A STUDY OF THE SAFE YIELD AND REPLENISHMENT CONDITIONS FOR THE YUCAIPA BASIN AREA, CALIFORNIA.

by

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for the degree of

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Plate I. Above: View looking east into the Yucaipa Ridge hills and western slopes of San Bernardino Mountains.
Below: From west side of Yucaipa basin, view looking southeast into banks and terraces of Wildwood Canyon.

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ABSTRACT

A ground water inventory made for a basin area of about 51 square miles and situated 6 miles southeast from Redlands, California, disclosed that a mean annual recharge of 4322.5 acre-feet from rainfall on foothill and mountain areas plus a mean annual deep penetration volume of 1693 acre-feet from water artificially applied (irrigation and domestic uses) are exceeded by local consumptive uses plus exportation losses. Detailed studies showed that no appreciable contribution from rainfall in irrigated and non-irrigated valley lands occurs to the sub-surface ground water body.

Elimination of the net basin drawdown loss caused by exportation will still put the overdraft within the order of 3000 acre-feet per year. An inevitable increase of land cultivation brings about no chance to mitigate that figure in the near future.

Increasing volumes of water extraction are shown by a mean annual drop in water level of wells, from 1.67 feet for the period 1927-1942 to 7.5 feet for the period 1942-1954.

An estimated specific yield of 0.1085 for the ground water reservoir places the time-life of Yucaipa basin within 35 years, assuming the existence of a 250 feet thick aquifer under the 400 feet deepest wells.

A depth of 650-750 feet in water wells is arbitrarily established as a limit for the economic and profitable exploitation of the basin.

A conservative figure of 5000 acre-feet plus minus 1000 acre-feet annual safe yield is based on the mean annual recharge to valley

lands from foothill and mountain areas. This quantity is likely to be increased by additional yields from the aquifer, upon rebounding and expansion.

The low porosity value and its close specific yield (0.12 and 0.1085 respectively) associated with a rather low specific retention value, seem to indicate that the hydrological properties of the Yucaipa aquifers reflect the existence of a type of rock near to a sandy gravel, with locally abundant interstitial materials. Plio-Pleistocene(?) San Timoteo beds can well appear in Yucaipa basin at aquifer depths. Younger Quaternary fanglomerates, stream gravels, weathered soils and modern alluvium occur widely distributed in the surface area of Yucaipa. These sediments are bordered to the north, east, and southeast by hills and mountains of basement complex rocks which are probably pre-Cambrian, but most certainly pre-Cretaceous in age.

INTRODUCTION.

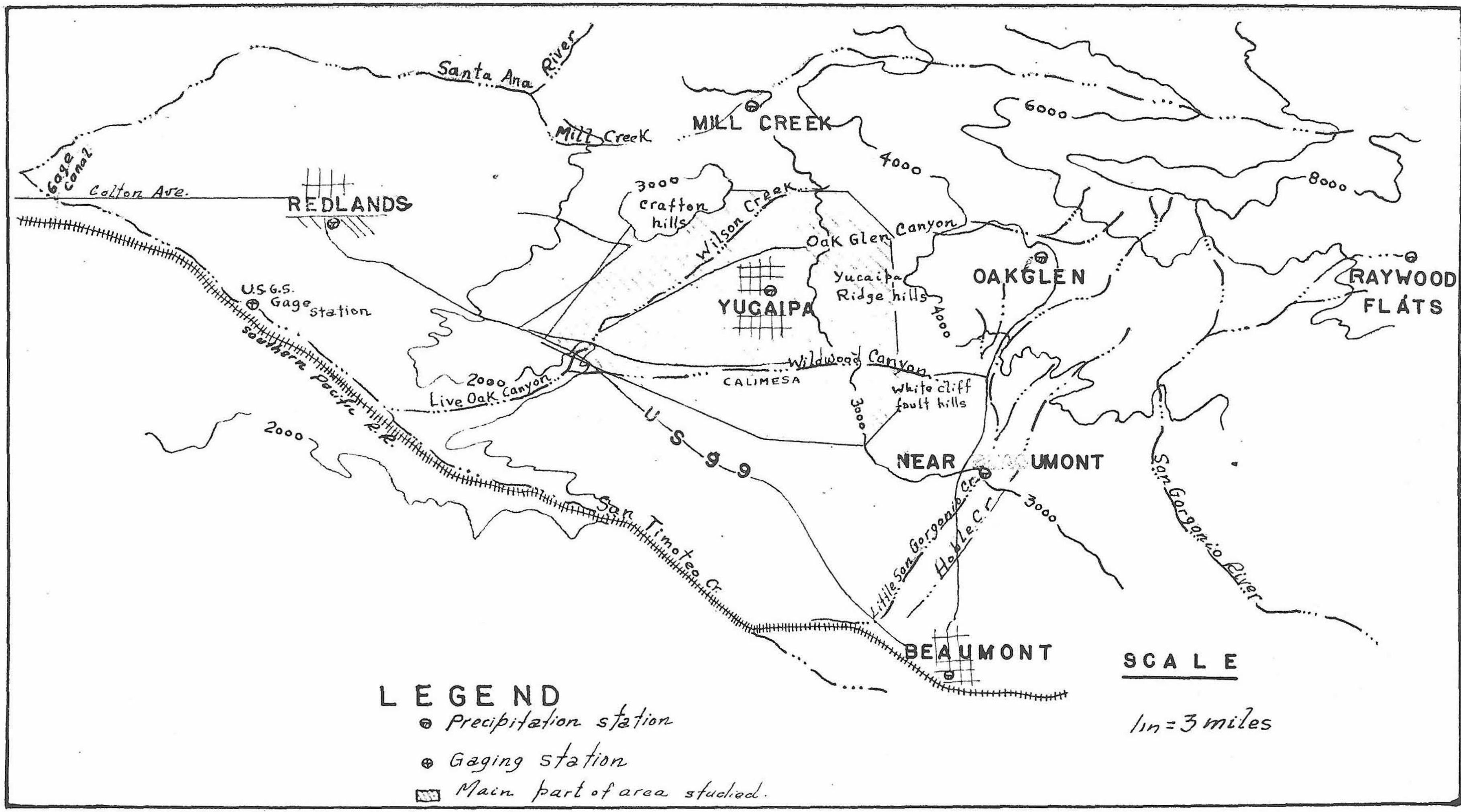
Location and general features.

The Yucaipa Basin area is 6 miles airline distance southeast of Redlands, California. It occupies a large part of the southern half of the Crafton Hills Quadrangle, San Bernardino and Riverside Counties, California.

The valley floor and foothill areas of the basin cover approximately 40 square miles, and have median altitudes of 2400 and 3000 feet above sea level, respectively. About 11 square miles of hilly country with altitudes over 3000 feet above sea level border the basin to the east, north and northeast.

The Crafton Hills occupy the northern part of the area; the maximum altitude there is 3517 feet above sea level. They are separated from the San Bernardino Mountains to the northeast by Mill Creek. A well paved road follows this canyon, and connects to the west with U.S. Highway 99. To the northeast, areas with an altitude of more than 6000 feet above sea level are located on the San Bernardino Mountains, the frontal slopes of which face towards the Yucaipa Basin to the southwest.

To the east, the Yucaipa Ridge Hills record a maximum altitude of 4000 feet and are divided to the south by the White Cliff fault hills. Wildwood canyon cuts in between them, and it forms the main drainage line of the basin in a general direction east-west. (See, for example, Figure 2.)



INDEX MAP

FIG. I

The southern part of the Yucaipa area is bordered by low rolling hills; the town of Calimesa is situated along the northern front of these hills.

The area is widely accessible. From the west well paved roads start from U.S. Highway 99 and reach easily the towns of Yucaipa and Calimesa. A paved road runs along Wildwood Canyon, and connects, farther east, with Oak Glen Road, to the north, and with a South trending road, which crosses Little San Gorgonio Creek and reaches the town of Beaumont, Riverside County, California, 7.5 miles southeast of Yucaipa town. (See Index Map, Figure 1.)

A short distance west of the town of Beaumont, Little San Gorgonio Creek gives way to a northwest trending more important drainage system, San Timoteo Creek, which runs for several miles in a general northwestward direction. Live Oak Canyon, which is born in the intersection of the system formed by Wildwood Canyon, on the east, and Oak Glen and Wilson Creeks discharging from the northeast, is a tributary to San Timoteo Creek. The Southern Pacific Railroad and a well paved U.S. Highway run along San Timoteo Creek most of its way. A runoff U.S.G.S. Gaging Station is located 2 miles southwest of Redlands, being accessible through Fern Street from Redlands to San Timoteo Creek.

Earth and gravel roads built by farmers on the valley and foothill areas, and firebreaks opened in the hills by the U.S. Forest Service are common in the Yucaipa Basin area.

Scope and Nature of the Study.

The purpose of this study is to examine in great detail the direct and indirect methods through which an estimation of water losses and replenishment conditions can be made for the Yucaipa Basin area. A Ground Water Inventory implies the gathering, summary and interpretation of factual and indirect data in order to obtain, as accurately as possible, a figure representing the economic yield of water in a certain basin. A combination of field geology methods and hydrological engineering has been used to accomplish the Yucaipa Basin Ground Water Inventory.

Field and Office Work.

Geological mapping of the basin and its surroundings took about two weeks. The mapping was made on 1:24000 scale air-photographs, delivered by the U.S.G.S. Topographic Division from Washington, D.C. By the time this paper was being written the U.S.G.S. Topographic Division of Sacramento, California, provided the writer with excellent 1:24000 scale topographic blueprints of the Crafton Hills Quadrangle, which include most of the area studied.

A total of approximately five weeks was spent in building up the hydrological information collected from different sources, such as well logs, water level in wells and mean annual pumpage, gathered from water companies in Yucaipa, Calimesa, San Bernardino and Redlands, and individual farmers in the area of Yucaipa.

The preparation of illustrations, writing, and revision of the Manuscript took 6 weeks.

Acknowledgments:

Each one of the ground water basins of Southern California presents problems which are not common to other basins, and a complete

understanding of their ground water behavior is achieved largely by a previously gained broad knowledge and experience. Dr. J.P. Buwalda, of California Institute of Technology, directed and advised the writer on the general nature of the problem, and carefully considered the methods chosen for the attack of the Yucaipa Basin Water Inventory. Moreover, consistent and methodic discussions were sustained while the work was progressing. Invaluable assistance was given by him through the reading, revision, and criticism of the paper. The writer wishes to express to Dr. Buwalda his limitless gratitude.

Due thanks are given to Mr. Harold C. Troxell, of the U.S.G.S. Water Resources Branch, L.A. California, and to Mr. Harry F. Blaney of the U.S. Department of Agriculture, California, for their valuable information provided in, and the permission given, to consult unpublished reports connected with the Geology and Hydrology of the Yucaipa Basin.

Several other persons, from Los Angeles, Redlands, San Bernardino, Calimesa and Yucaipa area, too numerous to cite in this paper, facilitated the progress and completion of both field and office work in several ways.

GENERAL GEOLOGY.

Stratigraphy.

The Yucaipa Basin area includes igneous and metamorphic rocks of possible pre-Cambrian and pre-Cretaceous age; continental deposits of Plio-Pleistocene age (the San Timoteo beds); recent stream terraces, and alluvium.

Basement complex.

Crafton Hills, which border the northern part of the basin, cover approximately 4.2 square miles. Several samples collected at random show a rather typical gneissic structure, locally well developed: elliptical lenticles of quartz and feldspar are surrounded by light, fine grained, secondarily recrystallized material of feldspathic and silicic composition. The ferromagnesian minerals are present in variable amount at different parts.

To the northeast of Crafton Hills, Vaughan (1922) described a series of rocks made of fine to coarse grained, well cemented sandstones and conglomerates, locally intercalated with limestone and shale. This group of tertiary rocks was called Potato sandstones. The hills in which these rocks occur are separated from Crafton Hills by a span of alluvium which is dissected by Mill Creek farther north. The area covered by these hills is several square miles.

To the east and northeastern parts of the basin, the Yucaipa Ridge Hills consist of a complex assemblage of rocks, the lithology of which is very heterogeneous: it includes coarse igneous rocks, metasedimentary, as well, complexly interrelated. In some parts, the metasedimentary character is shown by a distinct banding and gneissic structure, with easy parting along individual planes; a color alternation is present and the intercalation of meta-volcanics suggests original layered structure; a dip of 36° S was recorded to the north of Wildwood Canyon. Pegmatite dykes cross the general body in several places.

In the White Cliff fault hills meta-granites are largely abundant; intense kaolinization of feldspars produces white weathering surfaces. Layers of shiny, powdery mylonite are common in fracture zones. Minerals such as chlorite, epidote and hydromicas occur rather abundantly throughout the heterogeneous and complex body.

East of Barton ranch (see Figure 2) the White Cliff fault hills consist largely of white quartz-diorite, gray hornblende-biotite diorite, banded metamorphics and secondary veinlets of quartz. The approximate area of Yucaipa Ridge and White Cliff fault hills which contribute runoff water to the basin is 4 square miles.

An isolated, smaller body of basement complex rocks sticks out from sedimentary formations in the westernmost part of the Yucaipa area. U.S. Highway 99 goes through it for about a half mile. It contains igneous rocks ranging in composition from quartz-diorite to granodiorite. Numerous dykes, bearing very coarse constituents of quartz and feldspar, cross out the plutonic body here and there. In one place porphyritic quartz-dacite-latite dykes showing flow structure are observed; other minor dykes up to one inch in thickness, weathering dark green are locally present. Samples described from this body disclose a gneissic structure; micaceous folia embody grains of feldspar and quartz; mineral lenticles are very conspicuous, and segregation of minerals has occurred to a large degree.

Age.

A pre-Cambrian age is postulated for the basement complex rocks. It is reasonable, however, to compare the dyke and other minor intrusions with rocks of similar history in Southern California, where a Mesozoic age is assigned to batholith intrusions and Sierran Plutons.

Sedimentary rocks.

San Timoteo beds.

Frick (1921) has named continental deposits of probably Plio-Pleistocene age, outcropping south and west of Yucaipa area, the San Timoteo beds. Where the exposures are good, to the north of Southern Pacific Railroad, the San Timoteo beds consist largely of rudely stratified, poorly sorted, rarely well bedded, sub-angular gravels, coarse sand and silty clay. The predominant type of rock among the major constituents is a quartz-diorite light brown to light gray. A maximum thickness of 4600 feet has been assigned to those beds by Shuler (1953). To the east they are separated from basement complex rocks by the White Cliff fault which is pre-Recent-Post-Pliocene in age, because the evidence seems to indicate that it has not disturbed recent sediments.

San Timoteo beds form an indiscriminate contact with younger sediments that have been partially derived from them and that apparently have been laid down under similar conditions. A sharp contact is therefore difficult or impossible to find.

The general attitude of San Timoteo beds is to dip towards the north-northeast; their areal extent and increase in thickness is to the south; and, finally, an increase in the content of igneous constituents also to the south suggest that the source area lay to the south and southwest of Yucaipa area.

The general lithology and stratigraphy of the sediments that make up the San Timoteo beds are indicative of deposition under conditions of rapid transportation; a continuous supply of materials suggests continuous uplift on a land mass to the south. A semi-arid climate is postulated. The fossil content as cited by Fricks indicates a terrestrial environment.

Recent sediments.

Three groups of sediments younger than San Timoteo beds may be distinguished in the Yucaipa Basin area:

1) A mantle of red-brown detrital materials associated with San Timoteo beds, but difficult to distinguish from them on account of a transitional lithological gradation and because they overlie San Timoteo beds almost parallel to them. Those sediments form conspicuous colored patches on the edges of the basin and on the high parts of the low hilly country that makes up the foothill areas of the Yucaipa Basin. Apparently, they were washed off from higher parts to the south and southeast after the formation of San Timoteo beds; it seems probable that the red materials present to the southeast of Redlands are correlated in lithology and age with them. The orange to red maroon color observed is due to the presence of a large amount of minerals such as limonite

andhematite. It is very likely that the soluble minerals have been leached out by weathering agencies; an enrichment of residual clays with a high proportion of insoluble oxides such as Fe_2O_3, Al_2O_3 and SiO_2 has taken place to a considerable degree. To the west and south of Calimesa highly colored patches are very conspicuous; field evidence indicates that at least the 10 uppermost feet of San Timoteo beds have undergone the same type of surfaces weathering to the south of Calimesa.

2) Coalescing fanglomerates formed at the foot of Crafton and Yucaipa Ridge hills occupy a small area. They grade rapidly basinward into finer, better sorted sediments.

3) Stream terraces and alluvium.

The bottom valley floor of Yucaipa basin is covered with recent alluvium and stream terraces, made out of a heterogeneous mixture of igneous and metamorphic constituents, ranging in size from finer sand grades up to cobbles and boulders more than 2-3 feet across. In several places, the stream terraces adjacent to the alluvial deposits exceed 30-40 feet in height, and it appears improbable that they would be washed away by the next flood. This consideration leads to the designation of the semi-consolidated, coarse clastic sediments as terraces, rather than loose very porous alluvium.

The thickness of the alluvial materials is unknown. Water wells have been drilled to several hundreds of feet in depth at different places in the center of the basin, without having reached bedrock.

