Runoff Characteristics of California Streams

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2009-A

Runoff Characteristics of California Streams

By S. E. RANTZ

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2009-A

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTE^IOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 72-600016

For sale by the Superintendent of Documents, U.S. Government Printing Office Washington, D.C. 20402 - Price 70 cents (paper cover) Stock Number 2401-00216

CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

RUNOFF CHARACTERISTICS OF CALIFORNIA STREAMS

By S. E. RANTZ

ABSTRACT

California streams exhibit a wide range of runoff characteristics that are related to the climatologic, topographic, and geologic characteristics of the basins they drain. The annual volume of runoff of a stream, expressed in inches, may be large or small, and daily discharge rates may be highly variable or relatively steady. The bulk of the annual runoff may be storm runoff, or snowmelt runoff, or a combination of both. The streamflow may be ephemeral, intermittent, or perennial; if perennial, base flow may be well sustained or poorly sustained. In this report the various runoff characteristics are identified by numerical index values. They are shown to be related generally to mean annual precipitation, altitude, latitude, and location with respect to the 11 geomorphic provinces in the California Region.

With respect to mean annual precipitation on the watershed, streamflow is generally (1) ephemeral if the mean annual precipitation is less than 10 inches, (2) intermittent if the mean annual precipitation is between 10 and 40 inches, and (3) perennial if the mean annual precipitation is more than 40 inches. Departures from those generalizations are associated with (a) the areal variation of such geologic factors as the infiltration and storage capacities of the rocks underlying the watersheds, and (b) the areal variation of evapotranspiration loss as influenced by varying conditions of climate, soil, vegetal cover, and geologic structure.

Latitude and altitude determine the proportion of the winter precipitation that will be stored for subsequent runoff in the late spring and summer. In general, if a watershed has at least 30 percent of its area above the normal altitude of the snowline on April 1, it will have significant snowmelt runoff. Snowmelt runoff in California is said to be significant if at least 30 percent of the annual runoff occurs during the 4 months, April through July. Storm runoff is said to be predominant if at least 65 percent of the annual runoff occurs during the 6 months, October through March. Base flow (ground-water outflow), as a factor in the regimen of streamflow, is qualified on the basis of the percentage of the mean annual runoff that occurs during the fair-weather months of August and September. If the sum of the August and September runoff exceeds 3.0 percent of the annual runoff, base flow is considered to be well sustained; if the percentage is between 1.5 and 3.0, base flow is con-

sidered to be fairly well sustained; if the percentage is less than 1.5, base flow is considered to be poorly sustained.

The characteristics of duration curves of daily streamflow are influenced by the regimen of runoff. The distribution of daily flow is skewed for all streams, but it is more skewed for streams whose flow is predominantly storm runoff than for streams that carry significantly large quantities of snowmelt. Least skewed is the distribution for streams that carry large quantities of base flow. Either of two characteristics of the duration curve may be used as an index of skew—the percentage of time that the mean discharge is equaled or exceeded or the ratio of the median discharge to the mean discharge. As for variability of daily discharge, the variability of storm-runoff streams is greater than that of snowmelt streams, and the lowest values of variability are associated with streams that carry large quantities of base flow. The index of variability used in this study was the ratio of the discharge equaled or exceeded 10 percent of the time to the discharge equaled or exceeded 90 percent of the time.

The identification of streamflow characteristics by numerical index figures greatly facilitates comparison of the diverse runoff regimens of streams in the California Region.

INTRODUCTION

The climatologic, topographic, and geologic factors that affect streamflow regimen have great variation in the California Region. Mean annual precipitation ranges from about 2 inches in the southeast to 120 inches in the northwest. Altitudes range from 282 feet below mean sea level in Death Valley to 14,495 feet above mean sea level at the summit of Mount Whitney. With respect to infiltration potential, surficial rock types range from the highly permeable volcanic rocks of the Cascade Range and Modoc Plateau in the northeast (pl. 1) to the relatively impermeable rocks of the Franciscan Formation in the Coast Ranges to the west. Because of the wide range of these physical and climatological factors in California, there is a correspondingly wide range in runoff characteristics.

PURPOSE AND SCOPE

The purpose of this report is (1) to describe the runoff characteristics of streams in the California Region, (2) to categorize runoff characteristics by numerical index values, and (3) to relate those characteristics to mean annual precipitation, altitude, latitude, and location with respect to the 11 geomorphic provinces in the California Region (Hinds, 1952). The California Region, as defined in many regional water-resources studies, includes all the State of California, except for 147 square miles of Rogue River drainage in the northwest corner of the State; the region also includes those parts of the Smith River, Klamath River, and Goose Lake basins that lie in Oregon (pl. 1). The total area of the California Region is 165,120 square miles.

Plate 1 delineates geomorphic province boundaries and climatologic zones in the region and shows the location of selected drainage basins whose runoff characteristics are discussed in this report. Also shown on plate 1 are the stream-gaging stations where runoff from those basins is measured. The measured flows are either virtually unaffected by man's activities, or, where necessary, they have been adjusted to virtually natural flow by the use of records of significant upstream diversion. The runoff characteristics at a gaging station are a property of the drainage area upstream from the station. Consequently, it is the location of the drainage area—not the location of the gaging station—with respect to geomorphic province and precipitation zone that is considered in this study. Several of the stations shown on plate 1 are not in the same geomorphic province or precipitation zone in which the great bulk of their drainage area lies.

To avoid complications in the study of runoff characteristics, the basins selected for study lie almost wholly within a single geomorphic province and generally within a single precipitation zone. The selection was so made because a basin that includes parts of more than one province will have runoff characteristics that are a composite of the characteristics of the several provinces contributing runoff; significant features of the runoff regimen of individual provinces will thereby be obscured.

This report does not include any discussion of the random variation of total annual runoff from year to year, nor is it concerned with the analysis of magnitude-frequency-duration relations of high and low flows. The report is concerned solely with the systematic within-year characteristics of streamflow and with the variability of streamflow as indicated by duration curves of daily discharge. The purpose of the study is to present a generalized picture of those runoff characteristics. Departures from the general situation are discussed only when they are common to areas large enough to be delineated easily on a map of the scale of plate 1 (1:2,500,000).

DESCRIPTION OF GEOMORPHIC PROVINCES

The factors that affect the runoff regimen of streams in the California Region have wide geographic variation (p. A2). Latitude and longitude (distance from the ocean) are factors; annual precipitation, and therefore annual runoff, tends to increase from south to north and from east to west. The principal topographic factor affecting the runoff regimen is altitude. Annual precipitation and runoff increase with altitude, but at a given altitude, less precipitation falls on the leeward side of mountain barriers than on the windward side. Then too, basins that have an appreciable part of their area at high altitude will have an appreciable part of their annual runoff occur as snowmelt. The principal geologic factor affecting the runoff regimen is the permeability of the soil and surficial rock; the greater the permeability in a basin, the greater the percentage of annual runoff that occurs as base flow.

The simplest way of considering topographic and geologic factors on an areal basis is by use of the geomorphic province boundaries delineated by Hinds (1952, pl. 2) and shown on plate 1. Within each of the provinces the geologic factors tend to be somewhat uniform, although variations that affect the general pattern of runoff do occur. Those variations, when areally significant, are noted in this report.

As a preliminary to a discussion of runoff characteristics, each of the provinces is described briefly in the paragraphs that follow. The descriptions, abstracted in part from the report by Hinds and from a report by the California Division of Mines and Geology (1966), are oriented to stress those factors that affect the runoff regimen.

COAST RANGES

The Coast Ranges lie between the Pacific Ocean and the Central Valley and extend more than 500 miles in a generally northwest-southeast direction. They consist of numerous, often indistinct, ridges, ranging in altitude generally from 2,000 to 7,500 feet. The ridges are separated by the valleys of numerous streams, the largest of which are the Eel, Mad, Russian, and Salinas Rivers. The only area of significant size in the province where altitudes are high enough to maintain a seasonal snowpack is in the Yolla Bolly Mountains. That area is shaded appropriately on plate 1 for easy identification.

The Coast Ranges are composed chiefly of a complex assemblage of marine sedimentary rocks with local inclusion of metamorphosed rock and bodies of basic intrusive rocks that are largely altered to greenstone and serpentine. Folding and faulting and subsequent erosion have yielded the series of northwest-trending ridges and valleys. Some of the valleys, particularly in the south, are broad and flat and contain thick deposits of gravels and sands derived from erosion of the surrounding mountains; other valleys are narrow and contain almost no gravel or sand and are still being actively eroded. In the mountains, soils are shallow, and the soil and surficial rock have low permeability.

KLAMATH MOUNTAINS

The Klamath Mountains occupy the northwest corner of California. They adjoin the Coast Ranges along the South Fork Mountains which have the rock types of the Klamath Mountains, but the topography of the Coast Ranges. The Klamath Mountains have a complex structural pattern and a well-defined arcuate trend. Much of the area lies above an altitude of 4,500 feet and the highest peaks—Mount Eddy and Thompson Peak—ascend to about 9,000 feet. The drainage is transverse and irregular, and the principal rivers—the Klamath, Trinity, and Smith—have cut deep twisting gorges. The only large drainage basins with appreciable area below 4,500 feet are those of the Smith and South Fork Trinity Rivers, but many small basins in the southern and western part of the province lie below that altitude.

The Klamath Mountains are composed primarily of highly metamorphosed volcanic and sedimentary rocks that were intruded by granitic and ultramafic rocks. The soil and surficial rock are more permeable than in the Coast Ranges geomorphic province.

CASCADE RANGE

The Cascade Range, lying to the east of the Klamath Mountains, is a north-south trending chain of volcanic cones terminating in the south beyond Lassen Peak, the only active volcano in the conterminous United States, and continuing northward into Oregon and Washington. In the California Region, the Cascade Range is dominated by Mount Shasta whose altitude is 14,162 feet. The range is transected by deep canyons of the Pit River which flows east between Lassen Peak and Mount Shasta. The province includes no large drainage basins with appreciable area below an altitude of 4,500 feet.

Lavas and pyroclastic rocks predominate in the Cascade Range,

475-891 O - 72 - 2

but lake sediments are found in several of the structural depressions. The soil and surficial rock are highly permeable.

MODOC PLATEAU

The Modoc Plateau lies to the east of, and merges with, the Cascade Range. The Modoc Plateau has an average altitude of about 5,000 feet, above which numerous volcanic cones rise as much as 2,000 feet. The plateau consists of a thick accumulation of lava flows and tuff beds with an interlaying of lake sediments, soils, and stream deposits. The surface drainage pattern is poorly developed because the highly permeable volcanic rock allows ready infiltration of precipitation and snowmelt. Seeps are common and large springs are numerous, even in areas of light precipitation. Lakes and marshes are a notable feature of the landscape in many areas of the geomorphic province. The principal streams draining the Modoc Plateau are the Pit River and its tributaries and the headwater tributaries of the Klamath River.

