine the water available for replenishment, but at present much of the flow is stored by reservoirs or diverted for irrigation or city water. Thus the question arises as to how much water could be replaced during drought years and how long the drought might last. The records available for the Sweetwater River, which go back farther than any of the others given, indicate that the longest drought period was six years. During this time very little water flowed in the River. After this six years, however, a quantity of water in excess of average was available. This would not mean, of course, that no water would enter the underground supplies during that time, but it does mean that rainfall was small. All water not lost by evaporation or transpiration percolated into the ground. In view of the rainfall data for the drought period in the few years at the turn of the century, (see page A-14) only three consecutive years were much below average and the fourth, 1901, was almost average. There was little or no runoff in the streams however, since ground water supplies were being replenished. Thus in a drought, ground water is replaced before much stream flow occurs. It seems reasonable and conservative to assume that the drought period during which there would be no replacement of ground water (to make results more conservative) would not be over four years in duration. In addition, it is reasonable to assume that after these four years ground water supplies will be back to normal before another four year drought ensues. Scrutiny of each set of data indicates that these assumptions are on the conservative side and are therefore satisfactory in estimation of the safe yield. The net safe yield would thus be

(see table page 15) $\frac{129,600}{4 \times 365 \times 2 \times 1.55} \doteq$ 28.5 million gallons per day.

The breakdown among the various valleys is as follows:

Valley	River	Total A.F. Available	Available A.F./yr.	Avail. m.g.d.	Avail. m.g.d. each River
Santa Margarita	Santa Margarita	13,700	3,420	3.0	3.0
San Luis Rey (Upper)	San Luis Rey	23,000	5,740	5.1	7.8
San Luis Rey (Lower)	San Luis Rey	12,300	3,070	2.7	
San Pasqual	San Dieguito	13,200	3,300	2.9	4.5
San Dieguito	San Dieguito	7,300	1,830	1.6	
Lakeside	San Diego	16,400	4,100	3.6	5.6
Mission	San Diego	8,880	2,220	2.0	
Sweetwater (Upper)	Sweetwater	5,620	1,410	1.2	2.4
Sweetwater (Lower)	Sweetwater	5,500	1,380	1.2	
Tia Juana	Tia Juana	23,700	5,920	5.2	5.2
			32,390	28.5	

An analysis of this problem as to how much water is replaced each year in underground basins is complicated, and only approximate solutions based on assumptions are possible. This is especially the case when reservoirs are built upstream and effects therefrom on underground supplies downstream are practically unknown.

E. Surface Water.

Investigation of the safe yield of surface water is basically a study of the reservoirs which have been constructed on each river. Without these reservoirs, the safe yield of streams in San Diego County would be zero because they all have periods of no flow which sometimes last for months or even years. When there is only one reservoir on a stream the safe yield can be determined rather easily. However, when several reservoirs are existent and the waters are emptied from the upper into the lower, determination of yield becomes very difficult. It is impossible to distinguish the natural flow intering the lower reservoir from the water released from the upper storage. This can only be attained from very detailed reservoir release, inflow, and outflow records which are beyond the scope of this report.

The net safe yield of each reservoir which is at the head of a stream with only natural flow entering can be approximated as follows (see page A-26): First calculate the gain or loss in reservoir storage based on inflow with evaporation from the maximum water surface at all times. Evaporation is estimated from records at several reservoirs already mentioned. After the gain or loss for the years has been found, a mass diagram is constructed for the net flow into the reservoir. This is plotted assuming evaporation from the maximum reservoir area. A straight line representing constant outflow is then constructed on the mass diagram. In no instance can this line be a distance above the mass curve which is more than the total capacity of the reservoir in question. The slope of the line represents the maximum constant flow which can be directed from the reservoir without emptying it completely. Another set of calculations has been carried out taking into account the lowering of the reservoir water surface and consequent decrease in evaporation. The line of maximum constant flow obtained in this latter case is then a very close approximation to the safe yield of the reservoir.

Each major river of San Diego County will be discussed in turn, starting at the north with the Santa Margarita River and ending at the south with the Tia Juana.

The Santa Margarita River.

Temecula Creek, as the Santa Margarita is known at its head, rises on the western slope of the San Jacinto Mountains in the northwestern part of San Diego County, just north of the San Luis Rey River basin. It flows north into Riverside County, then west fifteen miles to Temecula where it turns to flow southwest through Temecula Canyon into San Diego County and subsequently into the ocean. The highest elevation in the basin is 5,500 feet on the divide between Temecula and San Luis Rey. Temecula Creek has few tributaries. The topography of the country through which it flows is rather broken but there are several valleys in its upper reaches. The annual precipitation ranges from ten inches at the ocean to thirty inches in the highland area, falling principally in the form of rain. Discharge is heavy during the spring flood season but light during the rest of the year.

Table A-10 is a record of the annual runoff of the Santa Margarita River. Diversions from the River are in the form of pumping, wells, and direct flow. As is indicated in the table, the O'Neill ditch, which is one of the principal diversions, takes an average of about 2500 acre feet of water annually.

There are no dams on the River but three are projected according to a report issued by the City of San Diego in 1923. The total storage would be 450,000 acre feet with an estimated safe yield of 20,000,000 gallons per day. The data available is not sufficient to permit a check of these figures.

The San Luis Rey River.

The San Luis Rey River drains about 565 square miles of territory lying wholly in northern San Diego County and extending from the Coast Range to the Pacific Ocean, a distance of sixty five miles. The maximum width of the drainage area is about sixteen miles.

The River is formed by many small streams which head in the higher elevations and join at the lower end of Warner's Valley. From here, the stream flows through ten miles of deep narrow canyon with a heavy grade, then over a sandy and gravelly bed with a light grade for some forty miles until it discharges into the Pacific Ocean at Oceanside.

The highest point in the watershed is Palomar Mountain at 6,126 feet. The upper portion of the drainage area is rolling with several cultivated valleys. In general the basin is poorly forested, most of the vegetation being brush.

The mean precipitation varies from ten to fifty inches, depending upon the altitude as already mentioned. The runoff data is given on page A-11.

At present there is only one major reservoir in operation on the River, and that is Lake Henshaw, with a capacity of 203,000 acre feet, located near Warner's Hot Springs. The safe yield for this reservoir is given by the tables and curves on pages A-16 to A-19 inclusive. The method used for determination of the safe yield was as described on pages 17 and 18. Calculations were first made to determine the safe yield assuming a maximum possible evaporation each year. Using the safe yield found and assuming it as a constant outflow, evaporation loss was adjusted as the reservoir lowered. Rainfall was of course added as a gain in reservoir capacity. Since complete rainfall data was not available at Warner's Hot Springs, it was necessary to make a comparison with the more complete record for Mesa Grande. The exact storage-area curve for Lake Henshaw was not available but the maximum water surface area was known. The curve was therefore approximated for evaporation calculations. That the approximation was of sufficient accuracy is evident, since the safe yield of 14.8 m.g.d. found checked very well with the data given in the 1923 report of the city of San Diego.

The only other reservoir in addition to Henshaw is the one operated by the city of Escondido. It has a capacity of 3,000 acre feet and a safe yield of 1.0 m.g.d.

There are two additional projected reservoirs on the San Luis Rey River at Monserate and Bonsall with a combined storage of 300,000 acre et and a safe yield of 15 m.g.d. as given by the San Diego City report f 1923.

Thus the total safe yield on the San Luis Rey River is now 15.8 m.g.d. and in the future it will be 30.8 m.g.d.

The San Dieguito River.

The San Dieguito River, or Santa Ysabel Creek, as it is sometimes known, rises in the Volean Mountains on the western slope of the Coast Range and flows westward through San Pasqual Valley, discharging into the ocean midway between Oceanside and San Diego. It has a drainage area of 340 square miles, is fifty miles long, and has a basin of fifteen miles maximum width.

The upper basin is very rough with many canyons. About halfway to the ocean is San Pasqual Valley in which some irrigation is carried on.

At present there is only one reservoir, Lake Hodges, in operation on the San Dieguito River. It has a capacity of 37,700 acre feet and a minimum net safe yield of 8.1 m.g.d. as determined by the calculations on pages A-20 to A-23 inclusive. These calculations were based on the data given in U.S.G.S. records and a report of the California Department of Public Works, Bulletin No. 5, "Flow in California Streams". The first series is based on the period of 1924 to the present, the second on the period from 1897 to 1906 during a time of severe drought. This minimum found is more than the 5.6 m.g.d. value as given in the report by Ready

Hill, and Buwalda. This disagreement is probably caused by insufficient data as to losses and diversions upstream. Since Lake Hodges is on the lower reaches of the San Dieguito River, variations in flow could be large.

The other reservoirs proposed on the San Dieguito River are Sutherland and Pamo with a combined storage of 113,000 acre feet and a safe yield of 10.0 m.g.d. as given by the city of San Diego report. A check of this safe yield is not possible since sufficient data are not available.

The San Diego River.

The San Diego River rises in the Cuyamaca Mountains on the western slope of the Coast Range. It flows to the southwest, discharging into the Pacific Ocean at Mission Bay after traversing a channel about fifty miles in length. Several small tributaries, Coleman, Cedar, and Boulder Creeks all enter from the east and south above Lakeside, California. San Vincente Creek joins the main stream at Lakeside. About half of the River lies above Lakeside in territory which is rough with numerous valleys and areas of high mesa land. The highest peak in the watershed is Cuyamaca with an elevation of 6,028 feet.

Irrigation is carried on extensively in the area between Lakeside and San Diego, making stream flows recorded downstream rather questionable.

There are two principal reservoirs on the River. They are Cuyamaca with a storage of 11,000 acre feet and a safe yield of 0.9 m.g.d., and El Capitan Reservoir with a storage of 116,400 acre feet and a safe yield of 11.6 m.g.d. Two more reservoirs are proposed for the San Diego River. They are San Vincente and Mission with storages of 174,500 and 79,200 acre feet respectively. The safe yields are not given specifically in the report by Ready, Hill, and Buwalda, but the completed system will have a net safe yield of 29 m.g.d.

San Vincente and Mission are impossible to calculate for safe yield because of lack of data. The safe yield for El Capitan, however, can be checked by assuming a steady and maximum diversion at Cuyamaca exactly equal to the safe yield of 0.9 m.g.d.

The total safe yield from the San Diego River reservoirs will be considered as 29 million gallons per day for the future and 12.5 m.g.d. at present.

The Tia Juana River.

The major portion of the Tia Juana River and its watershed lie in Mexico. However, Cottonwood Creek, its principal tributary, rises in the United States in the Laguna Mountains. Cottonwood Creek joins Pine Valley Creek and flows southwest until it joins the Tia Juana about twenty miles from the ocean. The River then empties into the sea just south of San Diego in the United States. The drainage basin of Cottonwood Creek covers 340 square miles.

The topography of the Cottonwood basin is rough, although there are some mountain valleys at 3000 feet. The basin is poorly forested with some pines and live oaks. Most of the vegetation is brush.

The safe yield data for this river is impossible to develop without very detailed data, because (1) the principal drainage area is located in Mexico, and (2) Cottonwood Creek, the United States' branch, has two dams on it. Mexico has placed a dam across its branch of the Tia Juana River to further complicate matters. Also, the water from the two dams, Morena and Barrett, on Cottonwood Creek, is diverted from the drainage area by the Dulzura conduit and flows into Otay Reservoir on the Otay River.

Morena Reservoir, with a capacity of 67,200 acre feet, has a safe yield of 5.0 m.g.d. Barrett Dam, with a capacity of 42,800 acre feet, has a safe yield of 4.8 m.g.d. It is proposed in the future to enlarge Barrett Reservoir to 133,000 acre feet, thus increasing its safe yield to

9.3 m.g.d.

The total safe yield for Cottonwood Creek is thus 9.8 m.g.d. now but will be 14.3 m.g.d. in the future.

Other Rivers., and Summary.

There are a number of minor streams and stream valleys in San Diego County, but there are no data at present to justify the assigning of any safe yields. The only exception is the Otay River on which is the Otay Reservoir. Otay Reservoir has a capacity of 56,300 acre feet and a net safe yield of 3.8 m.g.d. Water for this reservoir is diverted from the Tia Juana River watershed as previously mentioned.

Table A-32 is a summary of the safe yield of the water resources of San Diego County, at present and in the future.

