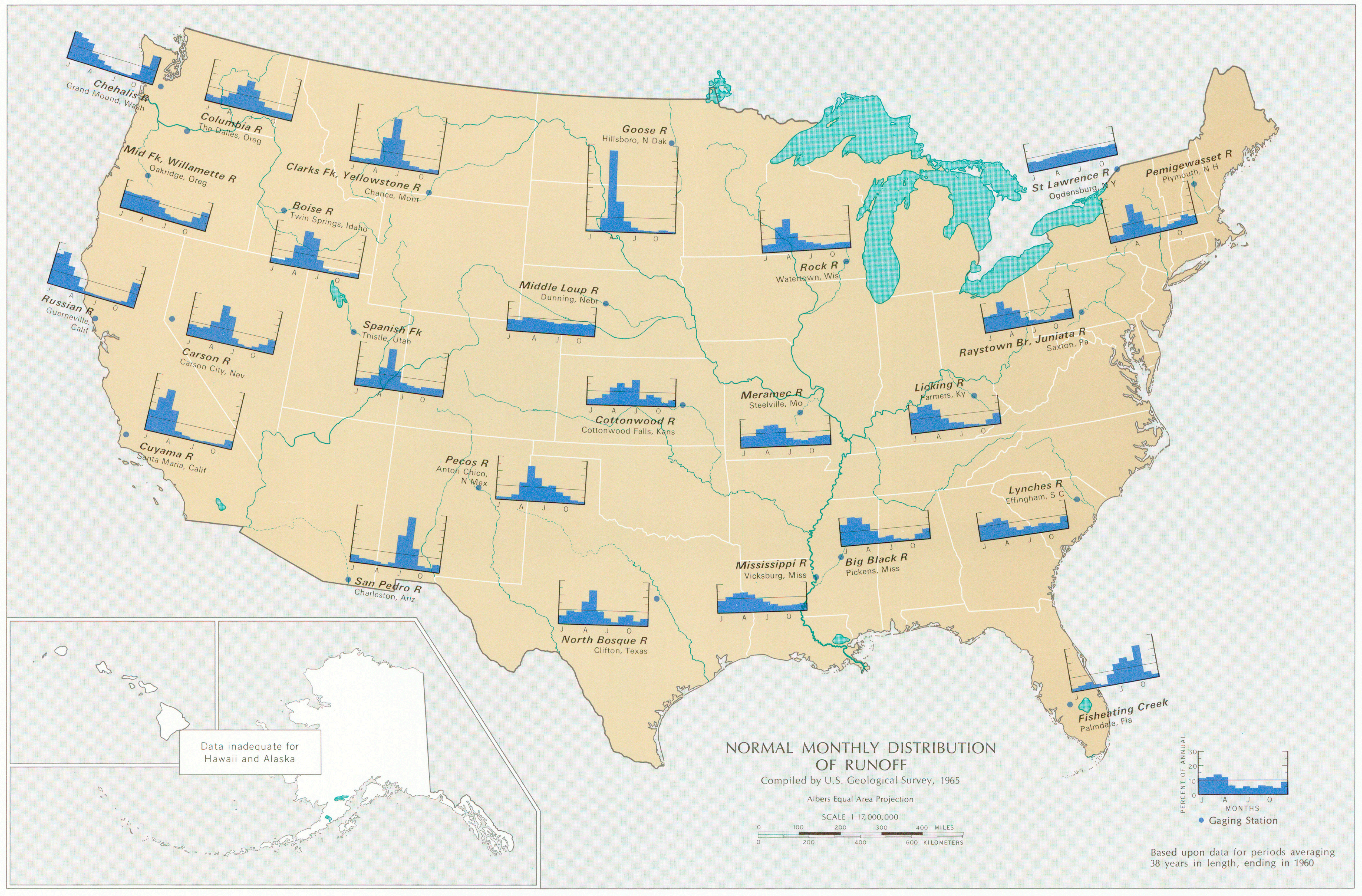


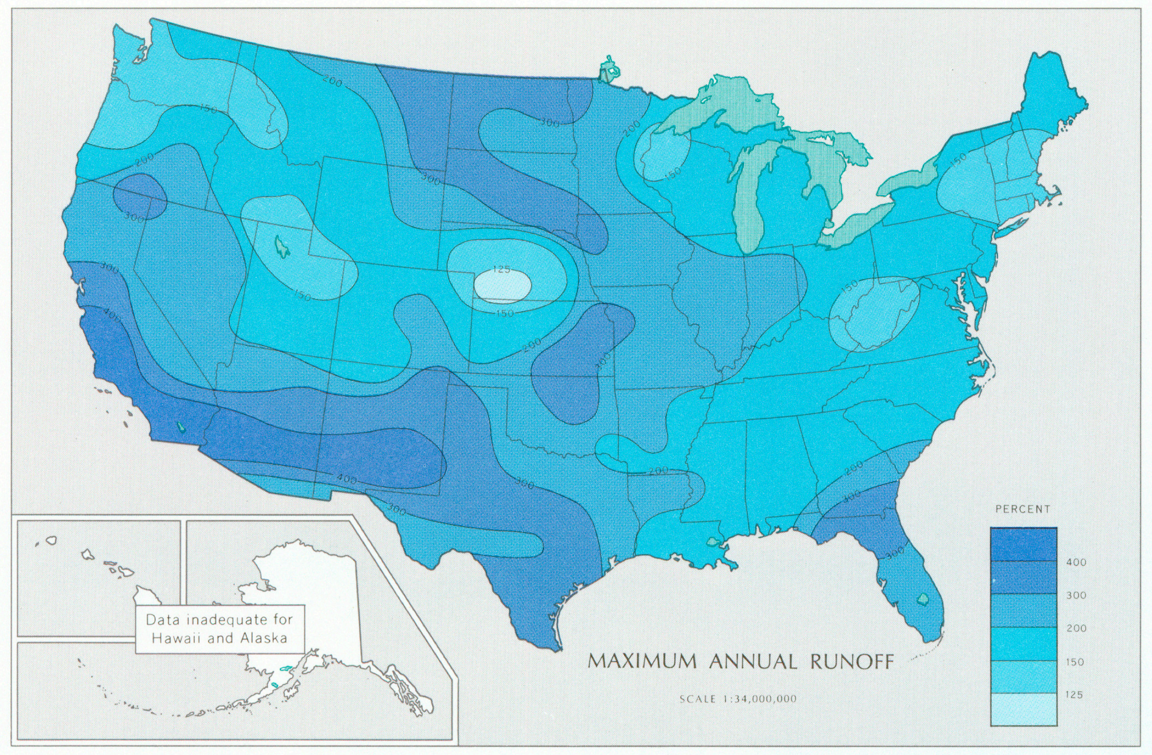
NORMAL MONTHLY DISTRIBUTION OF RUNOFF

