HYDROLOGY

OF THE

SAN BERNARDINO

AND

EASTERN SAN GABRIEL

MOUNTAINS

CALIFORNIA

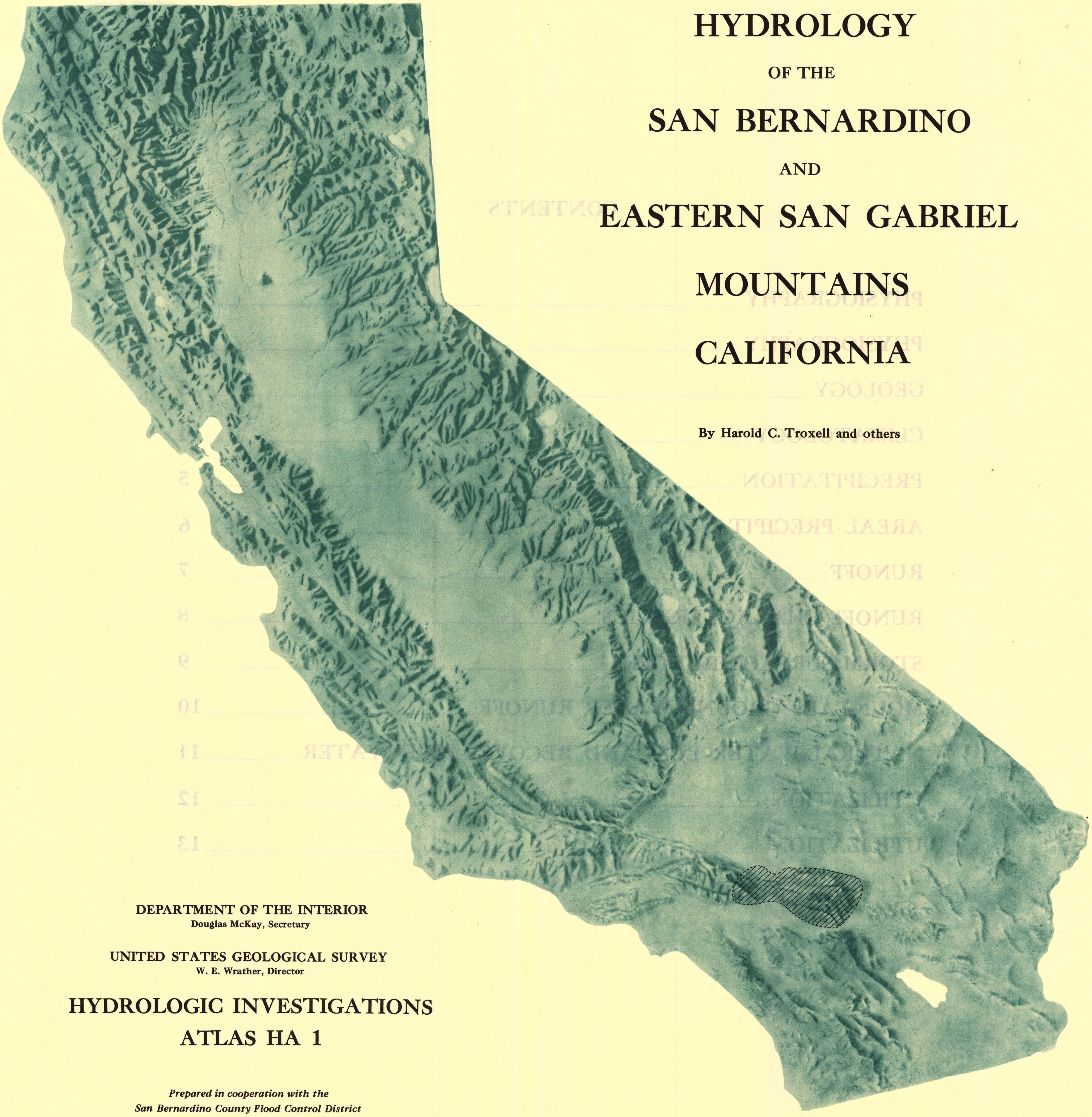
DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS

ATLAS HA 1

Prepared in cooperation with the
San Bernardino County Flood Control District



HYDROLOGY

OF THE

SAN BERNARDINO

AND

EASTERN SAN GABRIEL MOUNTAINS CALIFORNIA

By Harold C. Troxell and others

DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

UNITED STATES GEOLOGICAL SURVEY
W. E. Wrather, Director

HYDROLOGIC INVESTIGATIONS ATLAS HA 1

Prepared in cooperation with the San Bernardino County Flood Control District

Washington, D.C., 1954

For sale by the U.S. Geological Survey
Washington 25, D.C. — Price $3.50

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UNCONTROLLED PHOTOMOSAIC OF PARTS OF SAN BERNARDINO AND THE SAN BERNARDINO MOUNTAINS, CALIFORNIA

Scale $\frac{1}{31,680}$

1 0 2 Miles

INTRODUCTION

Man's successful occupancy and development of the arid and semiarid parts of the earth will always be a planned and slow process. Planning is necessary because the amount and distribution of the precipitation will generally not support the food crops to which he is accustomed. To provide the soil with enough moisture for crops, supplemental waters must be obtained from ground-water sources, distant surface streams, or from storage in mountain reservoirs. The planning, financing, and development of these supplemental sources require the united effort of many individuals, and as the population increases, water supplies that were once adequate may become insufficient. Thus, man is continually faced with the problem of obtaining enough water of high enough quality to meet his increasing demands. The problem requires an understanding of the natural laws of occurrence and distribution of the water in the air, on the earth's surface, and underground. All life is dependent on these sources of water.

The purpose of this atlas is to analyze, mostly by illustrations, the complicated pattern of the circulation of water in and above the San Bernardino and eastern San Gabriel Mountains of southern California, for these mountains are responsible for much of the moisture that reaches the crops in the agriculturally rich Upper Santa Ana Valley.

In this study the circulation of water, or the hydrologic cycle, as it is generally designated, can be considered as beginning in the Pacific Ocean. Cold Arctic air masses draining southward over the relatively warm ocean waters absorb through evaporation considerable amounts of moisture which is temporarily stored in the atmosphere as water vapor. Circulation of this moisture-laden air under varying conditions will cause its vapor to condense and fall as rain, snow, or dew.

Circulation of this air in the southern California coastal mountain areas is caused by the unequal temperatures existing among air masses and by the prevailing winds which lift these masses over mountains where lower temperatures cause the water vapor to precipitate. On being precipitated, the moisture is temporarily stored on the leaves of plants from which it may be evaporated or it is stored on the surface of the ground. Some of that stored on the surface of the ground will be evaporated and the rest will either move over the surface as storm runoff or will penetrate the soil and mantle rock. The precipitation that becomes storm runoff may be absorbed into the stream-bed gravels to recharge the ground-water storage or be artificially spread by irrigation channels to recharge this same ground-water storage or it may be passed into the ocean.

That part of the precipitation which is not evaporated from the surface of plants or the ground and which is not run off into the ocean first saturates the soil and then penetrates below the root zone of the plant cover to recharge ground-water storage. The soil moisture retained within the root zone returns to the atmosphere as water vapor through the process of evapotranspiration. Seepage from ground-water storage provides the summer, or dry season, flow in streams, which, with the water pumped from other ground-water storage bodies, is used for the domestic, industrial, and agricultural requirements of the area. After being used, the water may be returned to the air as vapor, returned to ground-water storage, or be passed into the ocean. Thus, all of the water is returned to the ocean or the atmosphere where it is available again for recirculation, or another hydrologic cycle.

Man's activity has considerably modified the complex interrelationships of the hydrologic cycle which has just been somewhat oversimplified. For example, large parts of the very absorptive mantle rock of the Upper Santa Ana Valley floor have been made, in effect, impermeable by street pavements, sidewalks, and the roofs of houses and other buildings. Storm runoff is no longer allowed to meander as it would over the absorptive valley floor, but is confined to narrow channels and speeded to the ocean. These modifications create a new chain of situations, some of which may be desirable and others unfortunate.

It is the intent of this atlas to show by simple graphic methods some of the important relationships among hydrologic factors in an effort to encourage a more efficient use of our water resources. The area studied is the San Bernardino and eastern San Gabriel Mountains and the adjacent Upper Santa Ana Valley in southern California. The mountains are part of the east-west system of coastal ranges whose north-facing slopes are generally tributary to the Great Basin and whose south-facing slopes drain into the Pacific. The Upper Santa Ana Valley is an irregularly shaped oblong valley with its long axis in an east-west direction parallel to that of the San Gabriel and San Bernardino Mountains. It comprises roughly the valley floor area of the Santa Ana River basin above the Santa Ana Canyon.

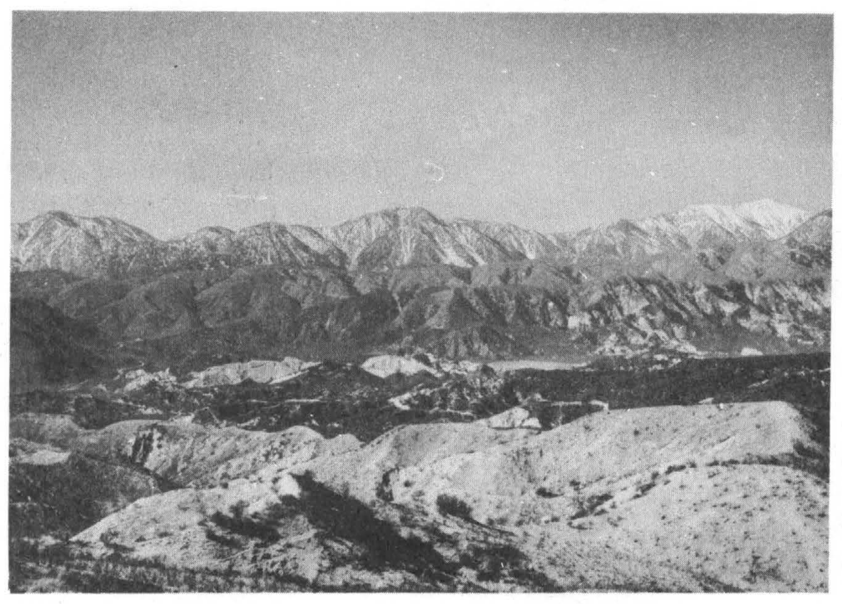
This atlas has been developed from an administrative report of the same title. In the preparation of both, the senior author was assisted by Harold V. Peterson, K. R. Melin, Marion B. Scott, P. Eldon Dennis, and Kenneth B. Garner, all of the United States Geological Survey, and by Jerome S. Horton of the California Forest and Range Experiment Station, United States Forest Service.

PHYSIOGRAPHY

PRINCIPAL LAND FORMS

A

The physiography of the region lying roughly 35 miles north and south of Los Angeles and extending about 100 miles inland from the Pacific Ocean determines in large measure the lives of its more than 4 million inhabitants. The more important land forms, larger streams, fault zones, and urban areas are shown in part A of this plate. The part of this region studied in the present report is outlined and will be called, for the purpose of this atlas, the "mountain area." It consists of the eastern San Gabriel Mountains, the San Bernardino Mountains, and their foothills.



The eastern San Gabriel Mountains, looking south from Cajon Pass

Immediately south of the mountain area are the agriculturally rich Upper Santa Ana Valley and Yucaipa-Beaumont plains. North of the mountain area is the vast Mojave Desert, potentially rich agriculturally if it had sufficient water.

Of the more important faults in and adjacent to the mountain area the San Andreas fault zone is the best known (also see frontispiece). It extends along the coast of California from a point north of San Francisco Bay to the Salton Sea area in southern California. This fault passes diagonally across the mountain area from the northwest corner to the southeast corner.

The main urban areas in the region lie between the mountain area and the ocean. Distances from Los Angeles, the largest city in the region, are shown by concentric circles.

TOPOGRAPHY

B

Many of the hydrologic influences affecting the water resources of the mountain area are directly associated with its land forms. For that reason, a topographic map of the San Bernardino Mountains and parts of the San Gabriel and San Jacinto Mountains is shown as part B.

EASTERN SAN GABRIEL MOUNTAINS

C

As shown in part C by the cross section *A—A'*, the San Gabriel Mountains are a series of upward-thrusted fault blocks of bold relief. The steep frontal mountain slopes (for a definition, see plate 2) on the southside of the mountain area represent a fault escarpment whose base forms a sharp line with the alluvial fill of the Upper Santa Ana Valley. This contact closely follows the 2,000-foot contour. On the north side of the mountain area the contact with the alluvium of the Mojave Desert at an altitude of about 5,000 feet is less well defined.

SAN BERNARDINO MOUNTAINS

D

Cross section *B—B'* of the San Bernardino Mountains shown in part D suggests that these mountains are also upward-thrusted fault blocks tilted northward. At an altitude of 2,000 to 3,000 feet the south-facing frontal slopes of the fault scarp form a distinct boundary with the valley floor alluvium of the Upper Santa Ana Valley and Yucaipa-Beaumont plains. On the Mojave Desert side of the mountain area the contact with the desert alluvium is at an altitude of near 4,000 feet.

Summit of San Antonio Peak (altitude 10,080 feet) from saddle (altitude 7,800 feet) between San Antonio Creek and North Fork Lytle Creek

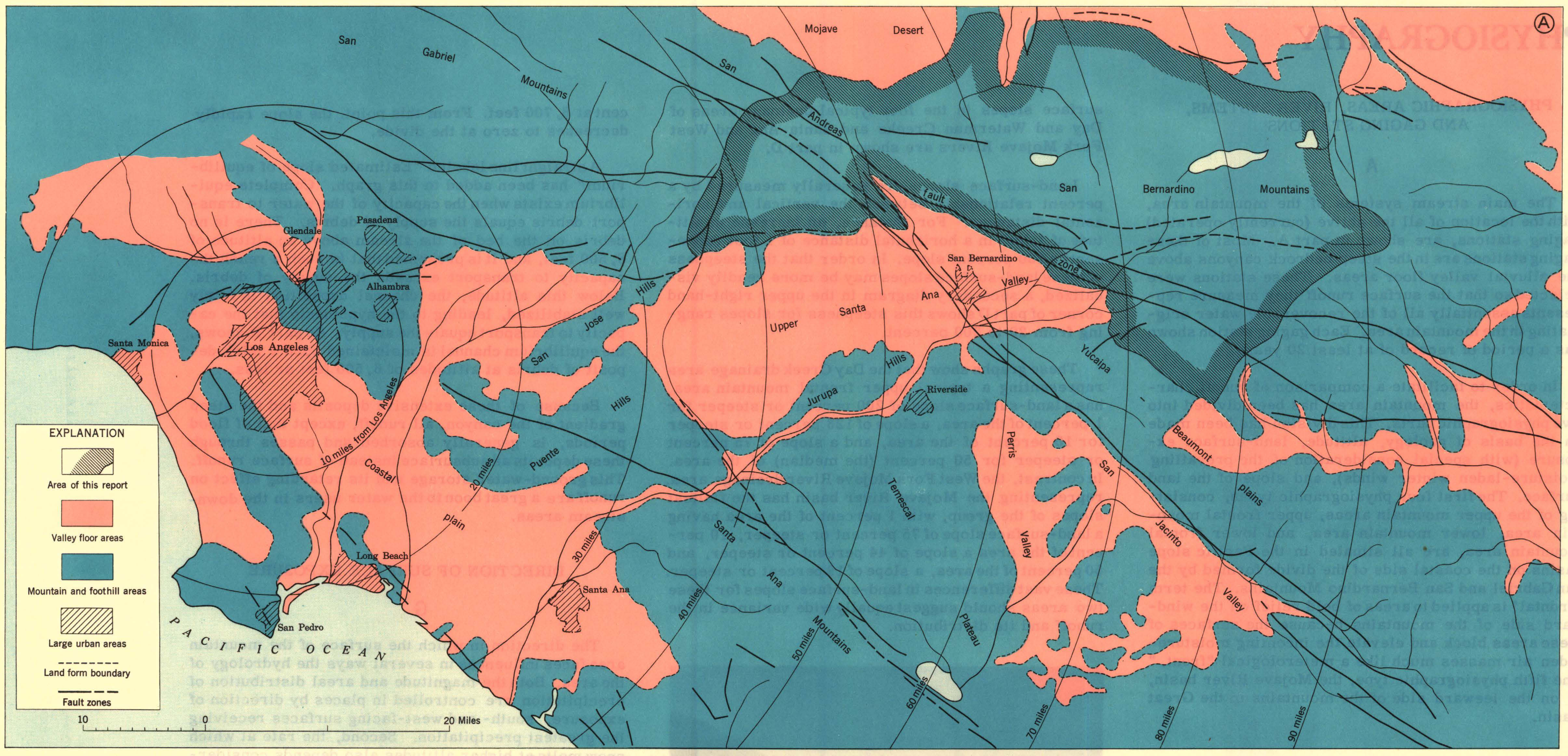
ALTITUDE DISTRIBUTION OF AREA

E and F

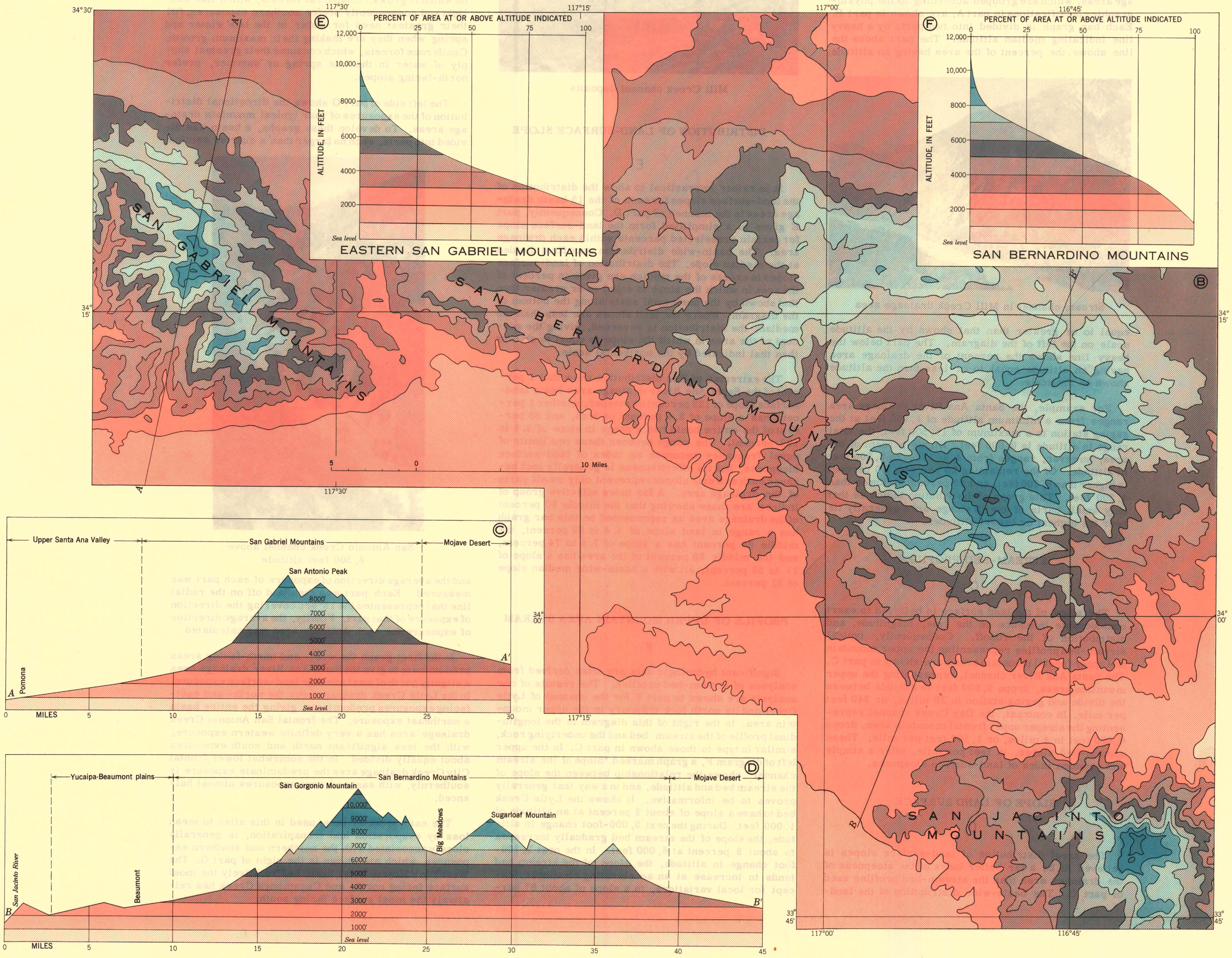
Altitude exerts considerable influence on hydrologic factors such as temperature and its effects. For this reason, the over-all relationships between area and altitude of the eastern San Gabriel and San Bernardino Mountains are given in parts E and F.

As shown in part E, this block of the eastern San Gabriel Mountains, lying about 40 miles inland from the ocean, ranges in altitude from 2,200 to 10,080 feet, and has a median altitude of 4,400 feet. The quartiles (25 percent and 75 percent) show that 50 percent of the area ranges from 3,200 to 5,800 feet.

Part F, which is a similar diagram, shows that the San Bernardino Mountains range in altitude from 1,300 to 11,500 feet, and have a median altitude of 5,300 feet. The quartiles show that 50 percent of the area has an altitude of 3,800 to 6,700 feet. On this basis, the San Bernardino Mountains are from 600 to 900 feet higher than the San Gabriel Mountains.



INDEX MAP SHOWING PRINCIPAL LAND FORMS



TOPOGRAPHY AND PROFILE SECTIONS

PHYSIOGRAPHY

PHYSIOGRAPHIC AREAS, RIVER SYSTEMS, AND GAGING STATIONS

A

The main stream systems of the mountain area, with the location of all the active (currently operated) gaging stations, are shown in part A. Most of these gaging stations are in the steep bedrock canyons above the alluvial valley floor areas. These stations were selected so that the surface runoff they measure represents essentially all of the recoverable water originating in the mountain area. Each gaging station shown has a period of record of at least 20 years.

In order to facilitate a comparison of runoff characteristics, the mountain area has been divided into five physiographic parts. This division has been made on the basis of geology, altitude, land-surface exposure (with special consideration of the prevailing moisture-laden winter winds), and slope of the land surface. The first four physiographic types, consisting of the upper mountain areas, upper frontal mountain area, lower mountain area, and lower frontal mountain area, are all situated in the Pacific slope basins on the coastal side of the divide formed by the San Gabriel and San Bernardino Mountains. The term "frontal" is applied to areas of bold relief on the windward side of the mountains because the surfaces of these areas block and elevate the incoming moisture-laden air masses much like a meterological "front." The fifth physiographic type, the Mojave River basin, is on the leeward side of the mountains in the Great Basin.

AREAL DISTRIBUTION OF ALTITUDE

B

The altitude distribution within each of the drainage areas, which are grouped according to the physiographic classifications in part A, are shown in part B. Each bar graph is divided into two parts by a heavy line indicating median altitude. The part above the line shows the percent of the area having an altitude equal to or greater than that shown by the altitude scale on the left of the diagram. The part below the heavy line shows the percent of the drainage area having an altitude equal to or less than the altitude shown on the scale.

Stream channel in Mill Creek drainage area

For example, the Santa Ana River drainage area ranges from a minimum altitude of 1,900 feet at the gaging station to a maximum of 11,500 feet; the total range in altitude is 9,600 feet. Eighty percent of the area, however, ranges from 4,200 feet to 8,300 feet in altitude. Of the remaining 20 percent, 10 percent is higher than 8,300 feet, and 10 percent is lower than 4,200 feet. This graph of distribution indicates that only small parts of the drainage area generally lie near the highest or lowest altitudes.

STREAM-BED PROFILES

C

The slope of the land surface is believed to exert considerable influence on the type, magnitude, and distribution of the runoff. Consequently, typical stream-bed profiles representing the upper mountain and upper frontal mountain areas are shown in part C. The Santa Ana River channel, representing the upper mountain areas, drops 9,600 feet in altitude between the divide and gaging station in 28 miles, or 340 feet per mile. In contrast, the Day Creek channel representing the steeper upper frontal mountain area, drops 6,000 feet in 4 miles, or 1,500 feet per mile. These stream-bed slopes, in feet per mile, offer a simple and common index of land-surface steepness.

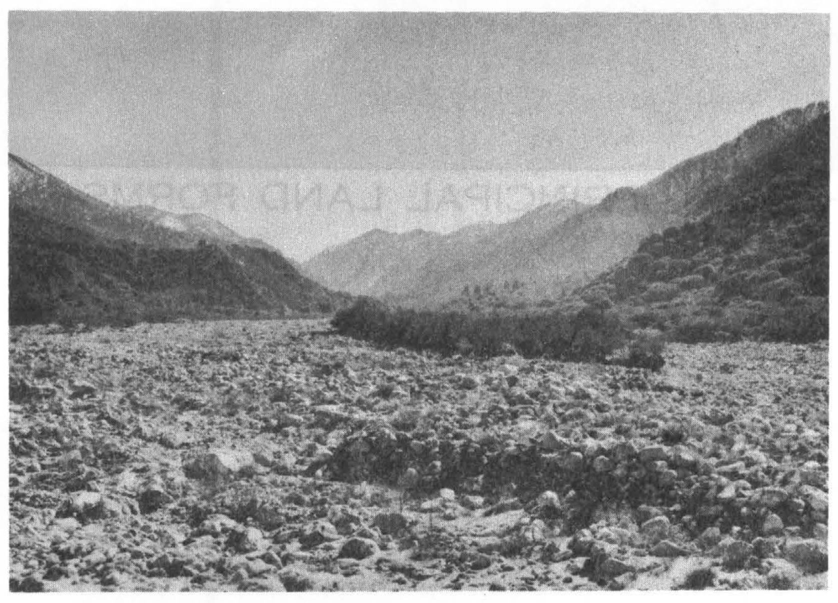
SLOPE OF LAND SURFACE

D

The areal distribution of land-surface slopes is believed to be a far better index of the steepness of the drainage area than the stream-bed profiles used in part C. The basin-wide distribution of the land-surface slopes in the four typical drainage areas of Day and Waterman Creeks and Santa Ana and West Fork Mojave Rivers are shown in part D.

Land-surface slopes are generally measured by a percent relationship between the vertical and horizontal distances. For instance, an increase in altitude of 1 foot in a horizontal distance of 1 foot represents a 100 percent slope. In order that the steepness of these land-surface slopes may be more readily visualized, a secondary diagram in the upper right-hand corner of part D shows this steepness for slopes ranging from 20 to 200 percent.

These graphs show that the Day Creek drainage area representing a typical upper frontal mountain area, has a land-surface slope of 200 percent or steeper for 1 percent of the area, a slope of 123 percent or steeper for 10 percent of the area, and a slope of 75 percent or steeper for 50 percent (the median) of the area. In contrast, the West Fork Mojave River drainage area, representing the Mojave River basin has the flattest slopes of the group, with 1 percent of the area having a land-surface slope of 75 percent or steeper, 10 percent of the area a slope of 44 percent or steeper, and 50 percent of the area, a slope of 19 percent or steeper. These vast differences in land-surface slopes for these two areas should suggest equally wide variance in the runoff and its distribution.



Mill Creek channel deposits

DISTRIBUTION OF LAND-SURFACE SLOPE

E

It is rather impractical to show the distribution of the land-surface slopes for each of the 15 basic drainage areas in the manner of part D. Consequently, part E gives in a simplified form the land-surface slope for certain preselected percents within each drainage area. The basin-wide distribution was first divided at the median slope. The distribution of land-surface slopes in excess of the median are given in percent of the area in which the slope is equal to or greater than that shown by the horizontal scale along the bottom of the diagram. Where the land slopes are less than the median, the distribution is reversed, giving the percent of the area in which the slope is equal to or less than that indicated by the horizontal scale.

The extremes of this distribution show that 1 percent of the Santa Ana River drainage area has a land-surface slope of 122 percent or steeper, another 1 percent has a slope of 2.4 percent or less, and 98 percent of the entire basin has a range in slope of 2.4 to 122 percent. The range between these two limits of equal frequency becomes an index of land-surface steepness, but its effectiveness is generally lost because such extreme slopes represent only small parts of the drainage area. A far more effective group of indices are those showing that the middle 90 percent of the drainage area as represented on this bar graph has a range in land slope of 4.6 to 89 percent, the middle 80 percent has a slope of 7.5 to 74 percent, and the middle 60 percent of the area has a slope of 11 to 59 percent, all with a basin-wide median slope of 31 percent.

PROFILE OF UPPER MOUNTAIN AREA STREAM

F

Significant hydrologic data are often derived from analyses of stream-bed profiles. The results of one analysis are shown in part F for the channel of Lytle Creek and its north fork tributary in the upper mountain area. In the right of this diagram is the longitudinal profile of the stream bed and the underlying rock, similar in type to those shown in part C. In the upper left of diagram F, a graph marked "Slope of the stream channel" shows the relationship between the slope of the stream bed and altitude, and in a way that generally proves to be informative. It shows the Lytle Creek bed to have a slope of about 2 percent at an altitude of 1,000 feet. During the next 5,000-foot change in altitude, the slope of the stream bed gradually increases to about 8 percent at 6,000 feet. In the next 2,700-foot change in altitude, the slope of the stream bed tends to increase at an accelerating steepness, except for local variations, to a slope of about 87 percent at 8,700 feet. From this point, the slope rapidly decreases to zero at the divide.

A straight line labeled "Estimated slope of equilibrium" has been added to this graph. Complete equilibrium exists when the capacity of the water to transport debris equals the supply of debris. There is no debris on the bed of the stream above an altitude of 6,500 feet, and it is presumed that in such a reach the capacity to transport exceeds the supply of debris. Below this altitude, the channel deposition is fairly well stabilized, leading to the hypothesis that the capacity to transport equals the supply. As part F shows, the equilibrium channel is maintained upon a thick deposit of debris at altitudes of 6,500 feet or less.

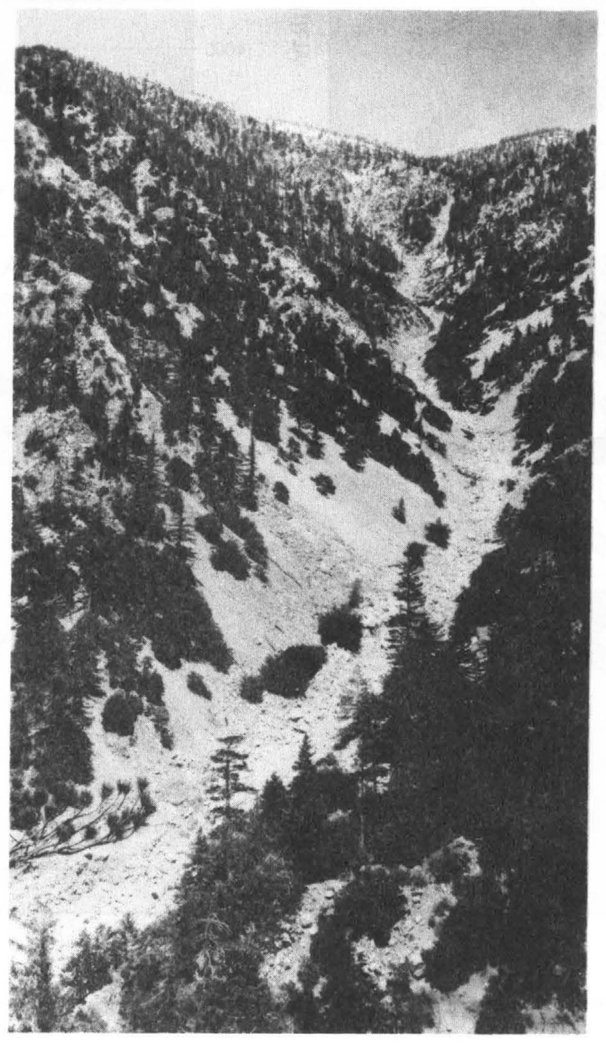
Because of these extensive deposits and the steep gradient of the canyon, all runoff, except that of flood periods, is generally absorbed and passes through these deposits as subsurface instead of surface runoff. This ground-water storage and its retarding effect on runoff are a great boon to the water users in the downstream areas.

DIRECTION OF SURFACE EXPOSURE

G

The direction in which the surface of the mountain area faces influences in several ways the hydrology of the area. Both the magnitude and areal distribution of precipitation are controlled in places by direction of exposure, south- and west-facing surfaces receiving the greatest precipitation. Second, the rate at which snow melts at higher altitudes also depends considerably on the direction in which the land surface faces. Third, the sun accelerates the rate of evaporation especially from the south-facing slopes, and from these facing east and west. And fourth, plant life is determined in part by the direction of slope of the land on which it grows. Chaparral forests, which like sunlight and consequently prefer southern exposures, fill their greatest need for water in the late winter and spring when they are making their maximum growth. Coniferous forests, which consume their greatest supply of water in the late spring or summer, prefer north-facing slopes.

The left side of part G shows the directional distribution of the exposures of four typical mountain drainage areas. To develop these graphs, a basin was divided into parts, each no larger than a quarter section,

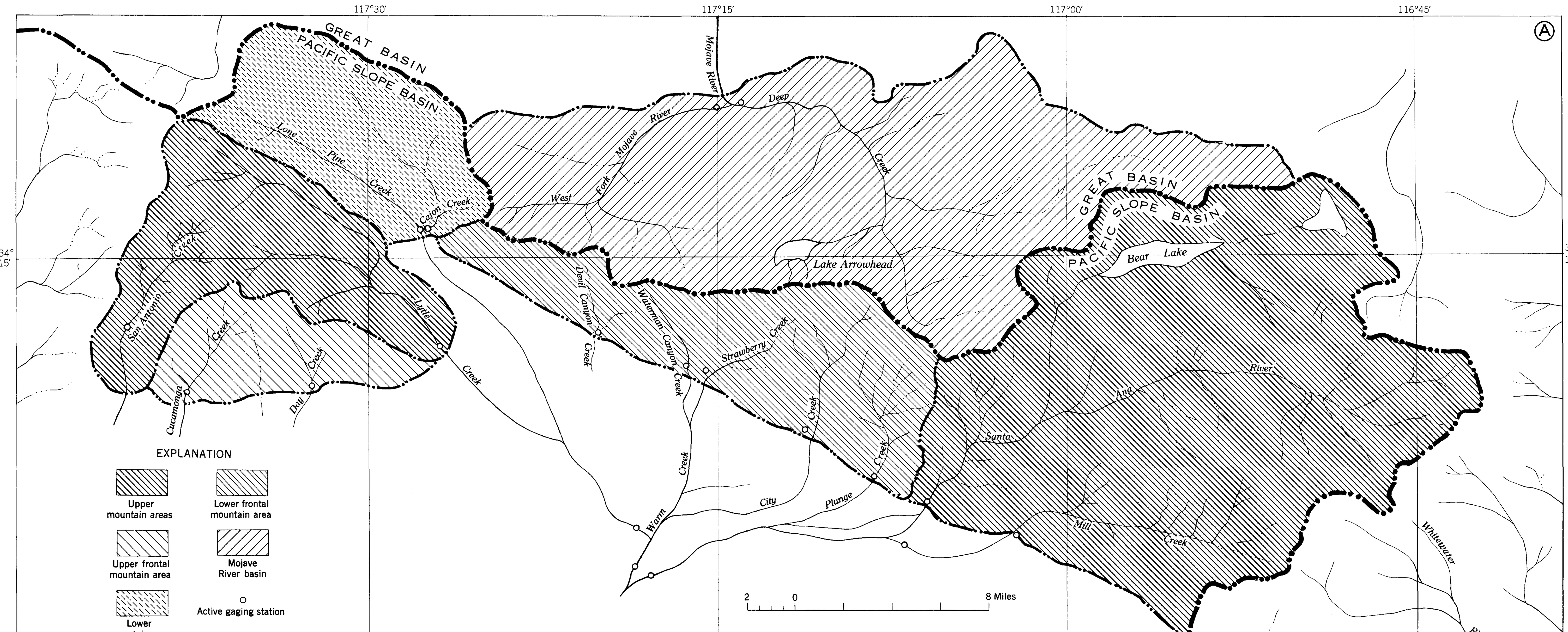


San Antonio Creek channel above
6,500 feet altitude

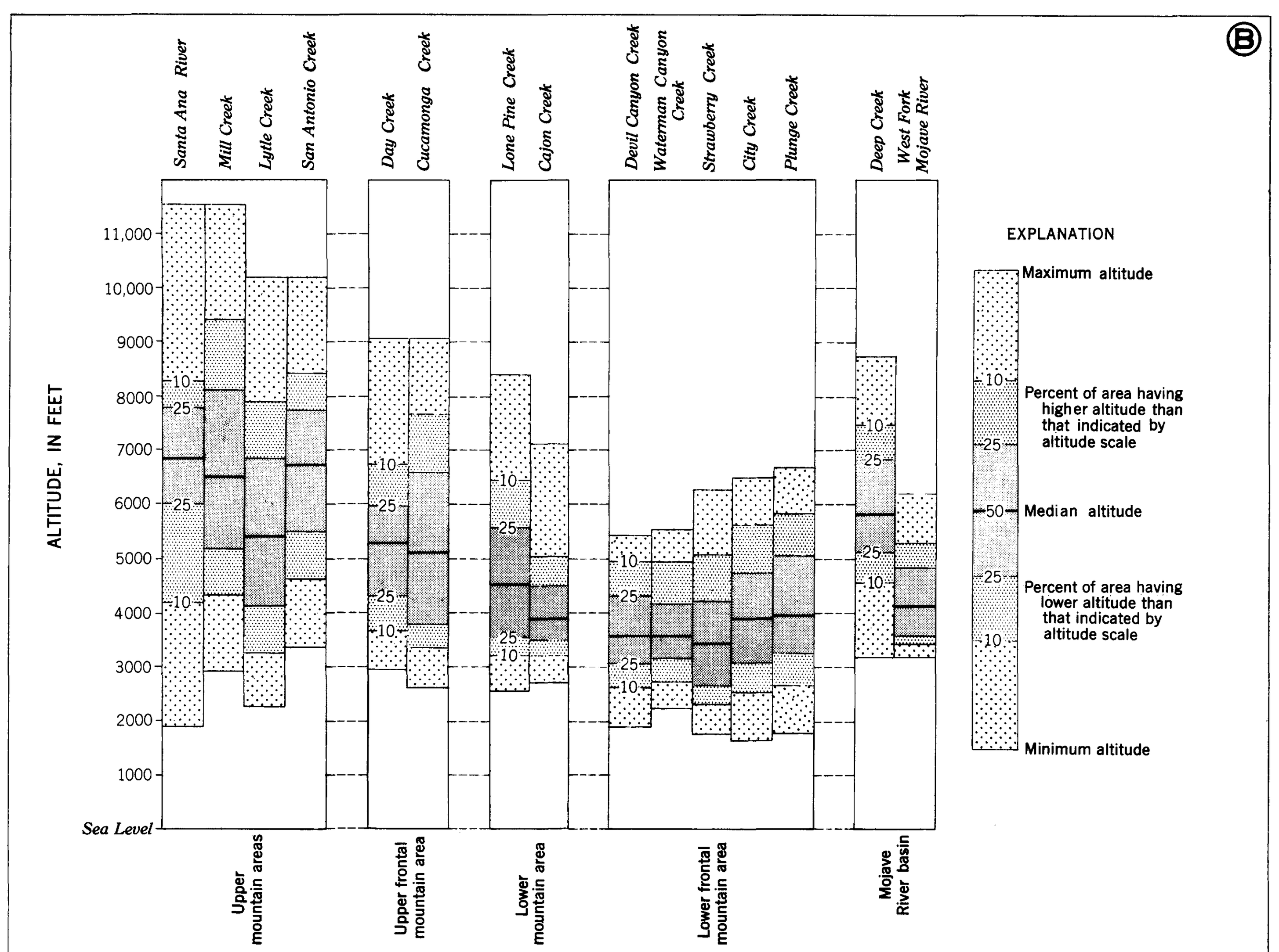
and the average direction of exposure of each part was measured. Each part was then laid off on the radial line that represented the 15° arc covering the direction of exposure of that part. Finally, the average direction of exposure for each drainage area was calculated.

In the first graph the west- and north-facing areas predominate to give the Santa Ana River drainage area a slightly north of west average land-surface exposure. In the Lytle Creek drainage area the north- and east-facing exposures predominate, giving the entire basin a northeast exposure. The frontal San Antonio Creek drainage area has a very definite western exposure, with the less significant north and south exposures about equally divided. In the somewhat lower frontal City Creek drainage area the predominate exposure is southernly, with east and west exposures almost balanced.

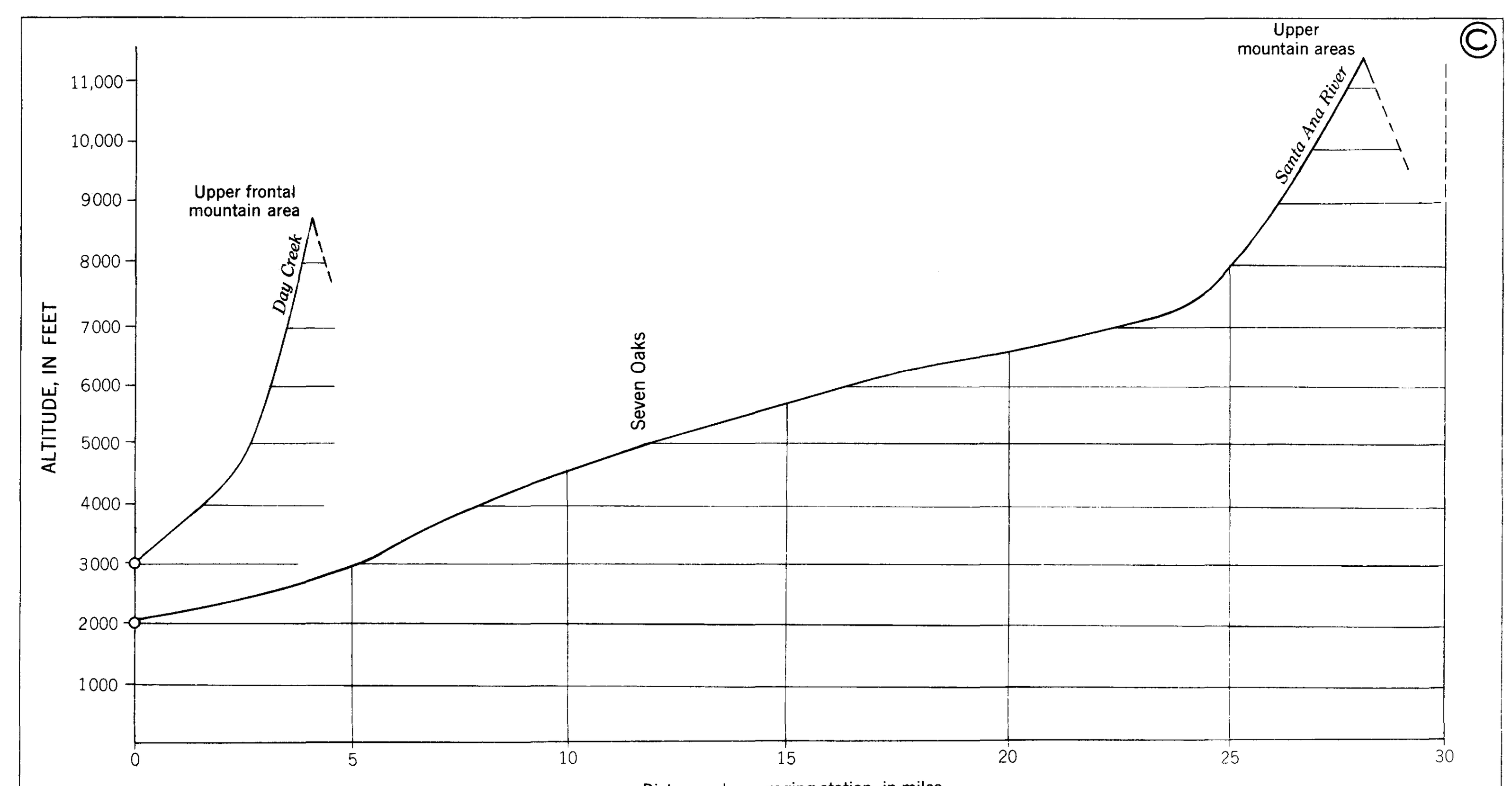
The natural water loss, used in this atlas to mean loss by evaporation and transpiration, is generally closely associated with the northern and southern exposures, which are shown in the right of part G. The West Fork Mojave River basin has relatively the most surface facing north, and Cucamonga Creek has relatively the most surface facing south.



