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THE ECONOMICS OF IRRIGATION

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Water Requirements of Plants

QUITE recently Dr. Penman (of the Rothamsted Laboratory of Soil Physics and Fellow of the Royal Society) has established the theorem, based on the simple laws of physics, that water requirements for all crops must be about the same, if they are grown on the same soil and for the same growing season. Virtually the whole of the plant's marginal requirements for water are to transpire in order to keep its temperature down within its limit of toleration. If the maximum temperature is not to be exceeded the cultivation must have a "thermal balance."[1] It is clear that nearly all the factors determining evaporation are independent, or virtually independent, of the nature of the crop being grown.

Dr. Penman's researches must necessarily lead to the drastic revision of all previous ideas about the economics of irrigation. Irrigating a given area, at a given time of the year for a given length of growing season, will use up much the same amount of water almost irrespective of the crop which is being grown; irrigators therefore should always grow the crop which, at that time of the year, and at the prices then prevailing, yields the highest economic return per unit of time. Often in the past charges for a given amount of water have been differentiated in such a way as to encourage the growing of the less economic crops, sometimes (in India) from a mistaken desire to make each region self-sufficient in grains.

1. Thornthwaite, *Geographical Review*, January 1948. See also Thornthwaite for theoretical calculations of water requirements under given climatic conditions, and their confirmation by observations of total water flow into and from certain valleys in the United States and Dominican Republic.

Another example of this favouring of the less economic crop has been in the Murrumbidgee area in Australia, where at one time rice took two-thirds of the entire water supply available for the whole area, but yielded a comparatively low return, in comparison with certain alternative fruit crops, for each unit of water used. Extravagant use of water on rice was encouraged by the price[2] charged; namely 0.2 cents/m^3 as against 0.8 for other growers. These charges, which are much lower than in most countries, cover interest and maintenance, but no redemption of capital.

Many irrigation engineers and administrators have asserted that the water requirements for a given area vary according to the nature of the crop.[3] More careful examination shows that these differences arise from one of the following causes: (1) some crops have a longer growing period; (2) some crops are grown at seasons of the year when solar radiation is greater; (3) water requirements may be somewhat reduced when plants have glossy leaves which reflect back the sun's radiation, or with crops which leave some of the soil bare, and therefore not requiring so much cooling; (4) the different soils in which the crops are grown, some being much more subject to seepage to the sub-soil than others.

Of all crops, rice is the most dependent upon irrigation, because of its need for flooding at a certain stage of growth. Only under very rare circumstances can its needs be satisfied by natural rainfall. Average water requirements for rice in tropical climates have been estimated at 1.5 metres in all.[4] A figure of 1.9 was estimated for Iraq, but the general estimate of about 1.5 was confirmed in two provinces of Pakistan. An experiment in India showed that ad-lib watering of rice, with total supplies up to 3½—4 metres, did not increase yields in comparison with control plots with a supply of 1.6 metres.[5]

The effects of persistent watering to excess can be very serious indeed. In his study of the Khaipur area in West Pakistan (quoted above) Naylor recommends concentrated watering at the rate of 1.2 metres/year with adequate drainage to obviate both water-logging and salinisation.

We now proceed to a general consideration of available information on gross and net marginal returns to each m^3 of water applied in irrigation (Table I). Net marginal return is estimated after deducting all additional costs incurred including wages payable to additional labour (which is assumed to be available). These deductions are often considerable, and it is important not to confuse gross and net returns.

The most generous responses are shown by potatoes, a shallow-rooted crop particularly dependent upon abundant water supplies, selling (in Europe and

2. All water quantities are measured in cubic metres (written m^3): 10,000m^3 will suffice to water 1 hectare to the depth of a metre, which should constitute a year's supply : all money values are converted to present-day American dollars and costs—not at current exchange rates, but on the estimated true purchasing power of the money—in the case of India, at 25 cents to the rupee.

3. See for example Studies in the Economics of Farm Management, Madras, 1954-55, Ministry of Food & Agriculture, Government of India.

4. International Rice Commission at Bangkok, Newsletter No. 8, December 1953.

5. *International Journal of Agrarian Affairs*, October 1963, Naylor's study of Khaipur.

