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
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By Harold C. Troxell and others

DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

UNITED STATES GEOLOGICAL SURVEY
W. E. Weather, Director

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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 Lower 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 all 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 it will penetrate the soil and mantle rock. The precipitation that becomes storm runoff may be absorbed into the streambed gravels to recharge ground-water storage or it may be artificially spread by irrigation channels to recharge this same ground-water storage or it may be passed into the ocean.

In this study 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 generates 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. Runoff 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 temporarily stored on the surface of the planet and then passed into the ocean or the atmosphere where it is temporarily stored on the sur-

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. Norton of the California Forest and Range Experiment Station, United States Forest Service.

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.

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 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.
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 purposes of this atlas, the "mountain area." It consists of the eastern San Gabriel Mountains, the San Bernardino Mountains, and their foothills.

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-thrust 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 3,000 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-thrust 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.

ALTIMETRY 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 3,200 to 10,000 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 5,000 feet.

Part F, which is a similar diagram, shows that the San Bernardino Mountains range in altitude from 1,200 to 11,500 feet, and have a median altitude of 4,400 feet. The quartiles show that 50 percent of the area has an altitude of 3,000 to 6,700 feet. On this basis, the San Bernardino Mountains are from 600 to 900 feet higher than the San Gabriel Mountains.
PHYSIOGRAPHY

PHYSIOGRAPHIC AREAS, RIVER SYSTEMS, AND GAGING STATIONS

A

The main stream systems of the mountain area, with the inclusion of all the active gaging stations, are shown in part A. Most of these gaging stations are in the 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 30 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 landscape. The first four physiographic types, consisting of the upper mountain areas, upper frontal mountain areas, lower mountain areas, and lower frontal mountain areas 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 of the occurrence of these areas block and elevate the incoming moisture-laden air masses much like a meteorological "flying barrier.

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, when standardized according to the physiographic classifications in part A, are shown in part B. Each of these areas 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 beneath the diagram. The part below the line shows the percent of the area having an altitude equal to or less than the altitude shown on the scale.

For example, the Santa Ana River drainage area ranges from a minimum altitude of 1, 700 feet at the gaging station to a maximum of 11, 800 feet; the total range is 10, 100 feet.

The elevation band from 0 to 2, 500 feet 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 beneath the diagram. The part below the line shows the percent of the area having an altitude equal to or less than the altitude shown on the scale.

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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, middle, and lower stream areas are shown in part C. The Santa Ana River channel, representing the upper mountain areas, drops 5, 600 feet in altitude between the windward divide and the gaging station in 28 miles, or 340 feet per mile. In contrast, the San Gabriel Creek representing the upper mountain areas 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 drainage system area than the average stream-bed profiles used in part C. The basin-wide distribution of the land-surface slopes in the four typical drainage areas and the adjacent mountain area are shown in part D. Land-surface slopes are generally measured by a percent relationship between the vertical and horizontal distances. For example, 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 readily visualized, a secondary diagram in the upper right-hand corner of part D shows this steepness for slopes ranging from 0 to 200 percent.

These graphs show that the Day Creek drainage area representing a typical upper 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 19 percent of the area, and a slope of 75 percent or steeper for 35 percent (the median) of the area. In contrast, the West Fork Mojave River drainage area, representing the Mojave River basin has the flattest slope of the group, with 1 percent of the area having a land-surface slope of 15 percent or steeper, 10 percent of the area a slope of 4 percent or steeper, and 50 percent of the area, a slope of 19 percent or steeper.

These wide differences in land-surface slopes for these two areas should suggest equal land-wide variance in the runoff and its distribution.

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 percent within each drainage area. The basin-wide distribution was first divided at the median slope. The area consists of the four typical drainage areas, 1 percent of the area having a land-surface slope of 75 percent or steeper, 10 percent of the area an area slope of 4 percent or steeper, and 50 percent of the area, a slope of 19 percent or steeper. These wide differences in land-surface slopes for these two areas should suggest equal land-wide variance in the runoff and its distribution.

