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By Arthur M. Piper

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By Arthur M. Piper

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As geologists and engineers, all of us are sure to become ever more deeply concerned with problems of water supply in the United States and their many ramifications. Roots of this concern lie in the expectation that the use of water in the United States, measured at the points of withdrawal from the streams or from the ground, will double by about 1980. What, then, is present use in relation to potential supply?

As of 1955, the latest year for which comprehensive estimates are available[1], total withdrawal of water in the United States averaged about 240 billion gallons per day. Water used for generating electric energy is here excluded; it is six-fold greater in volume. For each family of four persons the major categories of use average as follows:

	Gallons per day	Percentage of total
Municipal and rural-domestic supplies	445	8
Irrigation	2,520	46
Industry (self supplied)	2,520	46
Total	5,485	100

Possibly each of you will balk at accepting these averages—that your family's share in the Nation's rapacious thirst for water is equivalent roughly to 9 barrels for personal use, and 500 barrels each for its share in irrigated crops and in the products of industry—each day. Consider, however, the ever growing number of kitchen-refuse disposers, mechanical dishwashers, and home swimming pools. Each of these is a water-hungry component in a standard of living that we take for granted and that is rising steadily; too much of the Earth's population, that standard is luxurious indeed. Consider also that, in manufacturing the component materials in your personal automobile, the water used would have filled a tank of dimensions roughly equal to those of your home.

In regard to the Nation's total use of water, several instructive comparisons can be drawn. Of all water withdrawals, 73 percent is taken from streams, lakes, and reservoirs; 19 percent is fresh water drawn from the ground; 8 percent is saline water, largely from the ocean; and about 0.1 percent is reclaimed sewage. Of the water withdrawn for municipal supplies, about 10 percent is consumed; of that for irrigation, about 60 percent; and of that for industry, about 2 percent only—in total, about 30 percent is consumed and 70 percent returns to streams. However, a substantial part of the return is contaminated or is warmer than natural so that, unless pretreated, its availability for re-use is depreciated. This is true of essentially all return from municipal and domestic use, of a considerable fraction of that from industry, and of some return from irrigation.

How is water use distributed geographically? Municipal and rural-domestic withdrawals are greatest in the densely populated Northeast. Withdrawals for industry are dominant east of the Mississippi River; those for irrigation are dominant west of that river. Of total withdrawals, that from ground-water sources is greater in the southern half of the Nation, and greatest in the Southwest.[2] As of 1955, the 10 most water-hungry States accounted for 55 percent of the Nation's water use. In rank by water use, (as shown in table on the following page).

[1] MacKichan, K. A., 1957, Estimates use of water in the United States, 1955: U. S. Geol. Survey Circular 398, 18 p.

[2] Piper, A. M., 1953, The Nation-wide water situation: The physical and economic foundation of natural resources, Part IV, Interior and Insular Affairs Committee, House of Representatives, U. S. 81st Congress, p. 1—4.

Rank	State	Withdrawal of water, 1955[3]	Principal use
1	California	30,706	Irrigation
2	Texas	17,176	Do.
3	Idaho	15,425	Do.
4	Wyoming	11,148	Do.
5	Pennsylvania	11,014	Industry
6	Ohio	10,756	Do.
7	Montana	10,101	Irrigation
8	Illinois	9,879	Industry
9	New York	8,884	Do.
10	Oregon	7,456	Irrigation

In 6 of these 10, water is used principally for irrigation; the 6 include the top-ranking 4 and account for 38 percent of the Nation's total use. The remaining 4 States use water principally for industry; they account for 17 percent of the Nation's total use.

Wherein does the prospect that these uses will double by about 1980 cause us concern? Superficial consideration in terms of Nationwide totals or averages might suggest, falsely, that no serious problems exist. Specifically, the United States receives about 30 inches of rainfall yearly; this is the gross natural supply. Of this gross, about 70 percent or 21 inches returns to the atmosphere by evaporation and by transpiration from nonirrigated crop plants, forest trees, forage plants, and native vegetation. The residual 9 inches constitutes the net supply available for man's use. Presently, about 6 inches continues to flow to the oceans. Only 3 inches is withdrawn by man for his use, and of this only about 1 inch is consumed.[4] Alone, these averages might be misconstrued, to indicate that even though present use were doubled about three-fourths of the natural net supply would remain unconsumed.