Compiled by U.S. Geological Survey, 1965

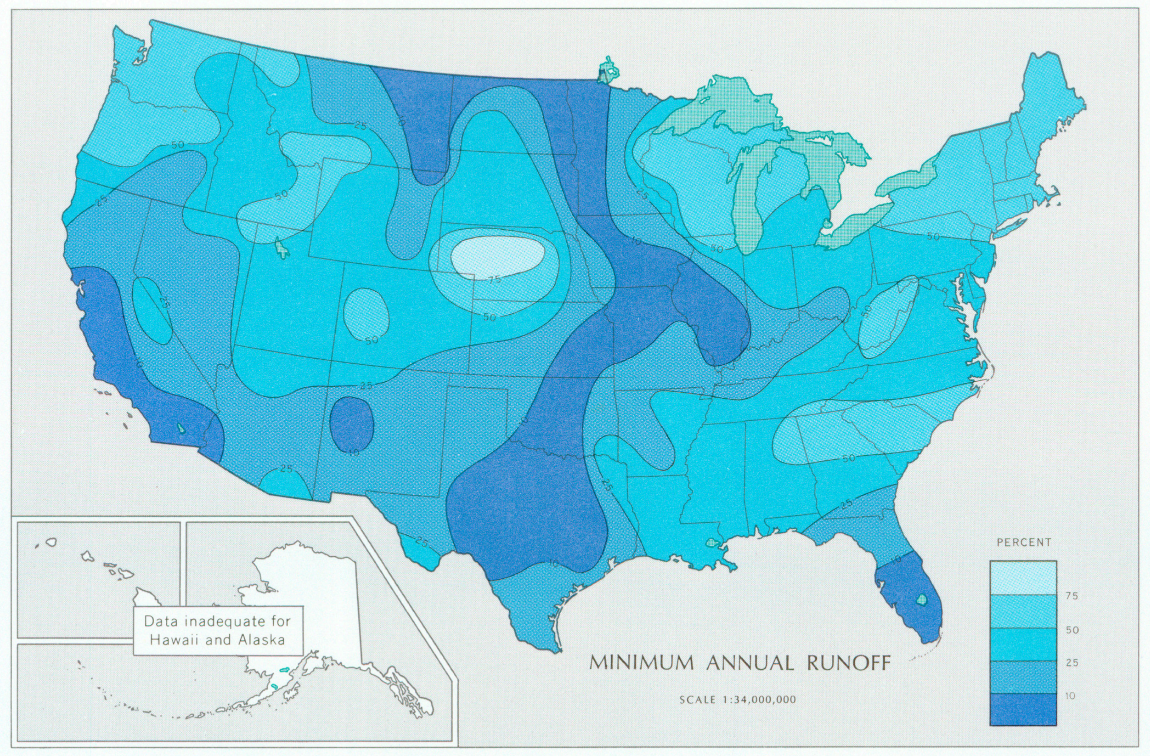
Based upon data for periods averaging 38 years in