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WATER—OUR SECOND MOST IMPORTANT NATURAL RESOURCE

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Along with air, without which man cannot survive for more than a few minutes, water is one of our most essential natural resources. Without replenishing his internal supply of water, man cannot survive for more than about a week. In fact, were it not for water, no organic matter would exist, for water is the most abundant element in protoplasm, the essential material of which plants and animals are composed. Water comprises approximately 66 percent of the weight of an adult human. The amount of water by weight in animals varies from as high as 97 percent in the jellyfish to as little as 48 percent in the pea weevil. Resting stages such as seeds and spores may contain proportionately less water than fully developed animal life; however, there is some water present even at the least advanced stage of development. Thus from a purely physical viewpoint, all life is dependent upon water.

In addition to its indispensability for biological survival, water is of crucial importance to business and industry. Water is used in many manufacturing processes and in construction, either as an aid in production of, or as an ingredient in, the final product. While it is conceivable that substances other than water could be used for some processes, the cost and the technology of the processes would be unfavorably affected by such a change because of water's relatively low cost and its unique characteristics. This article, after a brief summary of the physical and chemical properties which make water unique as a substance and necessary to the sustenance of life, will survey the present supply of and demand for water and estimate future demand therefor. Methods of using the existing supply of water more efficiently through reuse and redistribution will be suggested. The engineering and technological aspects of these problems are beyond the scope of this article and will not be discussed.

I. PROPERTIES OF WATER

Although a discussion of the chemical and physical properties of water is more properly within the realm of a paper dealing with the

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physical sciences, an acquaintance with some of water's peculiarities may serve to underscore the importance of our water resources. The physical and chemical properties of water make it a unique substance. Some of these properties produce reactions which are not found in other substances. Other properties of water result in reactions which while consistent with the normal pattern as found in other substances are extreme as compared to them.

Chemically, water is an extremely stable compound. Indeed, it may be broken down into component parts, hydrogen and oxygen, only with the expenditure of great amounts of energy. A similarly great amount of energy is released when hydrogen is combined with oxygen to form water.[1] As a result of this property, water may be depended upon to remain stable during any normal usage.

Water is exceptional in that its specific heat is among the highest known to man—only liquid ammonia and hydrogen have higher specific heat values.[2] Specific heat represents the amount of energy which must be applied to a substance to raise its temperature a specified amount. Specific heat is thus a representation of the capacity of a substance to absorb heat. Due to its high specific heat value, water absorbs much heat, which when released, causes the surrounding area to be warmed. This property is therefore responsible for the existence of less extreme changes of temperatures at the seashore than at an inland location since the nearby water has absorbed and must give up much more heat than the land surfaces at an inland area.

The latent heat of fusion of water is an additional factor which has an influence on climatic conditions. Latent heat represents the amount of heat which a substance absorbs without any increase in temperature until it is entirely melted. Conversely, it represents the amount of heat which a substance gives up without any lowering of temperature as it freezes. The amount of heat given up on freezing and absorbed during melting must be exactly equal for any single substance. Water's latent heat is unusually high, thus when water is being frozen it gives up heat, moderating the temperatures of surrounding areas. A reaction similar to that which occurs at the freezing point also occurs at the temperature for evaporation and condensation. This is the so-called latent heat of vaporization which for water is, in fact, the highest such value for any substance.[3] This factor is responsible for the milder temperatures at the seashore than at inland locations.

Still another thermal property of water is its unusual capacity to

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[1] Water may be produced by exploding a mixture of two volumes of hydrogen with one volume of oxygen at a temperature above 1190° F.

[2] Liquid ammonia has a specific heat of 1.12 at 50° F., hydrogen has a specific heat of 3.50 at 50° F., and water has a specific heat of 1.00 at 50° F.

[3] Water has a latent heat of vaporization of 1071. Ammonia, the substance with the next highest latent heat value, has a latent heat of vaporization of 480.

expand in a situation when almost every other liquid would be shrinking in volume. Most substances shrink in volume as their temperature goes down, growing more dense as they contract. As a result of this property of most liquids, the solid form of a substance will always sink in the liquid form. Water follows this rule until it reaches 4°C. (39°F.) at which point further cooling causes water to expand and become lighter until it finally gains about nine percent in volume at 0°C. (32°F.). In the absence of this characteristic of water there would soon be no life on Earth for the water would become perpetuated in ice on the beds of oceans, lakes and streams. As water froze it would sink to the bottom and gradually build up into solid bodies of ice from bed to surface. Such an occurrence would change the Earth's climate by removing the influence of the great surface waters as moderating factors on climate, with resulting temperature fluctuations of a severe character.