TABLE I—GROSS AND NET RETURNS TO IRRIGATION

Country	Crop or Product	Conversion factor (kg. wheat/kg. crop)	Irrigation Water Input cms. Specified	Irrigation Water Input cms. Not specified-approx. estimated	Gross marginal return (kg. wheat/m³	Net marginal return[1]
Australia	Butter fat[2]	14.7	45		0.50	
	Rice[3]				0.17	
India	General :[4] Senapur					0.25
	Orissa					0.24
	Bihar					0.45
	Bombay					0.3—0.5
Italy	Maize[5]	0.75		50	0.30	
	Wheat			50	0.26	
Pakistan	Cotton unginned	2.41	50		0.24	
	Rice milled	1.2	120		0.12	
	Sugarcane	0.13	100		0.13	
	Sorghum	0.6	20		0.08	
U.S.A.	Potatoes :[6] Long Island	0.65	7		5.83	
	Wisconsin		8		9.50	6.55

1. After meeting additional costs (kg. wheat equivalent/m³).
2. Waring, Review of Marketing and Agricultural Economics, Sydney, December 1959.
3. Publications of Murrumbidgee Irrigation Authority.
4. Indian Statistical Institute Planning Unit : Price Policy for Irrigation Undertakings—A Preliminary Study, August 1961, p. 62. See also Gokhale Institute of Politics and Economics: Publication No. 17—Economic Effects of Irrigation, and Economics of a Multipurpose River Dam, 1960.
5. Gruner, *Bewasserungs Anlagen*, Zurich, 1944.
6. Department of Agriculture Year Book, 1955.

America) at a comparatively high price in relation to their carbohydrate content. We must also bear in mind that these results are only obtained by the use of costly equipment, which has to stand idle for most of the year, in the hands of very skilled growers. Similar considerations apply in explaining the high yields from tobacco, cotton and tomatoes in U.S.A., fruit, vegetables, wine and flax in France, and fruit in Italy and Australia. In the low-income countries, the net marginal returns to water appear unfortunately to be lower than in the high income countries. "To him that hath shall more be given." But well cultivated plants, of good strain might well be expected to be better able to take advantage of additional water than can poorer plants.

An estimate of the marginal productivity of irrigation water under Indian conditions, which accords well with what other information we have, was made by Hopper,[6] using production functions, for the village of Senapur in the Ganges valley. The net marginal productivity of a cubic metre was found to be 0.25 kg. wheat or 0.36 kg. barley. (It is clearly better to express results in this physical form rather than in terms of changeable prices). Some irrigation areas in India appear however to have a marginal product per m^3 which is considerably lower.

THE COSTS OF IRRIGATION

If it can be shown that the costs of a particular irrigation project are in excess of the expected economic return from it, there are many advocates of irrigation who, without seeking to exploit "public romanticism," or the natural tendency of politicians to like having large dams, will nevertheless urge that the project may be proceeded with on what they believe to be genuine economic grounds that irrigation schemes bring indirect economic benefits, in the form of secondary employment, and additions to public revenue, which outweigh the direct loss.

The economist must however, debit against whatever farmers, local traders, etc., may produce on an irrigation settlement the value of what they might have been producing elsewhere without irrigation, and only credit the net difference.

The costs of irrigation water may vary greatly according to its origin in wells, simple diversion channels or dams. In U.S.A., for example, the cost of water per unit delivered have been about 0.1 c/m^3 for water drawn by gravity from the natural flow of streams, 0.3 for water pumped from streams, and 0.7 for water pumped from wells.

Diminishing returns naturally to be expected, as succeeding irrigators have to make use of less naturally favoured streams and dam sites, have shown themselves in U.S.A., India, and Pakistan. For example average costs, expressed in present-day dollars per hectare irrigated for irrigation works in India between 1901-1955 are shown in Table II.

TABLE—II DAM IRRIGATION IN INDIA AND PAKISTAN (EXCLUDING BURMA))
SPECIFIED IRRIGATION WORKS

Date	Total Area irrigated million hectares	Period of Construction	Area irrigated million hectares	Average cost $ per hectare irrigated
		Before 1900	5.1	114
1901	12.5	1901 — 1910	1.1	87
1911	17			
		1911 — 1920	1.3	125
1921	18			
		1921 — 1930	0.75	153
1931	19			
		1931 — 1940	1.2	215
1941	23			
1951	29			
1955	31.5			

6. Quoted by T. W. Schultz : Transforming Traditional Agriculture, Yale University Press New Haven and London, 1964, pp. 46-47.

We have some information about costs of well-irrigation by the simplest possible methods in low-income agriculture (converting the rupee at 25 cents, but considering costs also in grain equivalents). Table III shows the costs of various methods of raising water from a water table of 9 metres depth. These costs are in excess of the marginal value of the water, as calculated by Hopper.

TABLE III*

	Required power		m^3/hour delivered	Hectares watered	Capital cost cents/m^3	Operating cost cents/m^3	Operating cost in kg. wheat equivalent /m^3
	Men	Bullocks					
Picottah ..	4	—	3	0.5	0.7	3.3	0.26
Well sweep ..	5	—	6	—	0.4	2.1	0.17
Mhote ..	2	2	7	1.2	0.3	4.3	0.35
Persian Wheel ..	2	2	9	1.5	0.2	3.3	0.26

*A.R. Tainsh, Stockholm, private communication, and Dias, "*Tropical Agriculturist*," Ceylon 1956. The area which can be watered by each device appears to have been calculated on the assumption of one metre depth and some 1,800 hrs./year as maximum practicable time of operation.

