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Dry Lands and Desalted Water

Desalination can supply water to create new living space; can it also create useful new farmland?

Gale Young

Men spread now, with the whole power of the race to aid them, into every available region of the earth. Their cities are no longer tethered to running water and the proximity of cultivation . . . they lie out in the former deserts, those long-wasted sun baths of the race, they tower amidst eternal snows. . . . One may live anywhere.
—H. G. WELLS, *The World Set Free —A Story of Mankind* (*1*).

Mounting population and pollution exert pressure on man to enlarge his living space. At present, the most rapidly growing part of the United States is the desert of the Southwest, into which the Colorado and Rio Grande rivers have been largely diverted. Water from the Feather River will shortly be added, crossing over a mountain range 2000 feet (600 meters) high, by way of conveyance facilities now under construction.

The building of the Colorado Aqueduct of the Metropolitan Water District of Southern California was undertaken 40 years ago. Since then, the assessed valuation of the region served by this water supply has increased by $20 billion, or by $5 for each 1000 gallons of water that has flowed through the pipes.

These remarks are not intended to impute some exaggerated value to water, but are made, rather, to point out that people seem to like desert climates (better than, say, rain forests or frozen tundras) and that they will move into them and build vigorous societies. Since the water is essential to the welfare of all, whether they be large direct users or not, the cost of the water in arid areas is often carried in part as overhead. For example, the Metropolitan Water District derives funds to meet about half of its costs from water revenues and levies taxes for the balance.

Water-supply projects tend to proceed by large steps. When they are first completed there is an excess of water, and this can be used for agriculture while population and land values build up (*2*). Later on, the suburban farmland and its water allotments are absorbed in urban growth. This process is now under way around the large cities in our dry Southwest.

A third of the world's land is dry and virtually unoccupied, while half of the world's people are jammed—impoverished and undernourished—into a tenth of the land area. A major part of the coming increase in population will occur in the less-developed countries and, as *Nature* expressed it (*3*), "this huge army of uneducated, untrained, underfed, underprivileged recruits to humanity is being bred at the very moment when science and technology are rapidly undermining the need for and the status of the unskilled. . . . What stands out most emphatically is in fact the insufficiency of economic factors or motives if the challenge is to be met."

The past decade has seen a quickening of interest in the large-scale desalting of seawater as another means of opening up dry areas of the earth for human occupancy. Thus, Jacob Bronowski writes (*4*), "let me ask first what is going to be the single greatest technological change in the physical sciences over the next twenty or thirty years. My guess is that desalting of seawater is going to be the most important advance for overall world development. Without this the whole complex program of bringing under-developed countries to an acceptable level of economics, education and political maturity is insoluble." And Charles Lowe writes (*5*), "The desert is man's future land bank. Fortunately, it is a large one, offering eight million square miles of space for human occupation. It is also fortunate that it is a wondrously rich bank, which may turn green when man someday taps distilled seawater for irrigation. Bridging the gap from sea to desert will be greatly facilitated by the geographical nearness of most of the world's deserts to the oceans. When this occurs it will surely be one of the greatest transformations made by man in his persistent and successful role in changing the face of the planet." As an example, imagine what changes would follow if Baja California were to be opened up for settlement with the help of desalting and power stations. What might another thousand miles of southern California be worth in a few generations?

This process has already begun to take place on a small scale in certain locations. Thus, Kuwait on the Persian Gulf and Shevchenko on the barren eastern shore of the Caspian Sea, where the Russians are building the world's largest desalting unit, are two oil field communities which depend upon desalination for their water supply. As in other locations where desalination would be employed, no cheaper sources of fresh water are available.

In general, desalination will be able

The author is assistant director of Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

Table 1. Amount of water used in growing rice in various countries.

Location	Pounds of water per pound of paddy rice	Gallons of water used per pound of milled rice
Thailand	10,000	1,800
India	10,000	1,800
Japan	4,900	900
California	3,300	610
Australia	2,900	530

to meet the freshwater needs of municipalities and industries located along the ocean shore, or in some interior regions having salty lakes or groundwater. And anywhere that cities go, some agriculture, for fresh fruits and vegetables at least, tends to follow. For example, Kuwait, in one of the most devishly hot and sandridden environments on earth, has recently ordered acres of enclosed greenhouses at a cost of many thousands of dollars per acre to supply garden produce which will be fresher and reportedly cheaper than imported produce. But it is less clear whether agriculture that depends on desalted water ("desalination agriculture") may someday expand to include substantial production of staple foods as well. Here opinions differ, and, as the saying goes, the less light sometimes generates the more heat.