The extremes of this distribution show that 1 percent of the Santa Ana River drainage area has a land-surface slope of 123 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 193 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 40 percent has a slope of 1.5 to 78 percent, and the middle 60 percent of the area has a slope of 12 to 49 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, a way that generally proves to be informative. It shows the Lytle Creek bed to have a slope of about 3 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. During the next 2, 500-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. This line shows that the capacity to transport equals the supply of debris. There is no debris on the bed of the stream above an altitude of 8, 700 feet, and it is presumed that in such a reach the capacity to transport exceeds the supply of debris. Below this altitude, the channel deposits are fairly well stabilized, leading to the hypothesis that the capacity to transport equals the supply. In this area, the equilibrium channel is maintained upon a thick deposit of debris at an altitude of 6, 200 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 a subsurface instead of surface runoff.

This ground-water storage and its retarding effect on runoff makes a great bonus 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. The magnitude and area 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, the precipitation is determined in part by the direction of the slope of the land on which it grows. Chaparral forests, which like midday and consequently prefer southern exposures, fill these facing east and west. And fourth, plant life is especially from the south-facing slopes, and

In the Lytle Creek drainage area the north- and east-facing exposures predominate, giving the entire basin closely associated with the northern and southern exposures an east-west exposure.

In the City Creek drainage area the predominant exposure is southerly, with east and west exposures almost balanced.

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GEOLOGY

A

One of the major factors affecting the recoverable waters in the geology of the mountain area is 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 locations 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.

and varied structural features affecting the character of the rock. Furthermore, 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 for 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 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 assigned to represent an intermediate stage of relatively moderate flood and summer runoff.

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 predominant 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 phaneritic rocks
Saragossa quartzite
Least absorptive and retentive mantle rock
Cajon formation
Granitic rocks
Horsethief formation
Potato sandstone
Santa Ana sandstone

The hydrologic properties of the mantle rock are at times almost indeterminate because of the many changing structural and climatic factors. The areal distribution of the mantle rock and its associated factors is shown in part B. Superimposed are the boundaries for the 15 main drainage areas.

B

The hydrologic properties of the mantle rock are at times almost indeterminate because of the many changing structural and climatic factors. The areal distribution of the mantle rock and its associated factors is shown in part B. Superimposed are the boundaries for the 15 main drainage areas.

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.
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," P-E. This index represents the sum of the 12 monthly precipitation-effectiveness ratios, each of which can be expressed as

\[ P - E = \frac{\sum P - E}{12} \]

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

\[ P - E \]  

index

Humidity province

138 and above

Wet

64 - 121

Humid

32 - 63

Subhumid

16 - 31

Semiarid

Less than 16

Arid

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 Run station, situated near the divide of part A at an altitude of 5,700 feet, is classified as arid, with about 23 percent of the years being wet enough to be classified as semiarid. In contrast, Victorville, situated in the Mojave Desert about 14 miles north of Squirrel Run, is classified as humid, with about 80 percent of the years being wet enough to be classified as humid.

VARIATIONS IN CLIMATIC TYPES

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 of 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 111.7°F in August, or a range of 57°F. The average annual temperature at Los Angeles is only 68.4°F.

The Lake Arrowhead record shows the average daily temperature to reach a minimum of 35°F on January 10 and a maximum of 73°F on July 22. The distribution of the maximum and minimum temperatures agrees quite closely with the distribution of the average daily temperature. The highest observed temperature was 102°F on July 15, 1938 and August 1, 1938, and the lowest was 2°F on January 31, 1937. This range of extreme temperatures was 104°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 63°F to 69°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 6,800 feet. From the mountain area northward the average annual temperature again increases to 60°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°F at Los Angeles increases to 24°F at San Bernardino, to 31°F at Lake Arrowhead, and to 37°F at Barstow. This range in monthly temperatures appears to be a function of distance from the ocean.

RELATION OF TEMPERATURE TO ALTITUDE

E

Temperature has considerable influence on the hydrology of the mountain area through its effect on the type of vegetation, the snow melt, and the natural water flow. The correlation between altitude and monthly air temperature shown in part E was determined at about 700 feet per mile. The highest observed temperature was 90°F in January 21, 1937. This range of extreme temperatures was 104°F.

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 shows the maximum and minimum temperatures observed, the average annual, maximum and minimum temperatures, and the mean temperature for each day of the year at Lake Arrowhead for the period 1932 to 1942. The record obtained at this station, situated at an altitude of 5,100 feet, is believed to be typical of the mountain area at this altitude.