SIERRA NEVADA

The Sierra Nevada is a gigantic fault block, about 80 miles wide and 385 miles long, that extends from the Cascade Range on the north to the Mojave Desert on the south. The fault block is tilted westward, and the gentle western slope is traversed by about a dozen major streams that flow into the Sacramento and San Joaquin Rivers in the Central Valley. Many of those westward-flowing streams occupy deep valleys, some as much as a half-mile deep. In contrast to the gentle western slope of about 2°, the eastern side of the Sierra Nevada presents a high, rugged, multiple scarp face, dissected by numerous short steep streams. This scarp, for much of its length, drops precipitously into Owens Valley.

The Sierra Nevada has a high continuous crestline which reaches its highest altitude, 14,495 feet, at Mount Whitney in the south near the eastern scarp. The altitude of the crestline, in general, declines toward the north where the altitude of the highest peaks is less than 8,500 feet. A number of valleys in the north, such as Sierra Valley, have been formed as structural depressions in the main Sierra block. These valleys have been filled with alluvial and lacustrine sediments and form important ground-water basins.

The Sierra Nevada fault block is composed primarily of granitic and metamorphic rocks overlain by remnants of Tertiary volcanic and sedimentary rocks. The permeability of the surficial rock in the various basins varies widely; it is greatest in eastward-draining basins in the southern Sierra where the surficial rock is extensively fissured, and least, in several westward-draining basins in the central Sierra.

CENTRAL VALLEY

The Central Valley is an extensive alluvial plain, 400 miles long by about 50 miles wide, whose floor ranges in altitude from about sea level to a few hundred feet above sea level. It is bounded on the east and southeast by the Sierra Nevada and its southern extension, the Tehachapi Mountains; on the north, by the Cascade Range and Klamath Mountains; and on the west, by the Coast Ranges, one of whose ranges, the San Emigdio Range, forms the southwestern boundary. The northern part of the Central Valley is drained by the southward-flowing Sacramento River. The southern part, except for the Tulare Lake basin of interior drainage in the extreme south, is drained by the northward-flowing San Joaquin River. About 30 miles west of the city of Stockton, the two drainage systems converge, and the combined flow reaches the ocean through San Francisco Bay, which is the only exit from the moutain-rimmed valley.

The thickness of the alluvium overlying the older consolidated rocks in the Central Valley ranges from zero at the borders of the valley to several thousand feet. Although the permeability of the surficial alluvium ranges widely, it generally is high and valley streams lose water by seepage through their beds.

TRANSVERSE RANGES

The Transverse Ranges consist of a complex series of mountain ranges that are distinguished by a dominant east-west trend. This trend contrasts with the northwest-southeast direction of the Coast Ranges and Peninsular Ranges, between which the Transverse Ranges lie. The ranges attain maximum altitudes of about 10,000 feet in the San Gabriel Mountains and about 11,000 feet in the San Bernardino Mountains. Their slopes are traversed by numerous short steep streams most of which are in the headwater areas of such larger streams as the Los Angeles, San Gabriel, Santa Ana, and Mojave Rivers.

The western part of the province—roughly, that part west of Los Angeles County—is composed primarily of Cenozoic sedimentary rocks; granitic rocks, chiefly of Mesozoic age, predominate in the east. The permeability of the surficial rock in the province varies widely, but it is generally greater in eastern basins. The streams lose water by seepage through their alluvial beds after leaving the mountain canyons.

PENINSULAR RANGES

The Peninsular Ranges, in the southwest corner of California, are a gigantic fault block that has been raised and tilted so as to form a high steep scarp on its eastern side. To the west of the scarp the topography is marked by a series of ranges separated by longitudinal valleys that have a predominantly northwest-southeast trend. The geomorphic structure is conditioned by erosion along faults. The highest peak in the range is Mount San Jacinto at an altitude of 10,831 feet, but the general altitude of the range crests is variable and much lower. The streams draining to the east in the high-altitude area near Mount San Jacinto are short and steep.

Although the directional trend of the topography is similar to that of the Coast Ranges, the geology of the Peninsular Ranges is more like that of the Sierra Nevada. The dominating rocks are granitic ones that intrude into older metamorphic series. The permeability of the surficial rock varies widely, and the variation follows no discernible areal pattern. Highly permeable alluvial fans, however, have formed at most canyon mouths, and streams lose water by seepage through their beds as they leave the mountains and traverse the fans and (or) coastal plain.

BASIN-RANGES

The Basin-Ranges geomorphic province in eastern California is characterized by roughly parallel fault-block ranges alternating with basins or troughs, the most notable of which are Death Valley and Owens Valley. One small part of the province (designated "A" on the index map on pl. 1) lies to the northeast of the Modoc Plateau; a second small part (B) lies to the southeast of the Modoc Plateau; the largest part of the province (C) lies to the east of the Sierra Nevada. The Basin-Ranges province is further characterized by topographically closed drainage that terminates in playas and lakes, such as Goose and Honey Lakes in the north, and Mono, Owens, and Searles Lakes in the south.

Altitudes on the basin floors in the two northern parts of the province range from 4,000 to 5,000 feet. Altitudes of several mountain peaks in the north, however, exceed 8,000 feet and reach a maximum of 9,883 feet at Eagle Peak. The southern part of the province, which lies to the east of the Sierra Nevada, includes several extremely rugged linear ranges that attain altitudes of more than 10,000 feet. The highest peak is White Mountain Peak whose altitude is 14,242 feet. Altitudes on the southern basin floors range from 6,000 feet near Mono Lake to −282 feet (below mean sea level) in Death Valley.

The bedrock in the Basin-Ranges province consists primarily of granitic and volcanic rocks, similar to those found in the adjacent provinces. The valleys form ground-water basins filled with alluvial and lake deposits.

MOJAVE DESERT

The Mojave Desert geomorphic province lies south of the Sierra Nevada and Basin-Ranges geomorphic provinces; it is separated from them by the Garlock fault and its eastern extension. The Mojave Desert province is a broad interior region of isolated mountain ranges that are separated by expanses of desert plains. Except in the vicinity of the Colorado River, the drainage is topographically closed and terminates in playas. The bedrock is composed chiefly of granitic rocks of Mesozoic age, and the desert valleys form ground-water basins filled with alluvial deposits.

SALTON TROUGH

The Salton Trough geomorphic province in southeastern California is a low-lying desert basin much of which is below sea level —its lowest point is 274 feet below sea level. The Salton Trough is a depressed block of alluvium-covered sedimentary rock between active branches of the San Andreas fault. Its dominant feature is the Salton Sea, a saline lake whose surface area of about 350 square miles occupies the lowest part of the trough. The Salton Sea receives not only the runoff from the Transverse and Peninsular Ranges but also large quantities of irrigation drainage and waste water that was originally imported from the Colorado River.

RUNOFF CHARACTERISTICS

The runoff characteristics used in this report to describe the regimen of streams are briefly discussed below and are assigned numerical index values so that quantitative comparisons may be made. A 30-year base period, 1931–60, was used to compute mean annual basinwide precipitation, but no common period of years was used to compute mean annual runoff and the other index values. They were computed from whatever length of record was available prior to 1968, but most streams studied had records covering at least 30 years. The index values, therefore, are not precisely comparable for all streams; nevertheless, they are sufficiently accurate to identify the regimen of flow of each stream.

RUNOFF CLASSIFICATION BY PRECIPITATION ZONES

Precipitation is distinctly seasonal in the California region, and the bulk of it occurs in frontal storms during the months, November through March. Localized convectional storms occur in the summer, but they are of hydrologic significance only in the arid southeastern part of the region where runoff, aside from the flow of isolated springs, is ephemeral. Because the seasonal pattern of precipitation is common to virtually the entire region, it has little value as an index to the areal variation in streamflow regimen. Total mean annual precipitation, however, is a satisfactory climatologic index for that purpose.

Mean annual precipitation generally increases from south to north (increasing latitude) and from east to west (approach to Pacific Ocean). Also, mean annual precipitation usually increases with altitude, but at a given altitude, less precipitation usually occurs on leeward slopes of mountain barriers than on windward slopes (p. A4). Mean annual runoff, being related to mean annual precipitation, has the same general areal pattern as precipitation. For the purpose of this study, mean annual precipitation is used to identify four "climatic" zones—arid, semiarid, subhumid, and humid. (This nomenclature is used for convenience in referring to the various precipitation zones and is not intended as a substitute for the geographer's classical identification of climate, which involves both precipitation and potential evapotranspiration.) The precipitation zones are defined in table 1, and each is indicated by an individual shading pattern on plate 1.

TABLE 1.—*Runoff classification by precipitation zones*

Precipitation zone	Mean annual precipitation (inches)	Mean annual runoff (inches)	Duration of flow in an average year
Arid	Less than 10	Less than 0.5	A few days to a few weeks
Semiarid	10–20	0.3–5.0	A few days to 275 days
Subhumid	20–40	3–20	90–365 days
Humid	More than 40	More than 10	335–365 days

Table 1 also shows the mean annual runoff, in inches, to be expected from the various precipitation zones and the number of days in an average year when flow may be expected. These figures are, of necessity, gross generalizations, and there is overlap in the runoff quantities and durations for the various precipitation zones. In general, streamflow is ephemeral in the arid zone, intermittent in the semiarid and subhumid zones, and perennial in the humid zone.

The wide range in magnitude and duration of runoff associated with each precipitation zone reflects both the range of precipitation encompassed in each zone and the areal variation of such geologic factors as the infiltration and storage capacities of the rocks underlying a drainage basin. Furthermore, the annual runoff resulting from a given annual precipitation will vary areally because of differences in evapotranspiration loss associated with varying conditions of climate, soil, vegetal cover, and geologic structure. In arid regions the quantity and duration of runoff in any year is especially sensitive to the quantity and distribution of the sparse precipitation in that year. Streams that traverse two or more precipitation zones that are progressively drier in the downstream direction often have flow whose duration decreases in the downstream direction. Such streams may be perennial in their upper reaches, intermittent in their middle reaches, and ephemeral in their lower reaches.

