WATER OF THE WORLD

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DISTRIBUTION OF MAN'S LIQUID ASSETS IS A CLUE TO FUTURE CONTROL

Most people know that water is unevenly distributed over the earth's surface in oceans, rivers, and lakes, but few realize how very uneven the distribution actually is. It is instructive to consider the total inventory of water on the planet earth, the areas where the water occurs, and the long-term significance of the findings.

The world ocean—139,500,000 square miles of it—contains 317,000,000 cubic miles of salt water. The average depth of the ocean basins is about 12,500 feet. If the basins were shallow, seas would spread far onto the continents, and dry land areas would consist chiefly of a few major archipelagoes where high mountain ranges projected above the sea.

Considered as a continuous body of fluid, the atmosphere is another kind of ocean. Yet, in view of the total amount of precipitation on land areas in the course of a year, one of the most astonishing world water facts is the very small amount of water in the atmosphere at any given time. The volume of the lower seven miles of the atmosphere—the realm of weather phenomena—is roughly four times the volume of the world ocean, but the atmosphere contains only about 3,100 cubic miles of water, chiefly in the form of invisible vapor, some of which is transported over land by air currents. If all vapor were suddenly precipitated from the air onto the earth's surface it would form a layer only about one inch thick. A heavy rainstorm on a given area may remove only a small percentage of the water from the air mass that passes over. How, then, can some land areas receive, as they do, more than 400 inches of precipitation per year? How can several inches of rain fall during a single storm in a few minutes or hours? The answer is that rain-yielding air masses are in motion, and as the water-depleted air moves on, new moisture-laden air takes its place above the area of precipitation.

The basic source of most atmospheric water is the ocean, from which it is derived by evaporation. Evaporation, vapor transport, and precipitation constitute a major arc of the hydrologic cycle—the continuous movement of water from ocean to atmosphere to land and back to the sea. Rivers return water to the sea along one chord of the arc. In a subterranean arc of the cycle, underground bodies of water discharge some water directly into rivers and some directly to the sea.

Estimated average annual evaporation from the world ocean is roughly 39 inches. The conterminous United States receives an average of 30 inches of precipitation every year, or about 1,430 cubic miles in total volume. Evapotranspiration returns approximately 21 inches of this water to the atmosphere

All water comes from the ocean and is returned to it in the continuous Hydrologic Cycle.

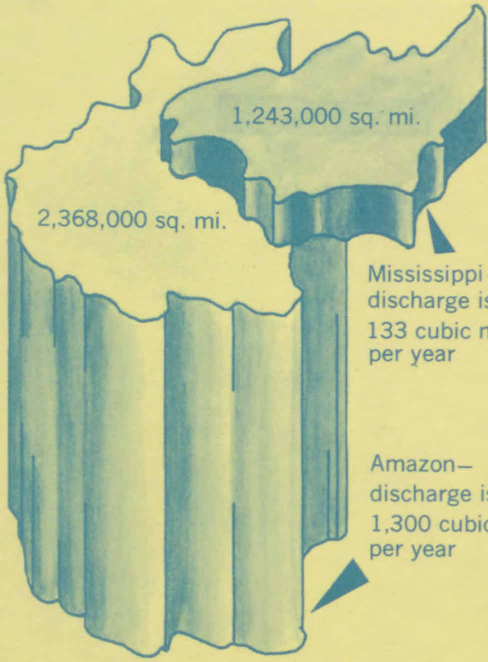
(about 1,000 cubic miles). Obviously, some rain is water that was vaporized from the land areas and is being reprecipitated. Evidently the global hydrologic cycle, which sends water from sea-to-air-to-land areas and back to the sea again, has short circuits. These are called subcycles.

There are many complexities and variations in the fate of water that falls as rain or snow. For example, high in the central Rocky Mountains of North America, the Yellowstone River heads in Yellowstone National Park just east of the Continental Divide. The river water discharges through the Missouri and Mississippi Rivers into the Gulf of Mexico about 1,600 airline miles distant from the head.

On the west side of the Continental Divide, not far from the Yellowstone, rises the Snake River, which flows across Idaho to join the Columbia near Pasco, Washington, and its waters eventually reach the Pacific Ocean about 700 airline miles from their source and about 2,200 miles from the mouth of the Mississippi.