Actually, prospective problems of water supply are perplexing indeed. A principal causative factor is that the natural gross and net supplies are distributed most unevenly and greatly out of proportion to current and prospective demands. Specifically, among 12 major drainage basins spanning the United States, gross supply (rainfall) ranges about from 51 to 10 inches, or from 170 to 33 percent of the Nation-wide mean. Net supply (runoff) ranges from about 19 inches to 1 inch, or from 235 to 15 percent of the Nationwide mean. East of the Mississippi River, net supply ranges from 50 percent of the gross in the north Atlantic Coast basins to about 35 percent in south Atlantic Coast basins. West of the Mississippi River, net supply ranges from nearly 60 percent of the gross in the Pacific Northwest to about 10 percent in the Missouri River, west Gulf Coast, Colorado River, and Great Basin areas.[5]

Withdrawals range from about 5 to 85 percent of runoff among the several major basins. Percentage of net supply committed to use is least in the south Atlantic Coast and Pacific Northwest basins. It is greatest by far in the Colorado River and Great Basin areas. There, even allowing for re-use, net supply is little more than reasonably sufficient in ordinary years and is deficient in the driest years. In many areas of concentrated use, both in these areas and elsewhere, the demand for water is beginning to exceed local net supply. In certain areas, the net local supply has been deficient chronically and present withdrawals in part are "mined" from ground-water storage. Thus, a basic future problem will be that of conveying water in large volumes from natural sources to places where it is desired. Not all the prospective deficiencies can be resolved by conveyance, within acceptable limits of cost. Disturbing corollaries of this are that in some areas economic development will be limited by availability of water; in certain present areas of water mining, economic depreciation may ensue ultimately; remaining areas must absorb much more than the Nationwide average in expanded water demand. Few areas can do so easily.

A second factor in our prospective concern is that net water supply varies greatly from year to year, season to season, and even from day to day. Its extremes, flood and drought, impose large damages to property and to crops. In few areas is the natural dry-season flow of streams equal to the local demand for water, either presently or prospectively. Up to some limit of economic feasibility that has not been reached as yet, the extremes and the variability of supply with time must be reduced by further regulation of streamflow and by thoughtful management of all water sources, on and under the land surface.

[3] In million gallons per day.
[4] Leopold, L. B., 1959, The nature of our water problems: Missouri Basin Inter-Agency Committee, Minutes of 109th meeting, p. 3.
[5] Piper, A. M., op. cit., p. 4—6.

The potential for management of ground-water reservoirs calls for emphasis. These are functional components in Nature's system for draining the land. They are recharged continually by water that infiltrates the land surface, in whatever amount the infiltrate exceeds the sum of evaporation, transpiration, and the retentive capacity of the soil. They convey water by slow movement. They discharge water from springs and seeps and so sustain the flow of streams when no rain falls. These reservoirs are a potential source separate and distinct from the streams.

Ground-water reservoirs contain the largest fresh-water storage in the Nation—in the aggregate possibly in the order of 10 years' average rainfall or 35 years' average runoff. A small part, and only a small part of this storage is available for use by man.

Ground-water reservoirs now yield about 19 percent of the Nation's withdrawals of fresh water. Although some have been and are being overdrawn, others are underdeveloped and could yield much more. Some can be operated to store, and later to yield, water that otherwise would escape as unused runoff or would be dissipated by evaporation and transpiration. In other words, some but not all can be operated to increase the supply of withdrawable water.

These two factors in our concern about water will have their strongest impact in industrial areas, where the expected demand for water is two and a half or three times that of the present. In contrast the expected water requirement for municipal and rural-domestic supplies is about one and a half times that of the present; the expected requirement for irrigation supplies is about one and a third times.

Other aspects of water supply for industry are instructive. About 75 percent of such water is for cooling or heat exchange, and half of this for condensing the spent steam at steam-electric plants. Next in volume is water for washing, grading, or moving materials or products and for flushing wastes. For such uses, much of the water need not be high quality. A substantial and increasing percentage of the remaining industrial water must be virtually free of organic or mineral matter, acids, or gases. For example, feed water for the boilers of modern steam-electric plants must be of very high quality to inhibit corrosion and formation of scale. Processed foods, beverages, many of the synthetics, and other commodities require water as a raw material. For many of these the water not only must be of high quality in general, but also must be virtually free of particular mineral substances that would impair grade or stability of the product.

