Our Growing Demands for Water

—What To Do About Them—

By CARL G. PAULSEN, B.S.C.E.

THE BLEAK RUINS of the cliff dwellings in the southwest and the associated remnants of irrigation ditches built by a people long forgotten suggest that a former civilization of our country was a mortal victim of a shortage of water. Water is also the key resource of our present civilization, and, as population increases and industry expands, we are confronted more and more frequently by the question of what to do about our growing demands for water. Fortunately, we of the present day have the knowledge and mechanical facilities to deal with problems of water supply in ways infinitely better and more effective than those antecedent tenants of our country.

Taken as a whole, the earth has a marvelously efficient water supply system. In a sense the sun acts as a huge pump circulating water in a closed circuit, the hydrologic cycle. As water comes within our reach, we use it as we need it, and after its temporary service, it continues its natural course in the cycle. Notwithstanding the remarkable efficiency of this system, a serious problem of utilization is presented by its lack of uniformity. The quantity and quality of our water supply are variable in time and place. The present extended drought in the south and southwestern States and many of the numerous public water supply shortages experienced throughout the United States during the last few years are evidence of this variability.

The shortages are also aggravated by our ever-increasing requirements for water. Our withdrawal use of water increased fourfold between 1900 and 1950, and it has been estimated that it will double between 1950 and 1975. Modern domestic conveniences have greatly increased our water requirements. Air conditioning, automatic home laundries, and automatic dishwashers were unheard of 50 years ago and were not common even 25 years ago. Many household appliances that are not ordinarily thought of as heavy users of water have greatly increased the electric power consumption, and that, in turn, has increased the water use at the central hydroelectric or steam powerplants.

Advances in technology have added greatly to industrial water requirements, both in quantity and quality. Synthetic fibers, such as rayon and nylon, require much larger quantities of water for processing than the natural materials they replace. Synthetic rubber produc-

Mr. Paulsen, chief, Water Resources Division, Geological Survey, Department of Interior, has served continuously in the Survey since 1913, as a hydraulic engineer on water investigations. He is the author and co-author of many technical papers and articles on water and of many water supply papers of the Geological Survey. Mr. Paulsen's paper was presented at the annual meeting of the American Association for the Advancement of Science, December 27, 1954, at Berkeley, Calif.

tion requires large quantities of water not needed in production of natural rubber. Each additional stage in oil refining requires additional process water, increasing the quantity required per unit of crude oil considerably above that needed by earlier simple stills.

Large Supply—Unevenly Available

Much has been said and written concerning the nationwide water situation. If we use long-term average runoff as an index, we can estimate our annual available water supply at about 1,300 million acre-feet, as compared with a withdrawal use at present of about 195 million acre-feet. Even regionally the situation is not serious, but in certain local areas it is critical. The total average annual supply in the 17 western States is about 390 million acre-feet, as compared with the present withdrawal use of about 100 million acre-feet. Except for irrigation, only a small part of the water withdrawn for use is consumed; some estimate the amount to be as little as 10 percent. Therefore, the ratio as a whole between supply and demand appears even more favorable if consumptive use, rather than withdrawals, is taken into account.

We can see that nationwide this country is blessed with a plentiful supply of water. However, some areas have a surplus of water all of the time, whereas other areas may have a surplus during some seasons, and still other areas seldom have sufficient water. Differences in water supply are striking. Using the runoff as an index of available supply, the greatest supply at any place in the United States is along the coast of the Pacific northwest, particularly in the Olympic Mountains, where the average annual runoff of Wynoochee River at Oxbow, Wash., would cover its drainage to a depth of about 150 inches. On the other hand, several areas in the southwest have an average annual runoff of less than one-fourth inch, and no streams flow out of the Great Basin.

The variation in daily streamflow may be very great. In some arid or semiarid regions 90 percent of the annual runoff may occur in a single week. On the other hand, some streams have an exceptionally uniform rate of flow. The Loup River and its tributaries draining the Sand Hill region of Nebraska are noted for their uniform flow. The average flow on about 75 percent of the days is within 10 percent of the average annual flow. The Deschutes River, a spring-fed stream in Oregon, is another example of uniformity of flow.

The annual runoff of most streams, however, is highly variable. A stream in which the variability is especially high is the San Gabriel River in California in which, during the 56-year period 1896 to 1951, the annual runoff averaged 116,000 acre-feet but ranged from 10,000 acre-feet in 1899, or less than 9 percent of the average in 1922, to 410,000 acre-feet or 353 percent of the average.