Several well logs examined by the writer disclosed the same lithological description for members of clay, sand and gravel. As projected from the south, the San Timoteo beds would have been reached at a depth of 300-400 feet, but the absence of a marked lithological break would have made them practically indistinguishable.

Structural Geology.

The most important structural feature is the White Cliff fault, recently referred to by Allen(*) as the Banning fault. This fault is dip slip in nature and has a general strike of N 63° W; it shows the abrupt termination of San Timoteo beds against the basement complex in the southernmost part of the area studied (see Figure 2). As previously stated, it does not offset recent sediments, and the northeast displacement of San Timoteo beds took place after the Pliocene, taking into account that the age of those beds is probably Pliocene-Pleistocene. The fault apparently goes beneath the alluvium in Yucaipa basin and dies out near Redlands, because southwest of the basin a thick section of San Timoteo beds dipsstrongly towards the northeast, and do not show any depositional contact relationship whatsoever with the isolated patch of basement complex that outcrops in that part of the area.

The structural history of the nearby mountain areas to the north and to the east of Yucaipa basin demonstrates that intense tectonic activity has occurred during several geological periods. An inheritance of such episodes of structural deformation is the degree to which rocks of the basement complex have been jointed and moderately fractured. In the southwesternmost patch of basement complex two main

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* Personal talk.

sets of joints are recognized: they follow NE-SW and NW-SE directions respectively, and may be observed at depths of several tens of feet where artificial cuts for U.S. Highway 99 were made. Elsewhere in the other bodies of basement complex a random distribution of fractures occurs and, very probably, they prevail down to some depth. Probably, the forcible injection of dykes and other minor intrusives reopened zones previously weakened.

<u>Hydrological properties of the rocks in the Yucaipa basin.</u>

The open spaces of the basement rocks afford zones of high local porosity and permeability; therefore, they constitute a good source of local infiltration. Taken as a whole, however, porosity of rocks of the basement complex is greatly reduced because of the predominance of tight, highly non-voided areas.

Stream gravels of recent alluvium are the best porous media for percolation of water in the Yucaipa basin.

In between these two extremes, the San Timoteo beds, coalescing fanglomerates and the red-brown detrital materials have low to moderate porosity and permeability.

An estimation of areas and values of porosity for different kinds of rocks is given in the following table:

TABLE I

DISTRIBUTION OF POROSITY IN YUCAIPA BASIN

	Area	Porosity
Basement Complex rocks	6,200 acres	Verylow (< 5 per cent)
San Timoteo Beds	26,000 acres	Low
Fanglomerates		Medium (15-20 per cent)
Old Alluvium and Terraces		Low - Medium (< 15 per cent)
Stream gravels		Medium - High (> 25 per cent)

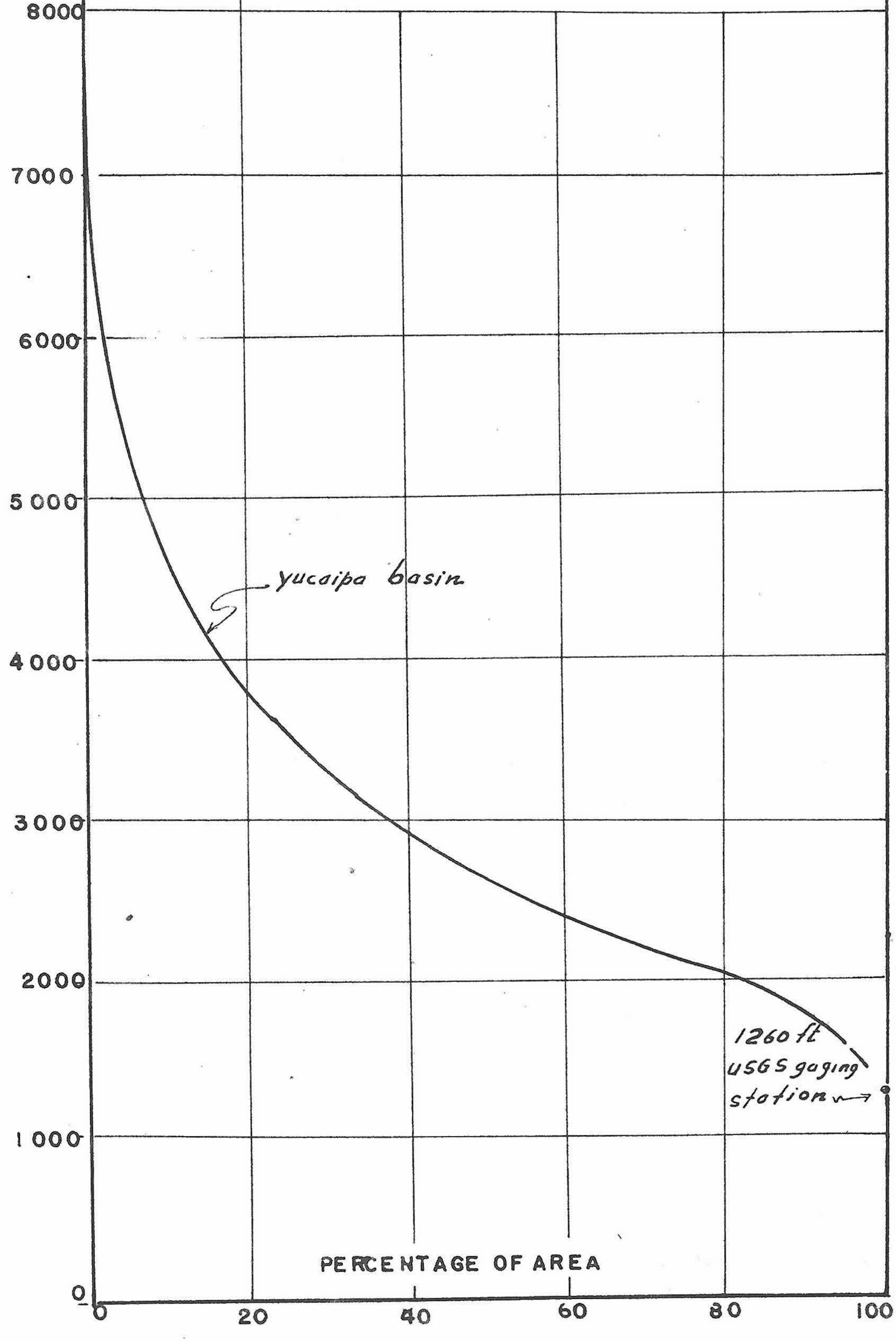
Geomorphology.

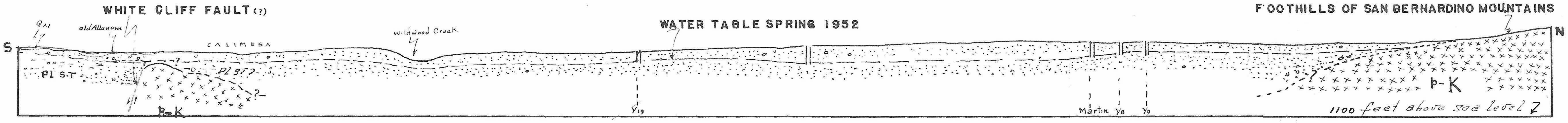
Physiography and climate.

Figure 3 illustrates the altitudes of the Yucaipa Basin area as a function of the area. It may be noted that three main physiographic elements are present in the basin: 19 per cent of the total area corresponds to mountain slopes, with altitudes of more than 4000 feet. About 24 per cent includes foothill areas with altitudes ranging from 3000 to 4000 feet above sea level; and 57 per cent corresponds to valley floor with altitudes of less than 3000 feet. Geological cross sections along north-south and east-west directions (Figures 4,5) disclose the main topographic profiles of the area; they show that the Yucaipa basin forms a unique ground water reservoir: mountain areas that capture most of the precipitation are located to the north, northeast, east and south parts of the basin affording the most important contribution of seepage to the ground water, as will be demonstrated farther on. From the center of the basin, and towards the west, the topography becomes more level. The most important outlet of both surface and ground water heads towards San Timoteo Creek and is located at the westernmost end of the basin. A general cross section there shows a narrower area through which flow occurs (Figure 6).

The climate is typically semiarid. The landscape and epigenetic profile have evolved by the mass wasting of the mountain slopes which recede parallel to themselves. Had it not been for the renewal of tectonic activity from time to time, the geomorphic cycle would be nearly completed by the filling of the intermontane basins

FIG 3 ALTITUDE AND AREA OF YUCAIPA BASIN ABOVE USGS GAGING STATION





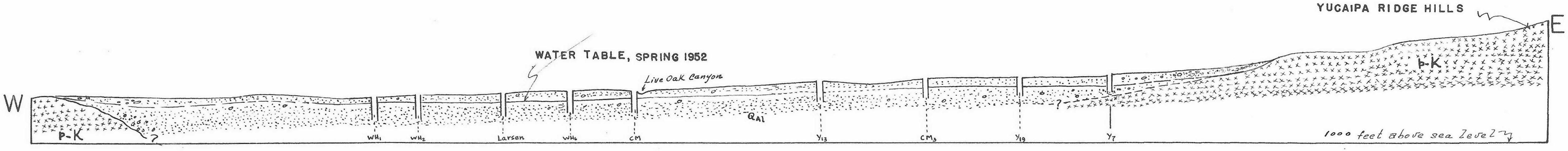
SECTION N-S YUCAIPA BASIN, CALIF

SCALE 1:24000

FIG. 4.

Explanation:

QAl -	Quaternary alluvial sediments
Pl. S.T.	Plio-Pleistocene San Timoteo beds
P-K -	Pre-Cretaceous basement complex
(fault symbol)	fault
Y8	Yucaipa Co. Water Well



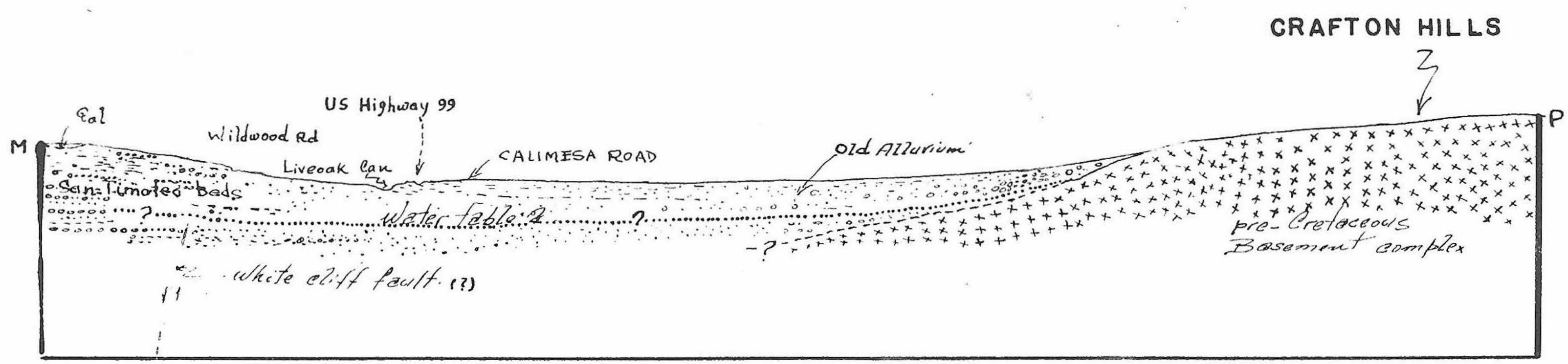
SECTION E-W, YUCAIPA BASIN, CAL.

SCALE: 1:24000

FIG. 5

Explanation

QAL	Quaternary alluvial sediments & soils.
p-K.	Pre-Cretaceous basement complex.
Y13	Yucaipa Co. Water well
CM	Crafton Mesa Co. Water well
WH	Western Heights Co. Water well



GENERAL CROSS SECTION M-P

SCALE 1:24 000

FIG. 6.

with alluvium, as would happen in Yucaipa and many others in the semi-arid Southern California.

During summer average temperatures range from 70°F to 90°F. In winter values as low as 30°F have been recorded.

Vegetation.

Part of the foothill areas and most of the valley floor are used for crops raised by water artificially applied. Orchards, citrus fruits, grapes, hay and alfalfa are some of the products obtained.

The native vegetation is scanty. Spare grasses and medium size bush (chaparral) are rather abundant in the low parts of foothill areas. With increasing altitude the native vegetation turns out to be more vigorous: Oak, Sycamore, Cottonwood, Greasewood, Willow, Sauboak, Sagebush, Elderberry, and black-white sage, are some of the representatives very common in higher areas.

Rainfall is concentrated largely during winter months, from October to February. Statistical records show a great deal of variation in the mean annual precipitation figures. For the last 26 years (1926-1952 inclusive) the average value of mean annual precipitation is,

Yucaipa area	(2650 feet altitude)	18.6 inches
Redlands	(1352 feet altitude)	16.0 inches
Beaumont	(2558 feet altitude)	20.7 inches
Raywood Flats	(7200 feet altitude)	40.0 inches
Oak Glen	(4700 feet altitude)	27.6 inches

All the streams are of the intermittent type and remain dry during a large part of the year. Surface runoff lasts only a short time after each storm rainfall. Several years ago, perennial streams were sustained by artesian water produced on the western edge of the basin.

At the present, several springs flow after the wet season is over; they occur in fracture zones (see map, Figure 2) and at points where the water table intersects the ground surface. Their discharge is small, never reaching more than a few gallons per minute.

Evaporation from soils and transpiration from plants reach a high order of magnitude in a semi-desert climate. These items, treated in detail farther on, are difficult to evaluate precisely, because the methods involved in their estimation are inaccurate.

During the rainy season the relative humidity may reach values as high as 70-80 per cent, but in summer the aridity is such that figures as low as 5 per cent for moisture content in the air have been recorded.

At times of low temperatures, usually in winter time, a considerable amount of evaporation may be facilitated by the wind. The following table is a summary of values or figures estimated for some of the important factors that characterize a climate, with emphasis in the Yucaipa basin:

TABLE II

	Temperature	Wind	Humidity	Precipitation
Mean(1)	* 59°F	30100** miles	-	18.6
Diurnal	-	-	-	see Table V
Extremes(2)	58°F 1944 61°F 1940	25860 mi. (1933) (1945) 33373 mi.	5-75%	8.22" - 35.97" (1950-51)(1936-37)
Frequencies(3)	-	-	-	see graphs in Figure 9

(1) Mean seasonal average of annual values.

(2) Maxima and minima values recorded.

* For Beaumont, a nearby station.

** Mean annual value for the period 1928-1952.

<u>Soils.</u>

They are generally considered to be the mantle cover of bed rock and well consolidated sediments. Their study, in connection with a water Inventory is of utmost importance, inasmuch as percolation and movement of water are initiated in the general body of soil.

In the Yucaipa basin soil profiles have not been developed. The continuous accretion of materials to the basin from higher parts and the continuous wash-off of sediments from foothills and mountain areas during times of storm precipitation have precluded the delicate adjustment between soils and their environment(*) so necessary to develop profile zones.

(*) By soil environment is meant the climate, surface drainage, vegetal covering and parent material.

Actually, groups of recent detrital materials covering the Yucaipa basin may be distinguished in terms of texture, ranging in size from clay loams to stony sandy soils. Blaney (1952) has adopted a classification of soils in the upper Santa Ana Valley area. For the Yucaipa area his studies disclose five main types:

TABLE III
TYPES OF SOILS IN YUCAIPA BASIN.

Texture	Soil Group	
1L light	1	Loam. Uniformly permeable top soil, sub-soil, and substrata, withlittle or no profile development.
2L light	2	Loam. Moderately reduced permeability in sub-soil
3L light	3	Loam. Greatly reduced permeability in sub-soil, with strong clay pan development.
5g-s Unclassified	5	Uniformly permeable top soil and sub-soil, formed on impervious bedrock(g) or pervious bedrock(s)**

(**) Suffix s indicates sedimentary rocks
Suffix g indicates granitic rocks.

Decomposed granite is a term commonly used for weathered material of basement complex rocks encountered at different depths in different places.

If a comparison is made between the foregoing considerations and Table I it will be observed that soils of Group 3 correspond to what has been considered in this paper as the upper parts of old alluvium and terraces.

Drainage.

The normal stream pattern of mountain areas is radial (see Figure 2). The high resistance afforded to stream erosion by igneous complex rocks and the predominantly high altitude of such bodies of rock are responsible for the radial pattern.

The foothill areas in the Yucaipa basin disclose a pattern of streams trending basinward, but in several places they die out before reaching the center of the basin. The increase in precipitation and run-off with altitude in mountain areas and, to a certain extent, the recent southwest tilting of the fault blocks involving basement complex rocks have caused a more intense carving by streams debouching from the eastern Yucaipa Ridge hills.

An irregular stream pattern prevails in the flatter areas and on the valley floor. In general, the streams trend east-west and have not reached a stage of maturity; vertical cutting and lateral corrasion attain considerable importance during storms.

The approximate area covered by stream courses is less than 5 per cent of the total.

