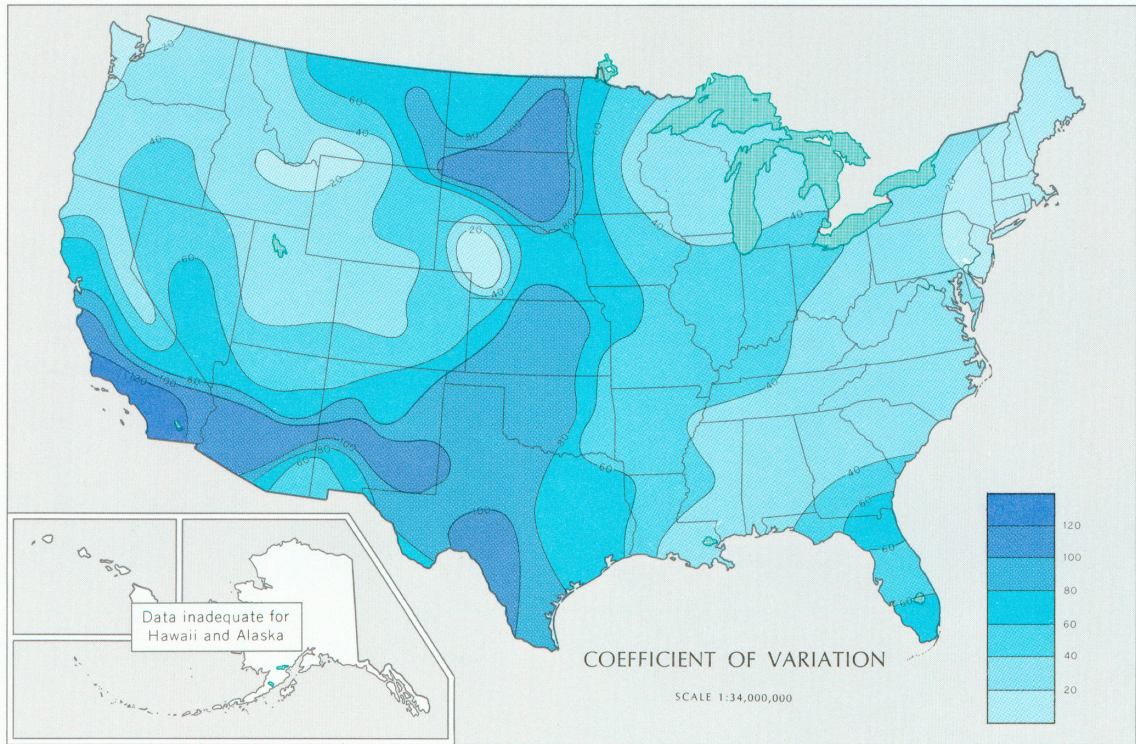
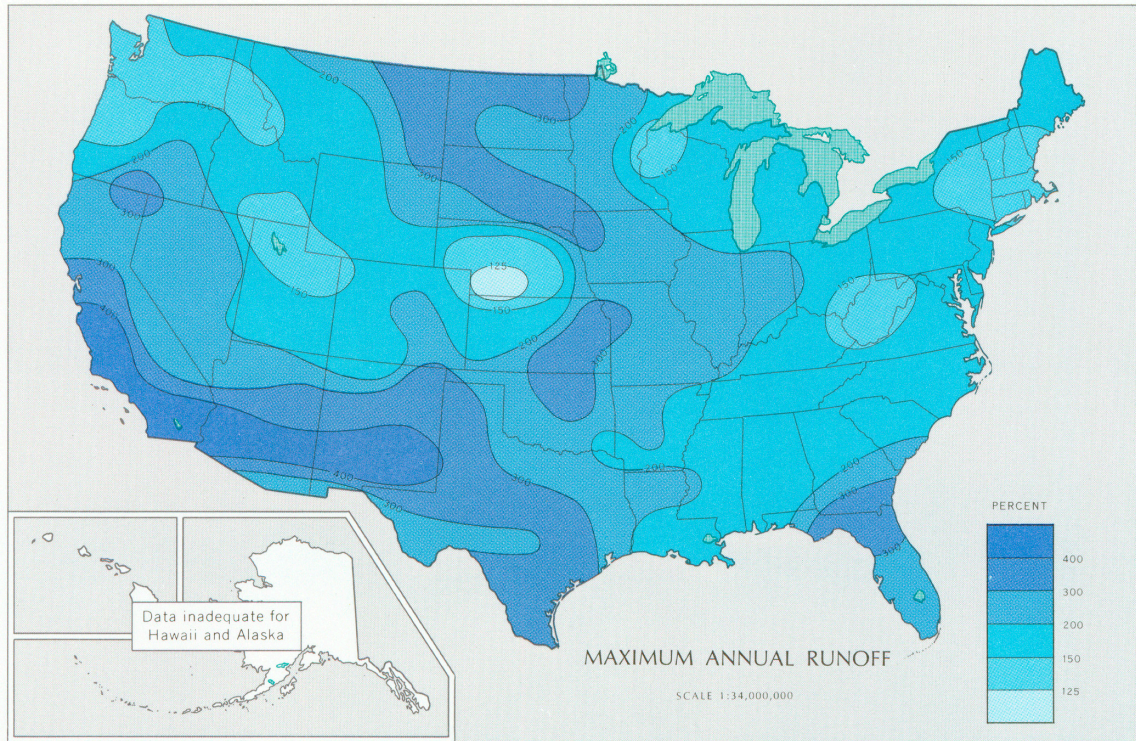