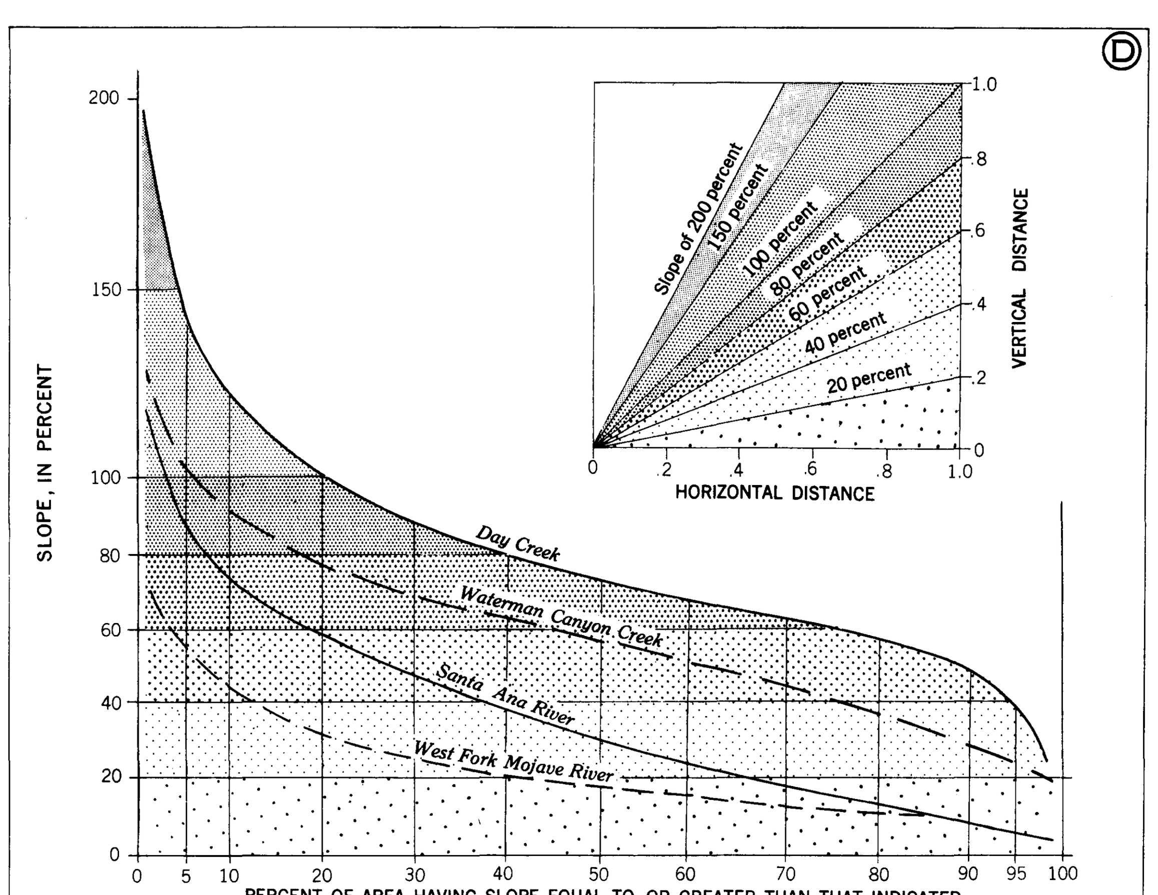
PHYSIOGRAPHIC AREAS, RIVER SYSTEMS, AND GAGING STATIONS



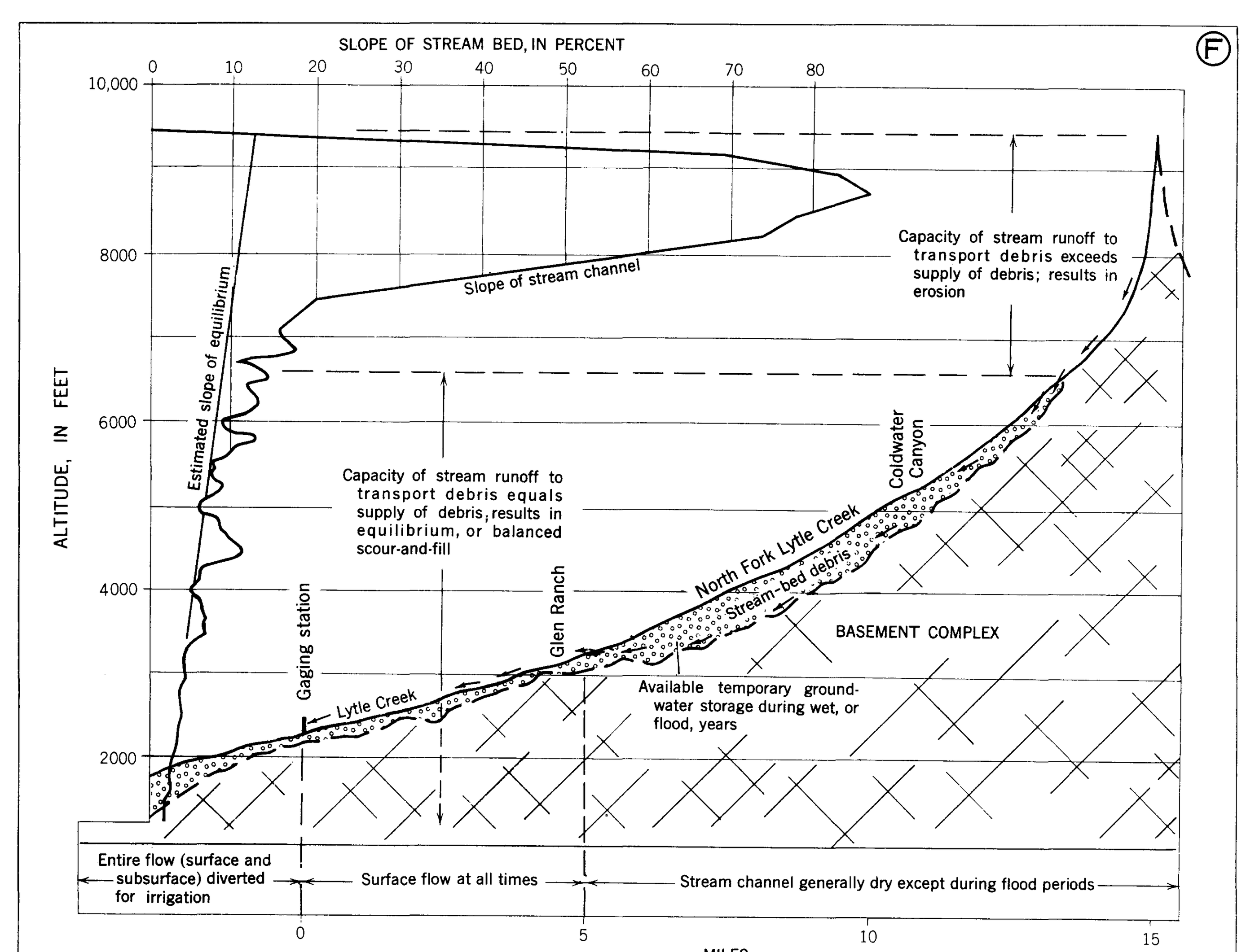
AREAL DISTRIBUTION OF ALTITUDE



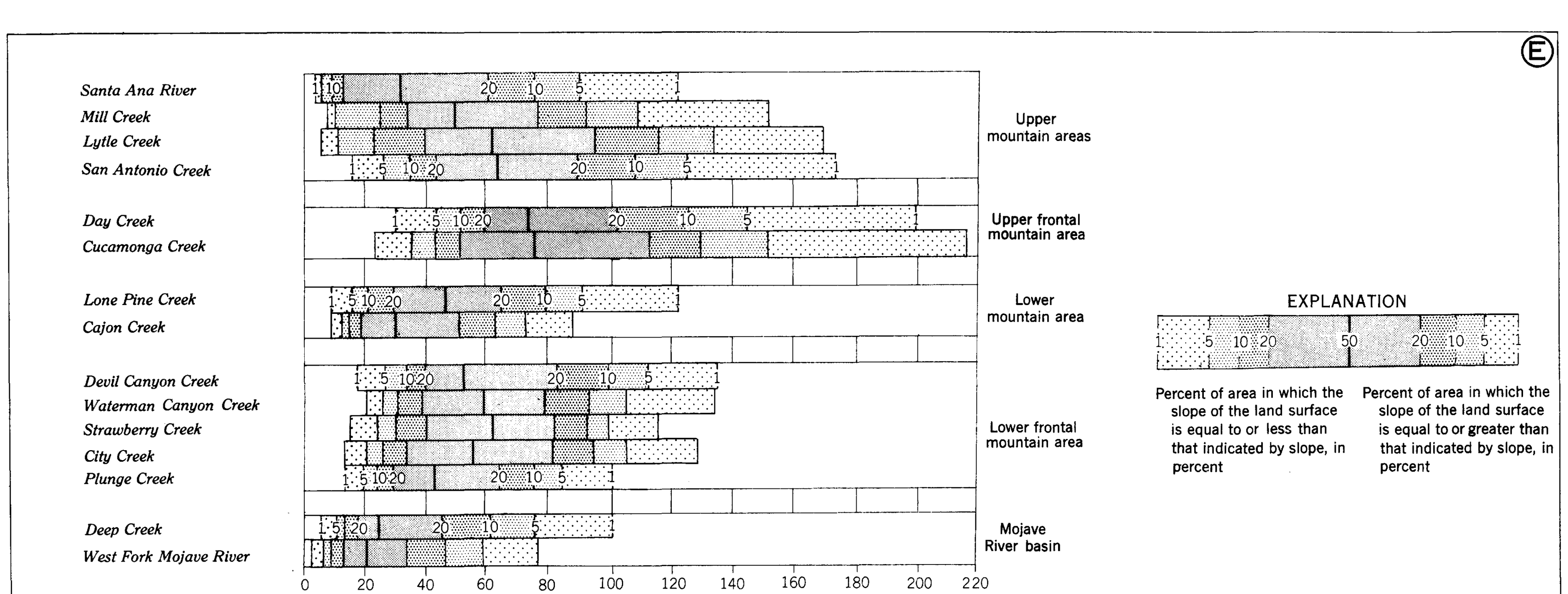
TYPICAL STREAM-BED PROFILES



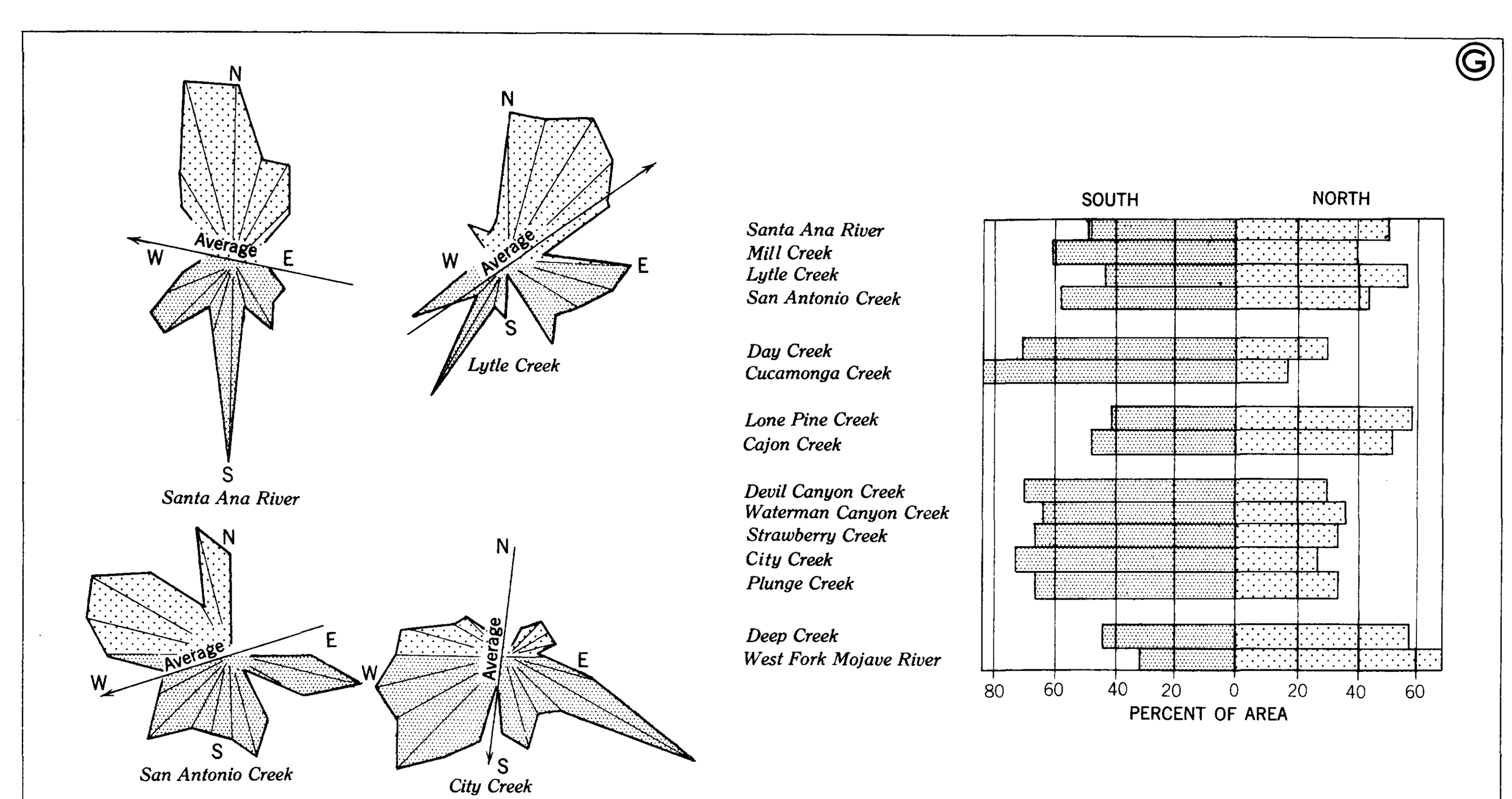
SLOPE OF LAND SURFACE



STREAM PROFILE IN TYPICAL UPPER MOUNTAIN AREA



DISTRIBUTION OF LAND SURFACE SLOPE



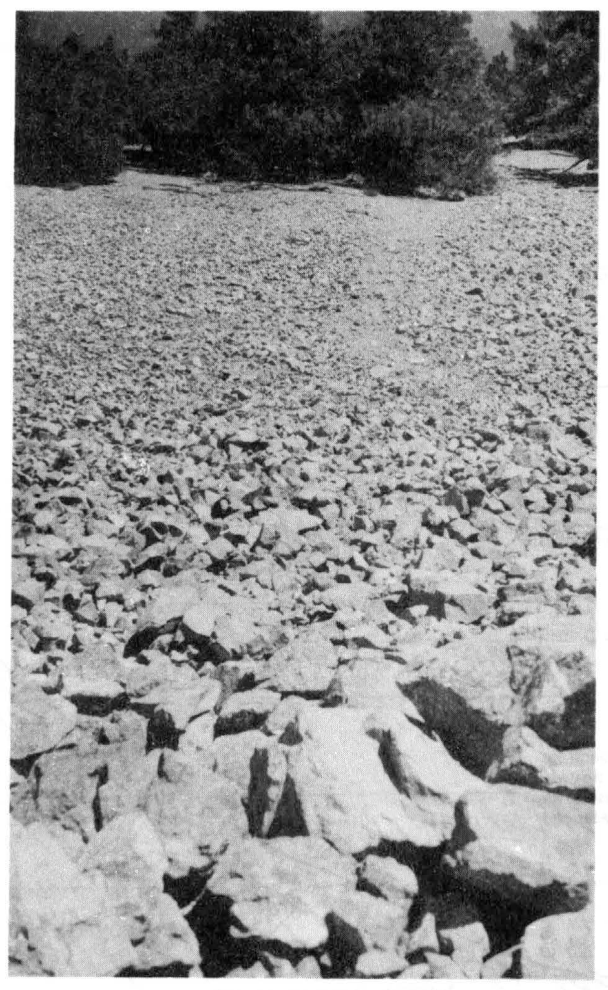
DIRECTION OF SLOPE OF LAND SURFACE

GEOLOGY

A

One of the major factors affecting the recoverable waters is the geology of the mountain area: the character, depth, and absorptive and retentive qualities of the mantle rock, and the fracturing of the bedrock. The amount of ground-water storage and the seepage from it depend on the geology of the area.

For these reasons a geologic map showing the principal igneous, metamorphic, and sedimentary rocks in the mountain area is included (part A). In age these rocks range from pre-Cambrian (?) to Recent. In texture they range from felsites and andesite to gravels containing boulders several feet in diameter. In many parts of the mountain area, particularly near faults and in fault zones, the indurated rocks have been fractured and broken to a remarkable degree; but in other localities where jointing and fracturing are of only ordinary intensity, the rocks retain much of their original texture and have a minimum number of cracks or other types of openings. Soils and other weathered products derived from the slow disintegration and decomposition of these rock types are likewise variable in character and composition. Some are coarse, granular, and porous; others contain a high percent of silt and clay, and are dense and impervious. It is thus obvious that the hydrologic characteristics of these mountain drainage areas will vary between wide limits, depending upon the properties of the rock mantle and underlying bedrock to absorb, store, and transmit the precipitation falling on the surface of the land.

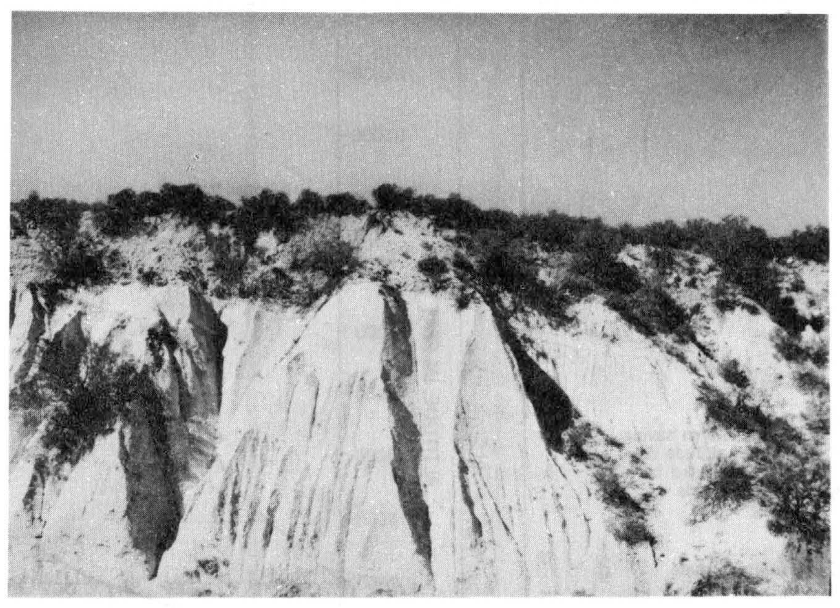


Talus deposits in the San Antonio Creek drainage area, representing the most absorptive and retentive type of mantle rock

HYDROLOGIC CHARACTERISTICS OF THE MANTLE ROCK

B

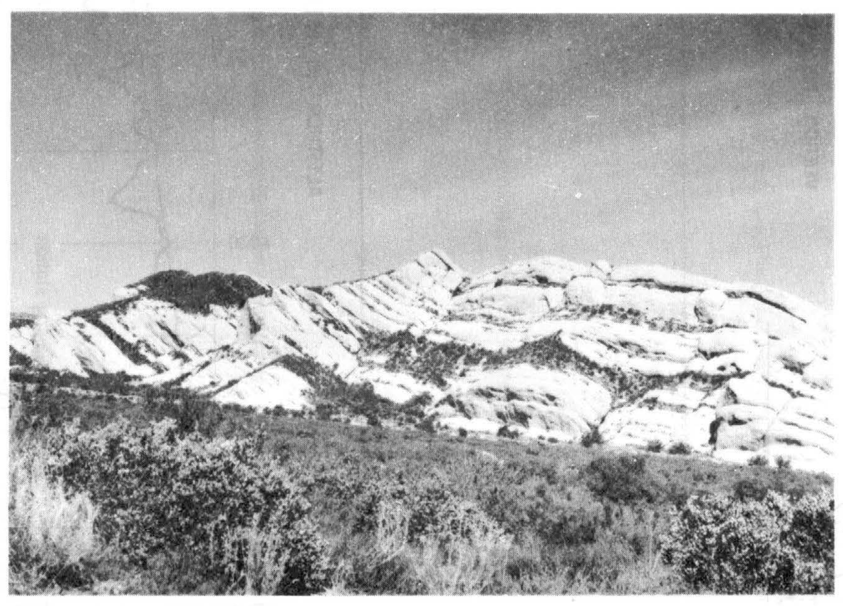
The hydrologic properties of the mantle rock are at times almost indeterminate because of the many and varied structural features affecting the character of the rock. Futhermore, weathering due to humidity, temperature, and exposure further influence these hydrologic properties. The combined effect of all these factors is so complex that a field inspection will often not disclose these hydrologic properties. In fact, the only satisfactory method of determining them is by detailed analysis of precipitation and runoff. Runoff is affected by the absorptive and retentive qualities of the mantle rock, by the soil moisture deficiencies in this rock before each storm, and by the availability



Horsethief formation in the Cajon Creek drainage area, representing the least absorptive and retentive type of mantle rock

of mountain ground-water storage. The observed distribution of runoff over a long period of time in any area indicates the composite effect of these factors.

Many of the factors involved are so intangible that it is impossible to give them finite values. Consequently, a simple relative index has been developed for use within the mountain area. A "most absorptive and retentive mantle rock" in the mountain area is identified by comparatively low flood runoff and high summer drought runoff. A "least absorptive and retentive mantle rock" tends to produce, under identical conditions of precipitation, excessive flood runoff and a low summer runoff. A third classification of "moderately absorptive and retentive mantle rock" has been used to represent an intermediate stage of relatively moderate flood and summer runoff.



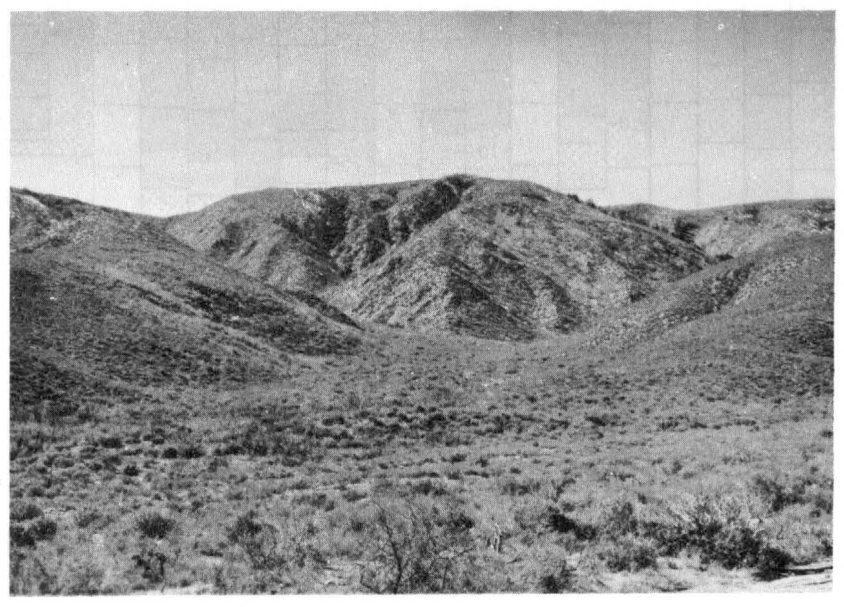
Cajon formation in the Cajon Creek drainage area, representing the least absorptive and retentive type of mantle rock

It has been possible to obtain the areal distribution of these hydrologic characteristics by assuming that the amount and time of runoff in each drainage area is influenced by the predominate rock types. On the basis of this assumption, certain hydrologic qualities are assigned to the following rock types:

Most absorptive and retentive mantle rock
- Alluvium, Recent and older
- Landslide
- Pelona schist
- Talus
- Till, glacial
- Undifferentiated crystalline rocks

Moderately absorptive and retentive mantle rock
- Furnace limestone
- Heterogeneous plutonic rocks
- Saragossa quartzite

Least absorptive and retentive mantle rock
- Cajon formation
- Granitic rocks
- Horsethief formation
- Potato sandstone
- Santa Ana sandstone



Pelona schist in the Lone Pine drainage area, representing the most absorptive and retentive type of mantle rock

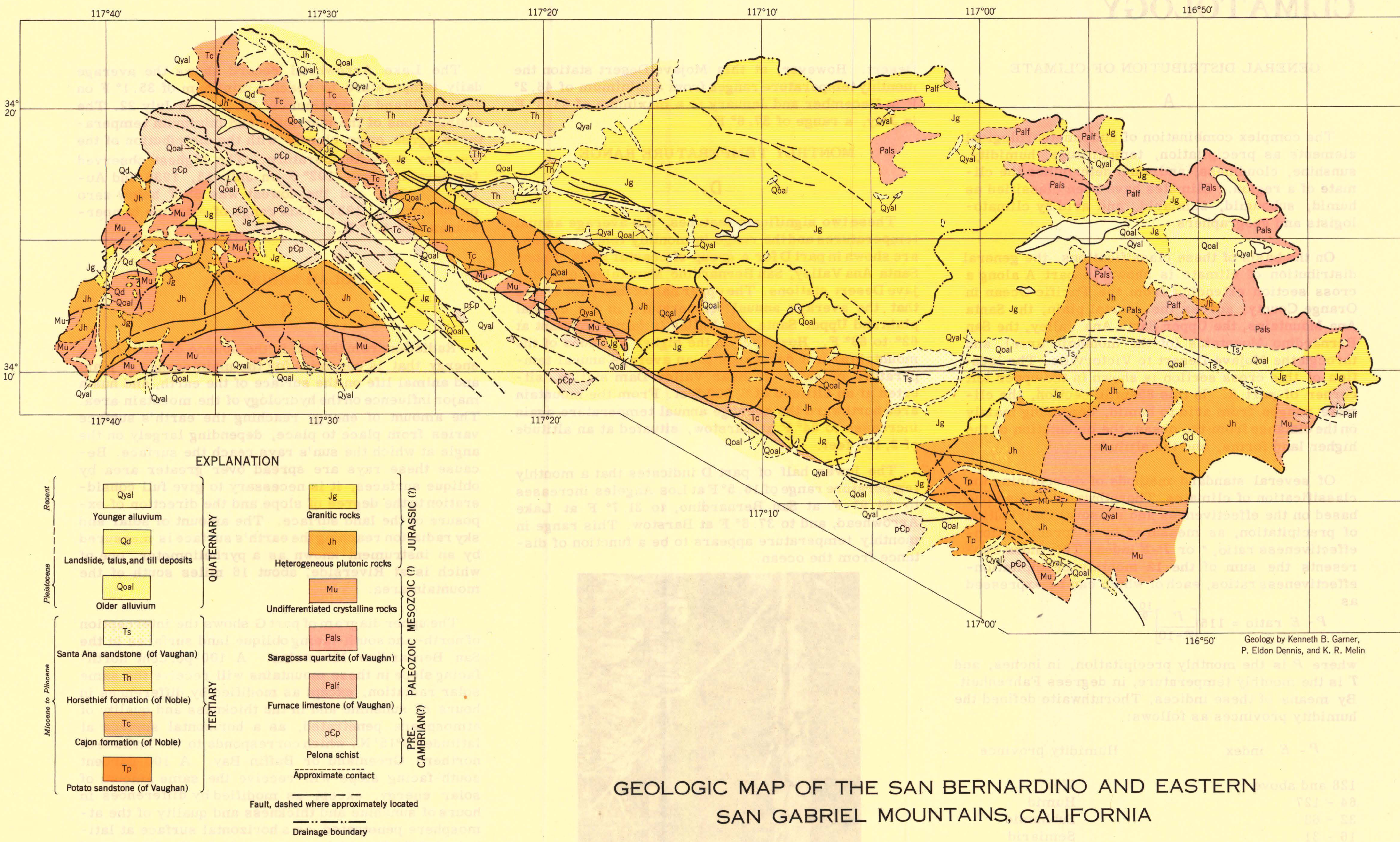
These classifications are always subject to considerable modification depending on the extent of the local faulting and fracturing in the mountain block.

The distribution of the hydrologic classifications of the mantle rock is shown in part B. Superimposed are the boundaries for the 15 main drainage areas.

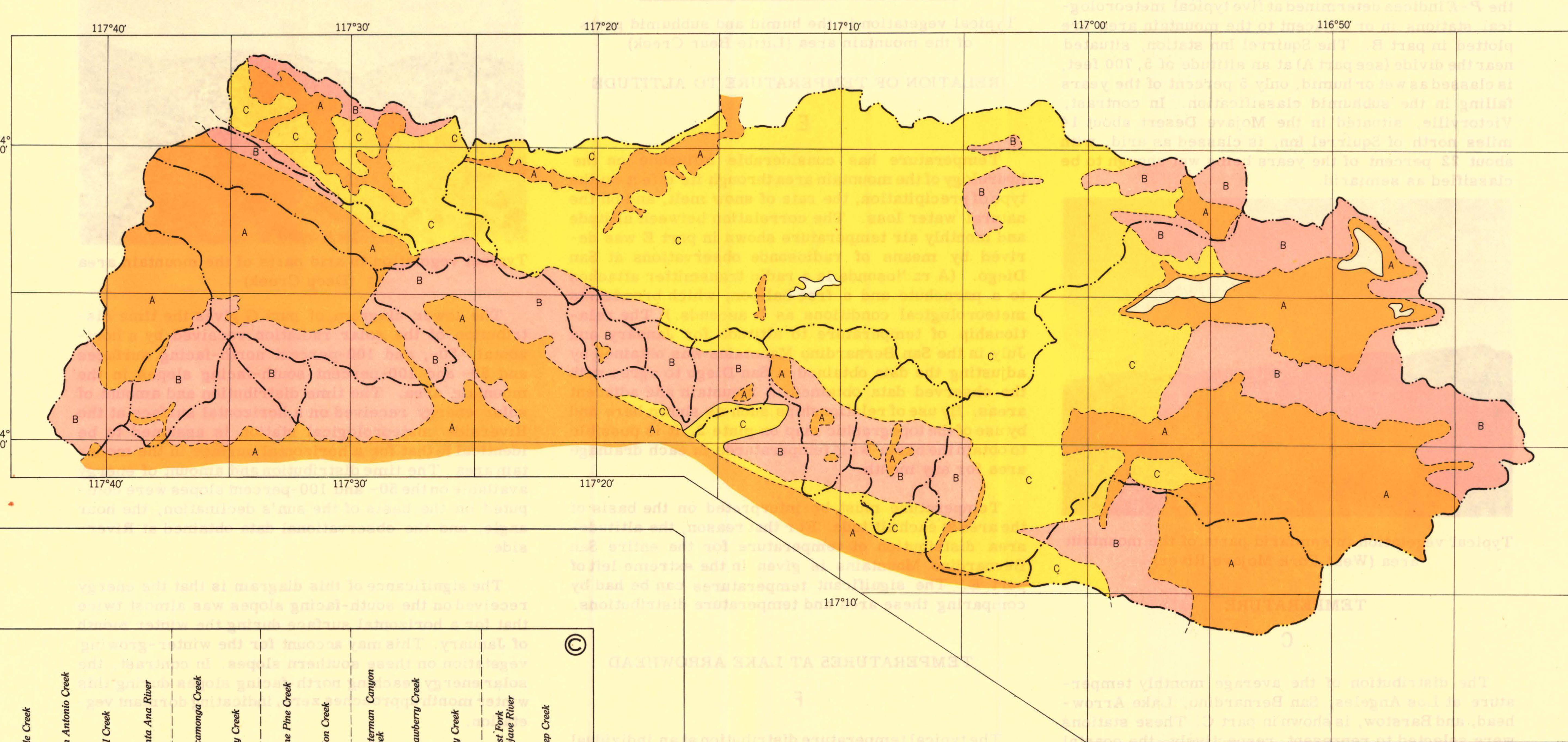
DISTRIBUTION OF TYPES OF MANTLE ROCK

C

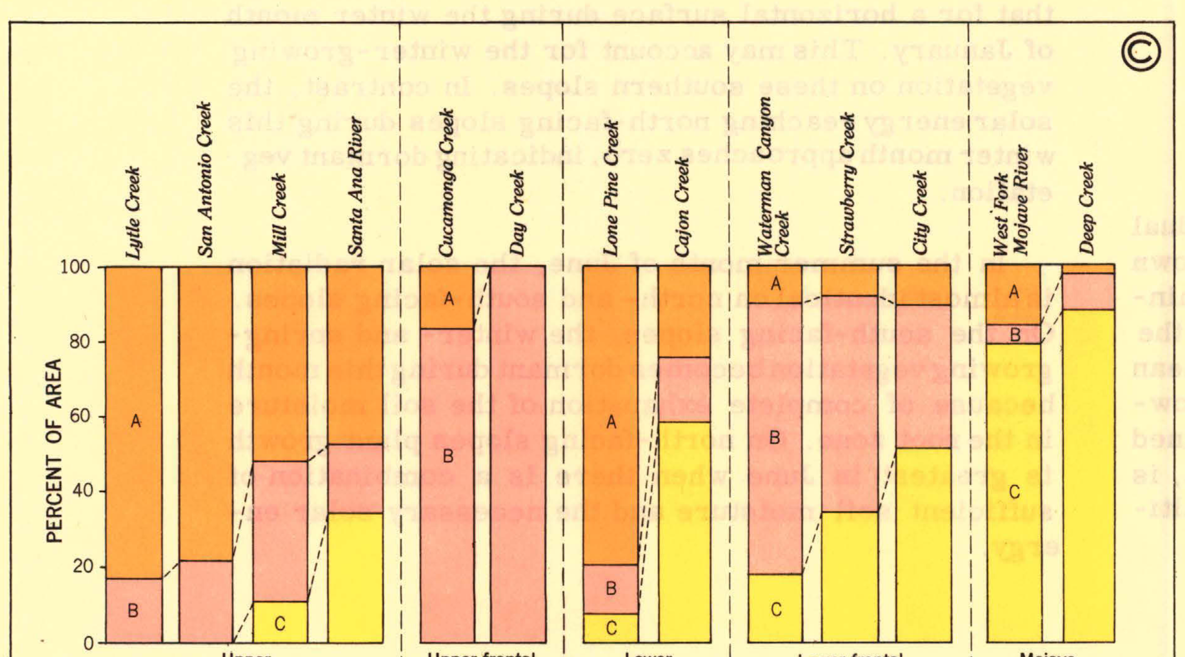
The basin-wide distribution of the mantle rock of varying hydrologic qualities is shown in part C for 13 drainage areas. The drainage areas are grouped according to physiographic units. From left to right the areas, in general, range from those having the most absorptive and retentive mantle rock to those having the least absorptive and retentive mantle rock. Letter symbols are those of part B.



GEOLOGIC MAP OF THE SAN BERNARDINO AND EASTERN SAN GABRIEL MOUNTAINS, CALIFORNIA



GENERAL HYDROLOGIC CHARACTERISTICS OF THE MANTLE ROCK



DISTRIBUTION OF HYDROLOGIC CHARACTERISTICS OF THE MANTLE ROCK

CLIMATOLOGY

GENERAL DISTRIBUTION OF CLIMATE

A

The complex combination of such meteorological elements as precipitation, temperature, humidity, sunshine, cloudiness, and wind determines the climate of a region. Climates have been classified as humid, subhumid, semiarid, and arid by climatologists and geographers.

On the basis of these classifications, the general distribution of climate is shown in part A along a cross section extending from the Pacific Ocean in Orange County, across the coastal plain, the Santa Ana Mountains, the Upper Santa Ana Valley, the San Bernardino Mountains (of the mountain area), and through the Mojave Desert to Victorville. The location of this cross section is shown in the upper left corner of part A. In this 85-mile section, the climate ranges from arid to humid, depending mainly on the distance from the ocean, the orientation of the higher land forms, and the altitude.

Of several standard methods of determining the classification of climates, Thornthwaite devised one based on the effectiveness and seasonal distribution of precipitation, as measured by a "precipitation-effectiveness ratio," or ***P-E* index**. This index represents the sum of the 12 monthly precipitation-effectiveness ratios, each of which can be expressed as

$$P\text{-}E \text{ ratio} = 115\left[\frac{P}{T-10}\right]^{\frac{10}{9}}$$

where P is the monthly precipitation, in inches, and T is the monthly temperature, in degrees Fahrenheit. By means of these indices, Thornthwaite defined the humidity provinces as follows:

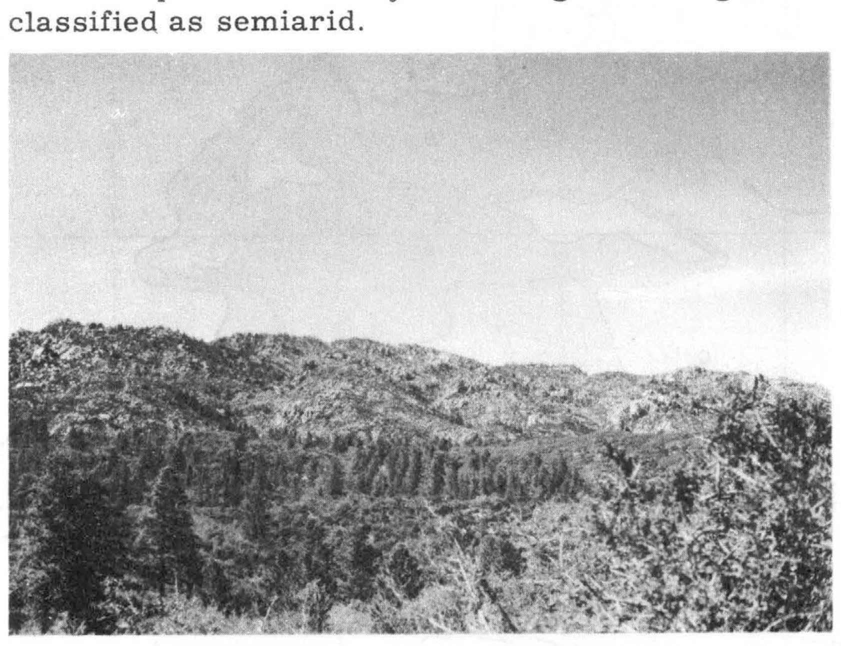
P - E index	Humidity province
128 and above	Wet
64 - 127	Humid
32 - 63	Subhumid
16 - 31	Semiarid
Less than 16	Arid

The system of classification has been the basis for climatic determination in this atlas.

VARIATIONS IN CLIMATIC TYPES

B

Because precipitation and temperature vary considerably from year to year, a similar degree of variation is to be expected in the annual classifications of climate. To indicate variations, frequency curves of the *P-E* indices determined at five typical meteorological stations in or adjacent to the mountain area are plotted in part B. The Squirrel Inn station, situated near the divide (see part A) at an altitude of 5,700 feet, is classed as wet or humid, only 5 percent of the years falling in the subhumid classification. In contrast, Victorville, situated in the Mojave Desert about 14 miles north of Squirrel Inn, is classed as arid, with about 22 percent of the years being wet enough to be classified as semiarid.



Typical vegetation in semiarid parts of the mountain area (West Fork Mojave River)

TEMPERATURE

C

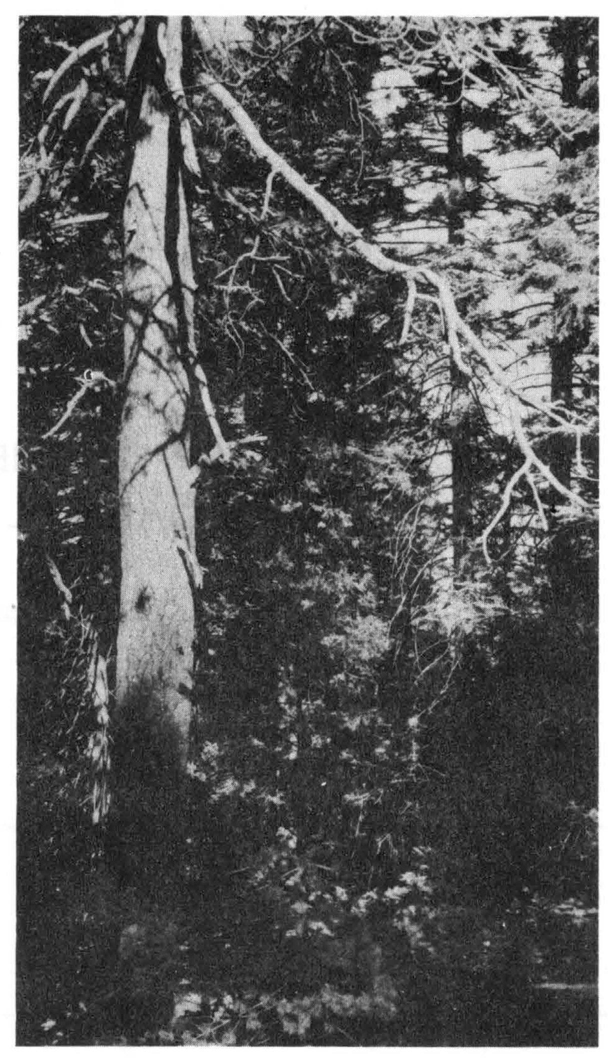
The distribution of the average monthly temperature at Los Angeles, San Bernardino, Lake Arrowhead, and Barstow, is shown in part C. These stations were selected to represent, respectively, the coastal plain, the Upper Santa Ana Valley, the mountain area, and the Mojave Desert. Because of coastal influences, the average monthly temperature at Los Angeles ranges from a minimum of 54.6° F in January to a maximum of 71.1° F in August, or a range of 16.5°F. The average annual temperature of 62.4° F at Los Angeles is only 1.4° F lower than the average annual temperature at Barstow, situated about 30 miles northeast of Victorville and representing the Mojave Desert. However, at this Mojave Desert station the monthly temperature ranges from a minimum of 46.2° F in December and January to a maximum of 83.8° F in July, a range of 37.6° F.

MONTHLY TEMPERATURE RANGE

D

These two significant features, the average annual temperatures and the range in monthly temperatures, are shown in part D for a group of coastal plain, Upper Santa Ana Valley, San Bernardino Mountains, and Mojave Desert stations. The upper half of this part shows that the average annual temperature in the coastal plain and Upper Santa Ana Valley is fairly constant at 62° to 63° F. However, in the higher altitudes of the mountain area it decreases to an average annual temperature of 45° F at Bear Valley Dam station, situated at an altitude of 6,850 feet. From the mountain area northward the average annual temperature again increases to 64° F at Barstow, situated at an altitude of 2,100 feet.

The lower half of part D indicates that a monthly temperature range of 16.5° F at Los Angeles increases to 24.9° F at San Bernardino, to 31.7° F at Lake Arrowhead, and to 37.6° F at Barstow. This range in monthly temperature appears to be a function of distance from the ocean.



Typical vegetation in the humid and subhumid parts of the mountain area (Little Bear Creek)

RELATION OF TEMPERATURE TO ALTITUDE

E

Temperature has considerable influence on the hydrology of the mountain area through its effect on the type of precipitation, the rate of snow melt, and on the natural water loss. The correlation between altitude and monthly air temperature shown in part E was derived by means of radiosonde observations at San Diego. (A radiosonde is a radio transmitter attached to a parachute and a free balloon, which broadcasts meteorological conditions as it ascends.) The relationship of temperature to altitude for January and July in the San Bernardino Mountains was obtained by adjusting the data obtained at San Diego to agree with the observed data obtained in mountain and adjacent areas. By use of relationships such as shown here and by use of the topographic map on plate 2, it is possible to obtain the basin-wide temperatures in each drainage area for any month.

Temperature must be interpreted on the basis of the area at each altitude. For that reason, the altitude-area distribution of temperature for the entire San Bernardino Mountains is given in the extreme left of part E. The significant temperatures can be had by comparing these area and temperature distributions.

TEMPERATURES AT LAKE ARROWHEAD

F

The typical temperature distribution at an individual meteorological station in the mountain area is shown in part F. This diagram gives the maximum and minimum temperatures observed, the average of all the maximum and minimum temperatures, and the mean temperature for each day of the year at Lake Arrowhead for the period 1922 to 1942. The record obtained at this station, situated at an altitude of 5,150 feet, is believed to be typical of the mountain area at this altitude.

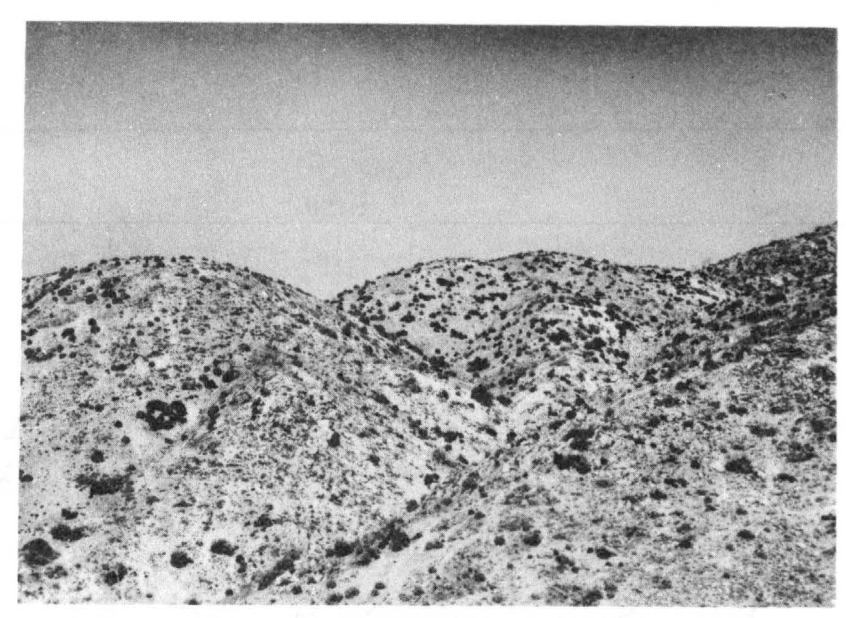
The Lake Arrowhead record shows the average daily temperature to reach a minimum of 35.1° F on January 20 and a maximum of 73.1° F on July 22. The distributions of the maximum and minimum temperatures agree quite closely with the distribution of the average daily temperature. The highest observed temperature was 102° F on July 15, 1936 and August 1, 1938, and the lowest was 5° F below zero on January 21, 1937. This range of extreme temperatures was 107° F.

SOLAR RADIATION

G

Radiation from the sun is the source of most of the energy that is essential for the maintenance of plant and animal life on the surface of the earth, and has a major influence on the hydrology of the mountain area. The amount of energy reaching the earth's surface varies from place to place, depending largely on the angle at which the sun's rays reach the surface. Because these rays are spread over greater area by oblique surfaces, it is necessary to give full consideration to the degree of slope and the direction of exposure of the land surface. The amount of solar and sky radiation reaching the earth's surface is measured by an instrument known as a pyrheliometer, one of which is at Riverside, about 16 miles south of the mountain area.

The upper diagram of part G shows the interception of north- and south-facing oblique land surfaces in the San Bernardino Mountains. A 100-percent north-facing slope in these mountains will receive the same solar radiation, except as modified by differences in hours of sunshine and in the thickness and quality of atmosphere penetrated, as a horizontal surface at latitude 79°15' N., which corresponds to the latitude of northern Greenland or Baffin Bay. A 100-percent south-facing slope will receive the same amount of solar energy, except as modified by differences in hours of sunshine and thickness and quality of the atmosphere penetrated, as a horizontal surface at latitude 10°45' S., which corresponds to the latitude of central Peru, northern Bolivia, and central Brazil. Surface slopes of 100 percent in the mountain area occur as small isolated units, and the solar energy they receive has only a very minor effect on the area. However, as the slopes of the mountain area flatten, the influences of solar radiation become more significant, because of the increased percent of area having flatter slopes.