More than any other substance, water is most nearly the universal solvent. When an element or a compound breaks into its individual atoms or molecules in a fluid, it is considered to be dissolved. Different types of substances require different fluids to produce dissolution. Man has constantly been looking for a fluid in which every substance dissolves. At least 50 elements have been recovered from solution in seawater. As a result of this property, water is capable of carrying nutrients which are necessary to the survival of living organisms. Food taken in by humans, for example, must be dissolved before it can enter the bloodstream.

Water has a high ionizing power which permits the occurrence of many chemical reactions which would not take place if a particular substance was placed in any other fluid. The ionization process involves the separation of a substance into positively and negatively charged particles called ions. In the absence of ionization, chemical reactions including those which are necessary to provide both the materials and the energy to sustain life would not occur.

Due to the "hydrogen bond" which is the method by which water molecules are joined together, the surface of water is pulled together into a taut sheet known as surface tension. Only mercury has a higher surface tension value than water. The phenomena of capillary action—water's ability to creep uphill under certain conditions—and diffusion—the force that is primarily responsible for injecting molecules of water through the pores of a plant membrane which are far too small to permit passage in drop form—are caused by this property of water. Without these characteristics of water, nutrients would not reach the plant life and blood would not be able to complete the circuit in the human body.

Compressibility represents the measure of the amount of compaction which occurs when pressure is applied to a substance. Water is nearly incompressible, making it ideal for use in hydraulic systems.

This short summary of some of the more unique characteristics of water has been less than exhaustive. It should be sufficient, however, to instill some understanding of the many-faceted services that water performs for man. Comprehending the paramount importance of water to life itself, the problems to be considered in the balance of this paper and in the other papers in this symposium will hopefully take on an added significance.

II. Water Supply

The question is often asked whether we are running out of water. This question does not ask what we really want to know. We are certainly not running out of water. The total amount of water in the Earth's hydrosphere[4] today is approximately the same as that which has existed since the Earth's formation. Very little new water has been created through chemical combination and very little water has been destroyed by reduction to its chemical elements.[5] The question that should be asked is whether we are running out of *usable* water. There are two major factors which affect man's ability to use water. First, there is a problem of distribution, that is, are the water resources available for use where they are needed. Second, there is a problem of water quality, that is, are the water resources which are available in terms of location of sufficient quality to allow their use in the manner desired.

In order to determine the supply of water which is usable, an inventory of the Earth's total water supply will be taken and from that inventory, those parts which are not usable for one reason or another will be subtracted, leaving an approximate yet hopefully accurate accounting of usable water. The distribution of water available at any one time in the Earth's hydrosphere is shown in Table 1.[6] It is at once obvious from a perusal of Table 1 that the oceans are the Earth's greatest storage place for water. Although not shown on Table 1, the oceans account for approximately 97 percent of the Earth's total water supply. The waters of the ocean are not readily usable by man because of the high concentration of dissolved salts. While for most purposes the waters of the oceans are unavailable, in recent years the use of salt water in certain industries[7] and the devel-

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[4] The hydrosphere is that portion of the Earth and its atmosphere which contains water.

[5] Electrolysis is the process by which electricity is passed through water (containing a sufficient amount of an ionized substance to carry the current) causing the water to break down into its two components, hydrogen and oxygen.

[6] E. Ackerman & G. Löf, Technology in American Water Development 12 (1959).

[7] Salt water is presently used in industry primarily for cooling and cleaning purposes.

TABLE 1

Estimated Relative Quantities of Water Available Within the Earth's Hydrosphere

Item	Million acre-feet	Percent of total estimated fresh water present
1. Oceans	1,060,000,000	—
2. Atmosphere, earth's crust,* fresh water bodies	33,016,084	100
a. Polar ice and glaciers	24,668,000	74.72
b. Hydrated earth minerals	336	0.001
c. Lakes	101,000	0.31
d. Rivers	933	0.003
e. Soil Moisture	20,400	0.01
f. Ground water:		
(1) Fissures to 2500 ft.	3,648,000	11.05
(2) Fissures 2500 to 12,500 ft.	4,565,000	13.83
g. Plants and animals	915	0.003
h. Atmosphere	11,500	0.035
3. Hydrologic cycle (annual):		
a. Precipitation on land	89,000	—
b. Stream runoff	28,460	—

* To 12,500 ft. depth only.

opment of desalinization techniques have created the possibility of large scale use of ocean water in the future.

Table 1 next reveals the amount of fresh water which is in the Earth's hydrosphere. Almost 75 percent of this fresh water supply is located in glaciers and in the polar ice caps. Because of the location of the glaciers and the ice caps and the form in which they are found, the fresh water which they represent is unavailable for man's use. Thus combining the waters of the ocean and the waters of the ice caps and glaciers, 99.2 percent of all the water in the Earth's hydrosphere is unusable.