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 earth's surface, 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 areas 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 energy reaching the earth's surface is measured by an instrument known as a pyrheliometer, one of which is at Riverside, about 15 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 amount of 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 34°N, which corresponds to the latitude of northern Greenland or Baffin Bay. A 100-percent south-facing slope will receive twice the same amount of solar energy, except as modified by differences in hours of sunshine and in the quality of atmosphere penetrated, as a horizontal surface at latitude 34°S, which corresponds to the latitudes 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 humid and subhumid parts of the mountain area (Little Bear Creek)

Typical vegetation in arid parts of the mountain area (Deep Creek)
Our water resources are replenished annually by precipitation. Our seasonal and annual tree rings have been established to measure the precipitation, but systematic records have been kept only since 1895. 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 sequence 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.

**LENGTH OF WET AND DRY PERIODS**

The lengths of the wet and dry periods in these 560 years of records were plotted as cumulative frequency curves 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 30 percent of the dry periods will be 8 years in length or shorter. At the other extreme, it shows that 9 percent of all periods will be 22 years or more in length. Consequently, the most probable length for 50 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**

The southern fringes of the polar maritime air masses, originating over the Arctic seas and the subarctic interior of Siberia and Alaska, is the principal source of winter precipitation in the mountain areas, 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 areas.

The infrequent summer storms in the mountain areas 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**

Ninety-five percent of all the precipitation in the mountain area occurs in the 8-month period of October through March. Seasonally, 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 1881-1943, representing the mountain area. The vertical scale gives the percentage of time a daily precipitation of 0.1 inch or more was observed. In order to obtain 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, occurs for about 23 percent of the days. From this date, the possibility of precipitation gradually increases until it is expected that for 7 to 8 percent of the time in the latter part of August, the daily precipitation will exceed 0.1 inch in the mountain area. With the passage of this convective storm period, the probability of precipitation gradually decreases to about 2 percent of the time, or 5 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 part of April and May. It was to determine the reason for 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**

A typical record of the distribution of maximum daily precipitation in the mountain areas, that obtained at Bear Valley Dam, is shown in part F. In order to simplify preparation of this diagram, daily precipitation for this 80-year period of record from 1883 to 1963 was grouped into 5-day periods, such as July 1-5, 5-10, and 10-15.

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 10 inches in February.

An additional series of 4 solid curved lines in part F gives the daily precipitation to be expected once in 10 years, once in 5 years, once in 4 years, and once in 2 years.

**FREQUENCY OF STORM PRECIPITATION**

Precipitation in any one year is not of purely random occurrence, but is associated with the movement of typical air masses through southwestern 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 disturbances 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 areas. 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 in part G is based on all the storms having a precipitation in excess of that for a storm that can be expected in part G is based on 5-day periods, such as July 1-5, August 1-5, etc.

**FREQUENCY OF ANNUAL PRECIPITATION**

The frequency distribution of annual precipitation at the five typical sites of Squirrel Inn, Bear Valley Dam, Seven Oaks, Mouth of Santa Ana Canyon, and San Bernardino is shown in part H. The frequency of occurrence are divided into two parts by the dashed line representing the median value, with the frequency of occurrence increasing in either direction with distance from the median. The left-hand part of this diagram gives the percentage 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 percentage 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 was 22 inches or more once in 10 years, 24 inches or less once in 50 years, 31 inches or less once in 100 years, and 40 inches or less once in 500 years.
AREAL PRECIPITATION

The accurate determination of the areal distribution of precipitation over basins or regions of such bold topography as the mountain areas is extremely difficult. Areal distribution is largely controlled by the height, shape, and position of each land mass in reference to the principal moisture-laden air masses. These air masses, upon approaching highland 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 shows how precipitation was distributed in time at definite points of observation.