Departures from even the broad generalizations in table 1 are common. For example, despite a semiarid classification, large areas in northeastern California that are underlain by highly permeable volcanic rocks have perennial runoff. Also, isolated springs, many with perennial flow of only slight variability, are found in arid areas as well as in the more humid ones. Some steam channels have alternating reaches of perennial and intermittent flow as a result of variation in the local geology. Unusual situations are always interesting to discuss, but, as stated in the introduction, the purpose of this study is to present a generalized picture of the runoff characteristics of California streams. Departures from the general situation will be discussed only when they are common to areas large enough to be delineated on plate 1.

RUNOFF CLASSIFICATION BY LATITUDE AND ALTITUDE

Basins that lie at high altitudes store an appreciable part of their precipitation in mountain snowpacks for later release during the spring and early summer as snowmelt runoff. Latitude is also a factor because winter temperatures are lower in the north than in the south; consequently, a snowpack will form at lower altitudes in the north than in the south. The accumulation of snow is generally at a maximum on about April 1 of each year, and snow surveys are made at that time for the purpose of forecasting the volume of runoff to be expected in the following months. From those surveys the average altitude of the snowline on April 1 was determined for various latitudes, and that information was used to derive criteria for estimating whether or not a basin will have a significantly large snowmelt component in its annual runoff. The definition of "a significantly large snowmelt component" is given in the next section under the heading "Runoff Classification by Seasonal Indexes." At this point we merely state that snowmelt runoff was found generally to be significant if 30 percent or more of a drainage basin lay above the approximate snowline of April 1.

It is realized that the percentage of area above the snowline is only one factor affecting the magnitude of the snowmelt-runoff component of total annual streamflow. The range and distribution of basin altitude above the snowline is also a factor. For example, if the part of the watershed above the snowline in one basin is a plateau that is only slightly higher than the snowline, its snow accumulation will be far less than that for a basin that rises to great heights above the snowline. However, a simple criterion for identifying snowmelt streams was sought, and the one stated above–30 percent of the area above the snowline–was considered to be satisfactory.

Table 2 shows the approximate altitude of the April 1 snowline

TABLE 2.—*Approximate altitude of snowline on April 1 by latitude zones*

Latitude zone	Altitude of snowline (feet)	Latitude zone	Altitude of snowline (feet)
South of 37°00′	6,000	38°30′ to 40°00′	5,000
37°00′ to 38°30′	5,500	North of 40°00′	4,500

NOTE.—Snowmelt is a significant factor in the runoff of a basin if 30 percent or more of the drainage area lies above the altitude of the snowline.

at various latitudes, and that information was used in delineating areas of significant snowmelt runoff on plate 1. High-altitude areas in the arid zone of southeastern California are not shown on plate 1 because they do not receive sufficient precipitation to maintain a snowpack of significant size throughout the winter.

RUNOFF CLASSIFICATION BY SEASONAL INDEXES

Because precipitation in the California Region is distinctly seasonal, the percentages of total annual runoff carried seasonally by a stream provide a measure of the relative importance of the two principal types of surface runoff—storm runoff and snowmelt runoff. The paragraphs that follow describe indexes to identify the two types.

Storm-runoff index

The bulk of the annual precipitation occurs during the months November through March, and in some years an appreciable amount of precipitation occurs in October. Low-altitude basins will store little or no snow during those months for subsequent runoff as snowmelt, and most of the runoff in those basins will occur as storm runoff in the fall and winter. The index of storm runoff adopted for this study, therefore, was the percentage of the total annual runoff that occurs during the 6-month period, October through March. Criteria associated with this index are given in table 3.

TABLE 3.—*Seasonal runoff indexes*

Type of runoff	Seasonal indexes		Remarks
	Months used	Critical value (in percent of total annual runoff)	
Storm	October–March	65	Storm runoff predominates if index exceeds 65 percent.
Snowmelt	April–July	30	Snowmelt runoff is of significant magnitude if index exceeds 30 percent.
Base flow	August and September	1.5 and 3.0	Base flow is well sustained if index exceeds 3.0 percent; fairly well sustained if index is between 1.5 and 3.0 percent; poorly sustained if index is less than 1.5 percent.

475-891 O - 72 - 3

It should be noted that a part of the streamflow during the October-March period, for all but ephemeral streams, includes base flow (outflow from ground-water reservoirs), but to determine the relative magnitude of the base-flow component for a group of streams would require detailed study of each annual discharge hydrograph for each stream. For the purpose of this report, a study so detailed would be unwarranted. The storm-runoff index of 65 percent (table 3) is of such magnitude that it would not be exceeded by a stream that did not have a significantly large volume of storm runoff.

Snowmelt-runoff index

Basins that have at least 30 percent of their area above the altitude of the April 1 snowline—in accordance with the criteria shown in table 2—will have an appreciable part of their annual runoff occur as snowmelt. Snowmelt has a characteristic diurnal fluctuation, and the presence of a fluctuation of that type in the stage or discharge hydrograph of a stream readily identifies the stream as being one that is fed by snowmelt. In all areas except those on the eastern flank of the high southern Sierra Nevada, the snowmelt season is April through June, but in those mountain areas the season continues through July or even later. For consistency in comparing streamflow regimens throughout the California region, the index of snowmelt runoff adopted for this study was the percentage of the total annual runoff that occurs during the relatively dry 4-month period, April through July. That period is referred to as being "relatively dry" because in April of many years rainfall is sufficiently intense to produce storm runoff. There can be no absolute cutoff date separating storm runoff from snowmelt runoff; but March 31 is a satisfactory date for use in this study because April snowmelt runoff is invariably a significant part of the total snowmelt runoff for the year, whereas April storm runoff is seldom large with respect to the total runoff experienced in the preceding 6 months. Criteria associated with the snowmelt-runoff index are given in table 3.

Base flow, as well as occasional storm runoff, contributes to the April-July runoff of high-altitude streams, but a detailed analysis of each annual streamflow hydrograph to determine the magnitude of those contributions is unwarranted for the purpose of this study. However, it should be mentioned that the critical snowmelt-runoff index of 30 percent can be exceeded by spring-fed streams that carry no snowmelt surface runoff, if throughout the year the streams carry only base flow whose discharge is exceptionally steady. However, not only are such streams relatively uncommon, but they are readily identifiable from the magnitude of their storm- and snowmelt-runoff indexes and from the percentage of their annual runoff that appears in the months of August and September. A discussion of summer base flow will follow, but first let us examine table 3 again. We see from the table that the sum of the storm-runoff and snowmelt-runoff indexes is 95 percent. That means that if the volume of the summer base flow is no more than 5 percent of the total annual flow, it is possible for a stream to have both significant storm runoff and snowmelt runoff. We will see later that such a situation exists in an area in the Coast Ranges and undoubtedly exists in ungaged mountain basins elsewhere where altitudes are such as to bring about the required proportions of storm and snowmelt runoff.

Base-flow index

During the months of August and September convective-storm runoff occurs in ephemeral streams in the arid southeastern part of California, and some snowmelt runoff occurs in some years in small streams high on the eastern flank of the southern Sierra Nevada. Elsewhere in the California region, however, virtually no surface runoff of significant proportion occurs, and streamflow consists almost entirely of base flow. Consequently, the index of base flow adopted for this study was the percentage of the total annual runoff that occurs during that 2-month summer period of generally fair weather. Table 3 presents criteria for classifying base flow with regard to its steadiness, or the degree to which it is sustained. A well-sustained base flow indicates that a significant part of the water supply—precipitation or snowmelt—infiltrates into subsurface storage for slow release into surface channels. A poorly sustained base flow is generally indicative of lesser infiltration in a basin where the soil and surficial rock have low permeability. In semiarid and arid environments, however, base flow will commonly be poorly sustained, even in basins of high permeability, because of deficiency in the supply of precipitation. The natural regulation of streamflow afforded by lakes in such geomorphic provinces as the Sierra Nevada and Modoc Plateau is also a factor in sustaining the late summer flow of some streams.

RUNOFF REGIMENS IN INDIVIDUAL GEOMORPHIC PROVINCES

The response of runoff to precipitation varies throughout the California Region, but four general types of response are easily recognizable. In low-altitude humid areas, such as in the Coast Ranges geomorphic province, the great bulk of the streamflow occurs as winter storm runoff. That regimen is illustrated in figure 1 in the graph showing the monthly distribution of runoff for the

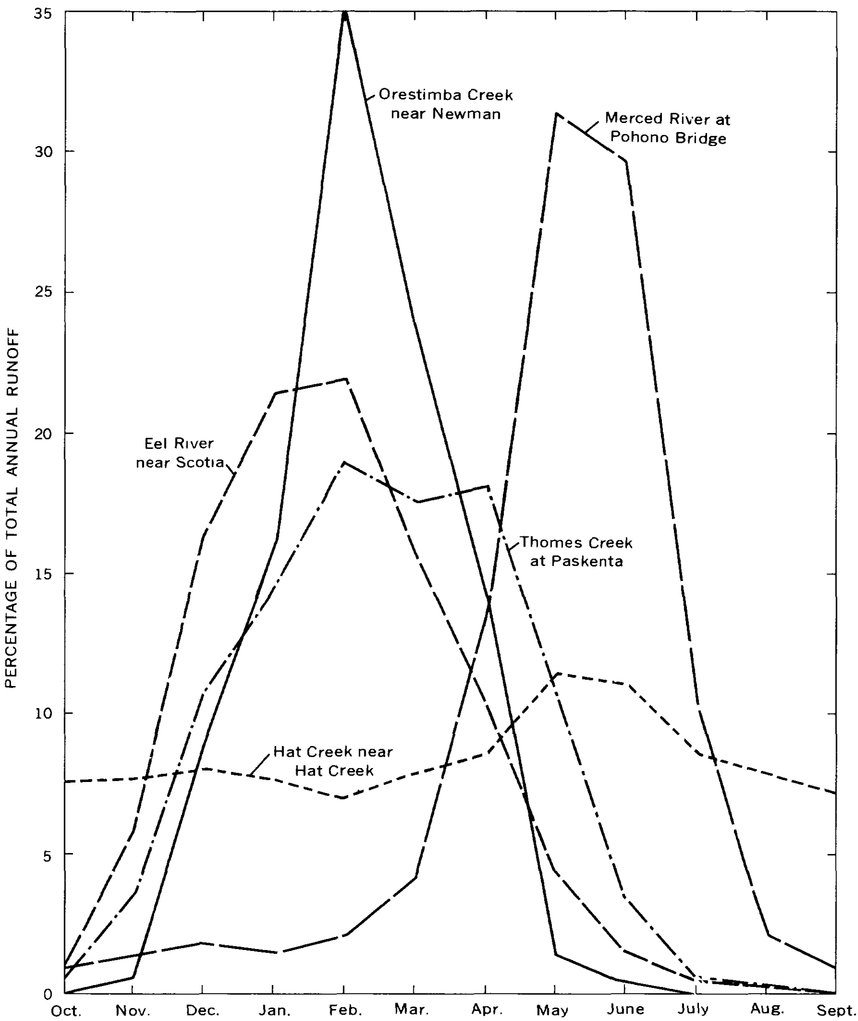


FIGURE 1.—Mean monthly distribution of runoff at selected gaging stations.