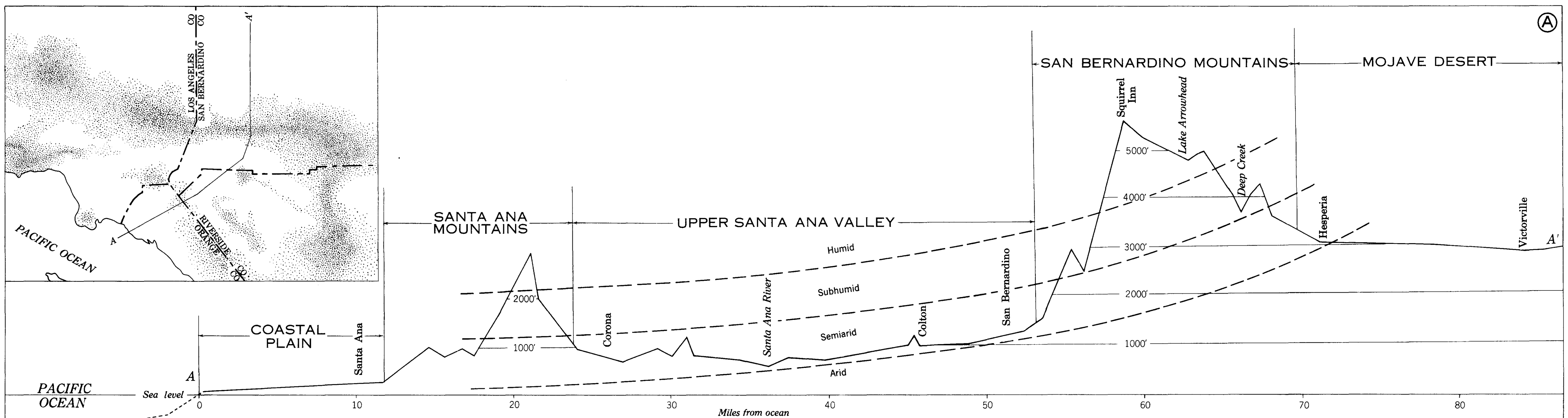


Typical vegetation in arid parts of the mountain area (Deep Creek)

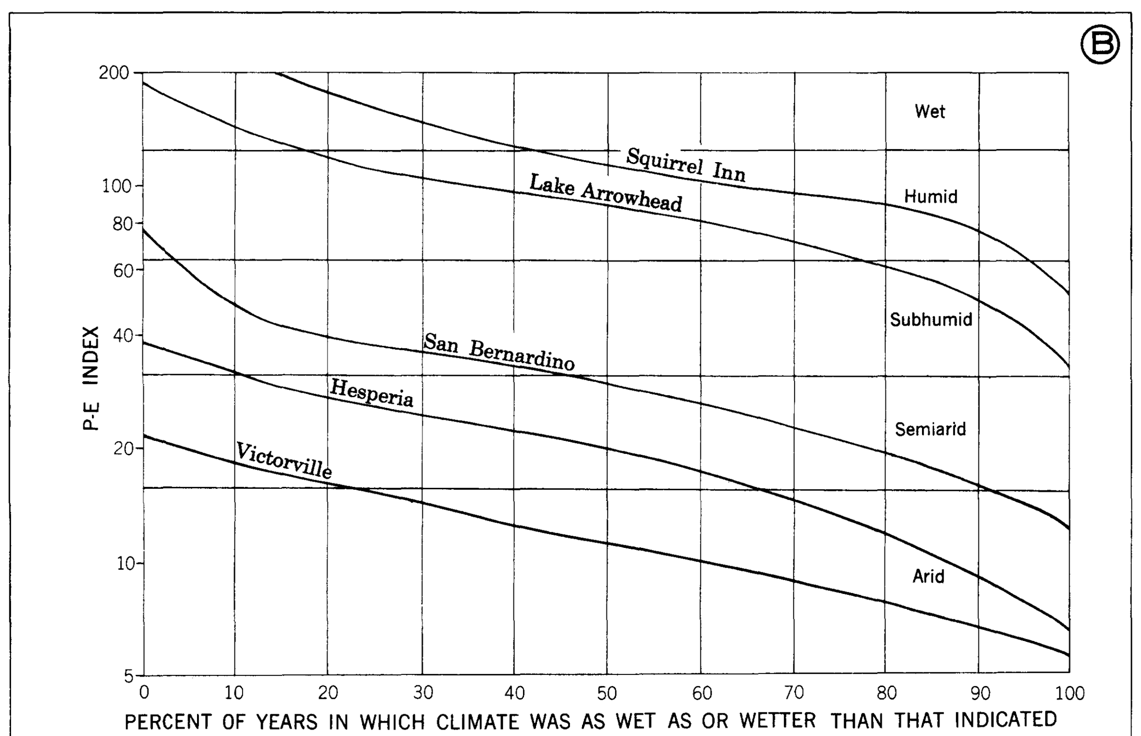
The lower diagram of part G gives the time distribution of the solar radiation received by a horizontal, 50-, and 100-percent north-facing surfaces and 50- and 100-percent south-facing slopes in the mountain area. The time distribution and amount of solar energy received on a horizontal surface at the Riverside meteorological station is assumed to be identical to that for a horizontal surface in the mountain area. The time distribution and amount of energy available on the 50- and 100-percent slopes were computed on the basis of the sun's declination, the hour angle, and the observational data obtained at Riverside.

The significance of this diagram is that the energy received on the south-facing slopes was almost twice that for a horizontal surface during the winter month of January. This may account for the winter-growing vegetation on these southern slopes. In contrast, the solar energy reaching north-facing slopes during this winter month approaches zero, indicating dormant vegetation.

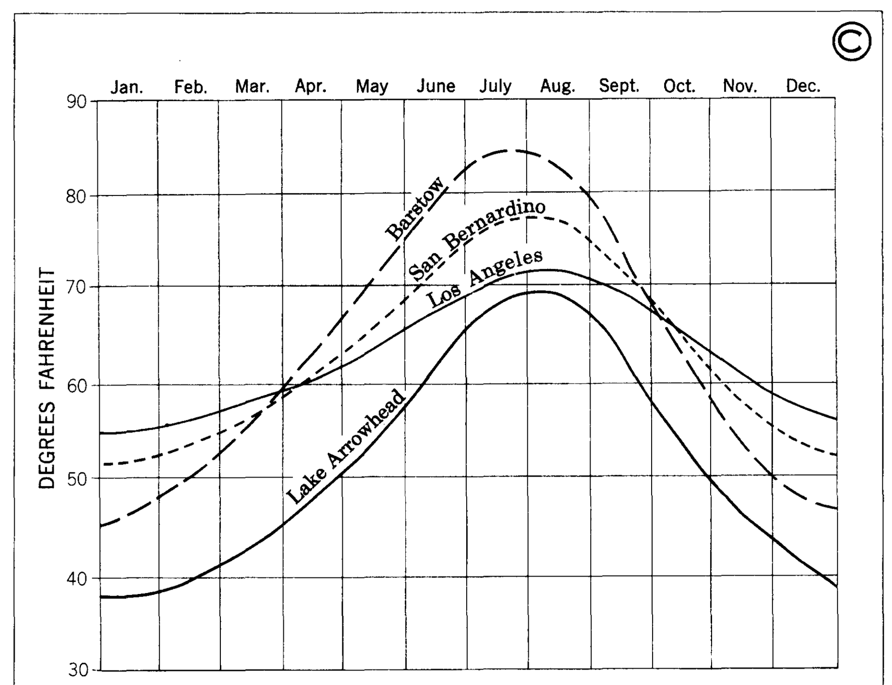
In the summer month of June, the solar radiation is almost identical on north- and south-facing slopes. On the south-facing slopes, the winter- and spring-growing vegetation becomes dormant during this month because of complete exhaustion of the soil moisture in the root zone. On north-facing slopes plant growth is greatest in June when there is a combination of sufficient soil moisture and the necessary solar energy.



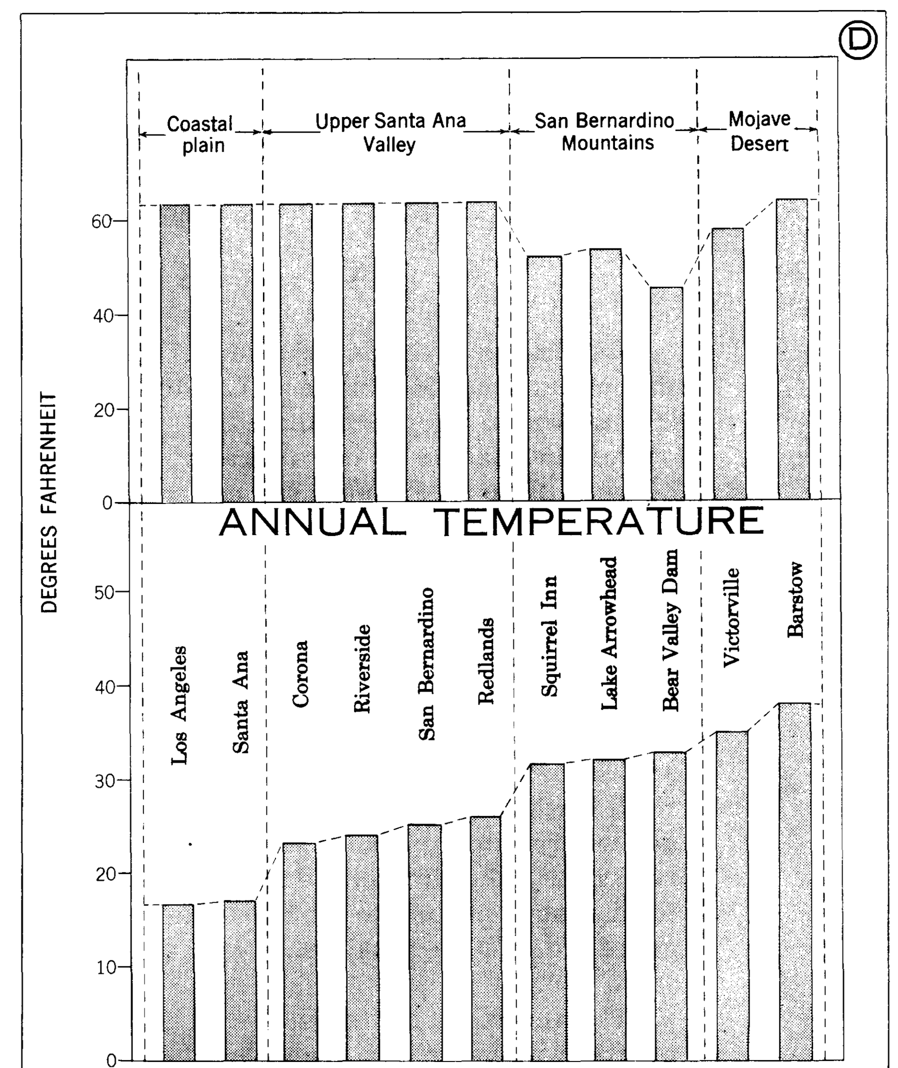
GENERALIZED CROSS SECTION SHOWING CLIMATIC DISTRIBUTION



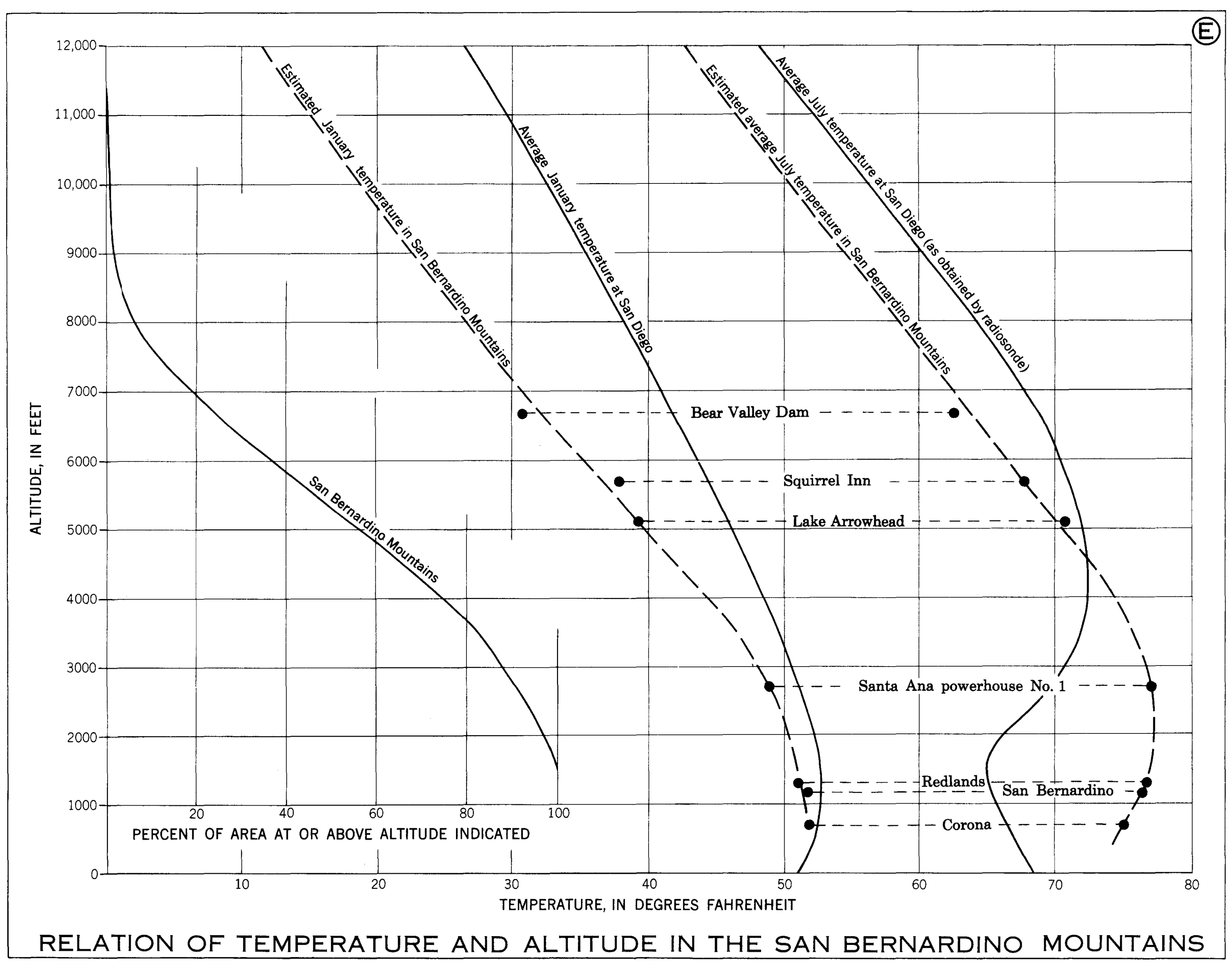
FREQUENCY DISTRIBUTION OF CLIMATIC TYPES



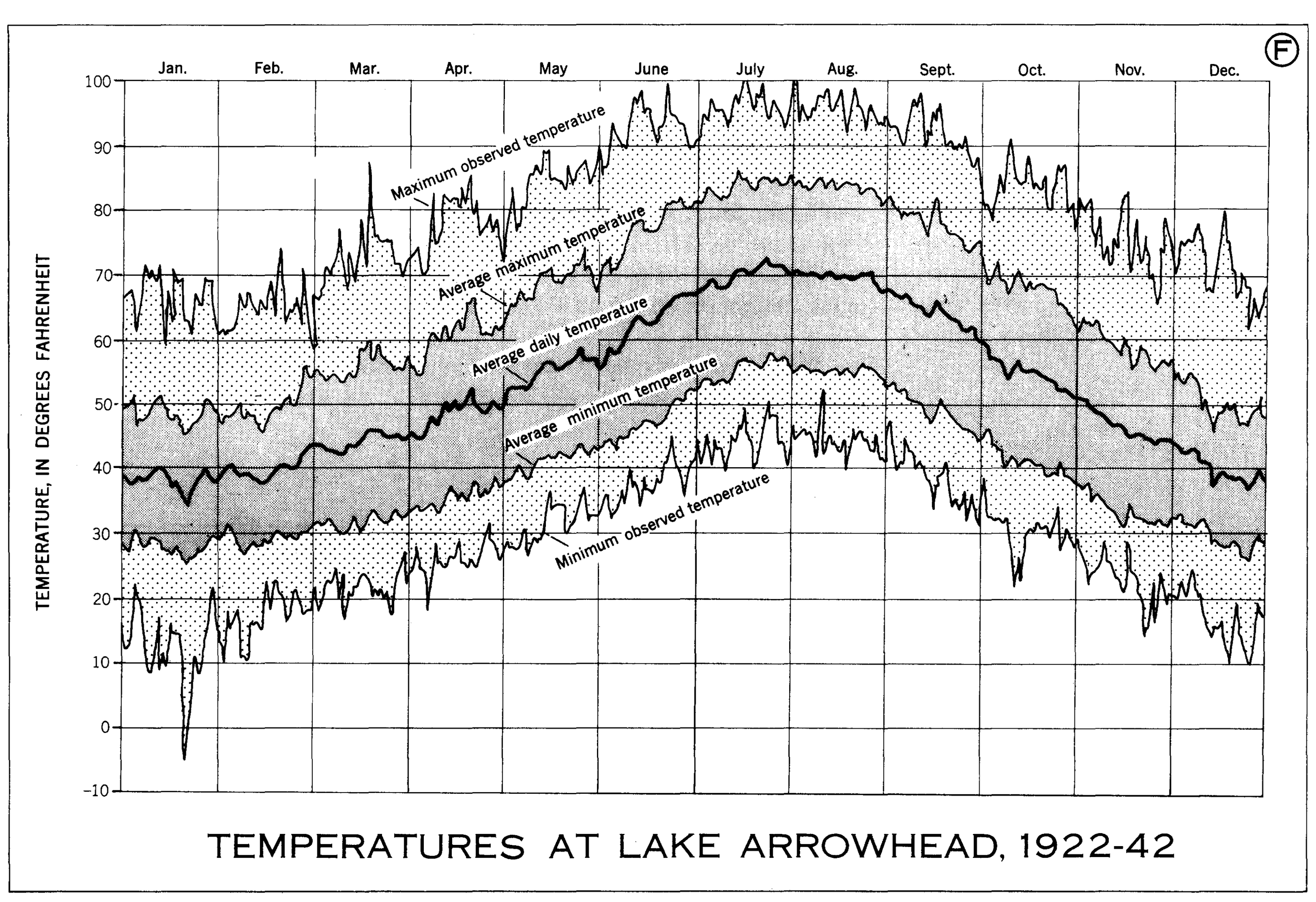
AVERAGE MONTHLY TEMPERATURE



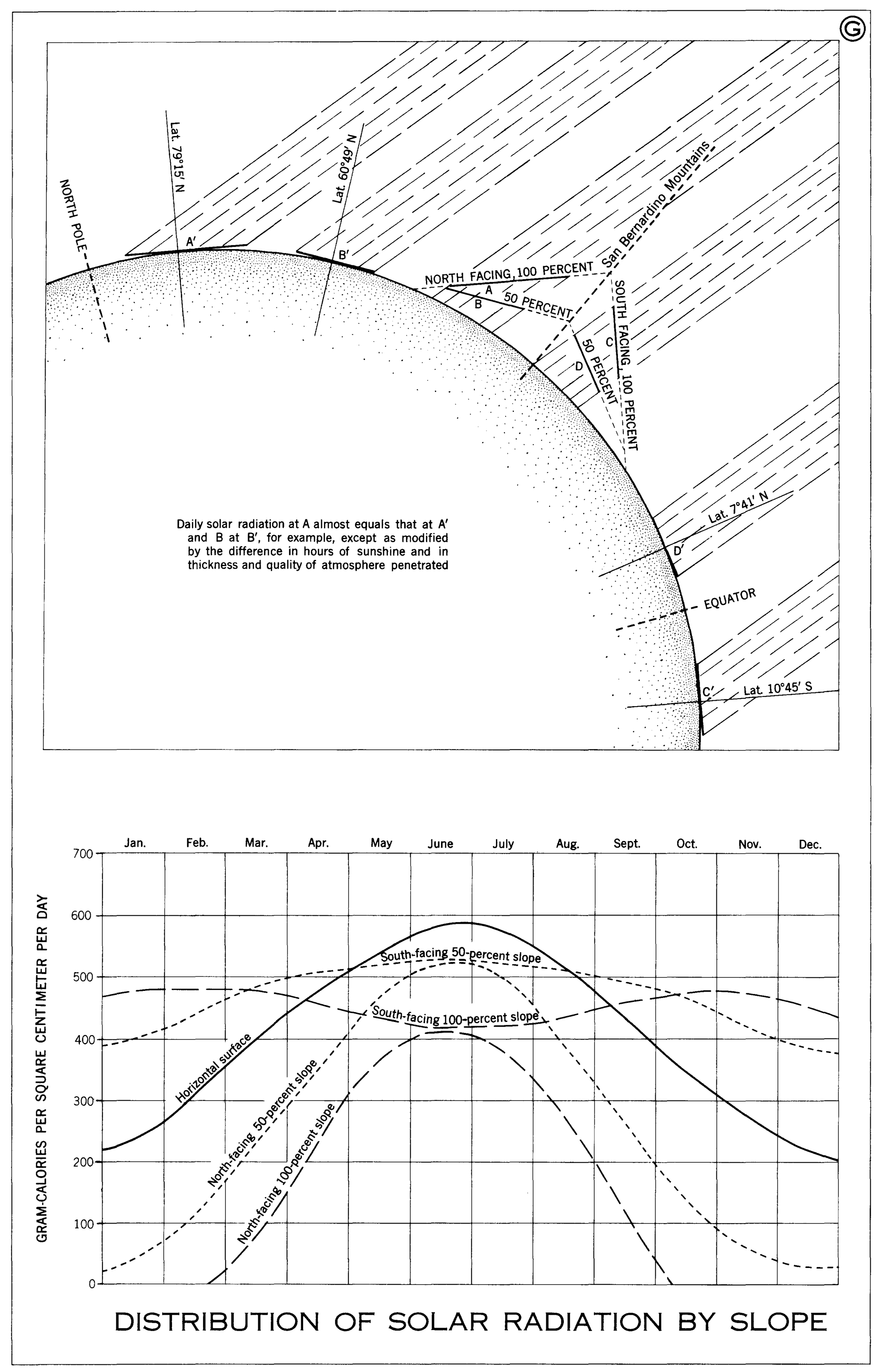
MONTHLY TEMPERATURE RANGE



RELATION OF TEMPERATURE AND ALTITUDE IN THE SAN BERNARDINO MOUNTAINS



TEMPERATURES AT LAKE ARROWHEAD, 1922-42



DISTRIBUTION OF SOLAR RADIATION BY SLOPE

PRECIPITATION

Our water resources are replenished annually by precipitation. In the mountain area several stations have been established to measure the precipitation, but systematic records have been kept only since 1880. These 70 years of observational data show that the amount of annual precipitation has varied greatly from year to year. Furthermore, these variations are not of random nature but show a tendency for the wet years to occur in sequences and for the dry years to occur also in sequences. The lengths of these wet and dry periods have considerable significance in any investigation of water resources. In general, however, the precipitation record of 70 years is entirely too short to indicate the average length of these wet and dry periods and the frequency with which they occur.

TREE-RING GROWTH

A and B

Available records of annual tree-ring growth in the mountains of southern California since 1385, or for a period of more than 560 years, provide a far better indication of the average length and frequency of wet and dry periods than do precipitation records. Conversion of annual tree-ring growth to wet and dry periods is based on the assumption that trees tend to produce a new ring each year and that the width of this ring is a measure of growing conditions. Thus tree-ring growth is primarily a measure of consumptive use of water and secondarily a measure of precipitation. To insure significant data, trees to be studied are carefully selected in areas of marginal precipitation, where there is little likelihood of surface runoff and where soil moisture seldom penetrates below the root zone. Under such conditions the annual recharge to the soil moisture around the tree tends to be a measure of precipitation.

The annual variation in tree-ring growth for a large number of very old trees in the San Gabriel, San Bernardino, San Jacinto, and Palomar Mountains of southern California was measured by Schulman a/ of the University of Arizona. The annual values for the entire period were averaged to obtain the mean, or normal, annual growth. The annual growth for each year, expressed in terms of this mean, becomes an index of relative wetness for each year of the more than 560 years of record.

The time distribution of tree-ring growth is best illustrated by plotting the cumulative departures from the mean as shown in part B. In this diagram the annual growth for 10 sample years is plotted in terms of the mean annual growth, using the scale on the left side of the graph. The initial year is a percent below the mean value; consequently, the cumulative departures will start below the mean with a value equal to the deficiency of this first year (-17 percent in this instance). In the second year, the tree growth had a deficiency of b percent of the mean, which when added to a percent gives for the 2 years the total minus cumulative departure ($a + b$, or 43 percent) from the mean growth, as indicated by the small circle within the bar graph for the second year. By continuing this process, through the adding of plus departures and subtracting of negative departures, the resulting line drawn through the small circles tends to develop into an irregular cyclic-shaped curve controlled by the chronological distribution of wet and dry years. This analytical graph gives the length of wet and dry periods, with upward-sloping curves representing greater than average tree growth, and downward-sloping lines representing deficient tree growth. The peaks or valleys in this graph represent a change in trend and mark the beginning and end of wet or dry periods.

The graph of the cumulative departures from the normal, or mean, annual tree growth shown in part A groups the more than 560 years of record into wet and dry periods. This cyclic pattern shows wet and dry periods ranging from fewer than 5 to more than 40 years in length. It is evident that within each wet period there are some dry years and that during dry periods there are a few wet years. But the change in trend is generally rather definite at the beginning of the period, and the trend continuous throughout the entire period.

Also included in part A is a graph based on the precipitation record at San Bernardino since 1875. For comparative purposes this record is shown as a cumulative departure from the mean. It is evident that there is considerable conformity between the precipitation and the tree-ring record in respect to the beginning and end of wet or dry periods.

LENGTH OF WET AND DRY PERIODS

C

The lengths of the wet and dry periods in these 560 years of record were plotted as a cumulative frequency curve to show the time distribution of each. This curve (part C) shows the median dry period to be about 14.5 years in length. This same curve also shows that 20 percent of the dry periods will be 8 years in length or shorter. At the other extreme, it shows that 20 percent of the dry periods will be 23 years or more in length. Consequently, the most probable length for 60 percent of the dry periods will range from 8 to 23 years.

The wet periods appear to be slightly shorter, with the median period being 12.5 years in length. The most probable length of 60 percent of the wet periods will range from 7 to 21 years.

ORIGIN OF PRECIPITATION

D

The southern fringe of the polar Pacific maritime air masses, originating over the Arctic seas and the subarctic interiors of Siberia and Alaska, is the principal source of winter precipitation in the mountain area, as shown in part D. The tropical Pacific maritime air masses, originating in the Pacific Ocean south and southwest of California, are the secondary sources of winter precipitation in the mountain area.

The infrequent summer storms in the mountain area generally owe their origin to the tropical gulf air masses developed over the warm waters of the Caribbean Sea and Gulf of Mexico.

PROBABILITY OF PRECIPITATION

E

Ninety-five percent of all the precipitation in the mountain area occurs in the 8-month period of October through May, with 74 percent occurring in the 4-month period of December through March. Consequently, the probability of precipitation is greatest in the winter and least in the summer months. The daily probability of precipitation is shown in graphic form for the two very long records, one obtained at San Bernardino for the period 1891-1943, representing the valley floor area, and the other obtained at Bear Valley Dam for the period 1883-1943, representing the mountain area. The vertical scale gives the percent of time a daily precipitation of 0.1 inch or more was observed. In order to smooth the graph and improve its accuracy, the computation of probability of precipitation was based on 5-day periods.

This diagram indicates that in the period July 1-10 in the mountain area a daily precipitation, in excess of 0.1 inch, occurred for about 2 percent of the days. From this date, the possibility of precipitation gradually increases until rainfall can be expected for 7 to 8 percent of the time in the latter part of August, the midst of the summer convectional storm period. With the passage of this convectional storm period, the probability of precipitation gradually decreases to about 2 percent of the time, or 2 days in 100, in mid-September. With the advent of winter, the probability of daily precipitation in the mountain area rapidly increases to a maximum of 24 percent of the time, or 24 days in 100 during early February. From this maximum the probability of precipitation decreases to zero in late June.

Throughout the year, there are several periods of apparent nonconformity to the probability curve, such as the latter parts of April and May. It was to determine the realness of these apparent nonconformities that the valley floor record obtained at San Bernardino was included in part E. This record generally shows the same periods of nonconformity and suggests that these variations in precipitation probability may actually exist.

FREQUENCY OF MAXIMUM DAILY PRECIPITATION

F

A typical record of the distribution of maximum daily precipitation in the mountain area, that obtained at Bear Valley Dam, is shown in part F. In order to simplify preparation of this diagram, daily precipitation for this 60-year period of record from 1883 to 1943 was grouped into 5-day periods, such as July 1-5, 6-10, and 11-15.

The maximum observed daily precipitation in each of these 5-day periods is shown by a series of points, each two in sequence connected by a dashed line to show trends. An additional smooth curve has been drawn through some of the highest points to give the estimated probable maximum daily precipitation at this station. This curve shows a range in probable maximum daily precipitation from about 3 inches in July to 16 inches in February.

An additional series of 4 solid curved lines in part F gives the daily precipitation to be expected once in 20 years, once in 10 years, once in 4 years, and once in 2 years.

FREQUENCY OF STORM PRECIPITATION

G

Precipitation in any one year is not of purely random occurrence, but is associated with the movement of typical air masses through southern California. During the passage of these air masses precipitation generally occurs over a 2- to 5-day period. By definition, storm precipitation is the amount of rainfall occurring over a number of consecutive days in which the daily precipitation exceeds 0.1 inch. This allows the segregation of extended periods of precipitation into individual storms, which rather closely associate themselves with the individual meteorological disturbance creating the rainfall.

The storm precipitation records at the five typical stations of Squirrel Inn, Bear Valley Dam, Seven Oaks, Santa Ana River, and San Bernardino were used to show the complete range in both valley floor and mountain area. The frequency distribution given in part G is based on all the storms having a precipitation in excess of that for a storm that can be expected once a year on the average. Frequencies are expressed in terms of recurrence intervals.

The curve for the Squirrel Inn station, in the zone of greatest precipitation, indicates that a storm precipitation of 31 inches occurs about once in 100 years, a precipitation of 23 inches about once in 25 years, and a precipitation of 18 inches about once in 10 years.

The curve for the San Bernardino station, in the area of least precipitation, indicates storm precipitation of 11 inches once in 100 years, 8.3 inches once in 25 years, and 6.6 inches once in 10 years.

FREQUENCY OF ANNUAL PRECIPITATION

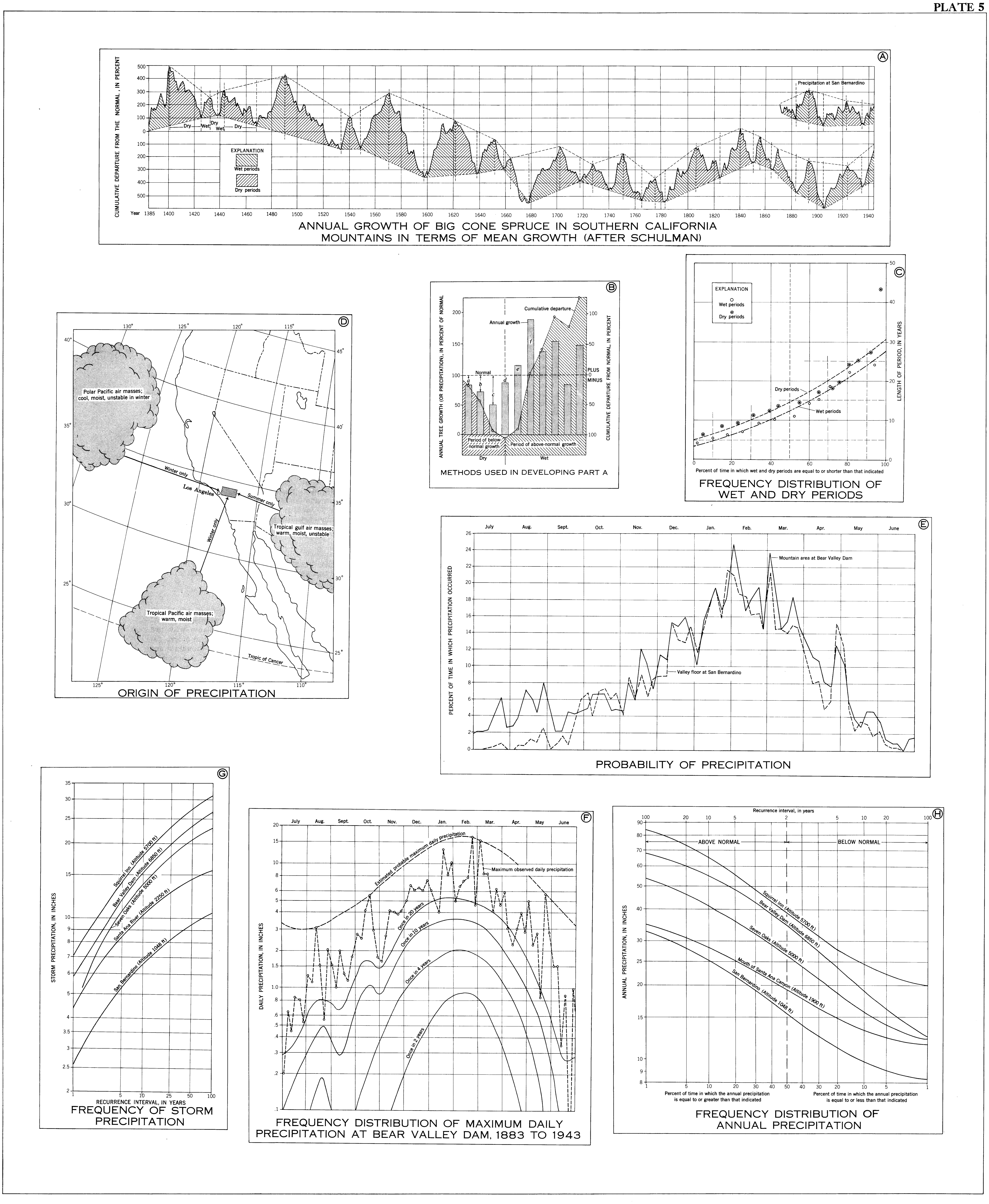
H

The frequency distribution of annual precipitation at the five typical stations of Squirrel Inn, Bear Valley Dam, Seven Oaks, Mouth of Santa Ana Canyon, and San Bernardino is shown in part H. The frequency curves are divided into two parts by the dashed line representing the median value, with the frequency of occurrence decreasing in either direction with distance from the median. The left-hand part of this diagram gives the percent of time in which the annual precipitation is equal to or greater than that indicated by the vertical scale of annual precipitation. The right-hand part gives the percent of time in which the annual precipitation is equal to or less than that indicated.

By way of interpretation, the annual precipitation at Squirrel Inn will equal or exceed 84 inches for 1 percent of the time, or once in 100 years, and will be 20 inches or less once in 100 years. For 10 percent of the time the annual precipitation will be equal to or greater than 65 inches, and for another 10 percent of the time it will be 24 inches, or less. Thus the most probable annual precipitation for 80 percent of the time will range from 24 to 65 inches.

Frequencies computed as percent of time are readily converted into recurrence intervals, as shown at the top of part H.

a/ Schulman, Edmund, 1947, Tree-ring hydrology in southern California, University of Arizona, Laboratory of Tree-ring Research Bull. 4.


A
ANNUAL GROWTH OF BIG CONE SPRUCE IN SOUTHERN CALIFORNIA MOUNTAINS IN TERMS OF MEAN GROWTH (AFTER SCHULMAN)
CUMULATIVE DEPARTURE FROM THE NORMAL, IN PERCENT
Precipitation at San Bernardino
EXPLANATION
Wet periods
Dry periods
Dry
Wet
B
METHODS USED IN DEVELOPING PART A
ANNUAL TREE GROWTH (OR PRECIPITATION), IN PERCENT OF NORMAL
CUMULATIVE DEPARTURE FROM NORMAL, IN PERCENT
Cumulative departure
Annual growth
Normal
PLUS
MINUS
Period of below-normal growth
Period of above-normal growth
C
FREQUENCY DISTRIBUTION OF WET AND DRY PERIODS
EXPLANATION
Wet periods
Dry periods
LENGTH OF PERIOD, IN YEARS
Percent of time in which wet and dry periods are equal to or shorter than that indicated
D
ORIGIN OF PRECIPITATION
Polar Pacific air masses; cool, moist, unstable in winter
Winter only
Los Angeles
Summer only
Tropical gulf air masses; warm, moist, unstable
Winter only
Tropical Pacific air masses; warm, moist
Tropic of Cancer
E
PROBABILITY OF PRECIPITATION
PERCENT OF TIME IN WHICH PRECIPITATION OCCURRED
July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June
Mountain area at Bear Valley Dam
Valley floor at San Bernardino
G
FREQUENCY OF STORM PRECIPITATION
STORM PRECIPITATION, IN INCHES
RECURRENCE INTERVAL, IN YEARS
Squirrel Inn (Altitude 5700 ft)
Bear Valley Dam (Altitude 6850 ft)
Seven Oaks (Altitude 5000 ft)
Santa Ana River (Altitude 2250 ft)
San Bernardino (Altitude 1048 ft)
F
FREQUENCY DISTRIBUTION OF MAXIMUM DAILY PRECIPITATION AT BEAR VALLEY DAM, 1883 TO 1943
DAILY PRECIPITATION, IN INCHES
Estimated probable maximum daily precipitation
Maximum observed daily precipitation
Once in 20 years
Once in 10 years
Once in 4 years
Once in 2 years
H
FREQUENCY DISTRIBUTION OF ANNUAL PRECIPITATION
Recurrence interval, in years
ABOVE NORMAL
BELOW NORMAL
ANNUAL PRECIPITATION, IN INCHES
Squirrel Inn (Altitude 5700 ft)
Bear Valley Dam (Altitude 6850 ft)
Seven Oaks (Altitude 5000 ft)
Mouth of Santa Ana Canyon (Altitude 1900 ft)
San Bernardino (Altitude 1048 ft)
Percent of time in which the annual precipitation is equal to or greater than that indicated
Percent of time in which the annual precipitation is equal to or less than that indicated

AREAL PRECIPITATION

The accurate determination of the areal distribution of precipitation over basins or regions of such bold topography as the mountain area is extremely difficult. Areal distribution is largely controlled by the height, shape, and position of each land form in reference to the principal moisture-laden air masses. These air masses, upon approaching high land forms, are forced upward into zones of lower temperature where the moisture tends to condense and precipitate. On the leeward side of these land forms, except for a very short distance near the divide, the air mass is descending, becoming warmer, and tending to absorb rather than precipitate moisture as it moves leeward. The combination of this general pattern of precipitation distribution and many local topographic influences tends to create a complex areal distribution.

This plate shows the effect of geographic position on precipitation, while the preceding plate 5 shows only how precipitation was distributed in time at definite points of observation.

ANNUAL PRECIPITATION

A

Part A is an isohyetal map showing the average annual precipitation for the 60-year period from 1883 to 1943 and the location of the following observation stations:

SAN GABRIEL MOUNTAINS

1 Tanbark Flats	11 Glenn Ranch
2 Table Mountain	12 Lytle Creek (Scotland store)
3 Big Pines Park	13 Lytle Creek intake
4 Big Pines Park, no. 2	14 Lytle Creek ranger station
5 San Antonio Canyon	15 Lytle Creek (mouth of)
6 San Antonio Canyon (mouth of)	16 Fontana Union intake
7 Camp Baldy	54 Brydon ranch
8 San Antonio intake	86 West Cajon
9 Kelly's camp	
10 Cycamonga	

SAN BERNARDINO MOUNTAINS

17 Summit	38 Daly Summit
18 Cajon ranger station	39 Squirrel Inn no. 2
19 Burton's ranch	40 Squirrel Inn
20 Devore	41 Ash Meadows
21 Devil Canyon (mouth of)	42 Deep Creek
22 Upper Toll House	43 Heaps Creek
23 Huston Flat	44 Holcomb Creek
24 Devil Canyon	45 Santa Ana River
25 Arrowhead Springs	46 Mill Creek no. 2
26 Forks of Mojave River	47 Holcomb Valley
27 Tunnel no. 2	48 Bear Valley Dam
28 Lake Arrowhead (gate house)	49 Seven Oaks
29 Ridge	50 Forest Home
30 Grass Valley	51 Oak Glen
	52 Raywood Flat
31 Flemings	76 Santa Ana Canyon (mouth of)
32 Lake Arrowhead	90 Millard Canyon
33 Talmadge	91 Millard Forks
34 Kuggel	92 Whitewater Canyon
35 Measor	93 Whitewater
36 Morse	94 Mission Canyon
37 Strawberry Flat	95 Cabazon

UPPER SANTA ANA VALLEY

53 Pomona	66 Cucamonga (Mission Winery)
55 Padua Hills	67 Bennett ranch
56 Claremont, Indian Hill (White)	68 Fontana
57 Live Oak Canyon	69 Fontana power house
58 LaVerne (Sheldon)	70 Newmark reservoir
59 Claremont	71 San Bernardino
60 Alta Loma (D. J. Dahlem)	72 Highland (Corwyn)
61 Upland (Johnston)	73 Highland (Ewing)
62 Ontario (Southern Pacific Co.)	74 East Highlands (Perry)
63 Alta Loma (Victor Cherbak)	75 Redlands
	77 Mentone
64 Alta Loma (L. A. Smith)	78 Craftonville
65 Etiwanda (Scott)	79 Craftonville (King)

YUCAIPA-BEAUMONT PLAINS

80 Yucaipa (Arnett)	81 Beaumont (near)

SAN JACINTO MOUNTAINS

96 Decker's ranch	98 Hurley Flat
97 Stratton ranch	99 Snow Creek

The general distribution of precipitation is further emphasized by the cross section *A—A'* which starts at the Pacific Ocean in Orange County, crosses the coastal plain, the Santa Ana Mountains, the Upper Santa Ana Valley, the San Bernardino Mountains, and ends on the fringe of the Mojave Desert about 76 miles from the ocean. The orographic influences of the frontal slopes of the Santa Ana and San Bernardino Mountains on the incoming maritime air masses are clearly shown. Altitudes of almost 3,000 feet in the Santa Ana Mountains caused the annual precipitation to increase from 15 inches to more than 30 inches near the divide. Immediately across the divide the annual precipitation decreases to 15 inches in a distance of about 3 miles. Across the Upper Santa Ana Valley the annual precipitation ranges from 12 to 18 inches. Then the lifting influence of the San Bernardino Mountains causes the precipitation to increase from less than 20 inches to 45 inches at the divide. To the leeward of the divide it increases slightly, then rapidly diminishes in a distance of 6 miles to 15 inches at an altitude of 5,000 feet. At Barstow (not shown on this plate) about 30 miles from the divide, the average annual precipitation has decreased to 4 inches.

FREQUENCY OF STORM PRECIPITATION

B

Most of the precipitation occuring in the mountain area and adjacent valley areas is a result of the landward movement of the Pacific maritime moisture-laden air masses. The intensity, the speed, the course, and many other characteristics of these air masses vary continuously from one storm precipitation period to another.

In the mountain area storm precipitation is so distributed that 2 percent of the storms produce 14 percent of all the precipitation, as shown in the following table. Furthermore, 10 percent of all the storms

Percent of storms	Percent of total precipitation
2	14
3	21
5	29
10	46
20	63
30	74
40	83
50	90

produced 46 percent of all the precipitation, and 20 percent of the storms produced 63 percent of the precipitation. Consequently, in developing frequency distribution curves or making other analyses of storm precipitation in this report only the larger storms have been included.

The frequency distribution of the basin-wide storm precipitation, in terms of recurrence interval, is given in part B for 17 mountain area drainage basins. This diagram shows that in the San Antonio Creek drainage basin a basin-wide storm precipitation of 33 inches or more could be expected once in 100 years, a storm precipitation of 26 inches or more once in 25 years, and a storm precipitation of 8 inches or more once in a year.

This diagram also gives the "mean annual storm precipitation" for each drainage area. By definition, the mean annual storm precipitation is the average of the largest storms of a number equal to the number of years of record. For example, in a 60-year period of record, the 60 largest storms would be selected; more than one of these storms might have occurred in 1 year of record.

AREAL DISTRIBUTION OF PRECIPITATION FREQUENCIES FOR TYPICAL STORMS

C

As already indicated, storm precipitation patterns in the mountain area vary considerably. In order to show this wide degree of variability, the areal distribution of recurrence intervals for the precipitation that occurred in three typical storm periods--December 31, 1909 to January 2, 1910, February 13-18, 1927, and January 21-24, 1943--is given in part C.

In the first storm, the most infrequent precipitation occurred north of Cajon and in the lower reaches of the Mojave River. During the second storm, the most infrequent precipitation occurred in the Ontario-Upland area and in the Mill Creek area near Forest Home. In the third storm, the most infrequent precipitation occurred in the northwest sections of the mountain area.

FREQUENCY DISTRIBUTION OF ANNUAL PRECIPITATION

D

The range in magnitude and the frequency distribution of the annual precipitation are defined by the meteorological stations in the mountain area, typical records of which were shown in part H of plate 5. On the basis of these records, the frequency distribution of the basin-wide average annual precipitation is shown in part D for 17 drainage basins in the mountain area. The bar graphs are divided at the median value (heavy line) with the upper part indicating the percent of time in which the basin-wide annual precipitation is equal to or greater than the amount shown on the vertical scale. Below the median, each bar graph gives the percent of time in which the basin-wide precipitation is equal to or less than that indicated.

In San Antonio Creek drainage area, the basin-wide precipitation will be equal to or exceed 77 inches for 1 percent of the time, or once in 100 years. Also the basin-wide annual precipitation will be equal to or less than 19 inches for 1 percent of the time, or once in 100 years. For 10 percent of the time the basin-wide annual precipitation will be equal to or greater than 61 inches, and for 10 percent of the time, equal to or less than 25 inches. Thus, the most probable basin-wide annual precipitation for 80 percent of the time will range from 25 to 61 inches.