ANNUAL PRECIPITATION

Part A is an isohyetal map showing the average annual precipitation for the 30-year period from 1913 to 1943 and the location of the following observation stations:

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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

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 II of plate 5. On the basis of these records, the frequency distribution of the basin-wide average annual precipitation is shown in part II.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 basin, the basin-wide annual 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 15 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 exceed 41 inches, and for 10 percent of the time, equal to or less than 25 inches. The 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

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 B, the 1915-16 annual precipitation would be equalled or exceeded for only 5 percent of the time, or once in 20 years. Around this narrow front there was a precipitation of 30 percent of the time, or once in 3 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 in the valley areas. 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 Arrow Springs and Cucamonga a cumulative frequency of about 5 percent of the time, or once in 20 years; and 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 a uniform frequency distribution over the entire mountain area during any given year. For this reason, the areas of precipitation observed at a single meteorological station cannot be safely used as an index of basin-wide precipitation for any given year.
In the mountain area, precipitation is a far less complex and difficult subject for analysis than runoff. Runoff is a residuum 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 ability and capacity of the mantie rock and bed rock to store water, the temperature, and other factors less easily identified. Because of these many factors the interannual time of runoff will be considerably influenced by area to area, assuming that all receive identical amounts of precipitation.

**LOCATION OF GAGING STATIONS**

Data on runoff from the mountain area are obtained by systematic observations of the streamlet at selected sites. The equipment generally consists of a broad-crested weir and a stage-to-record gage that contains a given volume of water. Recent very accurate 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 stations in the stream-bed deposits will be zero or extremely small. The location of these gauge stations and their drainage areas is shown in part A.

**ANNUAL RUNOFF**

The longest continuous record of runoff in the moun­tain area, which covers the 52-year period of 1898 to 1948, has been used to show the time distribution of amounts of runoff. More recently during the so-called water year beginning October 1 and ending September 30, a continuous record of runoff from 1892 to 1943 has been obtained at a number of stations in the Santa Ana basin. These stations are widely distributed throughout the mountain area, covering the 52-year period of 1898 to 1948. For this reason, part B 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 is equal to or exceeded 3,000 acre-feet per square mile 1 percent of the time, or once in 100 years. It is to be equal to or less than 240 acre-feet per square mile 1 percent of the time. Thus, for 98 percent of the time the most probable annual runoff will range from 240 to 9,000 acre-feet per square mile. For 60 percent of the time the most probable annual runoff will range from 460 to 1,300 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 mean (heavy horizontal line) which is an index of time distribution. In the San Antonio Creek drainage area the mean annual runoff is 1,000 acre-feet per square mile 19 percent greater than the mean 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 1901-02 consecutive years is approximately 20 percent above the mean, the index of runoff and in here defined as the "safe yield." Currently, the safe yield would be obtained by the mean annual runoff for the 10-year period of 1898 to 1908, which is shown in the frequency diagrams for each drainage area. In the San Antonio Creek drainage area this 10-year mean is 530 acre-feet per square mile, or about 60 percent of the mean annual runoff.

**MONTHLY DISTRIBUTION**

As already indicated, runoff is a residual component of precipitation, occurring usually in the small part of a month. One of the most important physical factors affecting the amount of runoff is the temperature of the ground and the 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 differences 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 B, the upper 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, and half the precipitation occurs before and after this date.

The time distribution of runoff observed in San Antonio Creek drainage basin is used in this diagram as a representative of the monthly time distribution of runoff in the mountain area. A mean annual runoff of 18.9 inches in all is shown to be feasible from the basin-wide mean annual precipitation of 41.8 inches. The diagram shows this range of 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**

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 longer 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 mountain area. This graph of distribution indicates the dates after the beginning of the water year in which the accumulation of precipitation or runoff is equal 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 winter and spring months, more than 60 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 20. Rearranged, this analysis indicates that 60 percent of the precipitation was concentrated in the 3.2 months between December 20 and March 20.

In the Mojave River basin 60 percent of the average annual runoff was concentrated in a 1.7-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 front mountain drainage area 60 percent of the average annual runoff was concentrated in a 3.0-month period ending April 31. Here a slightly longer period was noted, the delay in the cumulative de­

**ANNUAL RUNOFF**

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 San Ana River near Mentone. Similar results for slightly different forms are given for 15 mountain areas drainage basins in part D for the 51-year period 1892 to 1943. The annual runoff is given in acre­feet per square mile at at the records comparable throughout the mountain area. The frequency distribution scale is divided into parts at the median value (heavy horizontal line). The upper half gives the percent of time in which the 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.