VARIATIONS IN RUNOFF  
Compiled by U.S. Geological Survey, 1965



MAXIMUM ANNUAL RUNOFF  
Numbers show maximum annual runoff, in percent of the 1931-60 average, from representative drainage basins less than 4,000 km<sup>2</sup>. 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.

"Every human enterprise is the mixture of a little bit of humanity, a little bit of soil, and a little bit of water."  
—Jean Brunhes

The Water Resources section contains a summary of data compiled or adapted from various sources by the staff of the U.S. Geological Survey with text and coordination by Harold E. Thomas.

From other parts of the universe water, H<sub>2</sub>O, appears to be the most abundant substance on Earth: about 71 percent of its surface is formed by oceans and another 3½ percent by polar ice caps; the remaining 25½ percent, constituting the land masses, is at various times and places obscured by clouds, covered by ice and snow, and draining or storing liquid water. But mankind has restrictive specifications for water—it must be suitable for his use, and it must be available where he wants to use it—which reduce drastically this apparent abundance. The oceans and polar ice caps, together containing more than 99 percent of the world's water, typify respectively the water unsuitable for use and inaccessible for use by man.

By modern technological processes we can remove the impurities from any natural or artificially-contaminated water and render it suitable for any intended use. Also, we can lift water from great depths and transport it long distances to make it available at any place of desired use. These technological processes for water purification and distribution involve costs in energy and equipment—costs which a man is willing to pay if he can and if he has no cheaper alternative, because suitable water is essential for life. In practically all times and places, however, there has been a cheaper alternative, provided by a natural system of purification and distribution of water, as a part of the hydrologic cycle.

Although the term "water resources" is variously defined or left undefined, it generally includes only the water occurring naturally, and of a quality suitable for man's use—in common parlance, "fresh" water. The U. S. Public Health Service in its drinking water standards recommends that concentrations should not exceed 250 parts per million of chloride, 250 ppm of sulfate, and 500 ppm total dissolved solids, but considers that water containing as much as 1,000 ppm of solids is acceptable where purer water is not available. Some individuals have adapted themselves to drinking water containing as much as 1,500 ppm chloride, 2,000 ppm sulfate, and 5,000 ppm total dissolved solids, and several of the common domesticated animals and plants have similar limits of tolerance for dissolved salts in their water supply. The requirements as to quality of water range widely according to the use intended, but generally when people speak of "water resources" they are thinking of a product that is more than 99.9 percent pure, and frowning on any whose purity is less than 99.5 percent.