The ready availability of the large quantities of good water required by our modern communities was not a consideration in their original establishment, and, as those communities grow, the problems of water become more and more difficult and costly of solution. Los Angeles is an extreme example of this kind of situation. There, 3 percent of the Nation's population lives in an area that receives only 0.04 percent of the Nation's precipitation and has less than 0.0005 percent of the Nation's streamflow. Consequently, it has been necessary to import large quantities of water great distances at great expense.

This is the broad picture then, the base from which we must proceed: In terms of the entire country, we have a generous supply of fresh water, but it is so unevenly distributed that the supply is more than ample to meet our present requirements in some places and insufficient in others. Our water supply, very large though it may be, is variable in time, place, and quality. We must recognize, therefore, that in many areas there will never be as much water as can be used. Consequently, our concern is to take stock of these variables so that we may undertake such steps as seem feasible to derive more benefit and service from our water resources.

Several possible steps are suggested: It may be possible to develop new sources of supply, as by inducing artificial precipitation and demineralizing saline waters. The present supplies may be developed further by storage, control of pollution, and so forth. Water losses may be reduced. Existing supplies may be utilized further through more efficient use and by re-use.

Developing New Sources of Supply

The possibility of increasing precipitation by cloud seeding is being explored by several groups, but definite conclusions as to the success of cloud seeding in stabilizing or increasing to a substantial extent water supplies in areas of short supply seem not yet conclusively demonstrated.

The prospect of increasing our fresh water supply by converting saline water to fresh water appears to be promising under certain conditions.

Congress, in 1952, passed Public Law 448, providing for research which may lead to development of practical processes for converting saline water to fresh water. The Saline Water Conversion Program is conducted by the Department of the Interior by coordinating and encouraging research in this field through federally financed grants and contracts.

It is possible that converted saline water can be used economically by some municipalities, especially those in water-short areas of high productive value, if fresh water can be provided at the cost of about $125 an acre-foot, and for irrigation in highly productive areas if fresh water can be supplied at a cost of $40 an acre-foot or less.

One of the processes being investigated—the ion-permeable membrane process—might prove to be an answer to some water needs since its cost is proportional to the dissolved solids content of the raw water. Typical preliminary cost estimates of conversion of fresh water are about $450 an acre-foot for sea water, $40 an acre-foot for saline water from Texas containing about 10,000 p.p.m. of dissolved solids, and $4 an acre-foot for water from South Dakota with a dissolved solids content of about 855 p.p.m.

The present fresh water supplies can, of course, be developed further and in many places quite extensively by the use of additional storage reservoirs and by improving the quality of the water. As our water resources become more highly developed, water quality becomes increasingly important. Poor quality is detrimental to the utility of a supply because it makes the water unsuitable for some use and for certain other uses, such as irrigation, it necessitates the application of larger quantities to prevent an undesirable accumulation of minerals in the soil.

Storage facilities, both surface and underground, enable us to extract more service from our water supply. During the last 7 years the surface reservoir capacities for the Nation have been increasing at an annual rate of more than 16 million acre-feet. In January 1954 there were 1,300 reservoirs in the United States having a usable capacity of more than 5,000 acre-feet. Their combined usable capacity was 278 million acre-feet.

In the 17 western States, the total usable reservoir capacity amounted to 193 million acre-feet of which more than 59 million acre-feet is provided for irrigation. Many additional reservoirs of less than 5,000 acre-feet capacity are used for irrigation. According to the Bureau of the Census, about 5,500 reservoirs having a capacity of less than 1,000 acre-feet were used for irrigation in the 17 western States in 1950.

Although the water stored at any one time in all the rivers and lakes of the Nation is enormous, the volume of fresh water stored in the countless natural openings in the soil and rocks beneath the water table is probably several times greater. The volume of water stored beneath the land surface is dependent primarily upon the physical characteristics of the rocks and the climate. Nevertheless, the continued usefulness of a ground water reservoir ultimately must depend, not on its extent and the quantity of water originally contained but on the conditions affecting both replenishment and transmittal of the water from recharge areas to the point of use.