Assuming other hydrologic factors to be the same in all five physiographic units, the runoff distribution that the mantle rock in the Mojave River basin would be equal to or less than 240 acre-feet per square mile 1 percent of the time in the period of record exceeded the mean annual runoff. In November the average runoff is the least, being only 4 percent of the average annual runoff. The difference between that and the average monthly quantity in is only 0.4 percent of the average annual runoff. Deep Creek below Green Valley Creek, having the greatest ratio of the drainage area and the cumulative distribution of precipitation as Mill Creek and an identical climatic basin, has 260 acre-feet in 1915-16 to a minimum 60 acre-feet in 1898-99. For this reason, part G shows the range between the maximum and minimum runoffs in the Deep Creek drainage basin to be less absorptive and retentive than the mantle rock of the Mill Creek drainage basin.

San Antonio Creek gaging station

Using annual precipitation and the difference between minimum and maximum runoffs (recorded 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 and retentive the ground-water resources are, the smaller is the range in runoff in the least. For this reason, part G shows the range between the maximum and minimum runoffs, in percent of annual runoff, for 15 mountain area streams.

**RUNOFF**

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 property identified. This diagram shows that about 16 percent of the years have greater than mean annual runoff, and 64 percent have less. This indicates that the mean is only a fair index of runoff, especially where chronologi­cal distribution has great significance.
RUNOFF CHARACTERISTICS

TYPES OF RUNOFF

A

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

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 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 defined for purposes of this study.

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 intermittent springs is frighteningly large, 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. Such streams have 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. Perennial ground-water sources are continuously diminishing, as shown by 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. This combined runoff represents absorptive and retentive qualities of the mantle rock.

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 soil infiltration capacity. To demonstrate this, part E shows a correlation among the 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 mantled 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 1.3 inches, about 3.5 percent of it, or 0.37 inch, would be disposed of as storm 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 9 to 18 inches, then about 24 percent of it, or 3.67 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 4.5 percent of it, or 0.67 inch, would run off during the maximum 5-day-period. If the moisture retention decreased before the period of this storm arrived, about 7 percent of the 15 inches of storm precipitation, or 1.05 inch, would run off during the maximum 5-day-period.

By means of these and similar diagrams it is possible to draw the relationship between the amount of storm precipitation, percent of storm precipitation which penetrated into the soil, and, far more important, to be able to estimate the maximum amount of storm runoff which would result from ground-water storage occurring when the mantle rock was saturated.

RELATIONSHIP BETWEEN VOLUME AND TIME OF RUNOFF

G

The absorptive and retentive qualities of the mantle rock affect the period of runoff; a portion of the storm precipitation occurring during one period may be retained during another. This retention must be considered in determining the volumes of runoff for any basin unless the time periods involved are very short. 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, the time of concentration is the time required for water to travel from the most remote part of the basin to the outlet. The physical characteristic of each drainage area determines its time of concentration, a fact which greatly complicates the analysis of peak discharges.

DIFFICULTY IN DEFINING RUNOFF

In the Fern Canyon watershed no. 3 the rates of runoff precipitation cannot be classified as in part F, even though the rates of rainfall were almost identical. This difficulty in defining runoff precipitation arises from the fact that the storm runoff for storms that occurred before the period of runoff precipitation and storm runoff throughout the area. From this it is possible to estimate the time of concentration occurring in this area and, far more important, to be able to estimate the maximum amount of storm runoff which would result from ground-water storage occurring when the mantle rock was saturated.

It is evident from this diagram that storm runoff can be largely a function of the antecedent precipitation. More specifically, a function of the soil moisture deficiency of the area. If this deficiency is large, a major storm may produce only negligible runoff from yet another storm exactly like this one could produce a disastrous flood if it were to occur after this runoff had been fully reflected in the rates of runoff. Consequently, the time of concentration is the time required for water to travel from the most remote part of the basin to the outlet. The physical characteristic of each drainage area determines its time of concentration, a fact which greatly complicates the analysis of peak discharges.
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 1888 flood on the mountain runoff plot in Fern Canyon. However, during this storm, major flood runoff did occur in the small Fern Canyon drainage area as a result of the sudden release 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 successive 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

Part B of plate 7 suggests that the distribution of storm-period runoff within any 1-year period varies greatly from year to year. The intent of the upper diagram in part A of plate 8 is to show the irregular distribution of storm runoff by giving the number of days each year in which daily discharge of the basin represented by the storm runoff in Fern River near Jenome was equal to or greater than 200, 300, 400, and 500 cubic feet per second (cfs). The lines defining these three zones indicate that for identical storm precipitations, the variability of storm runoff for the sake of simplicity. Also, no attempt has been made during periods of successive 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.