length, ending in 1960

VARIATIONS IN RUNOFF

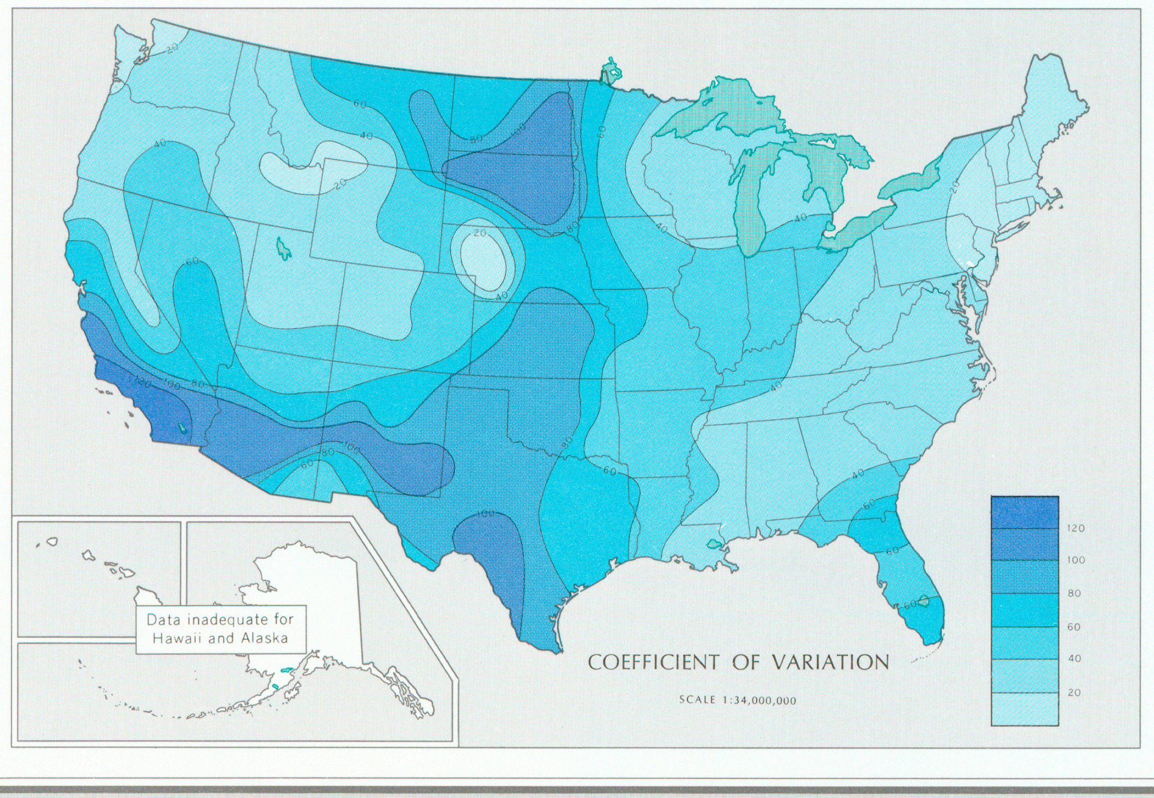
Compiled by U.S. Geological Survey, 1965