Surface and subsurface reservoirs have several characteristics in common. Sufficient water must be available to replenish them. Both are refilled during wet periods, so, in order to be of maximum use, water should be withdrawn during dry periods to make room for a new supply. A reservoir which is full all of the time is not serving its primary function. This is a characteristic of subsurface reservoirs that may be overlooked since they are not visible.

A ground water reservoir is similar also to a surface reservoir in that to be useful a supply of water must be available to refill it. The natural recharge rate of some ground water reservoirs may be low, but under favorable conditions artificial recharging can be effected by spreading storm runoff on the recharge area, or by injecting water through recharge wells. Artificial recharge by water spreading is not new; it has been practiced on the cone of the Santa Ana River in California since 1912 and in other places as well.

Improving the Quality of Water

The quality of water in storage can be improved by mixing low flows that are high in dissolved solids with less concentrated flood flows that are wasted, by reducing or preventing undesirable wastes reaching the streams, and by reducing or preventing salt water encroachment both in our streams and in our ground water reservoirs. The chemical and physical quality of surface waters, other than lakes, varies almost continuously. Flood flows are usually less mineralized than dry weather flows. By storing the better quality flood waters and gradually releasing them to mingle with the more mineralized low flow, we can improve the quality of the low flow. Stored water can generally be used more advantageously than natural flow because of its more uniform and better quality.

Surface water storage upstream may improve the quality of water in tidal reaches of a stream. The water in the estuaries of many streams is a mixture of fresh water and sea water. The distance that the saline water flows up the tidal stream depends on the flow of the stream; the lower the flow, the farther upstream the saline water extends. When low flow is increased by storage and release of flood flows, the saline water is flushed toward the mouth of the stream. Although this does not increase the total supply of fresh water, it does make fresh water available along a reach of the stream that would otherwise have been contaminated by salt water.

Abatement of unnecessary pollution would increase the usable supply of water in many areas. For example, brine wastes from oilfield operations in the Arkansas River Basin have increased the dissolved solids in the river water in some places to an undesirable extent, and have also contaminated ground water in some places, either directly from brine-disposal ponds or indirectly by infiltrating contaminated river water.

The usefulness of large quantities of fresh ground water has been destroyed by encroachment of saline water. This occurs where large quantities of fresh water have been pumped from wells and a nearby body of salt water is hydraulically connected to the fresh ground water supply. When the water level in a fresh ground water reservoir is lowered to such an extent that salt water will flow into it, contamination of the fresh water supply will occur, with ruinous results. Salt water encroachment may occur from deep-lying strata through improperly constructed or corroded wells, or, in coastal areas, from the sea. In one place, encroachment from the sea has been halted by inserting a fresh water barrier between the two bodies of water. The barrier is erected by introducing fresh water into a row of recharge wells in large enough quantities to create a hydraulic gradient from the barrier to the salt water.

Sometimes salt water encroachment can be reduced or prevented by a better distribution of wells and by plugging abandoned wells which form the connection between ground water formations. As larger and larger quantities of ground water are developed, especially in coastal areas, the opportunity for encroachment will increase. Therefore, we must be ever watchful to keep salt water encroachment to a minimum. The shortage of water and devices for the control of its quality offer very effective means for further developing available supplies to meet the growing demands.

Practicing Water Conservation

Many millions of acre-feet of water are lost annually by useless evaporation and transpiration. To the extent that these losses can be reduced, the usable supply of water can be increased.

Evaporation from water surfaces is an unavoidable and nonrecoverable loss. In the 17 western States evaporation from reservoirs is roughly estimated to be about 15 million acre-feet per year. This does not include evaporation from water surfaces of natural streams. Although the evaporation process is unavoidable, the total loss by this cause can be held to a minimum by careful locations of reservoirs and by establishing suitable operating procedures. Climatic factors affecting evaporation often vary widely within a drainage basin. If alternate reservoir sites are available, evaporation losses can be held at a minimum when the site selected is one which has the smallest surface area and climatic conditions that are least favorable for evaporation. Water losses from a system of reservoirs can be reduced by using water from those reservoirs having a high evaporation potential first so that their surface area is appreciably reduced.

The Geological Survey of the Department of Interior in collaboration with several other Federal agencies has completed a research project to test several methods of measuring evaporation reliably from large bodies of water. The results of these tests are now being applied to Lake Mead, Nev.