AREAL DISTRIBUTION OF PRECIPITATION FREQUENCIES FOR TYPICAL STORMS

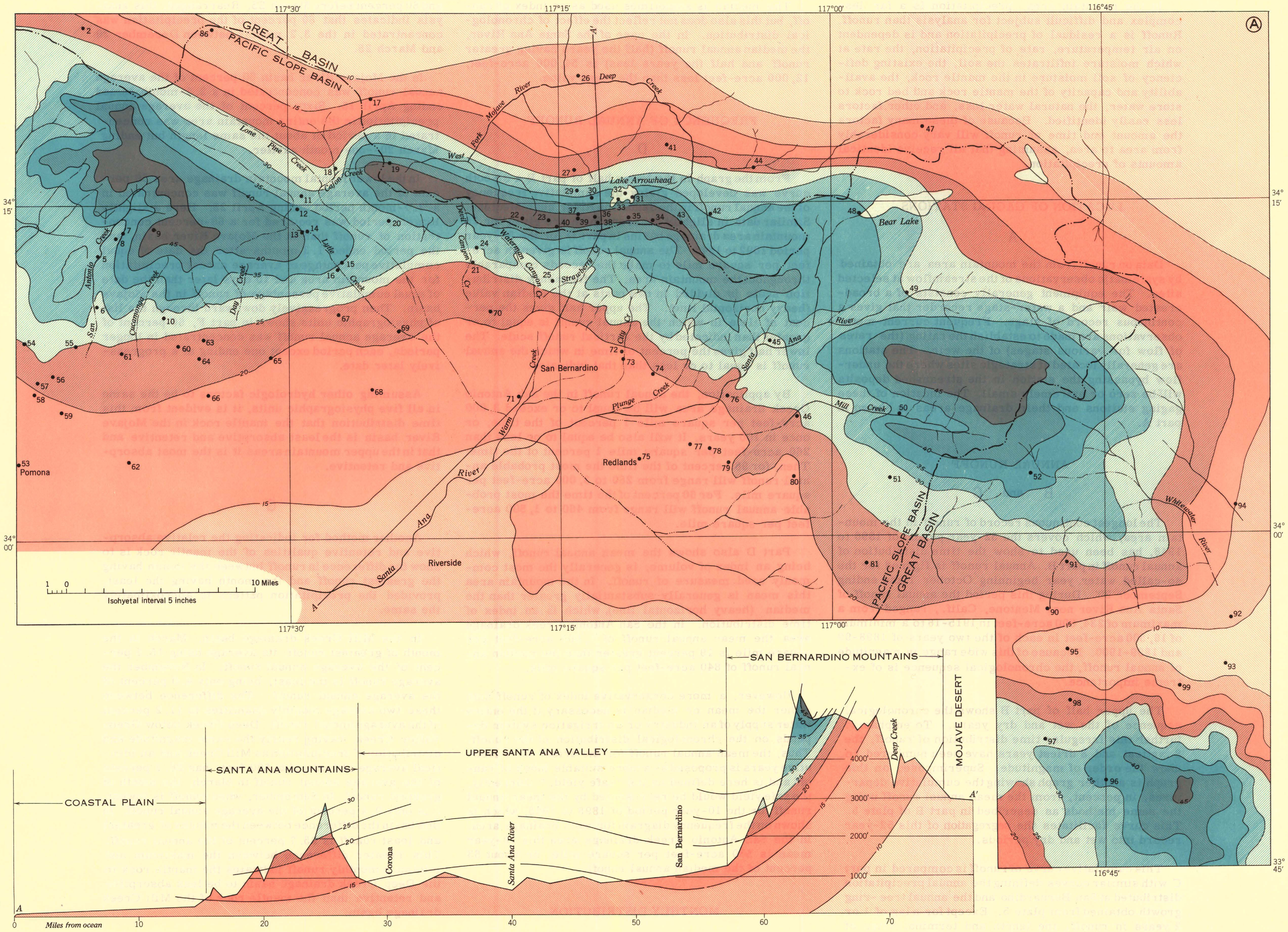
E

In part D, the cumulative frequency of annual precipitation is given for an entire drainage area. Although this analysis represents the basin-wide precipitation, the innumerable variations in storm patterns from year to year in the entire mountain area are not taken into account. Seldom will the precipitation in the five type areas exactly duplicate the distribution given in part A. In some years, the storms tend to be concentrated in the western part of the mountain area; in others, along the frontal areas or in the valley floor areas adjacent to the mountain area. The storms may also be concentrated in almost any combination of areas. The areal distribution for the two wet years of 1915-16 and 1940-41 is shown in part E.

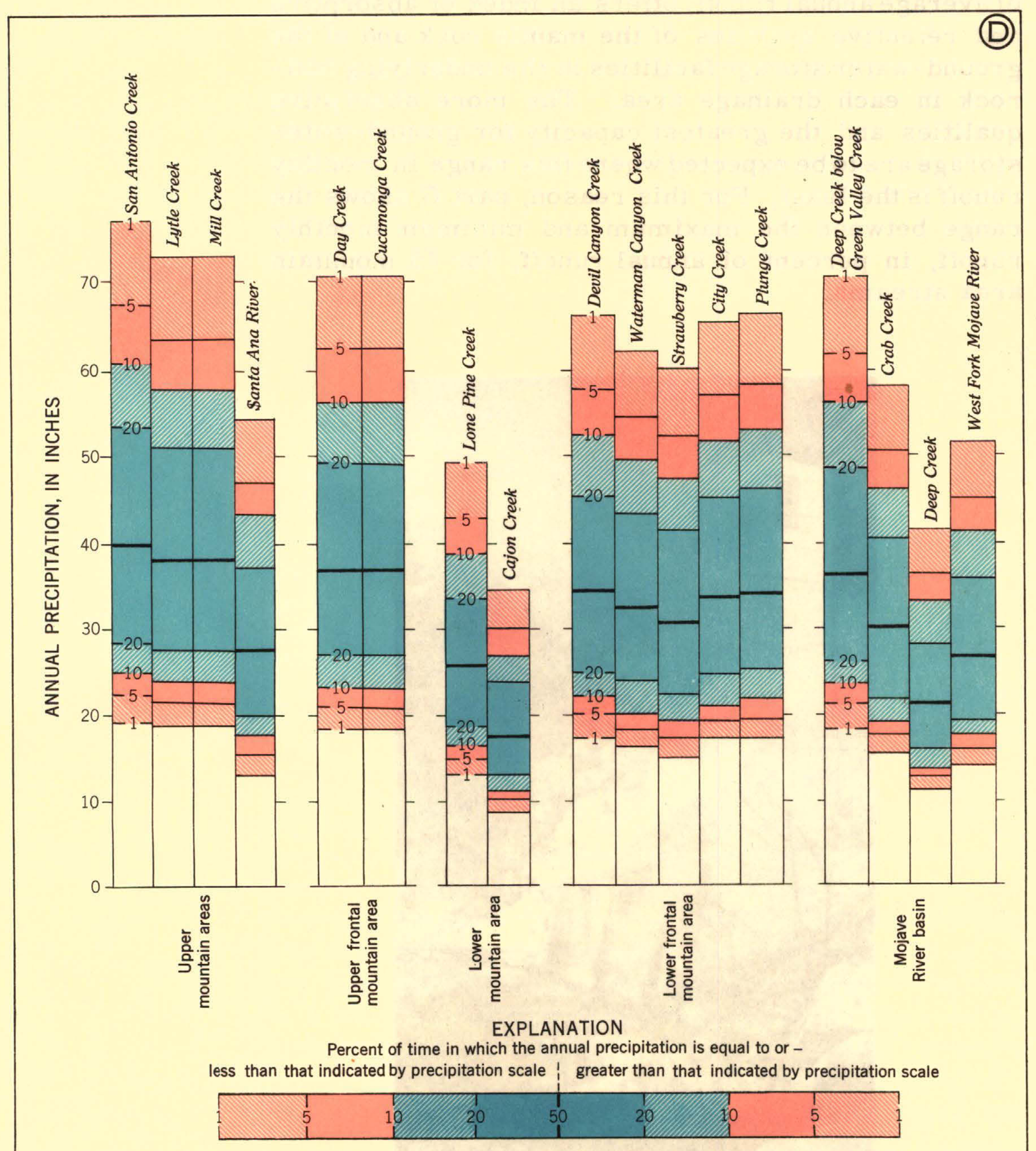
In 1915-16 the least frequent annual precipitation was concentrated in the frontal sections of the mountain area from San Antonio Creek to Seven Oaks. In this area, as shown in the upper half of part E, the 1915-16 annual precipitation would be equaled or exceeded for only 5 percent of the time, or once in 20 years. Around this narrow frontal bank of excessive precipitation, the cumulative frequency diminishes to 20 percent of the time, or once in 5 years, at such stations as Camp Baldy, Cajon, Redlands, and Forest Home.

In 1940-41 the annual precipitation had a completely different pattern, with the least frequent precipitation occurring on the valley floor in the southwest corner. During this year the precipitation at Ontario and Upland had a cumulative frequency of 1 percent of the time, or once in 100 years; at Arrowhead Springs and Crestline a cumulative frequency of about 5 percent of the time, or once in 20 years; and at Bear Lake a cumulative frequency of about 10 percent of the time, or once in 10 years.

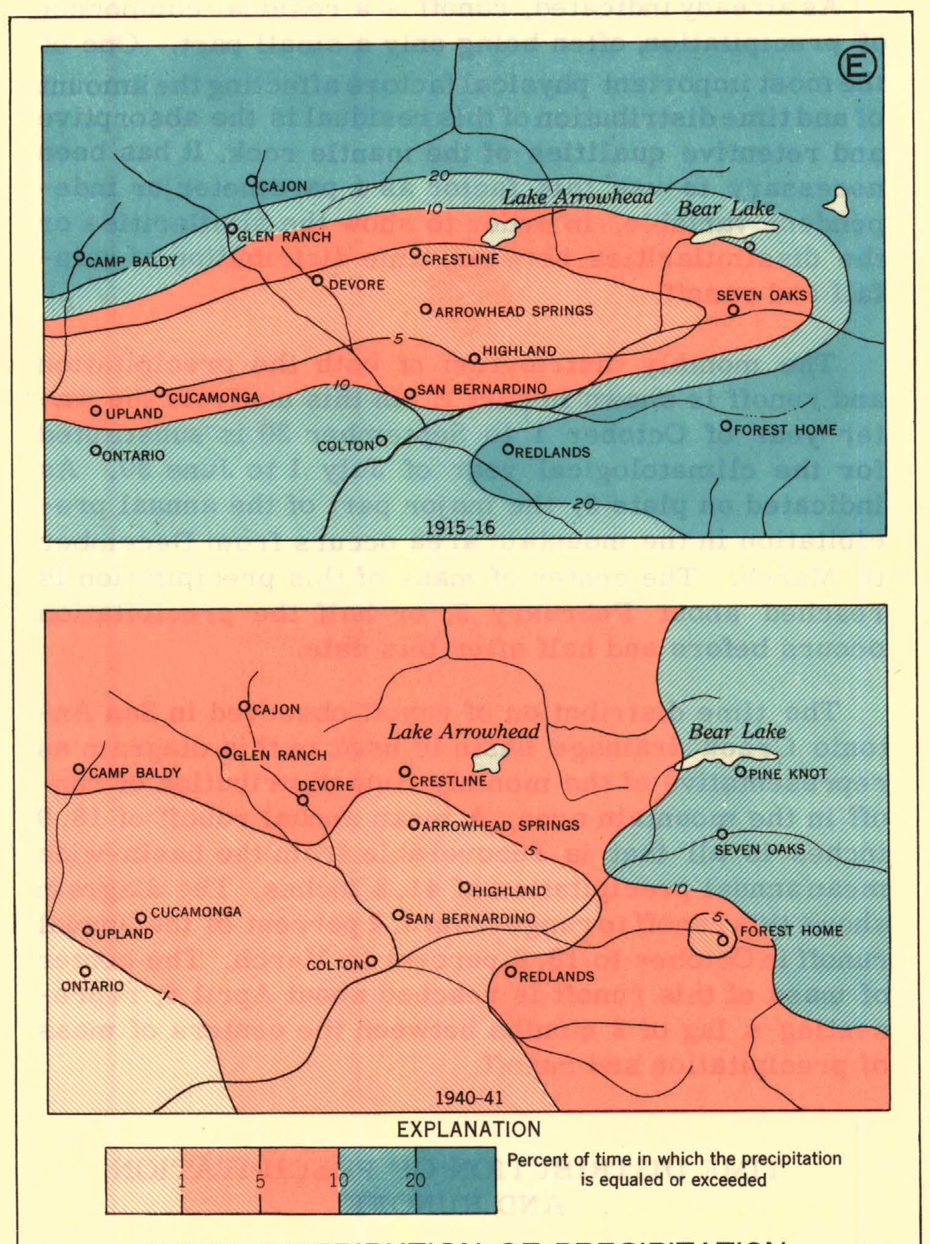
Examination of these diagrams shows that the annual precipitation does not have uniform frequency distribution over the entire mountain area during any given year. For this reason, the annual precipitation observed at a single meteorological station cannot be safely used as an index of basin-wide precipitation for any given year.



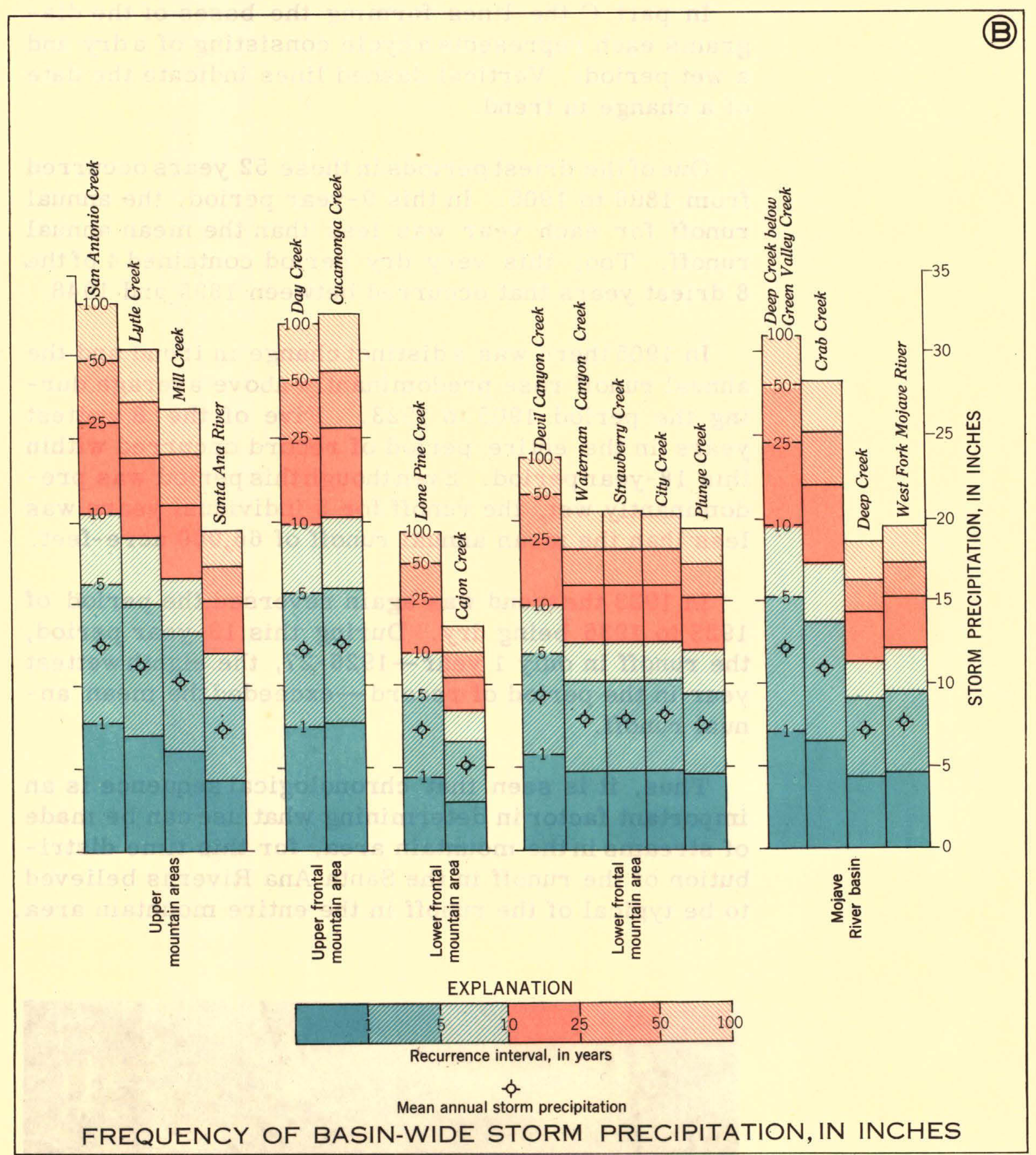
AVERAGE ANNUAL PRECIPITATION, IN INCHES, FOR THE PERIOD 1883 TO 1943



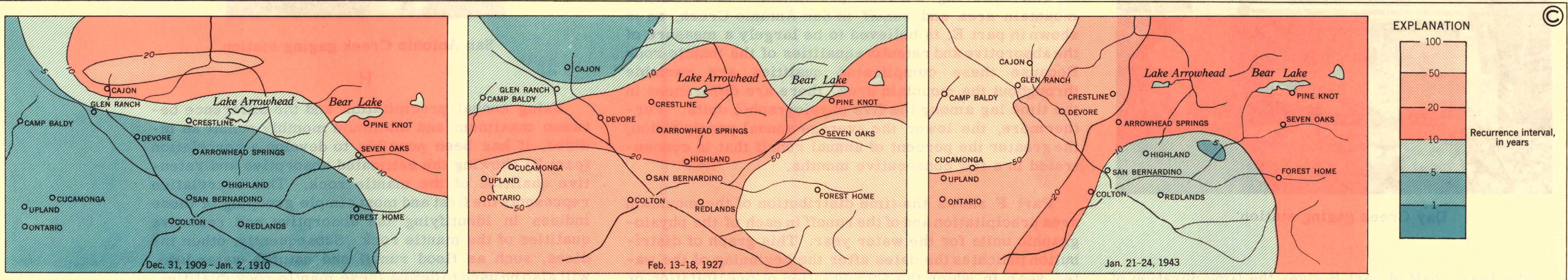
FREQUENCY OF BASIN-WIDE ANNUAL PRECIPITATION, IN INCHES



AREAL DISTRIBUTION OF PRECIPITATION FREQUENCIES FOR TYPICAL YEARS



FREQUENCY OF BASIN-WIDE STORM PRECIPITATION, IN INCHES



AREAL DISTRIBUTION OF PRECIPITATION FREQUENCIES FOR TYPICAL STORMS

RUNOFF

In the mountain area, precipitation is a far less complex and difficult subject for analysis than runoff. Runoff is a residual of precipitation and is dependent on air temperature, rate of precipitation, the rate at which moisture infiltrates the soil, the existing deficiency of soil moisture in the mantle rock, the availability and capacity of the mantle rock and bed rock to store water, the natural water loss, and other factors less easily identified. Because of these many factors the amount and time of runoff will vary considerably from area to area, assuming that all receive identical amounts of precipitation.

LOCATION OF GAGING STATIONS

A

Data on runoff from the mountain area are obtained by systematic observations of the streamflow at selected sites. The equipment generally consists of a broad-crested weir and a water-stage recorder that gives a continuous record of stage. Frequent current-meter observations are made to establish the rating (the rates of flow for various stages) of the weir. The stations are generally located at strategic sites where the underflow bypassing the station in the stream-bed deposits will be zero or extremely small. The location of these gaging stations and their drainage areas is shown in part A.

ANNUAL RUNOFF

B and C

The longest continuous record of runoff in the mountain area, which covers the 52-year period of 1896 to 1948, has been used to show the time distribution of annual runoff in part B. Annual runoff is figured for the so-called water year beginning October 1 and ending September 30. During this period the annual runoff of Santa Ana River near Mentone, Calif., ranged from a maximum of 234,000 acre-feet in 1915-16 to a minimum of 16,500 acre-feet in each of the two years of 1898-99 and 1899-1900. Because of this wide range in magnitude of annual runoff, the chronological sequence is of extreme importance.

The upper half of part B shows the chronological sequence of the wet and dry years. To emphasize further this irregular time distribution of runoff, the 8 wettest and 8 driest years have been numbered to show the order of magnitude. Superimposed on this graph is another graph showing the cumulative departures, in percent, from the mean annual runoff using the same methods as described in part B of plate 5. This curve facilitates the segregation of this 52-year record into wet and dry periods.

This cumulative curve of runoff is compared in part C with similar curves defining the annual precipitation distributed at San Bernardino and the annual tree-ring growth obtained from plate 5. Except for a lag of 1 or 2 years in runoff, the length and terminal dates of these wet and dry periods correspond closely.

In part C the lines forming the bases of the diagrams each represents a cycle consisting of a dry and a wet period. Vertical dashed lines indicate the date of a change in trend.

One of the driest periods in these 52 years occurred from 1896 to 1905. In this 9-year period, the annual runoff for each year was less than the mean annual runoff. Too, this very dry period contained 4 of the 8 driest years that occurred between 1896 and 1948.

In 1905 there was a distinct change in trend and the annual runoff rose predominantly above average during the period 1905 to 1923. Five of the 8 wettest years in the entire period of record occurred within this 18-year period. Even though this period was predominantly wet, the runoff for 5 individual years was less than the mean annual runoff of 66,000 acre-feet.

In 1923 the trend was again reversed, the period of 1923 to 1936 being dry. During this 13-year period, the runoff in only 1 year—1926-27, the eighth wettest year in the period of record—exceeded the mean annual runoff.

Thus, it is seen that chronological sequence is an important factor in determining what use can be made of streams in the mountain area, for this time distribution of the runoff in the Santa Ana River is believed to be typical of the runoff in the entire mountain area.

Day Creek gaging station

The lower half of part B gives the time duration of each of the 52 annual runoff values arranged in order of magnitude, with the 8 wettest and driest years properly identified. This diagram shows that about 34 percent of the years have greater than mean annual runoff, and 66 percent have less. This indicates that the mean is only a fair index of runoff, especially where chronological distribution has great significance.

The median is sometimes used as an index of runoff, but this also does not reflect the effect of chronological distribution. In the case of the Santa Ana River, the median annual runoff (half the years having greater runoff and half the years less) is 54,000 acre-feet, 12,000 acre-feet less than the mean value.

FREQUENCY OF ANNUAL RUNOFF

D

From the graph in the lower half of part B a smooth curve was developed giving the cumulative frequency of the annual runoff in the Santa Ana River near Mentone. Similar data in slightly different form are given for 15 mountain area drainage basins in part D for the 51-year period 1892 to 1943. The annual runoff is given in acre-feet per square mile to make the records comparable throughout the mountain area. The frequency distribution scale is divided in two parts at the median value (heavy horizontal line). The upper half gives the percent of time in which the annual runoff is equal to or greater than indicated by the vertical runoff scale. The lower half gives the percent of time in which the annual runoff is equal to or less than that indicated.

By application, the annual runoff in the San Antonio Creek drainage area will be equal to or exceed 3,000 acre-feet per square mile 1 percent of the time, or once in 100 years. It will also be equal to or less than 260 acre-feet per square mile 1 percent of the time. Then, for 98 percent of the time the most probable annual runoff will range from 260 to 3,000 acre-feet per square mile. For 60 percent of the time the most probable annual runoff will range from 460 to 1,500 acre-feet per square mile.

Part D also shows the mean annual runoff, which being an index of volume, is generally the most commonly used measure of runoff. In the mountain area this mean is generally substantially greater than the median (heavy horizontal line), which is an index of time distribution. In the San Antonio Creek drainage area the mean annual runoff of 1,000 acre-feet per square mile is 19 percent greater than the median annual runoff of 840 acre-feet per square mile.

However, a more conservative index of runoff than either the mean or median is necessary if the entire water supply of an industry or an irrigation system depends on the chronological distribution of the runoff. Thus, the mean annual runoff for the driest 10 consecutive years is proposed as a more suitable index of runoff and is here defined as the "safe yield." Currently, the safe yield would be represented by the mean annual runoff for the 10-year period of 1895 to 1905, which is shown on the frequency diagram for each drainage area. In the San Antonio Creek drainage area this 10-year mean is 530 acre-feet per square mile, or about 63 percent of the median annual runoff.

MONTHLY DISTRIBUTION

E

As already indicated, runoff is a residual component of precipitation, often being only a small part. One of the most important physical factors affecting the amount of and time distribution of this residual is the absorptive and retentive qualities of the mantle rock. It has been necessary to use this factor as a parameter or independent variable, in order to show the similarities or the dissimilarities between time distribution of rainfall and runoff.

The monthly distribution of both the precipitation and runoff is shown in part E. In this analysis the water year of October 1 to September 30 is substituted for the climatological year of July 1 to June 30. As indicated on plate 5, the major part of the annual precipitation in the mountain area occurs from December to March. The center of mass of this precipitation is reached about February 5, or half the precipitation occurs before and half after this date.

The time distribution of runoff observed in San Antonio Creek drainage basin is used in this diagram as representative of the monthly time distribution of runoff in the mountain area. A mean annual runoff of 18.9 inches is all that is recoverable from the basin-wide mean annual precipitation of 41.8 inches. The diagram shows this runoff to range from 3.2 percent of the annual runoff in October to 18.2 percent in March. The center of mass of this runoff is reached about April 5, representing a lag of 2 months between the centers of mass of precipitation and runoff.

TIME DISTRIBUTION OF PRECIPITATION AND RUNOFF

F

The time lag between precipitation in the entire mountain area and runoff in San Antonio Creek, as is shown in part E, is believed to be largely a measure of the absorptive and retentive qualities of the mantle rock. Because these complicated qualities are variable throughout the mountain area, there are differences in the time lag among the five physiographic units. Furthermore, the lower the average annual precipitation, the greater the percent of annual runoff that is concentrated in a few consecutive months.

Part F shows the time distribution of the mountain area precipitation and of the runoff in each of the physiographic units for the water year. This graph of distribution indicates the dates after the beginning of the water year in which the accumulation of precipitation or runoff is equivalent to 20, 40, 60, and 80 percent of the average annual precipitation or runoff. (Part E has shown that most of the mountain area precipitation occurs in the winter and spring months, more than 40 percent falling in January and February). About 20 percent of the precipitation occurs before December 20; 40 percent before January 20; 60 percent before February 20; and 80 percent before March 25. Rearranged, this analysis indicates that 60 percent of the precipitation was concentrated in the 3.2 months between December 20 and March 25.

In the Mojave River basin 60 percent of the average annual runoff was concentrated in a 2.7-month period ending April 15. Sixty percent of the average annual precipitation in the entire mountain area was concentrated in a period of about the same length but ending March 20--one month earlier.

In the lower frontal mountain drainage area 60 percent of the average annual runoff was concentrated in a 3.0-month period ending April 25. Here a slightly longer period was required for a 60-percent concentration of runoff than in the Mojave River basin, and the period ended 1.3 months after the date of equal cumulative percentage of average annual precipitation for the mountain area and 10 days later than the date of equal cumulative percentage of runoff in the Mojave basin. Then progressively downward through the list of physiographic units shown in part F, 60 percent of the average annual runoff was concentrated in longer periods, each period except one ending at a progressively later date.

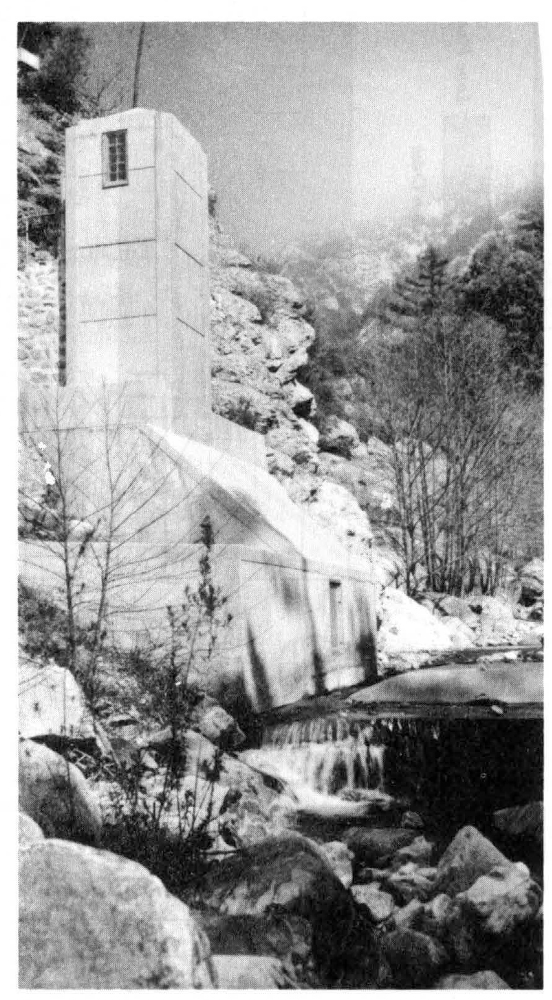
Assuming other hydrologic factors to be the same in all five physiographic units, it is evident from this time distribution that the mantle rock in the Mojave River basin is the least absorptive and retentive and that in the upper mountain areas it is the most absorptive and retentive.

G

Another method for indicating the relative absorptive and retentive qualities of the mantle rock is to show the difference in runoff between the month having the greatest runoff and the month having the least, provided the precipitation pattern is approximately the same.

In the Mill Creek drainage basin, March is the month of greatest runoff, its average being 15.2 percent of the average annual runoff. In November the average runoff is the least, being only 4.0 percent of the average annual runoff. The difference between these two average monthly quantities is 11.2 percent of the average annual runoff. Deep Creek below Green Valley Creek, having nearly the same magnitude and distribution of precipitation as Mill Creek and an identical average altitude of 6,600 feet, has 26.1 percent of the average annual runoff in March, the month of greatest runoff. In September, when runoff is lowest, it is only 0.4 percent of the average annual runoff. In this basin the difference between the months of greatest and least runoff is 25.7 percent of the annual runoff. This greater difference between the maximum and minimum monthly runoff indicates the mantle rock in the Deep Creek drainage basin to be less absorptive and retentive than the mantle rock of the Mill Creek drainage basin.

Thus the difference between the maximum and minimum monthly runoff (measured in terms of percent of average annual runoff) offers an index of absorptive and retentive qualities of the mantle rock and of the ground-water storage facilities in the underlying bedrock in each drainage area. The more absorptive qualities and the greatest capacity for ground-water storage are to be expected where this range in monthly runoff is the least. For this reason, part G shows the range between the maximum and minimum monthly runoff, in percent of annual runoff, for 15 mountain area streams.

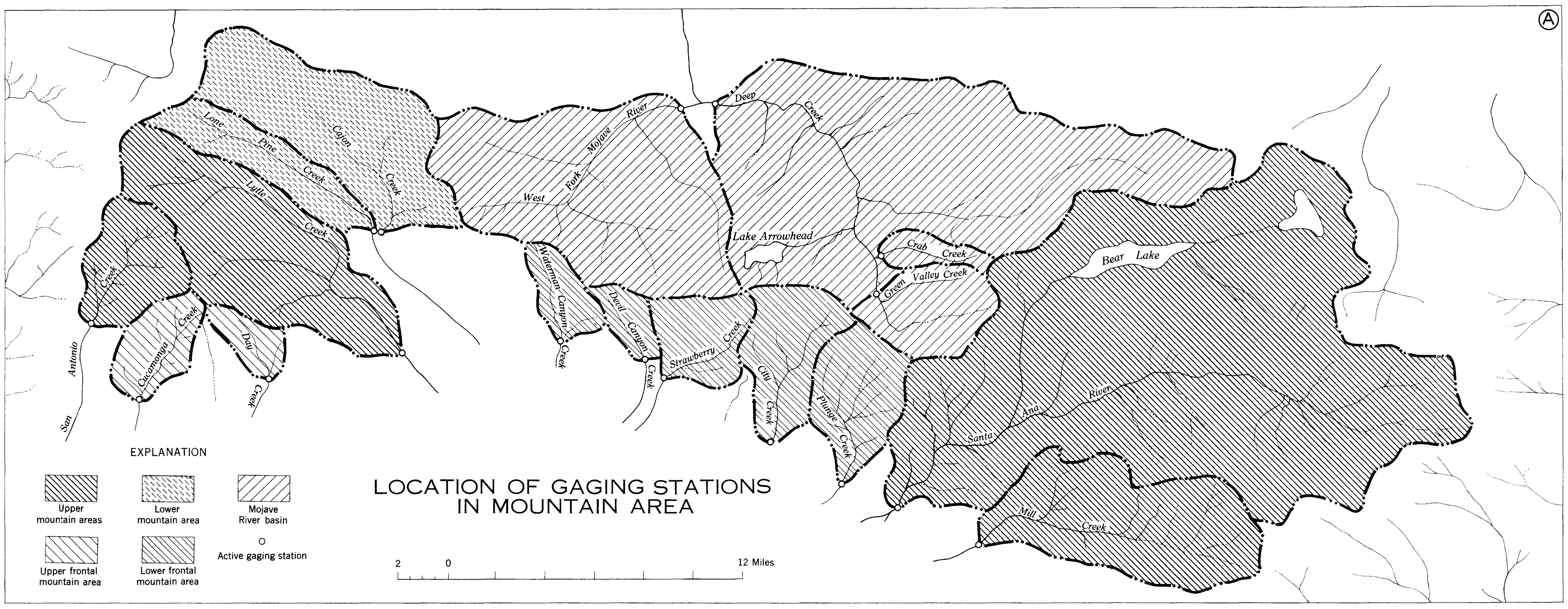


San Antonio Creek gaging station

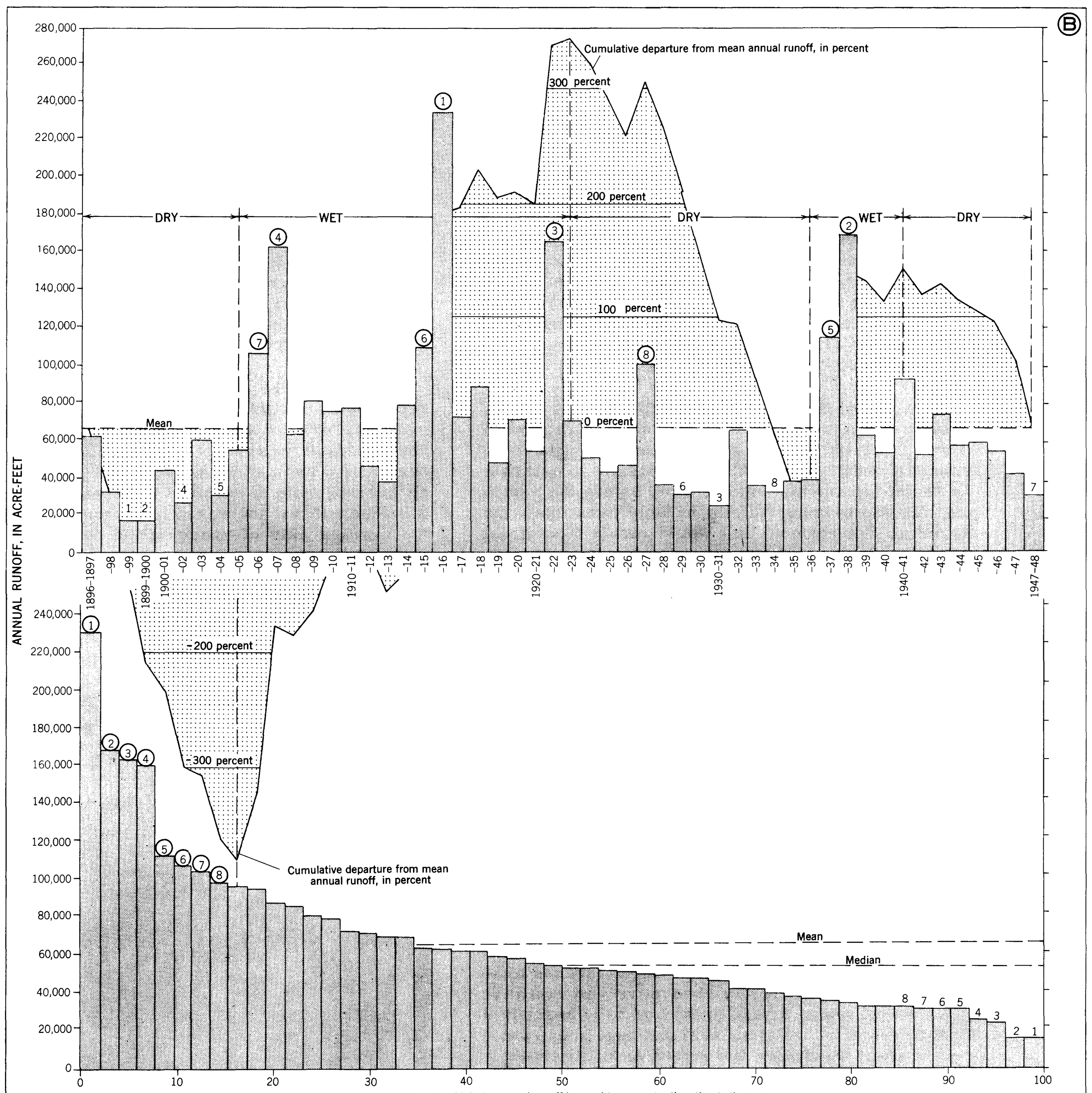
H

Using annual precipitation and the difference between maximum and minimum monthly runoff as indices, it has been possible to develop a correlation (part H) showing the estimated absorptive and retentive qualities of the mantle rock. This correlation represents the first and most simple grouping of these indices in identifying the absorptive and retentive qualities of the mantle rock. Subsequently, other indices, such as flood runoff and natural water loss, will also be used to define these mantle rock qualities.

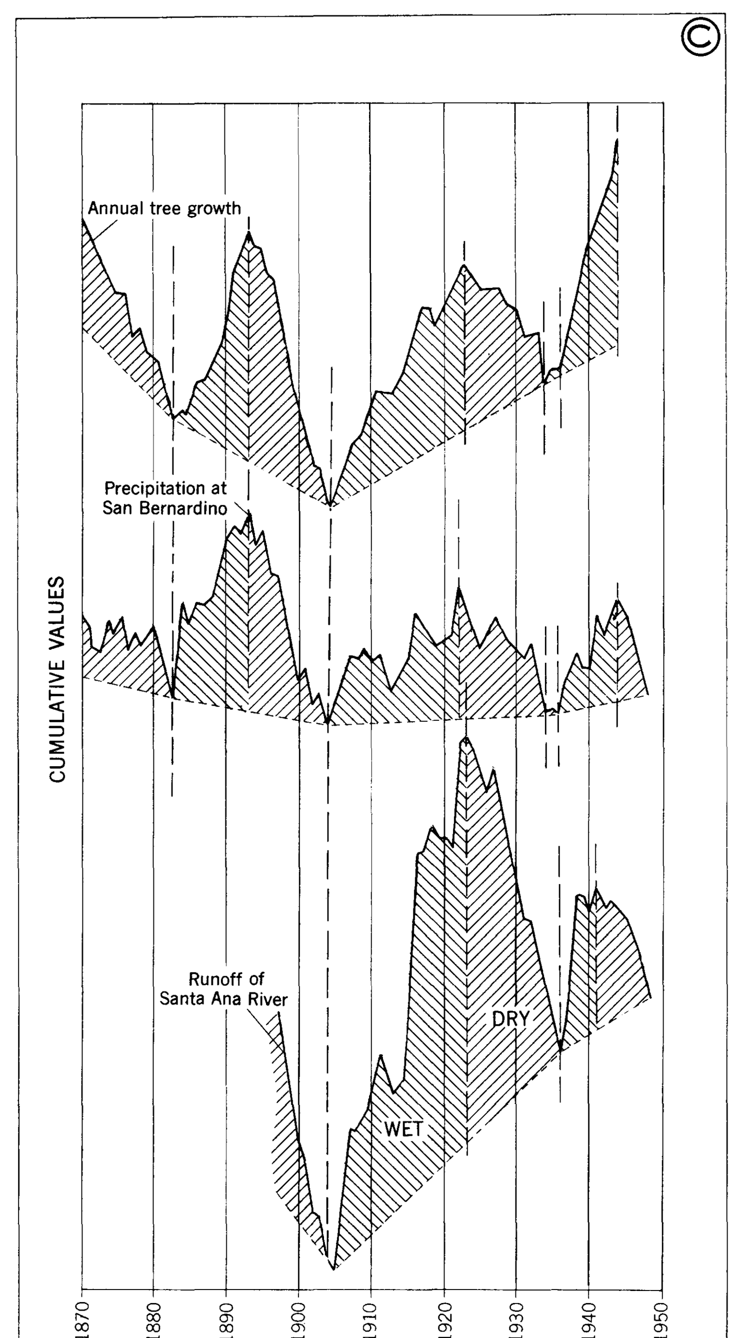
This correlation, resulting in the classification of mantle rock according to its capacity to absorb and retain moisture, is not necessarily presumed to be applicable outside the mountain area. There are too many factors that defy accurate measurements to warrant application elsewhere.