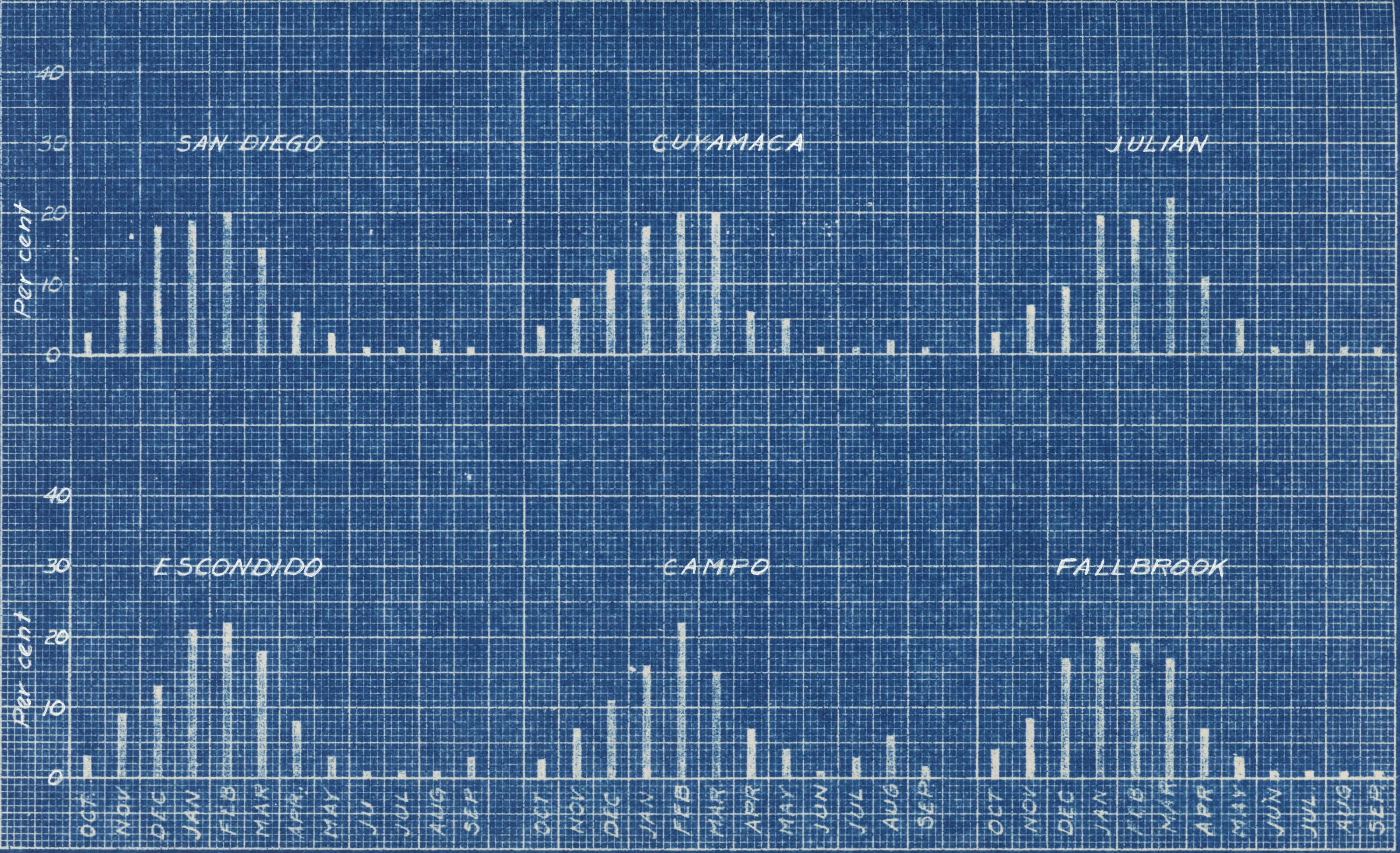
It will be noted from the table that the safe yield of ground water will be less in the future than it is now. That is because of the fact that installation of a complete series of dams on each river will eliminate a large amount of the runoff which replaces the water tables in the major valleys. It is estimated that the safe yield of ground water will be cut down about one third in the future.

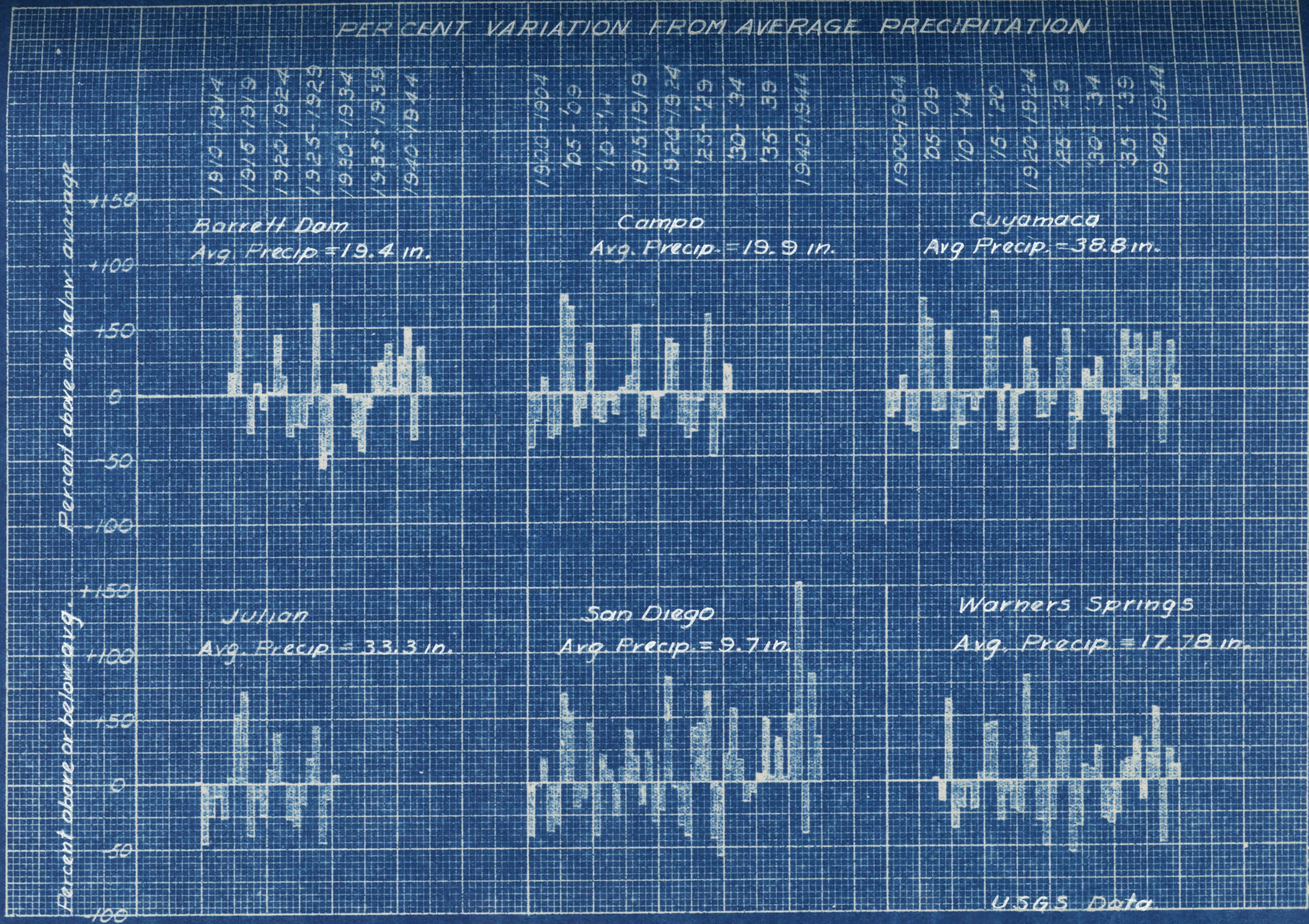
Bibliography

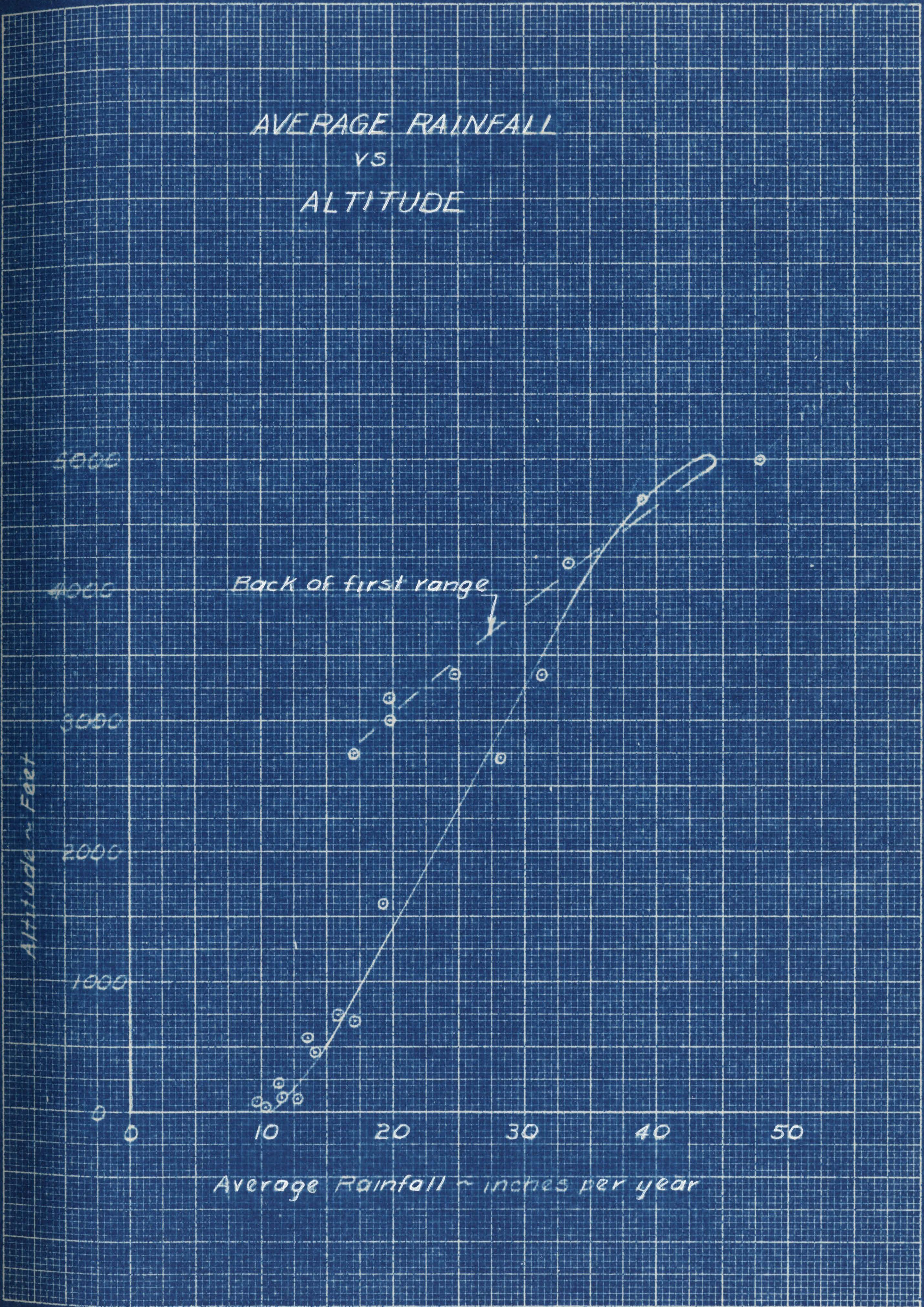
1. Reports of the City of San Diego.
2. "Report on Program of Water Development, the City of San Diego and the San Diego Metropolitan Area", Lester S. Ready, Louis C. Hill, and J. P. Buwalda.
3. "Geology and Ground Waters of the Western Part of San Diego County, California", United States Geological Survey, Water-Supply Paper 446, Arthur J. Ellis and Charles H. Lee.
4. "Flow in California Streams", Bulletin No. 5, California Department of Public Works.
5. United States Weather Bureau Records for Rainfall.
6. United States Geological Survey Water Supply Papers for Stream Flow Data.

