Review Article

Waterlogging and Salinity in West Pakistan: An Analysis of the Revelle Report

by

GHULAM MOHAMMAD AND CHRISTOPH BERINGER*

In 1961 during the state visit by President Mohammad Ayub Khan to the United States, the two Presidents discussed the problem of waterlogging and salinity and its implications for economic development in Pakistan. As a result of this meeting, a Panel of U.S. experts was assembled to study the problem. This Panel was composed of specialists in agriculture, hydrology, engineering and social sciences; its chairman was Dr. Roger Revelle, Science Adviser to the United States Secretary of the Interior. The Panel's *Report*[1] was submitted to the President of Pakistan in September 1962, with the comment that it should be considered as being still in preliminary draft form and subject to continuing revisions as comments from other experts in the field are received.

The present article is based on this preliminary version of the *Revelle Report*. While there may be changes in detail, we have assumed that the broad conclusions embodied in the *Report* will remain unchanged.

BACKGROUND OF THE REVELLE REPORT

The historical records indicate that the engineers who planned and constructed the Indus Basin canal network expected that over a period of years the groundwater table would rise significantly throughout the river basin[2]. These expectations proved to be largely correct. It has been estimated that out of the average annual diversion of about 75 million acre feet[3] from the rivers into the canals, only about 34 to 41 million acre feet of water is avail-

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*The authors are Senior Research Economist and Research Adviser respectively in the Institute of Development Economics, Karachi.

[1]Draft Report of President Kennedy's Science Advisory Committee, White House, Interior Panel on *Waterlogging and Salinity in West Pakistan*, Washington, D.C., September 1962.

[2]The Indus Plains of West Pakistan with 33 million acres of agricultural land served by over 10,000 miles of irrigation canals constitute the largest irrigation system in the world. Irrigation in one form or another has been practised in the Indus Basin for centuries; the construction of permanent canals whose waterflow is controlled by low dams or barrages was started in the middle of the nineteenth century.

[3]One acre foot is the amount of water required to cover 1 acre to a depth of 1 foot. It is one of the most commonly used measures of irrigation water supply.

able for actual use by crops; the remainder either evaporates or seeps into the underground reservoir. The result has been an average rise of the groundwater table between ½ and 2 feet per year so that even as early as 1940 the water table came to within 10-15 feet of the ground surface in many of the irrigated areas of the Indus Plains[4]. In the last century, before the canals were constructed the water table was at 50-70 feet in the centre of the *Doabs*[5].

In areas where the water table has risen to a level even with the surface of the land we find 'waterlogging'. Plant roots being deprived of their normal supply of air by the presence of water are unable to grow and the land becomes unfit for agricultural production. In areas where the water table does not come quite to the surface but rises to within a few feet of it, capillary action, coupled with the intense heat during most of the year, results in excessive water evaporation. Since the groundwater always contains a certain amount of dissolved salts and since these are left behind when water evaporates, salts will accumulate in the top layers of the soil. A closer the groundwater level comes to the surface of the land, the more water will evaporate and the greater will be the degree of salinity. Since most agricultural crops have only a limited salt tolerance, the land becomes useless when the salt concentration in the soil begins to exceed that limit.

The process by which agricultural lands become unfit for agricultural production through waterlogging and salinity is a gradual one and the extent to which individual tracts are affected differs. It is, therefore, difficult to get a precise figure on the amount of land presently affected and the rate at which land is going out of production every year. A Colombo Plan survey[6], conducted in 1953/54, estimated that in the Northern Zone of the Indus Basin, having about 20 million acres of cultivable commanded area, about 4.4 million acres are predominantly poorly drained or waterlogged, 1.6 million acres are predominantly severely saline and 4.1 million acres are of a nature where saline patches are common. Thus, approximately 30 per cent of the area is either waterlogged or so severely saline that it is of very limited use for agricultural production.

For the Southern Zone of the Indus Basin, which has about 13 million acres under the command of irrigation canals, 6.9 million acres are classified

[4]West Pakistan Water and Power Development Authority, *Programme for Waterlogging and Salinity Control in the Irrigated Areas of West Pakistan*, Lahore, 1961, p. 5. This document will subsequently be referred to as the 'WAPDA Masterplan'.

[5]The term *Doab* refers to an area of land located between two rivers. As there are 5 major rivers in the Punjab the land areas between them constitute the largest part of the canal-irrigated area in West Pakistan.

[6]*Landforms, Soils and Land Use of the Indus Plains, West Pakistan*, published for the Government of Pakistan by the Government of Canada; A Colombo Plan Cooperative Project, Toronto, February, 1958.

as predominantly poorly drained or waterlogged whereas 3.2 million acres are classified as predominantly severely saline. The proportion of the area affected in the Southern Zone appears, therefore, to be even larger than in the Northern Zone.