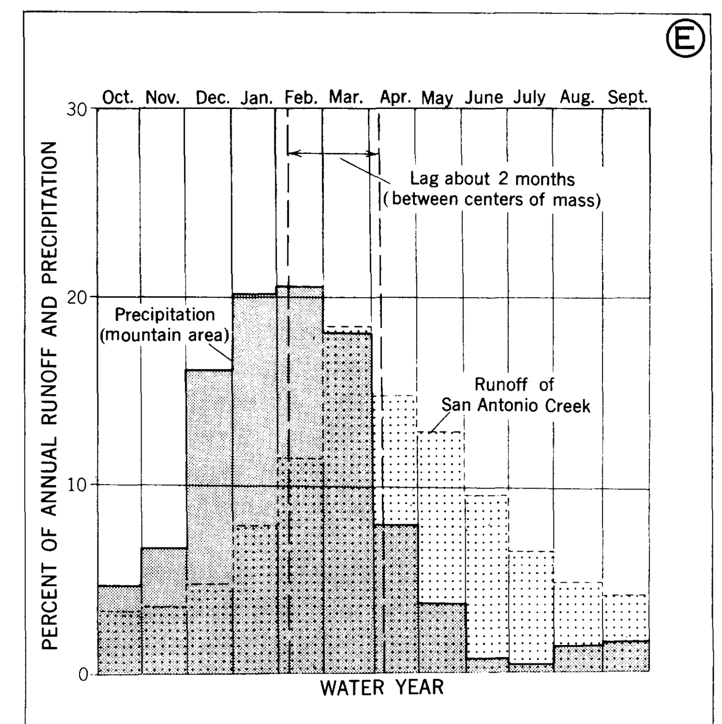
LOCATION OF GAGING STATIONS IN MOUNTAIN AREA



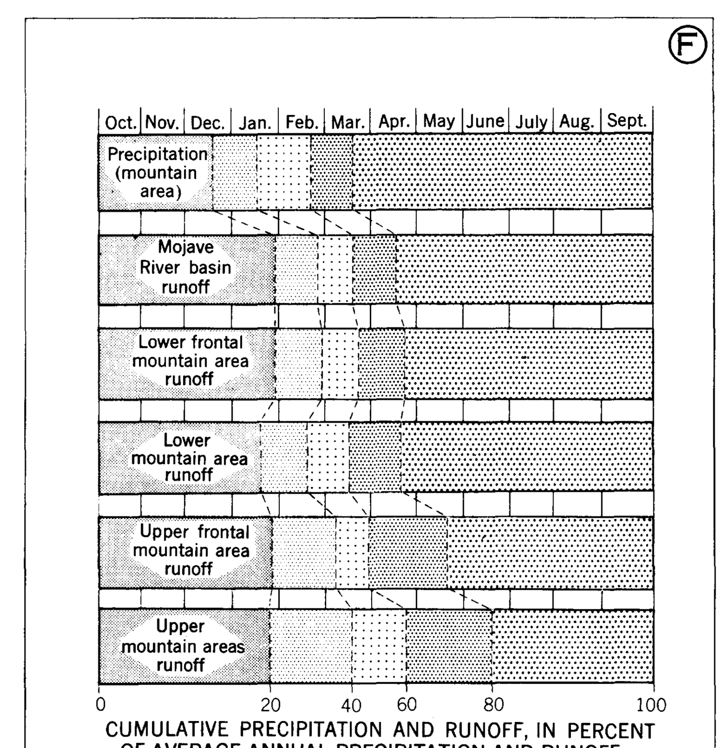
ANNUAL RUNOFF OF THE SANTA ANA RIVER NEAR MENTONE, CALIFORNIA, 1896 TO 1948



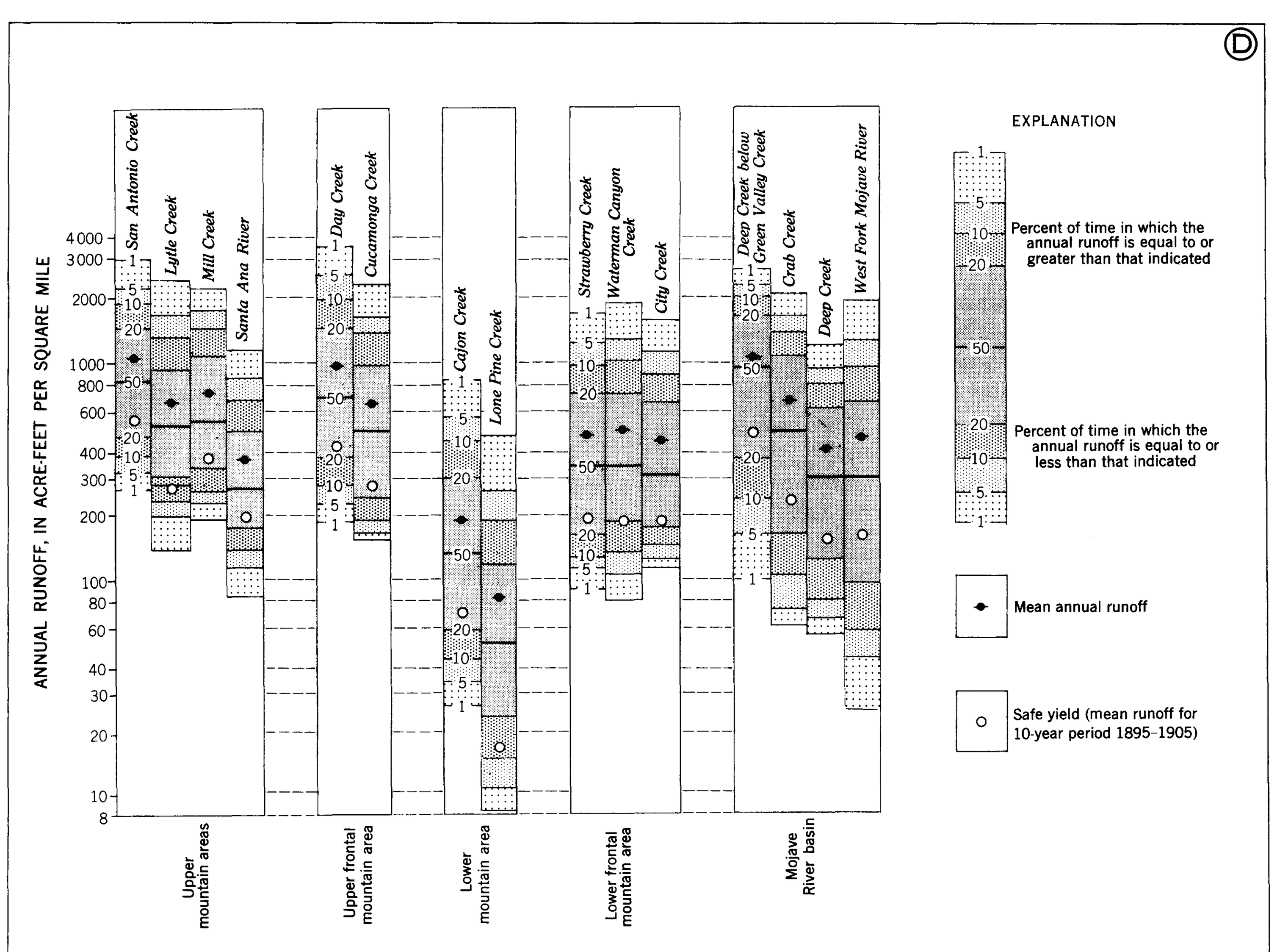
COMPARISON OF ANNUAL TREE GROWTH, PRECIPITATION, AND RUNOFF



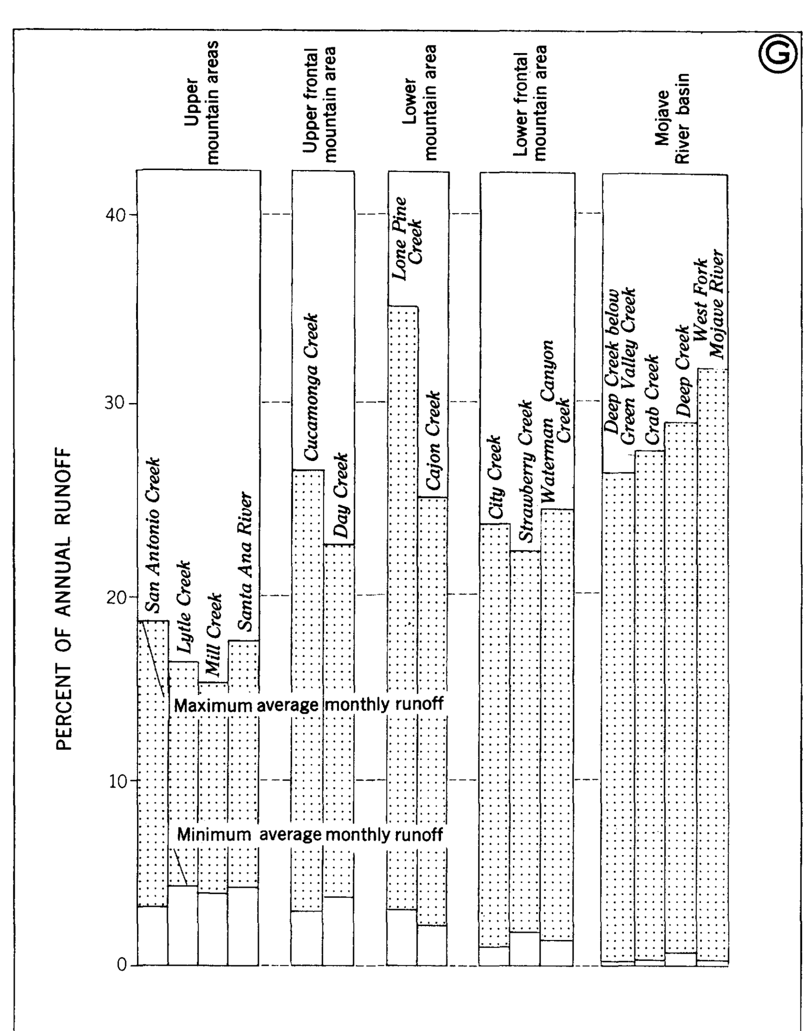
MONTHLY DISTRIBUTION OF RUNOFF AND PRECIPITATION



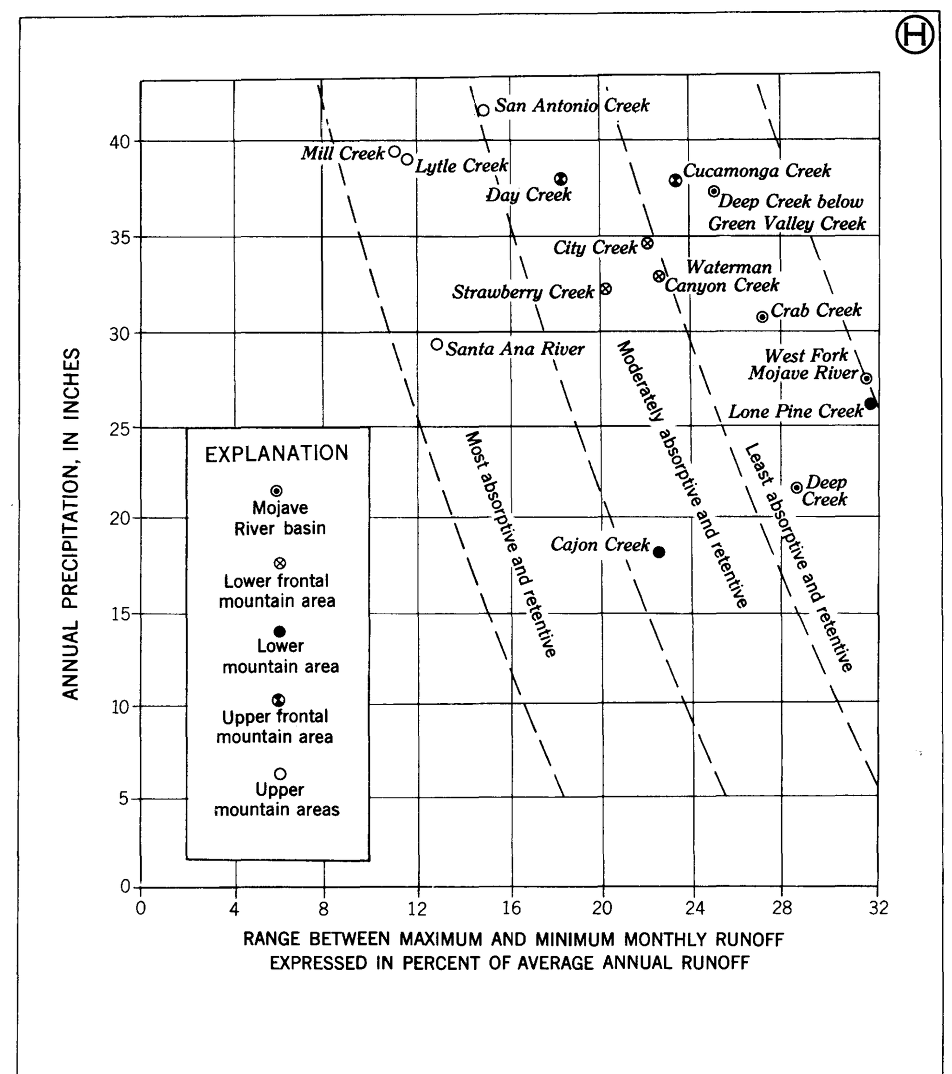
RELATION IN TIME BETWEEN PRECIPITATION AND RUNOFF



FREQUENCY DISTRIBUTION OF ANNUAL RUNOFF



MAXIMUM AND MINIMUM AVERAGE MONTHLY RUNOFF, IN PERCENT OF ANNUAL RUNOFF



ESTIMATED ABSORPTIVE AND RETENTIVE CHARACTERISTICS OF THE MANTLE ROCK ARRANGED TO SEGREGATE INFLUENCE OF ANNUAL PRECIPITATION

RUNOFF CHARACTERISTICS

TYPES OF RUNOFF

A

In analyzing runoff in the mountain area, it is first necessary to distinguish between storm surface runoff and storm ground-water runoff, as they will now be defined for purposes of this study.

Storm surface runoff results from intense rates of precipitation which exceed the rates of infiltration of the mantle rock. In many parts of the mountain area the rates of infiltration are extremely large. In such areas only a small part of the observed runoff can be classified as "storm surface runoff."

Because of the relatively high rates of infiltration associated with most of the mantle rock, storm surface runoff occurs only during a shower of unusual intensity. However, runoff from the storm may continue for days and even weeks after the storm has ceased. This delayed runoff originates from a very temporary type of ground-water storage, and may be designated as "storm ground-water runoff." For the purpose of this atlas and in the interest of simplicity, storm surface runoff and storm ground-water runoff have been combined and termed "storm runoff."

Some of the precipitation that infiltrates into the mantle rock recharges many small ground-water bodies situated at high altitudes in the mountain area. The seepage from this ground-water storage is intermittent, generally starting after the first rainfall of the year and ending by September or earlier, depending on the amount of precipitation. This type of runoff has been designated "seasonal ground-water runoff."

Other portions of the precipitation penetrate to the major ground-water bodies within the drainage area. These ground-water bodies are recharged at less frequent intervals, generally only in years of greatest precipitation. The seepage from these sources is of a gradually decreasing magnitude, often continuing for 4 or 5 years after the period of recharge. Because of this seepage certain mountain area streams have never been known to go dry, even in the most extended drought. This seepage has been designated "perennial ground-water runoff."

An idealized cross section of the mountain block is shown in part A giving the source and distribution of the various types of runoff. As the diagram indicates, storm runoff originates over the entire area and occurs mostly in the winter months, as shown by the first hydrograph. Seasonal ground-water runoff represents the seepage from intermittent springs. As shown by the second hydrograph, this runoff generally extends from January through August, the maximum runoff occurring in March or April. Runoff from perennial ground-water sources is continuously diminishing, as shown in the third hydrograph, except during periods of recharge in wet years.

The fourth hydrograph shows the typical distribution of the daily discharge when all types of runoff are combined. This represents the general daily discharge distribution observed at each mountain area gaging station, except as modified by differences in amounts of precipitation and variations in the absorptive and retentive qualities of the mantle rock.

Upper part of the North Fork Lytle Creek drainage area

B

The relative magnitude and importance of each of these three types of runoff are shown in part B for the Lytle, Strawberry, Cajon, and Deep Creek drainage areas. The quantitative determination of these various types of runoff has been obtained by a detailed analysis of the distribution, in time, of the daily discharge, which is explained in somewhat greater detail in the following plates. When the values of runoff are combined with those of the natural water loss, they represent the total disposal of the basin-wide precipitation.

In the 12-year period from 1931-43, the average annual precipitation in the Lytle Creek drainage area was 45 inches. Of this amount, 15.5 inches, or 34 percent, was recovered by drainage from the area in the form of surface and subsurface runoff. The residual of 29.5 inches represents the basin-wide average annual natural water loss (evapotranspiration). Of the recoverable water, 1.8 inches, or about 12 percent, can be attributed to storm runoff. The remaining 13.7 inches of runoff represents ground-water seepage, of which 5 inches has been designated seasonal ground-water runoff, and 8.7 inches perennial ground-water runoff.

In the very much less absorptive and retentive drainage area of Deep Creek, and average annual precipitation of 27.3 inches during the 10-year period of 1905-15 produced a total runoff of 10 inches. This runoff has been divided into an average annual storm runoff of 3 inches, an average annual seasonal ground-water runoff of 6 inches, and an average annual perennial ground-water runoff of 1 inch.

The wide variation in the way runoff is distributed among its three types in the four drainage areas shown in part B is typical of the mountain area and is believed to be closely associated with the physical properties of the mantle rock and ground-water storage facilities.

PRECIPITATION AND RUNOFF

C

A simple introduction to the influence of precipitation on runoff is obtained by graphic development of a relationship between cumulative quantities of each. Such a relationship is shown in part C and represents the average cumulative precipitation and runoff since October 1st in the Strawberry Creek drainage area. This relationship extends only through the winter and spring rainy season and does not include the runoff during the summer and fall recession. The cumulative values are based on an average relationship obtained during the 20-year period of 1921-41.

The first 20 inches of precipitation on this drainage area produced a combined runoff of 1.7 inches from surface and ground-water sources. As the season progressed a cumulative precipitation of 30 inches gave a cumulative runoff of 3.8 inches. Thus, the last 10 inches of this precipitation produced a runoff of 2.1 inches, or 21 percent of the rainfall. For each additional 10-inch precipitation increment, a larger and larger part of it appears in the stream channel as runoff. As a result, the sixth 10-inch precipitation increment produced 10 inches of runoff.

It is evident from this diagram that storm runoff can be largely a function of the antecedent precipitation; or more specifically, a function of the soil moisture deficiency in the mantle rock. If this deficiency is large, a major storm may produce only negligible runoff; yet another storm exactly like this one could produce a disastrous flood if it were to occur after this soil moisture deficiency has been completely satisfied. This has more than once proved true.

D

The characteristics of a deficiency in the soil moisture vary greatly from area to area, depending largely on the absorptive and retentive qualities of the mantle rock. At the beginning of the winter storm period, the most absorptive and retentive areas generally have the greatest soil moisture deficiency and consequently permit relatively less runoff. This is best illustrated by the series of graphs in part D. These graphs show the resulting runoff produced by each 5-inch precipitation increment from October 1 until 30 inches of precipitation has been cumulated. The runoff from the five typical mountain area drainage basins of Lytle, San Antonio, Strawberry, Cajon, and Deep Creeks is used to show the effect of the absorptive and retentive qualities of the mantle rock on soil moisture deficiency.

The retention in the mantle rock was enough for the first 5-inch precipitation increment to produce runoff amounting to only 4 percent or less of the precipitation in all five areas. As the soil moisture deficiency became smaller, the increment of retention also became smaller. As a result, the last 5-inch precipitation increment produced a runoff equivalent to about 8 percent of the precipitation in the most absorptive and retentive drainage areas of Lytle and San Antonio Creeks. In the less absorptive and retentive drainage areas of Cajon and Deep Creek the runoff increment ranged from 43 to 66 percent of the precipitation.

RELATIONSHIPS AMONG STORM PRECIPITATION, RUNOFF, AND RETENTION

E

It is evident from the preceding analysis that the quantity of storm runoff in each drainage area will depend on the soil moisture deficiency, as well as on the amount of the storm precipitation. To demonstrate this, part E shows a correlation among the four factors of storm precipitation, percent of storm precipitation occurring as runoff in the maximum 5-day-period, runoff for the maximum 5-day-period, and retention in mantle rock before the storm. This last factor is a substitute for soil moisture deficiency and represents the retention measured above the wilting point.

The left half of part E shows this correlation in an area of most absorptive and retentive mantle rock in the San Antonio Creek drainage basin. It indicates that if the first storm of the year produced a precipitation of 15 inches, about 3.5 percent of it, or 0.52 inch, would be disposed of as runoff in the maximum 5-day period. If, however, this storm occurred somewhat later in the season when the moisture in the mantle rock had increased from 0 to 18 inches, then about 24 percent of it, or 3.6 inches, would be disposed of as runoff during the maximum 5-day period.

The right half of part E gives a similar correlation in an area of least absorptive and retentive mantle rock in the Deep Creek drainage basin. Here, if the first storm of the year produced a precipitation of 15 inches, about 30 percent of it, or 4.5 inches, would run off during the maximum 5-day period. If the moisture retained in the mantle rock before this storm amounted to 18 inches, then about 76 percent of the 15 inches of storm precipitation, or 11.4 inches, would run off in the maximum 5-day period.

By means of these and similar diagrams it is possible to obtain a fairly reliable relationship between storm precipitation and storm runoff throughout the mountain area. From this it is possible to estimate the runoff for storms that occurred before the period and, far more important, to be able to estimate the maximum flood runoff that would result from great storms occurring when the mantle rock was saturated.

RELATIONSHIP BETWEEN VOLUME AND TIME OF RUNOFF

F

How the absorptive and retentive qualities of the mantle rock affect the period of runoff can be demonstrated by another correlation. This correlation (part F) is shown by a curve that indicates the relationship between the percent of volume and the percent of time of the daily discharges, based on the time distribution indicated by flow duration curves. The Lytle, Strawberry, and Cajon Creek drainage areas are used as examples.

This correlation shows that in Lytle Creek 16 percent of the runoff occurs in 1 percent of the time. At the same percent of time this volume increases to 20 percent in the moderately absorptive and retentive Strawberry Creek drainage area, and to 38 percent of the total runoff in the Cajon Creek drainage area, which has the least absorptive and retentive mantle rock.

This diagram also shows that 50 percent of the volume occurs in 2.5 percent of the time in Cajon Creek, in 6.5 percent of the time in Strawberry Creek, and in 17 percent of the time in Lytle Creek drainage area. The relationship between time of runoff and volume of runoff is a sensitive scale for measuring these absorptive and retentive qualities of the mantle rock.

STORM RUNOFF

G

The storm runoff, as already indicated, depends in part on the rate of rainfall exceeding the rate of infiltration. However, the storm runoff, being a residual of precipitation, is influenced by many of the other physical features of the drainage area. This is demonstrated by the curves in part G, showing the relationship between rates of precipitation and rates of runoff for various sized drainage areas in the San Gabriel Mountains for the flood of March 1938. b/

The first curve from the left gives storm runoff from a 0.025-acre mountain runoff plot in the Fern Canyon area situated at an altitude of 5,000 feet and having a land-surface slope of 60 percent. A maximum rate of precipitation of 1.56 inches per hour for a 10-minute interval produced a rate of runoff of 0.019 inch per hour. During the maximum 3-hour period an average rate of precipitation of 1.20 inches per hour produced an average rate of runoff of 0.014 inch per hour. A total storm precipitation of 20.4 inches on this plot produced a total runoff of 0.2 inch. The difference between 20.4 and 0.2 inches represents the amount of storm precipitation which penetrated into the mantle rock. The runoff from this plot is a measure of the storm runoff in the strictest sense.

The second curve represents the data obtained from 0.084-square-mile Fern Canyon watershed no. 3 in the vicinity of the mountain runoff plot in Fern Canyon. During the period of maximum precipitation the rates averaged 1.62 inches per hour for a 15-minute interval. After a short lag, the maximum 15-minute runoff produced an average rate of 0.33 inch per hour. This rate of runoff greatly exceeds that for the mountain runoff plot in Fern Canyon and represents the added contribution of storm ground-water runoff from recently observed precipitation. For the maximum 3-hour period the rates of rainfall averaged 1.35 inches per hour, while the rates of runoff averaged 0.29 inch per hour. For the entire storm period a basin-wide precipitation of 23.0 inches produced a storm runoff of 3.67 inches and a retention of 19.3 inches.

In the Fern Canyon watershed no. 2 the rates of runoff were almost double those in watershed no. 3, even though the rates of rainfall were almost identical. This difference is largely a measure of the rapidity with which the temporary storm ground-water storage drains back into the stream channel. The mantle rock in this drainage area appears to be much less retentive than that in watershed no. 3 because the total storm runoff amounted to 8.8 inches of the basin-wide precipitation of 23 inches. Retention was 14.2 inches.

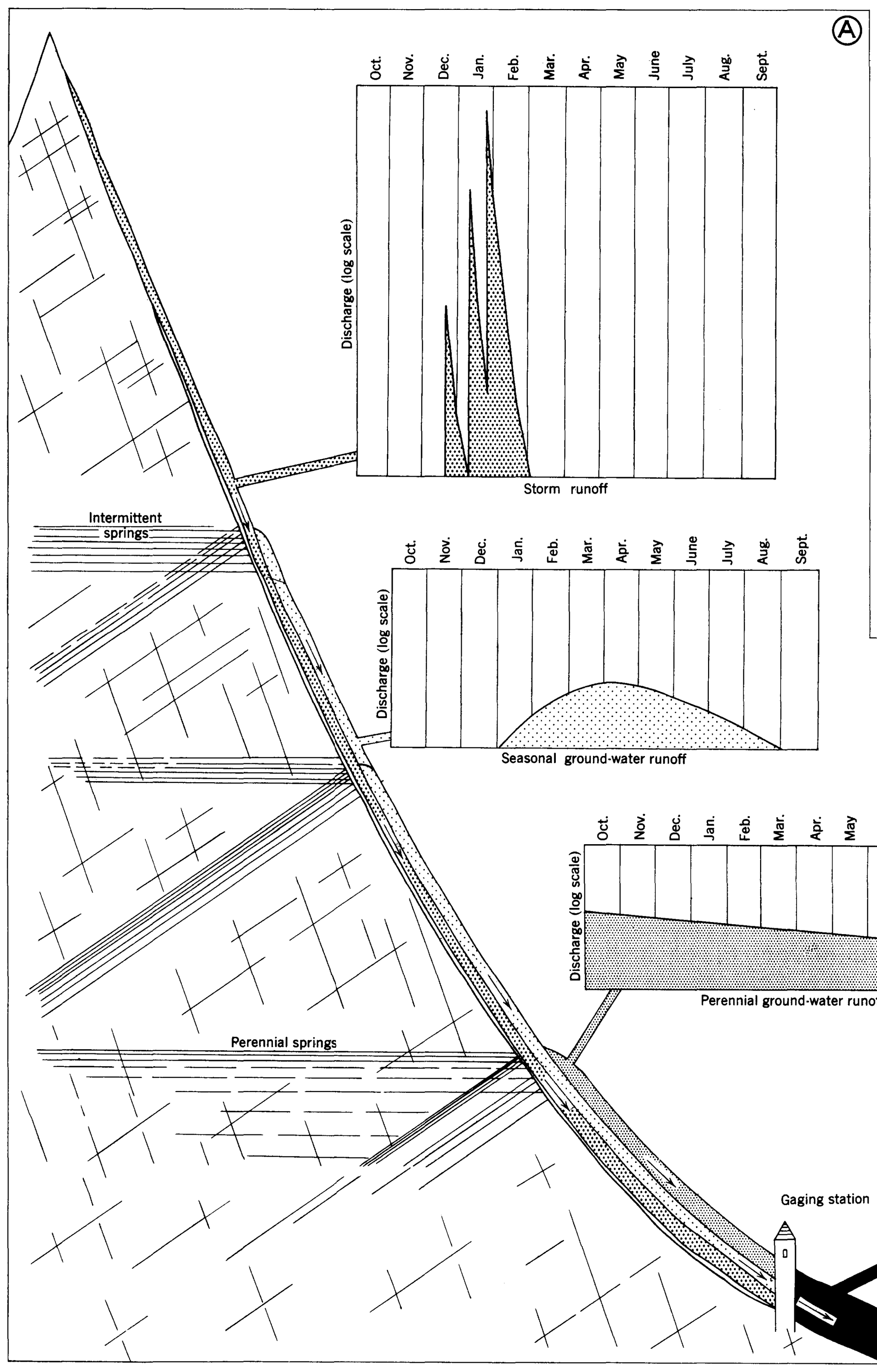
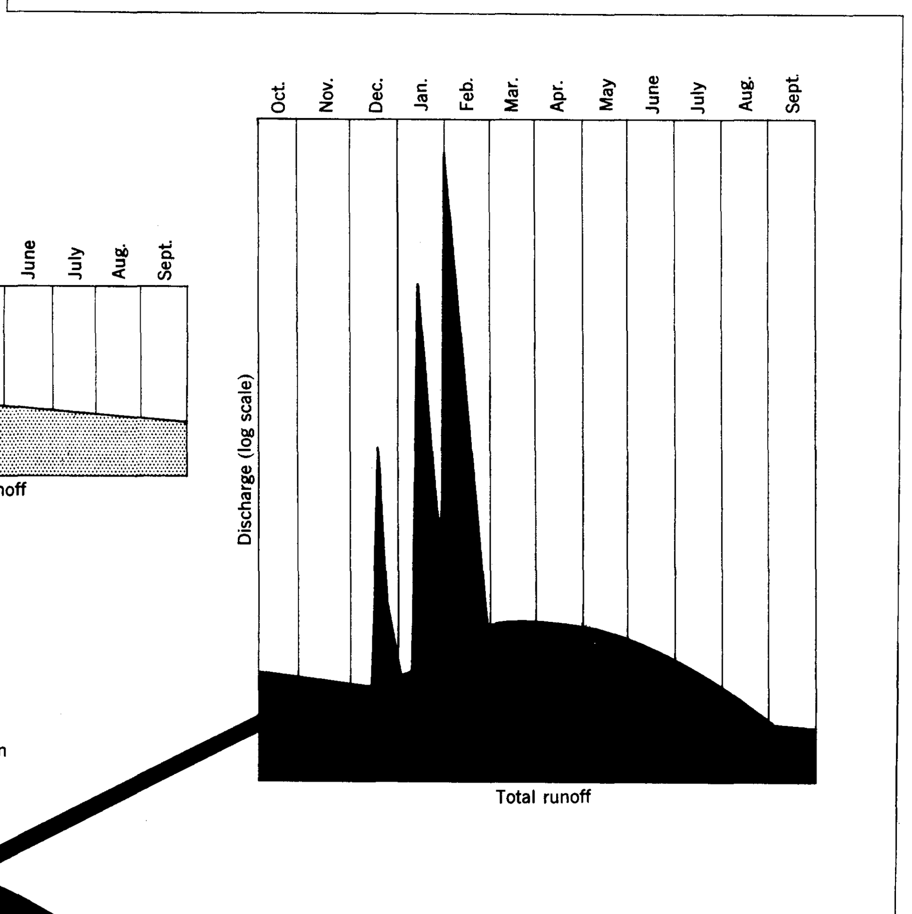
The curve in the extreme right of part G gives this relationship for the 40.4-square-mile drainage area of West Fork San Gabriel River. During this storm period, an average rate of precipitation of 2.45 inches per hour for the maximum 15-minute period produced an average rate of runoff of 0.98 inch per hour. As this time interval increased to the maximum 2 hours, the average rate of precipitation decreased to 1.41 inches per hour, and the corresponding average rate of runoff decreased to 0.91 inch per hour. It is evident that rates of runoff during these two periods do not reflect corresponding rates of precipitation. This is largely because these two time periods are shorter than the time of concentration (the time required for water to travel from the most remote part of the basin to the outlet). The unique physical characteristics of each drainage area determine its time of concentration, a fact which greatly complicates the analyses of peak discharges.

Stockton Flat, altitude 5,500 feet, in the Lytle Creek drainage area

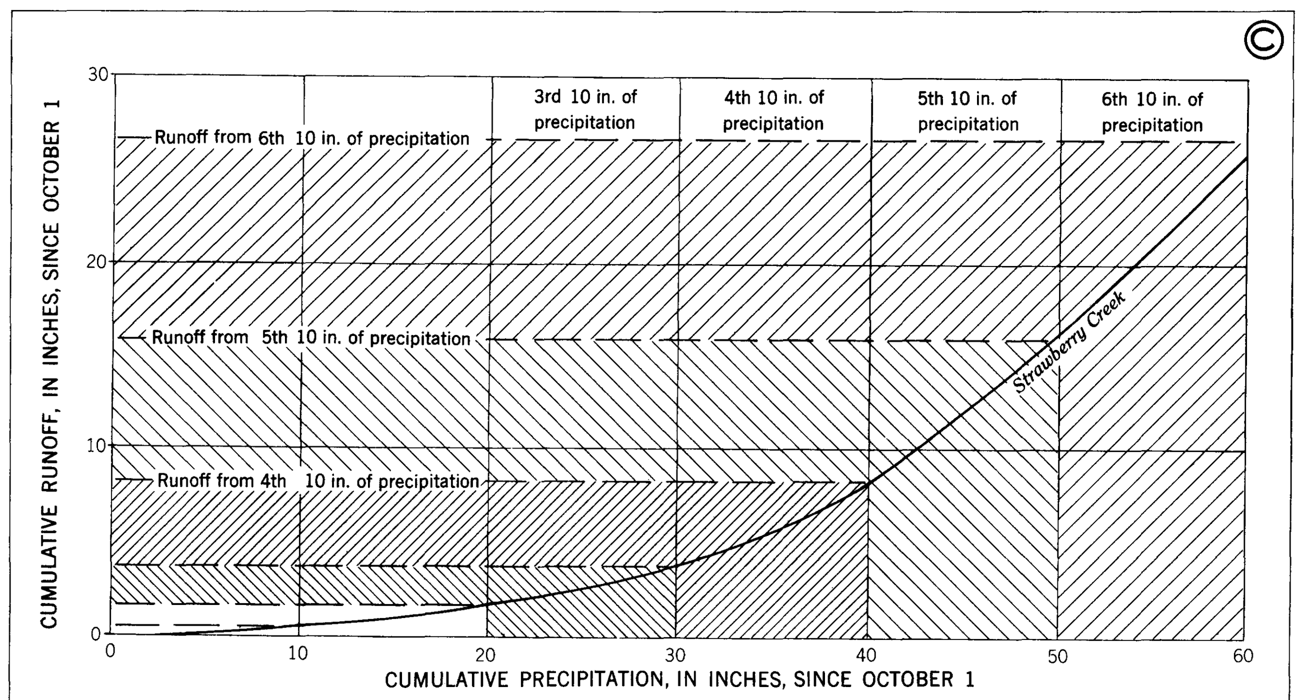
With the conclusion of the maximum 2-hour period there is a distinct change in trend in the relationship between rate of precipitation and rate of runoff for the West Fork San Gabriel River. This change in trend may represent the passing of the time of concentration. For maximum time intervals longer than the time of concentration all changes in rates of precipitation are fully reflected in the rates of runoff. Consequently, rates of precipitation cannot be used as indices of runoff in any basin unless the time periods involved are longer than the time of concentration.

Of the basin-wide storm precipitation of 23.6 inches in the West Fork San Gabriel River, the storm runoff was 12.0 inches and the retention was 11.6 inches at the end of the storm period. For Santa Anita Creek the basin-wide precipitation was 25.8 inches, with a storm runoff of 11.1 inches and a retention of 14.7 inches at the end of the storm period.

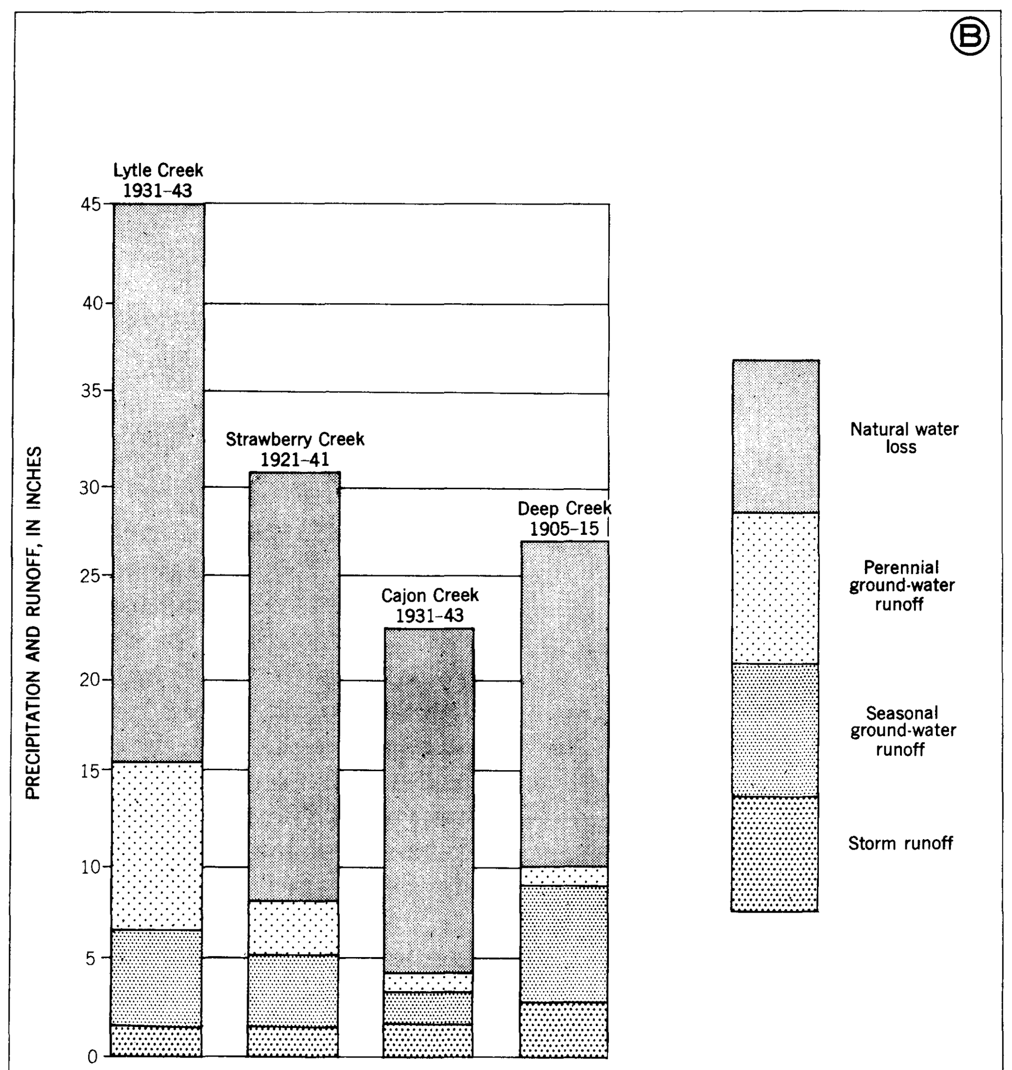
b/ Troxell, Harold C., and others, 1942, Floods of March 1938, in southern California, Water-Supply Paper 844, pp. 150-167.

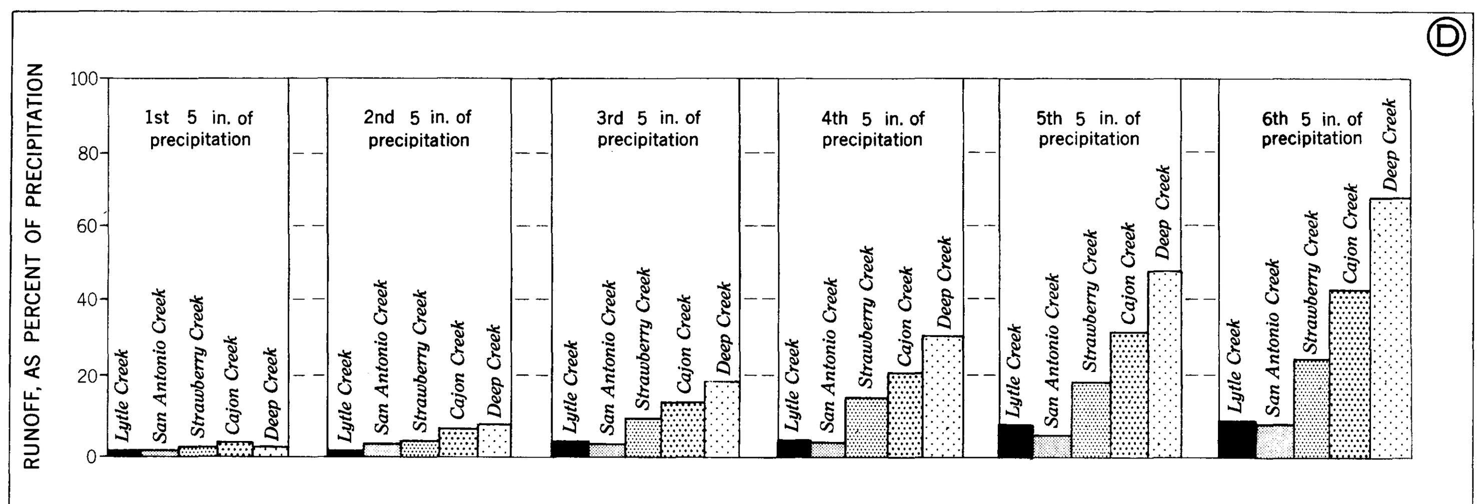
TYPES OF RUNOFF



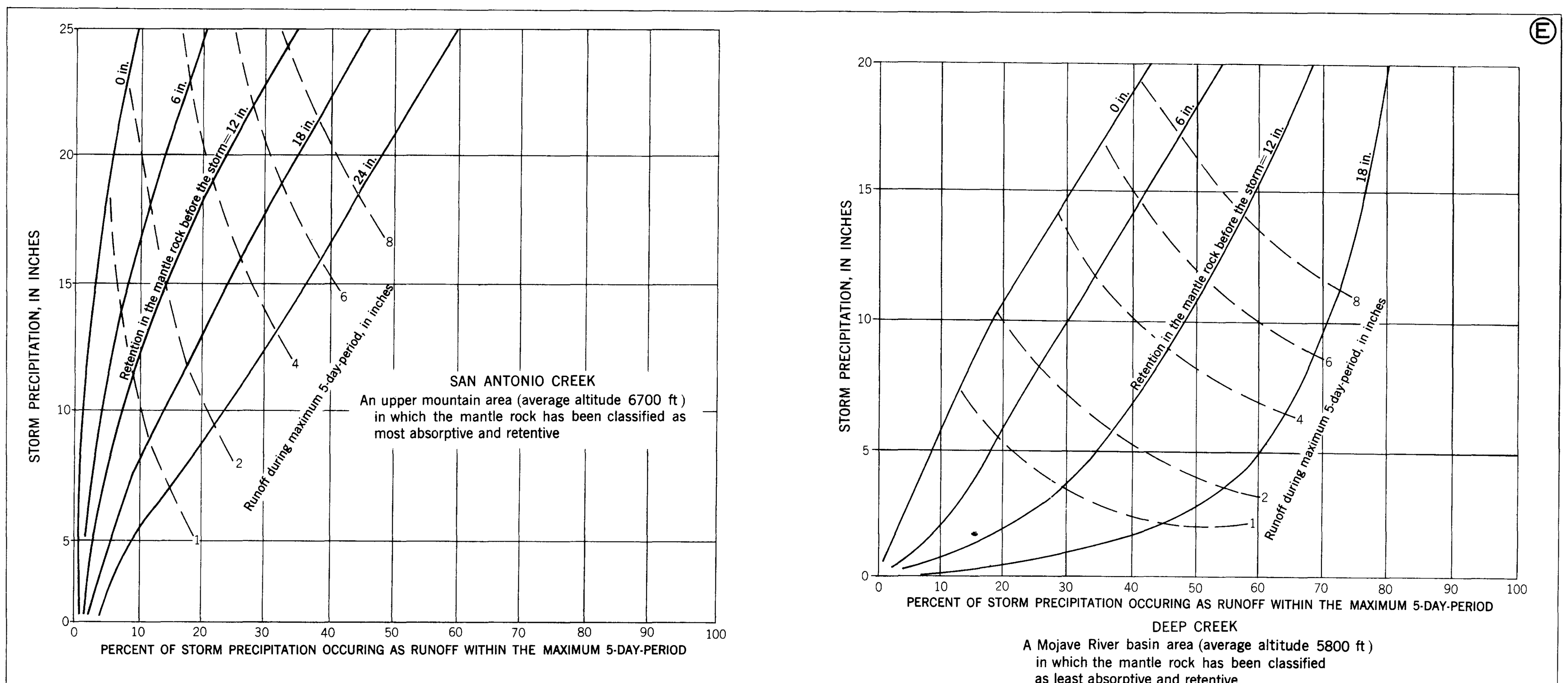
TYPICAL RELATIONSHIP BETWEEN CUMULATIVE PRECIPITATION AND RUNOFF



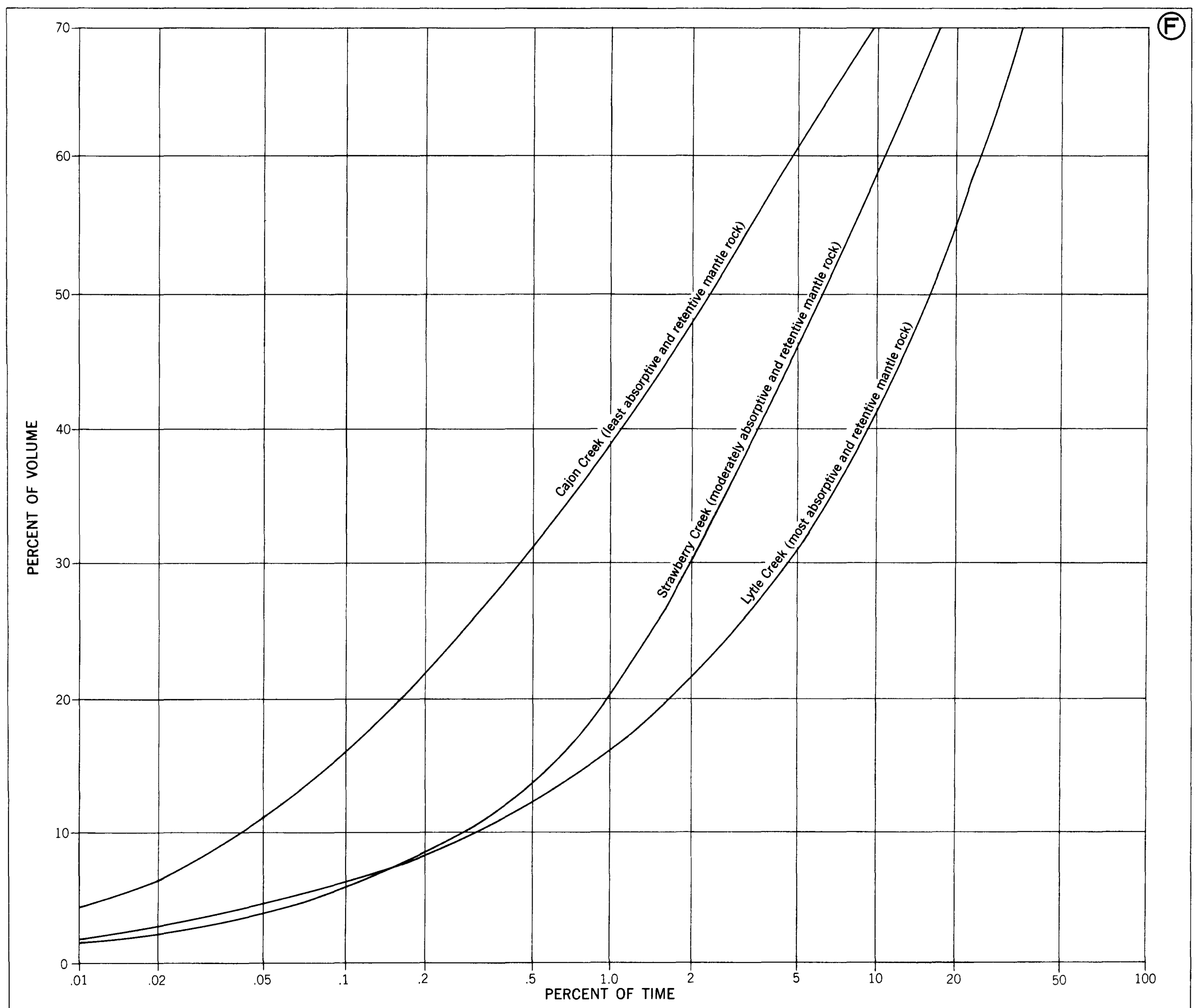
TYPICAL DISTRIBUTION OF ANNUAL RUNOFF



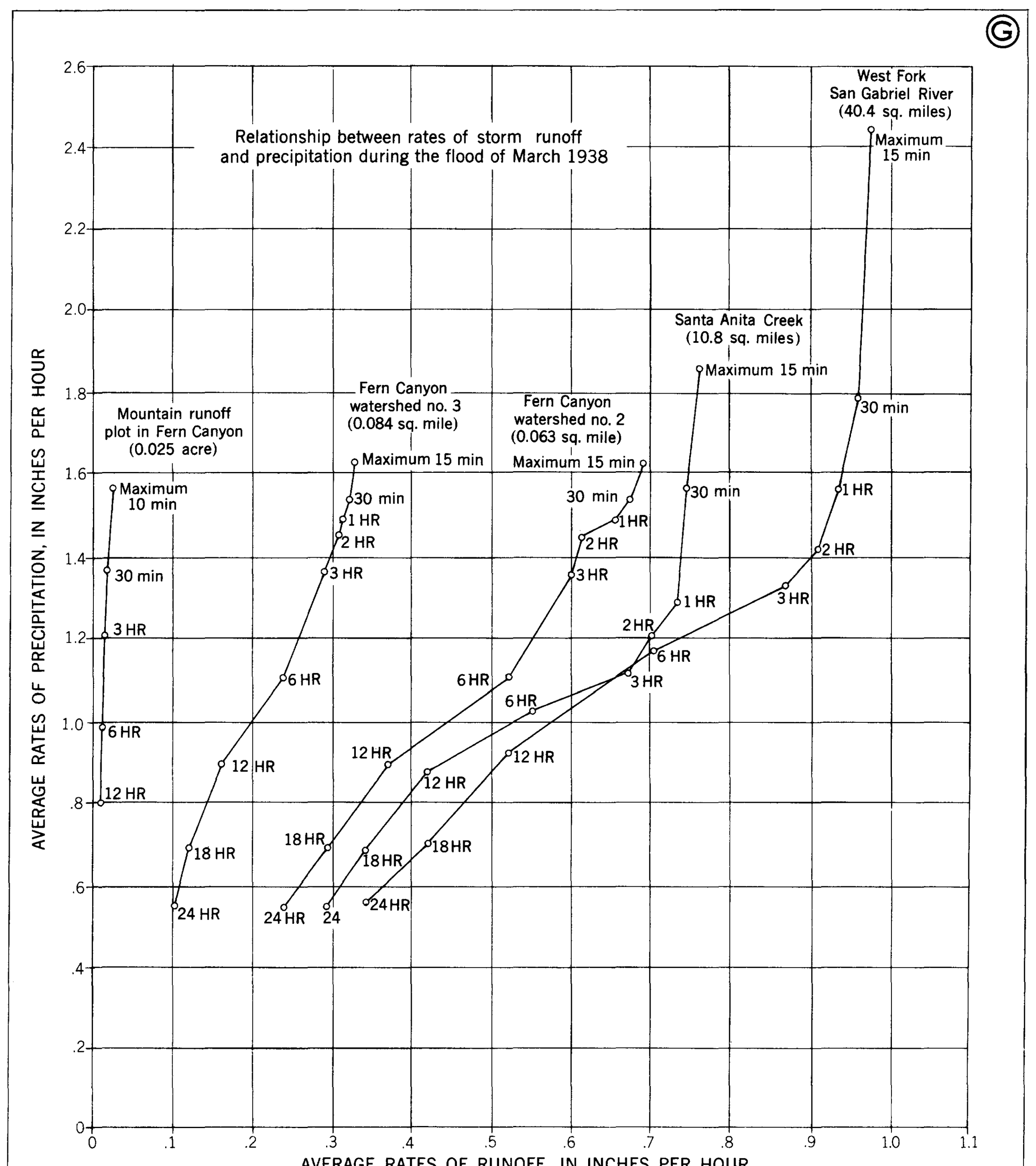
RELATIONSHIP BETWEEN PRECIPITATION AND RUNOFF



TYPICAL RELATIONSHIPS AMONG STORM PRECIPITATION, RESULTING MAXIMUM 5-DAY-PERIOD RUNOFF, AND ANTECEDENT RETENTION IN THE MANTLE ROCK



TYPICAL RELATIONSHIP BETWEEN VOLUME AND TIME OF RUNOFF



STORM RUNOFF

STORM SURFACE RUNOFF

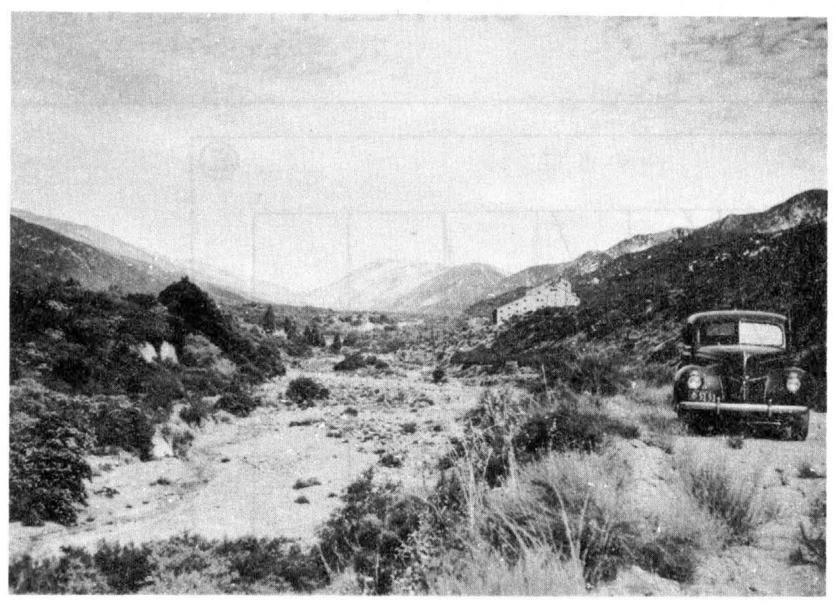
Storm, or flood, runoff is analyzed further on this plate.