Of the remaining fresh water, lake storage and the water in the rivers at any one time represent about three percent of the supply (.00009 percent of the total water supply) and in most cases is available for use. The water in earth minerals is negligible in quantity and unavailable to use. Soil moisture, which is available to growing plants also represents only a small portion of total fresh water resources, as does water in the atmosphere and water which is present in all plants and animals.

A significant amount of fresh water, approximately 25 percent of the fresh water supply (.0075 percent of the total water supply), is located beneath the Earth's surface. The figures are misleading, however, since they include the unavailable waters of the oceans and the ice caps and glaciers. If those figures are excluded, ground water accounts for 98.3 percent of the Earth's fresh water supply. Ground water from deep wells may, however, be high in dissolved minerals and thus require treatment for removal of those minerals before it is usable. Furthermore, the cost of raising ground water from depths of more than 2500 feet may be very high.[8] As Table 1 points out, however, almost half of the supply of ground water is within 2500 feet of the surface and is thus reasonably accessible.

Most important to man is that water which occurs in the hydrologic cycle.[9] The precipitation which falls on land and inland waters is the amount of water which is *potentially available* to man in a readily usable form. Approximately 50 to 75 percent of this precipitation is lost through evaporation and transpiration[10] and is, therefore, not available for man's use. The amount of water which does not evapotranspirate back into the atmosphere becomes stream runoff[11] and is that portion which is *readily available* to man. Therefore, the figure representing stream runoff should be considered as the basis for calculations of the usable water supply for man on Earth.

Stream runoff has been much studied in relation to its value as a measure of available water. It may not accurately be said that stream discharge to the ocean is water which is wasted because it has not been used. On the contrary, man may have used this water and returned it to the stream many times in its course from the mountains to the ocean. Therefore the amount of water available for use from stream runoff may be larger than the amount of water discharged to the oceans from stream runoff. Stream runoff is important for another reason, namely, it prevents salt water from encroaching upstream in an estuary. Numerous large cities, e.g., Philadelphia, Pennsylvania, and Poughkeepsie, New York, have their water intake on an estuary above the anticipated upper reach of salt water. When stream flow drops to a very low level, however, the salt water may reach the water intake.

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[8] The cost for drilling a six-inch well through unconsolidated soil is approximately $6.00 per foot (including the casing), whereas the cost through rock is about $3.00 per foot. Thus for a 10,000-foot-deep well, the capital investment would be between $30,000 and $60,000. In addition to the well itself, there is also a large investment in pumps. Moreover, if high pumping pressures are required (due to a lift from a great depth), extra strength pipe would have to be used in the well, thereby further increasing the initial capital costs. As for operational costs, energy requirements to raise 1000 gallons of water 1000 feet through a six-inch pipe are about $0.10. Thus pumping alone could cost as much as $1.00/1000 gallons for a 10,000-foot-deep well. (Surface water treatment systems in the United States today are capable of producing water for about $0.35/1000 gallons.)

[9] The hydrologic cycle is the cycle of condensation, precipitation, evaporation, and condensation. Between precipitation and evaporation there may be varying degrees of runoff, storage, or removal from the cycle. Some precipitation evaporates before it even reaches the earth.

[10] Transpiration is the vaporization of water through the leaves of plants. This transpiration is essential to the transport of nutrients to the plant and in the temperature control of plants. The combined vaporization of water from water surfaces and from plants is called evapotranspiration.

[11] Stream runoff is the flow in a stream at a certain location at any time. Total runoff is the amount of flow into the ocean. Total stream runoff is, therefore, the sum of the runoffs of all streams into the oceans.

Stream runoff also includes the underground flow into the ocean. The amount of water involved in underground runoff is approximately one percent of the total stream runoff[12] and is, therefore, not significant in terms of water available for use. The underground flow is essential, however, to prevent infiltration of salt water into the ground water aquifers.[13]

No analysis of the amount of water readily available would be complete without consideration of groundwater, the second greatest source of fresh water. Since the greatest source of fresh water, the glaciers and icecaps are unavailable for use, groundwater represents the greatest source of available fresh water.[14] Not only is the amount of ground water substantial, but the conditions of storage in the ground are desirable. First, groundwater should be considered as water in storage as opposed to the constantly flowing water on the surface. Except for flow which takes place in areas of fissured rock, the flow of groundwater is generally slight. As a result the discharge of groundwater into the ocean is slight as compared with the discharge of streams into the ocean. The difference is caused, of course, by the resistance to flow caused by soil particles. In addition to losing little ground water by flow to the ocean, the infiltration of salt water into groundwater storage areas is lessened, especially in areas of tightly bound soil because the soil resists the flow of salt water. Second, for obvious reasons, there is very little loss of groundwater due to evaporation as compared to surface water. Third, groundwater is generally filtered as it seeps through the soil and is thus free from man-made surface contamination such as bacteria and chemicals.