Eel River near Scotia (sta. 11–4770). The Eel River basin is underlain by rocks of low permeability, and base flow in the summer months is poorly sustained. In high-altitude humid areas, such as in the Sierra Nevada geomorphic province, the great bulk of the streamflow occurs as snowmelt runoff, as illustrated in figure 1 in the monthly distribution graph for the Merced River at Pohono Bridge, near Yosemite, Calif. (sta. 11–2665). The Merced River basin is underlain by more permeable rocks than the Eel River basin, and its summer flow is fairly well sustained. In areas underlain by highly permeable rocks, as in the Cascade Mountains and Modoc Plateau geomorphic provinces, effluent ground-water seepage often maintains the runoff at significantly high levels during the entire year. That regimen of runoff is illustrated in the graph for Hat Creek near Hat Creek (sta. 11–3555). It is seen in the graph for Hat Creek, a high-altitude stream, that a small increment of snowmelt runoff is superposed on the relatively steady flow; in low-altitude basins spring-fed streams may have a small increment of storm runoff superposed on their otherwise steady flow.

The fourth readily recognizable regimen of flow is that of streams draining arid or semiarid basins in south and central California. In arid basins runoff will be ephemeral and streams will generally be dry a few days after the end of a storm. In semiarid basins runoff will be intermittent, and streams may carry flow for a few weeks or a few months after the end of the rainy season. The monthly distribution graph in figure 1 for Orestimba Creek near Newman, Calif. (sta. 11–2745), is typical of that for an intermittent stream in the Coast Ranges geomorphic province.

Very commonly, the runoff regimen of a stream combines the attributes of one or more of the four distinctive regimens described above. A basin, for example, may cover a range of altitudes such that the volumes of snowmelt and storm runoff are both significantly large but neither clearly predominates. This fact is illustrated in the distribution graph in figure 1 for Thomes Creek at Paskenta, Calif. (sta. 11–3820), one of the few Coast Ranges streams of relatively high altitude. A stream that drains parts of more than one geomorphic province will have a runoff regimen that is a composite of those of the provinces it drains. An example of such a stream is the Shasta River in north-central California. From the east the Shasta River receives the steady runoff that is characteristic of the Cascade Ranges geomorphic province, and from the west it receives the snowmelt runoff that is characteristic of much of the Klamath Mountains geomorphic province. The lower reaches of the Sacramento River in the Central Valley carry runoff from seven geomorphic provinces.

In the light of those gross generalizations we will now examine the more specific runoff characteristics of streams in each of the geomorphic provinces of the California region. The shading patterns on plate 1 indicate the areal extent of the various climatic zones in each province. Table 4 lists the various indexes and other pertinent data for 34 streams that were selected to illustrate runoff characteristics. The last five columns of the table will be discussed under "Characteristics of Duration Curves of Daily Discharge."

A few of the items in table 4 require no detailed discussion under the individual geomorphic province subheadings that follow, but they can be treated collectively at this point. In accordance with the standards established in table 1 for a runoff classification by precipitation zone, all basinwide values of runoff in column 5 of table 4 and, except for a few perennial spring-fed streams in the semiarid zone, all values of duration of flow in column 6 of table 4, are consistent with the basinwide values of precipitation in column 4 of table 4. For example, if we examine the data for Arroyo Seco near Soledad on the first line of table 4, we see that the precipitation for that basin is 31 inches, which classifies the basin as subhumid according to table 1. Table 1 further indicates that mean annual runoff in the subhumid zone will usually be in the range of from 3 to 20 inches, and the duration of flow in an average year will usually be in the range of from 90 to 365 days. Table 4 shows the mean annual runoff for Arroyo Seco to be 9.0 inches, and the average duration of flow, 335 days.

In accordance with the standards established in tables 2 and 3, the volume of snowmelt runoff is significantly large when the snowmelt-runoff index is greater than 30 percent, and that occurs when the percentage of the drainage area above the snowline exceeds 30 percent. In other words, when the percentage of area shown in column 9 of table 4 exceeds 30 percent, the snowmelt index in column 11 of table 4 should exceed 30 percent; when the value in column 9 is less than 30 percent, the corresponding value in column 11 should be less than 30 percent. This criterion is met by all but one of the 34 stations listed in table 4. That station—

Middle Fork Eel River below Black Butte River, near Covelo—whose drainage basin lies in the Coast Ranges, will be discussed in the following section of this report. In that section, and in succeeding ones, we examine the seasonal runoff indexes in the individual geomorphic provinces, as summarized in table 4.

COAST RANGES

Plate 1 shows that the classification of mean annual precipitation in the Coast Ranges geomorphic province ranges from humid in the north to arid in the southeast. Annual precipitation increases with altitude, and at any given altitude it is greatest on the west-facing or windward slopes of mountains. Consequently, annual runoff generally decreases from north to south, and at any given latitude and altitude runoff is greater in streams draining to the west than in those draining to the east. Almost all streams in the humid north flow perennially, but in basins of lesser precipitation to the south, streamflow is often intermittent. In arid southeastern basins streamflow is ephemeral.

The seasonal runoff indexes of the six stations listed in table 4 are typical of those for the four principal environments in the province. The environments and their representative stations are as follows:

1. Humid low-altitude north:
   - 11–4560. Napa River near St. Helena, Calif.
   - 11–4770. Eel River at Scotia, Calif.
2. Humid high-altitude north (Yolla Bolly Mountains):
   - 11–3820. Thomes Creek at Paskenta, Calif.
   - 11–4730. Middle Fork Eel River below Black Butte River, near Covelo, Calif.
3. Subhumid south:
   - 11–1520. Arroyo Seco near Soledad, Calif.
4. Semiarid south:
   - 11–2745. Orestimba Creek near Newman, Calif.

The seasonal runoff indexes for the Coast Ranges in table 4 show that in all basins the volume of storm runoff is significantly large and base flow is poorly sustained. Only in the Yolla Bolly Mountains is snowmelt runoff an important component of the total annual runoff. However, because of the proximity of these mountains to the sea, air temperatures are more equable there than at areas of similar altitude and latitude farther inland. Con-

TABLE 4.—*Runoff characteristics*

Station No.	Stream-gaging station	Drainage area (square miles)	Mean annual basinwide values, in inches		Average number of days of flow per year
			Precip-itation	Runoff	
(1)	(2)	(3)	(4)	(5)	(6)
					Coast
11–1520	Arroyo Seco near Soledad, Calif	244	31	9.0	335
2745	Orestimba Creek near Newman, Calif	134	16	1.5	100
3820	Thomes Creek at Paskenta, Calif	194	46	19.0	350
4560	Napa River near St. Helena, Calif	81.4	43	15.0	360
4730	Middle Fork Eel River below Black Butte River, near Covelo, Calif	367	60	38.8	365
4770	Eel River at Scotia, Calif	3,113	59	31.0	365
					Klamath
11–3420	Sacramento River at Delta, Calif	425	61	36.9	365
5255	Trinity River at Lewiston, Calif	728	59	30.6	365
5290	South Fork Trinity River near Salyer, Calif	898	50	26.6	365
5325	Smith River near Crescent City, Calif	609	111	84.1	365
					Cascade Range
11–3555	Hat Creek near Hat Creek, Calif	162	51	11.1	365
3815	Mill Creek near Los Molinos, Calif	131	52	30.4	365
5010	Sprague River near Chiloquin, Oreg	1,580	22	4.8	365
5169	Little Shasta River near Montague, Calif	48.2	25	4.9	365
					Sierra
10–2657	Rock Creek at Little Round Valley, near Bishop, Calif	35.8	26	11.3	365
2818	Independence Creek below Pinyon Creek, near Independence, Calif	18.2	24	9.5	365
2960	West Walker River below Little Walker River, near Coleville, Calif	180	36	19.2	365
11–2105	Kaweah River near Three Rivers, Calif	519	37	14.5	365
2220	Kings River at Piedra, Calif	1,687	35	18.4	365
2590	Chowchilla River at Buchanan damsite, near Raymond, Calif	235	32	5.7	280
2665	Merced River at Pohono Bridge, near Yosemite, Calif	321	45	25.2	365
3350	Cosumnes River at Michigan Bar, Calif	536	41	12.1	360
4130	North Yuba River below Goodyears Bar, Calif	250	67	40.0	365
4465	American River at Fair Oaks, Calif	1,888	53	27.1	365
					Central
11–4245	Dry Creek near Wheatland, Calif	99.9	30	7.5	[1]240
					Transverse
10–2560	Whitewater River at White Water, Calif	57.4	25	5.0	365
2635	Big Rock Creek near Valyermo, Calif	22.9	29	9.1	365
11–0805	East Fork San Gabriel River near Camp Bonita, Calif	84.6	31	10.9	365
1040	Topanga Creek near Topanga Beach, Calif	18.0	21	3.8	290
					Peninsular
10–2558	Coyote Creek near Borrego Springs, Calif	144	10	0.21	365
2585	Palm Canyon Creek near Palm Springs, Calif	93.3	13	.54	130
2590	Andreas Creek near Palm Springs, Calif	8.61	20	3.1	365
11–0125	Campo Creek near Compo, Calif	85.0	16	.32	175
					Basin—
10–2687	Silver Canyon Creek near Laws, Calif	22.4	12	0.93	365

[1] Includes days when entire flow consisted of irrigation waste water.
[2] Daily figures of diversion not available.
[3] Data for 1941 omitted because inclusion of the unseasonally high flows during period April-September 1941, would bias the seasonal runoff indexes.