This is a good example of the continuous mixing and transfer of water in the hydrologic cycle. An air mass moving eastward across the Rocky Mountains contains water evaporated from the Pacific Ocean. Some of the water falls as rain or snow to the west and some to the east of the Continental Divide. Thus, two drops of rain falling side by side along the continental backbone may end up, one in the Pacific, the other in the Atlantic Ocean, although both were derived from the Pacific.

No one knows how much water moves from the Pacific to the Atlantic Ocean by vapor transfer, precipitation, and runoff, but we do know a great deal about runoff itself. Estimated total flow into the sea from rivers in the 48 adjacent States takes place at the rate of about 1,803,000 cubic feet per second (a cubic foot is about 7.48 gallons), which amounts to approximately 390 cubic miles per year. Values for runoff (390 cubic miles) plus evaporation (1,000 cubic miles) do not quite equal the precipita-



Amazon vs. Mississippi drainage

tion (1,430 cubic miles) because none of these values is precise. Moreover, some water is discharged into the sea directly from ground-water sources without passing through streams. The missing 40 cubic miles of water, roughly 10 percent of the value for streamflow, might represent direct ground-water discharge.

Hydrologists have not generally considered that direct ground-water outflow to the sea is so large, but there is really no good basis that can be used to dispute or support what the computations seem to indicate. At any rate, the data are sufficiently accurate for the present purpose, which is to show the relative magnitude of water volumes involved in the annual water cycle.

Some more specific data give a good idea of the relative importance of large and small rivers in maintaining continental water balances.

The Mississippi, North America's largest river, has a drainage area of 1,243,000 square miles (about 40 percent of the total area of the 48 conterminous States) and discharges at an average rate of 620,000 cubic feet per second. This amounts to some 133 cubic miles per year, or approximately 34 percent of the total discharge from all the rivers of the United States.

The Columbia, nearest American competitor of the Mississippi, discharges less than 75 cubic miles per year. Relatively speaking, the great Colorado River is a dwarf, discharging only about five cubic miles annually.

On the other hand, the Amazon, the largest river in the world, is nearly ten times the size of the Mississippi, and it discharges about four cubic miles per day and some 1,300 cubic miles per year—about three times the flow of all United States rivers.

Africa's great Congo River, with a discharge of approximately 340 cubic miles per year, is the world's second largest. The estimated annual discharge of all African rivers is about 510 cubic miles.

Measurements of only the principal few streams on a continent afford a basis for reasonably accurate estimation of the total runoff item in a continental water balance. The smaller streams are important

Grand Coulee Dam on the Columbia River. Franklin D. Roosevelt Lake holds nearly 2.8 cubic miles of water.

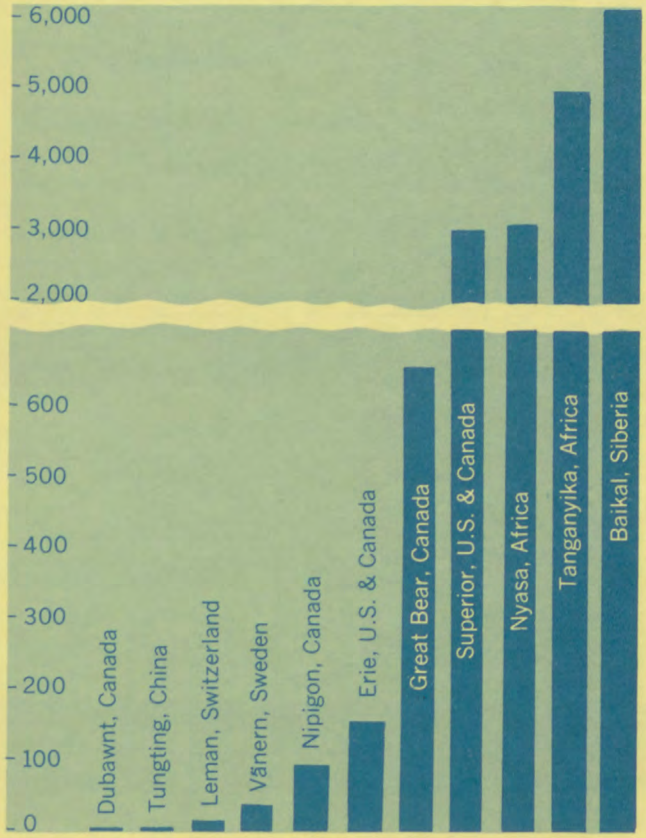
locally, but they contribute only minor amounts of the total water discharged. Thus it is possible to estimate the total runoff in all the rivers of the world, even though many of them have not been measured accurately. Sixty-six principal rivers of the world discharge about 3,720 cubic miles of water yearly. The estimated total from all rivers, large and small, measured and unmeasured, is about 9,200 cubic miles yearly (25 cubic miles daily).