The great quantities of groundwater and its other desirable qualities suggest that more extensive use should be made of groundwater. Before any large scale use is made, it is necessary to realize that all groundwater recharge[15] must come from surface water somewhere. Thus, it is possible that extensive use of groundwater in the absence of provision for recharging the source could result in the disappearance of certain surface waters.[16] In some instances this may be desirable in that the loss of ground water due to evaporation is much less than surface water. On the other hand, certain uses of water, such as naviga-

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[12] L. Leopold & W. Langkein, Primer on Water 30 (1960).

[13] An aquifer is a soil formation made up of a layer of gravel, sand, porous rock or other coarse formation through which water flows more freely than elsewhere in the ground.

[14] "Available" is here used in the sense of being readily usable without excessive effort or appreciable treatment.

[15] Recharge is the replenishing of ground water from surface water. The recharge area is the location where the surface water enters the ground.

[16] The equivalent use of surface water without replacement to the stream would also tend to cause disappearance of the stream; however, up to the limit of its capacity, groundwater from storage would contribute to the flow of the stream.

tion and recreation require surface water and would be adversely affected by a lowering of surface levels. A possible solution to this problem would be the removal of water from the ground for use and the subsequent return of the treated used water to the area of recharge for the ground water aquifer. In this way, the surface water would remain available for other uses and at the same time advantage could be taken of the natural filtration and purification process which occurs during the seepage of the water through the ground.

Table 2[17] indicates the water resources of the continental United States as opposed to the figures for the Earth that were presented in Table 1.

TABLE 2

Summary Data Concerning Water Resources of Continental United States

	Square Miles	Acre-feet
Gross area of continental United States[1]	3,080,809	
Land, area, excluding inland water[2]	2,974,726	
Volume of average annual precipitation		4,750,000,000
Volume of average annual runoff (discharge to sea)		1,372,000,000
Estimated total usable ground water		47,500,000,000
Average amount of water available in ground as soil moisture		635,000,000
Estimated total of lake storage		13,000,000,000
Total storage of reservoirs (with a capacity of 5,000 acre-feet or more)[3]		365,000,000

[1] Includes that part of the Great Lakes within United States territory.

[2] As defined by the U.S. Bureau of the Census.

[3] Includes reservoirs under construction as of January 1, 1954.

Conditions with regard to water and its storage in the continental United States are similar to global conditions in some respects and different in others. For example, the ratio of runoff to precipitation for the United States is similar to the ratio in the hydrosphere. In addition, the total estimated groundwater storage in the United States is, as in the hydrosphere, approximately ten times the average annual precipitation. Peculiar to the United States is the total estimated lake storage. The largest portion of this storage is made up of the Great Lakes whose combined storage provides the largest fresh water surface reservoir in the world.[18] Due to many varied interests, however, primarily depth of water for navigation, the amount of water which can be made available for use by man from the Great Lakes is only a small fraction of the total amount.

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[17] E. Ackerman & G. Löf, supra note 6, at 18.

[18] The storage in the Great Lakes is approximately two and one-half times the average annual precipitation on the continental United States.

III. WATER DEMANDS

Although the total amount of water is constant and is a function of precipitation, the demand for water has increased rapidly in the last few years. The total amount of water required by one person is only slightly over one-half a gallon per day. Although a man can survive by drinking this amount, he uses considerably more for his daily conveniences such as bathing, food preparation, waste carriage and cleaning. Depending primarily upon economic conditions, the total amount of water required to support an individual in his home is between 75 and 150 gallons per day. Table 3[19] shows the per capita water production in the United States over a period of years for both public and private water utilities serving populations of 10,000 or over.

TABLE 3
Daily Per Capita Water Production in the United States for Utilities Serving 10,000 or More Population

Year	Public water supplies	Private water supplies
1945	126	117
1950	139	124
1955	139	120
1960	132	120

All figures are gallons.

Prior to 1945 there was a gradual increase in per capita production, reflecting the increase in usage of automatic clothes washers, automatic dishwashers, garbage grinders, and larger homes with lawns which are constantly watered. Since 1945, however, the increase has been slight and between 1955 and 1960 there has even been a decrease in public water production, although the decrease is not considered statistically significant.[20] Predictions have been made that by 1980 the average per capita requirements for water will reach 192 gallons per day.[21] Publicity concerning water conservation and the imposition of increased water rates are partly credited with maintaining the per capita domestic water production fairly constant.

Domestic water use is small compared to the total amount of water which is required for all purposes. This latter amount represents water used in food production, manufacturing such things as auto-

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[19] Seidel & Cleasky, A Statistical Analysis of Water Works Data for 1960, 58 J. Am. Water Works Ass'n 1507, 1526 (1966).

[20] Id. at 1523. These figures do not reflect the increase in the number of small water utilities which have sprung up to serve the ever-increasing suburban areas having populations under 10,000.