Water Requirements for Crops

In enclosed agriculture, such as Kuwait will have, so little fresh water escapes that its cost is not important. The situation is quite different in open-field agriculture, since the amount of water lost to the atmosphere in evapotranspiration is generally (*6*) many times that actually involved in the plant's growth reactions, and the cost of supplying this total by desalination is of prime importance.

Some authors have stated that the cost of desalted water will be for many years "at least one whole order of magnitude greater than the value of the water to agriculture" (*7*). Other writers have been more optimistic. Thus, the value of distilled water for agriculture in Israel has been estimated by MacAvoy and Peterson (*8*) to be about 27 cents per 1000 gallons. A generalized study (*9*, p. 28) indicates that "arid tropical and semitropical regions with year-round growing climates appear potentially capable of growing food at costs in or near the world market import price range, using desalted water at prices like 20 cents per thousand gallons." Estimates have been made of the total (direct plus indirect) benefits of irrigation water in several U.S. locations. There is considerable variation, estimates of losses due to taking water away from crops being 25 to 36 cents per 1000 gallons for the Texas High Plains and 32 to 44 cents for the Imperial Valley (*10*).

As noted above, the growing of some high-value crops tends to follow the occupation of a dry area, and an economic enterprise would, of course, first seek to saturate the market for this produce. But one is not going to feed the teeming millions on orchids or avocados, so the inquiry turns inevitably to the bulk staple foods. Of the staples, the grains are the most important, and, of the grains, rice is the staple and preferred food of half the human race. Rice, because of this demand, has a value double that of wheat on the world market—but it is not usually talked about in connection with desalination agriculture. Let us, therefore, talk about it.

Rice is indigenous to southern and eastern Asia, where much of the world's starvation occurs. In the monsoon countries, where fields are flooded periodically, the rice plant has the great virtue of being able to conduct oxygen to its roots through a hollow stem, and to flourish where other crops suffocate. Cultivation under such conditions leads to heavy use of water. In Table 1, from a talk by the dean of agriculture of the University of Sydney (*11*), it may be seen that in Australia, the most favorable of the instances shown, a price for water of 20 cents per 1000 gallons would add 10.6 cents per pound to the cost of rice. This is more than the rice is worth and provides little basis for enthusiasm about desalination.

Table 2 gives data on yield and water use for several other crops which are widely used. The "Rice" row of Table 2 is left blank for the present. The water-use rates were estimated (and checked against measured rates for farms when these were available) for a coastal site in the southeastern Mediterranean area, an irrigation efficiency (the fraction of the applied water which is lost to the atmosphere in evapotranspiration) of 80 percent being assumed. The other 20 percent of the water is that part which evaporates before reaching the crop, or which is carried away by deep percolation below the root zone. With efficient sprinkler or soaker irrigation systems this efficiency can usually be bettered, even without allowing for partial recovery of the deep drainage water. The yields assumed are those obtained regularly today by efficient farmers in production areas specializing in the crops in question. Record yields are considerably higher—more than double in the case of wheat, potato, tomato, and maize and in the case of an assumed yield for rice, discussed below.

Table 1 shows that rice growers typically use several times as much water per pound of grain as is needed

Table 2. Relation of yield to water use for various crops.

Crop	Yield (10^3 lb/acre)	Food value (10^2 Cal/lb)	Water use		
			Inches	Gal/lb	Gal/10^3 Cal
		Grain			
Wheat	6.0	14.8	20.0	91	61
Sorghum	8.0	15.1	27.6	94	62
Maize	9.0	15.8	27.6	83	53
Rice					
		Vegetable			
Potato	48	2.79	16.0	9.0	32
Tomato	60	0.95	19.0	8.6	91
		Citrus			
Orange	44	1.31	53.1	33	250

Table 3. Estimated capital investment.