MAXIMUM ANNUAL RUNOFF



MINIMUM ANNUAL RUNOFF



COEFFICIENT OF VARIATION

MAXIMUM ANNUAL RUNOFF

Numbers show maximum annual runoff, in percent of the 1931–60 average, from representative drainage basins less than 4,000 km². The maximum runoff is necessarily greater than 100 percent of the average. The maximums for the individual streams occurred in various years.

MINIMUM ANNUAL RUNOFF

Numbers show minimum annual runoff from representative drainage basins, in percent of the 1931–60 average. The minimum runoff is necessarily less than 100 percent of the average. The minimums for the individual streams occurred in various years.

COEFFICIENT OF VARIATION

Contours are based on coefficients of variation as calculated for representative streams. (The coefficient of variation is the standard deviation of the annual runoffs divided by their arithmetic mean and multiplied by 100). Runoff is most stable in streams with low coefficient of variation. Annual runoff for the lightest color areas can be expected to be within 20 percent of the average in about 2/3 of future years.

The larger coefficients of variation are common in arid regions and in regions of continental climate. In these areas the annual runoff may deviate by more than 60 percent from the average in 1/3 of future years. Wherever the coefficient of variation exceeds 100, the runoff may be either negligible or more than twice the average in 1/3 of the years.

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES

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and unwanted products. Through geologic ages rivers have been the natural waste-disposal systems for the continents, carrying soil and rock waste, organic debris, and dissolved mineral matter that make the oceans what they are. Man's achievements and purposes in water developments have always been to intercept water while it is still fresh and before it can return to the atmosphere or ocean, use it, and then let it go again—to atmosphere or ocean.

RUNOFF

The water that flows in rivers, creeks, and ephemeral streams represents water from precipitation that could not infiltrate into soil and rock materials, or that could not be retained in surface reservoirs (including lakes, ponds, snow and ice fields) or in underground reservoirs. Thus runoff constitutes a residual or surplus that cannot be accommodated in the storage facilities of the continental area. The annual runoff is determined on the basis of continuing measurements of stage and discharge of streams at 8,400 gaging stations distributed throughout the U. S. The average annual runoff in the period 1931–60 is represented on page 118–119 in inches of water over the land surface, and thus provides ready comparison with the pattern of precipitation, shown on page 97.

Seasonal variations in runoff are characteristic of most streams. The average proportion of the annual runoff that occurs each month is shown graphically on page 120 for 22 streams draining basins of less than 4,000 square kilometers (1,600 square miles), and also for the three largest rivers in the country. The maximum runoff in several of the streams occurs during a marked rainy season: winter along the Pacific Coast, summer in southern Arizona, autumn in Florida. In most streams the greatest runoff occurs during the spring, because of snowmelt (especially in mountain streams), spring rains, or both. The flow of a few streams is fairly uniform throughout the year. The large rivers carry the aggregate runoff from many such streams. The Columbia commonly reaches its peak in June, but the flow is well sustained throughout the rest of the year. The Mississippi varies far less from month to month than do most of the streams that contribute to it. The flow of the St. Lawrence River, regulated by storage in the Great Lakes, varies little from month to month throughout the year.

The flow of all streams varies also from year to year. Two maps on page 120 show respectively the maximum and minimum annual runoff in percentages of the average. The greatest deviations above and below the average occur in the same general areas, as indicated by a third map depicting the variability of streamflow. There may be large local variations from the general pattern depicted, even in areas where precipitation is relatively uniform, owing in part to the effects of the aggregate facilities for storage (soil water, ground water, and surface water) within the individual drainage basins.