The Geological Survey is also making a study of the evaporation from Lake Colorado City in Texas. This lake is used as a cooling pond for a large steam powerplant. The object of the study is to determine evaporation from the lake, including the effect of added heat, and to determine the effect of added heat on the thermal structure of the lake. The results of this study will enable us to estimate the extent that ponds may be used for cooling and enable us to decide whether the use of cooling ponds is good conservation practice.

Bodies of ground water, like surface reservoirs, may be subject to large losses. One source of large losses is transpiration by phreatophytes, or water-loving plants, such as salt cedar which have little or no economic value. It has been estimated that salt cedar may transpire as much as 7 acre-feet of water per acre annually. A Geological Survey engineer has estimated that phreatophytes of all kinds now cover about 15 million acres in the 17 western States and may consume in the aggregate as much as 20 to 25 million acre-feet annually, a volume of water equal to about twice the average annual flow of the Colorado River at Lees Ferry, Ariz.

A second source of substantial loss from ground water is evaporation from areas where the water table is only a few feet below the land surface and its overlying capillary fringe extends up to the land surface. Evaporation from such areas is continuous, being sustained by water which rises through the capillary fringe, just as a flame is sustained by capillary rise of fuel in the wick of a kerosene lamp. Evaporation losses from such areas are large. In the Big Smoky Valley of Nevada evapotranspiration losses may be considerably in excess of 100,000 acre-feet a year.

Large losses from shallow ground water bodies by evapotranspiration have an adverse effect on the quality of the remaining water. Plants use only a very small part of the dissolved solid content of the water, and none of the minerals are carried away by the evaporated water. As a result, these dissolved solids become concentrated in the water that remains or are precipitated in the soil, to be redissolved by subsequent rains. Therefore, the reduction of losses in these various ways would not only increase the quantity of water available but would also improve its quality.

Re-use of Waste Water

Use of waste or polluted water, wherever quality requirements will permit, is another way of increasing the effective water supply. The practice of using sewage effluent for irrigation is not new; it has been known for almost 100 years. Treated sewage effluents have been used also as a source of water for industry and for ground water recharge. As an indication of this trend, the Shell Oil Company recently made arrangement to reclaim waste water from the Ventura, Calif., sewage disposal plant at the rate of 2 million gallons a day. Some sewage is not suitable for re-use, especially if the raw water contains a high concentration of dissolved solids, or if the sewage contains undesirable industrial wastes. In general, the domestic use of water will increase the dissolved-solids concentration by an average of 100 to 130 p.p.m.

The University of California Engineering

Department recently estimated that in California there is approximately 1 million acre-feet of waste water available for re-use. The Geological Survey estimated that about 4 million acre-feet of water was used for industrial and domestic use from public supplies in the 17 western States during 1950.

Industry frequently uses its waste water by recirculation. Re-use of water in industry does not reduce the consumptive use of water but greatly reduces the withdrawal use. The water requirements within an industry range widely, indicating a wide range in economy of water use.

Many examples can be cited where re-use of water has tremendously reduced the water intake. Probably the most frequently cited example is the Fontana Plant of the Kaiser Steel Company where the intake per ton of steel is only 1,100 gallons as compared with the industrywide value of 65,000. A steam electric powerplant recently constructed in Texas uses only 1 gallon of water per kilowatt hour output, as compared with 60 to 100 gallons for steam powerplants where the cooling water is not circulated.

The Water Resources Division of the Geological Survey recently made a survey of the water requirements of the pulp and paper industry. On the average, the maximum rate of water use per ton of paper produced was about 5 times the minimum rate in making similar products in the same general area. A similar survey of the water requirements of the carbon black industry shows an even wider range in water use. Process water required to produce a pound of carbon black ranged from 0.79 gallon to 20 gallons by the furnace process and from zero to 0.19 gallon by the contact process.

Much of the industrial water is used for cooling and, therefore, cooling towers and ponds become important where water is re-used. Each recycling of the water through a cooling tower reclaims about 95 percent of the water. The only loss from the system is that small quantity evaporated to accomplish the cooling and a small amount of blowdown to maintain reasonable concentrations of dissolved solids in the recirculated water. The loss from a cooling pond is the evaporation owing to the addition of warmed water plus natural evaporation and seepage. The present rate of installation of cooling towers indicates increased re-use of water. In 1953, the member companies of the Cooling Tower Institute sold 38 installations to private and public steam-electric generating plants having a combined capacity of 1 million gallons a minute.