Item	Dollars per acre
Irrigation and storage-well system	375
Land, land development, and roads	85
Drainage system	110
Water for initial leaching	130
Grain storage	85
Machinery	115
Farm buildings	25
Interest during construction	25
Total	950

for the other grains of Table 2. While some people may have doubted that rice requires this much water, this is the way the picture has stood historically. Just recently, however, results have appeared which do not support the classical view of rice as a water hog. In an experiment with IR 8 rice at India's Central Rice Institute, in Cuttack, a good crop [6350 pounds (2900 kilograms) per acre as paddy rice] was obtained with consumption of only 16.7 inches (42 centimeters) of water, irrigation being applied only when the soil was completely crusted. This work was reviewed and reported by J. S. Kanwar, deputy director general of the Indian Council of Agricultural Research (*12*). Kanwar states, "The common notion that continuous submergence is essential for paddy is belied." In a corresponding experiment based on the classical practice of continuous submergence, six times as much water (100 inches) was used and the yield was 6 percent higher. Obviously, most of the 100 inches of water was forced into the subsoil by the head of standing water.

If confirmed in subsequent tests and field experience, this finding may turn out to be one of the landmarks in the war against hunger. We add that rice can be grown the year round in warm climates; for example, in the Philippines three crops per year have been grown, yielding a total of 18,000 pounds of rice per acre.

If the results of the Indian experiment are taken at face value, the missing numbers for rice, which can now be added to Table 2, are as follows: yield, 4.2 (10^3 pounds per acre); food value, 16.5 (10^2 Calories per pound); water use—16.7 inches, 108 gallons per pound, 65 gallons per 10^3 Calories. This puts rice right in among the other grains as a user of water. It may be seen that to supply a person a minimum adequate allowance of 2500 Calories per day (*13*) in this highly intensive and scientifically managed type of agriculture would require an average of 160 gallons of water per day in the case of grain, or half this in the case of potatoes.

Production Cost Estimates for Grain

For any selected price of water, Table 2 enables one to compute the cost of water per pound of product, as illustrated for rice in Table 1. However, water is only one component of the total cost. We have, therefore, made some illustrative estimates of the total production costs for grain for a large, intensively operated farm. These costs are not expected to vary greatly with farm size. The estimates were made for a farm of 300,000 acres (120,000 hectares) which uses about a billion gallons of water per day.

Table 4. Estimated overhead costs.

Item	Dollars per acre per year
Maintenance	14
Pumping power	1
Water losses in storage and canal leakage	12
Experimental station	1
Management and miscellaneous	7
Total	35

Table 5. Estimated direct costs for grain production.*

Item	Dollars per acre per crop
Fertilizer	11
Pumping power	6
Seed	5
Labor	2
Machine operation	2
Storage and marketing	3
Other chemicals	3
Miscellaneous	8
Total	40

*Exclusive of the cost of irrigation water.

These estimates are summarized in Tables 3 to 5. Table 3 shows the capital investment per acre, while Table 4 gives annual out-of-pocket costs for items which cannot be allocated directly to specific crops in the year-round rotation. The costs which can be specifically assigned are shown in Table 5.

It should be noted that the water is priced at the farm inlet and that it is supplied to the farm at a rate that is constant throughout the year, except for the time when the desalting plant is shut down for maintenance or other reasons. Thus, because of seasonal variations in the requirement for irrigation water, it is necessary to resort to such measures as (i) making seasonal adjustments in the size of the irrigated area and (ii) storing water in underground aquifers at certain times of the year and pumping it back up at other times (10 percent of the stored water is assumed to be lost in this process). Allowance for such storage has been made in Tables 3 and 4 (*14*).

An interest rate of 10 percent on the investment shown in Table 3 amounts to \$95 per acre per year, and allowance for depreciation and for working-capital needs adds about \$10 more. With the overhead costs shown in Table 4, the total fixed charges are thus \$140 per acre per year. In regions where a second major crop, of the same or some other product, can be grown in the same year on the same land and share fixed costs with the grain, the cost of an acre crop of grain would be (\$140/2) + \$40 + cost of water = \$110 + cost of water. In some areas, such as parts of India, where it might be possible to grow three crops per year the corresponding cost would be \$87 + cost of water.

The resulting costs for milled rice and for wheat are plotted in Fig. 1, along with some representative prices.

In effect, what is here being contemplated is that the high cost of water may be at least partially offset by the opportunity to conduct intensive year-round "food factory" agriculture in favorable growing climates with many conditions under unusually good control. For example, recent observations suggest that very frequent or drip irrigation can cause substantial increases in the crop yield (*15*). In these experiments the nitrogen fertilizer was applied in the water. There is also speculation that slow release of carbon dioxide beneath the plant canopy might enhance yields. Thus it is entirely possible that future yields may exceed those of Table 2.