WATERSHED AREAS	Square Miles
Santa Margarita River	730
San Luis Rey River	565
San Dieguito River	340
San Diego River	434
Sweetwater River	215
Otay River	137
Tia Juana River	2000

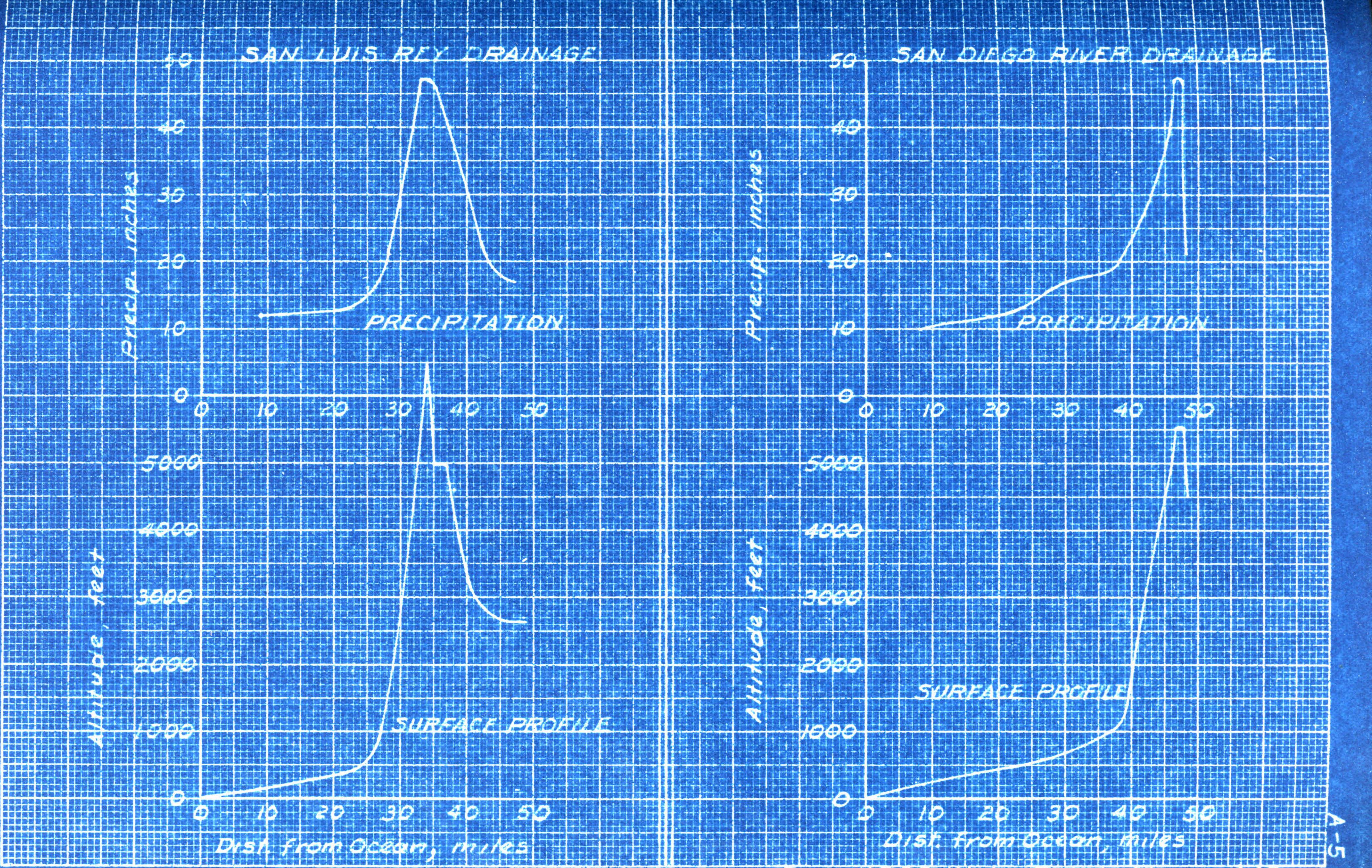
MONTHLY RAINFALL DISTRIBUTION




PERCENT VARIATION FROM AVERAGE PRECIPITATION
1910-1914
1915-1919
1920-1924
1925-1929
1930-1934
1935-1939
1940-1944
1900-1904
'05-'09
'10-'14
1915-1919
1920-1924
'25-'29
'30-'34
'35-'39
1940-1944
1900-1904
'05-'09
'10-'14
'15-'20
1920-1924
'25-'29
'30-'34
'35-'39
1940-1944
Barrett Dam
Avg. Precip. = 19.4 in.
Campo
Avg. Precip. = 19.9 in.
Cuyamaca
Avg. Precip. = 38.8 in.
Julian
Avg. Precip. = 33.3 in.
San Diego
Avg. Precip. = 9.7 in.
Warners Springs
Avg. Precip. = 17.78 in.
Percent above or below average
Percent above or below avg.
+150
+100
+50
0
-50
-100
USGS Data


AVERAGE RAINFALL
VS
ALTITUDE
Back of first range
Altitude ~ Feet
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
Average Rainfall ~ inches per year

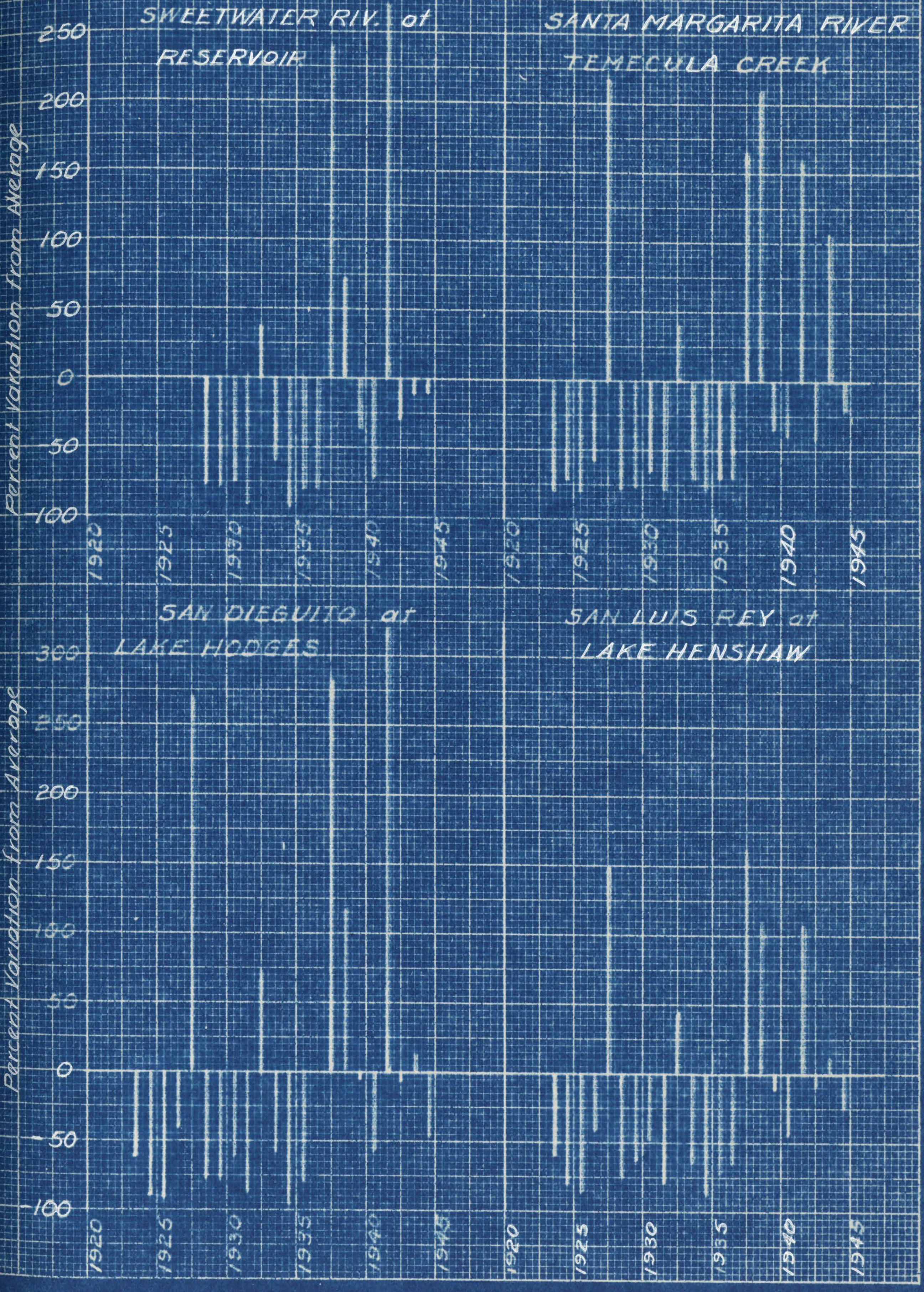
RELATION OF SURFACE PROFILE TO PRECIPITATION



From USGS Water Supply Paper 446

RUNOFF

PERCENT VARIATION FROM AVERAGE

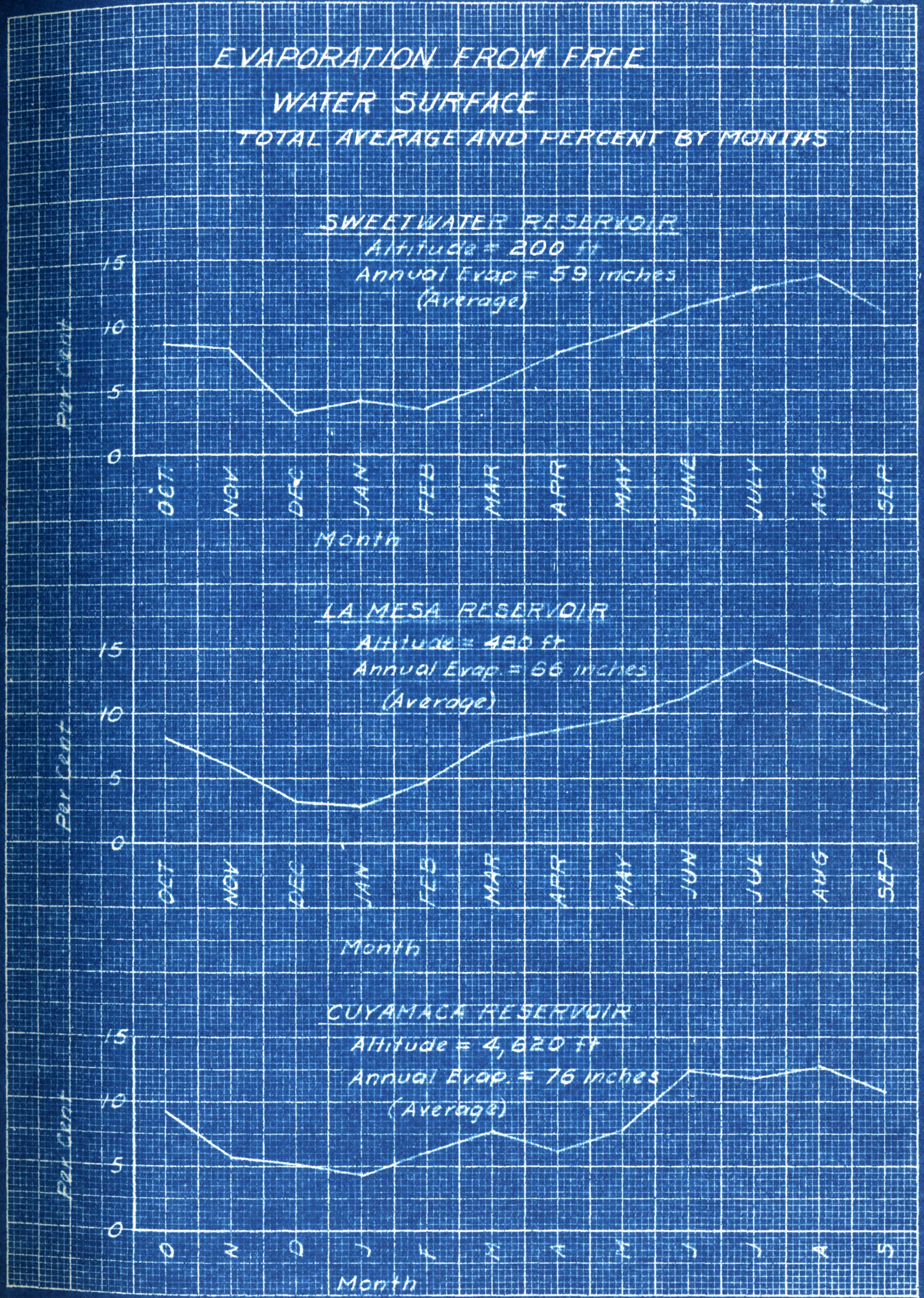


RUNOFF AS PERCENTAGE OF PRECIPITATION

YEAR	San Luis Rey R. Near Pala	Santa Ysabel Cr.* Near Ramona	San Diego River at Diver. Dam	Sweetwater River at Sw'tw'tr Dam
1887-88				3.3
88-89				10.3
89-90				6.9
1890-91				7.9
91-92				3.4
92-93				8.2
93-94				1.0
94-95				29.6
95-96				1.2
96-97				3.3
97-98				—
98-99			1.2	0.3
1899-1900			0.6	0
1900-1901			3.1	0.5
01-02			4.0	0
02-03			5.5	0
03-04	3.5		0.9	0
04-05	7.5		11.3	5.0
05-06	17.3		15.0	12.1
06-07	17.9	17.3	20.7	13.5
07-08	8.0	8.2	10.4	2.5
08-09	11.2	22.9	12.6	7.4
1909-10	12.8	21.1	10.4	5.3
1910-11	8.6	—	6.0	1.6
11-12	5.0	9.5	7.8	2.9
12-13	3.3	5.6	5.7	0.7
13-14	8.1	11.8	7.1	1.7
14-15	16.2	20.7	15.3	9.6
Average	10.0	14.6	8.1	4.9

* Same as San Dieguito River.