at selected stream-gaging stations

Snowpack parameters			Seasonal runoff indexes			Characteristics of the duration curve of daily discharge				
			(Percentage of total annual runoff)			(Percentage of mean discharge)				
Latitude of centroid of basin	Altitude of snowline, from table 2 (feet)	Percentage of basin area above snowline	Storm runoff season	Snowmelt season	Base flow season	Q_{10}	Q_{50}	Q_{90}	(Percentage of time) P_{mean}	Index of variability (Q_{10}/Q_{90})
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Ranges										
36°15′	6,000	0	79.6	20.0	0.4	214	17.1	0.08	19	>500
37°15′	5,500	0	83.3	16.7	0	111	0	0	11	>500
39°55′	5,000	50	67.6	32.1	.3	265	27.9	.72	28	368
38°30′	5,000	0	86.8	13.0	.2	191	8.9	.44	16	434
39°50′	5,000	54	72.7	27.0	.3	227	24.4	1.34	28	169
40°00′	4,500	14	82.1	17.6	.3	237	19.7	1.44	23	165
Mountains										
41°10′	4,500	44	60.0	36.8	3.2	223	51.0	17.0	32	13
41°00′	4,500	59	45.9	52.3	1.8	262	44.5	8.1	33	32
40°30′	4,500	28	79.5	19.6	.9	245	33.6	3.6	26	68
41°50′	4,500	9	77.8	20.8	1.4	233	43.8	7.2	29	32
and Modoc Plateau										
40°40′	4,500	98	46.4	38.9	14.7	135	97.0	64.9	43	2.1
40°15′	4,500	48	53.7	40.2	6.1	193	59.7	31.1	31	6.2
42°30′	4,500	98	43.6	49.5	6.9	211	60.3	36.1	26	5.8
41°45′	4,500	92	45.9	50.1	4.0	240	44.5	16.5	30	14.5
Nevada										
37°25′	5,500	100	24.2	61.0	14.8	237	60.9	35.4	28	6.7
36°45′	6,000	95	17.0	69.6	13.4	276	44.5	21.9	27	13
38°15′	5,500	100	14.2	79.2	6.6	304	32.7	13.3	28	23
36°30′	6,000	50	29.4	68.0	2.6	289	37.9	7.5	30	39
36°55′	6,000	74	20.9	74.9	4.2	298	37.2	8.7	29	34
37°25′	5,500	0	74.9	25.0	.1	221	11.2	0	19	>500
37°45′	5,500	96	15.3	82.1	2.6	318	27.8	4.2	27	76
38°40′	5,000	30	62.4	37.2	.4	263	21.5	1.3	27	202
39°35′	5,000	70	41.8	54.4	3.8	247	44.5	17.5	31	14
39°00′	5,000	45	46.9	51.7	1.4	265	37.1	5.9	32	45
Valley										
39°05′	5,000	0	88.9	11.0	0.1	178	6.2	0	15	>500
Ranges										
34°00′	6,000	42	46.1	38.1	15.8	(2)	(2)	(2)	(2)	(2)
34°25′	6,000	60	48.6	44.3	7.1	231	46.4	16.9	25	14
34°15′	6,000	44	57.3	37.9	4.8	232	40.6	14.0	22	17
34°05′	6,000	0	90.4	9.4	.2	62	3.6	0	7	>500
Ranges										
33°30′	6,000	0	54.1	28.0	17.9	127	87.2	55.0	33	2.3
33°40′	6,000	5	76.3	22.4	1.3	118	0	0	11	>500
33°45′	6,000	30	63.1	30.0	6.9	177	69.2	24.2	29	7.3
32°40′	6,000	0	[3]76.2	[3]23.1	[3].7	300	0	0	17	>500
Ranges										
37°25′	5,500	90	49.5	33.4	17.1	152	81.0	34.0	37	4.5

sequently, a smaller percentage of the winter precipitation is stored as snow; therefore, the volume of snowmelt runoff is correspondingly less, and its duration correspondingly shorter than that for comparable areas farther inland. This is illustrated by the two Yolla Bolly Mountain streams, Thomes Creek and Middle Fork Eel River, both of which carry snowmelt runoff in early spring. Despite the fact that these streams have from 50–54 percent of their drainage basins above the April regional snowline, the snowmelt-runoff index for Thomes Creek is only slightly larger than the criterion value of 30 percent, and that for Middle Fork Eel River is slightly less than the criterion value. The values of the storm-runoff index for both streams are significantly large. In short, the Yolla Bolly Mountain streams carry significantly large quantities of both storm runoff and snowmelt runoff, and neither type of runoff clearly predominates.

A notable difference between the runoff regimens of northern and southern streams in the Coast Ranges results from the fact that runoff-producing rains in the south generally occur later in the winter than they do in the north. Although storm-runoff indexes are similar in the north and south, the southern streams have a larger percentage of their total runoff in the months of February and March than do the northern streams.

KLAMATH MOUNTAINS

Plate 1 shows that the classification of mean annual precipitation in the Klamath Mountains geomorphic province ranges from humid in the west to semiarid in the east. The combined effects of a rapid decrease in precipitation with distance from the ocean and a pronounced orographic influence on the precipitation results in an exceptionally wide variation in mean annual precipitation in the province. At the higher altitudes in the Smith River basin, which is near the coast, mean annual precipitation is 120 inches; in the Shasta River valley in the east, it is 10 inches. Mean annual runoff follows the same areal pattern as the precipitation and therefore decreases from west to east and increases with altitude. The Smith River basin, with an average annual runoff of 84.1 inches, has the largest volume of runoff per square mile of any major basin in the California Region. Runoff is perennial, except in some very small low-altitude watersheds.

The seasonal runoff indexes of the four stations included in table 4 are typical of those for the three principal environments in the province. The environments and their representative stations are as follows:

1. Humid and subhumid high-altitude northeast:
   11–5255. Trinity River at Lewiston, Calif.
2. Humid low-altitude southwest and west:
   11–5290. South Fork Trinity River near Salyer, Calif.
   11–5325. Smith River near Crescent City, Calif.
3. Humid high-altitude southeast (headwater area of the Sacramento River):
   11–3420. Sacramento River at Delta, Calif.

The seasonal runoff indexes in table 4 show that the volume of snowmelt runoff is significantly large in the high-altitude basins, whereas the volume of storm runoff is significantly large in the low-altitude basins. The runoff characteristics of the headwater area of the Sacramento River differ from those of other high-altitude areas only in that base flow is well sustained in the upper Sacramento River watershed. Elsewhere in the Klamath Mountains province, base flow is fairly well sustained, except in a few very small low-altitude watersheds where streams are dry for short periods in the summer or early fall.

CASCADE RANGE AND MODOC PLATEAU

Because the rock types of the Cascade Range and Modoc Plateau geomorphic provinces are similar, the runoff characteristics of the streams draining the two provinces are similar. The two provinces are therefore treated as a single entity in this discussion of streamflow regimen.

Plate 1 shows that the classification of mean annual precipitation in the two provinces ranges from humid to semiarid, and the general tendency is for precipitation to decrease with distance from the ocean and to increase with altitude. Mean annual runoff follows a similar pattern. Because of the high permeability of the surficial rock, base flow is very well sustained and streamflow is perennial. Table 4 shows base-flow indexes ranging from 4 to 15 percent for the four representative stations in the two provinces. Because of the high altitude, snowmelt runoff is significant in volume throughout the provinces. In exceptionally steady-flowing streams, such as Hat Creek, most of the runoff during the snowmelt months of April through July is contributed by base flow, but nevertheless, the only significant increase in discharge during the year generally occurs during those four months when a small increment of snowmelt runoff is superposed on the steady base flow. Snowmelt runoff is therefore a noteworthy element in the runoff regimen of streams similar to Hat Creek. At no gaging station in the two provinces does the index of winter storm runoff reach the criterion value of 65 percent.

It is often difficult to determine the exact relation between mean annual precipitation and mean annual runoff in individual basins because the phreatic or ground-water basin divides do not always coincide with topographic watershed divides. As for the magnitude of the base-flow index of a stream, it depends primarily on the permeability of the rocks underlying the watershed; but where marsh areas or lake areas are extensive, water losses due to evapotranspiration or evaporation may reduce base flow significantly. Such losses, for example, occur in the extensive marsh areas of the Sycan River basin which is tributary to the Sprague River in Oregon.

SIERRA NEVADA

Plate 1 shows that the classification of mean annual precipitation in the Sierra Nevada geomorphic province ranges from humid at the higher altitudes to semiarid at the lower altitudes in the south and east. Precipitation increases with altitude and latitude, but for a given altitude and latitude, precipitation is greater on windward or west-facing slopes than on leeward or east-facing slopes. The wide range in mean annual precipitation—from 10 inches in areas in the semiarid zone to 90 inches in areas in the humid Feather River basin—causes a wide range in mean annual runoff.

The seasonal-runoff indexes of the 10 stations listed in table 4 illustrate the runoff regimens found in the province. The stations are grouped below under the commonly used designations for geographic subdivision of the Sierra Nevada. The northern Sierra Nevada is drained by the Feather River and its tributaries; the central Sierra Nevada is that part of the province between, and including, the American River basin in the north and the Merced River basin in the south; the southern or high Sierra Nevada includes all drainage south of the Merced River basin. The station numbers listed below that are prefixed by "10" designate streams draining to the east; those prefixed by "11," designate streams draining to the west.

1. Northern Sierra Nevada (crest altitudes between 7,000 and 8,000 ft):
   - 11–4130. North Yuba River below Goodyears Bar, Calif.
2. Central Sierra Nevada (crest altitudes between 9,000 and 11,000 ft):
   - 10–2960. West Walker River below Little Walker River, near Coleville, Calif.
   - 11–2665. Merced River at Pohono Bridge, near Yosemite, Calif.
   - 11–3350. Cosumnes River at Michigan Bar, Calif.
   - 11–4465. American River at Fair Oaks, Calif.
3. Southern Sierra Nevada (crest altitudes about 13,000 ft):
   - 10–2657. Rock Creek at Little Round Valley, near Bishop, Calif.
   - 10–2818. Independence Creek below Pinyon Creek, near Independence, Calif.
   - 11–2105. Kaweah River near Three Rivers, Calif.
   - 11–2220. Kings River at Piedra, Calif.
   - 11–2590. Chowchilla River at Buchanan damsite, near Raymond, Calif.

The seasonal-runoff indexes in table 4 show that the volume of snowmelt runoff is significantly large in all basins, except that of the Chowchilla River. The Chowchilla River, however, is the only stream listed that does not drain a high-altitude basin. The only other major low-altitude streams in the province are the westward-flowing Fresno, Calaveras, and Bear Rivers. In those four major streams and in the minor foothill streams draining to the west, storm runoff predominates.

The base flow of east-side streams is well sustained, particularly those that drain the high southern Sierra and are tributary to Mono Lake and the Owens River. Two such streams, each with a base-flow index of about 14 percent, are included in table 4—Rock Creek at Little Round Valley (sta. 10–2657) and Independence Creek below Pinyon Creek (sta. 10–2818). In the basins of those streams the rock is extensively fissured, and springs are numerous. Another factor contributing to high runoff in those streams in the late summer and early fall is the snowmelt that not only lasts throughout July in most years, but also continues through August in years of heavy precipitation. The combination of high altitude and steep east-facing slopes is not conducive to rapid snowmelt.