For storm periods it is often impractical to attempt to identify the sources of immediate origin of runoff. The graphs in part G of plate 8 indicate that actual storm runoff was of minor importance during the March 1938 flood on the mountain runoff plot in Fern Canyon. However, during this storm, major flood runoff did occur in the small Fern Canyon drainage areas as a result of the rapid return of large quantities of storm ground-water runoff to the stream channel. As already explained, both storm surface and storm ground-water runoff in this atlas have been designated storm runoff for the sake of simplicity. Also, no attempt has been made during periods of excessive runoff to segregate the seasonal or perennial ground-water runoff, because they are of less significance. Consequently, all the runoff quantities used on this plate represent combined surface and ground-water runoff.

DISTRIBUTION OF DAILY DISCHARGE

A

Part B of plate 7 suggests that the distribution of storm-period runoff within any 1 year varies greatly from year to year. The intent of the upper diagram in part A of plate 9 is to show the irregular distribution of storm runoff by giving the number of days each year in which daily discharge of the Santa Ana River near Mentone was equal to or greater than 200, 300, 500, and 1,000 cubic feet per second (cfs) during the period 1896 to 1943. These discharge quantities represent roughly 2, 3, 5, and 10 times the mean annual discharge of 95.2 cfs.



Looking up the Lone Pine Creek drainage area in the San Andreas fault zone

These graphs of daily discharge are intended to answer such questions as, "How many days each year can we divert 200 cfs or more?" The records (not included in graph) show that daily discharge equaled or exceeded 200 cfs for an average of 25 days per year from 1896 to 1943; however, an examination of the upper half of part A shows the great variability in the distribution of storm surface runoff from year to year. From 1896 to 1905 not a single year had as many as 15 days with a daily flow of this magnitude. Also, during the 14-year period of 1922-36 daily discharge equaled or exceeded 200 cfs on an average of only 3.4 days per year. In contrast, during the period of 1905-11 there was an average of 54 days per year in which the daily discharge equaled or exceeded 200 cfs. It is evident from this that the year-by-year distribution is of the greatest significance in any utilization of this flow.

The lower diagram in part A gives the frequency distribution of these daily discharge quantities and is a rearrangement of the data in the upper diagram in order of magnitude. The horizontal scale gives the percent of time (in years) in which the daily discharge is equal to or greater than that indicated. Thus, for 10 percent of the time, or 10 years in 100, the daily discharge will equal or exceed 200 cfs for 98 days or more. However, at the other extreme of the frequency scale, the daily discharge will not equal or exceed 200 cfs on a single day during 18 percent of the time, or 18 years in 100. Similar information for other frequencies and other discharge quantities can be obtained in the same manner.

The median, an index of time distribution, shows that half the years will have a daily discharge of 200 cfs or more occurring for 4 days.

FLOOD HYDROGRAPH

B

To explain certain terms that will be used, a typical flood hydrograph of a mountain area stream is sketched in part B. Generally, the two parts of a flood hydrograph most frequently used are the intensity of the peak discharge and the volume of flood flow. The peak discharge, expressed in cubic feet per second, is a measure of the intensity. As used in this atlas, the volume of runoff from any storm is confined to the maximum 5-day period and is given in acre-feet, cubic-feet-per-second days, or inches of water over the drainage area.

MAXIMUM 5-DAY-PERIOD RUNOFF

C and D

The volume of storm runoff for the maximum 5-day periods in the Santa Ana River for 47 largest floods in the 47-year period of 1896-1943 are shown in part C. Each item was selected on the basis of magnitude without regard to the year in which it occurred. Consequently, some years will be represented by two or more floods, and other years will not be represented at all. The smallest item will be equaled or exceeded 47 times in 47 years, thereby having a frequency of once a year.

The term "mean annual maximum 5-day-period runoff" is used throughout this atlas as an index of flood runoff. It is defined as the average volume of all the floods which are equal to or greater than the once-a-year flood. Part C shows that the total volume of the 47 largest floods divided by the 47 years gives a mean annual maximum 5-day-period runoff of 5,000 cfs-days. Because of the extreme skewness of the items, the median item is 3,200 cfs-days, or about 64 percent of the mean.

The correlation between the mean annual maximum 5-day-period runoff for each drainage area and the mean annual basin-wide storm precipitation for the same area is shown in part D. Both of these mean values were obtained by identical methods. Part D shows considerable variation in these data. In general, the data indicating the greatest storm runoff from identical storm precipitation were obtained in areas classified in part H of plate 7 as having a least absorptive and retentive mantle rock. Likewise, data indicating the least storm runoff from identical storm precipitation were obtained in areas classified as having a most absorptive and retentive mantle rock. A notable exception is Lone Pine Creek, which here plots as being most absorptive and retentive. This may indicate that the drainage area of Lone Pine Creek is highly absorptive but not very retentive for long periods of time. The three separate bands, or zones, shown in part D, average in a general way the data associated with each type of mantle rock.

The lines defining these three zones indicate that a basin-wide mean annual storm precipitation of 8 inches will produce a mean annual maximum 5-day-period runoff of 18 to 32 cfs-days per square mile in areas having a most absorptive and retentive mantle rock, 32 to 56 cfs-days per square mile in areas having a moderately absorptive and retentive mantle rock, and 56 to 95 cfs-days per square mile in areas having a least absorptive and retentive mantle rock. This would indicate that for identical storm precipitations, the flood runoff would be about three times greater in those areas having a least absorptive and retentive mantle rock than in areas having a most absorptive and retentive mantle rock.

FREQUENCY OF MAXIMUM 5-DAY-PERIOD RUNOFF

E

Part E shows frequency diagrams for each of the 16 drainage basins. Each diagram was derived from a smooth curve drawn through data of the same kinds as shown in part C and plotted as in part C. To make the diagrams comparable when the records of a basin do not include all the 47 years chosen as the base period (see part C), the curves were adjusted to give the time distribution and the total volume for the base period. Frequency is expressed as a recurrence interval, in years.

These frequency curves are given as bar graphs in part E. The maximum 5-day-period runoff in cfs-days per square mile for certain recurrence intervals, such as once in 100 years, once in 50 years, and once in 25 years, is shown by the steplike pattern. In the San Antonio Creek drainage area, the maximum 5-day period runoff for once in 100 years will be 330 cfs-days; for once in 50 years, 240 cfs-days; and for the once in 25 years it will be 170 cfs-days. Similarly, the maximum 5-day-period runoff can be obtained for any of the other 16 drainage areas shown in part E.

This diagram also includes the mean annual maximum 5-day-period runoff for each of the drainage areas.

FREQUENCY OF PEAK DISCHARGE

F

The peak discharges for certain recurrence intervals are given in part F for the 16 mountain area drainage basins. Also, the "mean annual peak discharge" is included as an index of the intensity.

Analysis of the frequency of peak discharges is made like that of the frequency of maximum 5-day-period runoff in part E and is to be read like the diagram in E. A peak discharge of 450 cfs per square mile in the San Antonio Creek drainage area can be expected once in 100 years, and a peak of 280 cfs per square mile once in 50 years.

For consistency with frequency computations in other parts of this report, the frequency of peak discharge has been computed on the basis of a duration series in which a recurrence interval of 100 years is assigned to the highest peak observed in 50 years of record. In analyses of the recurrence intervals of flood discharges the Geological Survey now uses a plotting procedure in which a recurrence interval of 51 years is assigned to the highest peak observed in 50 years of record.

The true average recurrence interval of the highest flood observed during a given period cannot be determined by any plotting procedure, because, for example, a 50-year record at one station may contain a 100-year flood, while at another station no flood greater than a 25-year flood may have been experienced. Thus, a short record at any one gaging station may be misleading. Analysis and combination of all recurrence interval diagrams in a given area, as presented in most flood frequency reports of the Geological Survey, tend to smooth out these irregularities. Nevertheless, the frequency of peak discharge for individual drainage areas as presented in this part is believed to be suited to the overall analysis of the hydrology of the mountain area.

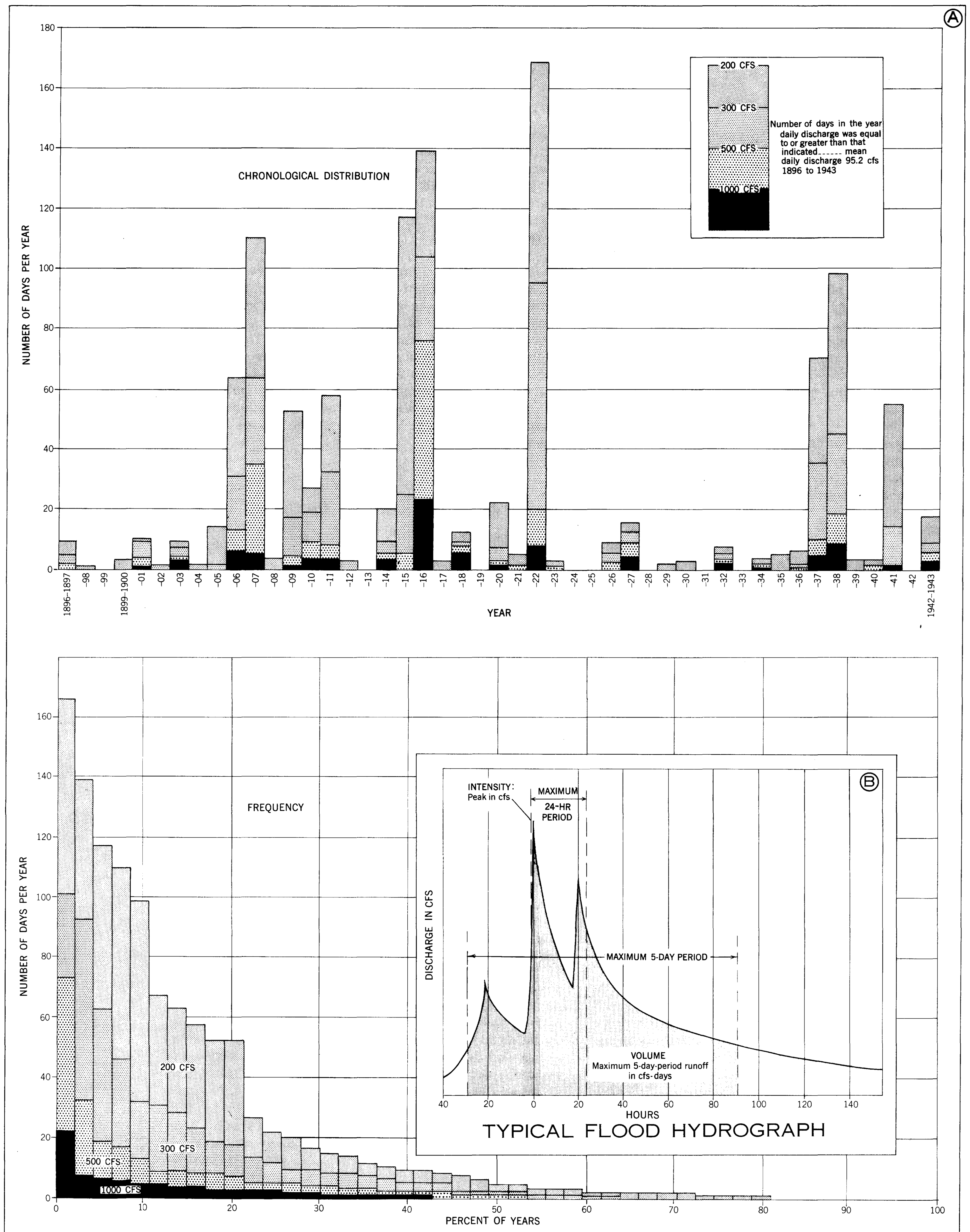
DISCHARGE DISTRIBUTION WITHIN THE MAXIMUM 5-DAY PERIOD

G

To obtain the maximum benefit from an analysis of flood runoff, the maximum 5-day-period volume must be divided into smaller units of time, such as the volume during the maximum 1-hour period or maximum 3-hour period. In an analysis of this time distribution, many hydrographs of mountain area streams were investigated. During each flood period, the volume of runoff occurring in certain standardized intervals of time was tabulated. These tabulations showed that an additional factor was necessary to provide a suitable correlation between maximum 5-day-period runoff and runoff for shorter periods. This third factor was taken as the ratio of peak discharge in cubic feet per second to the maximum 5-day-period runoff in cfs-days.

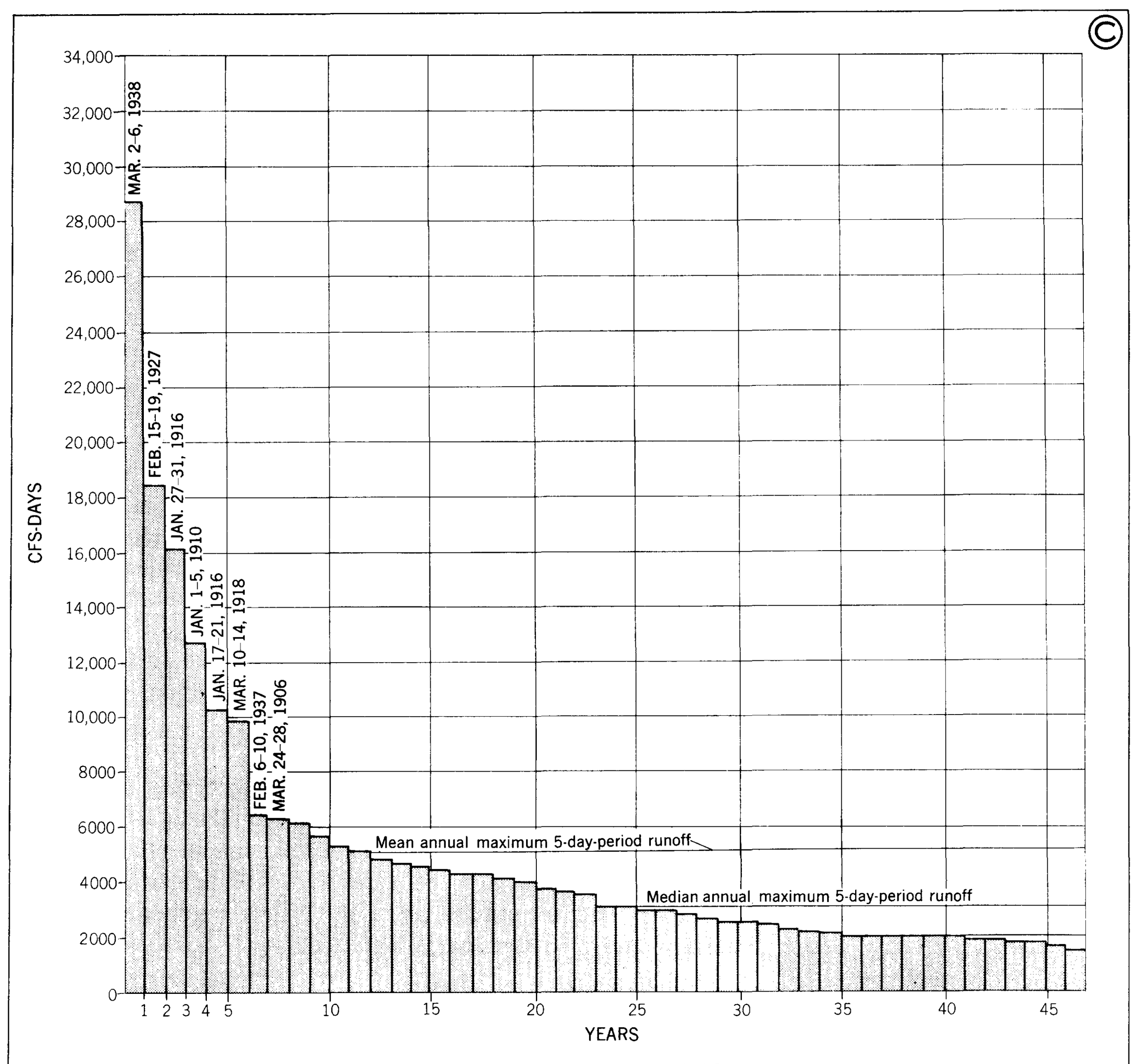
Part G shows that if the ratio between peak and volume were 2.0, then about 8 percent of the maximum 5-day-period runoff would occur in the maximum 1-hour period, 12 percent in the maximum 2-hour period, 32 percent in the maximum 6-hour period, 62 percent in the maximum 24-hour period, and 79 percent in the maximum 48-hour period. A similar analysis can be had for any other ratio value.

Further analysis of these data showed that seldom did the ratio between peak discharge and maximum 5-day volume exceed 2.5 in the winter rainy season. However, in summer convectional storms, ratios almost as great as 20 were experienced on the leeward sides of the mountain area.

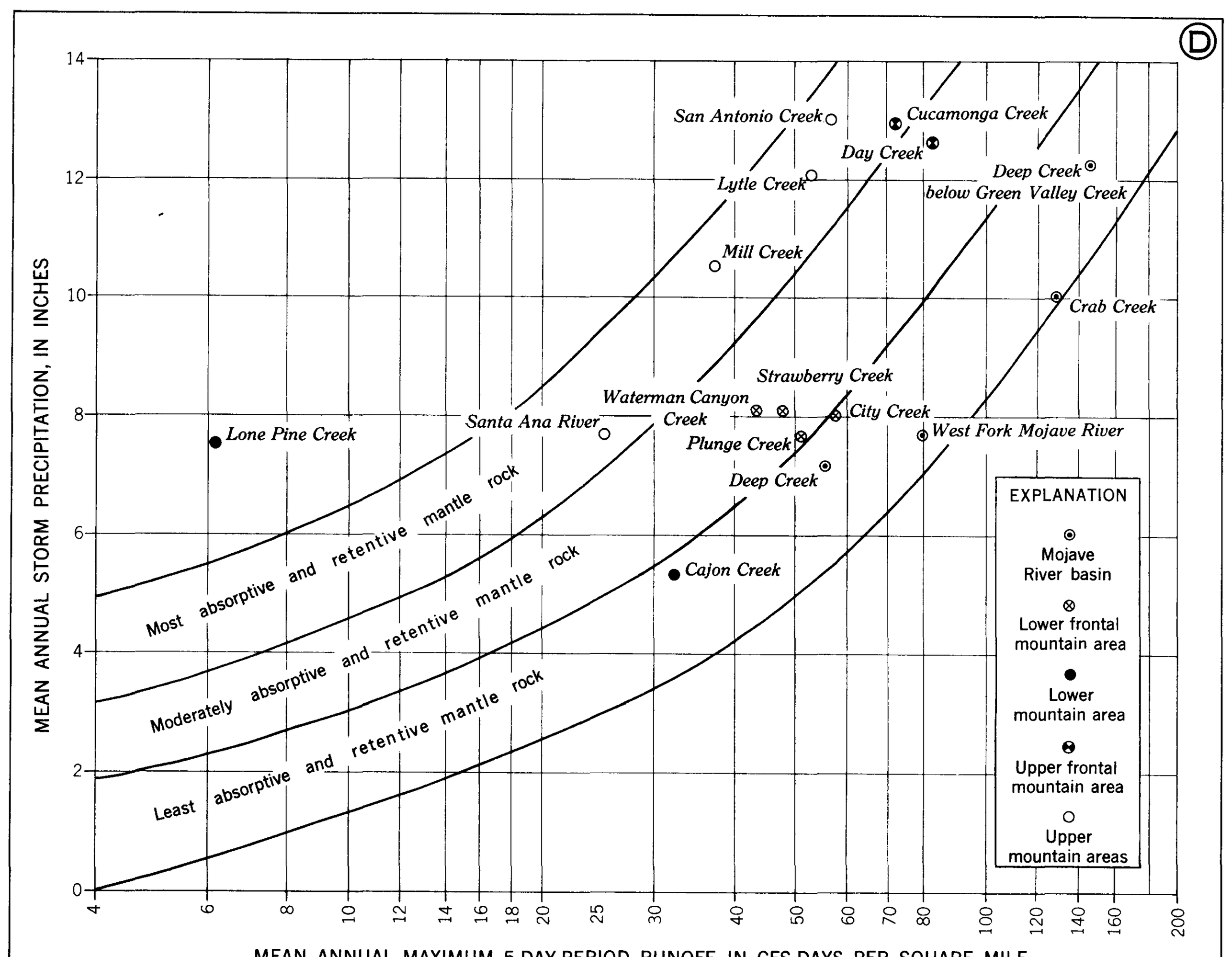


TYPICAL FLOOD HYDROGRAPH

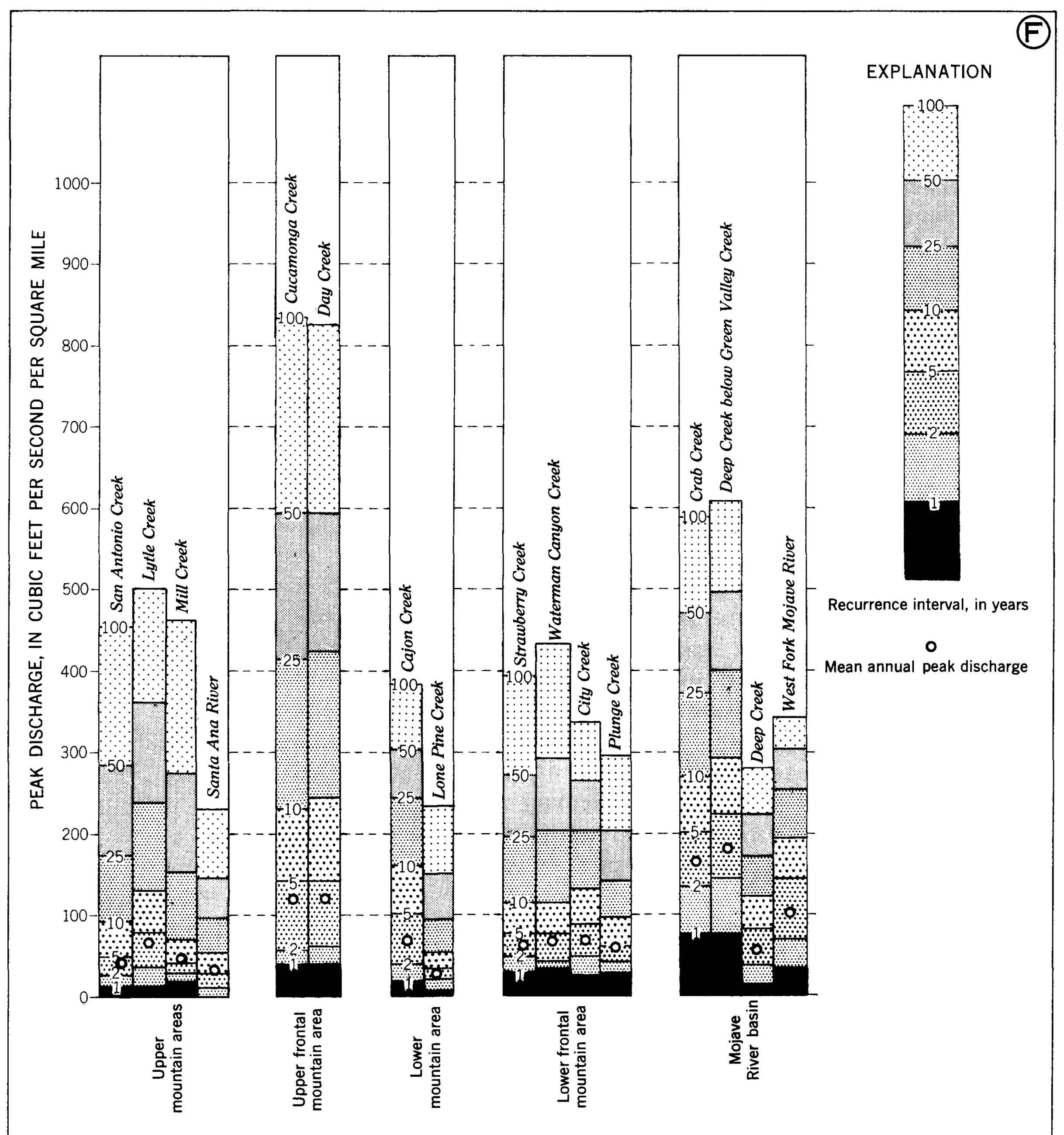
STORM RUNOFF IN THE SANTA ANA RIVER NEAR MENTONE



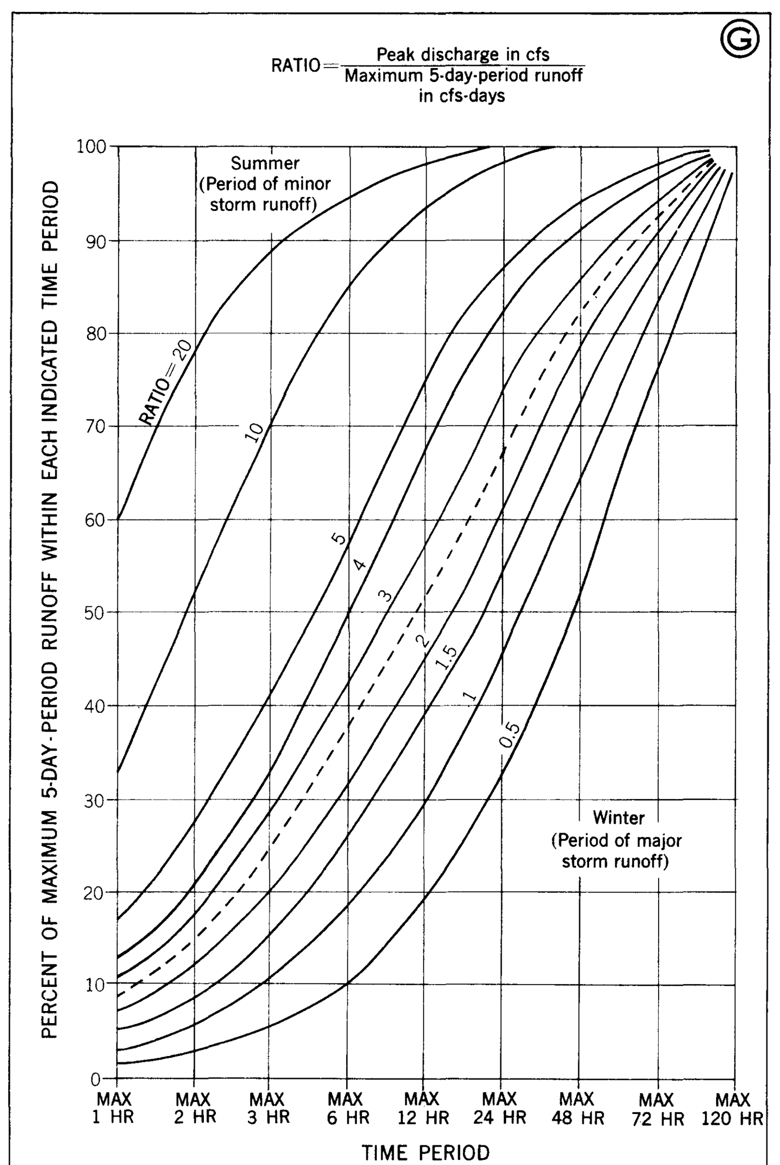
MAXIMUM 5-DAY-PERIOD RUNOFFS IN THE SANTA ANA RIVER NEAR MENTONE IN THE 47 YEARS OF RECORD, 1896 TO 1943



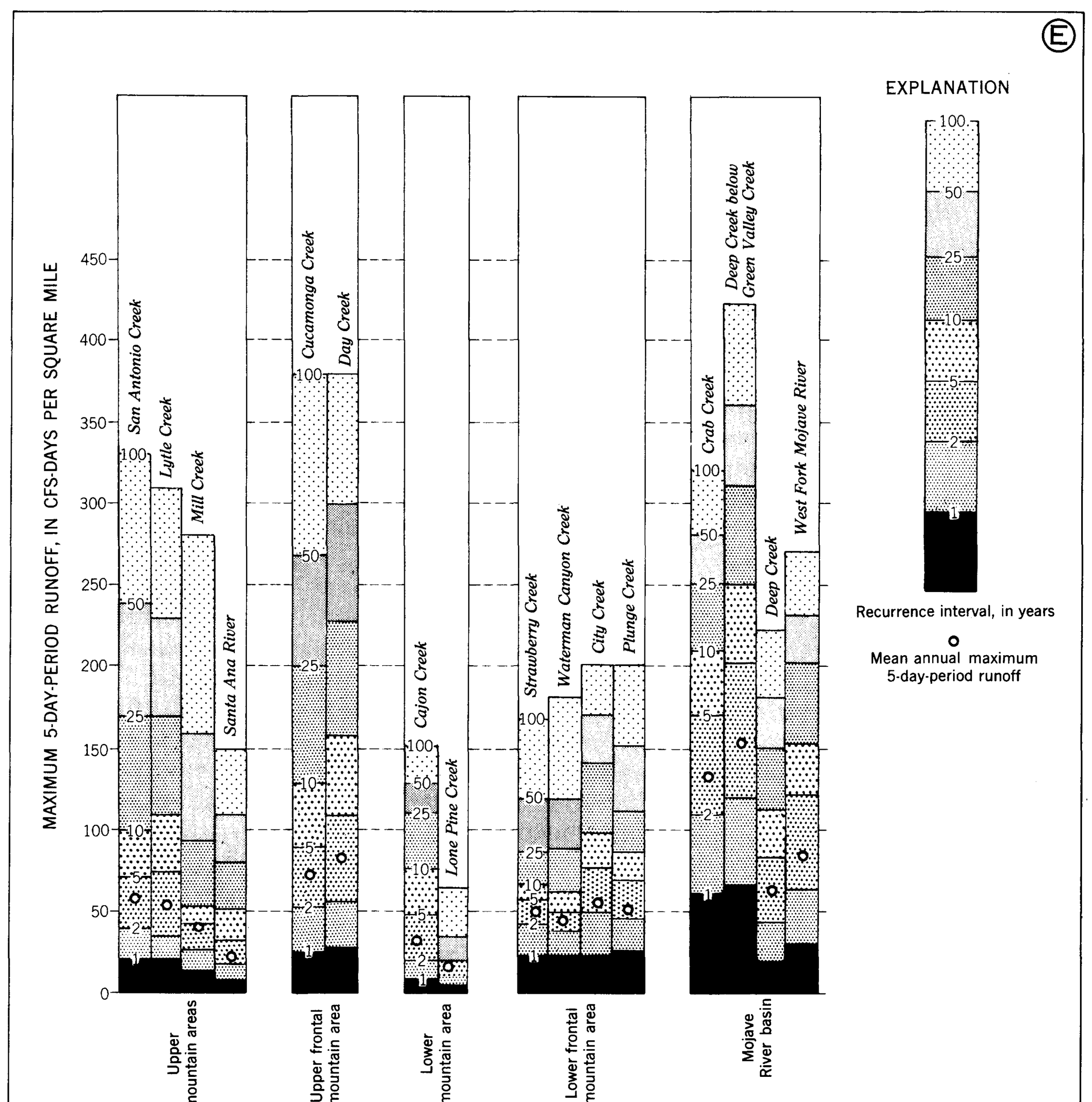
RELATIONSHIP BETWEEN MEAN ANNUAL STORM PRECIPITATION AND MEAN ANNUAL MAXIMUM 5-DAY-PERIOD RUNOFF



FREQUENCY OF PEAK DISCHARGE IN THE MOUNTAIN AREA



VOLUME DISTRIBUTION WITHIN THE PERIOD OF STORM RUNOFF



FREQUENCY OF MAXIMUM 5-DAY-PERIOD RUNOFF IN MOUNTAIN AREA

MOUNTAIN GROUND-WATER RUNOFF

The existence of mountain ground-water storage is most evident during the annual summer drought period or during those extended dry periods of 5 to 20 years in length. The long history of runoff in some parts of this mountain area indicate that many of these streams are not known to have gone dry even during extended dry periods.

After satisfying the existing soil moisture deficiencies in the mantle rock, some of the precipitation penetrates below the root zone to recharge ground-water storage. This storage may exist in the mantle rock or in the underlying bed rock. The position and type of aquifer in which the water is stored have considerable influence on the amount and distribution of the runoff from it.

The identification and segregation of the types of ground-water runoff are dependent largely on an analysis of the recurring depletional slopes in the annual hydrograph. The accuracy of this identification is not uniform over the mountain area but varies greatly from drainage area to drainage area.

PERENNIAL GROUND-WATER RUNOFF

A

The hydrograph of daily discharge in Mill Creek from March 1921 to September 1926 is shown in section A. As an interpretative aid, the daily discharge is plotted on a semilogarithmic projection. One advantage of this projection is that drainage from some types of ground-water reservoirs tends to vary as a straight line when plotted against time on a semilogarithmic projection.

In order to distinguish periods of precipitation from periods of nonprecipitation, the winter rainy period and the summer drought have been indicated. Each winter rainy period is assumed to begin with the first storm in the fall and to end with the last storm of the following spring. As an index of the snow cover, the depth of snow at Squirrel Inn is plotted immediately above the hydrograph.

Beginning in mid-December of 1921 the daily discharge of Mill Creek increased to more than 300 cfs following each of several storms. Concurrently with these storms, there developed an extensive snow cover, which is believed to have reached a maximum in February and March. Then during subsequent periods of melting, the snow gradually disappeared so that by the end of April the ground was bare. However, the runoff for this snow melt did not reach a peak until the end of May. From June to mid-October runoff diminished at a fairly gradual rate. It is evident that from the end of April till mid-October most of this runoff must have been of immediate ground-water origin.

Similar periods of runoff due to storm precipitation and snow melt are detectable during each succeeding year. However, there is a noticeable decrease in runoff from the spring of 1922 to the winter of 1926 due to the unusual dryness of this period. Even though the precipitation was extremely low during parts of this period, there was sustained flow in Mill Creek of a uniformly decreasing amount. The source of this sustained runoff has been designated "perennial ground-water storage." This deep-seated storage is believed to be in the mantle rock and fractured bed rock of the drainage area. Because of its location and intake conditions, this storage is subject to recharge only in the wetter years. However, once recharged, the seepage from this storage produces a sustained flow for many years.

In order to simplify this analysis, a straight line depletion curve has been drawn through the hydrograph to represent the seepage from this source for the period of May 1922 to December 1925. Other depletion curves have been prepared for all other dry periods occurring during the Mill Creek period of record. The great similarity in these depletion curves strengthens the belief in the existence of perennial ground-water storage.

The depletion curve has other significance: it offers the means for obtaining the volume of storage in excess of that at which seepage to the stream will cease. A perennial ground-water runoff of 40 cfs on June 1, 1922 would indicate a basin-wide storage of 73,000 acre-feet in excess of this minimum base. By January 1, 1926 this perennial ground-water runoff had decreased to 10 cfs representing a storage of 18,000 acre-feet above this same base. This indicates that 55,000 acre-feet, or about 65 percent of the total runoff of June 1, 1922 to January 1, 1926, had its origin in the perennial storage resulting from the large recharge in the spring of 1922. As indicated in part A, this recharge amounted to 48,000 acre-feet, or the equivalent of 21 inches over the drainage area. On January 1, 1926, the flow from perennial ground-water storage was less than it was before the recharge during the spring of 1922, which indicates a net decrease in ground-water storage during the period 1922 to 1926.

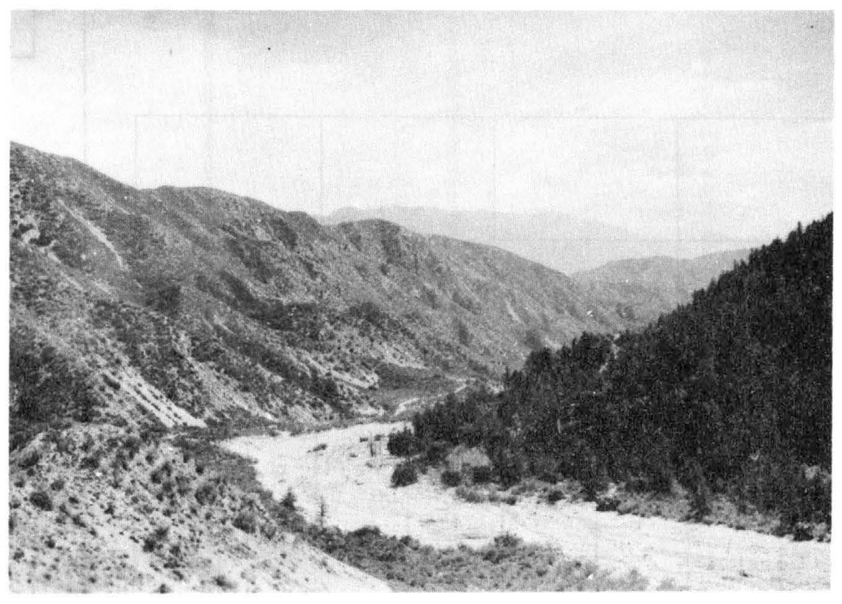
B

This recharge to perennial ground-water storage varies considerably from year to year, depending on the magnitude of the annual precipitation and the soil moisture deficiences. At times, as in the case of Mill Creek, it shows no recharge during many years. Because of differences in precipitation, geology, and existing soil moisture deficiencies throughout the mountain area, the annual recharge tends to vary from drainage area to drainage area during the same year.

To obtain an index of this annual variation, the recharge was obtained for each year for the period 1900 to 1942 in Mill, Lytle, and San Antonio Creeks of the upper mountain areas. These values were averaged for each year to obtain the indices given in the upper half of part B. This chronological distribution shows the same cyclic tendency illustrated in the preceding plates.

In the lower half of part B, these recharge items are arranged in order of decreasing magnitude. The time distribution is given in percent of time in which the annual recharge equals or exceeds that indicated.

To emphasize the irregularities of recharge distribution, the eight largest and eight smallest items have been numbered and the largest numbers circled.



Stream-bed deposits in Middle Fork Lytle Creek, an area of the most absorptive and retentive type of mantle rock

C

The perennial ground-water storage can exert considerable influence on the runoff of the stream during periods of drought. The magnitude of this storage will vary from area to area, depending on the physical structure. Whether it can be recharged depends largely on the magnitude of the precipitation and the absorptive qualities of the mantle rock.

To determine the magnitude of this storage, a continuous hydrograph of perennial ground-water runoff was drawn on all the daily discharge hydrographs in the mountain area. The maximum runoff from this source was identified, and the volume of ground-water storage required to sustain this flow was computed. These volume determinations represent the maximum perennial ground-water storage in excess of certain base quantities. These base quantities represent the necessary storage requirement before seepage occurs. As long as this basic storage is not used or exploited, its magnitude is of relatively little significance.

The relationship between maximum observed perennial ground-water storage and the mean annual precipitation is shown in part C. In both instances the units represent inches over the drainage area. The perennial ground-water storage in the Day Creek drainage area appears to be the greatest in the mountain area, amounting to 35 inches of water over the area, or 1,850 acre-feet per square mile. The drainage area of Deep Creek below Green Valley Creek, in a zone of equally high precipitation, appears to have a maximum storage of 12 inches, or 620 acre-feet per square mile. This difference in maximum perennial ground-water storage is believed to be closely associated with the geology of the respective areas.

In general, the data in part C tend to distribute themselves on the basis of the characteristics of the mantle rock, with the greatest storage occurring in areas having the most absorptive and retentive mantle rock and the smallest storage occurring areas having the least absorptive and retentive mantle rock.

Three separate zones indicating the relative absorptive and retentive character of the mantle rock have been sketched in part C.

D

The water user often fails to appreciate the magnitude of this mountain ground-water storage. In order to emphasize this factor, the relationship among the mean annual precipitation, mean annual runoff, and the maximum perennial ground-water storage is shown in part D. To make the comparison readily apparent, all the units are given in inches.

In the San Antonio Creek drainage area, a mean annual precipitation of 41.8 inches produces a mean annual runoff of 18.9 inches. The maximum perennial ground-water storage at any one time amounted to 24.9 inches, which was built up during years of heavy precipitation. This means that during unusual wet periods there are 1,330 acre-feet per square mile of available ground-water held in mountain storage. In many instances, these quantities exceed the most optimistic estimates of potential surface water storage available in the same area.

As a group, the four upper mountain drainage areas indicate a maximum perennial ground-water storage equal to 240 percent of the mean annual runoff. However, not all the drainage areas are so well provided with ground-water storage. For example, the drainage areas in the Mojave River basin show a maximum perennial ground-water storage equal to 53 percent of their mean annual runoff. These two groups of drainage areas show the wide extremes in amounts of perennial ground-water storage in the entire mountain area.

SEASONAL GROUND-WATER RUNOFF

E and F

The major part of ground-water storage in the mountain area is perennial storage, which has just been explained. However, scattered intermittent streams and springs throughout the area, whose flows are substantial enough to affect the distribution of daily discharge, indicate that there is another type of ground-water storage besides perennial.

The Mill Creek hydrograph, given in part A, shows a pronounced increase in daily discharge during each water year, followed by a steady recession often extending to October. In the Mill Creek basin this runoff is largely attributed to the recharge from melting snow. During these periods of recession, the slopes of the hydrograph are so much steeper than those for the perennial ground-water runoff that they suggest a different type of ground-water storage. The storage from which this runoff seems to originate has been termed "seasonal ground-water storage."