The channel characteristics on the whole basin have been formed as the result of topography, lithology and rainfall distribution. A quantitative knowledge of run-off is very difficult to get during rainfall season, mainly because the porosity and permeability varies from place to place within the area; much of the water that runs over the surface rapidly sinks down in the uppermost few feet of soil, on account of its absorptive and retentive properties. Actually, a run-off gaging station placed at the mouth of any stream would only give an idea of surface run-off for a rather small area, immediately surrounding, and in the vicinity of, the gaging station.

Hydrology.

General Statement.

The distribution of precipitation in the form of run-off, deep penetration and evaporation, is a function of several factors such as climate and topography; absorptive, retentive and textural properties of surface soils; evaporation rate, evaporation opportunity, vegetation, temperatures, etc. One of the features of this work is to attempt to know what the contribution to underground water of Yucaipa basin is from rainfall on the valley floor, the foothill and the mountain areas.

Precipitation.

An attempt to subdivide a certain area into climatological zones has been made in southern California by Troxell (1948).

Using Koppen (Haurwitz and Austin, Climatology, 1944) and Thornwaitte (The Climates of North America according to a New Classification, Geog. Rev. Vol. 21, 1931) approaches, the writer tried to establish a subdivision of climates on a belt extending from San Bernardino Mountains to the Pacific Ocean, including the Yucaipa area (see Figure 7). Koppens sets a boundary between dry and rainy climates according to the following table:

Annual mean temperature, deg F.	50	60	70	80	90	100
Annual Precipitation, in.	13.5	17.9	22.3	26.7	31.1	35.5

For the Yucaipa area the average annual precipitation for 27 years (1926-1953 inclusive) is 18.7 inches. Annual temperature data

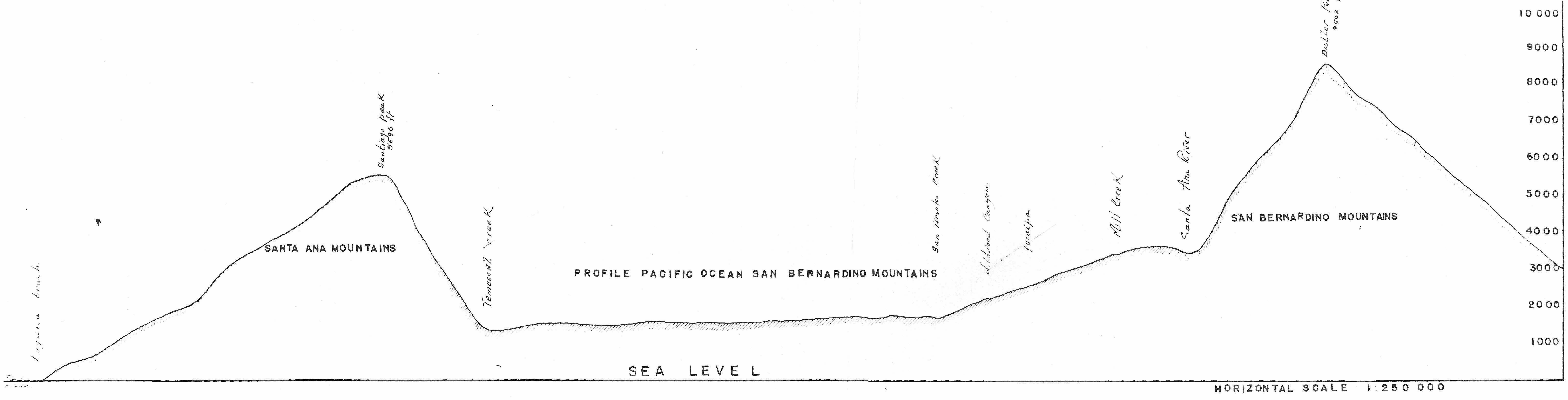

Santiago peak 5696 ft
Butler Peak 8502 ft
SANTA ANA MOUNTAINS
PROFILE PACIFIC OCEAN SAN BERNARDINO MOUNTAINS
SAN BERNARDINO MOUNTAINS
Temescal Creek
Mill Creek
Santa Ana River
Yucaipa
SEA LEVEL
HORIZONTAL SCALE 1:250 000
10 000
9000
8000
7000
6000
5000
4000
3000
2000
1000

FIGURE 7

could be obtained only for a nearby station (Beaumont) and the average for six years (1939-1945 inclusive) is 50F (see Evaporation from Water Surfaces in California, Basic data Div. of Water Resources, Bull 54-A). Therefore a "rainy" type of climate would be indicated according to the above criteria.

On the other hand, Thornwaite (op.cit.) uses the precipitation effectiveness index (P-E index) as a basis of climatic distribution. With "factual data" the P-E index is "ten times the sum of the twelve monthly P-E ratios",

$$I = \text{P-E index}$$

$$I = \sum_{n\,1}^{12} 10 \left[\frac{P}{E}\right]_n, \text{ or}$$

$$I = \sum_{n\,1}^{12} 115 \left[\frac{P}{T-10}\right]_n^{\frac{10}{9}} .$$

The computation of the P-E index is facilitated by the use of a nomogram (Pag. 641, op.cit.). Using the combined set of values of monthly precipitation for Yucaipa, and monthly temperature for Beaumont (the nearest station with temperature data) the following table is obtained:

TABLE IV

PRECIPITATION EFFECTIVENESS RATIO FOR THE YEAR 1945-46.

1945-1946			
Month	Precipitation (inches)	Temperature (F)	P-E Ratio
January	0.21	48	0.20
February	1.02	47	0.60
March	3.54	46	1.60
April	0.99	54	0.50
May	0.17	59	0.80
June	0.00	66	0.00
July	0.00	77	0.00
August	2.82	76	1.40
Septmeber	0.04	72	0.01
October	0.78	63	0.20
November	0.31	52	0.10
December	4.80	47	2.00
			7.61

$$I = 7.61 \times 10 = 76.1$$

This climate would be "humid" with a vegetation of "forest type" (P. 641, op. cit).

The general type of predominant vegetation and the notably high ratio

$$\frac{\text{mean annual evaporation from a free surface of a liquid}}{\text{mean annual precipitation}}$$

$$= \frac{91.4}{18.7} \simeq 5$$

for areas with altitudes in the vicinity of 3000 feet above sea level (Yucaipa 2650, Beaumont 2589), demonstrate that the climate is not humid nor rainy. It has been considered typically semi-arid and the writer advocates this general consideration.

The longitudinal profile San Bernardino Mountains-Pacific Ocean (Figure 7) shows that the winds from the Pacific Ocean are intercepted by the Santa Ana Mountains before they reach the frontal slopes of the San Bernardino Mountains, provided the moisture-bearing winds are southwesterdly. These facts result in other stations with same altitude than Yucaipa but closer to the ocean registering a larger annual precipitation.

Thermodynamic studies of a static atmosphere have led meteorologists to establish a fundamental equation:

$$\frac{dP}{dz} = -\rho g \quad ,$$

where

P = pressure

z = height

g = gravity

ρ = density.

Under ideal conditions (dry atmosphere) the density is expressed as:

$$\rho = \frac{P}{RT} \, ,$$

where

P = pressure

T = temperature

R = gas thermodynamic constant.

Combining both equations it is obtained:

$$P = P_o \exp\left(-\frac{g}{R}\int_o^z \frac{dz}{T}\right)$$

where P_o = pressure at sea level.

Because all the quantities involved in the above equation are positive it may be concluded:

The pressure decreases exponentially with height.
The density decreases exponentially with height.

Moreover, it is established (Sutton, 1953) that, for adiabatic processes there is a "dry adiabatic lapse rate"

$$\frac{dT}{dz} = -1^oC \qquad \text{per } 100 \text{ m.}$$

The above considerations are not fundamentally changed if the water vapor phase is introduced.

Thus condensation opportunity increases with height, i.e., the precipitation increases with altitude for a certain area. This last statement is not absolute: from a certain altitude up the precipitation becomes less than at lower levels; this is due to a depletion of moisture from upper layers once the dew point(*) has been reached in lower levels. Moreover, an inversion layer at 3000 feet impedes the uprising of moisture bearing strata at higher altitudes.

(*) Dew point is the temperature at which condensation in form of droplets begins to occur in the atmosphere.

Daily precipitation information for the Yucaipa area is available only since 1949. It shows the following maxima and the corresponding dates:

TABLE V

MAXIMUM DAILY PRECIPITATION, YUCAIPA BASIN.

Year	Month	Day	Precipitation (inches)
1949	Nov.	10	1.69
	Dec.	18	1.23
1950	Feb.	6	1.27
	Mar.	24	1.09
1951	Jan.	29	1.14
	Dec.	29	2.21
1952	Jan.	12	1.84
	Mar.	7	1.63
	Mar.	15	2.19
	Oct.	19	1.23
	Nov.	15	1.57
	Dec.	19	1.31
1953	Apr.	27	1.37

Most of the daily precipitation recorded ranges from hundreds to tenths of an inch. These data will be used farther on when run-off and evaporation are treated.

Monthly, annual, and mean annual precipitation are indicated on Table VI. On page 20 a comparison may be made between Yucaipa and other stations in the same general area, but with different altitudes.

Residual Mass curve.

- Figure 8 shows a residual mass curve of per cent normal of rainfall for Yucaipa area, Cal. Its construction may be briefly indicated as follows.. Table VII shows the per cent of normal rainfall; the last column to the right represents ratios of annual precipitation to mean annual precipitation (18.7 inches for the period 1920-21, 1952-53, inclusive) multiplied by 100. In Figure 8, the zero line represents the locus for points with 100 per cent normal precipitation. Amounts less than or in excess of 100 per cent normal precipitation, are subtracted or added, as the case may be, for each one of the years in order to obtain the residual mass curve. It may be observed that in a period of 33 years no cyclic variation occurs. Actually, two main zones characterize the graph: a highly irregular one, with a maximum amplitude of 83.5 above normal; and a very regular one with a maximum amplitude of 216 above 100 normal. Both zones have about the same period of 13-14 years. Consecutive 7 years with annual precipitation below normal cause the steep downward swing of the residual mass curve; values below normal are attained for the year 1950-51, 1952-53, and, in all probabilities, 1953-54. A cyclic variation of rainfall precipitation would be a highly desirable factor. A knowledge of dry and wet phases displaying a periodic behavior of maxima and minima amplitudes would provide a good means for utilizing the water to a better advantage.

For a large number of Southern California gaging stations, Troxell (1938) has worked out and averaged frequency distributions of

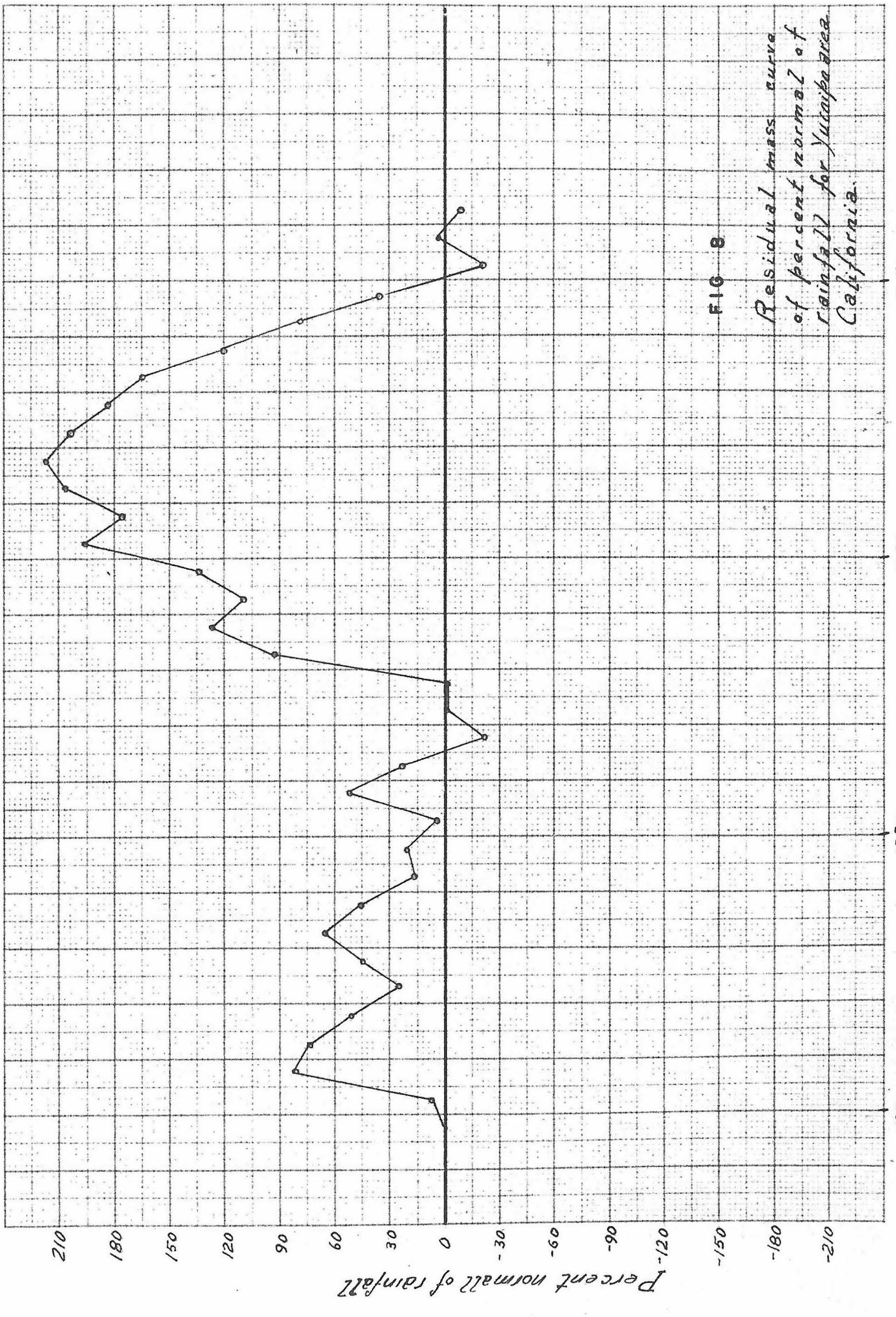


FIG 8

Residual mass curve of percent normal of rainfall for Yucaipa area California.

TABLE VI

YUCAIPA VALLEY RAINFALL RECORD (inches)

Season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
1920-21	0	0	.25	2.20	.51	1.99	4.34	1.31	4.99	.36	3.96	0	19.91
1921-22	0	.42	1.50	1.57	.30	14.05	5.59	3.86	2.45	1.63	1.45	0	32.82
1922-23	0	0	0	.90	2.68	4.05	2.82	1.32	1.35	3.08	.18	0	16.38
1923-24	0	.18	.36	.36	1.47	3.58	.48	.06	4.64	3.08	0	0	14.21
1924-25	0	0	.03	.51	1.68	2.93	.54	.74	2.61	3.19	.60	.15	13.98
1925-26	.03	.15	0	3.13	.75	1.56	.30	5.05	1.05	9.53	.72	0	22.28
1926-27	0	0	0	.02	1.96	3.26	.95	10.00	3.72	1.82	.74	.12	22.59
1927-28	.12	0	0	1.63	2.11	2.85	.73	3.09	2.03	.15	2.08	.16	14.95
1928-29	0	0	0	.89	1.24	2.25	2.25	2.07	1.84	2.78	0	0	13.28
1929-30	0	.11	1.24	0	0	0	5.45	1.00	5.38	.82	5.53	0	19.53
1930-31	0	.10	0	1.65	2.97	0	2.53	3.89	1.02	2.02	1.07	.22	15.97
1931-32	0	.72	.24	4.04	3.57	6.24	1.12	8.96	.51	1.14	0	.71	27.23
1932-33	0	0	0	1.09	0	3.77	5.15	.61	.19	2.09	.77	.14	13.81
1933-34	.14	.02	0	.15	.26	3.53	3.19	2.22	.10	.13	0	1.05	10.79
1934-35	0	.44	.45	2.71	.63	3.39	4.09	4.13	3.46	1.53	1.35	0	22.18
1935-36	0	2.59	.08	.13	.88	.69	.22	10.15	2.07	1.74	.05	0	18.60
1936-37	.99	.03	.31	3.72	.37	8.88	3.71	8.85	7.40	.67	1.00	.04	35.97
1937-38	.06	0	0	0	.06	2.47	2.71	5.92	11.17	1.97	.57	.01	24.94
1938-39	.06	.02	0	.40	0	5.28	3.18	2.34	2.75	1.38	.14	0	15.55

TABLE VI (cont.)