From U.S.G.S. Water Supply Paper 446


EVAPORATION FROM FREE
WATER SURFACE
TOTAL AVERAGE AND PERCENT BY MONTHS
SWEETWATER RESERVOIR
Altitude = 200 ft
Annual Evap = 59 inches
(Average)
Per Cent
0
5
10
15
OCT.
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEP
Month
LA MESA RESERVOIR
Altitude = 480 ft
Annual Evap. = 66 inches
(Average)
Per Cent
0
5
10
15
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Month
CUYAMACA RESERVOIR
Altitude = 4,620 ft
Annual Evap. = 76 inches
(Average)
Per Cent
0
5
10
15
O
N
D
J
F
M
A
M
J
J
A
S
Month

RUNOFF (ANNUAL)

SANTA MARGARITA RIVER BASIN

Station	Temecula Creek at Temecula	Fallbrook	Ysidora	Murieta Creek at Temecula	O'Neill Ditch
Drain. Ar.	592 mi.^{2}	645	740	220	—
Avg Runoff	23,000 A.F.	30,000	38,800	11,800	2,100
1944	18,200	21,900	27,800	7,500	4,900
43	47,600	57,900	74,300	31,300	1,200
42	13,100	15,800	16,900	1,500	1,600
41	59,300	83,100	117,600	31,300	1,800
1940	13,800	16,700	22,300	6,400	1,100
39	15,100	18,900	22,900	5,000	2,100
38	71,900	91,100	122,000	31,500	3,300
37	60,900	78,300	117,200	22,400	2,500
36	6,800	7,100	11,060	2,400	2,300
35	6,700	7,800	12,990	2,000	1,300
34	4,600	4,900	5,010	430	2,500
33	6,500	6,900	6,500	1,000	2,200
32	32,300	36,900	40,600	15,700	3,050
31	5,000	4,900	—		
1930	7,700	8,700	3,700	950	2,500
29	4,900	4,800	1,400		
28	4,950	5,500	4,000		
27	73,400	85,100	9,200		
26	9,600	12,500	15,700		
25	4,500	3,700	800		
24	6,200		2,400		
23	4,600		1,600		

USGS Data

O'Neill ditch is diversion from River.

RUNOFF (ANNUAL)

SAN LUIS REY RIVER BASIN

Station	Mesa Grande (into Henshaw)	Bonsall	Oceanside		Pala
Drain Ar.	209 sq. mi	514 mi^2			325 mi^2
Avg Runoff	34,000 A.F.	32,400 A.F.			59,400 A.F.
1944	25,700	15,800		1910	50,200
43	38,100	35,900		09	53,700
42	30,500	24,800	9,000	08	29,300
41	70,400	82,600	82,300	07	86,200
1940	18,600	14,740	11,400	06	110,600
39	29,900	22,100	19,300	05	46,400
38	72,300	75,700	74,900	04	8,600
37	89,600	109,900	103,100	03	55,500
36	12,000	5,600	1,500	02	22,500
35	8,800	8600	5,200	01	36,400
34	3,700	2,500	1,800	1900	17,300
33	12,000	9,000	4,800	1899	9,000
32	48,600	48,200	41,100	98	12,000
31	6,950	3,500	—	97	69,300
1930	17,500	8,200	2,900	96	10,400
29	12,200			95	93,600
28	8,200			94	13,900
27	85850			93	39,900
26	19,400			92	55,500
25	4,600			91	93,600
24	6,500			1890	147,300
23	13,700				

Lake Henshaw completed 1923

Data for Pala from Calif. Dept. of Public Works
Other data U.S.G.S.

RUNOFF (ANNUAL)

SAN DIEGUITO RIVER BASIN

Station	Santa Ysabel Creek at Mesa Grande	Lake Hodges
Drain Ar.	58 mi²	303
Avg Runoff A.F.	24,900 AF	42,500 AF
1944	12,900	22,200
43	18,000	46,700
42	9,100	39,600
41	43,000	179,300
1940	7,000	18,100
39	10,850	40,150
38	29,600	91,600
37	47,600	162,900
36		
35		8,500
34		1,550
33		17,300
32		73,100
31		4,800
1930		15,500
29		8,500
28	3,600	8,900
27	49,500	156,700
26	15,300	
25	1,700	
24	2,700	
23	9,600	
22		
21		
1920		
19		
18	7,400	
17	13,700	
16	95,200	
15	31,100	
14	10,400	
13	4,100	

	Santa Ysabel Creek at Escondido
	126 mi²
	33,000 AF
1910	33,900
09	47,100
08	11,200
07	35,700
06	63,300
05	68,300
04	2,000
03	31,300
02	10,200
01	20,100
1900	7,900
1899	2,600
98	4,600
97	38,300
96	4,300
95	52,500
94	5,900
93	21,400
92	32,300
91	52,500
1890	82,500

Santa Ysabel Creek at Escondido from Calif. Dept. of Public Works.

Other data U.S.G.S.

RUNOFF (ANNUAL)

SAN DIEGO RIVER BASIN

Station	El Capitan Dam	Santee	Cuyamaca Reservoir.		Lakeside
Drain Ar.	190 sq. mi	380 sq. mi	12 s.m.		207
Avg Runoff	—	30,000 A.F.	—		35,400
1944	28,780	6360	2,900	1921	6,600
43	33,810	4,880	3,400	1920	27,600
42	23,660	3,450	2,500	19	9,900
41	157,800	146,000	13,800	18	14,400
1940	17,210	3,200	1,800	17	21,000
39	29,350	13,100	5,500	16	200,600
38	62,340	36,200	13,200	15	55,400
37	88,320	34,700	14,200	14	14,600
36		4,000		13	5,000
35		3,500		12	15,800
34		50		11	15,500
33		17,400		1910	23,000
32		68,000		09	44,100
31		3,500		08	13,800
1930		5,400		07	49,200
29		1,700		06	80,600
28		1,200		05	75,100
27		133,000		04	2,200
26		25,900		03	30,900
25		1,400		02	11,000
24		3,100		01	21,000
23		10,100		1900	7,700
				1899	2,200
				98	5,500
				97	38,700
				96	4400
				95	55,200
				94	6,600
				93	22,100
				92	32,000

Data for Lakeside from
Calif. Dept. of Public Works

All other data from U.S.G.S.

RUNOFF (ANNUAL)

SWEETWATER RIVER BASIN

Station	Sweet-water Dam	Descanso
Drain Ar.	181 sq. mi	44 mi^2
Avg Runoff	18,000 A.F.	—
1944	16,000	
43	14,100	
42	10,400	
41	67,600	
1940	4,900	
39	11,100	
38	31,200	
37	62,100	
36	3,950	
35	3,800	
34	1,100	
33	7,000	
32	25,900	
31	1,400	
1930	4,600	
29	3,600	
28	3,900	
27		13,000
26		4,900
25		1,600
24		1,800
23		5,600
22		
21		
1920		
19		
18		7,400
17		6,100
16		6,100

	Sweet-water Dam	Descanso
	181 mi^2	44
	18,000 A.F.	—
1910	9,600	8,100
09	16,000	11,300
08	4,100	3,150
07	30,000	14,200
06	35,000	17,800
05	13,800	
04	0	
03	0	
02	0	
01	850	
1900	0	
1899	250	
98	0	
97	6,900	
96	1,300	
95	73,400	
94	1,300	
93	16,300	
92	6,200	
91	21,600	
1890	20,500	

RUNOFF (ANNUAL)

TIA JUANA RIVER BASIN

	1	2	3	4	5
Station	Into Morena Dam	Cottonwood Creek Tecate	Tia Juana R Dulzura	Tia Juana R Nestor	Campo Creek Campo
Drain Ar.	120 sq.mi	316 mi^2	478 mi^2	1,668 Tot. 1,198 in Mex.	84 Total 4 in Mexico
Avg. Runoff					
1944	16,800	5,900	14,000	107,200	4,200
43	13,100	5,100	10,000	15,100	3,600
42	8,700	8,600	15,500	29,600	5,300
41	47,100	67,300	98,200	334,800	9,800
1940	8,200	850	2,800	3,300	1,800
39	15,300	7,450	13,650	20,800	3,800
38	27,050	27,540	32,200	48,200	5,210
37	43,500	23,800	37,200	66,650	4,900

	6	7
Station	Cottonwood Creek Dulzura	Dulzura Conduit
Drain. Area		
1944	13,500	17,200
43	14,300	13,790
42	8,500	15,400
41	51,800	13,100
1940	5,600	4,900
39	13,000	
38	26,200	
37	60,000	
1915	10,500	22,000
14	2,000	4,800
13	850	5,400
12	2,000	6,600
11	1,100	5,100
10	5,100	14,500
09	20,100	30,800
08	10,300	
07	41,700	

Notes—

1. Cottonwood Creek into Morena Res.
2. Flow from Barrett Reservoir.
3. Flow into Tia Juana from Cottonwood Creek
4. Flow at mouth.
5. Very small
6. Flow out of Morena.
7. Diversion from Cottonwood Creek between 2 and 3.

MASS FLOW DATA

Lake Henshaw - Maximum Area for Evaporation.

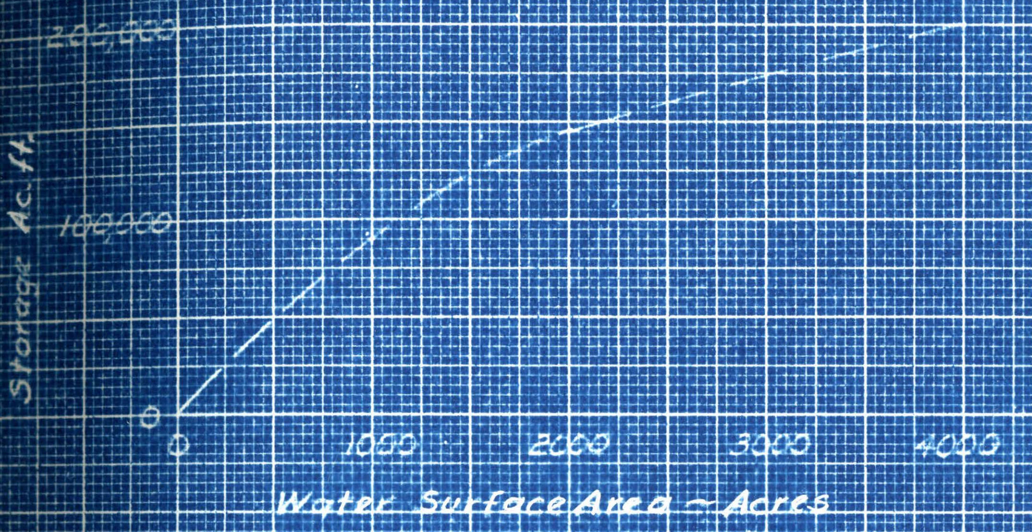
Year	Evap. in.	Precip. in.	Net Evap. in.	Evap. Loss. A.F.	Inflow A.F.	Gain or Loss A.F.	Sum. A.F.
1923	70	20	50	16,000	13,700	-2,300	-2,300
24	↑	18	52	17,000	6,500	-10,500	-12,800
25		20	50	16,000	4,570	-11,500	-24,300
26		26	44	15,000	19,400	+4,400	-19,900
27		26	44	15,000	85,900	+70,000	+50,100
28		18	52	17,000	8,200	-8,800	41,300
29		20	50	16,000	12,200	-3,800	37,500
1930		24	46	15,000	17,500	+2,500	40,000
31		23	47	16,000	7,000	-9,000	31,000
32		25	45	15,000	49,000	+34,000	65,000
33		20	50	16,000	12,000	-4,000	61,000
34		21	49	16,000	3,700	-12,300	48,700
35		21	49	16,000	8,800	-7,200	41,500
36		24	46	15,000	12,000	-3,000	38,500
37		24	46	15,000	90,000	+75,000	113,500
38		26	44	15,000	72,300	+55,300	168,800
39		22	48	16,000	30,000	+14,000	172,800
1940		25	45	15,000	19,000	+4,000	176,800
41		27	43	14,000	70,000	+56,000	232,800
42		19	51	17,000	31,000	+14,000	236,800
43	↓	20	50	16,000	38,000	+22,000	258,800
44	70	24	46	15,000	25,700	+10,700	269,500

Water Surface Area = 4,000 Acres.