Crude estimates have indicated that the total amount of water that is physically present in stream channels throughout the world at a given moment is about 300 cubic miles. Evidently, river channels, on the average, contain only enough water to maintain their flow for about two weeks. Some have much more water, others much less, but it seems to be a fair average. How, then, do rivers maintain a flow throughout the year, even during rainless periods much longer than two weeks? The answer to that question will appear later, in the discussion of ground water.

After oceans and rivers come lakes, which can be called wide places in rivers. This is certainly true of the many small lakes that are impounded by relatively minor and geologically temporary obstructions across river channels. But no single, oversimplified metaphor accurately describes all lakes, which are widely varied in their physical characteristics and the geologic circumstances under which they occur. The handsome little tarn occupying an ice-scooped basin in a glaciated alpine area is radically different from the deep and limpid Crater Lake of Oregon, which fills the crater of a now-extinct volcano. Lake Okeechobee in Florida is totally different from any of the North American Great Lakes, which occupy huge basins formed in a complex manner by glacial excavation at some places, moraine and outwash deposition at others, isostatic subsidence of that whole region of the earth's crust, and other factors. The Great Lakes of North America, in turn, bear no resemblance to Lake Tanganyika in the great Rift Valley of Africa. Processes that are poorly understood created the rift by literally pulling two sections of the earth's crust apart, leaving a deep, open gash, part of which is occupied by the lake. And these are only a few

examples of wide variations in the nature of lakes.

The earth's land areas are dotted with hundreds of thousands of lakes. Wisconsin, Minnesota, and Finland contain some tens of thousands each. But these lakes, important though they may be locally, hold only a minor amount of the world supply of fresh surface water, most of which is contained in a relatively few large lakes on three continents.

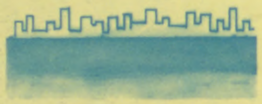


Water volume of lakes in cubic miles

Whether a lake contains fresh or salt water makes a considerable difference in its usefulness to man, so the earth's greatest lakes are considered in both of the categories, fresh and salt.

The volume of all the large fresh-water lakes in the world aggregates nearly 30,000 cubic miles, and their combined surface area is about 330,000 square miles. "Large" is a relative term that requires explanation. For this leaflet a lake is called large

DISTRIBUTION OF WORLD'S ESTIMATED WATER SUPPLY

Location	Surface area (square miles)	Water volume (cubic miles)	Percentage of total water
SURFACE WATER			
 Fresh-water lakes	330,000	30,000	.009
 Saline lakes and inland seas	270,000	25,000	.008
 Average in stream channels	—	300	.0001
SUBSURFACE WATER	—	—	—
 Vadose water (includes soil moisture)		16,000	.005
 Ground water within depth of half a mile	50,000,000	1,000,000	.31
 Ground water—deep lying		1,000,000	.31
TOTAL LIQUID WATER IN LAND AREAS	50,600,000	2,070,000	.635
 Icecaps and glaciers	6,900,000	7,000,000	2.15
 Atmosphere (at sea level)	197,000,000	3,100	.001
 World ocean	139,500,000	317,000,000	97.2
TOTALS (rounded)	—	326,000,000	100

if its contents are five cubic miles or more. Thus the listing includes Dubawnt Lake, Canada (about six cubic miles), but excludes the Zürichsee of Switzerland (about one cubic mile). The range of volume among the large lakes is enormous; from a lower limit of five cubic miles to an upper one of 6,300 cubic miles in Lake Baikal in Asiatic Russia, the largest and deepest single body of fresh water in existence. Some appreciation of its volume may be gained from the realization that Lake Baikal alone contains nearly 300 cubic miles more of water than the combined content of the five North American Great Lakes. The latter loom large on a map, but their average depth is considerably less than that of Baikal.