YUCAIPA VALLEY RAINFALL RECORD (inches)

Season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
1939-40	.08	.12	4.03	.62	2.04	.56	4.28	5.01	1.57	4.68	.08	0	23.07
1940-41	0	0	.02	1.56	1.05	5.22	2.09	6.04	8.53	4.58	.96	.18	30.11
1941-42	0	.83	0	3.39	.68	4.14	.68	1.23	1.52	2.46	0	0	14.93
1942-43	0	1.24	.04	.61	.26	1.88	8.46	5.05	4.02	2.72	0	.22	24.50
1943-44	0	0	.50	1.30	0	5.55	.96	6.77	2.50	2.29	.05	.12	24.04
1944-45	0	0	0	0	6.05	1.07	.19	3.22	5.57	.42	0	0	16.52
1945-46	0	2.82	.04	.78	.31	4.80	.21	1.02	3.54	.99	.17	0	14.68
1946-47	.48	0	.61	1.11	6.18	2.52	.65	1.91	1.14	.47	.23	0	15.30
1947-48	0	.25	.36	.02	.02	3.05	.16	2.68	2.13	1.33	0	.38	10.38
1948-49	-	-	-	-	-	-	-	-	-	-	-	-	11.00
1949-50	-	-	-	-	-	-	-	-	-	-	-	-	10.67
1950-51	-	-	-	-	-	-	-	-	-	-	-	-	8.22
1951-52	-	-	-	-	-	-	-	-	-	-	-	-	22.75
1952-53	-	-	-	-	-	-	-	-	-	-	-	-	16.16

AVERAGE FOR 33 YEARS 18.70

TABLE VII

COMPOSITE ANNUAL PRECIPITATION AND PER CENT NORMAL FOR YUCAIPA AREA, CALIFORNIA.

Year	Annual Precipitation	Per cent of Normal
1920-21	19.91	107
1921-22	32.82	176.5
1922-23	16.38	88.0
1923-24	14.21	76.4
1924-25	13.98	75.2
1925-26	22.28	120.0
1926-27	22.59	121.2
1927-28	14.95	80.4
1928-29	13.28	71.4
1929-30	19.53	105.0
1930-31	15.47	83.1
1931-32	27.23	146.5
1932-33	13.81	74.2
1933-34	10.79	58.0
1934-35	22.18	120.0
1935-36	18.60	100.0
1936-37	35.97	193.0
1937-38	29.94	134.0
1938-39	15.55	83.6
1939-40	23.07	124.0
1940-41	30.11	162.0
1941-42	14.93	80.3
1942-43	24.50	131.6
1943-44	20.04	109.6
1944-45	16.52	88.7
1945-46	14.68	78.9
1946-47	15.30	82.3
1947-48	10.38	55.8
1948-49	11.00	59.2
1949-50	10.67	57.2
1950-51	8.22	44.2
1951-52	22.75	122.0
1952-53	16.16	87.0

seasonal precipitation for many years. His standard curve is drawn on Figure 9. Taking advantage of data furnished by Table VII the ratios of seasonal precipitation to mean seasonal precipitation and their frequency distribution are plotted on log.-probability paper (Figure 9). It is observed that extreme values (high and low for the ratio) are considerably offset from the standard curve. A concentration of points occurs in the standard a little above and a little below the median value (1.0 ratio). According with such a curve and the series of values plot for Yucaipa basin, it may be learned the following recurrence interval in years:

TABLE VIII

YUCAIPA BASIN.

Recurrence interval in years	Ratio of seasonal precipitation to mean seasonal precipitation.
30	1.92
25	1.30
10	1.20
5	1.10
Median	1.02
5	0.89
10	0.80
25	0.72
30	0.442

For example, once every 30 years either a 1.92 or a 0.442 ratio of seasonal precipitation to normal precipitation may occur.

Relationship between altitude and precipitation.

In previous pages it was mentioned that precipitation is a function of altitude. In the following paragraphs a study of such a relationship is made for the Yucaipa basin area.

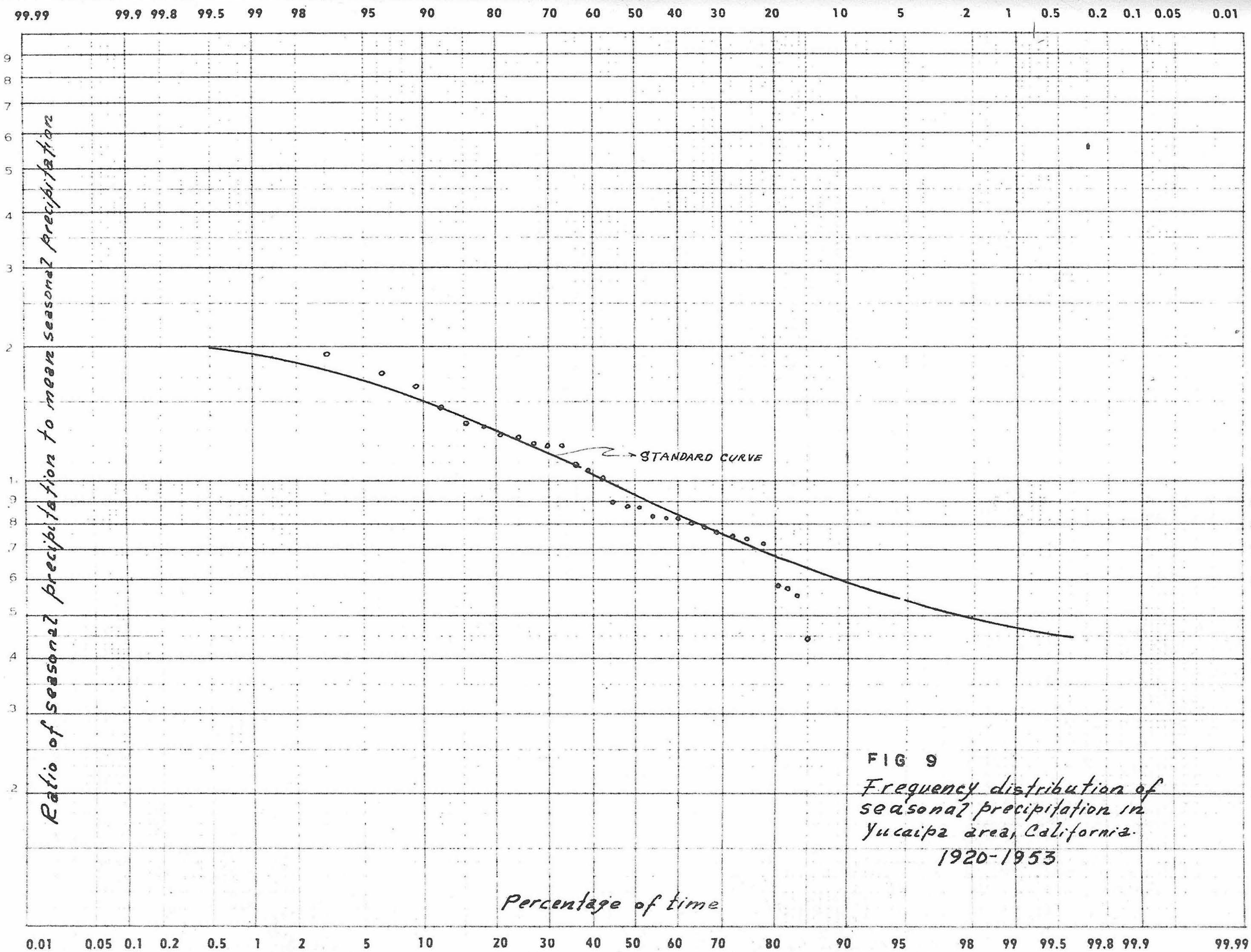


FIG 9
Frequency distribution of seasonal precipitation in Yucaipa area, California. 1920-1953

For a good number of stations and for a reasonable number of years, the average storm precipitation for stations of equal altitude in the frontal San Bernardino Mountains is shown in Figure 10 (Troxell). It was found that Yucaipa, Beaumont and Banning are offset from the Basic Frontal Relationship line. A parallel traced through those points intersects the sea level line at 3.0 _. This value is a negative adjustment, and represents the theoretical precipitation that those points would have, should they lie at sea level. Lines which are the locus of equal precipitation (isohyetals) may be contoured on a topographic map by plotting values of mean annual precipitation and making the necessary adjustment to the frontal areas relationship for each one of the points.

In selected stations for areas adjacent to, and in the vicinity of, Yucaipa basin, values for average seasonal precipitation during a period of 15 years versus altitudes in semilogarithmic scale are indicated in Figure 11. The dotted line is an approximation for the conditions existing in the Yucaipa basin; it is offset from the main line, and its construction was arbitrarily made by simply uniting a point (A), that represents the average seasonal precipitation for 33 years, with the extremes of the broken line. (Altitude of station at Yucaipa is 2650 feet above sea level.) Arbitrary as is the procedure, the main purpose is to get the influence of nearby areas into the picture, as far as the relationship precipitation-altitude is concerned. It is believed that the dotted line serves with enough accuracy for the construction of the isohyetals represented on Figure 2. These lines follow the contours.

Figure 10

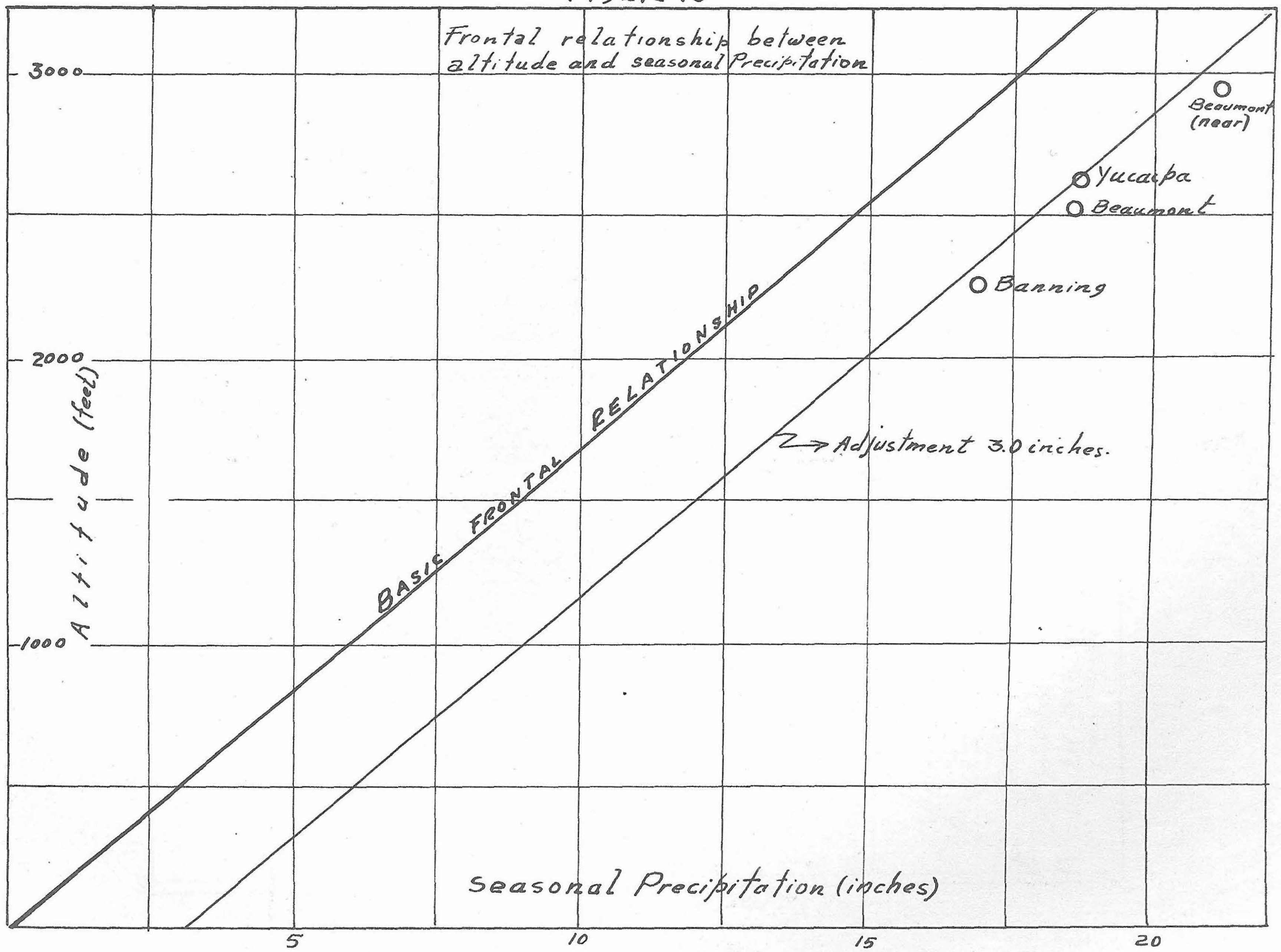
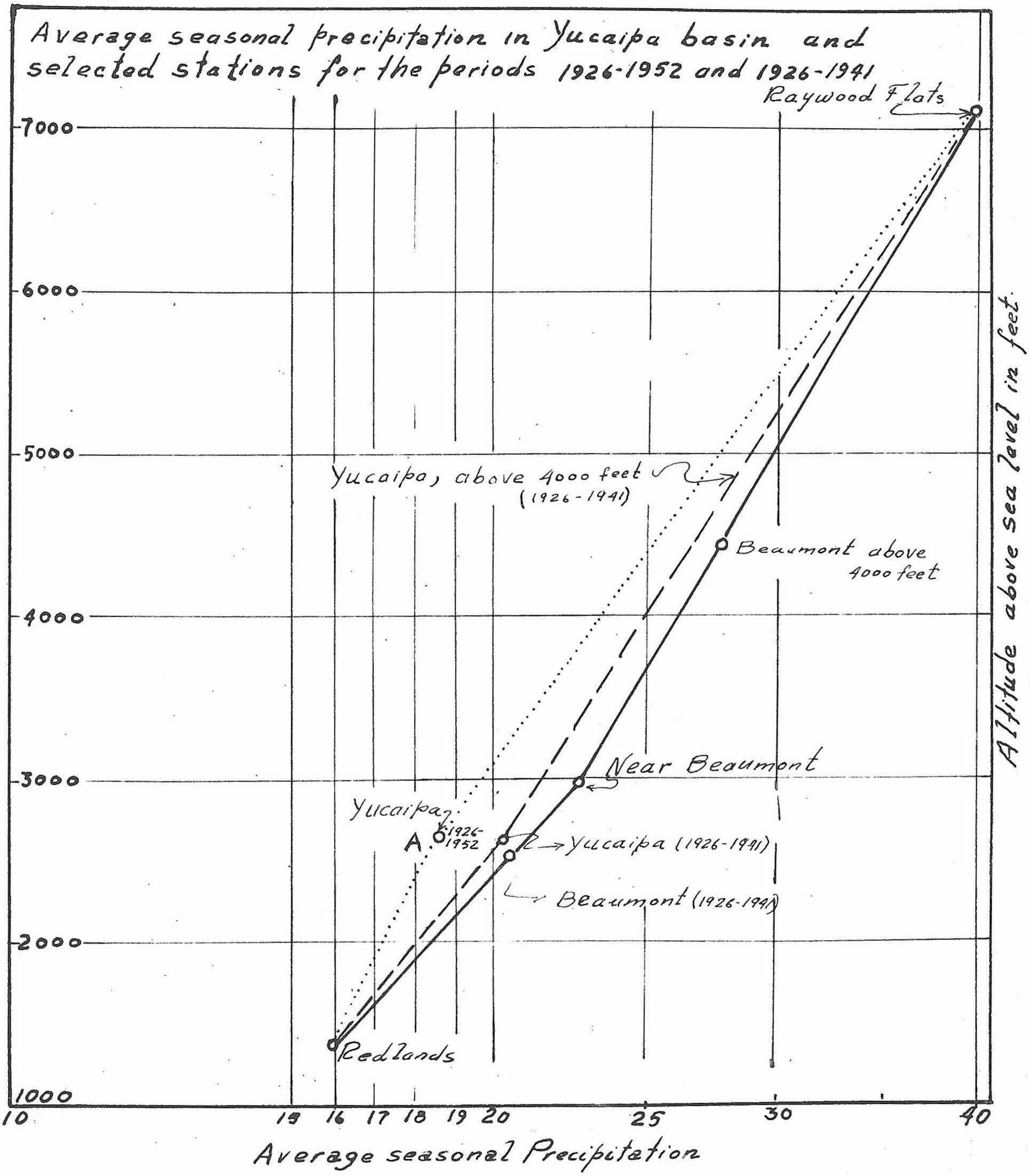

Frontal relationship between altitude and seasonal Precipitation
3000
2000
1000
Altitude (feet)
Beaumont (near)
Yucaipa
Beaumont
Banning
BASIC FRONTAL RELATIONSHIP
Adjustment 3.0 inches.
Seasonal Precipitation (inches)
5
10
15
20

Figure 11



Average seasonal precipitation in Yucaipa basin and selected stations for the periods 1926-1952 and 1926-1941
Raywood Flats
7000
6000
5000
4000
3000
2000
1000
Yucaipa, above 4000 feet (1926-1941)
Beaumont above 4000 feet
Near Beaumont
Yucaipa
A
1926-1952
Yucaipa (1926-1941)
Beaumont (1926-1941)
Redlands
10
15
16
17
18
19
20
25
30
40
Average seasonal Precipitation
Altitude above sea level in feet

The main application of all foregoing considerations will be made in the evaluation of water recoverable and natural water losses.

Run-off.

From the total seasonal precipitation a surprisingly small amount is discharged as run-off in the Yucaipa basin. This fact is due to the absorptive and retentive properties of the soils; to the soil moisture deficiency (*); to the irregular distribution of seasonal precipitation, mainly as a result of being a function of altitude.