[21] W. Picton, Water Use in the United States, 1900-1980 at 2, Business & Defense Services Admin., U.S. Dept. of Commerce (1960). See also Review, BDSA Extrapolates—By 1980: 494 BGD! 1960 Water Works Engineering 723.

mobiles and gasoline, construction of highways and buildings, and power generation. Table 4[22] presents figures on total water use in the United States for representative years from 1900 through 1955 and estimates of total water use for the years 1960 through 1980.

TABLE 4
Estimated United States Water Use
(in billions of gallons daily average)

			Self-supplied uses			
Year	Irrigation	Public water utilities	Rural domestic	Industrial & Misc.	Steam electric power	Total water use
1900	20.19	3.00	2.00	10.00	5.00	40.19
1910	39.04	4.70	2.20	14.00	6.50	66.44
1920	55.94	6.00	2.40	18.00	9.20	91.54
1930	60.20	8.00	2.90	21.00	18.40	110.50
1940	71.03	10.10	3.10	29.00	23.20	136.43
1945	83.06	12.00	3.20	41.00	31.20	170.46
1950	100.00	14.10	4.60	38.10	45.90	202.70
1955	116.30	16.30	5.40	49.20	76.60	263.50
1960	135.00	22.00	6.00	61.20	98.70	322.90
1965	148.10	25.00	6.50	73.20	118.90	371.70
1970	159.00	27.00	6.90	86.00	132.30	411.20
1975	169.70	29.80	7.20	98.40	144.60	449.70
1980	178.00	32.00	7.40	115.00	161.70	494.10

As indicated, water use has increased approximately tenfold in the course of 70 years. The largest increase in consumption has been in steam power generation while the smallest has been in domestic use. On the basis of a population of two hundred million which was achieved on November 20, 1967, it may be seen that the per capita use in the United States is approaching 200 gallons per day.

Table 5[23] expands somewhat on the disparate sources and uses of water in the industrial sector.

TABLE 5
Water Use by Industry in 1964
(billions of gallons)

	Water intake			Gross water used (Includes recirculation re-use)	Water discharge	
	Total	Fresh	Brackish		Total	Treated before discharge
Total U.S. Industry	14,055	11,218	2,839	30,645	13,171	3,833

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[22] W. Picton, supra note 21, at 2.

[23] U.S. Bureau of the Census, Preliminary Report MC 63(P)-10 (44 Chemical & Engineering News 24 (April 11, 1966)). It should be noted that the value for gross water use in industry in 1964 as shown on Table 5, when corrected for the differences in the unit of measurement, corresponds to the estimated value for 1965 from Table 4. This indicates that the value shown in Table 4 includes recirculation of industrial water.

In addition to gross water use, this table shows details of water sources, reuse, consumption, and treatment of the used water before discharge. A comparison of gross water use with total water intake indicates that industry uses its water at least twice. Some water taken by industry is consumed rather than used and discharged. This figure, representing 6.3 percent of total water intake is computed as the difference between total intake and total discharge. The table indicates that slightly more than one-quarter of the water discharged is treated prior to discharge. Since part of this water which is discharged may be cooling water which normally requires no treatment, the amount of discharged water which would not be harmful to the stream into which the water is discharged is actually greater than one-quarter of the total discharge.

While most of the United States' water demand results in use of the water followed by a return to a local watercourse, some of the demand for water results in the *consumption* of the water with the result that the water is not returned to a local watercourse. Water which is absorbed into plants and animals is said to be consumed. This water is merely displaced from the hydrologic cycle for a relatively brief period of time, for after the food is consumed or the plant or animal dies, the water contained therein ultimately gets back into the cycle. In addition, certain quantities of water are consumed by industry, particularly the construction industry by incorporation into concrete. This water may be considered to be permanently removed from this hydrologic cycle. Thus wherever water is taken for use and is not returned to the watercourse from which it was taken, the water is said to have been consumed although some day the water will be returned to some watercourse.

Table 6[24] provides a breakdown of the actual amount of water consumed. Although the data appear to be fairly old, the values are still relevant today. Approximately 70 percent of the water received disappears through evaporation and transpiration, one-third of which goes toward the production of nonirrigated crops and pastures. While nearly 50 percent of this evapotranspiration has little specific economic value in that no crop is produced for sale, it has some value for other purposes. For example, the plants which this evapotranspiration nurtures produce oxygen and thus maintain the oxygen balance on the Earth. The uncultivated lands which serve as refuges for wild life and thus provide a stock of animals and birds for hunting enthusiasts have no "specific" economic value yet this apparent "non-use" of water serves a useful purpose.

Of the total amount of water which is consumed, irrigation repre-

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[24] E. Ackerman & G. Löf, supra note 6, at 51.