The salinity and waterlogging problems in the Southern Zone of the Indus Basin are to a lesser extent 'man-made' than is the case in the Northern Zone. In most areas of the former Sind, soil salinity has always been high even before canal irrigation was undertaken on a large scale. This is partly explained by the fact that, due to the proximity to the sea, the groundwater table has always been much closer to the soil surface than was the case in the former Punjab before the canals were constructed.

The rate of deterioration of land due to waterlogging and salinity has been variously estimated to be between 50,000 and 100,000 acres annually.

The implications of this development for agricultural production, prosperity and wellbeing of the entire population of West Pakistan are obvious. Already more than one million acres of land and hundreds of once-prosperous villages in the canal colonies have been abandoned and their inhabitants have moved away in search of food and shelter. On the national level, it is reflected in stagnating agricultural production both of food crops and of cash crops. Upto 1951, there were no foodgrain imports into West Pakistan. Since then they have been steadily increasing and have now reached a level of approximately 1 million tons a year.

FIGHT AGAINST WATERLOGGING AND SALINITY IN HISTORICAL PERSPECTIVE

Attention was first drawn to waterlogging in the Western Jamna Canal district (now in India) in 1851, when malaria became a serious problem. Waterlogging was also reported in several other canal areas thereafter. Systematic observations on water levels were initiated in 1870. During 1927-29 a study was made by Wilsdon and Sarathy[7], for the Rechna and Chaj *Doabs* based on the data that had become available by then. This study concluded that the cause of rising water tables was the monsoon rainfall. Another analysis of the data for the Upper Chenab Canal area, made in 1933 by Taylor and co-workers[8], confirmed this conclusion and recommended

[7]a) B. H. Wilsdon and R. P. Sarathy, *Memoirs, Punjab Irrigation Research*, Vol. 1, No. 1, Lahore, 1927.
b) B.H. Wilsdon and R.P. Sarathy, *Memoirs, Punjab Irrigation Research*, Vol. 1, No. 2, Lahore, 1929.

[8]E. McKenzie Taylor, J.K. Malhotra and M.L. Mehta, *An Investigation of the Rise of Water Table in the Upper Chenab Canal Area*, Punjab Irrigation Research Institute, Lahore, April 1933.

the construction of storm-water drains for rapid removal of monsoon rainfall runoff.

Various attempts were made to reclaim affected lands or to reduce the rate at which land was going out of production. Control of canal seepage through periodic closure of canals and lowering of the canal water levels were attempted. Open-surface drains were constructed in 1936 to remove the rainfall runoff. Several tubewell projects were undertaken, some of these with the help of FAO[9] in the hope that the groundwater table could be lowered. Yet none of these measures proved to be adequate to cope with the problem in its enormous magnitude. The tubewell projects were apparently too small in scale with the result that the rate at which water was pumped out from the aquifer was not sufficiently larger than the rate at which recharge occurred from the area surrounding the tubewell projects. Besides, a large number of tubewells became inoperative due to lack of maintenance and non-availability of spare parts.

In the period after independence the efforts to cope with the problem were further intensified. A soil survey of the entire Indus Plain was initiated in 1953 under the Colombo Plan; the results have since been published[10]. The report classifies the different soil types found in West Pakistan and gives estimates of the degree of waterlogging and salinity found in different areas of the river basin.

In addition to this overall survey, detailed investigations of groundwater hydrology and soil salinity were started in the Rechna, Chaj and Thal *Doabs* with the help of the United States International Cooperation Administration[11]. The results of these investigations were published in several Water and Power Development Authority (WAPDA) reports[12]. Simultaneously with the

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[9] *a*) FAO Report to the Government of Pakistan on *Waterlogged and Salty Lands in the Provinces of West Punjab and Sind and Khairpur State of the Indus Valley, Some Observations and Tentative Conclusions*, by Milo B. Williams. Rome, November 1950.
b) FAO Report No. 207 to the Government of Pakistan on *The Punjab Tubewell Project*, by H. E. Selby. Rome, December 1953.
c) FAO Report No. 417 to the Government of Pakistan on *The Chuharkana Tubewell Reclamation Scheme*, by H. E. Olafson, Rome, November 1955.

[10] *Landforms, Soils and Land Use of the Indus Plains, West Pakistan, op. cit.*

[11] Now Agency for International Development.

[12] *a*) WAPDA, West Pakistan, *Salinity Control and Reclamation Project, Investigations and Background Information* (*Project No. 1*). Lahore, January 1959.
b) WAPDA, West Pakistan, *A Review of Project No. 1, Salinity Control Programme in West Pakistan*, Internal Report prepared by Tipton and Kalmbach, Denver, June 1959
c) WAPDA, West Pakistan, *Feasibility Report on Salinity Control and Reclamation Project No. 2*, (*Chaj Doab*), Internal Report prepared by Tipton and Kalmbach, Denver, December 1960.

investigations in the Northern Zone, studies were initiated in the areas under the command of the Guddu, Sukkur and Ghulam Mohammad Barrages[13].

