

If we assume that the bomb is detonated at a distance of 1 astronomical unit, we can calculate the magnitude of each weapon size as seen from a distance of 93 million miles. This does not imply that we could see a bomb detonated in space at such a distance; I am concerned only with bombs exploded in air. But if we were at such a distance from the Earth, then the flash of light would have the magnitudes shown in Fig. 7. However, at a distance of 1 astronomical unit the Earth is never dark, and, as indicated on the graph, its magnitude at quadrature is nearly -4 , or a little brighter than Venus as seen from the Earth. A 10-megaton weapon would be about $1/100$ as bright as the visible quarter of the Earth. The problem of seeing a flash of light 1 percent greater than the background might be circumvented

by using a telescope focused on the dark face of the earth, where the background would be quite dark.

It has been seriously suggested that the inhabitants of a planet belonging to one of the nearer stars could detect the light of the bomb with a super large telescope (7). It is reasoned that such a flash could not be explained on the basis of a falling meteorite or any other common geological phenomenon and hence would indicate the existence of intelligent life in the solar system. At a distance of 1 parsec, a little nearer than the nearest star, a 10-megaton weapon would have a magnitude of approximately $+28$, some one hundred times fainter than can be photographed with the 200-inch telescope at Palomar. It does not seem reasonable that such a faint pulse of light could be found above the background of the sun.

On the cosmic scale, the light of the atom bomb is quite weak, so faint in fact that we need not flatter ourselves that we will be noticed. On the local scale however, the light of the atom bomb exceeds all other man-made sources of light and is appropriately likened to a tiny star, indeed like a very small segment of the sun.

References and Notes

1. E. B. Roberts, *Smithsonian Inst. Publ. Rept.* 4394 (1959), p. 263.
2. F. K. Odencrantz, P. Saint-Armand, J. G. Moore, *J. Geophys. Res.*, in press.
3. F. G. Brickwedde, *Temperature, Its Measurement in Science and Industry* (Reinhold, New York, 1955).
4. S. Glasstone, *Effects of Nuclear Weapons* (U.S. Government Printing Office, Washington, D.C., rev. ed., 1962).
5. D. I. Lawson, *Fire Research Bulletin No. 1* (H.M. Stationery Office, London, 1954).
6. W. E. Forsythe, *Smithsonian Physical Tables* (Smithsonian Institution, Washington, D.C., ed. 8, 1954), p. 719.
7. O. Struve, *Phys. Today* 13, 23 (1960).

Human Water Needs and Water Use in America

A permanent water shortage affecting our standard of living will occur before the year 2000.

Charles C. Bradley

The current rapid rise in population poses many problems, among them the question, Where are the limits, if any? More carefully stated for America, the question seems to be, how many people can we sustain at what standard of living?

My purpose in this article is to examine one vital resource, water—(i) to show the minimum amount necessary to sustain human life, (ii) to show the amount we are now using in the United States to maintain our standard of living, and (iii) to indicate from these figures when we may expect to find certain ceilings imposed on the crop of human beings in this country.

The author is dean of the division of letters and science, Montana State College, Bozeman.

While water economics is admittedly important in the complex problem of water supply, no discussion of this aspect of the problem is attempted in this article.

Water Needs of Man

The 2 quarts or so of water which a man needs daily for drinking is a requirement obvious to anyone. Less obvious is the equally vital but much larger volume of water needed to sustain a man's food chain from soil to stomach. This is the water necessary to raise the wheat for his daily bread and the vegetables that fill his salad bowl. This is also the still larger volume re-

quired to raise alfalfa to feed a steer from which a man may get his daily slice of meat. All this water represents a rather rigid requirement for human life, and it is water which is consumed, in the sense that it is removed from the hydrosphere and returned to the atmosphere.

An adult human has a daily food requirement of about $2\frac{1}{2}$ pounds, dry weight. If he is strictly a vegetarian, an illustrative approximation of the water requirements for his food chain can be made by assuming man *can* "live by bread alone."

Wheat has a transpiration ratio of 500 (1); that is, ideally it takes 500 pounds of water circulating through the wheat plant from the soil to the air to bring 1 pound (dry weight) of wheat plant to maturity. If grain to be milled represents half the weight of the wheat plant, we can say that it takes 1000 pounds of water to make 1 pound of milling wheat, or (simplifying again) 1000 pounds of water to make 1 pound of bread. Therefore, it takes 2500 pounds of water, or approximately 300 gallons, to make $2\frac{1}{2}$ pounds of bread. Three hundred gallons per day per person is, therefore, probably not far from the theoretical minimum water requirement to sustain human life.