Desalination

The newest United States desalting plant, at Key West, Florida, produces 2.5 million gallons of fresh water per day at a cost of about \$1 per 1000 gallons. It is anticipated that the larger plants envisaged for future regional water supply will be able to attain lower costs through the economies of scale and the benefits of more advanced technology. A plant producing 8 million gallons per day (*16*), which will be built around a gas turbine, will have vapor-compressor heat pumps coupled to vertical-tube evaporators and will use the engine-rejected heat in flash evaporators, is expected to produce fresh water at a cost of about half that for the Key West plant (*17*).

Heat transfer enhancement is currently being introduced into evaporator designs. For example, doubly finned or doubly flutted vertical tubes give several times the heat transfer of plain smooth tubes, and their use can considerably reduce the size and cost of a plant (*18*). To some degree the heat transfer in the horizontal tubes of a flash evaporator can be similarly augmented. Such advances are now being tried in test units and pilot plants. The preferred large-plant design at present is a combined flash and vertical-tube evaporator with heat transfer enhancement (*19*).

Economies can be achieved through the design and construction of dual-purpose plants which produce both power and water, as compared to single-purpose plants that produce only water. In terms of 1967 dollars at 10 percent interest (*20*), the cost of water at a large (billion gallons per day) single-purpose plant, in which most of the steam bypasses the turbine without generating any power, was estimated (*9*, pp. 3, 4, 19, 20; *21*, p. 39) to be 26 to 32 cents per 1000 gallons, while at a dual-purpose station the range for incremental cost of water was 16 to 24 cents. At an interest rate of 9 percent, another study (*22*) indicated 15 to 26 cents for the dual-purpose cost range. These large-plant studies were based on the use of reactor heat sources, with technology ranging from reactors of the type (light-water) and size being built in the United States today to advanced fast and thermal breeder reactors of the type that will be operational some two decades hence. Since these estimates were made there have been sharp increases in reactor prices, and it may turn out that the costs of water will have to be revised upward by 2 or 3 cents per 1000 gallons (*23*). On the other hand, advanced evaporator and agricultural technologies appear to be moving ahead more rapidly than had been expected.