THE HYDROLOGIC CYCLE

The origin of practically all the fresh water on Earth is traceable to a natural distillation process powered by solar energy—that is, evaporation especially from the oceans and other water surfaces, transport as water vapor in the atmosphere, and precipitation upon the continents and islands. The rainwater is either absorbed in the soil or it accumulates on the surface and then starts to run off. Water has the same alternatives at every spot on earth during every storm: either infiltration, or accumulation on the surface (as snow, ponds, or lakes), or runoff downslope. This runoff may continue overland only until it finds a place where it can be absorbed in the soil, or it may enter a channel and eventually a river, as storm flow. The water absorbed by the soil may accumulate there as soil moisture; and it may continue downward through the openings within the rock materials, until it reaches a zone where all the pores are saturated. This ground-water zone is another place for accumulation, and for movement downslope similar to the overland runoff, but through small pores and thus far more slowly.

When it stops raining, the surface materials dry off—the water evaporates and returns as vapor to the atmosphere. Some of the water in the soil does likewise, and some is used in the life processes of vegetation, including transpiration which returns water as vapor to the atmosphere. The storm flow collects in the various channels of the drainage system, where it may create flood stages. The water in streams may be stored temporarily in lakes and reservoirs or along the streambanks; eventually it is debouched into the sea by the trunk river, except for that which is evaporated and returned to the atmosphere. The ground water moves slowly downward; in places it reappears at the land surface as springs; in other places it is shown enough that it can be reached by vegetation, so that there is discharge to the atmosphere; and it may discharge into streams, contributing a base flow that sustains the stream in dry weather and makes it perennial.

Thus, wherever we look upon this earth, we can see parts of a "perpetual-motion" system, of which the portions upon and under the earth constitute integrated flow system, replenished sporadically but persistently by precipitation. Man and living organisms generally have continuing requirements for water, even when it is *not* raining, and for these the aforementioned accumulations of water, stored as ground water or soil water or surface water, are essential.

The surface water, soil water, and ground water that originate in precipitation are obviously replenishable resources. The average annual precipitation is equivalent to a layer of water 760 millimeters (30 inches) thick over the area of the conterminous United States, of which 550 mm (21½ inches) is evaporated and returned to the atmosphere, and the rest is runoff to the seas or across the Nation's land boundaries. We say there is a natural equilibrium because of the long-range balance between inflow (precipitation) and outflow (evaporation and return of fresh water, but because of climatic variations there are continuing fluctuations at any point in everything we measure—streamflow, ground water, soil water, evaporation, etc.

In addition to the replenishable resources, there are fresh-water accumulations underground from bygone years (or centuries) of precipitation, which in the aggregate have a far larger volume than could be replenished by the annual precipitation and infiltration. Throughout the country there are wide variations in climate, geology, and other elements that affect the geographic distribution of the fresh-water resources, both replenishable and nonreplenishable.

Man's uses of water are similar to its disposal in nature. In consumptive uses such as boiling and irrigating, the water goes as vapor to the atmosphere, as it does in natural evapotranspiration processes. In nonconsumptive uses such as washing, processing, or cooling, the water carries off waste

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 accounted 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 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 Colorado River commonly reaches its peak in June, but the flow 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 15 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 a few days to several years, and even to several decades. During such periods the replenishment of soil moisture, 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.

WATER RESOURCES

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 occurs in almost all places 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 minuscule 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 the 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 the water 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 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 water 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, evaporation of surface 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

wastes, but organic wastes are putrescible, and therefore can be removed from the water by suitable processes of sewage treatment. Other byproducts of civilization include a variety of inorganic wastes that can be dissolved or suspended in water; some of these are lethal or toxic, others merely unpleasant or uneconomic, but most are persistent and not removable from the water by standard sewage treatment.

Only the natural inorganic impurities in waters are shown on pages 124 and 125. The maps are based upon determinations of the most common dissolved chemical constituents in water from streams or wells, and of the suspended sediment in streams. Thus the maps give no indication of the presence or absence of pollutants introduced by man, whether organic or inorganic. However, if human occupancy of a region has resulted in significant modification of sediment yield or of the common dissolved chemical constituents, the maps would show these modified characteristics rather than the "virgin" conditions.