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

These graphs of daily discharges 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 59 days per year from 1895 to 1914; however, an examination of the data indicates that the year-to-year variability in the distribution of storm surface runoff from year to year. From 1896 to 1905 not a single year had as many as 10 days with a daily flow of this magnitude. Also, during the 14-year period of 1895-20-20-200 cfs on an average of only 3.4 days per year. In contrast, during the period of 1910-1911 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-to-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 15 percent of the time, or 15 days 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, 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 17 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 by the average volume of all floods which are equal to or greater than the once-a-year flood. Part D shows that the total volume of the 47 largest floods divided by the 41 years gives a mean annual maximum 5-day-period runoff of 3,000 cfs-days. Because of the extreme skewness of the laws, the median item is 3,000 cfs-days, or about 64 percent of the mean.

The correlation between the mean annual maximum 5-day-period runoff for different drainage areas and the mean annual basin-wide storm precipitation for the same areas is shown in part E. Each of these mean values were obtained by identical methods. Part D shows considerable variation in these data. In general, the data indicates the greatest storm runoff from identical storm precipitations 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 precipitations 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, shows 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 maximum 5-day-period precipitation of 1 inch will produce a mean annual maximum 5-day-period runoff of 18 to 30 cfs-days per square mile in areas having a most absorptive and retentive mantle rock, 32 to 50 cfs-days per square mile in areas having a moderately absorptive and retentive mantle rock, and 50 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 1.6 to 2.5 times greater in these 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 the records of a rainfall area when the records of a rainfall area do not include all the 47 years chosen as the basis period (see part C). The curves were adjusted to give a smooth curve drawn through data of the same kinds and intervals, in years.

These frequency curves are given as bar graphs in part E. The maximum 5-day-period runoff in cfs-

deeper square foot for certain recurrence intervals, such as once in 100 years, once in 50 years, and once in 25 years, is shown by the step-like pattern. In the San Antonio Creek drainage area, the maximum 5-day period runoff for each of the 16 basins exceed 300 cfs; for once in 100 years, 240 cfs; and for the once in 25 years will be 170 cfs. 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 20 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. In analyses of the recurrence intervals of flood discharges the highest peak observed in 50 years is shown as occurring in 100 years. The mapping 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 intervals of the highest flood discharges for each of the drainage areas was 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 areas streams were investigated. During each flood period, the volume of runoff occurring in certain standardized intervals of time was tabulated. These tabulations showed that 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.
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 the long history of runoff in some parts of this mountain area. It indicates that many of these streams are either perennial or have gone dry even during extended dry periods.

After satisfying the existing soil moisture deficiency, runoff from meltwater percolates below the root zone to recharge ground-water storage. This storage may exist in the mantle rock or in the underlying bedrock. The position and type of aquifer in which the storage is held have considerable influence on the amount and distribution of the ground water it contains.

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

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 as a logarithmic 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 spring melting period have been designated. 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 depth of snow cover, a depth of snow at Squirrel Run is plotted 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. Cotently with these storms, there developed an extensive snow coverage over the area. It 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 from this snow melt did not reach a peak until the end of May. From June in mid-October runoff diminished at a fairly gradual rate. It is evident that from the end of April till mid-October most of the runoff must have been of the perennial type of ground-water storage.

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, which indicates a net decrease in ground-water storage during the period 1922 to 1926. Because of differences in precipitation, geology, and existing soil moisture deficiencies throughout the year, 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 1920 to 1943 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 some cyclic rhythm indicated in the preceding plates.

In the lower half of part B, these recharge items are expressed as a percentage of the mean annual precipitation. 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.