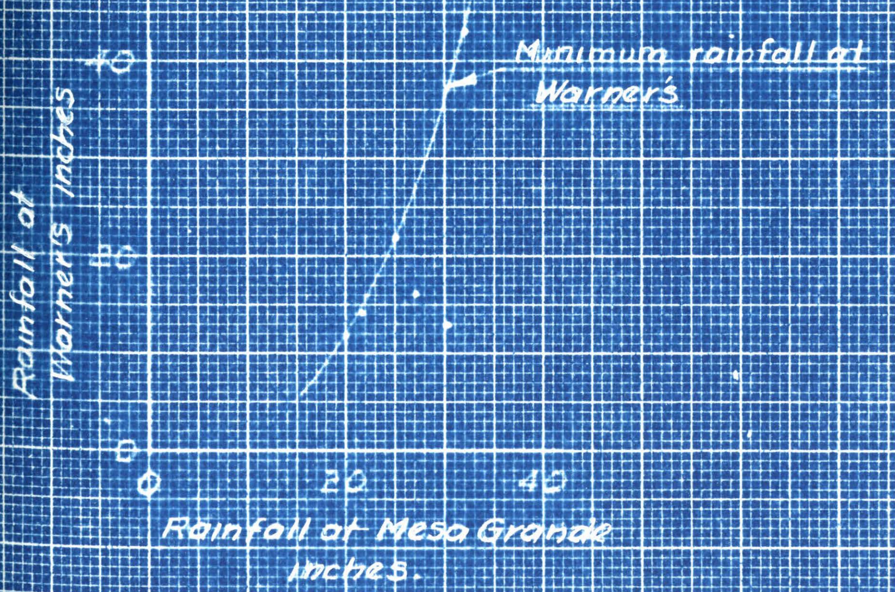
HENSHAW RESERVOIR

AUXILIARY CURVES FOR SAFE YIELD DETERMINATION

APPROXIMATE STORAGE-WATER SURFACE AREA CURVE HENSHAW RESERVOIR



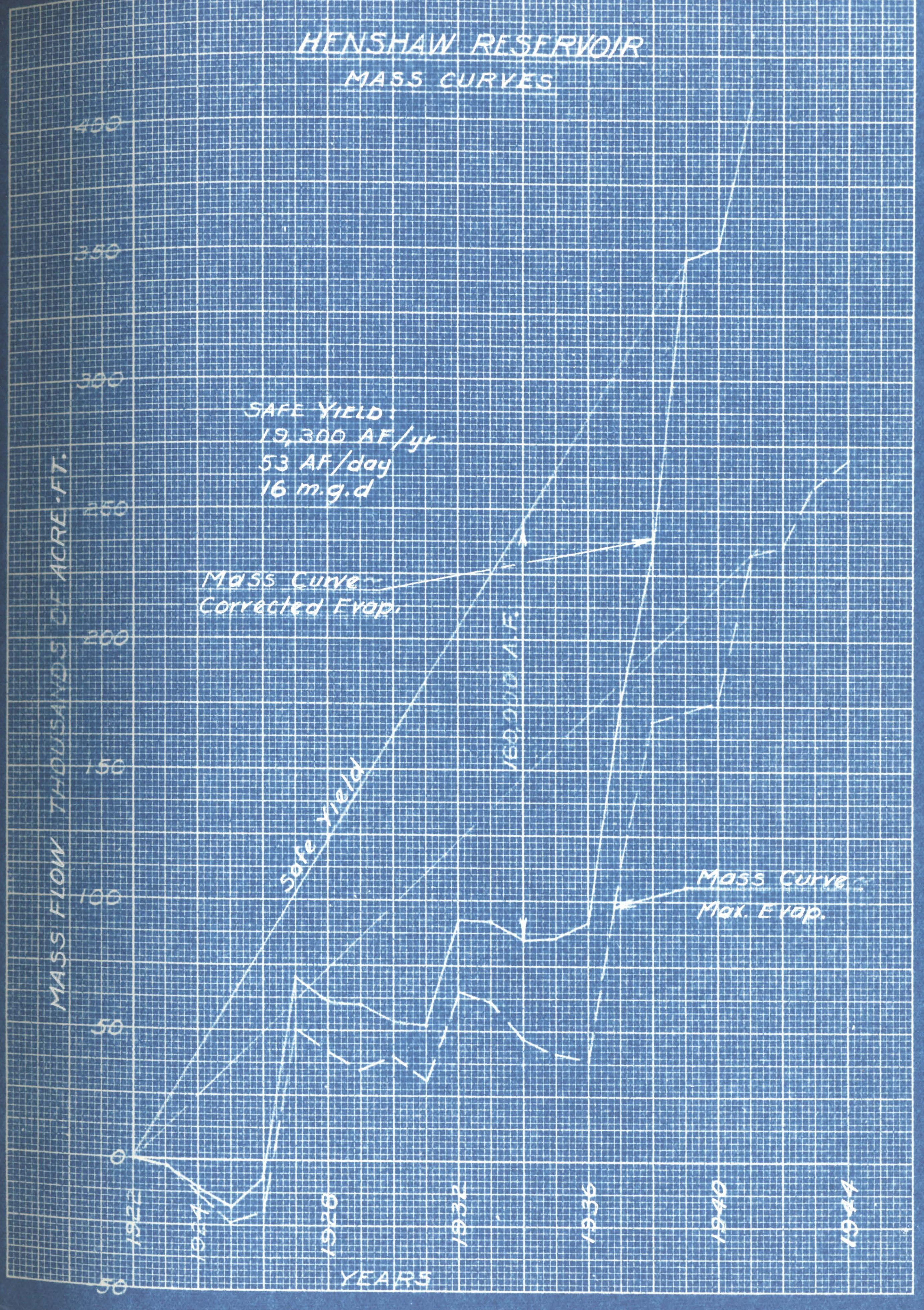
RAINFALL AT WARNER'S HOT SPRINGS



MASS FLOW DATA

Lake Henshaw – Evaporation adjusted for Res. Area.

Year	Orig. Storage A.F.	Res. Area Acres	Evap in.	Prec. in.	Net Evap.	Evapor. Loss A.F.	Inflow A.F.	Gain or Loss A.F.	Summation A.F.	Outflow (Approx) A.F.	Total Loss or Gain A.F.
1923	200,000	4000	70	20	50	16,000	13,700	-2,300	-2,300	10,000	-12,300
1924	187,700	3500		18	52	15,000	6,500	-8,500	-10,800	10,000	-18,500
1925	169,200	2900		20	50	12,500	4,600	-7,900	-18,700	10,000	-17,900
1926	151,300	2200		26	44	8,100	19,400	+11,300	-7,400	10,000	+ 1,300
1927	152,600	2200		26	44	8,100	85,900	77,800	70,400	10,000	60,400
28	200,000	4000		18	52	17,400	8,200	-9,200	61,200	10,000	-19,200
29	180,800	3200		20	50	13,400	12,200	-1,200	60,000	10,000	-11,200
30	169,600	2900		24	46	11,200	17,500	-6,300	53,700		-16,300
31	153,300	2300		23	47	9000	7,000	-2,000	51,700		-12,000
32	141,300	1900		25	45	7,100	49,000	+41,800	92,500		+31,800
33	173,100	3000		20	50	12,500	12,000	- 500	92,000		-10,500
34	162,600	2600		21	49	10,600	3,700	-6,600	85,400		-16,600
35	146,000	2000		21	49	8,200	8,800	+600	86,000		-9,400
36	136,600	1700		24	46	6,500	12,000	+ 5,500	91,500		-4,400
37	132,200	1700		24	46	6,500	90,000	83,500	175,000		+73,500
38	200,000	4000		26	44	14,700	72,300	57,600	232,600		
39	200,000	4000		22	48	16,000	30,000	14,000	346,600		
1940	200,000	4000		25	45	15,000	19,000	4,000	350,600		-6000
41	194,000	3700		27	43	13,200	70,000	56,800	407,400		+46,800
42	200,000	4000		19	51	17,000	31,000	14,000	421,400		
43	200,000	4000		20	50	16,600	38,000	21,400	442,800		
44	200,000	4000	70	24	46	15,400	25,700	10,300	453,100	10,000	


HENSHAW RESERVOIR
MASS CURVES
SAFE YIELD:
19,300 AF/yr
53 AF/day
16 m.g.d
Mass Curve
Corrected Evap.
Safe Yield
160,000 A.F.
Mass Curve
Max. Evap.
MASS FLOW THOUSANDS OF ACRE-FT.
400
350
300
250
200
150
100
50
0
50
1922
1924
1928
1932
1936
1940
1944
YEARS

MASS FLOW DATA

Hodges Reservoir – Max. Area for Evaporation

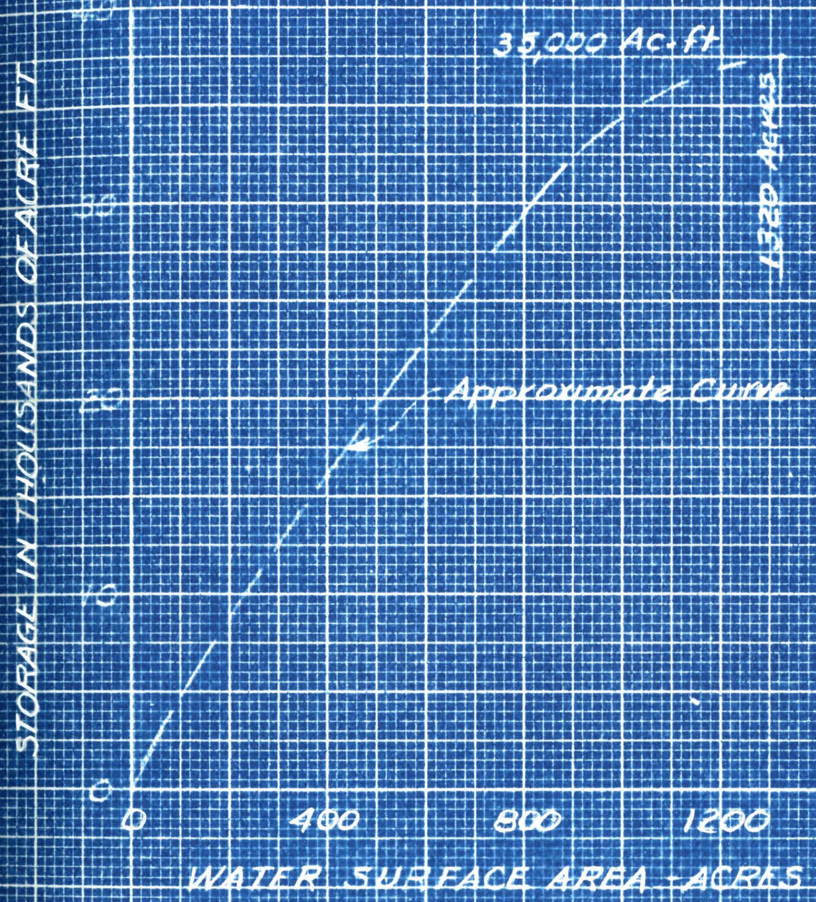
Year	Evap. in.	Precip in.	Net Evap in.	Evap. Loss A.F.	Inflow A.F.	Gain or Loss A.F.	Sum A.F.
1913	60	12	48	5300	7,000	+1,700	1,700
14		21	39	4300	18,000	13,700	14,400
15		25	35	3800	98,000	94,200	108,600
16		28	32	3500	100,000	102,500	211,100
17		12	48	5300	23,000	17,700	228,800
18	60	19	41	4500	12,000	7,500	236,300
19							
1923	60	10	50	5500	16,100	10,600	10,600
24		13	47	5200	4,500	– 700	9,900
25		12	48	5300	3,000	–2,300	7,600
26		21	39	4300	25,000	21,700	29,300
27		27	33	3600	157,000	153,400	182,700
28		11	49	5400	8,900	3,500	186,200
29		9	51	5600	8,500	2,900	189,100
1930		19	41	4500	15,500	11,000	200,100
31		19	41	4500	4,800	300	200,400
32		14	46	5100	73,000	67,900	268,300
33		12	48	5300	17,200	11,900	280,200
34		13	47	5200	1,600	–4,600	275,600
35		14	46	5100	8,500	3,400	279,000
36		18	42	4600	4,000	–600	278,400
37		13	47	5200	163,000	11,100	289,500
38		17	43	4700	91,600	86,900	376,400
39		13	47	5200	40,100	34,900	381,300
1940		19	41	4500	18,100	13,600	394,900
41		28	32	3500	179,300	175,800	570,700
42		9	51	5600	39,600	34,000	
43		23	37	4100	46,700	42,600	
44	60	16	44	4800	22,180	17,400	

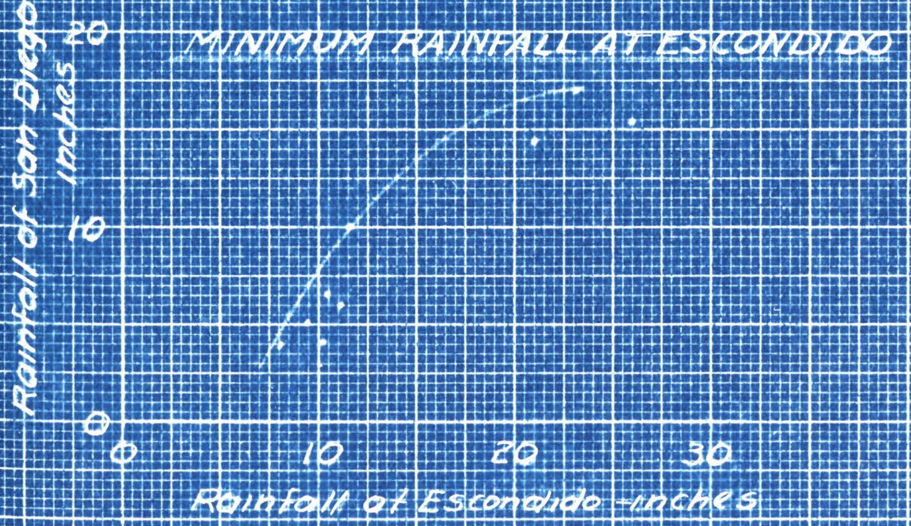
Water surface area = 1320 Acres.