Nevertheless, North American lakes are a major element in the earth's water balance. The Great Lakes, plus other large lakes in North America (chiefly in the 48 states and Canada) contain about 7,800 cubic miles of water—26 percent of all liquid fresh surface water in existence.

Similarly, the large lakes of Africa contain 8,700 cubic miles, or nearly 29 percent of the total fresh-water supply. Asia's large lakes contain about 6,400 cubic miles, or 21 percent of the total, nearly all of which is in Lake Baikal.

Lakes on these three continents account for roughly 75 percent of the world's fresh surface water. Large lakes on other continents—Europe, South America, and Australia—have only about 720 cubic miles, or roughly 2 percent of the total. All that remains to fill the hundreds of thousands of rivers and lesser lakes that are found throughout the world is less than one-fourth of the total fresh surface water.

Saline lakes are equivalent in magnitude to fresh-water lakes. Their total area is 270,000 square miles and their total volume is about 25,000 cubic miles. The distribution, however, is quite different. About 19,240 cubic miles (75 percent of the total saline volume) is in the Caspian Sea, and most of the remainder is in Asia. North America's shallow Great Salt Lake is comparatively insignificant with seven cubic miles.

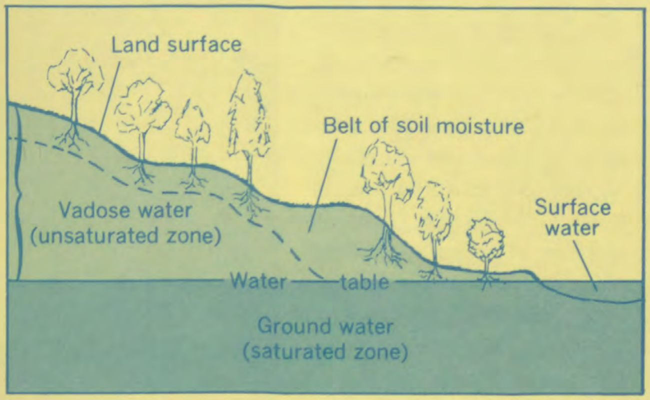
Laguna de Cotacatani, a morainal-dammed lake, in the Andean region of northern Chile.

All these water sources we have discussed are the obvious ones. There is another—soil moisture—that may be the most significant segment of the world's water supply because of the key role played by plants in the food chain. Some plants grow directly in water or marshy ground, but by far the greater mass of vegetation on earth lives on "dry" land. This is possible because the land is really dry at just a few places, and often only temporarily. How dry is dust? The dust of a dry dirt road may contain up to 15 percent of water by weight. However, plants cannot grow and flourish with so little water because the soil holds small percentages of moisture so tenaciously that plant roots cannot extract it. Aside from desert plants, which store water in their own tissues during infrequent wet periods, land plants flourish only where there is extractable water in the soil. Inasmuch as a quite ordinary tree may withdraw and transpire about 50 gallons of water per day, frequent renewals of soil moisture, either by rain or by irrigation, are essential. The average amount of water held as soil moisture at any given time is on the order of 6,000 cubic miles for the world as a whole—an insignificant percentage of the earth's total water, but vital to life. Relatively little vegetation receives artificial irrigation, and practically all of it depends on natural soil moisture, which, in turn, depends on orderly and timely operation of the hydrologic cycle.

Another little-considered water reservoir has been known to man for thousands of years. Scripture (Genesis 7:11) on the Noachian Deluge states that "the fountains of the great deep [were] broken up" (cleft open), and Exodus, among its many references to water and to wells, refers (20:4) to "water under the earth." Many other chronicles show that man has known from ancient times that there is much water underground. Only recently has he begun to appreciate how much.

Beneath most land areas of the world there is a zone where the pores of rocks and sediments are completely saturated with water. Hydrologists call this ground water, and the upper limit of the saturated zone is called the water table. The water table may be right at the land surface, as in a marsh, or it may lie hundreds of feet below the land surface, as in some arid areas. Water in the unsaturated zone above the water table is called vadose water and includes the belt of soil moisture. Water in the intermediate part of this zone has passed through the soil and is percolating downward toward the water table.