There is no perennial stream in the Yucaipa basin. Run-off is of flashy type. Rarely does water falling on Yucaipa Ridge hills cross the whole basin as surface run-off in order to be discharged in Live Oak Canyon. A gaging station placed in any stream would give an idea of run-off for a relatively small area comprising only the immediate vicinity of the station. This is the case of the U.S.G.S. gaging station placed at San Timoteo Canyon. However, it is believed that if a generalized, continuous and heavy storm would occur, then the gaging station would give a figure representing run-off for a drainage system formed by the basins of Yucaipa, Beaumont and San Timoteo Creek.

Situated 2 miles to the southwest of Redlands the gaging station records exclusively the free water surface. The stream channel is constricted there. Tight, non-water bearing San Timoteo beds make up the floor of the stream, and a good base of concrete eliminates the possibility of having underflow of water at that point.

(*) Soil moisture deficiency is defined as the amount of water which is necessary to add to the soil before downward movement by gravity begins to take place.

TABLE IX

RUN-OFF, U.S.G.S. GAGING STATION, SAN TIMOTEO CREEK, CALIFORNIA.

Year	Mean ft-sec day	Seasonal Run-off Acre-Feet
1926-27	10.2	7580.0
1927-28	0.43	312.0
1928-29	.25	181.0
1929-30	.36	262.0
1930-31	.14	97.5
1931-32	1.26	917.0
1932-33	.30	216.0
1933-34	.13	93.4
1934-35	.93	666.0
1935-36	.80	579.0
1936-37	6.36	4600.0
1937-38	7.26	5250.0
1938-39	.33	241.0
1939-40	.93	672.0
1940-41	2.74	1980.0
1941-42	-	15.0
1942-43	-	3270.0
1943-44	-	487.0
1944-45	-	811.0
1945-46	-	633.0
1946-47	-	471.0
1947-48	-	155.0
1948-49	-	20.2
1949-50	-	63.0
1950-51	-	10.0
		29581.6

AVERAGE FOR 25 YEARS: 1180.0 A.F.

for water passing through that Gaging Station.

The average annual run-off for 25 years is indicated in Table IX and has a value of 1180.0 acre-feet. It is estimated that the drainage area of San Timoteo Creek (including Yucaipa and Beaumont basins) is around 123 square miles. From considerations above mentioned, most of the water recorded as run-off at the gaging station comes from a rather reduced area in, and in the immediate vicinity of, the watershed. A hypothetical but conservative run-off figure for such an area would be 50 per cent of the average value for 25 years. This would leave for Yucaipa area a mean seasonal run-off of

$$\frac{50.5}{123.0} \times 590 = 242.0 \text{ acre-feet.}$$

$$= 0.091 \text{ inches.}$$

This value is $\frac{0.091}{18.60} = 0.49$ per cent of mean seasonal precipitation. Thus the old practice of distributing precipitation in equal parts of evaporation, run-off and deep penetration is not applicable. Each area represents a problem, with a particular set of conditions to consider. For example, on September 29, 1946 (Muckel and Blaney, 1952) an exceptionally heavy thunderstorm struck the western portion of San Bernardino County near the southern slope of the San Gabriel Mountains. Rainfall intensities reached a maximum of 3.2 inches in 80 minutes. A careful study of the Red Hill Reservoir watershed for the purpose of estimating the total rainfall retained by the soil, disclosed that the soil stored 1.0 inches. Thus, it could be estimated that 2.2 inches (= 68 per cent of total precipitation) were discharged as run-off in a relatively short period of time. (This example is representative of local, unusual conditions in semi-arid regions.)

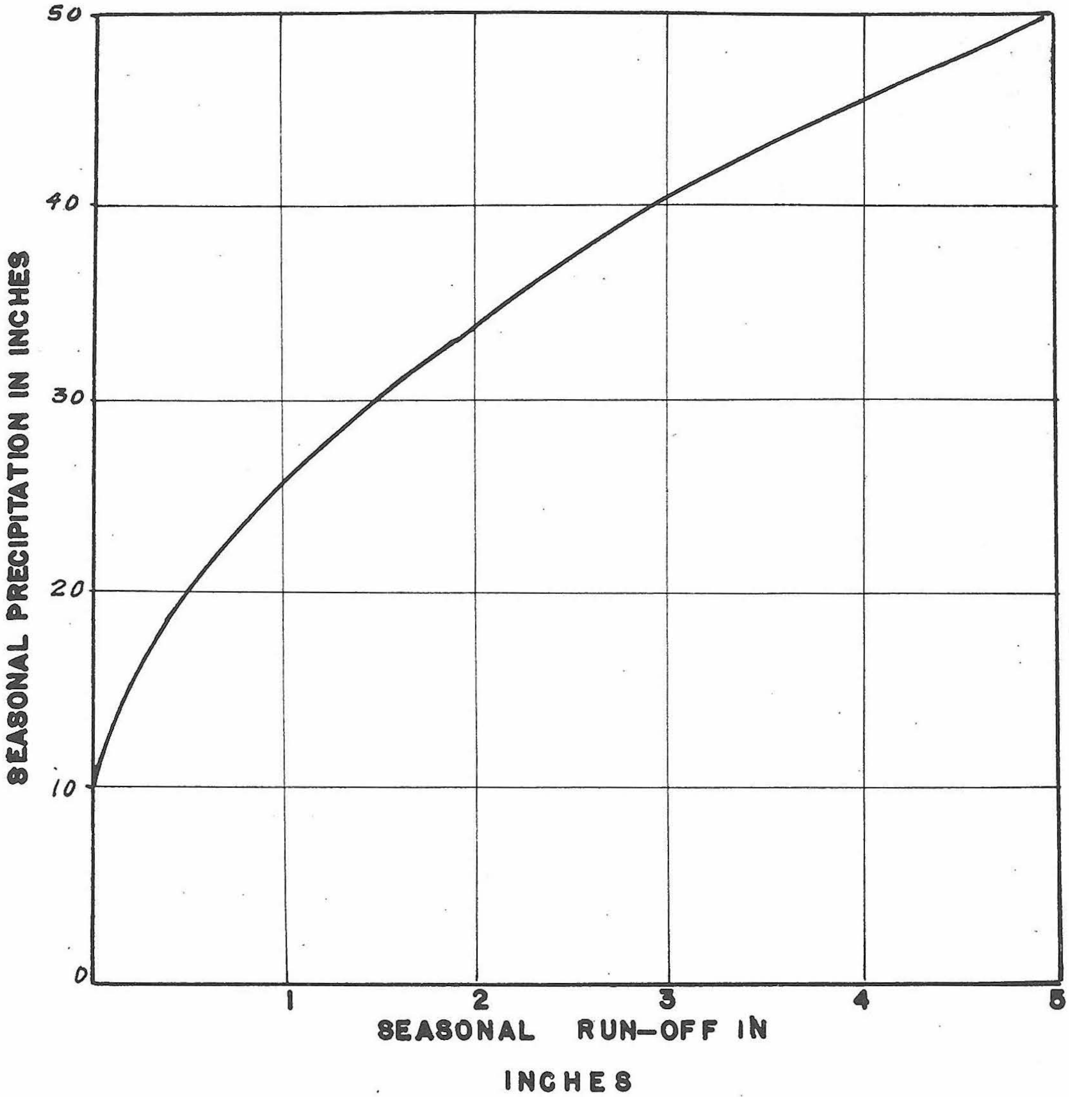
Troxell (1942) has shown that during the dry season of 1933-34 there was water in the stream (San Timoteo Creek) only six days during the entire season, ..."undoubtedly typical of those severe dry seasons that occur from time to time".

Daily discharge in a stream assumes the most variable behavior in semi-arid zones. Records for several years disclose that, in San Timoteo Creek, a daily discharge of about 1800 sec-feet, or more, is obtained for 0.04 per cent of time and about 1 sec-foot, or less, for 91.7 per cent of time.

For Mountain areas, in the western part of San Bernardino County, Troxell (1948) developed curves showing a relationship between seasonal precipitation and mean seasonal run-off. For valley lands of all land classification, except municipal areas, the U.S. Department of Agriculture (1952) developed a curve (Figure 12) showing precipitation run-off relationships having taken into consideration many stations in the Upper Santa Ana River area. That curve, therefore, is applicable to the valley lands of Yucaipa basin. As may be observed, seasonal run-off is not an important figure (0.05 inches) for a seasonal precipitation of 20 inches. This last value is slightly larger than the mean average for Yucaipa area (18.6 inches).

Of a very great importance in a ground water inventory is to know what is the amount of run-off which exceeds infiltration, soil moisture retention and absorption, evapo-transpiration, and interception, for a given storm precipitation in either mountain, foothill and valley lands. In mountain areas of complex hydrology, such as San Bernardino and San Gabriel mountains, it is a necessity to know, as accurately

Figure 12



Relation between seasonal run-off and seasonal precipitation on valley lands, Upper Santa Ana River Valley, Cal.

as possible the optimum natural water losses (*), and the water recoverable, from the precipitation conditions. Storm run-off of "A" type is a recoverable item. It is defined as the amount of water that exceeds the normal recession curves (1) in a hydrograph.

Via illustration, it is known that three main types of hydrographs may be obtained in country of semi-arid to arid characteristics.

There is first (Figure 13) a type of hydrograph representing the sustained seepage from the major ground water bodies; this run-off is known as perennial groundwater run-off. The recession curve has a gentle slope. Even during dry years this sustained seepage occurs. However, there is indication that, for a certain year, the perennial ground water run-off may be exceeded during winter months; during the drought period of such a year a more rapid decline in seepage occurs;

(*) Treated in detail later.

(1) A normal recession curve represents that portion of run-off from the perennial ground water storage. In a semilog. projection this recession line is near a straight line; the formulas

$$Q = Q_o K^t$$

$$R = Q(dt)$$

where

Q_o = initial discharge

Q = discharge after t months

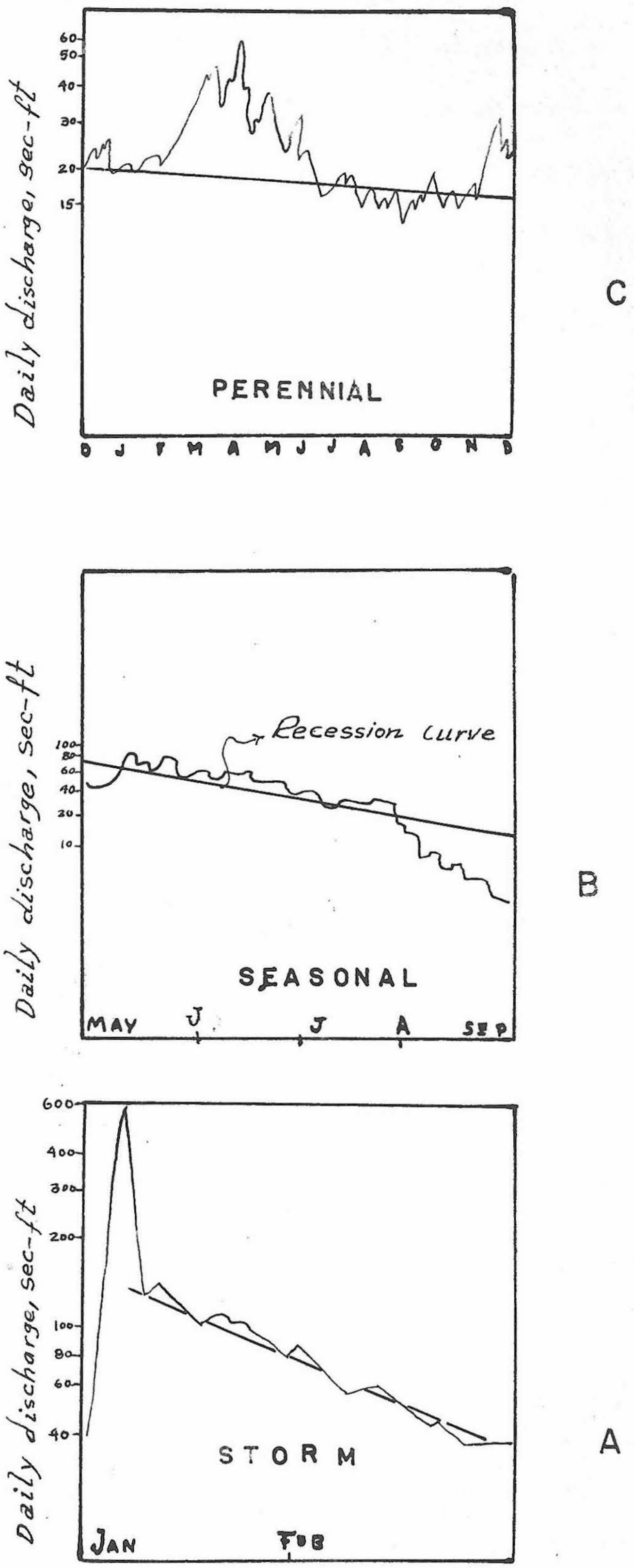
K = depletion factor for the element of flow being analyzed

R = volume of run-off,

are well-known in the literature.

It is evident that, from these formulas the accumulated daily discharge under the recession curve can be converted into storage volumes.

Fig 13. Examples of different types of hydrographs.



the recession curves are therefore steeper. "This steeper recessional slope suggests seepage through a more permeable discharge area than that containing the perennial ground water storage. That portion of the run-off in excess of the perennial ground water run-off and having the characteristics of this more rapid drainage has been designated seasonal ground water run-off". (Troxell, 1953).

For the Yucaipa basin area it is necessary to consider the "storm" type of ground water run-off. The hydrograph in this case shows that the recession slope is very much steeper than for either the seasonal and perennial types of ground water run-off. A more permeable discharge area and a more temporary type of storage than both types previously considered has been suggested.

Storm run-off of "A" type was recorded in Strawberry Creek for several altitudes in foothill and Mountain areas. The scattered points in Figure 14 may well be represented by the curve traced. For a good number of years Troxell (1942?) developed such a curve; a straight line is tentatively plotted for the San Timoteo Creek, with the aid of a few points. From the observation of curve in Figure 14 it may be remarked that no run-off is likely to occur for seasonal precipitation values of less than 25 inches. This is in close agreement with the observations carried on in the foothill and valley land areas of Yucaipa basin. Here, a little run-off of "A" type is available from foothill areas; most of it is obtained from mountain areas.

In Yucaipa basement-complex rocks run-off does not attain a large value. The fractured stage of these rocks and the absorptive nature of a thin cap of soil do not commonly permit the formation of a

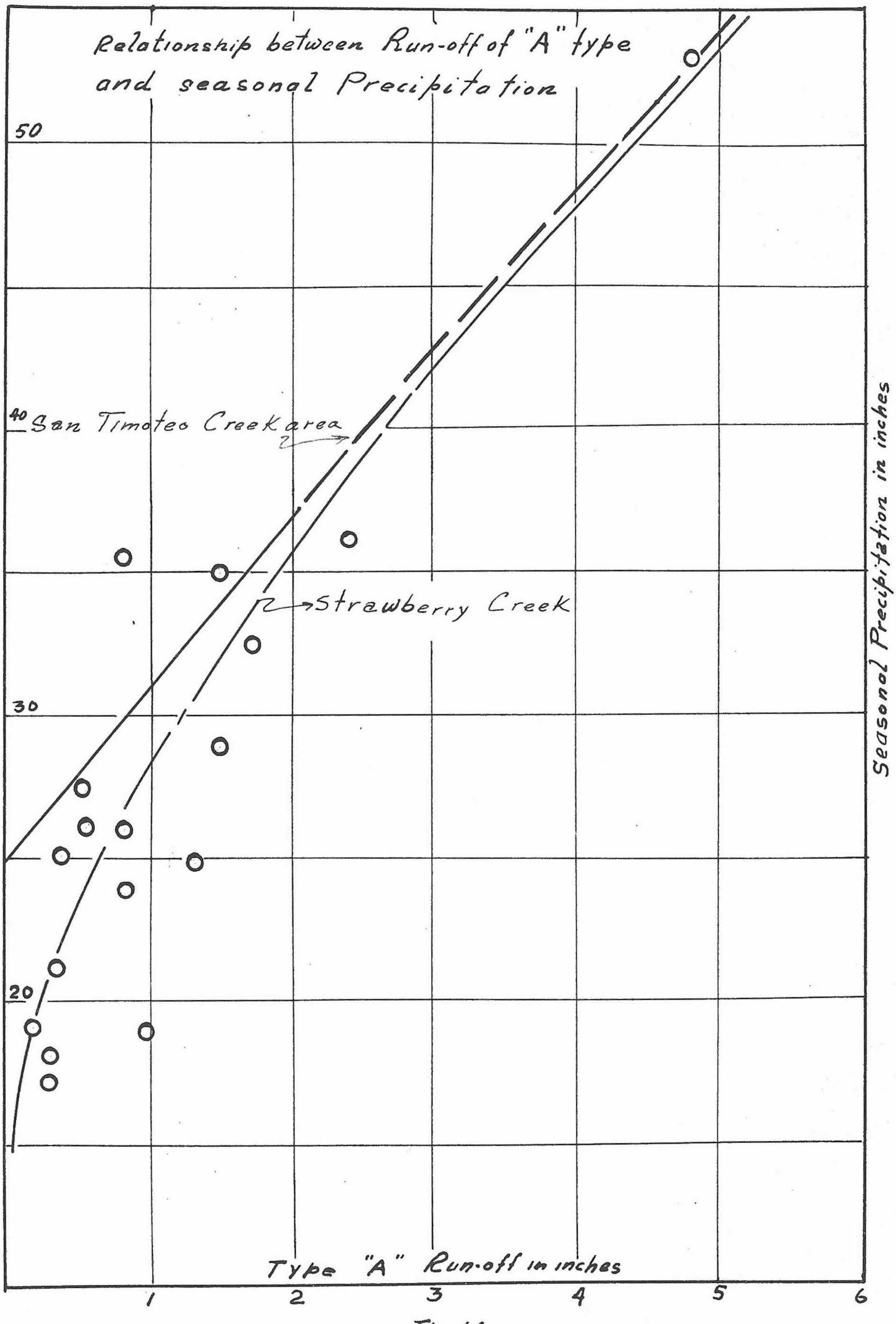

Relationship between Run-off of "A" type and seasonal Precipitation
50
40
30
20
San Timoteo Creek area
Strawberry Creek
Seasonal Precipitation in inches
Type "A" Run-off in inches
1
2
3
4
5
6

Fig. 14

sheet of water thick enough to flow down slope. Under conditions of heavy storm precipitation, however, run-off does occur; even then, at the foot of mountain areas, the retentive properties of soils and high porosity of coarse fanglomerates and alluvial deposits preclude further run-off waste toward the valley lands; as a matter of fact, it is in this belt at the foot of mountain areas that the most important contribution to ground water occurs.