The introduction of animal protein to a man's diet lengthens the food chain, thereby greatly increasing the water requirement. To illustrate, let us assume what might be called a

simplified but generous American diet of 1 pound of animal fat and protein (beef) and 2 pounds of vegetable foods (bread) per day. It takes about 2 years to raise a steer. If butchered when it is 2 years old, the animal may yield 700 pounds of meat. Distributed over the 2 years, this is about 1 pound of meat per day. It may be seen, therefore, that this diet requires a steady-state situation of about one steer per person.

A mature steer consumes between 25 and 35 pounds of alfalfa a day and drinks about 12 gallons of water (2). Alfalfa has a transpiration ratio of 800 (1), hence 20,000 pounds of water are required to bring 25 pounds of alfalfa to maturity. In other words, a little over 2300 gallons per day per man are required to introduce 1 pound of beef protein and fat into a person's diet. Add to this the 200 gallons necessary to round out his diet with 2 pounds of vegetable matter and we have a total water requirement of about 2500 gallons per day per person for a substantial American diet.

It should be remembered that these are conservative figures, because transpiration ratios are derived from carefully controlled laboratory experiments and not from data collected in the field, where perhaps half the total rainfall is lost directly by evaporation and does not pass through the plant body. It should be noted, too, that the water cost of a pound of meat is about 25 times that of a pound of vegetable. We should anticipate a similar ratio for the water cost of wool to that of cotton or for the water cost of butter to that of margarine. In any case, somewhere between 300 and 2500 gallons per day is the bare subsistence water cost for one naked human being.

Water Use in the United States

When we talk about "use" we have to add to the foregoing figures the water requirements for all our fibers, lumber, and newsprint, as well as the water needed to process steel, to run the washing machine, to flush the toilet, and to operate our air conditioning and our local laundries, and especially that required to sweep our sewage to the sea. It is therefore pertinent, at this point, to digress slightly in order to clarify our concept of the American standard of living, or at least that portion sustained by water use. The Amer-

ican standard of living is not a wholly unmixed blessing. In achieving such luxuries as the flush toilet, synthetic detergents, cheap newspapers, and atomic power we find ourselves also achieving polluted streams, sudsy well-water, radioactive milk, and poisoned oysters.

Underlying and supporting our standard of living are powerful industrial centers and a mass production scheme which creates inexpensive commodities. This scheme rests firmly upon certain prodigal wastes, polluted streams being a prime example. To clean up the streams would take a tremendous amount of money which might otherwise be spent on cheap commodities. On the basis of some standards of values, this could be construed as a lowering of the standard of living.

To illustrate the magnitude of the practical problems we have created for ourselves, we note that if river-disposal of waste were suddenly denied the city of St. Louis, the city fathers would have to decide what else to do with the daily discharge of 200,000 gallons of urine and 400 tons of solid body-wastes, to say nothing of all the industrial wastes. River disposal of human waste, though cheap, involves a double loss of resources. On the one hand there is the polluted river; on the other, the depleted soil. So long as these losses are deemed less important than the production of inexpensive commodities which they support, we will have to accept our befouled streams and depleted soil as part of the cost of our standard of living. In addition to waste disposal we can see that water power, river transportation, fisheries, and water recreation are all well-established items in our standard of living. Therefore, as we move into a discussion of water use, especially future use of surface waters, we must remember that most of our runoff is already committed to our living standard and is working hard to support it.

A figure for water use in the United States can be obtained by subtracting that water which we are *not* using from the total water available.

Thirty inches of annual rainfall on the surface area of the United States (exclusive of Alaska and Hawaii) gives us theoretically nearly 5000 billion gallons per day, a figure which represents the total water available for our use (3). Of this 5000 billion gallons, about 1300 billion gallons a day, or about

one-fourth of the rainfall, is discharged by our rivers (4). It may also be said that this discharge figure contains the groundwater increment, since stream flow is largely maintained by effluent seepage from the ground.

It can be seen that 75 percent of our rainfall is returned to the atmosphere through evaporation and transpiration. It is difficult to assess the relative contributions of these two factors. A ratio of 50:50 is probably not far from the truth. From a utilitarian standpoint, evaporation constitutes pure waste, and it may be that here some significant gains in water conservation can be made. But until this is done, we have to reckon this loss, too, as part of the price being paid for our standard of living.