The world volume of that part of the vadose water below the belt of soil moisture is probably somewhat more than that of soil moisture—say 10,000 cubic miles. It is highly important because, although it is not extractable by man, it is potential ground-water recharge, and ground water *is* extractable. Each new influx of water from precipi-



Relation of the water table to saturated and unsaturated zones.

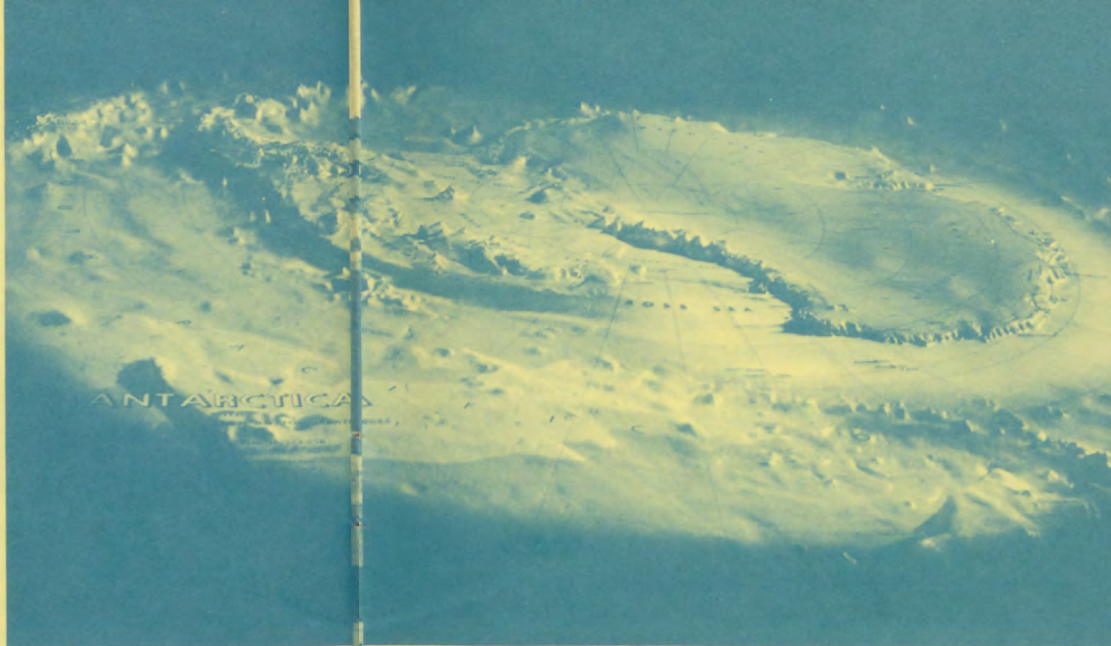
tation on the land surface followed by percolation through the soil provides a new increment of recharge to the ground water.

Below the water table, to a depth of half a mile in land areas of the earth's crust, there is about one million cubic miles of ground water. An equal if not greater amount is present at a greater depth, down to some 10 to 15 thousand feet, but this deeper water circulates sluggishly because the rocks are only slightly permeable. Much of the deep-lying water is not economically recoverable for human use, and a good deal of it is strongly mineralized.

Ground water flows through moderately to highly permeable strata, which are called aquifers, at rates of a few inches to perhaps several hundred feet per day; 40 to 50 feet per day would be a rather high rate of flow.

Depending on how far the ground water must travel to reach a surface discharge area, water in shallow to moderately deep zones may remain underground from a few hours to 100 years or longer. Water at great depth may take tens or hundreds of thousands of years to pass through an aquifer, and some is completely stagnant.

The volume of ground water in the upper half-mile of the continental crust probably is about 3,000 times greater than the volume of water in *all* rivers at any one time, and nearly 20 times greater than the combined volume of water in all rivers and lakes. It is easy to see, therefore, that ground-water reservoirs have tremendous importance as



Vast expanse of the Antarctic ice sheet, shown in relief model, represents 85 percent of all the ice in the world.

equalizers of streamflow. Under natural conditions, most ground-water reservoirs are full to overflowing, and the overflow water provides what is called the base flow of surface streams enabling them to flow even during long, rainless periods and after winter snows have melted.