The extreme events in variations of streamflow are designated *floods* and *droughts*. As generally defined, a flood is an overflow or inundation that comes from a river or other body of water and causes or threatens damage. The lands bordering rivers are among the most valuable in the country, whether for agriculture because of the fertile alluvial soils, or for communities and industries because of the facility with which communication and transportation can be developed. Human occupancy, however, raises the question as to the degree of security afforded against flooding. The answer to this question will vary from one property to the next, and will be modified by structures or techniques that have been developed for flood protection. The answer is also dependent in part upon the flood potential, including the frequency of recurrence of floods of various magnitudes. Two maps on page 121 show the geographic variations in potential of the mean annual flood and the 10-year flood in drainage basins of about 800 square kilometers (300 square miles). The potential of the 10-year flood is generally 1½ to 2½ times the volume of water of the mean annual flood.

Estimates of damage caused by floods are imprecise, because the losses are as diverse as the economic interests of modern society. Generally, the most spectacular damage occurs during one or two years of each decade, during a flood of exceptional magnitude in a specific river basin or region. A map on page 121 shows the principal areas affected by catastrophic floods in the 13 years of greatest flood damage in the 20th Century.

Drought occurs during a period when precipitation is significantly less than the long-term average, and is thus distinct from *aridity* which is the dryness of a region having a very low average precipitation. Periods of less than average precipitation may range from several days to several years, and even to several decades. During such periods the replenishment of soil mosture, surface water, and perhaps also ground water is reduced, and the accumulated storage of each may dwindle because of continuing use or outflow. Thus the deficiency in precipitation may be reflected in deficiencies in water available from a wide variety of sources on which man may depend to sustain him in his particular environment.

To constitute a drought as the term is generally used, the water deficiency must be great enough and continue long enough to hurt mankind. In regions of normally abundant rainfall, where crops are dependent entirely upon soil moisture replenished by rain, the lack of rain for only a few weeks is called a drought, even though there are untapped resources of ground and surface water. Such droughts have generally been encompassed within the growing season of a single year. In arid regions a rainless month or even an entire growing season without rain does not qualify as a drought, because these are usual occurrences, and agriculture and other human activity can succeed only where there is assurance of other water supply to supplement the inadequate rainfall. In such regions a drought is recognized when the *total* water supply is seriously reduced during several years of less than average precipitation over a broad region. A map on page 121 depicts the broad regions in which people have been vulnerable chiefly to short droughts, to long droughts, and to both. A chart on page 121 depicts annual variations in runoff of several streams with long records.

The variations in runoff that reach their extremes in floods and droughts have been reduced by storage in artificial reservoirs along the many rivers. Pages 118–119 show the locations of all reservoirs having a usable capacity greater than 100 million cubic meters (81,000 acre-feet). All these reservoirs can be used to modify the seasonal variations in runoff; those whose capacity exceeds the average annual inflow (that is, those with "holdover" storage) may also be effective in reducing the annual variations.

GROUND WATER

Ground water is the subterranean water that occurs where all pores in the rock materials are filled with water that is under greater than atmospheric pressure. These "pores" may be the spaces between boulders or pebbles, or between grains of sand or particles of clay, or the fractures or fissures or cavities in consolidated rocks. Ground water is discharged at the land surface in springs and seep areas in many places, and in other places it is discharged into streams, lakes, oceans, or inland seas. In many places it is tapped and used by various plants known as "phreatophytes", but most vegetation obtains its water from the soil and underlying zones which retain some moisture but habitually are not saturated.

Except where ground water comes to the surface or is close enough to be reached by shallow excavations, man's use of this resource is dependent upon wells. Wells penetrate rock materials until they reach an aquifer, or "water-bearer", which can yield water by gravity drainage to the well to replace the water withdrawn. Literally millions of wells in a wide variety of rocks and rock materials have yielded water enough for a family's needs for drinking, cooking, and washing. In extensive regions of the United States, ground water could be developed almost anywhere in quantities sufficient for such domestic use.