TABLE 6
Estimated Annual Water Disappearance in the United States
as Compared with Total Receipts of Water, 1955

		Million acre-ft. (approx.)
1. Precipitation received		4,750
2. Disappearance of dispersed supply through evapotranspiration (except irrigated crops)		3,380
a. Farm crop and pasture, nonirrigated	1,100 ±	
b. Forests, browse, vegetation, etc.	750 ±	
c. Evaporation plus transpiration from non-economic vegetation	1,530 ±	
3. Total concentrated supply		1,380
a. Runoff	1,372.4	
b. "Mined" water added to current supply from ground	6.1	
4. Total disappearance concentrated demand		90
a. Household and municipal consumption, disappearance	1.3	
b. Livestock watering	1.7	
c. Irrigation	74.0	
d. Industrial—from municipal supply	0.8	
e. Industrial—individual supply	12.3	
5. Unconsumed runoff		1,290

[Footnotes to table omitted.]

sents the largest demand—over 75 percent. This represents water which is evaporated from the surface, transpirated from the plants, and leached into the groundwater, as well as a small amount which is incorporated into the plants themselves. Approximately 15 percent of consumption is by industrial interests which generally incorporate the water into the products produced. Only small amounts of water are consumed by domestic uses and livestock watering. The unconsumed water results in total runoff to the ocean.[25]

In order to arrive at a meaningful comparison of water supply and water demand, a few mathematical conversions must be made. Based upon the present average daily use of 400 billion gallons per day as indicated in Table 4, there is an annual water use of 450×10^6 acre-feet per year. This figure should be compared with the average annual stream runoff of 1372×10^6 acre-feet per year as shown in Table 2. It may be observed that presently, water use is approximately one-third of the total annual stream runoff. Inasmuch as water is reused several times as it passes from mountains to ocean, the conclusion must be that there are large quantities of water available in

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[25] The slight discrepancy which appears in Table 6 is due to mathematical calculations. Generally, the runoff is calculated as the difference between precipitation and evapotranspiration. On this point the values for runoff on Table 2 and runoff item 3(a) of Table 6 correspond. Table 6, however, carries the calculation one step further by subtracting consumption from the runoff thus arriving at a more accurate figure for discharge to the ocean.

the United States which have not been used and which represent a potential additional supply of usable water. This potential supply is not necessarily unpolluted, however, since one of the means for disposing of used water is discharge into a watercourse. Nevertheless, there is water available in the United States for all the needs of man in the United States.

IV. FUTURE WATER DEMANDS

A consideration of future demands for water in the United States is necessary in order to plan now to meet those demands. Estimates of future demands must be based upon projections of present demands and present rates of increase. The most important factor affecting water demand is the population growth caused by a combination of medical and health technology and immigration. At the present rate of growth, the population of the United States will double in 50 years. This population growth is complicated by the unequal growth rates in various sections of the country. For example, Arizona and Nevada will double their populations in approximately 15 years, while West Virginia and Arkansas are expected to suffer a decrease over the same period. Great increases are also expected in the Great Lakes area, Southern California, and the Gulf Coast.

Another important factor contributing to the increased demand for water is the increasing standard of living which increases the demand for existing products, many of which require water for manufacturing and which will spur the development of new industries which will require the use of water to produce new products. As shown in Table 4, there has been a sharp increase through the years in water used by industry and in the generation of electrical energy. It has been estimated that by the year 2000, water use in the United States will have tripled.[26] In some areas of the country the increases will be even greater.[27] The development of new products and processes may, however, have some moderating effect upon the use of water as for example, is portended by the development of a waste disposal unit which does not use water as a medium for carriage.[28]

Balancing these factors, most estimates agree that by 1980, total water demands will exceed the total amount of water readily avail-

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[26] NAWAPA, Water for a Continent, Engineering Opportunities 10, 13 (October 1965).

[27] It has been estimated that water demands in the Delaware River Basin will increase fourfold in the next 50 years. Proudfit, Master Planning for Water Utility Systems, 58 J. Am. Water Works Ass'n 21, 23-24 (1966).

[28] Toilet units are now on the market which provide for complete destruction of the waste materials by heat. The heat source may be electricity or "bottled gas." These units are primarily for use in remote areas, but water shortages could increase their use, thus causing a decrease in water demand.

able.[29] Such estimates do not make allowance for reuse of water, which becomes permissible after treatment of the used water. As indicated in Table 5, industry already uses its water an average of twice. In some watersheds, the water is used more than twice.[30] While these figures do not provide specific information on how near we are to utilizing all of our available water resources, they do provide essential information on the scarcity which should be expected. This information should thus be valuable to water utilities in their planning for the future.