The maps Prevalent Concentrations of Dissolved Minerals and Prevalent Chemical Types of Water in Rivers are based upon analyses of water in streams during periods of low flow, when the water comes chiefly from ground-water reservoirs. Analyses of water from wells and springs show that there are great variations in chemical quality of ground water in many parts of the country, both geographically and in depth—variations too intricate to be depicted on a map at this scale even if adequate data were available. The low flow of streams is therefore used as a composite sample of the ground-water outflow. Storm runoff usually is much more dilute than the low flow, because the contact with soil and rock is less and for a shorter period. The prevalent concentration of dissolved solids is generally least in the regions of greatest rainfall and runoff—in the East and Southeast and the mountains of the West—and greatest in the semiarid Southwest and Great Plains. Concentrations are low also in regions of dominantly crystalline rocks, and high in regions where the rocks include substantial proportions of evaporites such as rock salt and gypsum. Thus, both climatic and geologic controls are factors in the patterns shown by the map. In about half the country the prevalent concentration of dissolved solids is less than 230 ppm, and in 90 percent of the area it is less than 900 ppm.

In more than half the country the prevalent water is of the calcium bicarbonate type containing subordinate amounts of magnesium and carbonate. The areas where this type of water contains less than 120 ppm total dissolved solids are discriminated on the map, because such waters are generally the "soft" waters of best quality for most uses.

The sodium potassium chloride sulfate types of water are prevalent in about one-eighth of the country. Although such waters are generally soft, a sodium potassium water having total dissolved solids greater than 800 ppm may have concentrations of calcium and magnesium that would make it very hard.

Mineralized ground water in the past has not been considered a water resource because of its unsuitability for most uses, and it has been avoided in many places for fear of contamination of fresh-water resources. Development of economic processes of desalination will inevitably lead to recognition of mineralized ground water as a valuable resource wherever natural fresh-water resources are insufficient, particularly in interior regions where such water is far more readily accessible than sea water. The meager information presently available on saline water—chiefly from unsuccessful water wells, oil wells and other borings, mines and other subterranean exploration, and geologic studies—is presented in a map on page 124.

The map of sediment concentration (page 125) is based on the average annual discharge-weighted means of measured streams—that is, the quantity of suspended sediment that passes a section on a stream in a given time divided by the volume of water discharge for the period. Sediment concentrations of a river may range widely during a year, the maximum concentrations being 10 to more than 1,000 times the minimum. The average annual sediment concentrations shown represent suspended sediment carried by the major flowing part of the stream, and do not include the bedload. The discharge-weighted suspended-sediment concentration is less than 600 ppm in 50 percent of the country, and less than 8,000 ppm in 90 percent of the country.

WATER USE

Of the diverse uses of water by mankind, several do not require the removal of water from its native environment: navigation; various forms of recreation including fishing, boating, and swimming; conservation of fish and wildlife; and disposal of sewage and other liquid and solid wastes. Certain minimum quantities of water may be essential for these uses, and the use may result in deterioration in the quality of some water, but the actual water use is not readily quantified. Hydroelectric power generation *does* require diversion through pipes, penstocks, and generators, but the water thereafter generally is returned to the stream undiminished in quantity. The total quantity of water used for hydroelectric power in 1960 in the continental United States was of the order of 2,700 cubic kilometers, (2,000,000 mgd) which is 165 percent of the average annual runoff from the country.

The map on pages 126-127 shows withdrawal uses as of 1960 but does not include use for hydropower or any non-withdrawal use. Four major types of withdrawal use are discriminated: irrigation, which accounted for 40 percent of the total withdrawal; fuel-electric power generation (chiefly for condenser cooling), 37 percent; other industrial use, 14 percent; and public supply, 8 percent of the total withdrawal. The total withdrawal use in the Nation in 1960 was about 375 cubic kilometers, or 270,000 mgd. Of this total, about 17 percent—65 cubic kilometers or 47,000 mgd—came from wells, and more than 99 percent of this was classified as fresh water. All other withdrawals came from surface water, which includes the water issuing from springs because that water is withdrawn after it reaches the surface. Of the total surface withdrawals of 310 cubic kilometers (220,000 mgd), about 45 km<sup>3</sup> or 32,000 mgd was saline water, pumped chiefly from tidal streams, estuaries, bays, or oceans and used for cooling.

ALASKA

Primarily because of Alaska's large areal extent, sparse population, and low temperature, the information concerning water resources in Alaska is distinctive from that in the other 49 states, both in amount and in type. Information concerning water-bearing rocks and rock materials, glaciation, and permafrost is assembled on page 128.