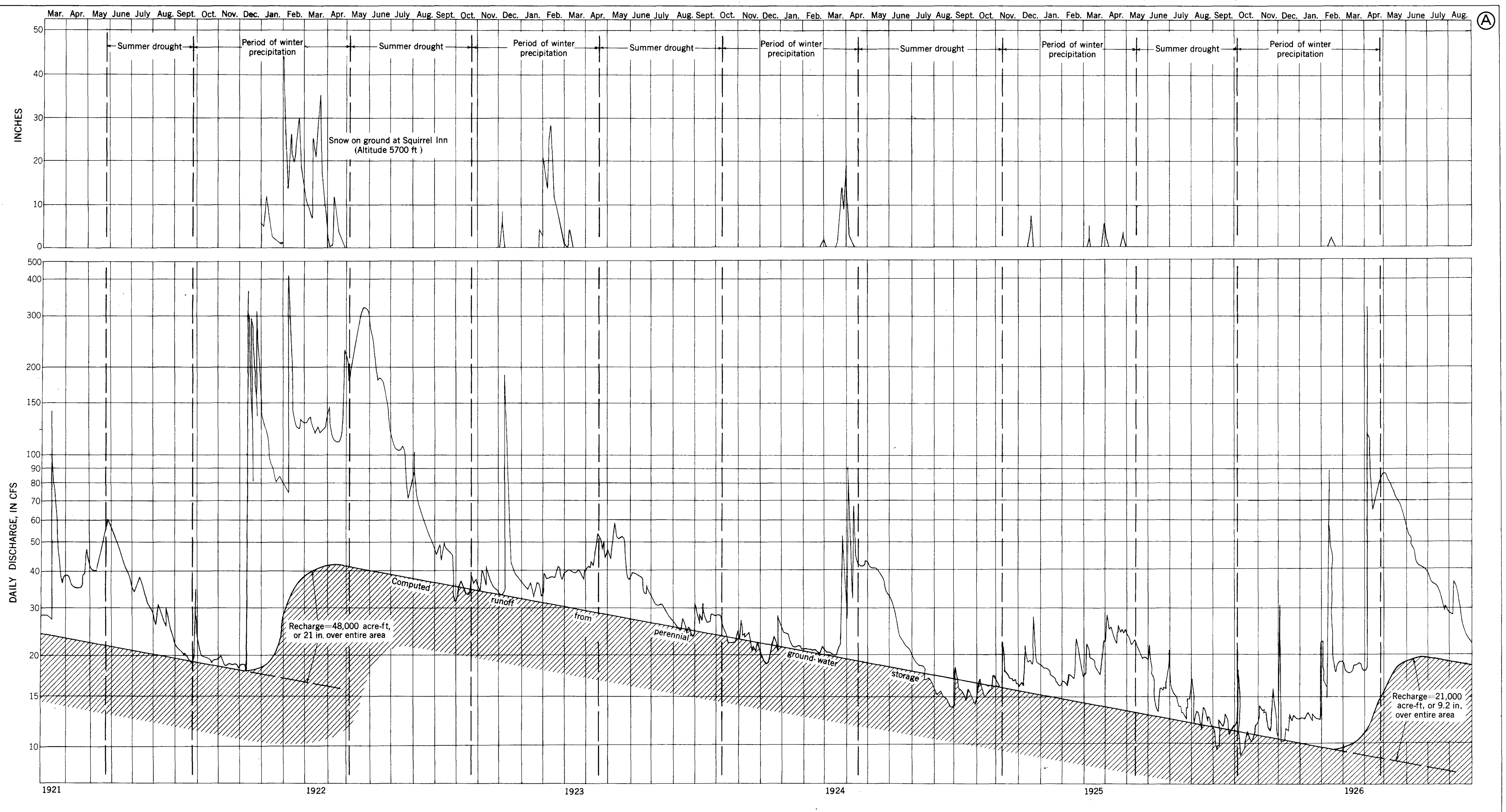
While seasonal ground-water runoff generally begins in midwinter, reaches a peak in midspring, and ceases by late summer, there are many modifications of this distribution from area to area, depending on physical conditions. These physical influences are so marked in the Lytle Creek drainage area that the hydrograph for the calendar year of 1932 has been included on the left side of part E. Above this hydrograph the computed water content of the basin-wide snow cover is shown. As this snow melted there was slight evidence of increase in flow but certainly nothing comparable to that on Mill Creek (see part A). The snow however did melt and did produce runoff. This runoff, in discharging from the smaller canyons into the debris-choked main channels, was immediately absorbed in stream-bed ground-water storage. For a distance downstream from these points of discharge, the main channels were dry throughout the entire snowmelt period.

A companion graph, part F, shows a few of the physical features in Lytle Creek and its main tributary, the North Fork. On the North Fork below an altitude of 6,500 to 7,000 feet this channel is filled to depths of 500 feet or more with debris. Only during periods of extreme flood is there any surface runoff across these deposits. At an altitude of about 3,800 feet there is an observational water well in the midst of the channel. The 1932 record of change in levels obtained there shows the ground-water surface about 100 feet below the land surface in mid-June. By the first of August, as shown in part E, the water level had risen to 50 below land surface; then it declined to about 100 feet below land surface by late November.

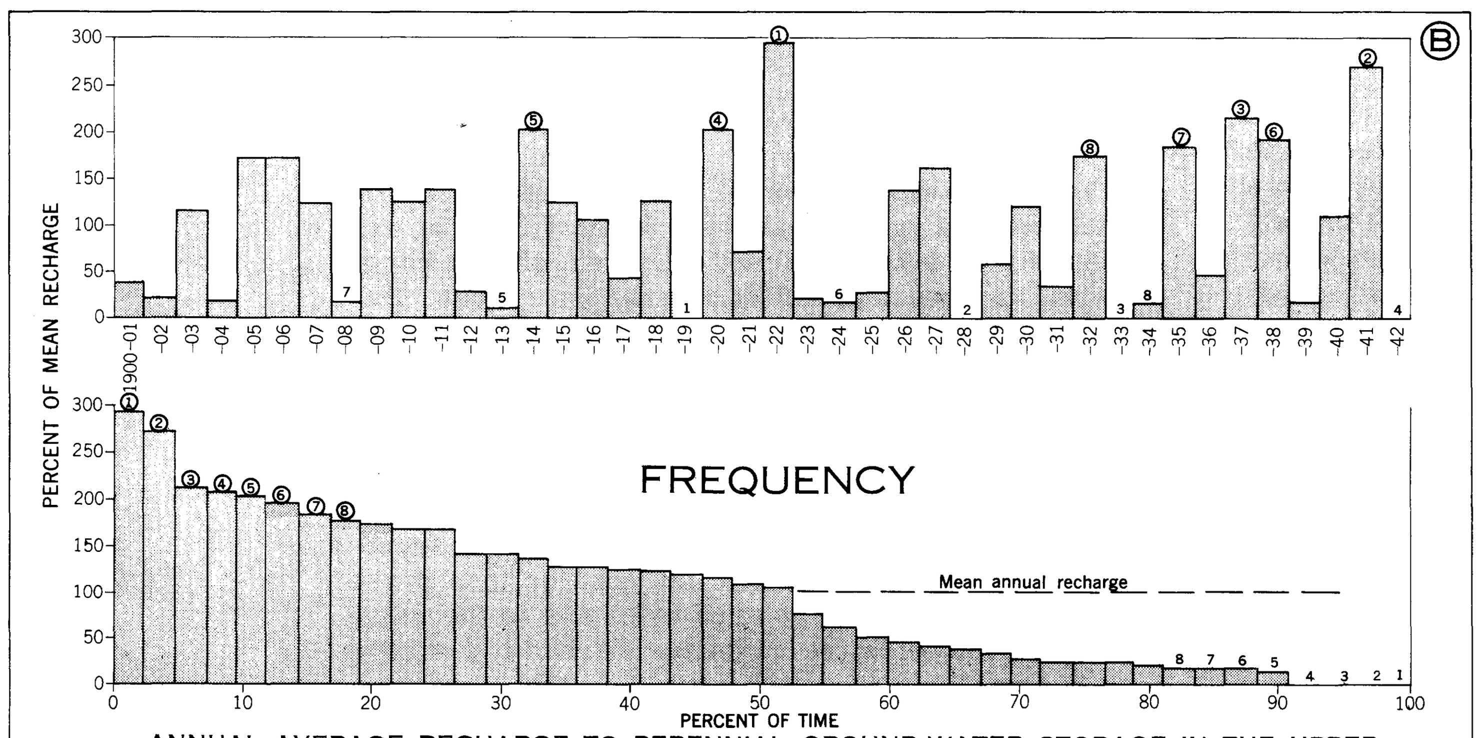
At Glen Ranch, immediately downstream from this well, are a series of fault barriers and a constricted stream channel. As a result, the steep canyon gradient forces a large part of the subsurface flow to the surface. From this point to the gaging station the stream flows continuously all year.

By again referring to the hydrograph in part E, it will be noted that the daily discharge showed a pronounced increase in amount beginning in late July, peaked about the first of September, and returned to normal runoff in December. This represents the passage out of the Lytle Creek drainage area of the seasonal ground-water runoff. This analysis is believed to be typical of this type of storage throughout the mountain area, with differences from area to area being largely confined to the period of lag.

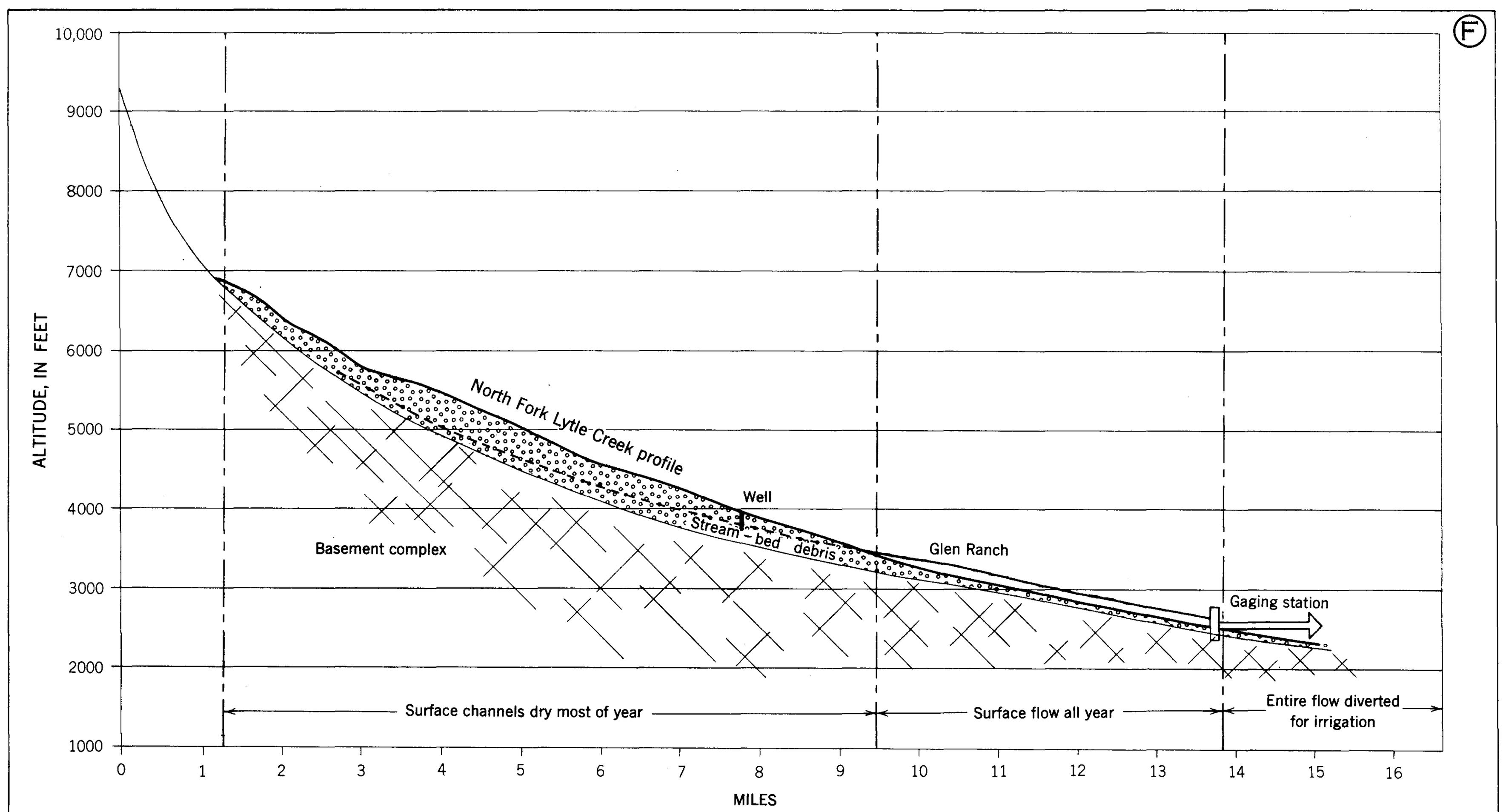
The hydrograph in the right half of part E, the daily discharge in San Antonio Creek for the period of September 1932 to November 1933, has been included for confirmation. As in the preceding diagram, the computed water content of the basin-wide snow cover is plotted immediately above the hydrograph. Superimposed on the hydrograph is a line showing the distribution of the perennial ground-water runoff which diminishes continuously throughout this period except for a small recharge in March. The flow in excess of this perennial flow represents the seasonal ground-water runoff which began in January, reached a peak in April, and ceased in late August.



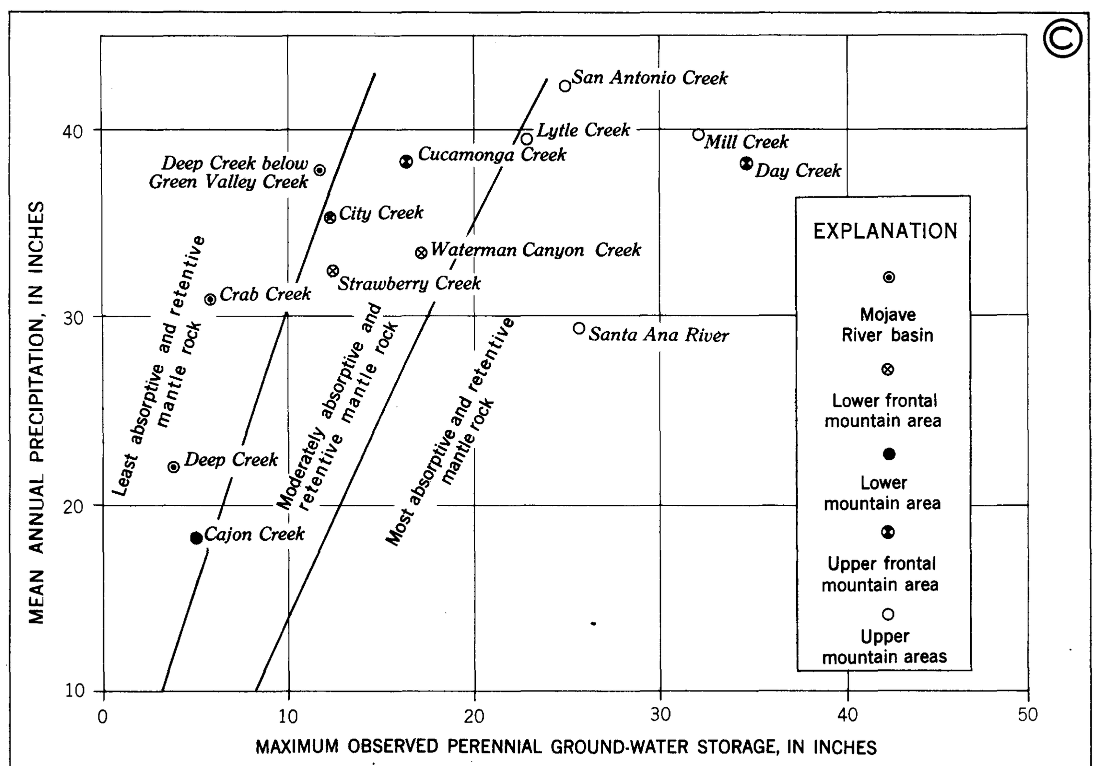
HYDROGRAPH OF MILL CREEK FROM MARCH 1921 TO SEPTEMBER 1926, SHOWING PERENNIAL GROUND-WATER RUNOFF



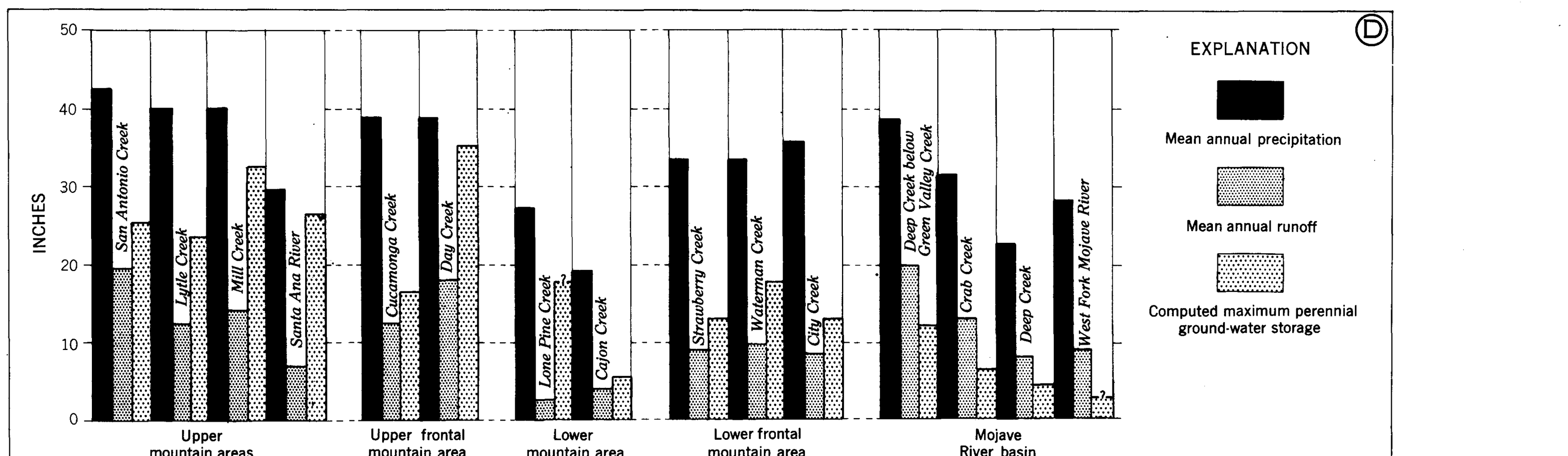
ANNUAL AVERAGE RECHARGE TO PERENNIAL GROUND-WATER STORAGE IN THE UPPER MOUNTAIN AREAS OF MILL, LYTLE, AND SAN ANTONIO CREEKS



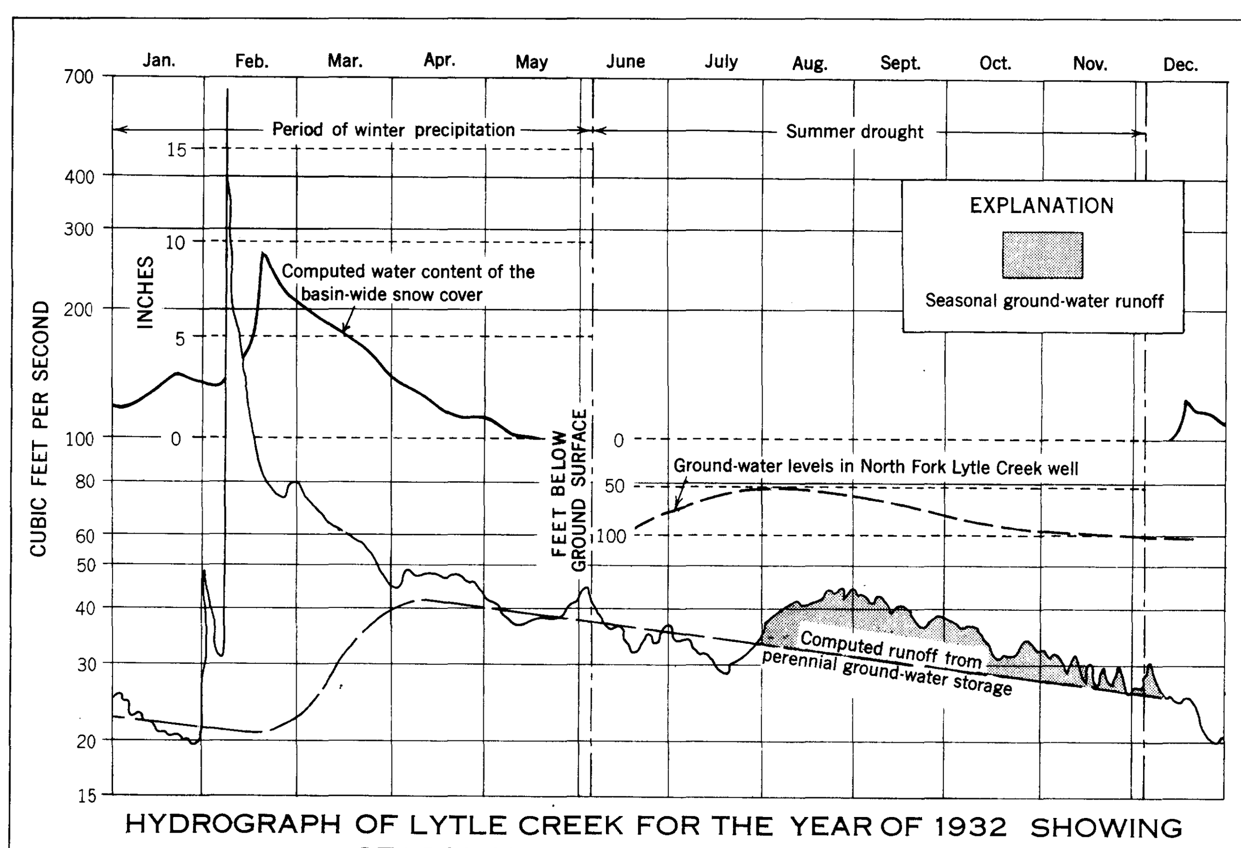
NORTH FORK LYTLE CREEK



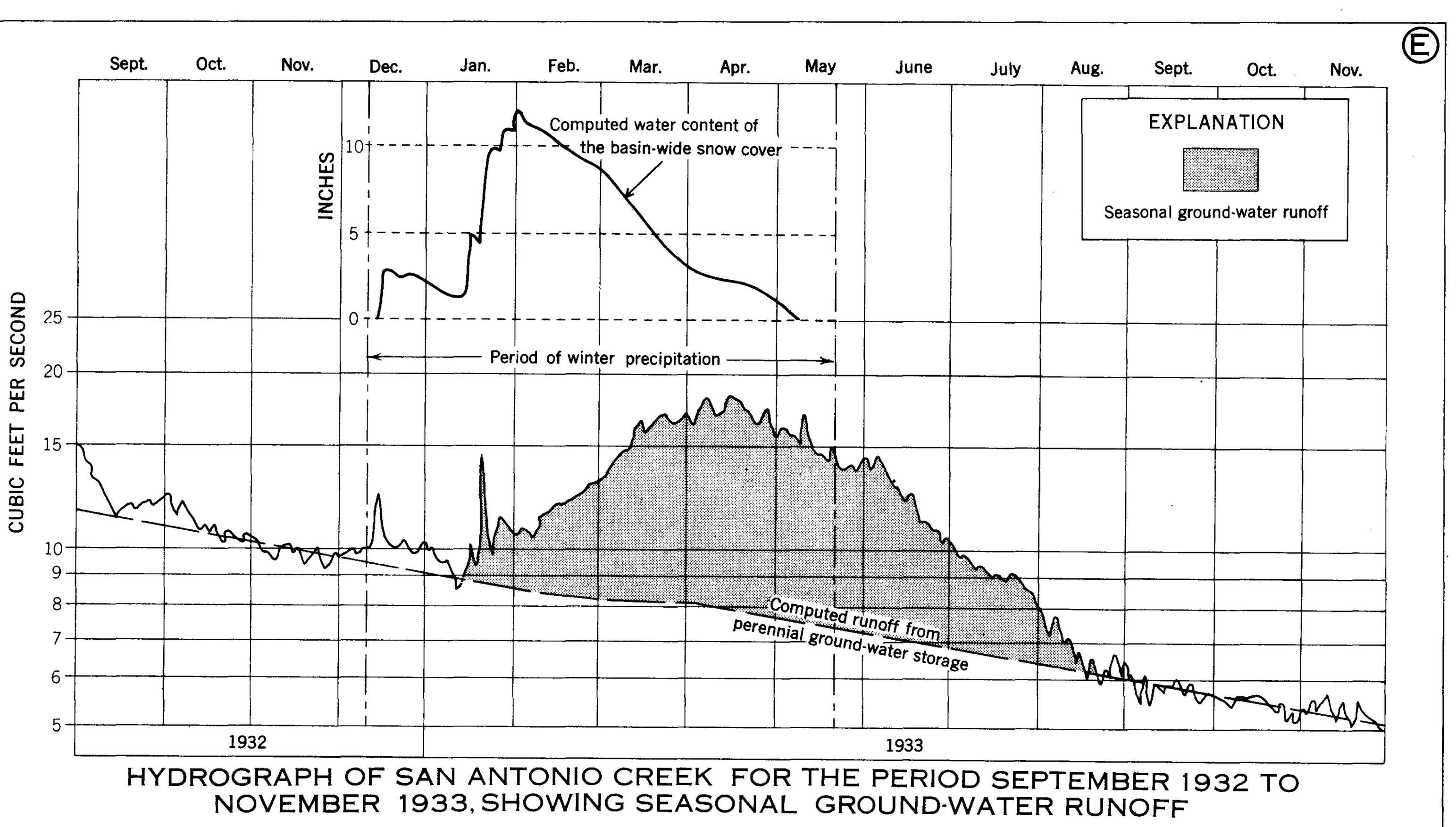
CHARACTERISTICS OF MANTLE ROCK AS INDICATED BY THE RELATIONSHIP BETWEEN PERENNIAL GROUND-WATER AND PRECIPITATION



PRECIPITATION, RUNOFF, AND COMPUTED MAXIMUM PERENNIAL STORAGE



HYDROGRAPH OF LYTLE CREEK FOR THE YEAR OF 1932 SHOWING SEASONAL GROUND-WATER RUNOFF



HYDROGRAPH OF SAN ANTONIO CREEK FOR THE PERIOD SEPTEMBER 1932 TO NOVEMBER 1933, SHOWING SEASONAL GROUND-WATER RUNOFF

SEASONAL GROUND-WATER RUNOFF

NATURAL WATER LOSS AND RECOVERABLE WATER

The only source of recharge to the water resources of the mountain area is the precipitation that falls on the area. However, not all of the precipitation that reaches the land surface is available for man's use because much of it is often required to satisfy the moisture deficiencies created during the preceding growing season within the root zone of the vegetation that covers the mantle rock.

Analyses of the natural water loss and recoverable water are combined in this plate, because these two factors of the hydrologic cycle account for the complete disposal of all the precipitation. Their influences are not uniformly distributed in time or area but vary continuously in relation to changing physical and meteorological conditions.

DISPOSAL OF PRECIPITATION IN LYTLE CREEK BASIN

A

Part A shows the cumulative precipitation and the complete disposal of it in the Lytle Creek basin for 3 typical years. A "spot-sampling" technique was used to obtain some data that could not be obtained directly throughout the basin. Other aspects of water disposal which do not lend themselves even to spot-sampling were estimated in whole. In order to simplify the analysis, all of those factors affecting the disposal of this water were consolidated into the following five general classifications: 1. runoff, 2. recharge to perennial ground-water storage, 3. water content of the snow cover, 4. natural water loss, and 5. moisture in the root zone.

The first of these diagrams represents the disposal of the precipitation in the typical dry year of 1932-33. The uppermost curve gives the cumulative distribution of the basin-wide precipitation since the beginning of the water year on October 1.

Starting in February, the very slight difference between this curve and the one immediately below represents the cumulative distribution of the runoff attributable to the precipitation of this year. The cumulative distribution of the recharge to perennial ground-water storage, also starting in February, is given immediately below the runoff. The cumulative sum of these two items gives the cumulative distribution of the 2. 5 inches of recoverable waters originating in this water year.

One factor leading to the selection of this 1932-33 record for analysis was that a substantial part of the precipitation occurred as snow. This snow cover, with an estimated water content ranging from 0 at the first of December to a peak of 14 inches on the first of February, had completely disappeared by the end of May. This represents merely the conversion of this moisture from one form to another.

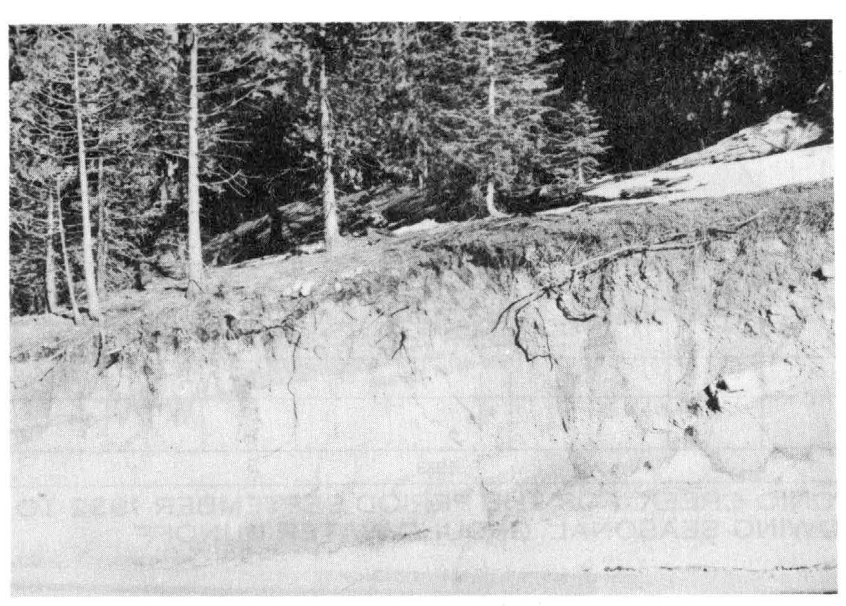
The curve nearest the bottom of this diagram indicates the gradual building up of the moisture in the root zone from the wilting point on the first of December to a maximum of 15 inches above the wilting point early in May by recharge from precipitation or snowmelt. After the first of May the natural water loss (loss through transpiration and evaporation) exceeded these recharge increments, and the moisture in the root zone was again reduced to the wilting point about September 30.

The cumulative residual of precipitation, shown between the recoverable waters (including the snow on the ground) and the soil moisture in the root zone represents the basin-wide natural water loss. In 1932-33 the natural water loss amounted to 24.2 inches, thereby accounting for 91 percent of the basin-wide precipitation.

The second diagram gives the same type of analysis for the flood year of 1937-38. As a result of the extreme concentration of precipitation during the March 1938 flood period, the cumulative runoff amounted to 33. 2 inches by the end of the water year on September 30, or 50 percent of the cumulative precipitation.

The cumulative recharge to perennial ground-water storage ranged from 0 on the first of February to a maximum of about 13 inches the first of April, then decreased to about 11 inches on September 30 by drainage as perennial ground-water runoff. The cumulative recoverable water (runoff and recharge to perennial ground-water storage) on September 30 accounts for 44. 2 inches, or two-thirds of the year's precipitation.

During this flood year the natural water loss consumed 22. 2 inches of the year's precipitation. It will be noted that this loss was somewhat less during this relatively wet year than in the very dry year of 1932-33. This tends to be typical during flood years and is due largely to the lack of opportunity for infiltration because most of the precipitation is confined to fewer storm periods.



Typical shallow soil and root systems of the least absorptive and retentive drainage areas

The third diagram of part A gives an analysis of the precipitation disposal during the wet, but nonflood, year of 1940-41. In this year, a precipitation of 72. 3 inches produced 24. 3 inches of runoff, and a recharge to perennial ground-water storage of 15. 8 inches. These phases when combined represent recoverable waters, which are equivalent to 40. 1 inches, or about 55 percent of the precipitation.

The natural water loss increased this year to 32. 2 inches because of the greater opportunity for evapotranspiration because of the more evenly distributed precipitation. In April the soil moisture available to the root zone was estimated at 30 inches, which is about twice as great as in 1932-33.

RELATIONSHIP BETWEEN NATURAL WATER LOSS AND RECOVERABLE WATER

B

Part B shows the relationship between natural water loss and recoverable water in the two drainage areas of San Antonio and Cajon Creeks. As in the preceding diagrams, the recoverable water represents the runoff originating from the current year's precipitation, together with the cumulative recharge to perennial ground-water storage as of September 30. The natural water loss is assumed to be the residual between the precipitation and these recoverable waters. Annual loss is plotted against the annual precipitation with each point being identified by the last two digits in the date of the water year.

For the San Antonio Creek drainage area, these observations show the natural water losses to range from 19 to 28 inches, and to bear little relationship to the amount of annual precipitation. In those years when the annual precipitation greatly exceeded the natural water loss, the observations suggest that these natural losses may be more or less uniform. That is, these annual losses would approach uniformity if all the secondary factors, such as distribution of the precipitation, could be identified and evaluated. Without data about these secondary factors that could cause a scattering of points, the upper part of the curve representing natural water loss is plotted as a vertical line that approximately averages the points.

When annual precipitations are relatively low, the curve representing natural water loss is no longer a vertical line. Because these losses cannot exceed the amount of precipitation, a 45° line has been drawn on the diagram from its point of origin to show the limiting values. The curve showing the natural water losses can be tangent to this radial line but cannot cross it. On this basis, the lower limits of the relationship in the San Antonio Creek drainage area have been sketched in part B to define completely the natural water loss for a basin-wide annual precipitation ranging from 16 to 90 inches.

When the annual precipitation in the San Antonio Creek drainage area exceeded 35 inches, the annual natural water loss averaged about 25 inches. This limiting loss has been designated as the "potential natural water loss" and has been so indicated.

The inset in part B shows a typical relationship between natural water loss and recoverable water in those areas where the annual precipitation is seldom great enough to exceed the potential natural water loss. Although the observational data on Cajon Creek do not accurately define the potential loss, they do define the lower part of this relationship curve, where precipitation ranges from 10 to 20 inches.

BASIN-WIDE DISTRIBUTION OF NATURAL WATER LOSS AND RECOVERABLE WATERS

C

The two preceding analyses showed the basin-wide relationships between the natural water loss and recoverable waters. Occasionally it becomes important to know the pattern of distribution of the natural water loss within a basin. From a water user's point of view, this is important, because the magnitude of the annual precipitation generally increases with altitude, and the natural water loss tends to decrease with altitude. It is for this purpose that the Mill Creek data have been incorporated into part C to show the point of origin of the recoverable waters.

One of the dominant physical aspects of this distribution is the relationship of altitude to area. This relationship is given in the left diagram of part C. It shows that 25 percent of the area is above an altitude of 8, 100 feet, 50 percent above an altitude of 6, 600 feet, and 75 percent above an altitude of 5, 200 feet. For the purpose of simplification, other dominant physical features, such as type of mantle rock, are assumed to be uniformly distributed over the area.

The basin-wide integration of all the influences affecting runoff in the Mill Creek drainage area indicates a basin-wide potential natural water loss of 32 inches. Locally, this potential loss will vary from 36 inches at 3, 000 feet altitude to 26 inches at 11, 000 feet, as indicated in the middle diagram of part C.

Below an altitude of 9, 500 feet, this potential natural water loss will exceed the mean annual natural water loss by the amount shown also in the middle diagram.

The curve of mean annual natural water loss is defined by altitude and precipitation. Below an altitude of 9, 500 feet, the natural water loss will be less than the potential natural water loss, and above that altitude the two will be identical.

When the mean annual natural water loss for any given altitude is subtracted from the mean annual precipitation at that altitude, the remainder is the recoverable water. These mean annual recoverable waters range from about 25 inches at 11, 000 feet altitude to 3 inches at 3, 000 feet, as shown by the third curve in the middle diagram. It is evident from this distribution that the regions of highest altitude will produce the greatest supply of recoverable water per unit of area.

For that reason, the cumulative areal distribution of the recoverable water is shown in the right-hand diagram of part C. This diagram indicates that about 25 percent of the recoverable water originates at altitudes of 9, 400 feet or higher, 50 percent at altitudes of 8, 100 feet or higher, and 75 percent at altitudes of 6, 700 feet or higher. It is interesting to note that more than 75 percent of the mean annual recoverable waters originate above the median altitude of 6, 600 feet.

D

The preceding graphs showed the basin-wide distribution of natural water loss and recoverable water for a year in which the basin-wide precipitation amounted to 39. 4 inches, the mean for the period of 1883 to 1943. However, as indicated in plate 6, part D, the Mill Creek basin-wide precipitation ranges from 18. 5 to 73. 3 inches for 98 percent of the time. Consequently, the amount and distribution of recoverable water will vary greatly within this precipitation range. During this wide range in precipitation, only the potential natural water loss and its distribution with altitude shown in part C, would remain unchanged.

This results in the amount of annual recoverable water at 10, 000 feet altitude ranging from 4 to 66 inches for 98 percent of the years (part D). At 3, 000 feet altitude, it will range from 0 to 17 inches for the same percent of years. A knowledge of this distribution is desirable for any program of water utilization in the drainage area. For this reason, distributions of the recoverable water in the Mill Creek drainage area are shown for certain key frequencies.

POTENTIAL NATURAL WATER LOSS AND ALTITUDES

E

The basin-wide potential natural water loss is plotted against median altitude in part E. For any given altitude, these observations tend to show a range of about 15 inches in potential natural water loss. Between altitudes of 6, 000 and 7, 000 feet, those losses ranged from about 19 inches in the Crab and Deep Creek drainage areas to 32 inches in the Santa Ana River. The altitudes of these basins being about the same, the smaller potential natural water loss in the Crab and Deep Creek drainage areas is believed to be due to the less absorptive and retentive characteristics of mantle rock, and the greater loss in the Santa Ana River drainage area to be due to the more absorptive and retentive characteristics of the mantle rock in that area. At lower altitudes, the same general distribution pattern seems to apply, with those areas having a most absorptive and retentive mantle rock indicating the greatest potential natural water loss, and those areas having the least absorptive and retentive mantle rock indicating least potential natural water loss. Consequently, three zones are shown to represent the different characteristics of the mantle rock.

RELATIONSHIP BETWEEN PRECIPITATION AND RECOVERABLE WATERS

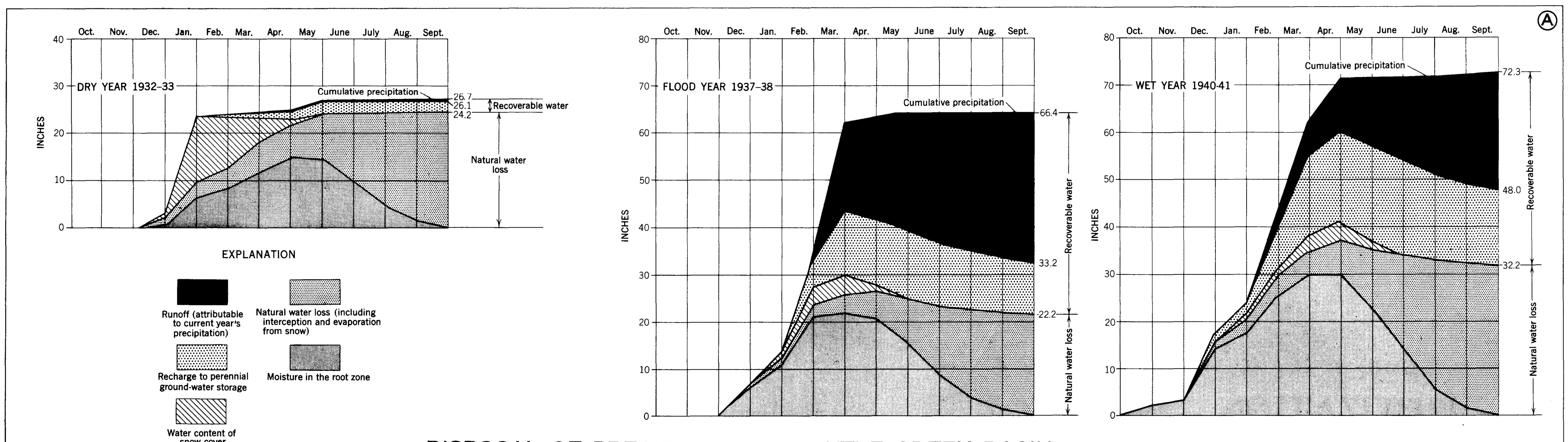
F

From the preceding analyses of runoff, ground-water storage, and natural water loss, it is evident by the wide scattering of field data plotted in part F that there is no simple correlation between precipitation and recoverable water. These data indicate that a mean annual precipitation of 38 inches will produce 11. 8 inches of mean annual recoverable water in the Cucamonga Creek drainage area and 19 inches in the Deep Creek below Green Valley Creek. These same data show that for a mean annual precipitation of 26 or 27 inches the recoverable water ranges from 1. 5 inches in the Lone Pine Creek drainage area to 8. 1 inches in the West Fork Mojave River drainage area.

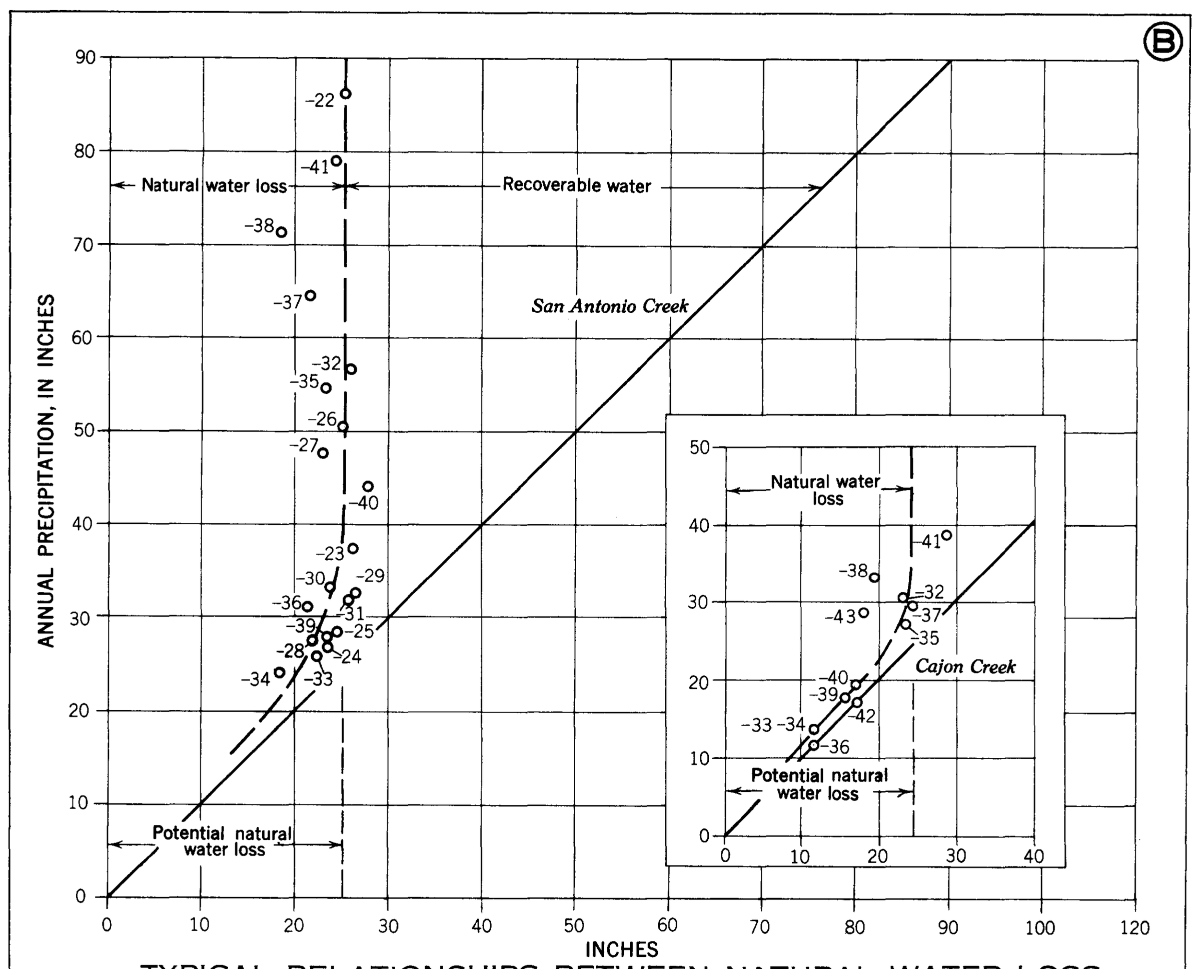
The data in part B suggest that if the potential natural water loss for an area were known, then the part of the mean annual precipitation that becomes recoverable water could be fairly well defined for that area. By making use of all the available data of this nature, a curve of dimensionless ratios was developed showing relationship among the mean annual precipitation, mean annual recoverable water, and the potential natural water loss. Then by the use of this dimensionless curve and selected values for the potential natural water loss, it has been possible to develop the entire series of curves given in part F.

By use of these curves, the recoverable water in other areas can be estimated if such minimum information as basin-wide precipitation, absorptive and retentive qualities of the mantle rock, and altitude of the area are available.