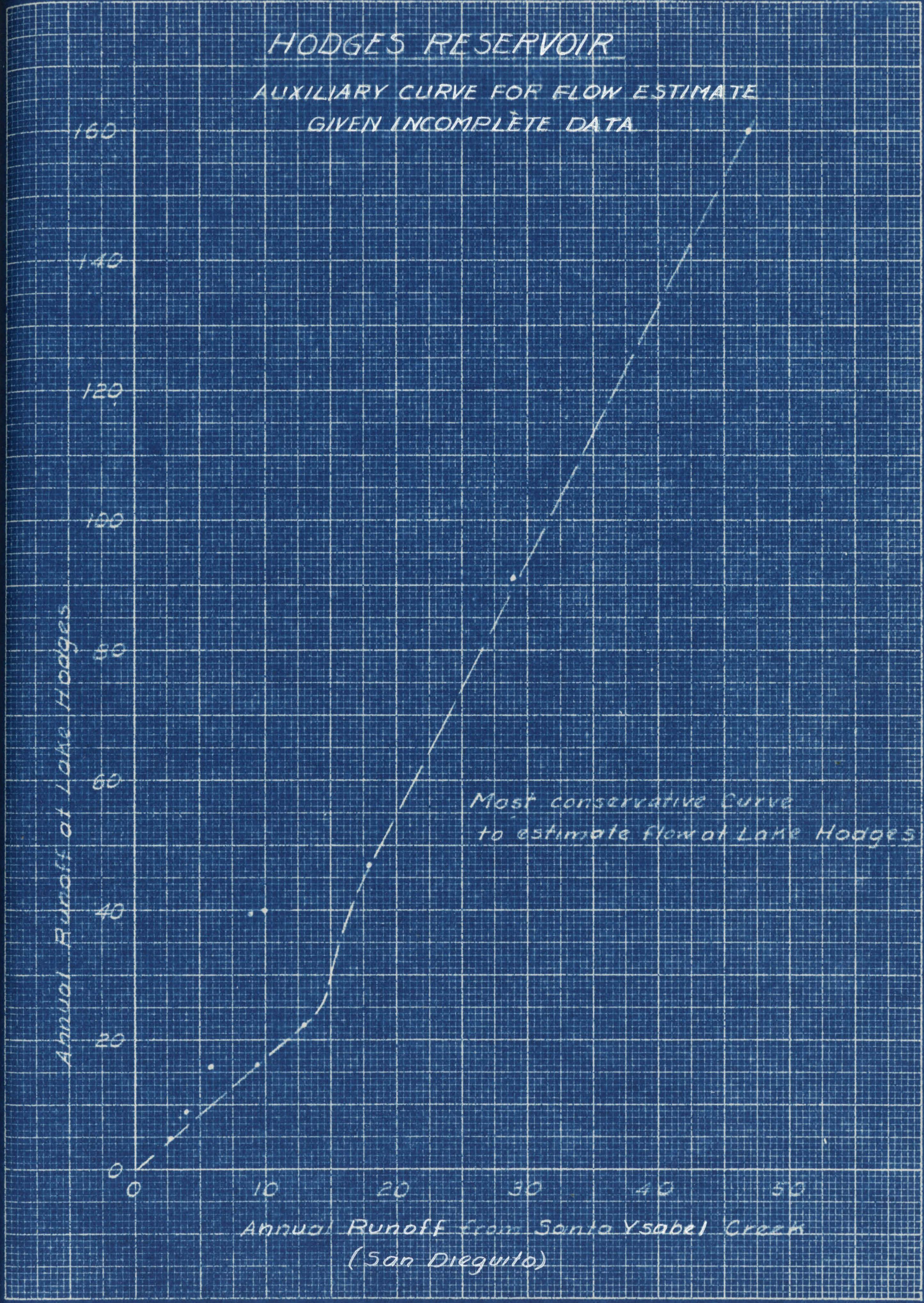
HODGES RESERVOIR

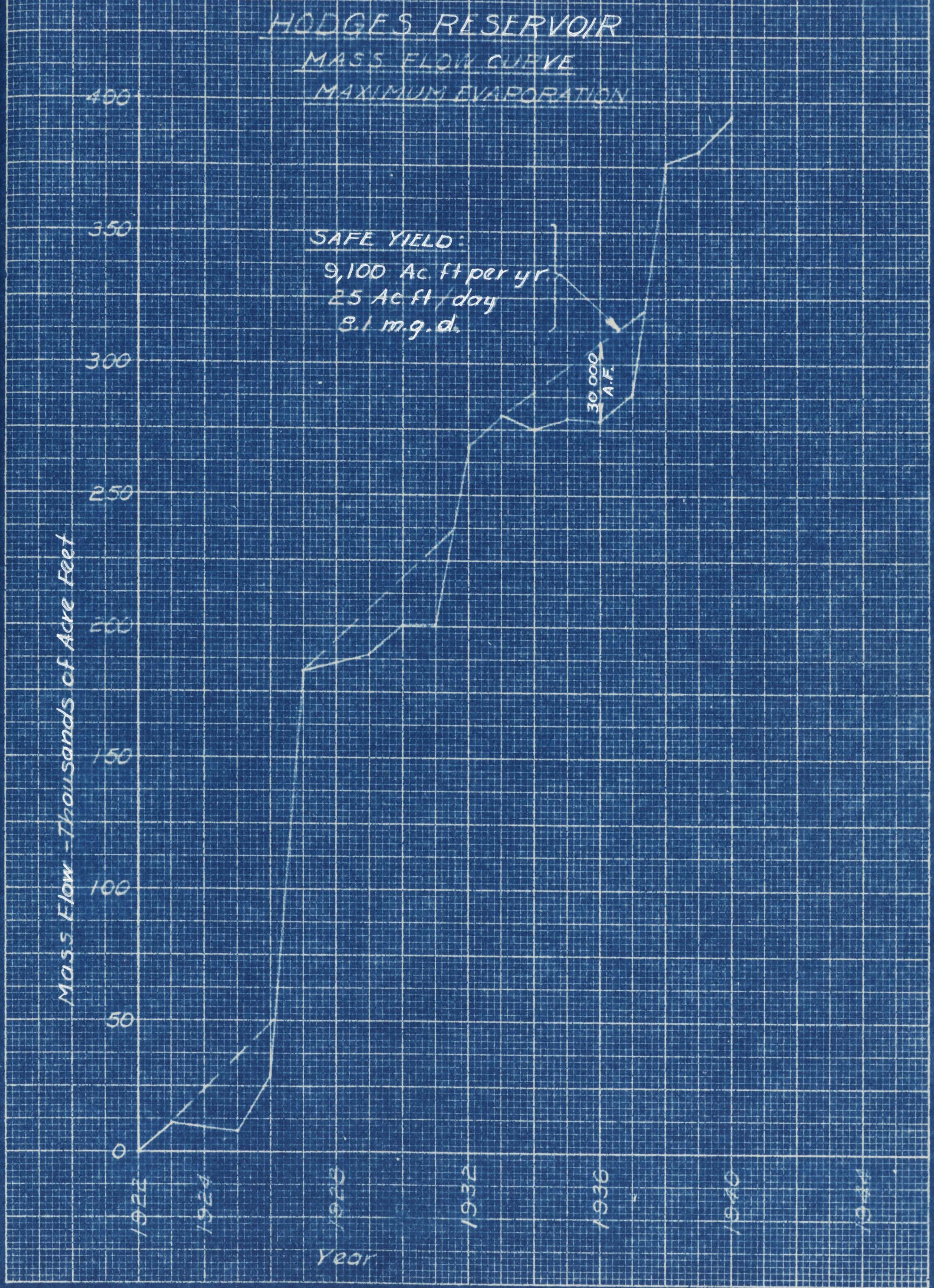
AUXILIARY CURVES FOR SAFE YIELD DETERMINATION

WATER SURFACE AREA






HODGES RESERVOIR
AUXILIARY CURVE FOR FLOW ESTIMATE
GIVEN INCOMPLETE DATA
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
Annual Runoff at Lake Hodges
Most conservative Curve
to estimate flow at Lake Hodges
Annual Runoff from Santa Ysabel Creek
(San Dieguito)


HODGES RESERVOIR
MASS FLOW CURVE
MAXIMUM EVAPORATION
SAFE YIELD:
9,100 Ac. ft per yr
25 Ac. ft / day
8.1 m.g.d.
30,000 A.F.
Mass Flow - Thousands of Acre Feet
400
350
300
250
200
150
100
50
0
1922
1924
1928
1932
1936
1940
1944
Year

MASS FLOW DATA

Sweetwater Res. – Maximum Area for Evaporation

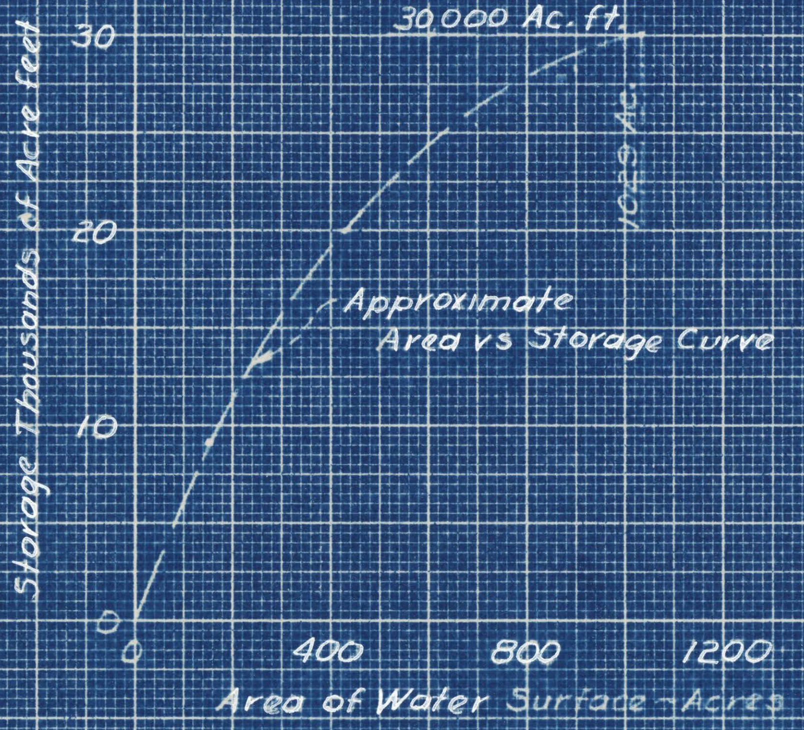
YEAR	EVAP. in.	Precip in.	Net Evap. in.	Evap. Loss A.F.	Inflow A.F.	Gain or Loss A.F.	Sum. A.F.
1901	75	10	65	5500	800	-4,700	-4,700
02		13	62	5300	0	-5,300	-10,000
03		7	68	5800	0	-5,800	-15,800
04		8	67	5700	0	-5,700	-21,500
05		23	52	4500	13,800	+9,300	-12,200
06		18	57	4900	35,000	+30,100	+17,900
07		12	63	5400	30,000	24,600	42,500
08		14	61	5200	4,100	-1,100	41,400
09		19	56	4800	16,000	11,200	52,600
1910		8	67	5700	9,600	3,600	56,200
11		13	62	5300	3,100	-2,100	54,100
12		15	60	5100	5,000	-100	54,000
13		10	65	5600	900	-4,700	49,300
14		16	59	5000	3,500	-1,500	47,800
15		21	54	4600	27,000	+22,400	70,200
16	75	24	51	4400	160,000	155,000	225,200
1928	75	8	67	5700	3,900	-1,800	-1,800
29		7	68	5600	3,600	-2,200	-4,000
1930		16	59	5100	4,600	-500	-4,500
31		18	57	4900	1,400	-3,500	-8,000
32		16	59	5100	25,000	+19,900	+11,900
33		11	64	5500	7,000	1,500	13,400
34		9	66	5600	1,000	-4,600	8,800
35		13	62	5300	3,800	-1,500	7,300
36		18	57	4900	3,900	-1,000	6,300
37		16	59	5100	62,000	56,900	63,200
38		19	56	4800	31,000	26,200	89,400
39		15	60	5100	11,000	5,900	95,300
1940		19	56	4800	4,900	100	95,400
41		28	47	4000	67,600	63,600	159,000
42		8	67	5700	10,400	4,700	173,700
43		17	58	5000	14,100	9,100	182,800
44	75	13	62	5300	16,000	10,700	193,500