Special emphasis on the synthetics is in order. Without exception, the products of synthesis require much more process water than the natural materials they replace—for example, rayon and nylon much more than natural fibers, synthetic rubber much more than natural rubber, and so on. Many synthesized materials and products are superior in quality; we can expect only that greater and greater reliance will be placed on synthesized rather than natural materials. This is compounded by processes of synthesis for which the raw materials may be grown as a crop. But growing such crops will require either soil water or irrigation water. What is the end-point water requirement? A reasoned answer seems progressively more remote.

Preceding aspects of the industrial-water situation lead to the third and final factor in our concern about water—namely, water quality. Desirable standards of public health and the requirements of industry both call for water of high chemical or bacteriologic purity, or both. Yet our major centers of population and industry create ever increasing quantities and kinds of toxins and pollutants that all too commonly have been discharged promiscuously and allowed to depreciate the usability of water sources. A present and expanding problem is that of improving the quality of naturally inferior waters, abating and inhibiting pollution, and conveying wastes to thoroughly "insulated" disposal areas.

There are no panaceas for prospective water-supply stringencies. Improved management of land and forests, weather modification, and desalting of brackish waters or brines may help to alleviate the stringencies in part. As to weather modification, for example, "cloud seeding" may cause a small increase in rainfall at some particular place or time and to that extent may seem to increase the local water supply. However, not yet has it been demonstrated that the increase would not have occurred naturally at another place or time. As to desalted brackish waters or brines, the cost now in prospect can compete only with that of the most costly of waters from conventional sources, and that where the desalted water can be produced within the area of use. The added cost of conveying desalted water from point of manufacture to a place of use that is either distant or at substantially higher altitude seems prohibitive for most potential uses within the foreseeable future.

Neither is there a single and simple means of resolving the prospective stringencies. In part, new industry can and will go to uncommitted water sources, but others will be too much constrained by the established pattern of transportation routes and market areas. Some areas now in irrigated agriculture will convert to industry, and certain of these conversions will diminish the local requirement for water. Increasingly, metropolitan areas will find a reasonable balance between concentration and dispersal of population in relation to availability of water for those populations and all their enterprises. In general the Nation must learn, and heed, ways to extract more service from its known waters. Re-use of water must increase. The Nation must accept the higher cost of water that will ensue. Otherwise many areas will become water short, eventually if not within the next quarter-century.

Two examples of re-use by industry are noteworthy. Most of the petroleum refining industry uses about 20 gallons of water for each gallon of product. The large refinery of the Humble Oil Co. at Baytown, Tex., in effect recirculates its water 15 times.[6] The plant of the Kaiser Steel Corp. at Fontana, Calif., recirculates its water and, according to its report, requires about 1,200 gallons of make-up water per ton of steel produced. The industry-wide average is about 65,000 gallons of water per ton of steel. These two examples are from plants where water is not available in abundance. They are extremes; their ratios of recirculation cannot reasonably be expected of all industry. Further, repeated re-use of water depreciates its quality and compounds the problems of water-quality control that have been outlined. It seems likely, however, that a considerable part of the water required by the expected two- to three-fold expansion of industry can be provided by re-use—at some increase in cost.

A large portion of the fluid wastes from municipalities and industries can be reclaimed feasibly, especially for uses that do not require water of the highest purity. Certainly, the Nation cannot indefinitely dispose of its wastes merely by keeping them dilute and discharging them promiscuously.

Beyond these measures of conservation in use, more and more we shall face the necessity of using each natural water source—stream, lake, or ground-water reservoir—at its optimum perennial yield. Streamflow will be regulated comprehensively by impounding water now passing to the oceans. Commonly, the regulating facilities will perforce be planned and operated as a single, integrated mechanism in and for each drainage basin. All this we must learn to do without unreasonable prejudice to individual uses that may be, in part, mutually exclusive.

For water-supply management of the scope implied, we are informed all too poorly. To cite only a suggestive few examples, we have incomplete or only rudimentary information on the geochemistry of natural waters—that is, on the relation between dissolved mineral constituents of the waters and geologic features of their source terranes; on variability of streamflow in relation to land forms, land-surface permeabilities, and other terrane features; on the "geometry" of alluvial stream channels at equilibrium with various rates of flow; or on the principles of sediment transport by streams. These areas of deficient information, and many others, offer an exceedingly broad field for research that will test severely the capability and imagination of geologist, engineer, and workers in numerous allied disciplines.