In April 1961, a meeting was called by the President of Pakistan to consider steps to be taken to cope with the waterlogging and salinity problem. As a result of this meeting WAPDA was requested[14] to make an overall appraisal of the magnitude of the waterlogging and salinity problem in West Pakistan and to propose a programme of engineering works (tubewells, drains, *etc.*) which will be required to reclaim lands already affected.

Drawing on the extensive studies which had been going on for several years, WAPDA prepared, within a relatively short time, a comprehensive "Programme for Waterlogging and Salinity Control in the Irrigated Areas of West Pakistan," referred to in this paper as the WAPDA Masterplan.

Under this plan, the entire irrigated area is to be subdivided into 26 project areas covering some 29 million acres presently under the command of the irrigation canals. The Northern Zone will have ten reclamation schemes, the remaining sixteen are to be constructed in the Southern Zone.

In the Northern Zone, the emphasis would be primarily on the installation of tubewells in the project areas so as to bring about a lowering of the groundwater table through vertical drainage. In the Southern Zone, the emphasis in the reclamation effort, would be primarily on open drains for the removal of subsoil and surface water, supplemented by tubewells. The entire programme calls for the construction of 31,000 tubewells, 7,500 miles of major drainage canals and 25,000 miles of supplemental drains. The total capital cost of the 26 projects[15], including additional power facilities, is estimated at Rs. 590 crores to be incurred over a period of ten years.

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[13]WAPDA, West Pakistan, *Sukkur-Guddu-Ghulam Mohammad Drainage and Salinity Control Project*, Internal Reports prepared by Hunting Technical Services.

Report No. 1: *Khairpur Command*, London, January 1961.
Report No. 2: *Gaja Perennial Area*, London, May 1961.
Report No. 3: *Khairpur Command Supplementary Report*, London, June 1961.
Report No. 4: *Ghulam Mohammad Barrage Command*, London, July 1961.
Report No. 5: *Sukkur-Guddu Right Bank Command*, London, October 1961.

[14]WAPDA Masterplan, *op. cit.*, p. i.

[15]One of the reclamation projects envisaged in this overall programme has already gone into operation in the central part of Rechna *Doab* of the Northern Zone. The project is known as 'Salinity Control and Reclamation Project No. 1' (SCARP 1) and it covers an area of approximately 1.2 million acres. In this project some 1,800 tubewells have been installed at an estimated capital cost of Rs. 10.5 crores. The total installed pumping capacity is 6,050 cusecs equal to 4.4 million acre feet. This will mean a net addition of 3-4 acre feet of irrigation water per acre over the entire project area. But the tubewell are proposed to be worked to supply 1.25 acre feet per acre of water annually.

The second project known as SCARP 2, located in the Chaj *Doab* of the Northern Zone, is presently under construction. The project is about twice the size of SCARP 1 and calls for the installation of about 3,300 tubewells out of with 3,240 will be for drainage and irrigation and 60 will be purely for drainage.

PRINCIPAL PROPOSALS OF THE REVELLE REPORT

The most important conclusion reached by the Revelle Panel can be stated as follows: the problem of waterlogging and salinity in West Pakistan is not merely an isolated technical problem but has to be approached in the context of a wide combination of potentially limiting productive inputs, technical as well as human and institutional. Neglect of any one of these interacting factors would in the opinion of the Panel limit the results which can be obtained from any one of the remaining productive inputs.

The Panel, therefore, recommends an integrated programme for the provision of drainage and additional water by tubewell pumping, more fertilizer, pure seed of improved varieties, pest and disease control and better cultivation practices. A development programme is proposed which subdivides the major part of the irrigated lands of the Indus Plain into 25 project areas of roughly one million acres each. Development efforts should be concentrated in these areas. New project areas should be brought into the programme at the rate of about one every year. With respect to administration, the Panel recommends a shift from a type based on function to one based on area. Although the recommendations with respect to administration are lacking in detail, the implication is that all the departments which presently operate more or less independently in the area would come under the supervision and control of a project director who would integrate their efforts towards the achievement of the development plan.

The report is divided into 7 chapters: the first chapter describes the present condition of agriculture, the land, the water and the causes that have led to salinity and waterlogging in West Pakistan. The second chapter analyses the role of water, fertilizer, pest control, improved seed and other improved practices in increasing agricultural production. The plan for the development of agriculture is presented in Chapter 3. Increases in output that may be expected from one million acres are given in the fourth chapter. In the fifth chapter estimates of fertilizer requirements, its cost of production and distribution are given. The sixth chapter is devoted to hydrology of the Indus Basin and describes the assumptions and calculation on which the expected yield of water from tubewells is based. The last chapter suggests further research that should be undertaken in various fields.