Because of the late snowmelt, the base-flow index of the high-altitude east-side streams is not strictly comparable with that for the west-side streams. Significant snowmelt runoff for the west-side streams generally ceases before the end of June, and by August and September, base flow has receded to its lower values. The east-side streams, on the other hand, may be carrying snowmelt throughout August, and base flow does not recede to its lower values until late fall or winter. However, even in the two consecutive months of lowest flow, whenever they occur, the percentage of the total annual runoff carried generally exceeds 5 percent, and base flow is therefore classed as "well sustained" on the east slopes of the Sierra Nevada.

The base flow of streams draining west-side basins is highly variable, ranging from poorly sustained to well sustained, because the permeability of the rocks underlying the basins is highly variable. The pattern of variability appears to be random on the basis of the following tabulation, which lists the base-flow index for west-side streams, in order, from north to south. Two streams not given in table 4—Fresno River and Kern River—are included in the tabulation.

	Station	*Base-flow index*
11–4130.	North Yuba River below Goodyears Bar	3.8
4465.	American River at Fair Oaks	1.4
3350.	Cosumnes River at Michigan Bar	.4
2665.	Merced River at Pohono Bridge, near Yosemite	2.6
2590.	Chowchilla River at Buchanan damsite	.1
2575.	Fresno River near Knowles	1.0
2220.	Kings River at Piedra	4.2
2105.	Kaweah River near Three Rivers	2.6
1860.	Kern River near Kernville	7.1

CENTRAL VALLEY

Plate 1 shows that the classification of mean annual precipitation in the Central Valley geomorphic province ranges from humid in the north to arid in the south. Altitudes in the province do not exceed 500 feet and therefore the orographic influence on precipitation, although noticeable, is not great. Snow is not a factor in the hydrology of the province. Latitude is the principal factor affecting mean annual precipitation which ranges from a high of 50 inches just north of Redding to a low of 5 inches just west of Bakersfield. Mean annual runoff follows the same areal pattern as the precipitation, for it is greatest in the north and least in the south.

The flow of a stream that has the major part of its watershed in the Central Valley is either intermittent or ephemeral, depending on the amount of precipitation it receives. This is due to the combination of high permeability of the valley alluvium and a long dry season each year. The larger tributary streams of the Sacramento and San Joaquin Rivers originate in the humid mountains surrounding the Central Valley, and most of them flow perennially for their entire length; but even they lose water by seepage through their beds as they traverse the alluvial valley floor. Most of the small Coast Ranges streams that are tributary to the San Joaquin River lose even their storm runoff through their alluvial beds in the valley, and their surface flow never reaches the main stream.

No long-term records are available for streams that have most of their drainage area in the Central Valley and whose flow is unaffected by man's activities. The streamflow record that comes closest to meeting those criteria is that for Dry Creek near Wheatland, Calif. (sta. 11–4245). Half the watershed of Dry Creek lies outside the Central Valley, in the foothills of the Sierra Nevada, and the stream receives irrigation waste water during the dry season. Nevertheless, the record for Dry Creek is useful for roughly illustrating the regimen of a Central Valley stream. Table 4 shows that the stream is dry for a third of the year and that about nine-tenths of its runoff occurs during the storm-runoff period, October through March.

TRANSVERSE RANGES

Plate 1 shows that the classification of mean annual precipitation in the Transverse Ranges geomorphic province ranges from subhumid to semiarid. In general, mean annual precipitation varies with altitude and reaches a maximum value of 40 inches in some areas. At any given altitude, precipitation is generally greater on south-facing slopes than on north-facing slopes. Mean annual runoff follows the same areal pattern as mean annual precipitation. The volume of snowmelt runoff is significantly large at the higher altitudes, particularly during years of heavy precipitation.

On the alluvial valley floors only the more intense storms cause runoff, and in an average year most of the runoff in small streams traversing the valleys may occur in a few days. In the mountainous areas the permeability of the surficial rock has wide areal variability. In many mountain basins where the underlying rock is relatively impermeable, little lag occurs between precipitation and runoff; 50 percent of the annual runoff may occur in less than 60 days, and streams will be dry in the summer. In other basins, the underlying rock may be more permeable, the time required for 50 percent of the annual runoff to occur may be in excess of 120 days, and base flow may be sustained throughout the summer. The duration of streamflow in a given year is dependent not only on the hydrogeologic characteristics of individual basins, but also on the total volume and time distribution of the precipitation. Some streams are spring fed, and their flow varies little during the year.

The seasonal-runoff indexes of the stations listed in table 4 are typical of the three principal runoff regimens in the province. Those regimens and their representative stations are as follows:

1. Predominant storm runoff:
   11–1040. Topanga Creek near Topanga Beach, Calif.
2. Significant snowmelt runoff:
   10–2635. Big Rock Creek near Valyermo, Calif.
   11–0805. East Fork San Gabriel River near Camp Bonita, Calif.
3. Spring-fed runoff:
   10–2560. Whitewater River at White Water, Calif.

Topanga Creek drains a low-altitude basin—its maximum altitude is about 2,500 feet—and almost 90 percent of its annual runoff occurs during the storm-runoff season. Base flow is poorly sustained. Big Rock Creek and East Fork San Gabriel River drain high-altitude basins; the volume of snowmelt runoff is significantly high, and base flow is well sustained in both streams.

The Whitewater River, draining the eastern end of the province, is spring fed, and flow is very well sustained throughout the year—in no month does the average percentage of the total annual flow fall below 7.2. Whitewater River is a high-altitude stream, but because of the permeability of the surficial rock in the basin, only a minor rise in streamflow occurs during the snowmelt months. However, because this minor rise generally represents the only prolonged period of greater-than-average flow that occurs during the year, and because the snowmelt-runoff index exceeds 30 percent, the Whitewater River is classed as a stream with significant snowmelt runoff.

The base flow indexes of the four streams, listed in table 4, illustrate the general tendency of the indexes to be higher in the eastern part of the province.

PENINSULAR RANGES

Plate 1 shows that the classification of mean annual precipitation in the Peninsular Ranges geomorphic province ranges from subhumid to arid. In general, mean annual precipitation varies with altitude and reaches a maximum value of 40 inches. However, precipitation is heavier on the western side of mountain crests than on the eastern side, and some areas in the eastern part of the province have a mean annual precipitation of only 3 inches. Mean annual runoff follows the same areal pattern as mean annual precipitation. The volume of snowmelt runoff is significantly large at the higher altitudes in the northeast in the vicinity of Mount San Jacinto, particularly during the years of above-normal precipitation.

The time and areal distribution of streamflow and its average duration are dependent on the hydrogeologic characteristics of individual basins and on the total volume and time distribution of precipitation. These streamflow characteristics can be described in precisely the words used on page A28 to describe streamflow characteristics in the Transverse Ranges geomorphic province.

The seasonal-runoff indexes of the stations listed in table 4 are typical of the three principal runoff regimens in the province. Those regimens and their representative stations are as follows:

1. Predominant storm runoff:
   11–0125. Campo Creek near Campo, Calif.
2. Significant snowmelt runoff:
   10–2590. Andreas Creek near Palm Springs, Calif.
3. Spring-fed runoff:
   10–2558. Coyote Creek near Borrego Springs, Calif.

Campo Creek drains a low-altitude basin—its maximum altitude is about 3,500 feet—and three-fourths of its annual runoff occurs during the storm-runoff season. Base flow is poorly sustained. Andreas Creek drains a high-altitude basin; its volume of snowmelt runoff is significantly high, and base flow is well sustained. Coyote Creek is spring fed, and flow is very well sustained throughout the year—in no month does the average percentage of the total annual flow fall below 6.0. Coyote Creek is a low-altitude stream, and the only significant variation in the steady runoff occurs in response to intense rainstorms, many of which occur in the summer. At those times ephemeral surface runoff is superposed on the relatively constant ground-water outflow. Neither the storm-runoff index nor the snowmelt-runoff index is significantly large for Coyote Creek.

The remaining stream included in table 4—Palm Canyon Creek near Palm Springs, Calif. (sta. 10–2585)—is in close proximity to Andreas Creek, and is included in the discussion to illustrate the difference in basin permeability that may exist in nearby watersheds. Palm Canyon Creek is an intermittent stream, whereas base flow is well sustained in the perennially flowing Andreas Creek. A part of the difference in base-flow characteristics of the two streams is undoubtedly related to deficiency in the supply of precipitation received by the Palm Canyon Creek watershed.

BASIN-RANGES

Plate 1 shows that the classification of mean annual precipitation in the Basin-Ranges geomorphic province generally ranges from arid to semiarid, but a small area in the extreme north lies in a subhumid environment. In general, mean annual precipitation, and therefore mean annual runoff, increase with altitude and increase from south to north.

One can only make gross generalizations concerning runoff characteristics because of the lack of streamflow records. Only one long-term gaging station in the province monitors unregulated flow. That station, Silver Canyon Creek near Laws, Calif. (sta. 10–2687), gages a spring-fed stream whose flow is remarkably steady. The rock underlying the basin is so permeable that no significantly large peak discharges from either storm or snowmelt runoff have been recorded in the 36 years that the station has operated. The mean discharge for that period is 1.54 cfs, and the maximum momentary discharge of record is 8.4 cfs. The streamflow record for Silver Canyon Creek, although fairly representative of that for spring-fed streams, is therefore of no help in deducing the general hydrologic characteristics to be described. In the discussion that follows, the northernmost of the three parts of the Basin-Ranges province will be designated "area A," the small central part will be designated "area B," and the large southern part will be designated "area C." These designations are shown on the index map on plate 1.

In areas A and B precipitation occurs during both winter frontal storms and summer convective storms. In the arid zone of the two areas the bulk of the runoff probably occurs as short-duration summer-storm runoff. In the semiarid and subhumid zones of areas A and B, snowmelt runoff is probably significant. Base flow will be well sustained in streams originating in those two precipitation zones in area A because of the permeability of the underlying volcanic rocks. Streams originating in area B, however, will probably have poorly sustained base flow because the surficial rocks in area B are primarily sedimentary rock of low permeability in the uplands and alluvial deposits in the valleys. Streams that enter area B from outside the province will probably have well-sustained base flow because the surrounding watersheds are underlain by permeable volcanic rock.