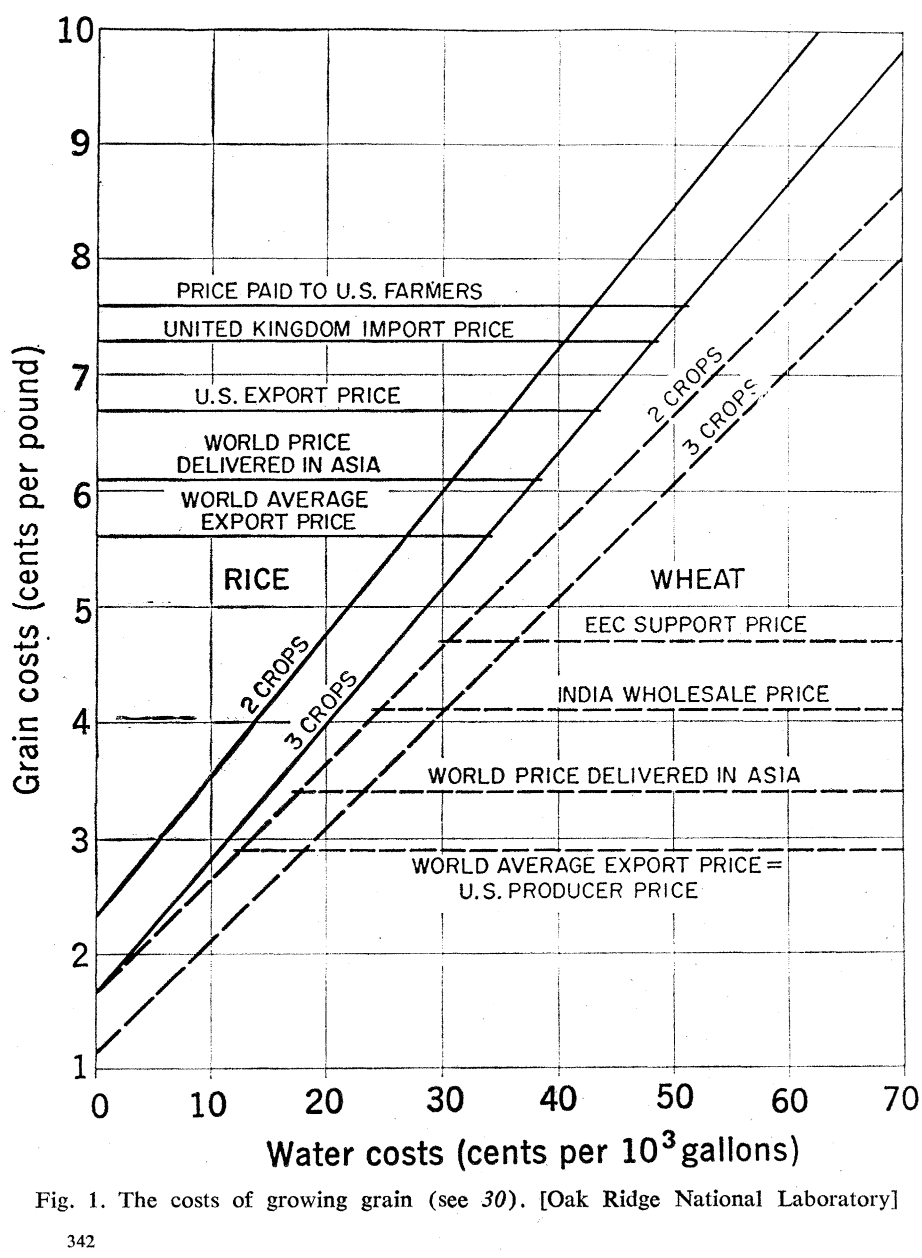

Fig. 1. The costs of growing grain (see *30*). [Oak Ridge National Laboratory]

The saving effected through dual-purpose operation works the other way as well. Once you have decided to build a single-purpose steam bypass water plant, the incremental cost of producing power also is very low—say, 1.5 mills per kilowatt-hour (*21*, p. 39) for reactor stations of the largest sizes being constructed today, such as Brown's Ferry (3000 electrical megawatts). This power may be transmitted to a network in some instances, or to adjacent industrial plants in a so-called agro-industrial complex, to help develop and build up the region. A number of industrial processes have been studied in this connection (*9, 21, 24*), as well as several possible locales (*25*) and some of the implementation problems (*26*). One of the large energy consumers is the production of ammonia for fertilizer by way of electrolytic hydrogen, with only air and water used as raw materials. Potassium fertilizer can be produced from the sea, as can other products, such as chlorine, magnesium, salt, and caustic. Hoyle writes (*27*):

> . . . the older established industries of Europe and America . . . grew up around specialized mineral deposits—coal, oil, metallic ores. Without these deposits the older style of industrialization was completely impossible. On the political and economic fronts, the world became divided into "haves" and "have nots," depending whereabouts on the earth's surface these specialized deposits happen to be situated. . . . In the second phase of industrialism, . . . no specialized deposits are needed at all. The key to this second phase lies in the possession of an effectively unlimited source of energy. . . . Low-grade ores can be smelted—and there is an ample supply of such ores to be found everywhere. Carbon can be taken from inorganic compounds, nitrogen from the air, a whole vast range of chemicals from seawater. So . . . a phase in which nothing is needed but the commonest materials—water, air and fairly common rocks. This was a phase that can be practiced by anybody, by any nation. . . . This second phase was clearly enormously more effective and powerful than the first.

Summary

The fastest-growing region in our country is the desert of the Southwest. This suggests that the vast, warm, dry areas of the world may be attractive for human occupancy as earth's population soars, if the water and power needs can be met. It may also be that nuclear energy—not tied by any umbilical cord to fossil deposits—will have a significant role in opening up these arid areas and creating usable land for human living space.

Since much arid land lies relatively near the sea and the aggregate length of the coastal deserts nearly equals the circumference of the globe, desalination is a freshwater source of broad potential applicability when cheaper alternative sources are not available. Cities and industries can now spread widely along the ocean shore, bringing with them some agriculture for garden produce.

A more difficult question concerns the extent to which desalination agriculture will be used in newly occupied arid lands for the production of staple foods. Since we cannot predict with any accuracy either the population growth or the increase in food production by various means, let alone the difference between these two large quantities, our knowledge of future food shortages is very poor indeed. It therefore appears prudent to conduct research, development, and pilot planting projects to investigate such potential methods for augmenting food production. These activities should be conducted on a scale sufficient to permit practical evaluation, so that the option of invoking such methods will be open, should circumstances require it. To quote R. R. R. Brooks (*28*), "The key to [the] . . . future of two-thirds of the human species is rising productivity in agriculture. All political dogmas, party slogans, planning strategies, and models of economic growth shrivel to irrelevance in the face of this fact."