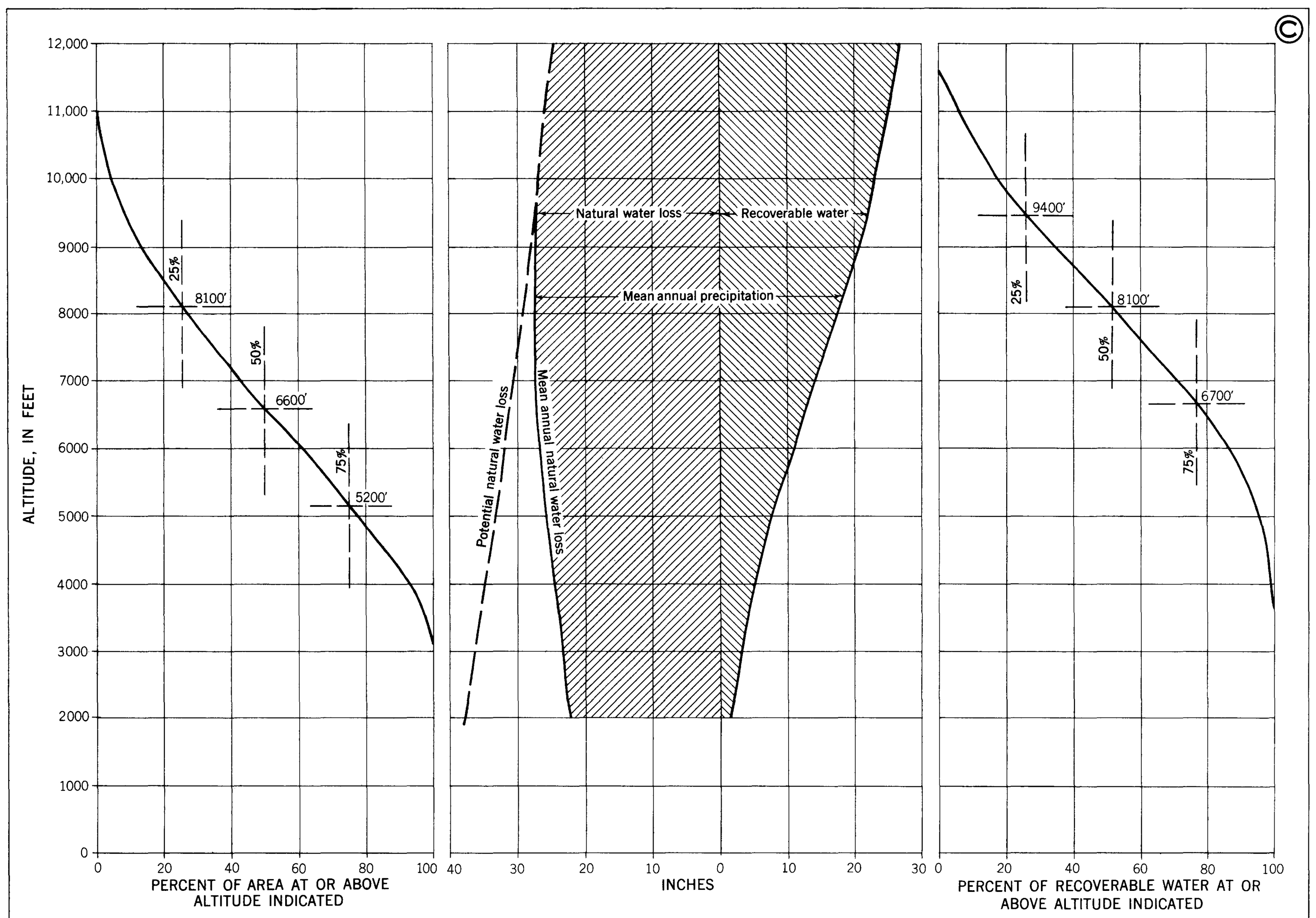
It will be noted that in some instances, the potential natural water loss, as obtained from part F for an individual drainage area, may differ somewhat from that used in developing the correlation in part E. This further serves to emphasize that many hydrologic factors are not absolute, often not completely understood, and always difficult to measure.



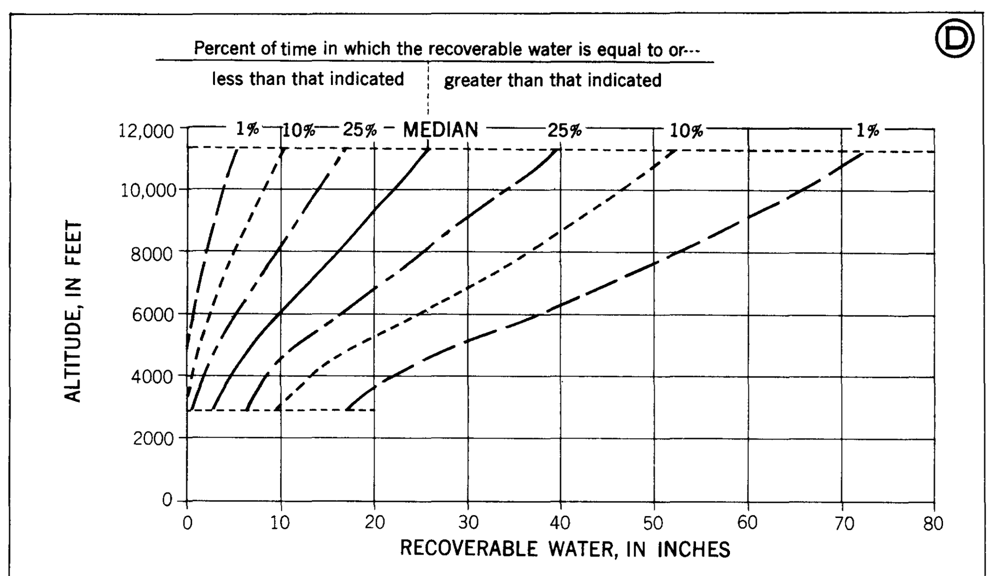
DISPOSAL OF PRECIPITATION IN LYTLE CREEK BASIN



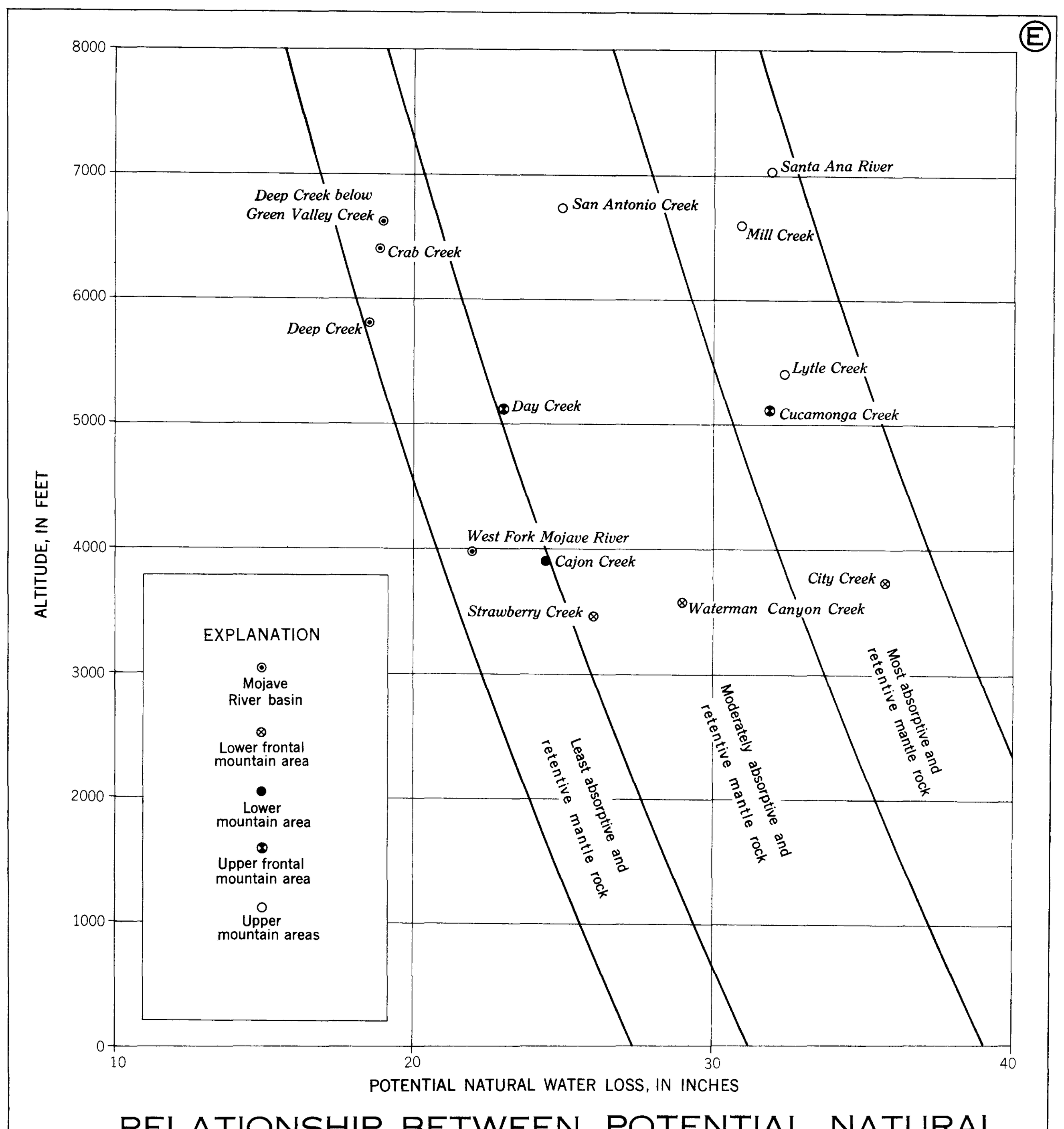
TYPICAL RELATIONSHIPS BETWEEN NATURAL WATER LOSS AND RECOVERABLE WATER



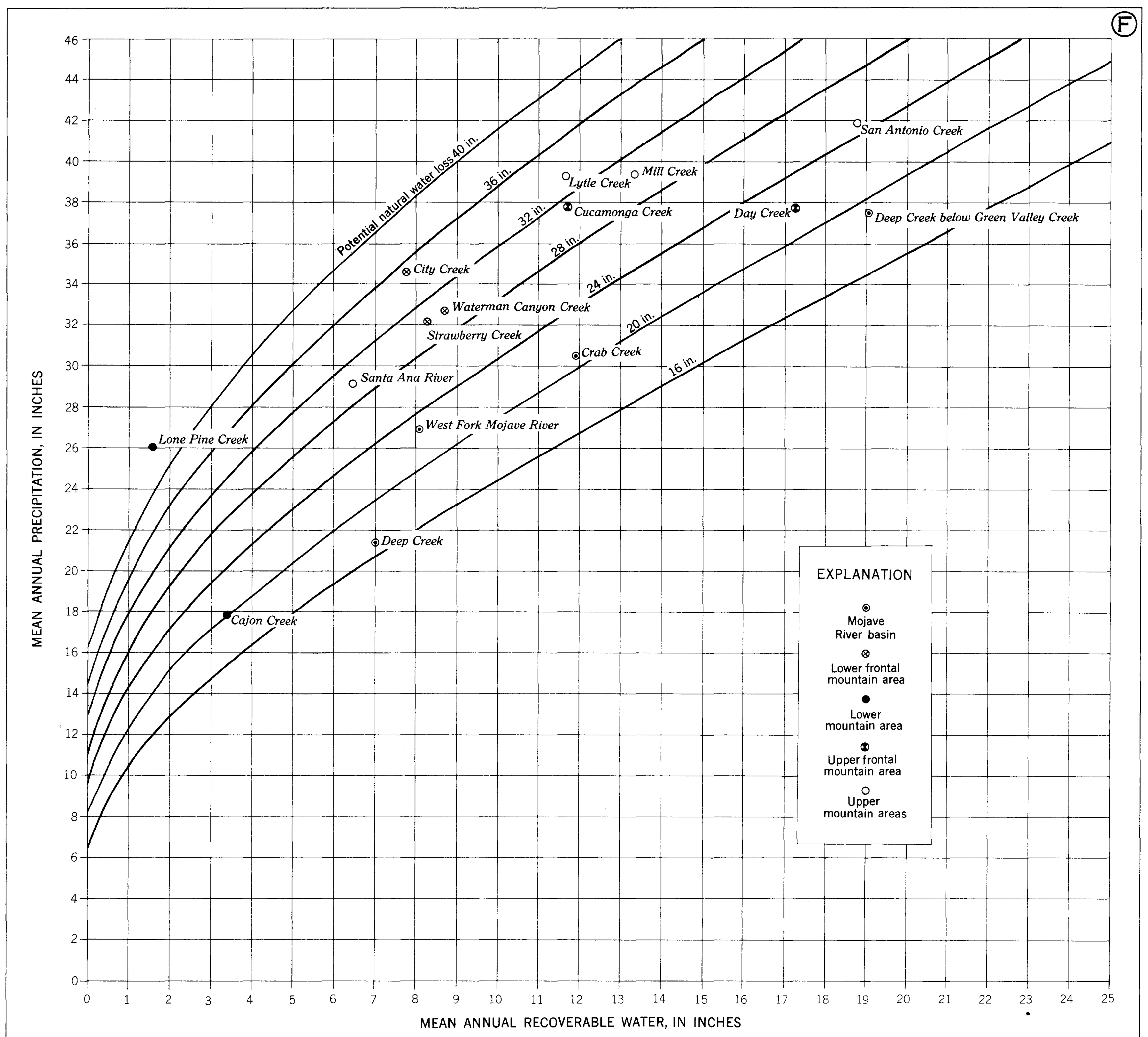
DISTRIBUTION OF NATURAL WATER LOSS AND RECOVERABLE WATER IN MILL CREEK BASIN FOR THE MEAN ANNUAL PRECIPITATION OF 39.4 INCHES



FREQUENCY DISTRIBUTION OF RECOVERABLE WATER IN MILL CREEK



RELATIONSHIP BETWEEN POTENTIAL NATURAL WATER LOSS AND ALTITUDE



RELATIONSHIP OF MEAN ANNUAL PRECIPITATION TO MEAN ANNUAL RECOVERABLE WATER

UTILIZATION

DISTRIBUTION OF WATER SURPLUS OR DEFICIENCY

A

The preceding analysis of recoverable water indicates that most of the water resources of the mountain area tend to originate in basins lying at high altitude, where the precipitation is normally the greatest and natural water loss is the least. This areal distribution is of vital interest to all water users in the valley floors adjacent to the mountain area.

The areal distribution of the average annual water surplus and deficiency is shown in part A. In most of the mountain area precipitation exceeds the natural water loss and, consequently, patterns indicate surpluses, which along frontal divides are as great as 25 inches. Northward and southward from these frontal divides the surplus of precipitation over natural water loss decreases rather rapidly.

On the northern side of the mountain area, the 0 line (or balance between precipitation and natural water loss) parallels the mountains in the vicinity of the 10-inch isohyetal (see plate 6, part A). In this area, the altitude, temperature, and absorptive qualities of the mantle rock restrict the meager plant cover to an average annual water requirement of about 10 inches. On the south side of the mountain area, however, the balance between precipitation and natural water loss occurs near the 20-inch isohyetal. These greater losses are largely due to the lower altitudes, the warmer temperatures, and the more absorptive mantle rock.

Most of the surplus waters originating in the Pacific slope basin of the mountain area are utilized in the Upper Santa Ana Valley. These surplus waters are either absorbed into the coarse mantle rock along the toe of the mountains to recharge the valley ground-water storage or are diverted for agricultural uses. The agricultural requirements in excess of the precipitation in this valley floor area are obtained by surface diversions or by pumping from ground-water sources. In areas of extremely deficient precipitation, such as in the vicinity of Riverside and Arlington, it is necessary to supplement the rainfall by amounts almost equal to average precipitation.

The deficiencies shown on this map represent the amount of this supplemental requirement. The very large negative quantities along the center of the valley are due to the water requirements of the native plant life along the Santa Ana River. To balance the water economy of the Upper Santa Ana Valley, the surplus of the mountain area should at least equal the deficiencies of the valley floor areas. If the valley floor water deficiencies exceed the surplus of the mountain area, then the Upper Santa Ana Valley is definitely overdeveloped so far as the local water supply is concerned.

B

The areal distribution of water surplus or deficiency in the valley floor, as shown in part A, was derived largely from George B. Gleason's report on the overdraft on the ground-water basins in the south coastal basin. c/ Gleason's data on the annual precipitation and consumptive use for certain subbasins in the Upper Santa Ana Valley is here given in graphic form so that the difference between these items will give the magnitude of the water surplus or deficiency in each subbasin.

CIRCULATION OF FLOW

C

The circulation of flow in the valley floor area is shown in part C. In the summer growing season almost all of the runoff from the mountain area is diverted for irrigation just upstream from the contact of the basement complex and the valley alluvial fill. In the nonirrigation season, this runoff is allowed to discharge on to the valley floor, where much of it is absorbed into the mantle rock to recharge the ground-water storage. This ground-water storage represents the principal medium of transmission and distribution of these waters throughout much of the valley. Then, after being pumped from this subsurface reservoir, the water is applied to all parts of the valley to satisfy local deficiencies of soil moisture.

However, in major flood periods, the runoff from the mountain area is too great to be absorbed completely into the coarse mantle rock along the toe of the mountains. In these periods the flood runoff flows across the entire valley to find outlet to the ocean through the deep Santa Ana Canyon along the north side of the Santa Ana Mountains. The restrictiveness of the narrow canyon between the foothills and Santa Ana Mountains, and the many faults or other types of geologic barriers, tend to stabilize and control the altitude of ground water throughout the Upper Santa Ana Valley. There is generally continuous spill, in the form of surface runoff, across these barriers such as shown in the lower left corner of part C. This spill does not represent waste, but merely the conversion of ground water to surface water for agricultural or domestic uses downstream.

INFLOW AND OUTFLOW TO THE UPPER SANTA ANA VALLEY

D

The difference between the amount of inflow from all the mountain area streams around the periphery of the valley and the amount of outflow in Santa Ana Canyon represents the major source of ground-water recharge. This recharge is, however, supplemented by deep penetration from precipitation on the valley floor areas and from the runoff from certain minor unmeasured mountain drainage areas not included in the preceding analysis.

The upper diagram of part D gives the chronological distribution of the surface inflow to and the surface outflow from the Upper Santa Ana Valley for the period 1920-48. Wet and dry periods are indicated by showing the cumulative departures from the mean annual precipitation at San Bernardino.

In the first year of this record (1920-21) the inflow measured about 140,000 acre-feet and the outflow 105,000 acre-feet, leaving a recharge of 35,000 acre-feet for ground-water storage. The next year (1921-22) being a very wet year, the inflow amounted to 570,000 acre-feet and the outflow 305,000 acre-feet. The difference, 265,000 acre-feet, represents the recharge for that year. These two consecutive years indicate the range in the magnitude of this recharge and the significance of the chronological sequence of this recharge factor.

These inflow and outflow data are reassembled in the lower part of this graph to show the frequency distribution. Of most significance is the fact that the mean annual inflow was 183,000 acre-feet, and the mean annual outflow was 104,000 acre-feet, providing a mean annual recharge of 79,000 acre-feet.

RATES OF INFLOW

E

The opportunity for stream-bed absorption in the multitude of irregular channels that cross the Upper Santa Ana Valley from the toe of the mountain area to the valley's outlet is very great. The rate of actual stream-bed absorption often varies considerably from month to month or even from day to day. Continuous flow of water in the same channel for long periods of time encourages the development of aquatic plant life and organisms which tend to seal the bed of the stream. Furthermore, a continuous supply of fine sand, silt, or colloidal materials would also tend to develop a tight impermeable film over the stream bed.

In those parts of the valley where the ground-water storage is artificially recharged by spreading the surface runoff over the ground, the water is periodically removed and the ground surface allowed to dry. This destroys organisms which tend to reduce the rates of infiltration. The surface layer of fine debris is sometimes plowed or reworked by mechanical equipment to destroy this soil crust which also reduces the rates of infiltration. When the water is again returned to the recharge area, the ground surface tends to possess all of its original absorptive qualities.

The only natural phenomenon comparable to this mechanical process is the occasional flood which erodes and reworks the channel deposits. A main purpose of part E is to show the effect of flood runoff on these absorptive qualities.

The inflow quantities in part E represent the combined average daily discharge for a single maximum 5-day-period in a flood in all the streams around the periphery of the valley. Stream-bed absorption is expressed as a percent of this inflow.

In the severe March 1938 flood, an average rate of 18,500 cfs for the maximum 5-day period from the peripheral streams was reduced by 46 percent before reaching the outflow area. In subsequent storms, 60 to 80 percent of the flood runoff was absorbed when rates of inflow were 4,000 cfs or less. Before the March 1938 flood only 20 to 50 percent of the inflow was absorbed during floods having a rate of discharge of 4,000 cfs or less.

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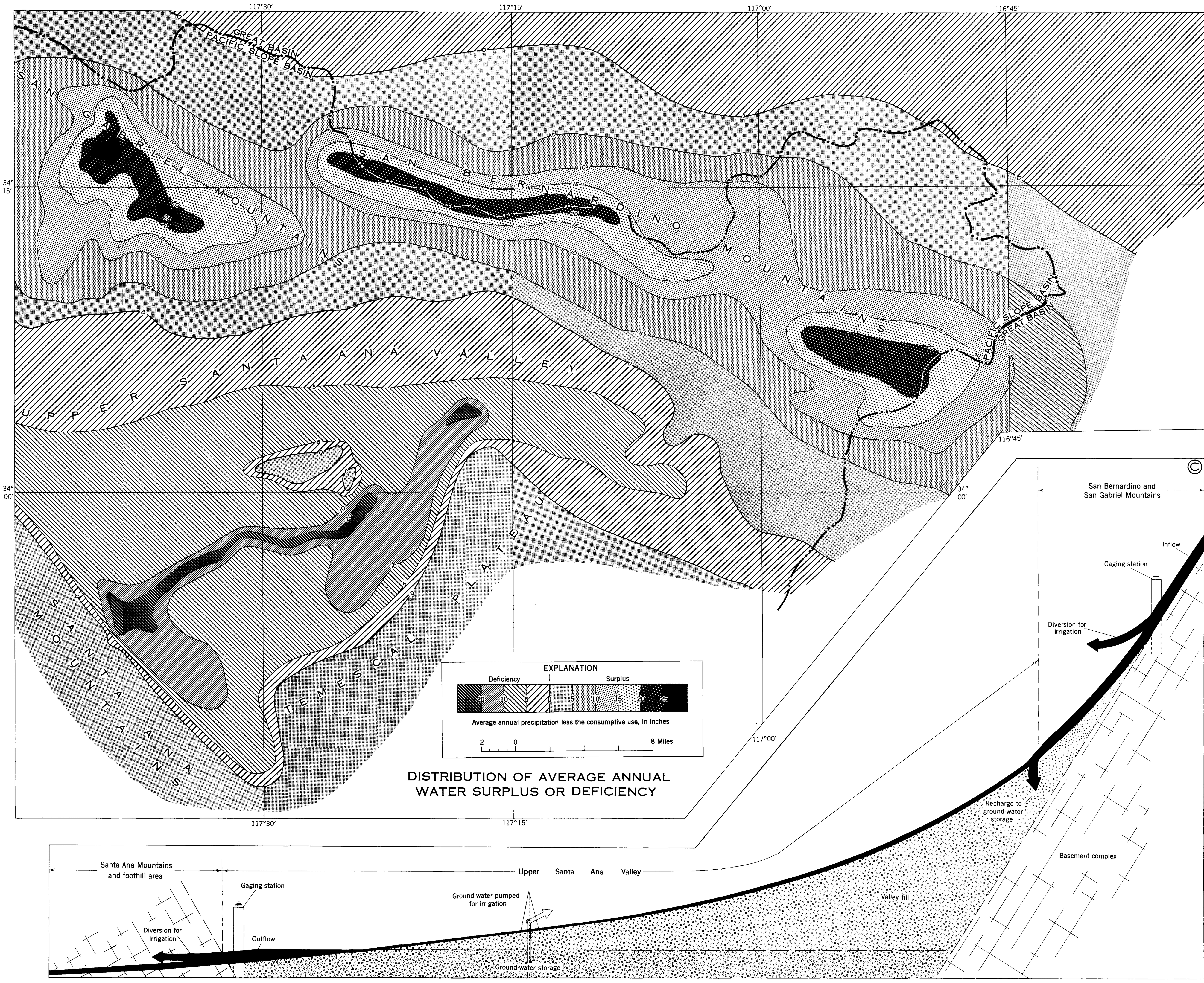
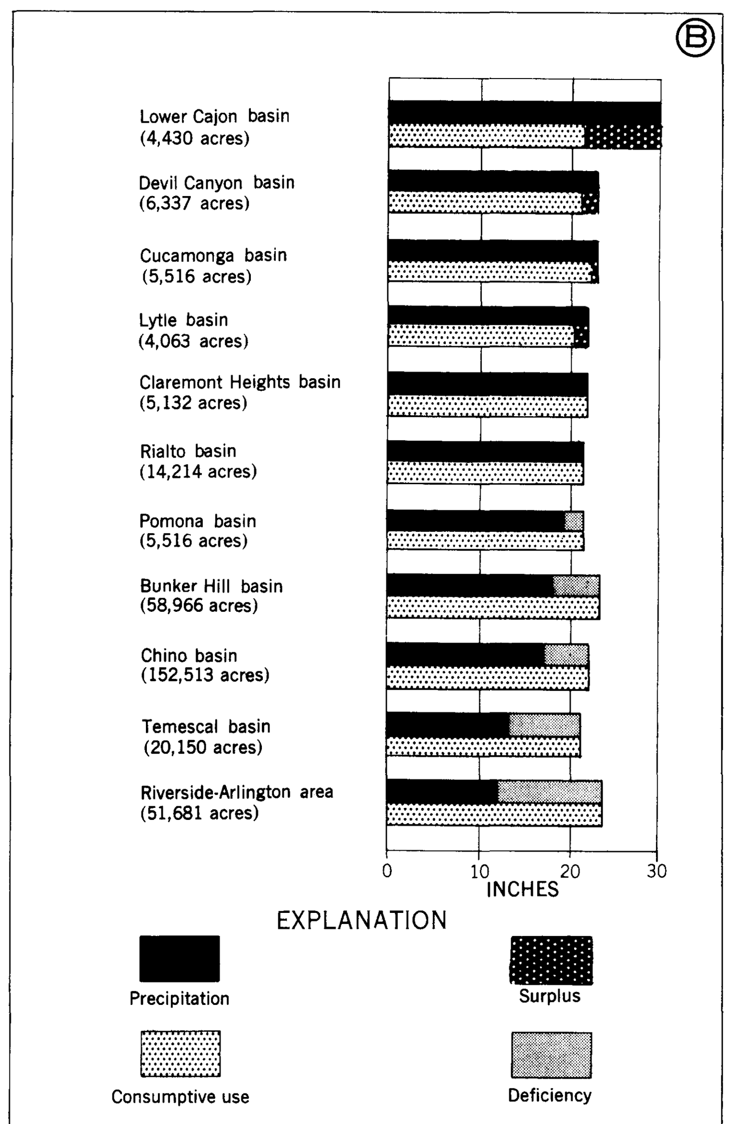
c/ Gleason, George B, 1947, South coastal basin investigation, overdraft on ground water basins: California Div. of Water Resources Bull. 53.

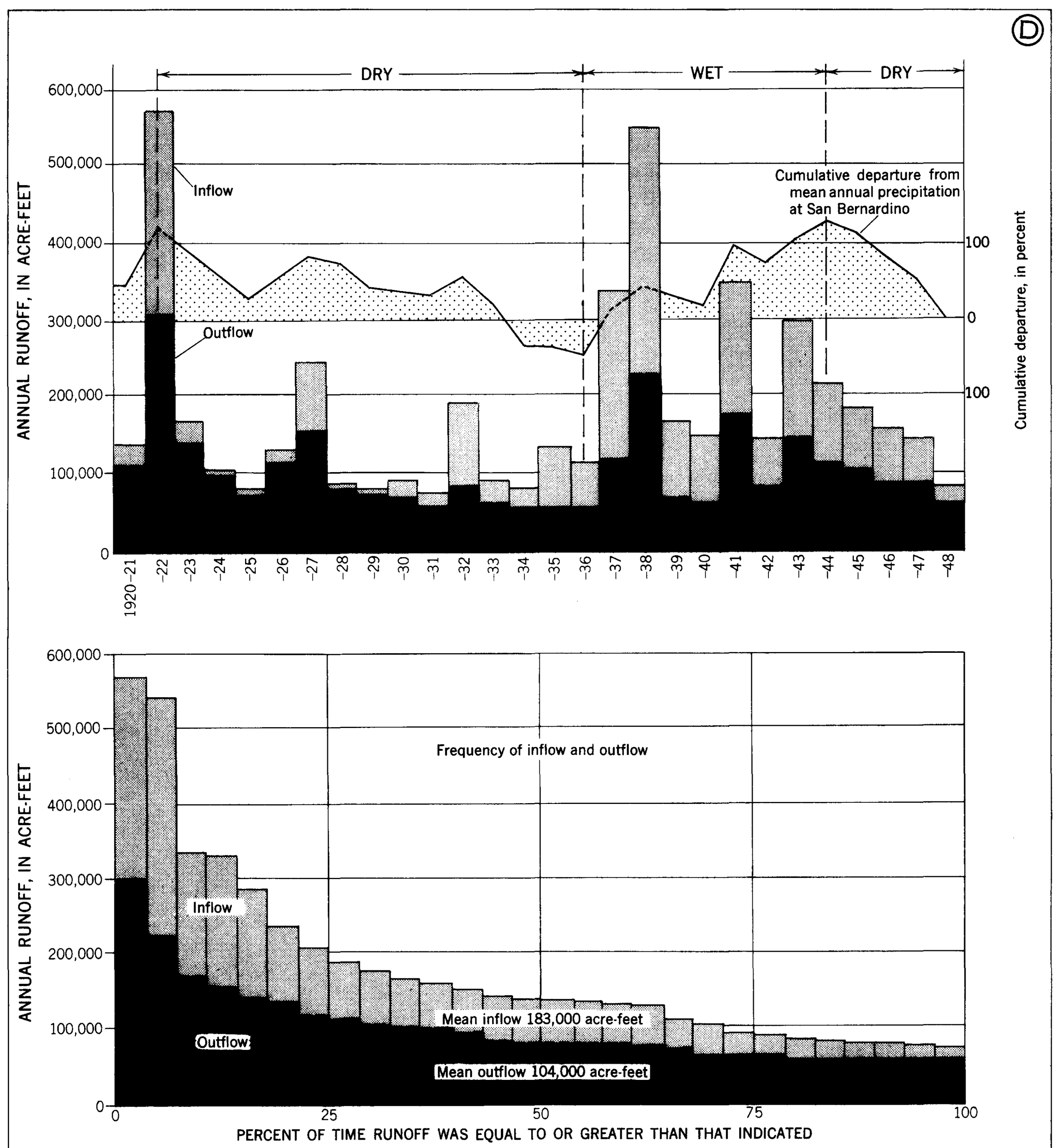


DISTRIBUTION OF AVERAGE ANNUAL WATER SURPLUS OR DEFICIENCY

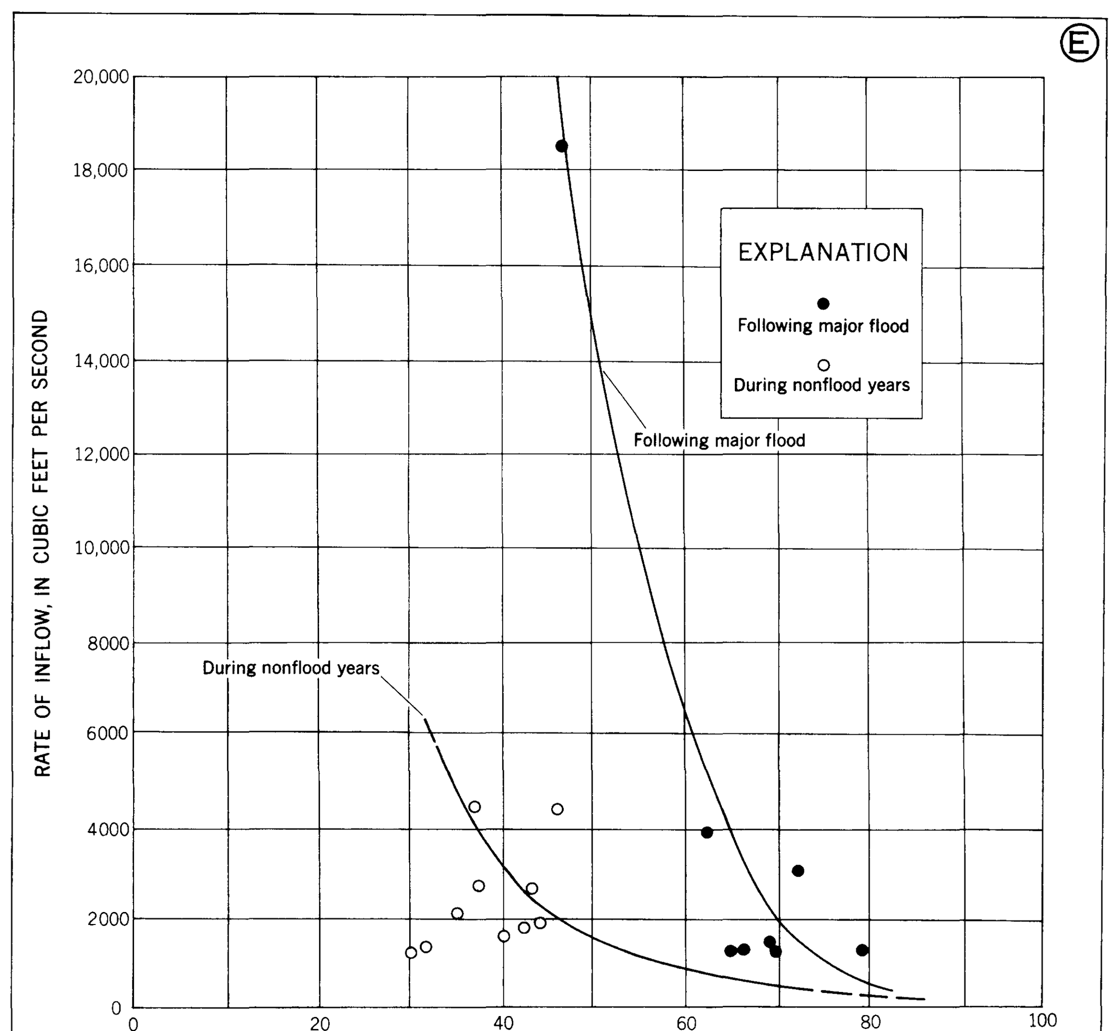
CIRCULATION OF FLOW



AVERAGE ANNUAL PRECIPITATION AND CONSUMPTIVE USE IN THE GROUND-WATER BASINS OF THE UPPER SANTA ANA VALLEY (AFTER GLEASON)



UPPER SANTA ANA VALLEY INFLOW AND OUTFLOW FOR PERIOD 1920-48



RELATIONSHIP BETWEEN RATES OF INFLOW TO UPPER SANTA ANA VALLEY AND STREAM-BED ABSORPTION (RATE OF RECHARGE TO GROUND-WATER STORAGE)

UTILIZATION

EAST-WEST RELATION OF GAGING STATIONS

A

Part A is a sketch map of the stream systems and the east-west orientation of certain land forms in the mountain area. The gaging stations along each stream channel above the periphery of the valley floor areas are also shown, as are the power houses and points of irrigation diversions. The gaging stations located along the Santa Ana River as it crosses the valley floor areas are shown too.

The Ontario power house, originally known as the Pomona plant, in the San Antonio Creek drainage area was the first hydroelectric installation for high-voltage transmission to be built in California. The plant was sponsored in 1890 by Dr. C. G. Baldwin, president of Pomona College, designed by Almerian Decker, and built by the Westinghouse Electric Manufacturing Company. The plant was placed in operation in 1892 and served both Pomona and San Bernardino.

In this same year, the Redlands Electric Light and Power Company was incorporated to build Mill Creek no. 1 plant and to construct the first alternating current transmission line in California and the second in the United States. d/

The quantity of water passing through these power houses is relatively small but the operating head on the impulse wheel of the generator is generally high. As shown in part A, the operating head at Mill Creek no. 3 power house is about 2, 000 feet, the highest in the entire mountain area.

DISTRIBUTION OF RUNOFF IN SANTA ANA RIVER

B

It is the intent of part B to show the complex distribution of runoff in the Santa Ana River between the mountain area and the Pacific Ocean. The distance from the ocean is used as the horizontal scale, and annual runoff, in acre-feet, is used as the vertical scale.

Where it leaves the San Bernardino Mountains the Santa Ana River has a mean annual runoff of 66, 000 acre-feet, all of which, except for 27, 000 acre-feet that runs off during the major flood periods, is diverted for irrigation. A short distance downstream, Mill Creek, which has a total annual flow of 28, 000 acre-feet, wastes 4, 000 acre-feet of that into the Santa Ana channel during flood periods. The flow in the Santa Ana River downstream from Mill Creek is further augmented by the flood runoff of Plunge, City, and San Timoteo Creeks.

After crossing the valley flood, this flood runoff is reduced to 16, 600 acre-feet at E Street bridge, just south of San Bernardino. Of this runoff, 1, 300 acre-feet came from San Timoteo Creek, immediately upstream from the bridge. Of the 32, 300 acre-feet of flood runoff annually entering the Santa Ana River channel, 15, 700 acre-feet, or almost 50 percent, becomes an annual recharge to ground-water storage above E Street, San Bernardino.

Immediately below E Street there is an intrabasin geologic ground-water barrier known as Bunker Hill dike. This barrier creates upstream a zone of high ground water, whose effluent has developed Warm Creek. The flood runoff from the mountain drainage basins of Lytle, Cajon, Devil, Waterman Canyon, and Strawberry Creeks also use the Warm Creek channel for outlet into the Santa Ana River. Of the 47, 000 acre-feet runoff from these sources at Bunker Hill dike, all but a small part of flood runoff is used for irrigation in the vicinity of Riverside and Arlington.

Another intrabasin geologic barrier, the Jurupa Mountains which are just downstream from Riverside, create another zone of high ground water. The seepage from this ground-water storage and the flood runoff from upstream have an average annual runoff of 45, 600 acre-feet.

Between the Jurupa and Santa Ana Mountains the ground water is tributary to the Santa Ana River throughout most of this 12-mile distance. Just upstream from the Santa Ana Mountains, the river has an average annual runoff of 105, 200 acre-feet, much of which came from ground-water storage. Immediately downstream, 20, 000 to 30, 000 acre-feet are diverted for irrigation, with the residual, except for about 13, 600 acre-feet that is wasted to the ocean, being the recharge to ground-water storage in the coastal plain.

The average annual wastage to the ocean, as measured at Fifth Street in the city of Santa Ana, is 18, 600 acre-feet, of which 5, 000 acre-feet is contributed by Santiago Creek.

DISTRIBUTION OF RUNOFF IN THE MOJAVE RIVER

C

Part C is similar to part B, except that the stream bed absorption has not been indicated, and shows the runoff distribution for the Mojave River. As time progresses, the increasing use of water for irrigation in this area may create a pattern of runoff almost as complicated as that of the Santa Ana River.

The combined flow of the West Fork Mojave River and Deep Creek discharge an annual average of 84, 500 acre-feet on to the adjacent valley floor. All of this runoff except for that of flood periods becomes a recharge to ground-water storage.

A geologic barrier across the natural channel of the Mojave River in the vicinity of Victorville creates a zone of high ground-water level. The annual seepage from this storage, together with the flood runoff, is 74, 200 acre-feet.

From Victorville to Afton the flow in the river is progressively decreased by recharge of ground-water storage and loss from plant life along its channel. Of the 84, 500 acre-feet of flow below the confluence, only about 6, 000 acre-feet is wasted into Soda Lake, a desert playa.

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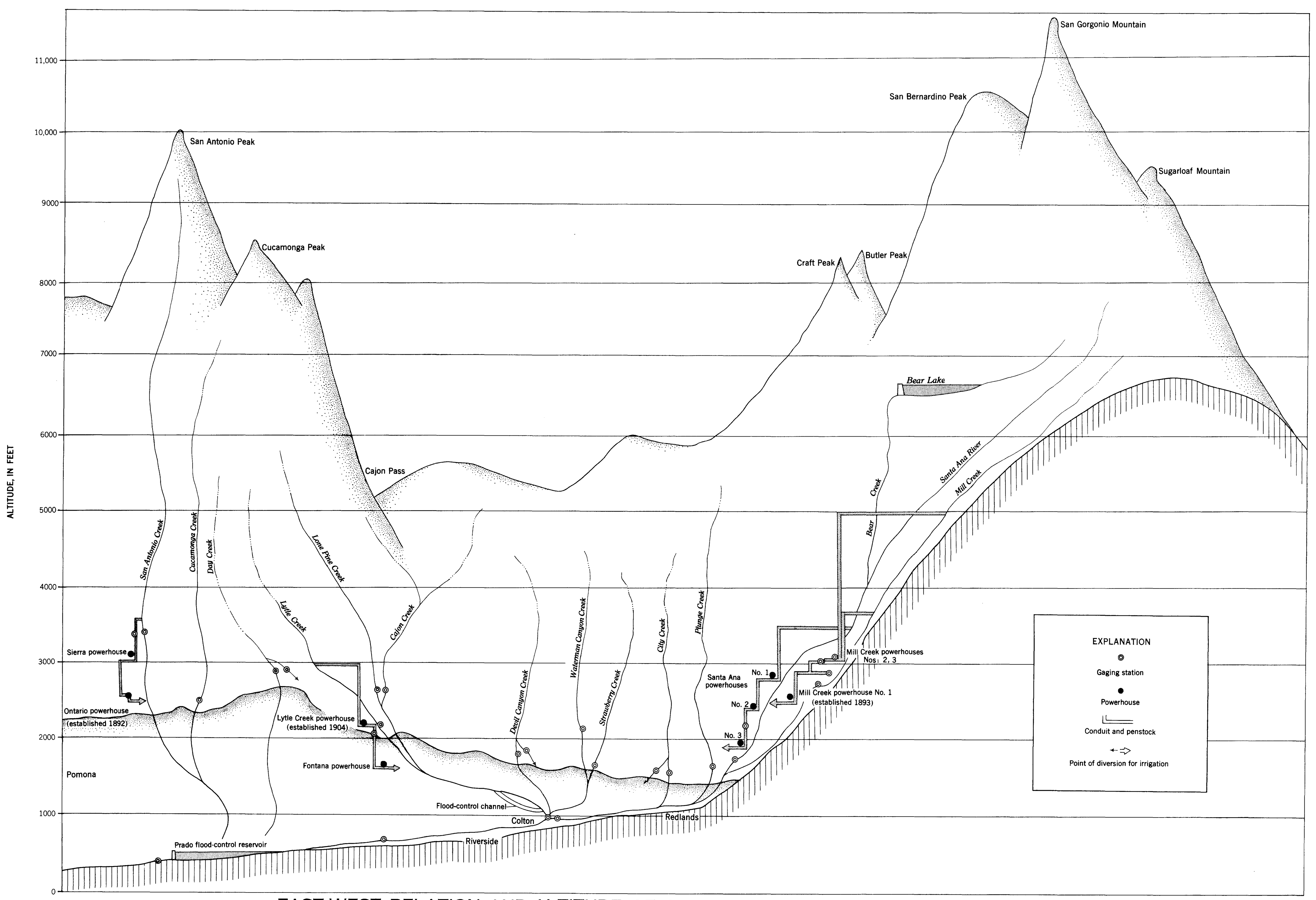
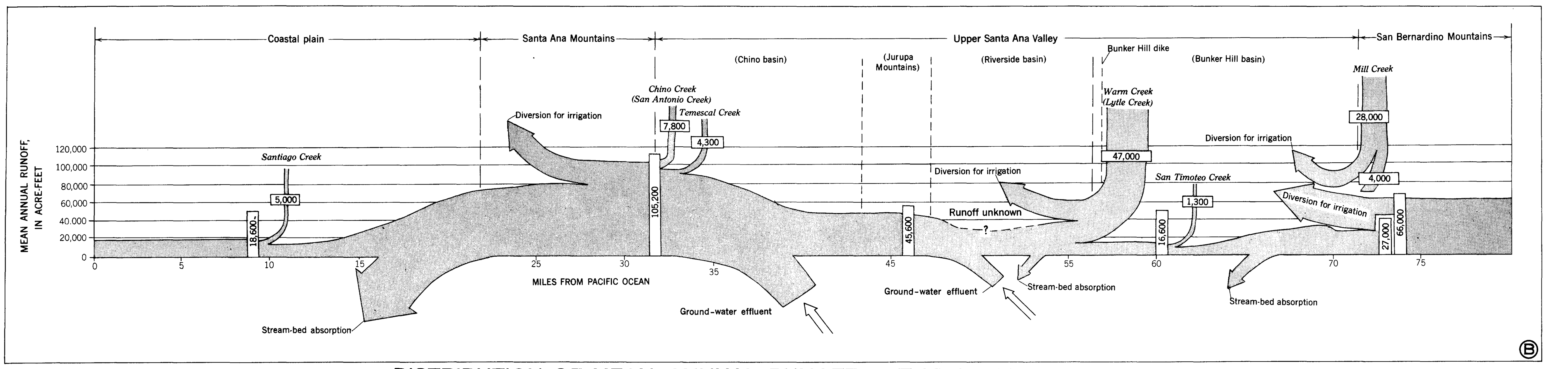
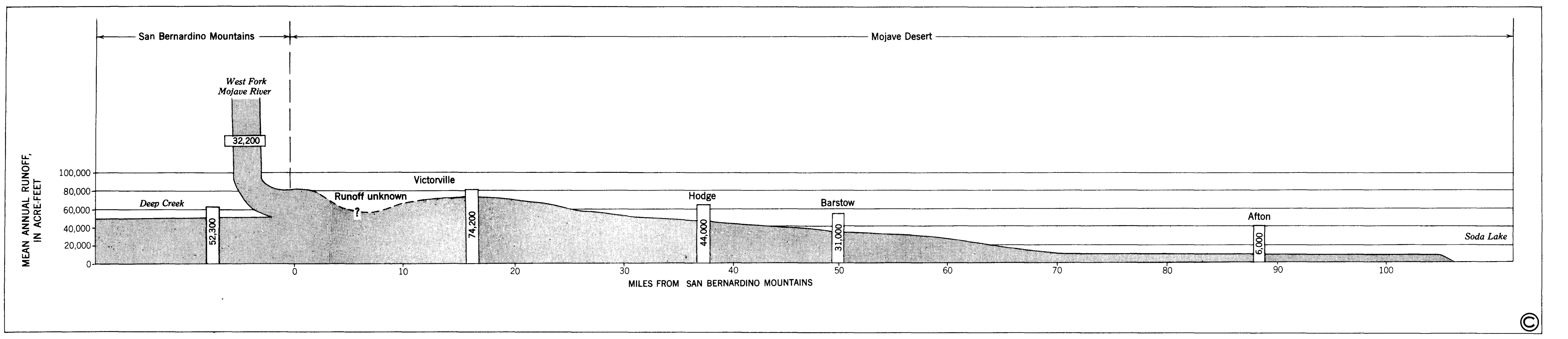
d/ Fowler, F. H., 1923, Hydroelectric power systems of California, Geological Survey Water-Supply Paper 493.



EAST-WEST RELATION AND ALTITUDE OF GAGING STATIONS AND POWERHOUSES



DISTRIBUTION OF MEAN ANNUAL RUNOFF IN THE SANTA ANA RIVER



DISTRIBUTION OF MEAN ANNUAL RUNOFF IN THE MOJAVE RIVER

EXPLANATION

52,300 — Gaging station on main stream and mean annual runoff, in acre-feet

32,200 — Gaging station on tributary and mean annual runoff, in acre-feet