V. PROVIDING NEEDED WATER

The problems of satisfying present and future demands for water from the existing supply of water depends in large part upon man's ability to reuse water and to transport water from water-rich to water-poor areas.[31] The development of methods for transporting water is becoming increasingly important as the nation's population shifts to areas of water shortage for reasons of health or convenience as is the modern trend. Moreover, farming activities have increased in the warm areas of the south and southwest which are water-poor but which have fertile soil where crops may be profitably grown during the winter season when supply is low and prices are high in the eastern markets. Industries which carefully calculate their costs and methods may as a result of those calculations locate close to their markets or their raw materials and at a distance from the nearest water supply thus necessitating transportation of the water. In all these cases, the individuals and industries assume that some means will be devised to provide the necessary water.

Arizona and California are examples of water-poor areas where because of extreme growth the demand for water has outstripped supply. The Hoover Dam on the Colorado River has greatly increased the usability of the waters of the Colorado. Notwithstanding this increase, the House Subcommittee on Irrigation and Reclamation, in hearings held early this year, was told that the water supply in the Colorado Basin was not sufficient to meet developing demands and that augmentation of the Colorado will be necessary.[32] Four potential methods were

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[29] Proudfit, supra note 27, at 21-22.

[30] The Ohio River Basin is an example of a watershed in which reuse is greater than the average. See Cleary, Horton & Boes, Reuse of Ohio River Water, 55 J. Am. Water Works Ass'n 683 (1963).

[31] Areas which experience occasional drought periods should not be classified as water-poor areas and are not considered as such in this article. While such areas may experience distress in drought periods, such conditions, because they will cure themselves, will not be further discussed. The more important problem arises in areas where there is a permanent insufficiency of water resources available to provide for the needs of the people including irrigation, industry, and domestic uses.

[32] Hearings on H.R. 3300 and S. 1004 Before the Subcomm. on Irrigation and

suggested for that augmentation, namely, desalting of sea water, surface water imports from areas of surplus water supply, weather modification, and water salvage measures.[33] Only the first two of these methods were considered capable of producing the supplies needed and the major emphasis of the report was on the first alternative.[34] The four possibilities for augmenting the water supply in the southwest are also available in other water-poor areas of the country and the world. A survey of some present developments in the use of these techniques is presently in order.

Present methodology makes it possible to transport water over great distances. Projects are presently underway in California for the construction of a 600-mile long pipeline from the center of the State to the water-poor southern areas.[35] Plans calling for the extension of this pipeline another 300 miles to the north are presently being made to take advantage of an even greater water surplus. This project was initiated in 1960 with the passage of a $1.75 billion bond issue and by 1967 the first phase, the San Luis Project, including the Oroville Dam, was completed.[36] Despite costs which are presently exceeding the initial bond issue, the second phase, the Feather River Project, which was originally scheduled for completion in 1975 may be completed by 1972. The necessity for this expensive project is caused by the fact that 70 percent of the water supply is located in the northern third of the State,[37] while 77 percent of the water needs are in the southern two-thirds of the State.

A further indication of man's ability to redistribute water is a project called North American Water and Power Alliance (NAWAPA).[38] This is a plan which encompasses all of North America in an effort to make the best use of the water available on this Continent. Long range plans are being considered to divert water from Alaska, Northern Canada, Hudson Bay and James Bay into areas of the United States. This diversion of water would make use of connections with the Great Lakes and the Mississippi River and interconnecting links with numerous tunnels through the Rocky Mountains continuing into Mexico. NAWAPA's goal is to coordinate demands for water supply, flood control, power production, navigation and recreation.

Reclamation of the House Comm. on Interior and Insular Affairs, 90th Cong., 2d Sess., pt. 2, at 760 (1968).

[33] Id.

[34] Id. at 761-86.

[35] California Dep't of Water Resources, The Delta and the Delta Water Project (1960); California Dep't of Water Resources, Water . . . Today and Tomorrow (1959).

[36] In 1965 the partially completed dam was credited with preventing a flood in Yuba City, California.

[37] In the extreme northern coastal areas of the state as much as 110 inches of precipitation fall in a season.

[38] NAWAPA, Water for a Continent, Engineering Opportunities 10 (October 1965).

While the preliminary engineering aspects of NAWAPA have been worked out, the organizational aspects are still somewhat beclouded. In 1965 a Senate Subcommittee under the chairmanship of Senator Frank E. Moss of Utah was formed to study the concept and recommend appropriate action. Senator Moss suggested that Congress ask the Administration to seek a study of the project by the International Joint Commission, the board which has jurisdiction over United States-Canadian boundary waters. As of this writing, no congressional action has been taken to give the International Joint Commission any jurisdiction. Behind the scenes, however, discussions have been held with Canadian officials in order to probe the cooperative possibilities, and Senator Moss is continuing his efforts to have legislation passed on this project.[39] Although this is obviously a far-sighted and long range project, the technology to accomplish it is presently available.