In the semiarid zone in area C, the large southern part of the Basin-Range province, most of the precipitation occurs during winter frontal storms; in general, snowmelt runoff is of significant magnitude and base flow is fairly well sustained. In the arid zone in area C, most of the precipitation occurs during summer convective storms, and the bulk of the runoff occurs as short-duration summer-storm runoff.

MOJAVE DESERT AND SALTON TROUGH

Because of the similarity in runoff characteristics of streams originating in the Mojave Desert and Salton Trough geomorphic provinces, the two provinces are treated as a single entity in the discussion that follows. Although no long-term records of streamflow are available, the regimen of flow is well known. Both provinces are entirely in the arid zone, and, although most of the annual precipitation occurs during general winter storms, a large part occurs during summer convective storms. The more intense storms—generally in the summer—produce runoff whose duration is rarely more than a few days, and sometimes many years elapse between runoff events in a particular basin. Perennially flowing springs are found, but, in general, their discharge does not travel far as surface flow before seeping into the ground.

CHARACTERISTICS OF DURATION CURVES OF DAILY DISCHARGE

The duration curve of daily discharge is perhaps the simplest means of expressing the time distribution of flow in a stream, showing as it does, the percent of time that a specified daily discharge is equaled or exceeded. The flow-duration curve does have one weakness in that it tells nothing of the chronology of flow, such as was discussed in preceding sections of this report. Nevertheless, the characteristics of the flow-duration curve are useful for analyzing and comparing the availability and variability of streamflow. If before comparing the curves for several streams, the daily discharges of each are expressed as percentages of the mean discharge, the effect of differences in the magnitude of mean annual runoff is eliminated and all streams are placed on a common basis for comparison.

Figure 2 shows duration curves of daily discharge, expressed as a percentage of mean discharge, for four streams that typify the four basic regimens of runoff in the California region. The Eel River is a perennial stream, the bulk of whose flow is storm runoff; the Merced River is a perennial stream, the bulk of whose flow is snowmelt runoff; Hat Creek is a steady-flowing spring-fed stream; Orestimba Creek is an intermittent stream draining a semiarid basin. The position of the lower, or right-hand, section of the curves in figure 2 provides a comparison of how well base flow is sustained in the streams. The base flow of Hat Creek is very well sustained; that of Orestimba Creek is very poorly sustained. (See p. A16–A17.)

Curves similar to those in figure 2 were plotted for each of the stations included in table 4 that had a record of daily discharge unaffected by storage or regulation. From those curves, characteristic discharges were selected for use in comparing the variability of flow in the basins studied. The characteristic discharges and the time percentile of mean discharge for each station are listed in the last five columns of table 4, and their significance is discussed in the paragraphs that follow.

Q_{10}

Q_{10} is the discharge, expressed as a percentage of the mean, that is equaled or exceeded 10 percent of the time. It is an index of high-water discharge, although not a particularly sensitive one. Perennial streams that have a significantly large volume of storm

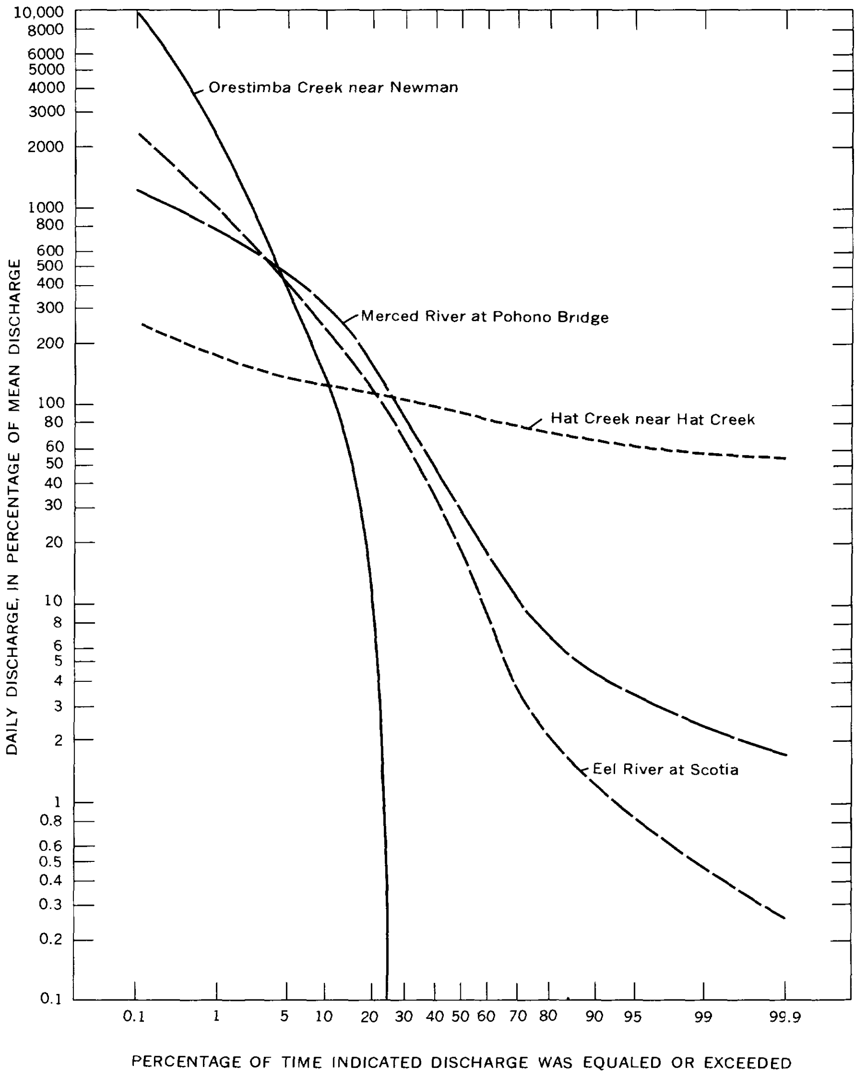


FIGURE 2.—Flow-duration curves for selected gaging stations.

and (or) snowmelt runoff generally have Q_{10} values between 200 and 300. Spring-fed streams, such as Hat Creek (sta. 11–3555), Coyote Creek (sta. 10–2558), and Silver Canyon Creek (sta. 10–2687), that have very steady flow, generally have Q_{10} values between 100 and 150. Intermittent streams have a wide range of Q_{10} values, in which individual values tend to vary directly with the average number of days a year that a stream carries flow.

Streams that flow less than 10 percent of the time will have Q_{10} values of zero.

The Q_{10} value by itself is not an important index; it is more useful when used in combination with Q_{90} to provide an index of stream variability. That use of Q_{10} will be discussed later in this section of the report.

Q_{50}

Q_{50} is the median discharge, meaning the discharge equaled or exceeded 50 percent of the time, expressed as a percentage of the mean. For streams with highly variable flow and little storage capability, the median discharge may be a more meaningful measure of water availability than the mean discharge. In this study, Q_{50} is of particular interest as a measure of the skewness of the distribution of daily discharges. Skewness reflects the fact that daily values of discharge are not symmetrical about the mean discharge; there are more days with discharge less than the mean than there are days with discharge greater than the mean. Skew will be great—which means Q_{50} will have a low value—for those streams where storm runoff predominates because much of the runoff occurs during relatively short periods of high flow. In intermittent or ephemeral streams, most of the runoff occurs in a shorter time than in perennial streams; hence, the distributions of daily discharges for nonperennial streams are more skewed than those for perennial streams. Values of Q_{50} for intermittent or ephemeral streams will therefore be extremely low, and will be zero for streams, such as Orestimba Creek (sta. 11–2745) and Palm Canyon Creek (sta. 10–2585), that have flow less than half the time. Inspection of table 4 shows that for those streams whose discharge is predominantly storm runoff, Q_{50} values are generally less than 27, and they decrease with decreasing values of the base-flow index.

Streams that carry large volumes of snowmelt runoff will have their flow distribution less skewed than those whose runoff is predominantly storm runoff, because the snowmelt streams will have more days of high, or above-average flow. Table 4 shows that for streams whose snowmelt index exceeds 30 percent, Q_{50} values will, in general, be greater than 27, and they tend to increase with increasing values of the base-flow index.

The distribution of daily discharges will be least skewed for steady-flowing spring-fed streams, and such streams will have the highest values of Q_{50}. That is demonstrated by the high Q_{50} values of about 90 for spring-fed Hat, Coyote, and Silver Canyon Creeks.

P_{mean}

P_{mean} is the percentage of time that the mean discharge is equaled or exceeded, and it, too, is an index of skewness of the distribution of daily discharges. The preceding general remarks about the skewness of the various distinct runoff regimens also apply to a discussion of P_{mean}, and figure 3 shows a general relation between the values of P_{mean} and Q_{50} listed in table 4. Streams whose predominant flow is storm runoff generally have values of P_{mean} that are less than 27; streams that carry large volumes of snowmelt runoff generally have values of P_{mean} that are greater than 27. The lowest values of P_{mean} are associated with ephemeral

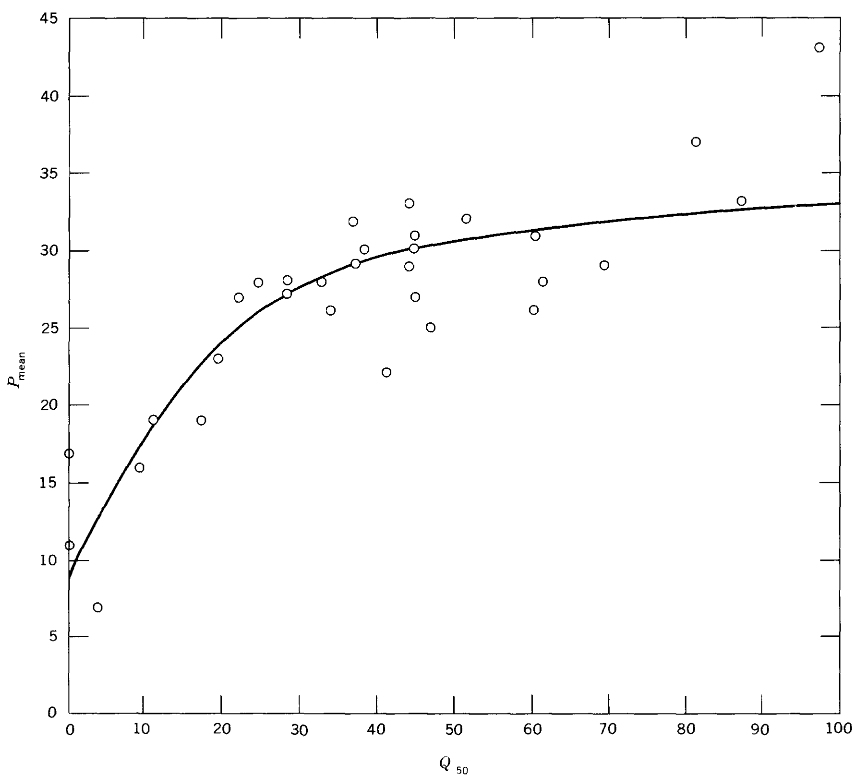


FIGURE 3.—Relation of P_{mean} to Q_{50}.

or intermittent streams; the highest values of P_{mean} are associated with steady-flowing spring-fed streams.