A preliminary and generalized study was conducted at the Oak Ridge National Laboratory with the collaboration of outstanding agricultural and engineering people from other countries and from U.S. government agencies, universities, foundations, and industries. This study considered intensive year-round farming in warm coastal deserts, based on the use of distilled seawater, in association with clustering industries. As indicated in Fig. 1, production costs for rice and wheat appear (*29*) to fall, for water costs of around 35 and 20 cents per 1000 gallons, respectively, in the general area of recent grain prices. These water prices, in turn, fall (barely) within the estimated future cost range for desalinated water.

The significant conclusion, we believe, is that desalination agriculture is in the realm of practical possibility, rather than being far afield. To our mind this appears of sufficient importance, in view of the population expansion and the interest in opening up new lands and communities, to warrant the development of advanced desalting plants and intensive scientifically managed agriculture. We hope that desert research farms running on distilled water, and controlled-environment agricultural test chambers, may become as well known to you on your TV screen in a few years as starving Biafran babies are today.

References and Notes

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4. J. Bronowski, *Saturday Rev.* **1969**, 45 (5 July 1969).
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6. There are xerophytic plants (such as pineapple) that carry on photosynthesis with closed stomata in the daytime, using stored carbon dioxide absorbed through open stomata at night. They thus transpire much less water per unit of plant matter produced than ordinary crops do.
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14. If suitable aquifers are not present and an above-ground storage reservoir is constructed in the farming region, there is an increase in cost such that the value $140 in the next paragraph of the text changes to about $150 per acre per year, it being assumed that the reservoir is of a size adequate to supply a farm region with an intake of about 10^9 gallons of water per day.
15. D. Goldberg, B. Gornat, M. Shmueli, "Advances in irrigation in Israel's agriculture," paper presented at the 1st World Congress of Engineers and Architects, Israel (1967). See also D. Goldberg and M. Shmueli, "Drip irrigation—a method used under arid and desert conditions of high water and soil salinity," unpublished.
16. This plant is now in the preliminary planning stage.
17. "Design and Economic Study of a Gas Turbine Powered Vapor Compression Plant for Evaporation of Seawater," *Office Saline Water Res. Develop. Progr. Rep. No. 377* (1968).
18. Such tubes are to be used in the gas turbine unit discussed in the preceding paragraph.
19. "Conceptual Design Study of a 250-Million Gallon per Day Combined Vertical Tube-Flash Evaporator Desalination Plant," *Office Saline Water Res. Develop. Progr. Rep. No. 391* (1968).
20. The cost of desalted water is sensitive to changes in interest rates because, like conventional means of providing new water supplies such as dams and aqueducts, the process requires a large capital outlay.
21. *Oak Ridge Nat. Lab. Rep. No. ORNL-4290* (1968).
22. "Nuclear Power and Water Desalting Plants for Southwest United States and Northwest Mexico" (1968), pp. 113 and 136; this is a preliminary assessment made by a joint United States–Mexico International Atomic Energy Agency study team.
23. This expectation is based on the assumption that combined flash and vertical-tube evaporators are adopted; otherwise, the increase in water costs would be expected to be larger.
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29. The estimates are based on an interest rate of 10 percent.
30. Figure 1 is based on data and publications as follows. The average price paid the U.S. producer for wheat in the period 1956–65; the average price per pound of milled rice, at 0.65 paddy weight (0.65 pound of milled rice from each pound of paddy), paid the U.S. producer in the period 1950–65; the average price of Siam Patna No. 2 rice imported into the United Kingdom in the period 1955–65; the average wholesale price of wheat in India (the Punjab) in the period 1951–65 [*FAO* (*Food Agr. Organ. UN*) *Prod. Yearb.* **20** (1966)]; the world average export value of wheat in the period 1961–67; the world average export value of rice in the period 1955–67 [*The State of Food and Agriculture: 1968* (Food and Agriculture Organization of the United Nations, Rome, 1968)]; the average U.S. export value of rice in the period 1960–65; the European Economic Community's wheat support price [*The World Food Problem* (President's Science Advisory Committee, Washington, D.C., 1967), vol. 2, pp. 145, 149]; recent world prices for wheat and rice delivered in Asia, as given by R. P. Hammond in a paper presented at the International Conference on Water for Peace, Washington, D.C., May 1967.

31. The research discussed here is sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corp.