Evaporation, Transpiration, and Consumptive use.

Under this general heading are included in this report the water losses in the form of water vapor. The combination of evaporation from soil surfaces plus water vapor eliminated from leaves of plants involved in the building up of tissue (transpiration) is called consumptive use, (or evapo-transpiration).

It is a matter of observation that evaporation from the surface of a saturated soil is roughly the same than that of a free surface of a liquid. Several times a year the agricultural soils of valley lands in Yucaipa basin are saturated, either due to water artificially applied, or to precipitation during winter months.

Other minor losses, such as interception of rainfall by leaves of foliage, are considered among the general group of evaporation, because shortly after water drops are intercepted by plants, the relatively large wet exposed surface of the leaves facilitates rapid evaporation.

In Table X, evaporation from pan surfaces of a number of years is indicated for the town of Beaumont, a nearby station. These evaporation values may be considered applicable for Yucaipa basin. It is

TABLE X

EVAPORATION AT BEAUMONT, RIVERSIDE COUNTY, CALIFORNIA.

Station:
Location .... Two miles east of Beaumont in San Gorgonio Pass. Lat. 33 56' N, Long. 116 56 W.
Elevation .... 2589 feet.

Evaporation pan:
Type .... U.S. Weather Bureau pan.
Description .... Diameter 4 feet, depth 10 inches, set on 2 x 4 inch timber grill.

Authority for data................ Div. of Irrig., SCS, U.S. Dept. of Agr.

Publication reference............. U.S. Weather Bureau Climatological data(4)

Meteorological data............... Temperature, wind.

Month	1939	1940	1941	1942	1943	1944	1945	Mean
			Evaporation in inches					
Jan.	-	-	2.62	4.82	4.54	4.75	3.20	3.99
Feb.	-	-	2.21	3.90	5.49	2.19	3.82	3.52
Mar.	-	-	4.50	6.83	4.04	6.61	3.60	5.12
April	-	-	4.10	4.73	5.55	5.95	6.41	5.35
May	-	-	8.57	9.72	9.89	8.71	8.24	9.03
June	-	12.47	8.53	12.10	10.91	8.68	9.43	10.35
July	13.45	15.00	13.65	16.25	13.04	12.97	12.84	13.88
Aug.	13.96	13.70	10.23	12.90	12.43	14.02	10.26	12.50
Sept.	8.84	9.38	9.23	10.90	10.70	10.39	8.87	9.69
Oct.	10.07	8.01	5.69	7.62	7.18	7.91	7.05	7.65
Nov.	6.44	6.85	6.24	6.52	7.77	3.31	5.66	6.11
Dec.	4.93	4.10	2.94	5.06	3.33	4.99	4.33	4.24
Annual	-	-	78.51	100.85	94.87	90.48	83.73	91.43

Exposure of station good except for a small building 25 feet south.

Information obtained from State of California, Dept. of Public Works,

Division of Water Resources
Bull. No. 54-A (1948)
Evaporation from Water Surfaces in California.
Basic Data.

noticed that the ratio of mean annual evaporation to mean annual precipitation $(\frac{91.4}{18.7})$ is almost 5. This figure, characteristic of semi-arid regions, is a good index of the evaporative power(*). During the summer months high rates of evaporation occur on account of high temperatures; and during the winter months higher wind velocities aid evaporation, compensating for lower mean monthly temperatures.

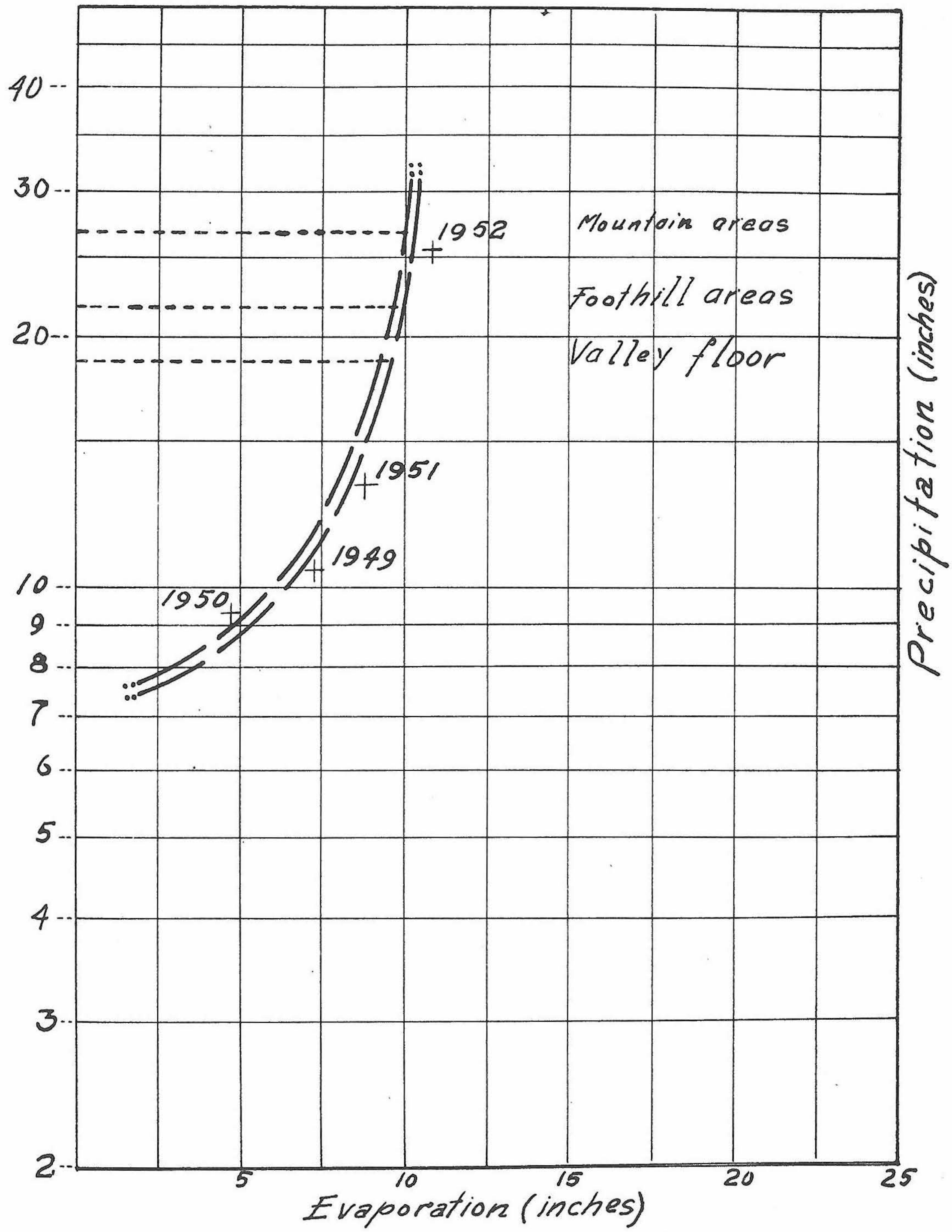
It has been estimated that daily storm precipitation with values of less than 0.50 inches is integrally lost as evaporation plus interception; and that daily storm precipitation of more than 0.50 inches contribute at least 0.50 inches to the atmosphere as evaporation loss. If for a good number of years the annual evaporation is computed from storm rainfall data (following the above empirical procedure) and the plot is made on semilogarithmic paper it is observed that, in general, evaporation increases with altitude up to 4-5000 feet; and that above this limit there is little variation and perhaps decrease with altitude (See Figure 15).

Although it is not possible to ascertain the behavior of evaporation as related to altitude on the fore-told empirical basis it is believed, however, that some approximation is obtained. It is true that evaporation increases with temperature, because the difference in vapor pressure between wet surface and atmosphere increases with temperature. It was previously seen that when altitude is gained, temperature decreases. On the other hand, evaporation decreases with increasing pressure and a reduction in pressure with increase in elevation

(*) Defined as a measure of the degree to which a region is favorable to evaporation as determined by evaporometers, etc.

Figure 15

Relationship between evaporation and storm precipitation for Yucaipa area.



would act to increase evaporation at higher elevations. Hence the relationships between altitude and evaporation are offset.

When surface soils are partially saturated with water the evaporation is correspondingly reduced. The evaporation opportunity gives an idea of how much water is available. The rate of water transfer from below would determine the amount of surface evaporation when the soils are not completely saturated. In the Yucaipa valley lands(*) experiments practiced with different orchards disclosed that evaporation from irrigation lands amounted to one inch per irrigation for a net wetted area. Correspondent adjustments are made when furrow system is used, in which case only a part of land is wetted.

On the other hand, evaporation after rainstorms on valley lands gives a little different picture. If after a rainstorm a soil is drained to field capacity(**) then the surface evaporation loss can be readily determined by soil sampling. It has been found (Blaney, 1952) that the average evaporation loss from top soil is about one half acre-inch per acre after each rainstorm.

The transpiration process is usually considered to be wasteful. Although atmospheric moisture may be absorbed by plants, however, water delivered by soils constitutes the main source of growth. In certain areas transpiration is reduced by dew, showers and increase of moist air. In the Yucaipa area the root systems of most annuals develop within the

(*) Muckel and Blaney, 1952.

(**) Term used to indicate the soil moisture content after gravity water has been drained out.

upper 1-3 feet of soil; but close growing perennials (for example, alfalfa) may reach 30 feet. Shrubs and trees that form tap-roots not uncommonly send their roots to depths of 15 feet (pine oak), whereas it is reported that cottonwood and spruce rarely go down more than 5 feet. The transpiration of plants has a maximum limit, which is not exceeded regardless the amount of water put into the soil.

In connection with the last statement is the so-called "efficiency in irrigation"; farmers that get water at some expense from their own wells or that buy water for irrigation purposes from water companies expect to have an optimum crop thru a minimum input of water; infiltration and run-off must be reduced to a minimum. Hence it is of vital importance to study what the values of transpiration for different kinds of plants are.

For this purpose different experiments in the Yucaipa basin and in nearby areas have been carried on and published periodically (Muckel, Blaney, etc.). By soil sampling methods(*) the transpiration may be estimated. Table XI gives an idea of such estimation in a mature peach orchard.

It has been observed that transpiration shows no appreciable change with time. It is possible to rely on estimated results of transpiration for different types of vegetation in a certain area.

For other irrigated crops transpiration depths are indicated in Table XII.

(*) For detailed information on estimation of transpiration the reader is referred to Muckel (1952), and Linsley (1949).

TABLE XI

TRANSPIRATION AND ROOT DISTRIBUTION IN A MATURE PEACH ORCHARD AS MEASURED BY WATER EXTRACTION FROM THE SOIL FOR DEPTHS SHOWN, YUCAIPA, CALIFORNIA, APRIL 26 TO SEPTEMBER 24, 1948.

Depth Feet	Transpiration 4-26 to 9-24 Ac. inc./Ac.	Root distribution based on water extraction: Per foot Per cent	Cumulative with depth Per cent
0-1	5.29	34.4	34.4
1-2	2.84	18.5	52.9
2-3	1.45	9.4	62.3
3-4	1.28	8.3	70.6
4-5	1.07	7.0	77.6
5-6	.95	6.2	83.8
6-7	.80	5.2	89.0
7-8	.65	4.2	93.2
8-9	.50	3.2	96.4
9-10	.35	2.3	98.7
10-11	.20	1.3	100.0
11-12	.00	0.0	
TOTAL	15.39	100.0	

TABLE XII

TRANSPIRATION FROM VARIOUS IRRIGATED CROPS, YUCAIPA AND BEAUMONT BASINS.

Crop(1)	Irrigation season, Apr. to Oct. inc. (2)	Transpiration depth in inches								
		Sept. (2)	Oct. (2)	Nov.	Dec.	Jan.	Feb.	Mar.	Apr. (2)	Annual
Annual(3)	13.0	1.3	0.9	0.8	0.5	0.5	0.5	0.8	1.0	16.1
Citrus	15.9	2.5	1.5	1.5	1.0	1.1	1.2	2.1	2.0	22.8
Deciduous	15.4	1.5	.5	.3	.2	.2	.2	.4	.8	16.7
Irrigated pasture	16.0	4.3	3.0	2.4	1.9	2.2	1.7	2.8	3.1	27.0
Alfalfa	28.0	4.0	2.8	2.2	.8	.8	.8	2.2	2.6	34.8

(1) The transpiration by winter cover crops is included.

(2) Overlap of September, October, and April is intentional.

(3) Principal crops are potatoes, corn, tomatoes, sweet potatoes, cabbage, lettuce, and onions.

Availability of water during the winter rainy season usually provides a soil moisture content for spring months. The number of irrigations per season are less during the winter months; the fall moisture deficiency(*) is usually an indication of the amount of water that the uppermost feet of soil are able to accumulate in spite of evaporation and transpiration losses. The wilting point is commonly defined as the amount of moisture content of a soil at which plants "wilt" and do not recover unless water is added. It is expressed as percentage of moisture based on the oven-dry weight of the soil.

The transpiration in non-irrigated lands, including native vegetation areas, is a direct function of the soil moisture as result of the winter months. It is a matter of observation that during part of spring, summer and fall the native vegetation remains in a dormant stage.

In order to have an idea of an average mean value, of the losses that include evaporation and transpiration in the Yucaipa basin the following procedure has been considered reliable, according to the information obtained.

Mean seasonal evapo-transpiration (consumptive use) may be computed, if

I. In irrigated lands (include mostly valley lands)

a) Transpiration figures, accurately determined under field conditions, for all and each one on the individual crops, are available.

(*) A term usually defined also as the difference between field capacity and soil moisture content.

b) The acreages for each one of the crops are accurately known,

c) Evaporation from soil surfaces is known under different conditions of saturation and shadowness.

II. In non-irrigated lands acreages and transpiration of crops for dry-farm country and native vegetation are known.

III. Estimation of such losses has been determined in municipal areas.

The main items contained in points I, II, and III have been included in tables XIII and XV.

Several (arbitrary) assumptions are made in the construction of such tables:

a) For non-irrigated lands the transpiration in summer is of little value and does not constitute an appreciable loss (no evaporation opportunity, no water available).

b) During winter months the transpiration has been determined experimentally, by sampling soil in the root zone of plants, before and after seasonal rainfall, having had good control on the other losses.

c) Consumptive use in municipal areas is computed in accordance with figures obtained from Table XIV.

All the acreages indicated are the result of a survey performed by the Soil Conservation Service, Department of Agriculture, in 1948. Since, then, an obvious expansion has occurred, both in agricultural

TABLE XIII

TRANSPIRATION-EVAPORATION
(Consumptive Use)

IRRIGATION

Irrigated Lands = 4218 Acres.

Crop	Acres Valley Floor	Acres Mountain		S.C.U.	S.C.U.	S.C.U. Acre-feet
Annual	137		*	16.1	1.34	183.8
Citrus	470	1	*	22.8	1.90	895.0
Deciduous	2952	126	**	17.9	1.49	4580.0
Permanent pasture	82		*	27.0	2.25	184.7
Hay and grain	58		**	17.5	1.46	84.7
Alfalfa	60		*	34.8	2.90	174.0
Walnuts	298	20	*	26.3	2.19	696.8
Grapes	14		*	13.6	1.13	18.2
	4071	147				***6817.2

Let us assume that from 1948 up to the present, the irrigated areas in Yucaipa basin have increased by 10 per cent, then the evapo-transpiration would have increased correspondingly by + 681.72.

∴ Probable S.C.U. in 1953, Irrigation, = 6817.2 + 681.72 acre-feet.