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 be distinguishable from daily discharge, indicate that there is another type of ground-water storage which has been termed "seasonal ground-water storage.

While seasonal ground-water runoff generally begins in midwinter, reaches a peak in spring, and ceases by late summer, there are many modifications of this distribution from area to area, depending on physical conditions. These physical differences are marked in the Lytle Creek drainage area. The annual hydrograph for the calendar year of 1932 has been selected for 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-hor domeilt and melt did produce runoff. This runoff, in discharging from the smaller canyons in the debris-choked main channels, was immediately absorbed in stream-ground-water storage. There is none of the direct evidence 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 of Lytle Creek, in a zone of equally high precipitation and altitude of 6,000 to 7,000 feet. This small town of 800 feet or more with many periods of extreme flood in which is any surface runoff across these deposits. At an altitude of 6,500 feet there is an observational water well in the midst of the channel. The 1932 records 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 90 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 debris barriers and a constructed 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 hydrographs in part E, it will be noted that daily discharge shows a pronounced increase in amount beginning in late July, peaked about August to December and returned to normal runoff in December. This represents the passage out of the Lytle Creek drainage area of the perennial ground-water runoff. This analysis is believed to be typical of this type of runoff throughout the mountain area, with differences from area to area confined to the period of recession.

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 is shown for confirmation. As in the preceding diagram, the computed water content of the basin-wide snow cover is plotted immediately above the hydrograph. Snow-melt forces a large part of the subsurface flow to the surface. From this point to the gaging station the stream flows continuously all year.

In the upper half of part E, the daily discharge in San Antonio Creek for the period of September 1932 to November 1933 is shown. As in the preceding diagram, the computed water content of the basin-wide snow cover is plotted immediately above the hydrograph. Snow-melt forces a large part of the subsurface flow to the surface. From this point to the gaging station the stream flows continuously all year.

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

FREQUENCY

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

NORTH FORK LYTLE CREEK

PRECIPITATION, RUNOFF, AND COMPUTED MAXIMUM PERENNIAL STORAGE

SEASONAL GROUND-WATER RUNOFF
NATURAL WATER LOSS AND RECOVERABLE WATER

The only source of recharge to the water resources of any drainage area is the precipitation falling on the area. However, not all of the precipitation that reaches the ground is available for man's use because much of it is often required to satisfy the moisture needs of the plants during the preceding growing season within the root zones of the vegetation that covers the mantle rock.

Analyses of the natural water loss and recoverable water of any drainage area are conducted in this plate, because these two factors of the hydrologic cycle account for the complete volume of precipitation that falls on the area. Other aspects of the water disposal which do not lend themselves even to spotting were estimated in whole. However, to simplify the analysis, all of those factors affecting the disposal of this water were considered 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 second diagram gives the same type of analysis for the year of 1937-38. As a result of the effects of the drought on the ground) and the soil moisture in the root zone at the time of the precipitation, together with the cumulative recharge to perennial ground-water storage, it is assumed that the natural water loss is the sum of the two items given immediately below the runoff. The cumulative recharge to perennial ground-water storage, 3. water content of the snow cover, 4. natural water loss, and 5. moisture in the root zone at the time of the precipitation, together with the cumulative recharge to perennial ground-water storage, is given immediately below the runoff. The cumulative recharge in this year is assumed to be uniformly distributed over the area. However, not all of the precipitation that falls on the area is available for man's use because much of it is often required to satisfy the moisture needs of the plants during the preceding growing season within the root zones of the vegetation that covers the mantle rock.

For the flood year of 1937-38. As a result of the effects of the drought on the ground) and the soil moisture in the root zone at the time of the precipitation, together with the cumulative recharge to perennial ground-water storage, it is assumed that the natural water loss is the sum of the two items given immediately below the runoff. The cumulative recharge to perennial ground-water storage, 3. water content of the snow cover, 4. natural water loss, and 5. moisture in the root zone at the time of the precipitation, together with the cumulative recharge to perennial ground-water storage, is given immediately below the runoff. The cumulative recharge in this year is assumed to be uniformly distributed over the area. However, not all of the precipitation that falls on the area is available for man's use because much of it is often required to satisfy the moisture needs of the plants during the preceding growing season within the root zones of the vegetation that covers the mantle rock.