Many of the industry's water requirements, particularly that for cooling, can be adequately fulfilled by salt water where it is available. To safely use saline water, industrial equipment must be fabricated of material to resist the chemical aggressiveness of the water. The quantity of saline water used is imperfectly known, but we do know that at least 14 million acre-feet is used annually and that the total quantity is probably much larger. If industry could afford to pay the higher installation and maintenance costs, a great deal more saline water could be used.

Stretching the Available Supply

Although over much of the Nation there is plenty of water, the supply is extremely variable, and many communities will at times not have enough to satisfy their growing needs. A major problem then is to derive the maximum benefit and utility from our water resources.

Several courses of action are open by which we can stretch the available supply to satisfy the optimum use:

We can develop our present supplies more intensively by construction of additional reservoirs, development of presently unused ground water reservoirs, and more extensive use of artificial recharge of ground water reservoirs.

We can increase the usable supply by reducing or preventing contamination from saline waters, urban wastes, or industrial wastes, along the lines encouraged by the Public Health Service under the Water Pollution Control Act. Many acre-feet of water are lost annually by unproductive evaporation and transpiration. Reduction of these losses will in effect increase the quantity and improve the quality of our usable water supply. Our water supply will go further if we closely match water quality and water requirements, that is, if we use high quality water for uses that require high quality water and use water of poorer quality where it can be tolerated. Thus, we may be able to use some sewage effluents and saline waters which are presently wasted. A large quantity of waste water can be salvaged by re-using or re-circulating water in our industrial plants. An acre-foot of water salvaged and re-used is just as effective as an acre-foot of newly developed water. Possibly some additional water can be provided by conversion of saline water to fresh water.

In many parts of the Nation many of the inexpensive sources of water have already been developed. As our water resources become more and more intensively developed, the cost of new developments will continue to increase. At the present time, most of the conservation measures that are mentioned are technically feasible. In some places they are economically feasible. The economic feasibility of these measures will become widespread as competition for water increases.

The solution of our problem requires facts—facts on a local scale involving all the variables of streamflow, storage, and movement of ground water, and the mineral and sediment concentration and temperature characteristics of the water. We have made considerable progress in collecting, compiling, and interpreting data on water resources, but we need to know more, especially more details on the local scale. We need to know more about evaporation and transpiration losses, their magnitude and methods of reducing them. We need to know more about reclaiming waste water and about the water requirements of industry both as to quantity and quality.

Detailed knowledge of our water resources and of their uses is a prime essential to assure the most benefit and utility from our water resources.

Departmental Announcements

Oveta Culp Hobby, Secretary of Health, Education, and Welfare, resigned from her position effective August 1, 1955. Mrs. Hobby was appointed Federal Security Administrator on January 21, 1953, and was made Secretary on April 11, 1953, when the Federal Security Agency became the Department of Health, Education, and Welfare. She resigned the positions of editor and publisher of The Houston Post and executive director of Station KPRC–AM–FM–TV, Houston, Tex., at the time of her appointment.

Mrs. Hobby came to her Cabinet post with a distinguished record of public service. She directed the Women's Army Auxiliary Corps in 1942. In 1943 she was appointed director of the Women's Army Corps with the rank of colonel. She was awarded the Distinguished Service Medal by the United States Government and the Military Merit Medal by the Philippine Government. The author of a textbook on parliamentary law, Mrs. Hobby served for several years as parliamentarian in the Texas House of Representatives. She also served on the board of directors of the American Society of Newspaper Editors.

Marion B. Folsom, Under Secretary of the Treasury since January 1953, has been named by President Eisenhower to succeed Secretary Hobby. Active in Government and private industry social security programs for more than a quarter of a century, Mr. Folsom was a member of President Roosevelt's advisory council which helped draft the original Social Security Act in 1934. In subsequent years, he served on advisory councils which studied operations of the social security system and made recommendations to the Congress. He worked with the Department of Health, Education, and Welfare on the plans which in 1954 resulted in congressional amendments to extend social security coverage and benefits. He also was chairman and a founder of the Committee of Economic Development.

Mr. Folsom was instrumental in the development of the group life insurance program for Federal employees which was put into effect in August 1954. Several years earlier he had helped organize the Group Medical Care Insurance Plan in Rochester, N. Y.

A graduate of the University of Georgia and the Harvard Business School, Mr. Folsom was treasurer and a director of the Eastman Kodak Company from 1914 until January 1953, before he came to the Department of the Treasury.