* Table 21 Muckel, Blaney (1952).
** Table 31 Muckel, Blaney (1952).
Basic Data Muckel, Blaney (1952).
*** In most calculations this figure is used.

TABLE XIV

CONSUMPTIVE USE IN MUNICIPAL AREAS

Residential - high type

Transpiration = 1.0 inch per month over 61 per cent of area for 6-month rainy season or 3.66 inches.
Evaporation = 0.5 inch per month over 100 per cent of area for 6-month rainy season or 3.00 inches.
Run-off = Precipitation over 9 per cent of area.

Residential - poor type (Bunker Hill and Yucaipa)

Transpiration = 1.0 inch per month over 53 per cent of area for 6-month rainy season or 3.18 inches.
Evaporation = 0.5 inch per month over 100 per cent of area for 6-month rainy season or 3.00 inches.
Run-off = Precipitation over 2 per cent of area.

Commercial and Industrial

Transpiration = 1.0 inch per month over 34 per cent of area for 6-month rainy season or 2.04 inches.
Evaporation = 0.5 inch per month over 100 per cent of area for 6-month rainy season or 3.00 inches.
Run-off = Precipitation over 22 per cent of area.

Parks

Transpiration = 1.0 inch per month over 74 per cent of area for 6-month rainy season or 4.44 inches.
Evaporation = 0.5 inch per month over 100 per cent of area for 6-month rainy season or 3.00 inches.
Run-off = Precipitation over 1 per cent of area.

Schools

Transpiration = 1.0 inch per month over 30 per cent of area for 6-month rainy season or 1.80 inches.
Evaporation = 0.5 inch per month over 100 per cent of area for 6-month rainy season or 3.00 inches.
Run-off = Precipitation over 24 per cent of area.

TABLE XV
CONSUMPTIVE USE, YUCAIPA BASIN.

Non-irrigated lands (except small units municipal).

Land Classification	Area			
Municipal and	Valley floor acres	Mountain acres	S.C.U. for a Normal Year	Acre-Feet
Fallow	1389	17*	10(in.) = 0.833(ft.)	1157.0
Residence, high type	474		3.66 + 3.00(in.) = 0.555(ft.)	266.5
Residence, low type	34		***3.18 + 3 (in.) = 0.515(ft.)	17.5
Vacant lots	19		(?) 4.8 (in.) = 0.400(ft.)	7.6
Irrig. grass, parks	5		***4.44 + 3.00(in.) = 0.620(ft.)	3.1
Paved	946		7.5 (in.) = 0.625(ft.)*	591.0
Schools ground	8		***1.80 + 3.00(in.) = 0.400(ft.)	3.2
Commercial and semi-comm.	85		***2.04 + 3.00(in.) = 0.420(ft.)	35.7
Chicken ranch	26		= 1.000(ft.)*	26.0
Grapes	47		****3.2(in.) + **9.00 (in.) = 1.020(ft.)	48.0
Deciduous	90		****3.5(in.) + **9.00 (in.) = 1.041(ft.)	93.7
Hay and grain	3482		****3.7(in.) + **9.00 (in.) = 1.058(ft.)	3660.0
Pasture	892		****3.7(in.) + **9.00 (in.) = 1.058(ft.)	943.0
Grass and weeds	834		****3.7(in.) + **9.00 (in.) = 1.058(ft.)	880.0
Brush, sparse	2009		****3.7(in.) + **9.00 (in.) = 1.058(ft.)	2120.0
Brush, medium	2716		****6.9(in.) + **9.00 (in.) = 1.325(ft.)	3600.0
Brush and trees, dense	99		****13.9(in.) + **9.00 (in.) = 1.900(ft.)	188.0
Eucalyptus trees	200		**** 6.0(in.) + **9.00 (in.) = 1.250(ft.)	450.0
Riverwash	103		****0.0(in.) + **9.00 (in.) = 0.750(ft.)	77.1
	13458	17		14167.4

* Arbitrary

** Evaporation is computed from graph on Fig. 15

*** Muckel's Table, p. 80(1952)

**** Sept.-April-transpiration Table 22 - Muckel and Blaney (1952).

and municipal areas. The writer estimates that an increase of 10 per cent in the seasonal consumptive use as a result of an expansion of cultivated lands is a conservative figure. A total seasonal consumptive use of

non-irrig. + nat. veg. + irrig. + arbitrary 10 per cent

14,167.40 + 6817.20 + 681.72

= 21,676.32 (acre-feet),

is estimated for the Yucaipa basin area. This figure is uncertain in the order of 600.00 acre-feet. It represents, however, a good approximation for practical purposes.

The availability of data for the Yucaipa basin has permitted an estimation of consumptive use as above described. Blaney and Criddle (1950) however, express the consumptive use as a function of temperature, daytime hours, and available moisture (precipitation, irrigation water or natural ground water) mathematically,

$$U = K \times F = k \times f,$$

where

U = consumptive use of crop in inches for any period.

F = sum of the monthly consumptive-use factors for the period (sum of the products of mean monthly temperature and monthly per cent of daytime hours of the year).

K = empirical consumptive use coefficient (irrig. season or growing period).

t = mean monthly temperature, ^{o}F.

p = monthly per cent daytime hours of the year.

$f = \frac{t \times p}{100}$ = monthly consumptive use factor.

k = monthly consumptive use factor according to this method.

It is possible to know F for areas in which monthly temperatures records are available. If K (consumptive use coefficient) is known for a particular crop in some locality, then, an estimate of consumptive use by the same crop in some other area may be made by application of $U = K \times F$.

It has been seen, so far, that the consumptive use is a function of precipitation, temperature, humidity, wind movement, growing season, and latitude (southern facing slopes of northern latitudes receive more heat than northern facing ones, therefore the evaporation is larger). Another factor, however, should be mentioned. This is the human factor. As stated by Blaney and Criddle (1950):

> "In the arid and semi-arid west where the major source of water is irrigation, both the quantity and seasonal distribution of the available supply will usually affect the consumptive use. Where water is plentiful there is a tendency for farmers to over-irrigate in both frequency and depth of application. If the soil surface is frequently wet and the resulting evaporation is high the consumptive use will likewise increase".

Ground Water Inventory.

A Ground Water Inventory represents the results of an accurate analysis made for gains and losses of water in a certain ground water body; from the comparison of the magnitude of both general variables arises the concept of safe yield, which is defined as the annual amount of water that a basin is capable of producing economically, without having a drawdown of the water table surface from a certain reference plane.

If a stable balance exists between seasonal intake and seasonal output the chances are that the basin will be maintained within economic levels indefinitely. It is the purpose of the present chapter to find out what the relation between output and intake is for the Yucaipa basin.

In short, the following frame may be made:

GAINS	LOSSES
Average annual ground water recharge from mountain and foothill areas.	Exported
Deept penetration from rainfall on valley floor mainly (in irrigated and non-irrigated lands).	Pumped, to be used in irrigation, domestic and municipal grounds.
Deep penetration from water artificially applied (Domestic and Irrig. areas).	(Consumptive use, non-irrig.lands) (Consumptive use in domestic and municipal areas.)

The Table XVII has been constructed with the purpose of estimating the recharge from mountain and foothill areas. Information

TABLE XVI

MOUNTAIN AREAS AND FOOTHILL SLOPES.

Adjustment of seasonal precipitation to altitude, through the aid of the graph (Figure 11).

	Mountain Area(above 4000 ft.)			Foothill Area(3500 ft.)		
Year	Redlands	Beaumont	Average Yucaipa	Redlands	Beaumont	Average Yucaipa
1940-1941	1.78x24.55 = 43.5	1.38x30.25 = 41.7	42.60	1.49x24.55 = 36.60	1.15x30.25 = 34.80	35.70
1941-1942	1.78x12.32 = 21.93	1.38x14.44 = 20.0	20.90	1.49x12.32 = 18.40	1.15x14.44 = 16.60	17.50
1942-1943	1.78x21.52 = 38.21	1.38x23.79 = 32.80	35.60	1.49x21.52 = 32.10	1.15x23.79 = 27.20	29.60
1943-1944	1.78x18.04 = 32.5	1.38x20.08 = 27.80	30.10	1.49x18.04 = 27.00	1.15x20.08 = 23.10	25.05
1944-1945	1.78x12.41 = 22.1	1.38x18.69 = 25.80	24.00	1.49x12.41 = 18.50	1.15x18.69 = 21.20	19.85
1945-1946	1.78x 9.83 = 17.50	1.38x15.39 = 21.20	19.35	1.49x 9.83 = 14.60	1.15x15.39 = 17.70	16.15
1946-1947	1.78x12.99 = 23.10	1.38x17.64 = 24.40	23.67	1.49x12.99 = 19.30	1.15x17.69 = 20.30	19.80
1947-1948	1.78x 7.35 = 13.10	1.38x11.54 = 15.94	14.55	1.49x 7.35 = 10.91	1.15x11.54 = 13.3	12.10
1948-1949	1.78x11.55 = 20.60	1.38x14.63 = 20.2	20.40	1.49x11.55 = 17.15	1.15x14.63 = 16.80	17.00
1949-1950	1.78x 9.38 = 16.70	1.38x12.93 = 17.90	17.30	1.49x 9.38 = 14.00	1.15x12.93 = 14.82	14.41
1950-1951	1.78x 5.76 = 10.41	1.38x 9.34 = 12.90	11.65	1.49x 5.76 = 8.56	1.15x 9.34 = 10.70	9.63
1951-1952	1.78x21.55 = 38.22	1.38x23.66 = 32.70	35.40	1.49x21.55 = 32.00	1.15x23.66 = 27.20	29.60
Average 1940-1941 1951-1952			24.60 inches			20.61 inches
Average 1926-1927 1940-1941			28.73 inches			22.80 inches
Average 1926-1927 1951-1952			26.60 inches			21.65 inches

TABLE XVII

YUCAIPA BASIN

Recharge from Mountain and Foothill Areas.

Mountain Area (more than 4000 feet above sea level)

Year	Adjusted Precipitation (inches)	Run-off type "A" (inches)	Natural water losses	Recharge
1940-1941	42.60	3.00	25.00	14.60
1941-1942	20.90	0.00	18.80	2.10
1942-1943	35.60	1.70	25.00	9.90
1943-1944	30.10	0.83	24.70	4.57
1944-1945	24.00	0.00	21.00	3.00
1945-1946	19.35	0.00	17.00	2.35
1946-1947	23.67	0.00	19.92	3.75
1947-1948	14.55	0.00	13.00	1.55
1948-1949	20.40	0.00	18.30	2.10
1949-1950	17.30	0.00	15.50	1.80
1950-1951	11.65	0.00	10.00	1.65
1951-1952	35.40	1.80	25.00	8.60
Average	24.60			4.66

Acreage of Mountain Area = 6200 Acres

∴ Mountain Recharge = $\frac{4.66}{12} \times 6200$

= 2410 Acre-feet

TABLE XVII (cont.)

YUCAIPA BASIN

Recharge from Mountain and Foothill Areas.

Foothill Area (3500 feet above sea level)

Year	Adjusted Precipitation (inches)	Run-off type "A" (inches)	Natural water losses	Recharge	Tot. comp. Ground Water Recharge
1940-1941	35.70	1.82	25.00	8.88	
1941-1942	17.50	0.00	15.60	1.90	
1942-1943	29.60	0.80	24.00	4.80	
1943-1944	25.05	0.01	21.92	3.12	
1944-1945	19.85	0.00	18.10	1.75	
1945-1946	16.15	0.00	14.20	1.90	
1946-1947	19.80	0.00	18.10	1.70	
1947-1948	12.10	0.00	10.00	2.10	
1948-1949	17.00	0.00	15.20	1.80	
1949-1950	14.41	0.00	13.00	1.41	
1950-1951	9.63	0.00	9.00	0.63	
1951-1952	29.60	0.82	24.00	5.60	
Average	20.61			1.32	5.98(in.)

Acreage of Foothill Area = 8500 Acres.

$$\therefore \text{ Foothill Recharge} = \frac{1.32}{12} \times 8500$$

$$= 935 \text{ Acre-feet.}$$

$$\therefore \begin{matrix} 1940\text{-}41 \\ \\ 1951\text{-}52 \end{matrix} \text{ Annual Recharge} = 2410 + 935 = 3345 \text{ Acre-feet.}$$

$$\begin{matrix} 1926\text{-}27 \\ \\ 1951\text{-}52 \end{matrix} \text{ Annual Recharge} = \frac{3345 + 5300}{2} = \frac{8645}{2} = 4322.5 \text{ Acre-feet.}$$

for a minimum of 10 years has been available, and therefore, a good "average" value may be obtained. Because the values for annual precipitation were recorded at an altitude of less than 4000 feet (Yucaipa station = 2650 feet) an adjustment is necessary to make in order to have more representative conditions of mountain areas. This adjustment is made with the help of Figure 11. Table XVI indicates the procedure followed. For example, for the year 1940-41, two abscisas were measured; one from the station of Redlands to the point corresponding with an altitude of 4000 in the dashed line (Yucaipa line). This length is 1.78 (logarithmic scale). The precipiation recorded in Redlands during that year is 24.55. Therefore the extrapolation to mountain altitude in Yucaipa area from Redlands data is 1.78 x 24.55 = 43.5 inches. The other abscisa is from the Beaumont station. Following the same procedure the adjustment gives 41.7 inches, and the average 42.60. It is clear that the more stations of nearby areas are brought into the picture the more representative the adjustment will be. In an analogous way the computation is indicated for foothill areas. The writer believes that there is more accuracy involved in this elaborate estimation of mountain and foothill area precipitation than by simply recurring to the isohyetal maps.

For a previous period (1926-1941), Troxell (1945) worked out, following different methods, the average precipitation in mountain and foothill areas. His average figures were averaged with those obtained by the writer. The final results of 26.60 inches for mountain areas and 21.65 for foothill areas are obtained. The next step in Table XVII is to subtract from the adjusted precipitation column the respective values for Run-off of type "A" obtained from graph in Figure 14, and which represent, as it may be recalled, surface run-off occurring as a result of rates of rainfall in excess of infiltration rates.

In the same Table XVII under the head of natural water losses in included

transpiration from plant life;
evaporation from soil and snow;
interception and subsequent evaporation of precipitation retained by the foliage of plant life during rainfall.

A procedure to separate natural water losses from water recoverable has been devised by Troxell (1949). The writer takes advantage of the data plotted for San Antonio drainage area, idealized in the graph of Figure 16 . This graph was built generalizing the trend of scattered points, which required the knowledge of

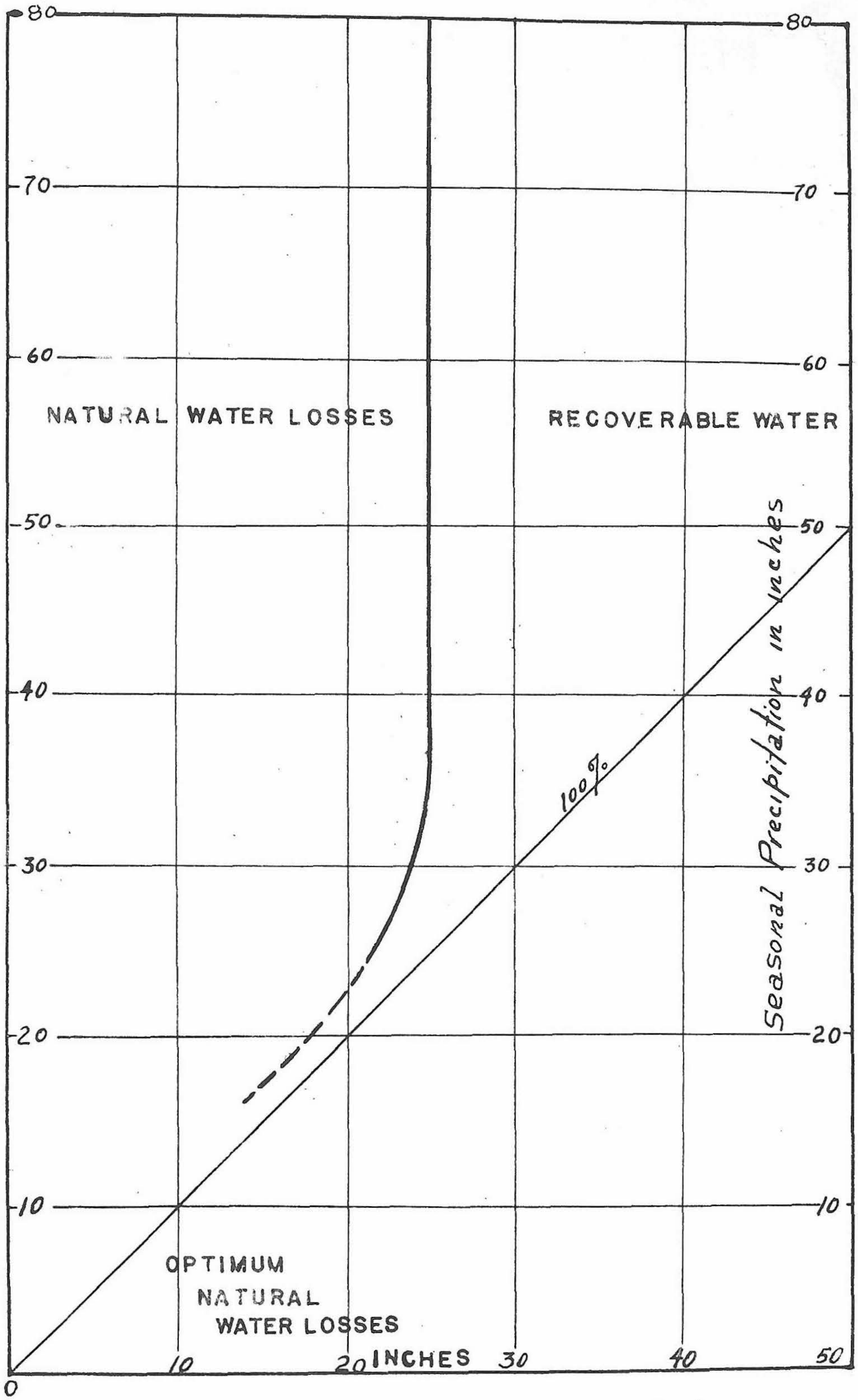
(a) average seasonal precipitation

(b) Recoverable water {
- run-off
- change in ground water storage (Function of excess values over recession curves, as discussed before).