Very little of the area of the United States which could produce crops for man is not actually doing so. The largest nonproducing area is, of course, our desert, and even here we are irrigating, using stream water exported from regions of water surplus. Additionally, we are forcing the desert to raise crops through the use of ground water. But in many such areas we have considerable evidence that the annual draft from the ground-water reservoir exceeds the annual recharge. Consequently, some of these operations will be short-lived and perhaps socially and economically catastrophic for the people involved.

About 2 percent or more of the surface of the United States is "paved" with cities and roads and will probably remain agriculturally unproductive until some far-sighted city planners provide for extensive roof gardens. Another 2 to 3 percent of the land in this country is devoted to wilderness and national parks. While these do not directly produce crops for man, we do include them and their waters in our standard of living. Finally, we can say that bad agricultural management has reduced the productivity of a fraction of our arable land, and that this percentage must be added to our total for unproductive lands. Let us make a quasi-educated guess and say that as much as 10 percent of our land in areas of abundant rainfall is, at the moment, non-productive.

Three-fourths of the nation's rain (3700 billion gallons per day) falls on about half the nation's area, and it is this three-fourths, largely unmetered, that does the big job of raising crops for America. As concluded previously,

perhaps one-tenth of this rain falls on unproductive areas. Hence we may say that 3300 billion gallons per day are productive of crops or surplus water. Of this, about one-fourth is unconsumed runoff, giving a remainder of about 2500 billion gallons per day which we are *consuming*, though perhaps wastefully, to raise our crops. In a population of 180 million people, this amounts to approximately 13,800 gallons per day per person. In addition, 240 billion gallons per day are metered out of our streams, lakes, and ground-water reservoirs to serve industry, municipalities, and rural areas (4); over half of it is consumed in irrigation and other processes. This 240 billion gallons per day is almost 1400 gallons per day per person, a figure which now must be added to the 13,800 gallons for a grand total of 15,200 gallons per day per person. Thus we find that the per capita daily use of water in the United States is in excess of 15,000 gallons, 95 percent of which is consumed.

Some Population Limits in the United States

How many people could we feed if all the rainfall in the United States were completely utilized? Since 300 gallons per person per day is needed for a vegetarian diet, we could, in theory, sustain about 17 billion people, or approximately 8 times the present world population. If, on the other hand, we decided to feed people on the "generous American" diet, we discover,

by the same sort of calculation, that we could feed about 2 billion people, or somewhat less than the present world population. If we admit that loss of water through evaporation is unavoidable, as discussed earlier in this article, we must cut these figures to 8 billion and 1 billion, respectively.

Assuming a population of 180 million and a rainfall of 5000 billion gallons per day, we discover that each person today theoretically has about 28,000 gallons per day for his use. We are now using 15,000 gallons per day per person, 95 percent of it consumptively. We might, therefore, conclude that if we could use every drop of rain that falls we could almost double our population with no decrease in the standard of living. But this is far from possible because there would then be no surface water to generate power, float ships, raise fish, and carry away the national sewage and waste.

The extent to which we can consume our runoff before our standard of living suffers is difficult to foresee. Involved are not only the waste-disposal and commercial uses of rivers but the fact that river water is generally most abundant and most available where it is least needed for agriculture.

Let us guess that we might safely and profitably use one-third of our remaining river water, or 400 billion gallons per day, for future development without expecting a resultant drop in our standard of living. Add to this figure the amount of water that falls on unproductive areas which might rather easily be made productive.

We now have a total of about 750 billion gallons per day for future development. At 15,000 gallons per day per person we seemingly can accommodate 50 million more people, or a total population of 230 million, before our standard of living starts to suffer. There is little doubt that America will have reached that population figure well before the year 2000. The evidence of the moment suggests, then, that young Americans alive today will see a significant deterioration in their standard of living before they are much past middle age. Improved cropping, mulching, and other conservation practices could, of course, extend the grace period by a few years.

How far deterioration in the American standard of living will progress depends, of course, upon what action Americans choose to take on their own numbers problem—upon *what* action, and especially upon *when* they take it. Fortunately we have at our disposal human intelligence and considerable time in which intelligence can function. At present rates of rainfall and of population growth we should have almost 200 years before the American standard of living drops to subsistence level and Malthusian controls eliminate the necessity for intelligent action.

References and Notes

1. N. A. Maximov, *The Plant in Relation to Water* (Macmillan, New York, 1929).
2. F. W. Woll, *Productive Feeding of Farm Animals* (Lippincott, New York, 1921).
3. It is doubtful whether artificial conversion of salt water will ever make a significant difference in this total, although it may be of great significance to certain communities.
4. L. B. Leopold and W. B. Langbein, *A Primer on Water* (U.S. Government Printing Office, Washington, D.C., 1960).