In Southern Rhodesia it has been estimated that the costs of irrigation from a bore hole, using a diesel pump with a capacity of 680—1360 m^3/month to supply 30—60 families, might permit the growing of vegetables, but certainly not of staple crops.

Hopper's work at Senapur makes the marginal value of one bullock-hour no less than 9 times that of a man-hour. A careful study in the Punjab by Shastri[7] showed that the full cost of a bullock, inclusive of interest and depreciation, was Rs. 558/year in 1950, and that it could usefully be used only about 160 days/year. In West Bengal[8] where oxen appear to be abundant, and the rainy season prolonged, so that there is less urgency about cultivation, the average agricultural wage worker is paid at the rate of 3.5 kg. rice/day, and only 6.6 if he provides the plough and a pair of oxen.

We now examine the extent to which costs can be reduced by power pumping. Naylor found that a large tubewell of 2.7 million m^3/year capacity working 70 per cent of the time at a depth of 60 metres, cost 0.8 to 1.1 c/m^3. This cost includes interest and depreciation on the electric power provision. Tube wells for irrigation in India, where electric power is already available, have much lower capital and operating costs. In the Gorakhpur area[9] capital costs are estimated at only 55—75$/hectare and operating costs including power 11$/hectare, *i.e.*,

7. *The Economic Weekly*, 29th October, 1960.
8. Ghosh, International Statistical Institute Proceedings, 1951.
9. Ansari, *International Journal of Agrarian Affairs*, October 1963, p. 42.

assuming average irrigation depth of 0.75 metres, only 0.15 c/m^3 for operating costs. This may, however, have been an exceptionally favoured area.

An electric pump of 153 cubic metres per hour (1½ cusecs) capacity can operate at an inclusive cost, covering power, labour, and depreciation of 0.19 c/m^3 in Pakistan (0.23 with a one-cusec pump).[10] With smaller pumps, and diesel engines, such as have been used where electric power is not available the cost figure may be as high as 0.67 c/m^3, rising to 1.07 for deep tube wells. Diesel engines have both higher capital and higher maintenance costs than electric motors. New power and energy costs may vary greatly between different places and may represent a considerable part of the running costs.

Net marginal returns to the use of water in India may be as low as 0.25 kg. wheat equivalents, *i.e.*, 1.7 cents/m^3 at world prices, or more than twice that at Indian grain prices. Even with diesel pumps therefore, a remunerative return may be expected from depths much greater than 20 metres, more so in the case of electric pumps. The man and ox-powered pumps, on the other hand, are only doubtfully worthwhile at a depth of 9 metres. In the U.S.A., where pumping costs are lower, the economic limits have been estimated[11] at 15—22 metres depth for watering lucerne (alfalfa) and as much as 90 metres for citrus.

Capital costs of water storage, per unit stored, are reduced when very large dams are built.

TABLE IV—CAPITAL COSTS OF WATER STORAGE IN C/M^3

Australia	Eildon	2.0
	Timaroo	3.3
	Large earth dams	3.2
	Small dams	6.1
Ceylon	Gal Oya	3.5
Egypt	Aswan 1902	3.0
	1912	3.6
	1933	2.3
	High Dam	0.7
	Gabal al Awala	1.3
India	Bhakra	2.0
	Mutha River	3.1
Italy	Tirso	3.0
	Small dams	9.0
Mexico	Miguel Aleman	2.4

What is gained by building these large water storages is, however, to a considerable extent lost again in the costs of the distribution network and of land levelling which necessarily accompany them. Thus in the Australian examples the ratio which these costs bear to the cost of storage is as high as 2.15 for a dam of some 700 million m^3, 0.25 for large earth dams, and of course nothing for spray irriga-

10. Shafi Niaz, Government of Pakistan, private communication. A similar estimate was made by the Punjab Board of Economic Inquiry.

11. Etcheverry and Harding : Irrigation Practice and Engineering, 1933.

tion from small dams. In India, the ratio was 0.81 for the Mutha River Project, 0.9 Hirakud and 2.2 for Bhakra. The Indus has an immense summer flow from melting snows, which for a large area in Pakistan is controlled by a comparatively low cost barrage at Sukhur. In this exceptional case, the cost of canals and water courses was four times that of the barrage and headworks.