It may be immediately shown that natural water losses (c),

(c) = (a) - (b).

Figure 16



Relationship among seasonal precipitation, natural water losses, and recoverable water, San Antonio Creek drainage area. (Adopted from Troxell's)

For the present intention, the graph is used in a rather inverse manner: with adjusted precipitation data the natural water losses are found. Then, the recharge is justly adjusted precipitation-natural water losses-run-off type "A". The method seems to work with reasonably accuracy for Yucaipa basin. The recharge from mountain and foothill areas is a legitimate contribution to the reserves of underground water in the basin. This value of deep penetration from rainfall is the most significant gain recorded in the inventory. Steps given for its calculation are accurate enough to rely on them within 85-90 per cent of approximation.

The value of annual recharge obtained is, for the period 1926-1952, ...

4322.5 acre-feet.

The deep penetration from rainfall on valley floor (including irrigated and non-irrigated lands) reaches an extremely low value. If the graph of Figure 16 is used it is found that for a seasonal precipitation of 18.6 inches (the average of years for Yucaipa valley lands) the natural water losses amount to 16.4 inches. Assuming that no appreciable run-off occurs for this precipitation value (see, for example Figures 12,14) then the recoverable water in valley lands would be 18.6-16.4 or 2.2 inches.

It is questionable whether 2.2 inches will reach the water table, for the following reasons:

a) The soils in the Yucaipa basin are just moderately absorptive and retentive.

b) It seems unlikely that 2.2 inches will go beyond the root zone, supply the soil moisture deficiency up to field capacity, and reach the water table.

Intensive investigations (Muckel, Blaney, 1952) showed that most crops in irrigated lands and non-irrigated lands, and native vegetation, have initial fall soil moisture deficiencies above 2.2 inches. Via-illustration is the detailed result presented in Table XVIII.

There is deep penetration in irrigated lands, due to water artificially applied, and it is of small value. Careful measurements relied upon soil sampling(*) have been carried on for different types of orchards. It was found that in several crops, about 0.5-1.5 inches out of 20 inches applied during the irrigation season reached a zone below the root horizon.

By considering in detail all the possible variables, the writer made an estimation of deep penetration from water artificially applied in irrigated lands. Table XIX shows pumpages (estimated average values, for different periods of years, according to the particular information recorded by each one of the users) as kindly informed by Water Companies and individual farmers.

In Table XX an estimation is made of water returned to the water table combining the data provided by Tables XIII, XV and XIX. It is observed that from 9435.7 acre-feet applied in irrigation only 1693.9 acre-feet return to the water table.

Most of the irrigations in the Yucaipa basin take place during summer months. Not rarely, however, irrigations are carried through during the winter months. A delay in rainy season, or insufficiency

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(*) At various depths, before, during and after the growing season.

TABLE XVIII

FALL SOIL MOISTURE DEFICIENCES, UPPER SANTA ANA RIVER VALLEY, CALIFORNIA, IN INCHES OF DEPTH FOR ROOT ZONE.

Crop	California State Bulletin No. 19	California State Bulletin No. 33	Field studies 1946-1948	Values used in computations
Irrigated				
Annual				3.0
Truck	3.0		4.72	-
Beans	3.0		4.58	-
Double crop	3.0			-
Beets	3.0			-
	3.0		3.71	-
Citrus, avocados	3.0	0.0-3.4		3.0
Walnuts	7.0	11.0-15.1		9.0
Deciduous	7.0	8.2-14.3	7.02	7.0
Pasture	3.0		2.80	2.5
Hay and grain	3.0			6.0
Alfalfa	3.0			4.5
Unirrigated crops				
Fallow	-		5.39	5.0
Grapes	7.0	7.1	9.47	9.5
Deciduous trees	7.0	14.3		9.0
Hay and grain	5.0	4.3	8.28-9.31	8.0
Pasture	5.0			8.0
Native vegetation				
Grass and weeds	5.0	4.6-7.6	8.75	8.5
Pasture	5.0			8.5
Sparse brush	5.0		9.00	9.0
Medium brush	7.0	8.0-12.5		10.0
Brush and trees, dense	1.0			2.0
Riverwash(bare)				1.0

TABLE XIX

PUMPAGE

Company or well owner	Exportation of water (Net loss) (Acre-feet)	Domestic and Municipal (Acre-feet)	Irrigation (Acre-feet)	Total (Acre-feet)	Domestic (Per cent)	Irrigation (Per Cent)
Western Heights	-	95.41	1267.59	1363	7	93
So. Mountain Co.	2382.0			-	-	-
Moreno Water Co.	2382.0			-	-	-
Yucaipa Water Co. No.1		1370.00	2080.0	2450	36.9	60.4
Gateway Co.			214.0	214		
Carter Well			107.0	107		
South Mesa		1112.00	1388.0	2500	44.5	
Dairy's Ranch Well			286.0	286		
Martin Well			400.0	400		
Section 30			301.0	301		
Crafton Mesa			814.7	814.7		
* others (Dundley well, etc.)		428.5	428.5	857	50	50
	4764.0	3005.91	7286.79	10292.7		
		** 2577.41	** 6858.29	** 9435.7		

* very dubious.

** Figures used in computations.

TABLE XX

Pumpage, Acre-Feet*			Consumptive Use			Deep Penetration
Irrigation	Domestic Use and Municipal Areas.	Total	Irrig. Lands	Domestic and Municipal Areas	Total	Water returned to water table (Total) A.F.
6858.29	2577.41	9435.7	6817.2	924.6	7741.8	1693.9

* Values of water pumped varied from year to year for each one of the companies. The arbitrary procedure of averaging annual pumpage for all the years in each one of the companies is made. No run-off is totally assumed, (Valley lands).

TABLE XXI

MINIMUM PRECIPITATION REQUIRED TO PRODUCE DEEP PENETRATION IN NON-IRRIGATED LANDS

	Fall soil moisture deficiency	Consumptive use Evapo-transp.	
Unirrigated crops			
Fallow	5.0	10	15.0
Grapes	9.5	12.2	21.7
Deciduous trees	9.0	12.5	21.5
Hay and grain	8.0	12.7	20.7
Pasture	8.0	12.7	20.7
Native vegetation			
Grass and weeds	8.5	12.7	21.2
Pasture	8.5	12.7	21.2
Sparse brush	9.0	12.7	21.7
Medium brush	10.0	15.9	25.9
Brush and trees, dense	2.0	22.9	24.9
Riverwash (bare)	1.0	9.0	10.0

of rain are not uncommon factors. It is therefore understood that most of the rainfall in irrigated valley lands is used up during the winter evapo-transpiration process and that no appreciable contribution is made to the water table.

As for rain falling in non-irrigated and native vegetation valley lands, where there is not control of ground water behavior, it results very difficult to ascertain how much water exceeds field capacity and drains down to the water table region.

With the information available by means of Tables XVIII and XV it is possible to know what value of mean-seasonal precipitation would be needed to produce deep penetration in non-irrigated lands. For that purpose the previous table was constructed (Table XXI).

The average mean seasonal precipitation for Yucaipa basin area is 18.7 inches, and most of the values obtained for minimum precipitation in the above table are over 18.7 inches. It is recognized that the figures representing initial fall soil moisture deficiency and consumptive use are not absolute; they are the product of intensive field work and experience. However, an idea is gotten for comparison basis. It may be concluded that very little, if any, deep penetration occurs in valley lands, non-irrigated areas.

Up to this point the ground water inventory would have the following characteristics:

Intake (acre-feet)	Output (acre-feet
Average annual ground water recharge from mountain and foothill areas.................................. 4322.50	Exported....................................... 4764.0
Deep penetration (return) of water artifically applied in irrigation and domestic use 1693.90	Total amount of water extracted (pumped) to be used for irrigation and domestic purposes....................................... 9435.70
6076.40	14,199.70

overdraft = 8183.30 acre-feet

An indirect check of such a large overdraft may be made in the following manner:

A typical well, almost on the center of the basin (136b or 136c = Yuc #5) shows the following water table level history:

Date	Elevation above sea level (feet)
Spring 1927	2250.00
Spring 1942	2225.00
Spring 1952	2151.89

Assuming this information as reliable (measurement of wells by U.S.G.S., Water Resources Branch, and Yucaipa Water Co. # 1) it is found that an average annual drawdown of the water table of 1.67 feet exists for the period 1927-1942; and that for the period 1942-1952 the drawdown has attained an average annual value of 7.3 feet.

If both figures are averaged, a very conservative result will be obtained, in that it will represent an annual average drawdown below the one produced under actual conditions of pumpage and exploitation.

If a medium porosity as low as 0.12 is assumed for the water-bearing beds, then the average annual overdraft of the Yucaipa basin, on this basis would be:

$$\frac{1.67 + 7.3}{2} \times 0.12 \times 17{,}500.$$

9440.0 acre-feet.

It is then found that the overdraft calculated under a more detailed analysis in previous pages is not inaccurate.

Specific yield, Safe yield, Time-life, Economic depth of wells in the Yucaipa basin.

The specific yield, by definition, measures the amount of water that is able to move by gravity in a certain volume of material. It represents water in the suspended zone that exceeds the field capacity (also known as specific retention) and may be estimated accurately if both total porosity and field capacity are known.

Some idea of the specific yield of the Yucaipa basin may be obtained as follows. In 1952 water level in wells was measured prior and after the irrigation season (i.e. in April and November, respectively). The average difference in elevation of the water level in most wells was about 15 feet. The average mean annual pumpage (Table XIX, p. 78) has been found to be (exclusively irrigation) 9435.7-2577.41 = 6857.29 acre-feet. Assuming that the abstracted water is drawn from an aquifer the dimensions of which are:

area 4218 acres(acreage of irrigated land)

vertical dimension, 15 feet, then

the specific yield is $\frac{6857.29}{4218 \times 15} = 0.1085$

or 10.85 per cent*.

By definition,

total porosity = effective porosity + specific retention.

Therefore, the specific retention or field capacity of the aquifer is 0.1200 - 0.1085 = 0.0115, or 1.15 per cent. This last figure indicates that 1.15 per cent of total volume of aquifer is occupied by water impossible to recover thru ordinary pumping methods. A sedimentary rock with the above hydrological properties, i.e.,

total porosity 12 per cent
effective porosity 10.85 per cent, and a small,
specific retention 1.15 per cent,

would correspond to a type of sandy gravel, the porosity of which is greatly reduced by finer interstitial material.

The continuous development of uncultivated land in the Yucaipa basin area well demonstrates an increasing demand of water year after year. The cultivated area of 4218 acres, as surveyed in 1948, might have increased by 10 per cent or more, since then. The question arises therefore, as to how much water can the Yucaipa basin yield to the increasing demand, economically.

An optimistic figure would be estimated as follows: Consider the 100 uppermost feet of the aquifer; and consider a specific yield of .1085 as previously estimated. If it is further assumed that the hydrological properties of the aquifer remain constant throughout, so as to maintain the specific yield constant, then the recoverable water would be

(*) This assumes no contribution to basin from stream gravels or from bedrock joints during pumping season.

$$17,500 \times 0.1085 \times 100 = 190,000 \text{ acre-feet.}$$

But the area of the aquifer is less than 17,500 acre feet, because the slopes of mountain areas dip towards the basin thereby reducing the surface area of valley lands; on the other hand it is very unlikely that the specific yield would be 0.1085 throughout, taking into consideration the rapid textural changes, both laterally and vertically, of the sedimentary formation which makes up the water-bearing rock. An arbitrary, but more conservative figure would be

$$15,000 \times 0.09000 \times 100 = 135,000 \text{ acre-feet.}$$

Assuming an average annual drawdown of 7.5 feet in the water table the time-life of an aquifer 100 ft. thick would be $\frac{100}{7.5} = 13$ years. On the basis of estimated water recoverable and actual annual overdraft the time-life for an aquifer also 100 feet thick would be

$$\frac{135,000 \text{ acre-feet}}{8623.3 \frac{\text{acre-feet}}{\text{year}}} = 16 \text{ years.}$$

If exportation losses are cut then the time-life is increased to $\frac{135,000}{3859} = 35$ years. This would give an annual drawdown on water table of $\frac{100}{35} = 3$ feet.

If an aquifer 250 feet thick is assumed under the approximate annual drawdown of water table 7.5 feet, the time-life of the Yucaipa basin would be $\frac{250}{7.5} = 33$ years(*). Several wells, for example

(*) The annual drawdown 7.5 feet results from 10 years (1942-1952) 7 or 8 of which were so dry that total precipitation was 60-70 per cent below normal. It is estimated that about 15 per cent of 7.5 feet average annual drawdown is due to that cause. For normal conditions, therefore, the time-life would be

$$\frac{250}{6.4} = 39 \text{ years.}$$

139 = Crafton Mesa #2, or Crafton Mesa #3, (see water table map), would then reach about 600 feet of depth. Because the degree of consolidation and compaction increase with depth it seems reasonable to assume that the specific yield will be less and less with increasing depth. The problem of having to consider the economic depth may then arise.

The optimum safe yield of Yucaipa basin is, practically, the mean annual recharge from foothill and mountain areas, i.e., 4322.5 acre-feet. Some of the water artificially applied returns to the aquifer. It has been previously estimated (see inventory) that for supplies of the order of 10,000 acre-feet, approximately 17 per cent of this amount is newly recovered in the form of deep penetration. This amount may be considerably reduced with more efficient irrigation and distribution methods. If exportation were stopped and deep penetration returned to normal for a number of years there still would be an overdraft of about 3000 acre-feet.

It seems unlikely that water needs will remain constant. A continuous increase is more probable and as a result, it is reasonable to assume, a continuous reduction of the estimated lifetime of the Yucaipa basin.

A summary of the main results obtained is indicated in Table XXII.

TABLE XXII

SUMMARY OF RESULTS OF GROUND WATER INVENTORY OF YUCAIPA BASIN, CALIFORNIA

Item	Magnitudes	Remarks: Accuracy
Acreage, Irrig. Valley (1948)	4218 Acres	Accurate
Acreage, non-irrig. valley lands and municipal areas	13475 Acres	Accurate
Acreage, Foothill Areas	8500 Acres	Medium
Acreage, Mountain Areas	6200 Acres	Medium
Rainfall, Valley lands	18.6 inches	Accurate
Rainfall, Foothill areas	21.65 inches	Medium-Accurate
Rainfall, Mountain areas	26.60 inches	Medium-Accurate
Consumptive use, irrig. valley land areas	6817.2 acre-feet	Medium
Consumptive use, non-irrig. valley land and municipal land	14167.4 acre-feet	Inaccurate
Surface and ground water run-off	Inappreciable	Medium
Water pumped out, exported	4764.0 acre-feet	Medium
Water pumped out, used for irrig. and domestic purposes	9435.7 acre-feet	Medium
Water pumped out, used exclusively in irrigation	6857.29 acre-feet	Accurate
Water pumped out, used in municipal and domestic	2577.41 acre-feet	Accurate
Ground water recharged from foothill and mountain areas	4322.5 acre-feet	Accurate
Deep penetration from water artificially applied	1693.9 acre-feet from 9435.7 A.F. 1 inch per each 20 inches appl.	Medium
Deep penetration, rainfall in irrig. and non-irrig. lands.	less than one inch	Medium

TABLE XXII (cont.)

Item	Magnitudes	Remarks: Accuracy
Overdraft, from G.W. Inv.	8623.3 acre-feet	Medium
Overdraft, from declination history of wells	7400.0 acre-feet	Inaccurate
Specific Retention of the aquifer	1.15 per cent	Inaccurate
Total Porosity of aquifer	12 per cent	Inaccurate
Specific yield	10.85 per cent	Medium
Safe yield	1322.5 acre-feet	Accurate
Time-life basin	33 years	Assumptions: Aquifer = 250 feet thick. No cut of exportation losses. Average annual drawdown = 7.5 feet Medium
Economic depth wells	600-700 feet	Inaccurate

Plate II. Above: View looking to the northeast into Crafton Hills and western slopes of San Bernardino Mountains.
Below: View to the north across the western part of Yucaipa basin into Crafton Hills and San ernardino Mountains.

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