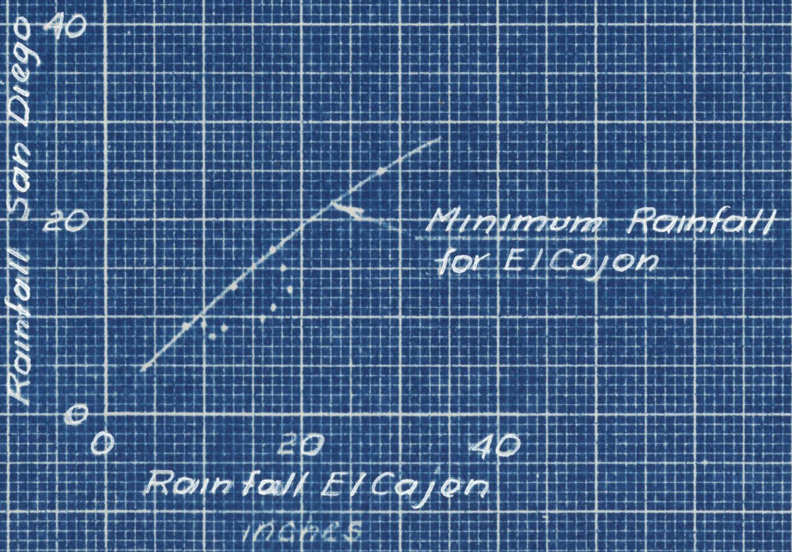
Water Surface Area = 1029 Acres.

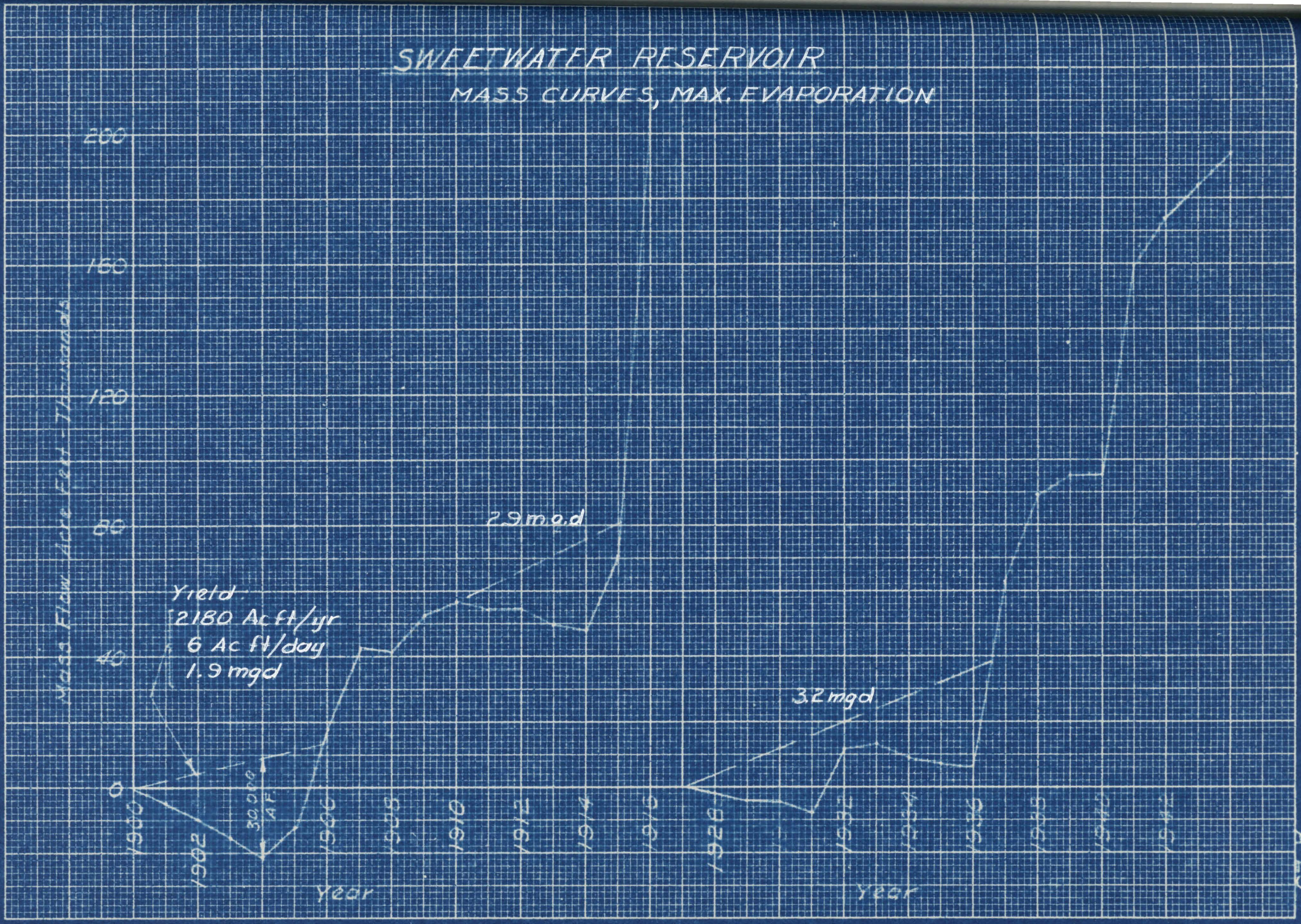
SWEETWATER RESERVOIR

AUXILIARY CURVES FOR SAFE YIELD DETERMINATION

CURVE FOR WATER SURFACE AREA






SWEETWATER RESERVOIR
MASS CURVES, MAX. EVAPORATION
200
160
120
80
40
0
Mass Flow Acre Feet - Thousands
Yield
2180 Ac ft/yr
6 Ac ft/day
1.9 mgd
30,000 AF
2.9 mgd
3.2 mgd
1900
1902
1906
1908
1910
1912
1914
1916
1928
1932
1934
1936
1938
1940
1942
Year
Year

MASS FLOW DATA - 1928-1944

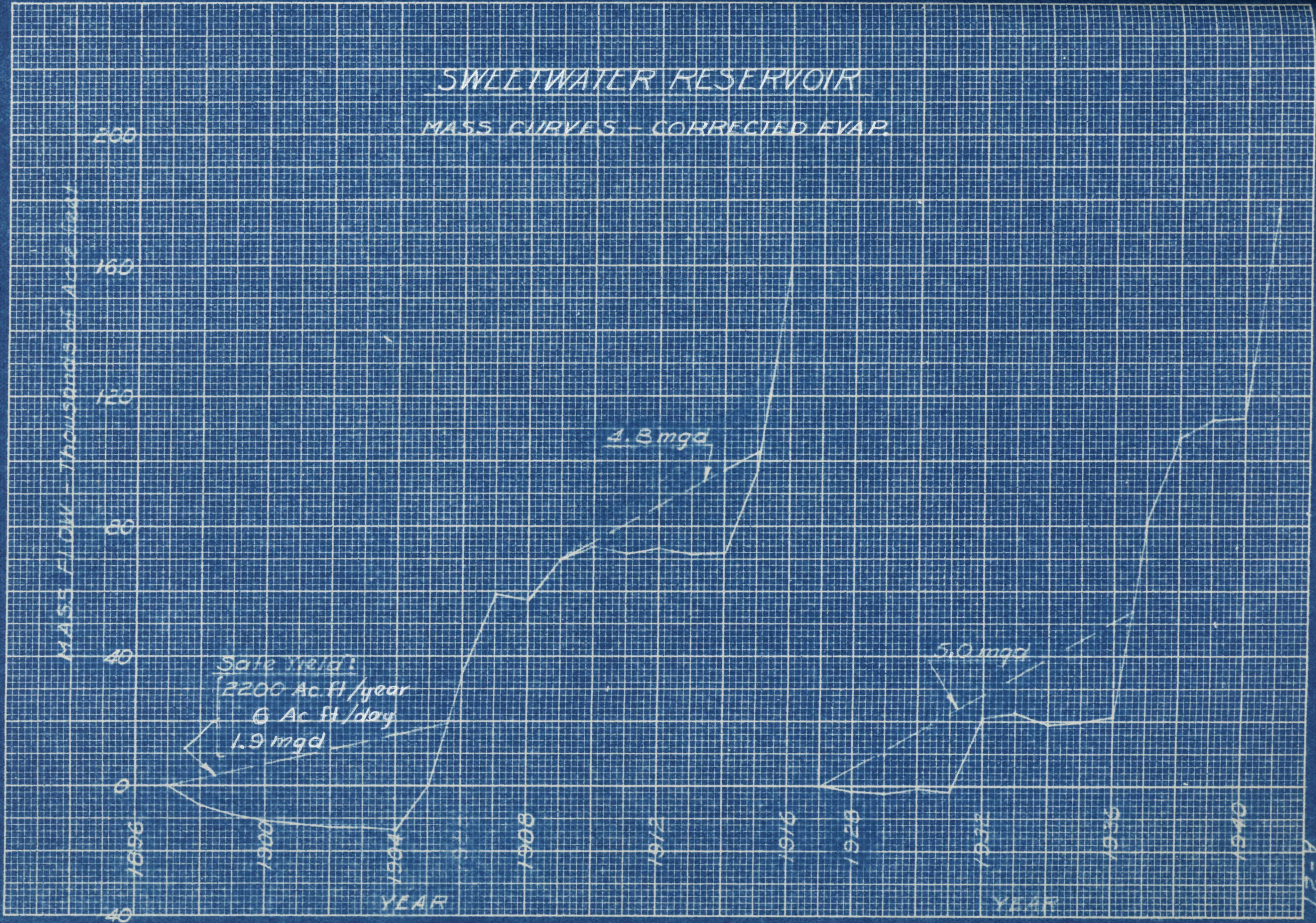
Sweetwater Reservoir - Evaporation adjusted for Res. Area

Year	Orig. Storage A.F.	Res. Area Acres	Evap. in.	Prec. in.	Net Evap. in.	Evapor. Loss. A.F.	Inflow A.F.	Gain or Loss A.F.	Summation A.F.	Outflow (Approx) A.F.	Total Loss or Gain A.F.
1928	30,000	1030	75	8	67	5700	3,900	-1,800	-1,800	-2,100	-3,900
29	26,100	700	↕	7	68	4000	3600	- 400	-2,200	↕	-2,500
1930	23,600	600		16	59	3000	4600	+1,600	-600		-500
31	23,100	550		18	57	2600	1,400	-1,200	-1,800		-3,300
32	19,800	450		16	59	2200	25,000	+22,800	+21,000		+20,700
33	30,000	1030		11	64	5500	7,000	1,500	22,500		-600
34	29,400	900		9	66	5000	1,000	-4,000	18,500		-6,100
35	23,300	550		13	62	2900	3,800	+900	19,400		-1,200
36	22,100	500		18	57	2300	3,900	1,600	21,000		-500
37	21,600	500		16	59	2500	62,000	59,500	80,500		+59,000
38	30,000	1030		19	56	4800	31,000	26,200	106,700		
39	30,000	1030		15	60	5200	11,000	5,800	112,500		
1940	30,000	1030		19	56	4800	4,900	100	112,600		-2000
41	28,000	800		28	47	3200	67,600	64,400	177,000		62,300
42	30,000	1030		8	67	5700	10,400	4,700	181,700		2,600
43	30,000	1030		17	58	5000	14,100	9,100	190,800		188,700
1944	30,000	1030	75	13	62	5300	16,000	10,700	201,500	-2,100	199,400

MASS FLOW DATA 1898-1916

Sweetwater Reservoir - Evaporation adjusted for Res. Area.