So far we have concerned ourselves with the gross costs of dams. In analysing the costs of irrigation or other water supply, however, we have to take into account the consideration that the dam may have also been built for the purpose of hydro-electric generation. The correct procedure appears to be to compute what it would have cost the authorities responsible for electrical distribution to have obtained from alternative sources, not only the same output, but also the same capacity for meeting peak demands. Under Indian conditions we should credit Rs. 1,500 per kilowatt of capacity. Such a credit would offset 53 per cent of the gross cost of Bhakra-Nangal, 29 per cent of Damodar, and 20 per cent of Hirakud.

We may now review the question of water resources. Estimates for the whole of India have been published in "River Valley Projects in India" (Central Power Irrigation and Navigation Commission). The average rainfall (Table V) is quite high, but a great deal of it evaporates before it reaches the river bed. And it is an awkward fact the evaporation is highest where the rainfall is least. It will be seen that on the east coast, below the Ganges Valley, it is hoped to conserve 40 per cent of the stream flow, as against 8 per cent at the present time. In the more humid Ganges and Brahmaputra Basin it is not proposed, in the present system of river plans, to attempt to conserve more than 20 per cent of the flow. Of the Indus 55 per cent now runs to waste, but under the new agreement between India and Pakistan it is hoped to reduce this proportion to 27½ per cent.

TABLE V—PRESENT AND POTENTIAL UTILIZATION OF INDIAN RIVERS

	Area million hectares	Average rainfall (metres)	Average run-off (metres)	Stream flow $m^3 \times 10^{10}$	Present use for irrigation $m^3 \times 10^{10}$	Proposed use for irrigation and power $m^3 \times 10^{10}$	Land irrigated million hectares*	
							Present	Proposed
West Coast river basin, excluding Indus ..	49.2	1.22	0.63	31.0	1.4	5.1	1.2	2.2
Indus Basin (excluding W. Pakistan) ..	35.4	0.56	0.22	8.0	1.3	3.0	1.6	4.3
East Coast river basins, excluding Ganges and Brahmaputra ..	119.0	1.09	0.34	41.2	3.0	16.1	7.5	12.1
Ganges Basin (excluding E. Pakistan) ..	97.7	1.11	0.50	49.0	3.2	6.1	7.8	11.8
Brahmaputra Basin (excluding E. Pakistan) ..	50.6	1.22	0.75	38.2	0.4	4.4	0.4	0.4
Rajputana (draining inland) ..	17.0	0.29	—	—	—	—	0.5	0.5
All-India ..	365.9	1.06	0.45	167.4	9.3	34.7	19.0	31.3

*To irrigate a million hectares to the depth of 1 metre requires 10^{10} m^3.

CHARGES FOR WATER

Charges made for irrigation water are often well below cost. The charges[12] made for water from the Bhakra Dam in India have been purely nominal (0.01—0.03 c/m^3, in comparison with the higher, but still low charge of 0.06 on old canals). A betterment levy after one year of collection of instalments had to be held in abeyance on account of widespread political agitation against it.

In the land benefited by the Hirakud Dam it is proposed to collect by instalments, a betterment levy of Rs. 185 to 370/hectare—only a small part of the capital cost. In Mysore (where irrigation costs are high) it was at one time customary not to begin an irrigation project unless the owners of two-thirds of the land benefited would agree to pay a betterment levy over Rs. 370/hectare. In modern India, however, it is considered that such methods are "incompatible with democracy." For sugarcane growing[13] in Maharashtra a charge is made of 0.31 c/m^3; it seems clear that the marginal productivity of the water is much higher than this, and that the water could have been better used on other crops.

De Haven[14] states that "inefficiency and waste are strongly indicated when a wide divergence of prices for the same product exist; a difference much greater than the transfer cost." Water should be sold, as nearly as possible, at a uniform price to all users, which price should reflect the full costs of obtaining and distributing it. The exceptionally low charges to agricultural users of water in U.S.A., as compared with charges to industrial and urban users are not justified. (Nor are they in other countries.)

Great hopes have been entertained about the possibilities of obtaining fresh water by desalinisation of sea-water. In a paper presented by the United Nations Department of Economic and Social Affairs at a conference in Milan in April 1964, it was stated that costs now were of the order of 25 c/m^3, but that the higher engineering costs in developing countries would make the minimum cost there 39 c/m^3. However, General Dynamics Corporation claim that a large plant could deliver fresh water at 7.1 c/m^3.[15] Water obtained even at this lower cost however, while solving the more serious problems of urban water supply, such water, however, would still be far beyond the reach of agriculturalists except perhaps for supplying expensive fresh vegetables to high income populations on a few isolated islands.

12. Ansari, *International Journal of Agrarian Affairs*, October 1963.
13. Gokhale Institute of Politics and Economics, Poona, private communication.
14. J. C. De Haven, *Journal of American Water Works Association*, 5th May, 1963.
15. San Diego, California, Press Release, 13th July, 1964.