In such management we shall perforce tamper ever more deeply with Nature's water-supply mechanism, the complex "hydrologic cycle." We shall do so with the hazard of effects more disadvantageous than the advantages sought. Our policies of water-management must be technically sound. As the basis for decisions on such policies we have a fair store of statistical records on the climatic and hydrologic variables. We could use more

[6] Paley, W. S., and others, 1952, Resources for freedom: President's Materials Policy Commission Rept., vol. 5, p. 94.

such records but there is no ground for hope that we can obtain them at every point and for every environment with which we shall be concerned. Far more fundamental is a present need to search deeply into the records now available, and to extract from them a more intimate knowledge of the many vagaries in the hydrologic cycle. Only so can we interpolate and extrapolate soundly from current records to anticipate water-supply problems. To prospective questions in this field, reasoned answers will rest with the earth scientist (using the latter term in a broad sense).

One example suffices to illustrate this point. There is suggestive evidence that, with a periodicity in the order of a century or possibly a few centuries, climate "swings" between extremes of warm-dry and cool-wet. How great and how regular is this swing? Rather than a "swing," is the variation a progressive trend more toward one of the extremes than the other? Where does our current environment fall in relation to the extremes? Answers to these questions would have a most practical application—the expected stringencies in water supply may prove to be either more or less severe than implied in this paper, to a substantial degree. Answers, or their orders of magnitude, might be found now through broadly based rather than overly specialized research.

Boldly conceived water-management works on a large scale, even a grand scale, will become numerous. These must be adapted soundly to their engineering and geologic environments; the skills of the engineer, the hydrologist, the geologist, and other specialists must be blended intimately if sound plans are to result. Three diverse examples will be outlined.

The so-called California water plan probably is fairly well known to all of you. In simplest terms it proposes to impound water that is surplus to expected requirements in the northern part of the State, and to convey that surplus southward to areas that are outreaching their local sources. Large reservoirs and dams, also uncommonly long canals and tunnels are among the component works. Applied earth science must answer the obvious questions as to stability of foundations and cuts, availability of construction materials, and the like.

In southeastern Idaho, the Bureau of Reclamation is studying the feasibility of recharging the highly pervious basalt of that area from the Snake River during years of excess runoff, and of withdrawing the detained runoff by pumping from wells during dry periods. The scheme is sound in principle but unprecedented in scale. The subsidiary problems in the field of earth science are just beginning to emerge.

As its flow has been depleted by use, the lower reach of the Colorado River no longer can transport to the Gulf of California all the sediment load. De-silting works and channel dredging have afforded local temporary relief, but may be inadequate for the long haul. Channel aggradation is evident along the reach of the river in Mexico, and effects adverse to the United States are increasing. Under the artificial regimen created by man, channel form is no longer in equilibrium with river flows. Pressure is mounting for a stabilized channel, but minimum outflow to the Gulf. No adequate plan to this end exists, but is becoming increasingly urgent. Such a plan can be derived only from applied earth science.

All three of these examples have aspects that call for serious reflection. First, the measures adequate for resolving the water-management problem outreach the competence or jurisdiction of private enterprises and are region-wide, State-wide, national, or even international in scope. We can expect only that the necessary scope of water-management works will enlarge rather than shrink. Second, the works that are planned or in prospect run counter, in some degree, to the commonly accepted "rights" of individuals in the use of water. In effect, the plans involve extensive "pooling" of individual rights, with those rights made whole from a common managed source rather than from individual sources. We can expect only that such pooling and then making whole will become more and more necessary.

Certain implications of these expected trends warrant emphasis. The earth scientist concerned about or involved in prospective problems of water-supply management will find his professional perspective tempered by, and adapted to, complexly interwined considerations of economics and sociology. This need not be a deterrent; it should be accepted as a challenge.

Water is essential to life but has not been valued accordingly. It has been taken for granted, and in the commodity market of the United States it usually is priced at less than 10 cents a ton ($135 an acre-foot). With little protest we pay far more, by weight, for disposing of household trash. This disparity between implied "value" and present cost points up an emerging fact—not much longer can we use water once, pollute it in some degree, and throw away a polluted residue which is two-thirds of the whole. The prospective water-supply situation can be managed and deserves our most serious attention.

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