Year	Orig Storage A.F.	Res. Area Acres	Evap. in.	Prec. in.	Net Evap in.	Evapor. Loss A.F.	Inflow A.F.	Gain or Loss A.F.	Summation A.F.	Outflow (Approx) A.F.	Total Loss or Gain A.F.
1898	30,000	1030	75	4	71	6100	4	-6,100	-6,100	2,100	-8200
99	21,800	500	↑	5	70	2900	200	-2,700	-8,800	↑	-4,800
1900	17,000	350		8	67	2000	0	-2,000	-10,800		-4,100
01	12,900	250		10	65	1400	800	- 600	-11,400		-2,700
02	10,200	200		13	62	1000	0	-1000	-12,400		-3,100
03	7,100	100		7	68	600	0	- 600	-13,000		-2,700
04	4,400	80		8	67	500	0	- 500	-13,500		-2,600
05	1,800	50		23	52	200	13,800	+13,600	+100		+11,500
06	13,300	250		18	57	1200	35,000	33,800	33,900		31,700
07	30,000	1030		12	63	5400	30,000	24,600	58,500		56,400
08	30,000	1030		14	61	5200	4,100	-1,100	57,400		-3,200
09	26,800	750		19	56	3500	16,000	+12,500	69,900		
1910	30,000	1030		8	67	5800	9,600	3,800	73,700		+1,700
11	30,000	1030		14	62	5300	3,100	-2,200	71,500		-4,300
12	25,700	650		15	60	3300	5,000	+ 1,700	73,200		- 400
13	25,300	650		11	65	3500	900	-2,600	70,600		-4,700
14	20,600	500	↓	16	59	2500	3,500	+ 1,000	71,600	↓	-1,100
15	19,500	450	75	21	54	2000	27,000	+25,000	96,600	2,100	+94,500
16				24	51		160,000				


SWEETWATER RESERVOIR
MASS CURVES - CORRECTED EVAP.
MASS FLOW - Thousands of Acre Feet
200
160
120
80
40
0
40
4.8 mgd
5.0 mgd
Safe Yield:
2200 Ac. ft./year
6 Ac. ft./day
1.9 mgd
1896
1900
1904
1908
1912
1916
1928
1932
1936
1940
YEAR
YEAR

PRECIPITATION RECORD

inches

Drainage	SAN LUIS REY				SAN DIEGUITO	SAN DIEGO			
Station	Amago	Mesa Grande	Nellie	Warner Springs	Escondido	Cuyamaca	El Cajon	Julian	San Diego
Elev.	2715	3350	5000	3165	750	4677	560	4222	87
Average	28.33	31.23	41.97	17.78	15.92	38.80	13.53	33.26	9.67
1944				19.7	15.9	42.8	13.2		13.1
43	34.50			21.9	21.5	43.1	17.4		17.7
42				9.3	11.2	22.8	7.6		5.9
41				27.7	30.7	55.4	28.1		24.9
1940				21.3	25.8	50.6	18.8		14.8
39				15.1	13.5	35.5	15.1		10.0
38				23.7	23.7	55.5	18.6		13.0
37				20.7	21.7	50.2	16.1		10.1
36	34.08			20.3	23.7	56.3	18.0		14.4
35	18.36			13.2	14.7	31.6	13.8		10.2
34	18.02			12.1	14.4	21.3	9.3		8.9
33	19.97			12.6	13.3	30.8	11.0		8.2
32	25.36			22.6	19.8	48.2	15.9		11.3
31	29.64			19.5	23.8	42.1	18.4		15.2
1930	31.2			19.7	19.1	44.7	16.3	35.2	11.7
29	15.4			12.0	8.6	29.6	7.4	29.1	4.1
28	14.7			8.4	10.9	21.6	8.3	18.3	5.5
27	36.7			24.4	26.8	56.7	24.6	47.9	16.4
26	37.5			24.3	21.4	48.0	16.8	40.7	14.1
25	25.8			12.4	12.4	34.3	14.3	28.4	9.9
24	25.2			8.9	12.7	31.2	10.2	22.5	5.7
23	20.4			12.5	10.4	30.5	9.5	24.2	6.5
22	30.6	25.7	50.2	22.3	19.3	43.8	15.6	34.0	9.2
21	39.8	43.8	62.1	32.0	23.2	51.6	23.2	46.1	17.6
1920	27.0	30.6	42.1	13.6	13.2	37.1	13.1	37.4	7.7
19	22.0	20.6	35.5	13.8	11.3	28.9	10.1	25.3	6.8
18	30.8	27.1	37.9	16.3	18.6	39.8	16.0	30.0	12.0
17	21.5	20.0	33.7	12.4	12.3	26.7	9.4	20.8	8.0
16	34.7	48.9	69.6	25.7	28.0	62.0	24.1	57.0	11.6
15	42.0	44.2	62.0	25.6	25.3	54.1	21.1	51.1	13.6
14	33.7	32.0	55.0	19.1	20.6	36.1	16.2	35.1	10.9
13	23.9	27.1	49.6	14.0	12.2	33.0	10.6	24.4	7.3

PRECIPITATION RECORD

inches

Drainage	SWEETWATER		Tia Juana	
Station	Bonita	Chula Vista	Barett Dam	Campo
Elev.	110	9	1600	3000
Average	11.64	10.05	19.36	19.92
1944	12.7	10.8	21.7	
43	16.2	14.9	23.1	
42	7.0	6.3	12.7	
41	24.4	24.9	29.0	
1940	15.6	14.8	24.8	
39	12.9	12.0	20.2	
38	12.5	11.2	26.7	
37	12.5	10.3	23.7	
36	14.5	13.7	23.4	
35	11.9	11.7	17.6	
34	7.4	6.6	10.9	
33	8.9	8.0	12.8	
32	12.3	11.9	19.9	
31	18.0	17.0	20.8	
1930	13.8	13.2	20.6	23.9
29	6.4	4.4	10.5	15.8
28	7.7	6.3	8.1	9.8
27	18.7	17.5	32.8	31.4
26	14.7	11.5	18.1	18.7
25	12.5	11.0	14.6	13.9
24	6.8	5.3	14.9	12.9
23	8.7	7.5	12.9	15.0
22	11.4	10.2	22.1	27.1
21	19.0	17.6	28.2	27.6
1920	9.6	9.4	19.8	19.4
19	7.8	7.4	17.3	15.9
18	11.9		21.2	19.8
17	9.0		13.5	13.2
16	14.9			30.0
15				22.1
14				20.6
13				16.6

Precipitation Record

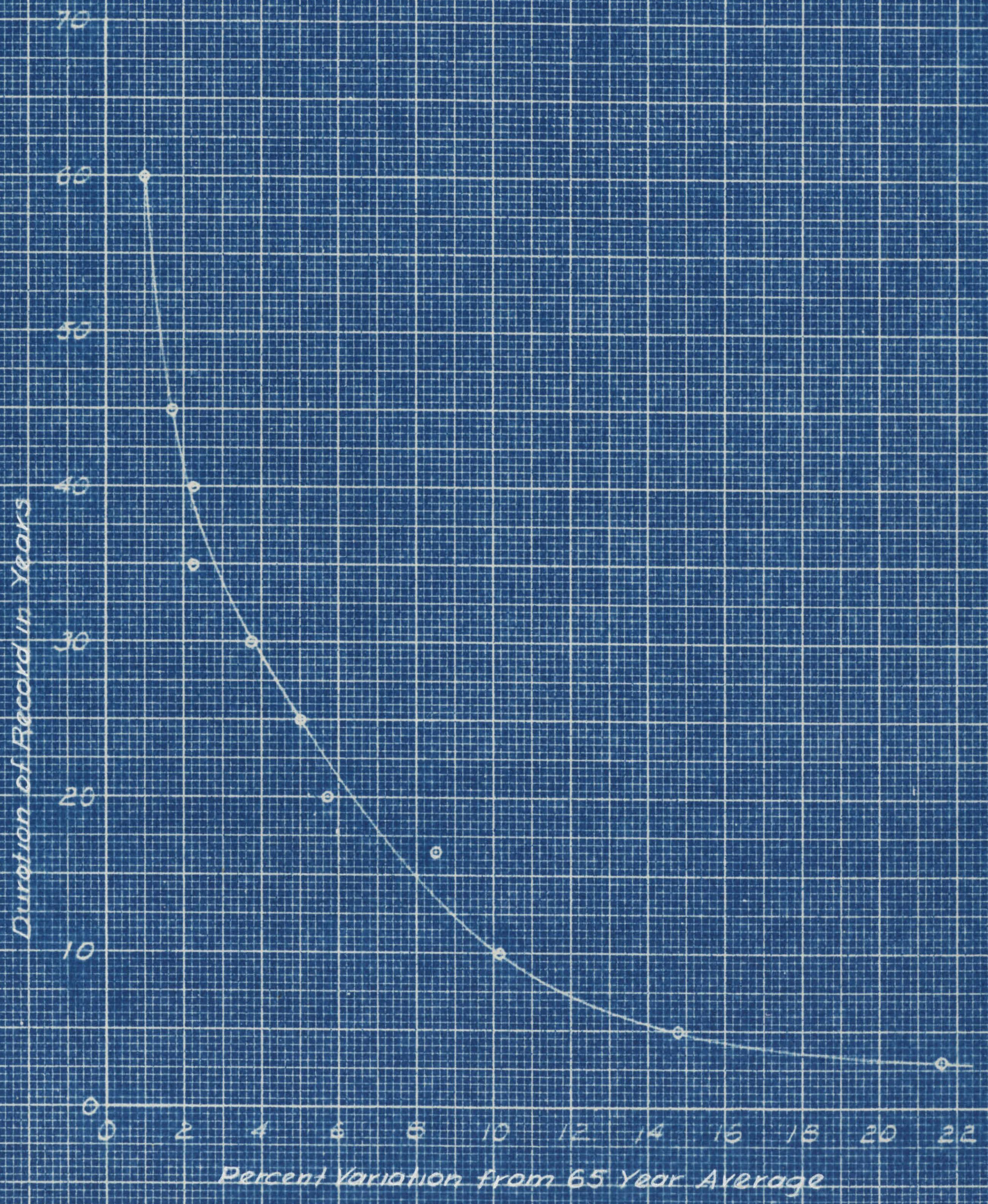
inches

Drainage	SAN LUIS REY		SAN DIEGUITO	SAN DIEGO			SWEET-WATER	TIA JUANA
Station	Nellie	Warner Springs	Escondido	Cuyamaca	Julian	San Diego	Descanso	Campo
Elev.	5000	3165	750	4677	4222	87	3400	3000
Average	41.97	17.78	15.92	38.80	33.26	9.67	22.35	19.92
1912	40.1	17.1	15.4	37.2	30.0	10.6	23.4	18.7
11	43.7	14.2	13.9	28.9	25.3	11.8	21.7	15.3
1910	24.6	11.3	9.7	21.3	17.7	5.8	27.5	15.8
09	68.3	29.1	26.4	56.4	33.2	14.1		27.2
08	—	15.1	14.1	32.8	24.5	8.6		17.7
07	—	18.4	13.9	33.8	32.5	8.0		14.6
06	77.4		27.2	59.9	45.5	14.9		32.9
05	54.7		26.7	66.1		16.4		34.5
04	24.9		9.9	26.8		6.6		13.3
03	–		12.4	28.6		6.1		12.9
02	43.2		16.3	43.2		11.5	21.6	22.1
01			11.2	33.0		9.5	25.3	15.6
1900			14.1	31.2		5.8	16.5	11.3
1899			9.5	26.3		6.1	11.9	
98			8.7	31.9		4.7	20.9	
97			15.5	41.9		8.9	27.3	
96			7.9	25.3		8.7	18.1	
95			18.6	57.3		11.9		
94				22.6		5.0		
93				44.0		9.3		
92				39.6		8.7		
91				62.5		10.5		
1890				74.9		15.0		

PRECIPITATION

SAN DIEGO

DURATION OF RECORD vs
PERCENT VARIATION FROM 65 YEAR AVG.



From U.S.G.S. Water Supply Paper 446

SUMMATION OF WATER SUPPLY
SAN DIEGO COUNTY.

		Surface Water				Underground Water		
River	Reservoir	Present Res. Cap. A.F.	Present Safe Yield mgd.	Future Res. Cap. A.F.	Future Sf. Yield mgd.	Capacity Water A.F.	Present Sf. Yield m.g.d.	Future Sf. Yield mg.d.
Santa Margarita	Temecula			150,000	20.0	13,700	3.0	2.0
	Fallbrook			50,000				
San Luis Rey	Henshaw	203,000	16.0		17.0			
	Escondido	3,000	1.0			35,300	7.8	5.2
	Monserat			150,000	15.0			
	Bonsall			150,000				
San Dieguito	Hodges	37,500	5.6	278,000	23.1			
	Sutherland			98,000	10.0	20,500	4.5	3.0
	Pamo			15,000				
San Diego	Cuyamaca	11,600	0.9					
	El Capitan	116,500	11.6		29.1	25,200	5.6	3.7
	San Vincente			174,500				
	Mission			29,200				
Sweetwater	Sweetwater	29,100	1.8	126,500	9.2	11,100	2.4	1.6
Otay	Otay	56,300	3.8	3.8		—	—	—
Tia Juana	Morena	67,200	5.0					
	Barrett.	42,800	4.8	133,000	8.7	23,700	5.2	3.5
Sub-Total Surface Water.-			50.5		132.1		28.5	19.0
Underground mgd.			28.5		19.0			
Total			79.0		151.1			