In ground-water development for public supply, for industry, or for irrigation, wells must yield far more than these miniscule quantities. On pages 122–123, all areas shown in color are underlain by at least one aquifer that is generally permeable enough to yield water to a well at rates exceeding 3½ liters per second (50 gallons per minute), which is the average water requirement of a community of 500 people. All the aquifers thus represented contain fresh water that is considered usable; in most of the country this means that the water contains less than 1,000 ppm of dissolved solids, but in numerous areas water containing as much as 2,000 ppm is used for irrigation and public supply. In the blank areas no productive aquifers of significant areal extent are yet known, although there are numerous productive wells.

In the search for permeable rocks, the general rule is that the loose rock materials—gravel, sand, silt, and clay—have greater porosity than do the consolidated rocks; but the pores in clay and silt are so small that a sizable proportion of clay and silt in any loose rock material makes it relatively impermeable. More than 80 percent of all the water pumped from wells in the United States comes from gravel or sand aquifers. The watercourses, shown in blue, are also sand-and-gravel aquifers, distinguished from those shown in yellow by the fact that they are in alluvial valleys in which ground and surface water are interrelated, and in which water withdrawn from wells is likely to be replenished eventually by infiltration from the river.

Sandstone has less pore space than sand because of the cement between the grains, but wells obtain large yields from sandstone that is poorly cemented or well jointed. Many limestones are sufficiently permeable to yield large volumes of water to wells, and some basalts are also excellent aquifers. In other consolidated rocks, whether igneous, sedimentary, or metamorphic, the permeability is generally limited to that provided by fractures; in a few States, such rocks yield water in the quantities needed for modest-scale irrigation or industry.

For all aquifers except the watercourses, the map gives no clue as to whether the withdrawals from wells can be sustained perennially. The rate at which water pours into a well from an aquifer gives no clue as to how long the well can continue to produce. The first water yielded by a new well comes from storage within the aquifer, and the well will continue to deplete the storage until recharge to the aquifer is increased, or until other discharge from it is decreased, in equivalent amounts. Many heavily-pumped aquifers, after an initial depletion of storage, appear to have approached a new equilibrium at present rates of pumping. The storage in some other aquifers is diminishing from year to year—in places because of progressively increasing aggregate withdrawals, in places because the present rates of withdrawal are far greater than the natural replenishment, and in places because of drought or artificial hindrance to natural replenishment.

The distribution of ground-water pumpage is indicated by dots, each representing an annual withdrawal from wells of about 100 million cubic meters (72 mgd or million gallons a day). In Alaska, Rhode Island, Vermont, New Hampshire, Maine, North Dakota, and Delaware the total withdrawal of ground water is less than 100 million cubic meters. In 10 other States no dots are shown, even though the statewide pumpage ranges from 100 to 300 million cubic meters, because that pumpage is widely dispersed. California, Texas, and Arizona account for about half the total pumpage of ground water in the entire Nation; this pumpage is chiefly for irrigation, and chiefly in the agricultural areas of California's Central Valley, Arizona's Gila River basin, and Texas' High Plains.

The statewide totals of pumpage reflect in some degree the geographic size of the respective States. Several Eastern States rate high in terms of pumpage per unit of area: on this basis, New Jersey's rate of withdrawal is as great as California's, and is exceeded only by that of Hawaii. The withdrawals of ground water per unit of area in Delaware, Massachusetts, and Rhode Island are less than in Hawaii, New Jersey, California, Texas, Idaho, and Arizona, but greater than in any other State.

IMPURITIES

In the hydrologic cycle water is most nearly devoid of impurities when it has just been condensed from atmospheric vapor. During precipitation the rain may absorb soluble solids and gases, and wash insoluble particles from the atmosphere. After reaching the earth anything in the path of water may contribute to its impurities: soluble minerals may be dissolved during overland flow and especially during sub-surface movement as soil water and ground water; surface water may also carry solid matter in flotation, in suspension, or as bedload. Consequently, practically all natural waters contain some impurities, and many of these persist in the water until it is evaporated and returned to the atmosphere—indeed, after such evaporation the impurities remain and accumulate on the land surface or in the soil or in the water left behind. In addition to the inorganic impurities, water contains impurities from the living world in great variety: fauna and flora ranging down to single-celled organisms, bacteria and viruses, plus all the products of their life processes and decay.

Many uses of water by mankind are for disposing of

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