According to calculations, the volume of ground water in storage in the United States to a depth of half a mile is equivalent to the total of all recharge during about the last 150 years. This estimate is crude, but it helps to emphasize the important fact that ground-water reserves, although immense, are not wholly self-renewing annually. At places where they have been depleted by pumpage they might take many decades to recover even if pumping were stopped completely.

Consider for example, a location in the dry southwestern United States where annual recharge to an aquifer is on the order of only two-tenths of an inch of water. In such areas it is not uncommon to pump two feet or more of water per year for irrigation or other uses. In this over-simplified example if the entire aquifer were pumped at that rate, yearly pumpage would be equivalent to 120 years' recharge, and ten years of pumping would remove a 1,200-year accumulation of water. New recharge during the pumping period would be negligible. Mechanical problems and economic factors would prevent complete dewatering of an aquifer, but the example is valid in principle.

The next big items on the water-balance sheet are icecaps and glaciers. They may seem unimportant in the water cycle because, although the ice masses alternately shrink or grow a little from time to time, new ice is added about as fast as old ice melts. The polar ice masses, however, have a great influence

on weather, and everything that happens in the polar regions indirectly affects everyone throughout the world (NATURAL HISTORY, October, 1963). Moreover, if a shift in climate led to extensive melting of icecaps, there would be a rise in sea level with important effects in all low-lying coastal areas.

Mountain glaciers, such as those of the Alps in Europe (after which alpine glaciers are named), the Himalayas of Asia, and the Cascades of North America, are like average rivers in some respects. They are important locally, but they contain only an insignificant fraction of the world's water. The total volume of all alpine glaciers and small icecaps in the world is only about 50,000 cubic miles (comparable to the combined volume of large saline and fresh lakes).

An alpine glacier is one that rises in mountainous uplands and, by plastic deformation, flows along a valley. A continental glacier, or icecap, is one that is plastered over the landscape, mountain and valley alike. Icecaps tend to flow radially outward from their center of accumulation. Wastage occurs by sublimation from the surface and by melting or caving away around the periphery. Average icecaps, like those on Novaya Zemlya, Iceland, and Ellesmere Land, are analogous to average lakes.

They are locally important, but hold only an insignificant share of the world's water and only a small part of the total volume of perennial ice.

The Greenland icecap is an entirely different matter. About 667,000 square miles in area and averaging nearly 5,000 feet in thickness, its total volume is about 630,000 cubic miles. If melted it would yield enough water to maintain the Mississippi River for somewhat more than 4,700 years. Even so, this is less than 10 percent of the total volume of icecaps and glaciers. The greatest single item in the water budget of the world, aside from the ocean itself, is the Antarctic ice sheet.

Since the advent of the International Geophysical Year 1957, considerable information has been accumulated about Antarctica. Data on the thickness of the ice sheet are relatively scarce, but there is enough information to permit an approximate estimate. The area of the ice sheet is about six million square miles; the total volume therefore is between six and seven million cubic miles, or some 85 percent of all existing ice and about 64 percent of all water outside the oceans.

The hydrologic importance of the continent and its ice may be illustrated quite briefly. If the Antarctic icecap were melted at a suitable uniform rate it could feed:

1. The Mississippi River for more than 50,000 years.
2. All rivers in the United States for about 17,000 years.
3. The Amazon River for approximately 5,000 years.
4. All the rivers in the world for about 750 years.

The statistics about water given here are rather simple, but they are sufficiently important to tabulate in order to get them more clearly in mind. The table on pages 10 and 11 gives a comparative view of the world's water.

About 97 percent of all water in the world is in the oceans. Most of the remainder is frozen on Antarctica and Greenland. Thus, man must get along with the less than one percent of the world's water that is directly available for fresh-water use. Obviously, he must find much more effective ways of management if he is to prosper.

Water is a global concern, and the water cycle recognizes no national boundaries. Man has become so numerous and his activities so extensive that he has begun to affect the water cycle—certainly on a regional scale and very likely on a global scale. To learn more about the world's water and how to use it, many countries have joined together in a program aimed at overcoming the now-existing critical deficiency in hydrologic knowledge on a global scale.

Created in 1849, the Department of the Interior—America's Department of Natural Resources—is concerned with the management, conservation, and development of the Nation's water, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States—now and in the future.

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