The natural water loss increased this year to 23. 2 inches because of the greater opportunity for evapo-transpiration because of the more evenly distributed precipitation. In April the soil moisture available at the root zone was estimated at 30 inches, which is about twice as great as in 1932-33.

RECOVERY RELATIONSHIP BETWEEN NATURAL WATER LOSS AND RECOVERABLE WATER

For the San Antonio Creek drainage area, these observations show that the natural water losses to range from 19 to 28 inches, and to bear little relationship to the amount of annual precipitation. In years when the annual precipitation greatly exceeded the natural water loss, the observations suggest that these losses may be somewhat less than uniform. That is, these annual losses would approach uniformity if all the secondary factors that influence the distribution of the precipitation, could be identified and evaluated. With the data on these 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 to begin 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 to the annual precipitation may be defined by the curve representing the natural water loss plotted as a vertical line that approximately averages the points.

When the annual precipitation in the San Antonio Creek drainage area amounts to 15 inches for a year in which the basin-wide precipitation is assumed to be 36 inches, the mean for the period of 1883 to 1943. However, as indicated in plate 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 shown in part C, would remain unchanged.

This results in the annual amount of recoverable water for 10, 000 square miles. This is for each 0.25 inches of water that is added to the basin-wide precipitation. 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 to begin 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 to the annual precipitation may be defined by the curve representing the natural water loss plotted as a vertical line that approximately averages the points.

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A knowledge of this distribution is desirable for any projection of the potential natural water losses in the drainage area. For this reason, the recoverable waters of the Mill Creek drainage area are shown for such key frequencies.

POTENTIAL NATURAL WATER LOSS AND ALTITUDES

The basin-wide potential natural water loss is plotted against median altitudes in part E. For each given altitude, these observations tend to show range in the recoverable water per unit of area. For instance, the recoverable water ranges 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 median altitude of 36 inches at

By use of these curves, the recoverable water in other areas can be estimated. Further, it is suggested that the potential natural water loss, 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 any individual drainage area, may differ somewhat from that used in developing the correlation in part E.

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

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

Typical shallow soil and root systems of the least absorptive and retentive drainage areas
basin. Then 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 supplied 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 diversion 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 of 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 slopes and from the runoff from certain 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 125,000 acre-feet, leaving a recharge of 15,000 acre-feet for ground-water storage. The next year (1921-22) being a very wet year, the inflow amounted to 370,000 acre-feet and the outflow 395,000 acre-feet. The difference, 25,000 acre-feet, represented 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 assembled in the lower part of this graph to show the frequency distribution of these items. The basin analysis shows that the mean annual inflow was 183,000 acre-feet, and the mean annual outflow was 194,000 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 collodial materials would also tend to develop a tight impermeable film over the stream bed.

In these 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 worked 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 substrate 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 F 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 18,000 cfs for the maximum 5-day period from the peripheral streams was reduced by 46 percent before reaching the outflow area. In subsequent storms, 40 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.

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

Average annual precipitation less the consumptive use, in inches.

DISTRIBUTION OF AVERAGE ANNUAL WATER SURPLUS OR DEFICIENCY

DISTRIBUTION OF AVERAGE ANNUAL WATER SURPLUS OR DEFICIENCY

CIRCULATION OF FLOW

EXPLANATION

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

EXPLANATION

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

EXPLANATION

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 show the periphery of the valley floor areas that are the power houses and points of irrigation diversions. The gaging stations located along the Santa Ana River at 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. The plant was placed in operation in 1892 and served the 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.

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 38,000 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 Pomona, City, and San Timoteo Creeks.

After crossing the valley flood, this flood runoff is reduced to 19,000 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 17,700 acre-feet of flood runoff annually entering the Santa Ana River channel, 15,100 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 San Antonio Mountains the ground water is tributary to the Santa Ana River throughout most of this 12-mile distance. Just upstream from the Jurupa Mountains, the river has an average annual runoff of 103,200 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 94,000 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 16,200 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 94,000 acre-feet of flow below the confluence, only about 6,000 acre-feet is wasted into Suda Lake, a desert playa.

PLATE 13

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