A second method of augmentation of water supply is water desalinization, the recovery of fresh water from salt water. Desalinization techniques have developed to such an extent that, today, the emphasis of engineers is on cost reduction and optimization of conditions. The Office of Saline Water has supported several desalinization plant studies.[40] Some of these studies have shown the most economical methods of desalinization for waters of different salt content. Other studies have shown the best operating conditions for long-term economy. The general conclusions are that (a) larger plants are more economical, (b) the larger the plant, the more economical nuclear fuel becomes, and (c) great economies can be attained by using waste heat from evaporation systems to generate electrical power.

Initially, the costs of desalinated water were over $1.00/1000 gallons. Plants producing 25 to 50 million gallons per day have reduced the cost to about $0.50/1000 gallons. It is anticipated that the combination nuclear-fueled evaporation plant-electric power plant which is being built on Long Island, New York, with a capacity of 100 million gallons per day will be able to produce desalinated water at a cost of $0.35/1000 gallons. To these production costs must be added the costs of delivering the water to the user. To assess the competitive posture of desalinated water in the water market, it must be remembered that the delivered cost of most water in the United States is $0.30 to $0.35/1000 gallons.

Purification and reuse of used water is a third method of augmenting the supply of usable water.[41] This method should be less

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[39] See 113 Cong. Rec. S11899 (daily ed. Aug. 21, 1967); 112 Cong. Rec. 20203 (daily ed. Aug. 29, 1966).

[40] Office of Saline Water, U.S. Dep't of the Interior, 1965 Saline Water Conversion Report 226-36.

[41] An extreme example of what can be accomplished by reuse of water occurred in the steel industry, an industry which uses large volumes of water. One steel plant, faced

expensive than desalinization because there are fewer dissolved salts in most used water than in sea water. One of the major technological problems that must be overcome is fouling of the system, particularly evaporators. A greater problem to be overcome is the attitude of many people that reusing sewage water and other types of contaminated water is undesirable. Actually, water reclaimed by these techniques results in water which is often purer than the original water. After purification, used water should be returned to its original source. This is particularly true if natural ground water aquifers are used for transporting water great distances. The cleaned used water would be returned to the area where the recharge of the aquifer occurs and the aquifer would then be used for transporting the water as well as filtering and polishing the water to make it of fine quality at the point of use. Moreover, return of the water to the ground would be less expensive than letting the water go out to the ocean where desalinization would have to be used in order to provide a new supply of fresh water. In addition, the use of the ground water aquifer would result in less loss of water through evaporation.

The fourth method of augmenting the supply of water involves man's attempt to increase precipitation by artificial rain making. Actually, the ultimate amount of precipitation which may be induced from a cloud is not changed. The change is primarily in the production of precipitation when and where it is needed. At the present time, the legal problems of artificial rainmaking are greater than the technological problems. The legal problems of rainmaking generally involve the liabilities of, or to, the rainmaker for rain that falls in the wrong place.[42]

In addition to augmenting the water supply, the water problem can be somewhat alleviated by reducing the demand by raising the price of water. The low cost of water may, in fact, be a major reason for water shortages. The cost of water treatment and delivery is little considered by the user. By increasing the costs to levels which will

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with an extreme shortage of water was able to reduce its water demands by 90 percent by various methods of in-plant control and reuse of cleaned waste water.

[42] The legal problems arising from artificial rainmaking operations present a group of intriguing issues. Assume, for example, that one man invests in rainmaking techniques (using either his own ground generators or a hired airplane system) only to have all of the rain fall on his neighbor's property. Can the party who caused the rain to fall sue his neighbor successfully for reimbursement? Or, if the neighbor did not want the rain, can the neighbor successfully sue the rainmaker on a tort cause of action? Suppose a severe storm with flooding follows an artificially produced rainfall. Can it be proven that the flood was a result of the rainmaking effort? Can the rainmaker or the man who hired him be successfully sued for damages? How could it be proved that the rain would not have fallen naturally? On the other hand, the rain may fall on the land where the rainmaking effort was employed and not further downwind where it might naturally have fallen. Does the person downwind have a right to recover against the rainmaker for depriving him of rain which might naturally have fallen on his property?

pay for the development of water supplies, adequate water treatment, and purification of the used water, a more realistic assessment of the value of water will be achieved. If increased costs result in decreased waste of water an actual saving of water will result.

VI. CONCLUSION

At present, there is a sufficient supply of water to provide for all man's needs, although this may not always be so. However, the water may not always be available where it is most needed, nor may it be of a quality satisfactory for use. As a consequence, man must develop systems for delivering a satisfactory quality of water when and where it is needed. Perhaps the watchword in accomplishing these purposes is planning. If there is a desire to start work now on a primarily regional problem which will not be of national proportions for 15 to 20 years, little readjustment will be necessary in that future period. The technology for improvements in supply is available today; thus the task of the planners is somewhat simplified. These efforts to make more efficient use of water would also be aided if water users recognize that water is not free and if they were required to bear the costs of providing adequate supplies of good water.