Q_{90}

Q_{90} is the discharge, expressed as a percentage of the mean, that is equaled or exceeded 90 percent of the time. Where streamflow is perennial, the 90-percentile discharge is often considered an appropriate measure of the quantity of water available for continous use, without resorting to surface storage and without permanently depleting water in underground storage. Because Q_{90} and the base-flow index are both related to geologic characteristics, we expect Q_{90} to be related to the base-flow index. That relation is shown in figure 4, where data from table 4 are plotted.

Another set of criteria for describing how well base flow is sustained could be derived from values of Q_{90}. The scatter of plotted points in figure 4 shows, however, that the new set of criteria would not be entirely consistent with the set already derived from the seasonal index. Because a base-flow index that directly in-

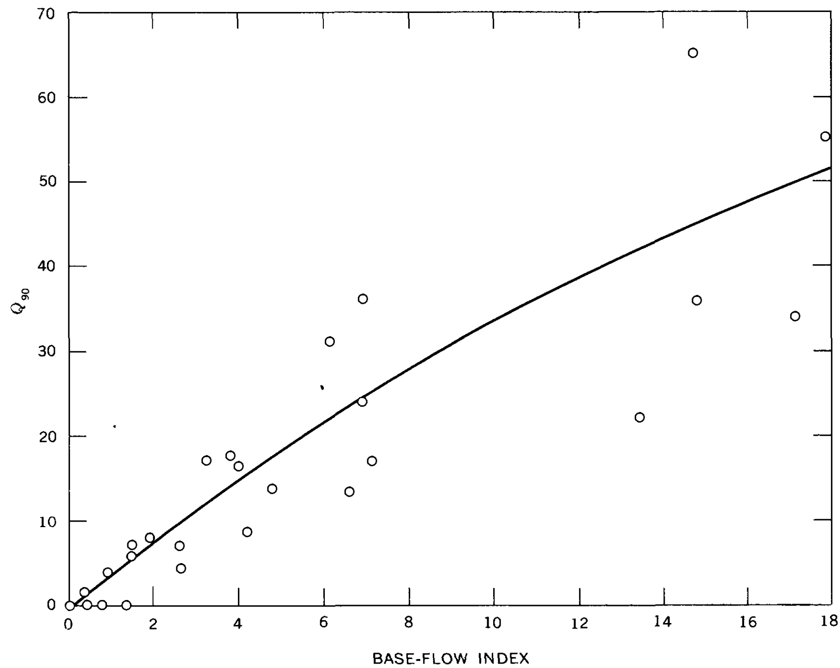


FIGURE 4.—Relation of Q_{90} to base-flow index.

volves the sequence or chronology of flow is considered more desirable for the purpose of this report, Q_{90} was not used to derive additional low-flow indexes. Q_{90} was used, however, along with Q_{50}, to compute an index of variability that will be discussed next.

INDEX OF VARIABILITY

For an index of variability, the ratio of Q_{10} to Q_{90} was used (Rantz, 1964, p. 41), because the flow-duration curves tend to be linear between durations of 10 and 90 percent when plotted on logarithmic normal probability paper. The index of variability provides a measure of the range between high and low flows. The index, however, loses significance when computed for streams that go dry or for streams of highly variable discharge whose low flows are minute. For such streams the index value is extremely high and reaches infinity for streams that are dry at least 10 percent of the time. In this report where the computed index exceeds 500, it is recorded as ">500" in table 4. Because Q_{90} varies much more widely than does Q_{10}, the index of variability is more closely related to Q_{90} than to Q_{10}.

Table 4 shows the great range in magnitude of the index of variability in the California region. In the Cascade Range and Modoc Plateau geomorphic provinces, where most streams are spring fed, the index ranges from 2 to 15. In the Coast Ranges province where base flow is poorly sustained, the index is seldom less than 150 and is often greater than 500. In the Sierra Nevada province, the highly permeable basins on the east side show a range in the index of from 6 to 23, whereas the range for the generally more impermeable basins on the west side is 14 to more than 500. The widest range in the index of variability within individual geomorphic provinces occurs in the Peninsular and Transverse Ranges, where spring-fed streams have indexes as low as 2 and intermittent streams have indexes greater than 500.

SUMMARY

This report describes, in a general way, the various runoff characteristics of streams in the California Region. Plate 1 shown the location of the four precipitation zones that were used in the study and also delineates the zone of snowmelt runoff; any basin with at least 30 percent of its area in the snowmelt zone will have a significant part of its annual runoff in the form of snowmelt. Table 1 gives the range in magnitude of mean annual runoff and the range in average annual duration of flow to be expected from streams in each of the precipitation zones. Table 3 presents seasonal indexes to identify runoff as to source—whether primarily storm runoff or snowmelt runoff. Table 3 also provides base-flow indexes that identify the fair-weather summer runoff as being either well sustained, fairly well sustained, or poorly sustained.

The runoff characteristics of streams in each of the 11 geomorphic provinces in the region were described in terms of the derived indexes. The regimen of streamflow was also discussed in terms of characteristic discharge indexes obtained from flow-duration curves for the streams. The identification of streamflow characteristics by numerical index figures greatly facilitates comparison of the diverse runoff regimens of streams in the Californis Region.

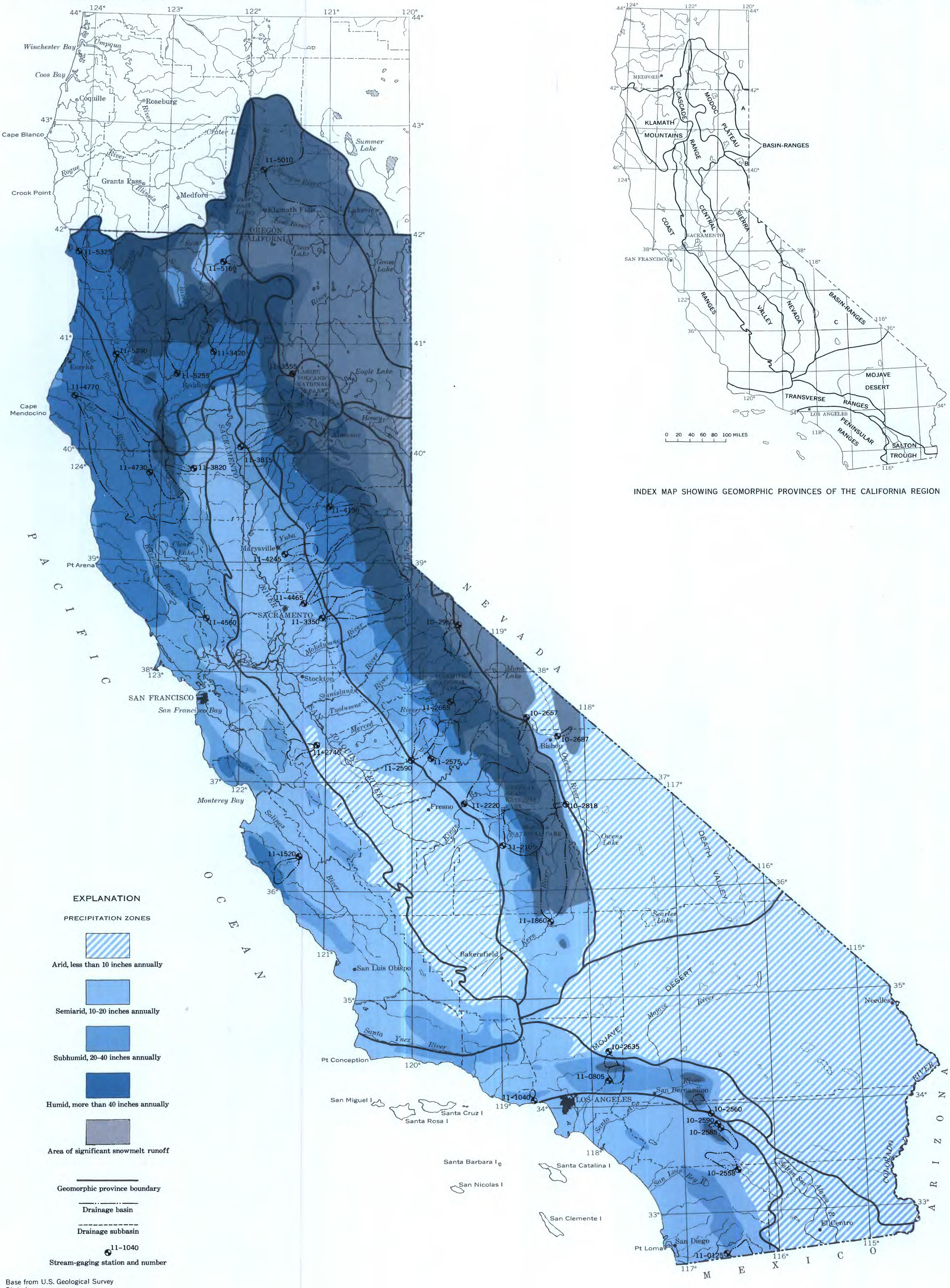
REFERENCES CITED

California Division of Mines and Geology, 1966, Mineral Resources of California: Bull. 191, 450 p.

Hinds, N. E. A., 1952, Evolution of the California landscape: California Div. Mines Bull. 158, 240 p.

Rantz, S. E., 1964, Surface-water hydrology of coastal basins of northern California: U.S. Geol. Survey Water-Supply Paper 1758, 77 p.

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 475-891



INDEX MAP SHOWING GEOMORPHIC PROVINCES OF THE CALIFORNIA REGION

SCALE 1:2 500 000

50 0 50 100 150 200 250 MILES

50 0 50 100 150 200 250 KILOMETERS

MAP SHOWING GEOMORPHIC PROVINCES, PRECIPITATION ZONES, AND THE LOCATION OF SELECTED BASINS AND STREAM-GAGING STATIONS IN THE CALIFORNIA REGION

475-891 O - 72 (In pocket)