With respect to technical aspect of reclamation, the Panel starts from the assumption that under the plains of the former Punjab and Bahawalpur lies a vast aquifer which should be used to supply and store large quantities of water. As in the WAPDA Masterplan, discussed earlier, the Panel proposes that tubewells should be installed in each project area for pumping of this water for intensification of cultivation, leaching out of salts, lowering the groundwater table, using increased amount of fertilizer and attaining better control over total water supply.

The size of one million acres for each project area has been suggested for a number of reasons. The most important consideration was that a project area of one million acres would be large enough for the tubewells to be effective in lowering the water table in a reasonable length of time. Smaller project areas have a relatively larger perimeter for lateral infiltration of groundwater from unpumped lands which would retard the rate at which the groundwater level could be lowered.

Analogue and digital computors were used to investigate areas of different shapes and sizes as well as different patterns of pumping, recharge and drainage. Working with three hypothetical areas of different sizes (20, 180 and 1,600 square miles), the Panel found that the maximum lowering of the water table in the centre of the smallest area (20 square miles) was only 14 feet in 20 years, whereas in the largest area (1,600 square miles equivalent to one million acres) it was 67 feet over the same time period.

Another analogue computer investigation on a hypothetical 300,000 acre tubewell project area comprised 500 tubewells of 0.5 and 1.5 cusec capacity[16]. It was found that 0.5 cusec capacity tubewells will be effective in lowering the water table if no lateral infiltration or recharge occurred; the 1.5 cusec tubewells will be effective in lowering the water table even in areas with heavy recharge from the rivers or canals and with permeable soils.

The rate of increase of groundwater salinity as a result of continuous pumping was also investigated. It was found that surface drainage of about 10 per cent of tubewell pumping is needed over a 50-year period to prevent eventual salt accumulation in the root zone of crops. In most cases the drainage can be delayed for 10 or even 20 years without excessive salt accumulation provided the total drainage in 50 years is equal to about 10 per cent of the total pumpage.

The gross rate of pumping is estimated as 46 million acre feet (Appendix Table I) out of which about 7 million acre feet will be recycled[17] and one million acre feet of highly saline water will be disposed of by downstream transport into the rivers. The remaining 38 million acre feet can be used for irrigation in the former Punjab and Bahawalpur. No increase in canal water sup-

[16]The capacity of pumps is usually expressed in terms of cubic feet per second (cusec). A pump with a capacity of 1 cusec will deliver 720 acre feet per year if operated continuously.

[17]The term recycling means that this amount of water after being pumped out will again seep down into the groundwater aquifer.

plies is expected during the next 20 years in this zone. These will remain at the existing level of about 45 million acre feet diverted at canal head or 24 million acre feet available at the fields for consumptive use by crops. Total farm availability in the Northern Zone will, thus, be 62 million acre feet.

For the former Sind area, the canal water supplies diverted at canal head will increase from the 1952-57 average of 30.4 million acre feet to about 38 million acre feet during the next 20 years. Out of this only 23 million acre feet including rainfall will be available for actual crop use. This means 1.77 feet per acre for the entire canal-commanded area of 13 million acres. It is, therefore, evident that actual cultivated area will have to be much smaller than 13 million acres. No pumping for irrigation can be undertaken in Sind because the groundwater is highly saline.

The Panel expects that after the first period of 20 years, total canal water diversions can be increased from 83 MAF per annum to 101 MAF per annum as a result of:

i) raising Mangla and Tarbela Dams over the presently planned levels	1.7 MAF
ii) constructing additional storage dams	13.0 MAF
iii) installation of recharge works to provide groundwater storage	14.6 MAF
Total	29.3 MAF

Thus, a total additional storage capacity of 29 million acre feet is expected to provide an average annual additional water diversion of 18 million acre feet[18]. Additional tubewells will be needed to utilize the additional groundwater storage of 14.6 million acre feet given under *iii*) above. The cost of storage works as well as the cost of additional tubewells is not indicated in the *Report*.

Fertilizers

It is proposed that about 45 to 50 million pounds of nitrogen be produced and applied annually in each million-acre project area. For 25 project areas, a total of 1,250 million pounds or 645,000 tons of nitrogen will be

[18]The need for excess storage capacity over and above the additional annual average diversion is explained by the high serial correlation in the flow pattern of the Indus river. Years of high and low flows do not alternate regularly but there is a definite bunching of high and low years. As a result more storage capacity is required to achieve a certain minimum average annual flow.

required. Subtracting the existing capacity, the additional production capacity required in the future would be 550,000 tons. For this purpose, 20 urea manufacturing plants, with a capacity of 50 million pounds of nitrogen each, are recommended by the Panel.

To provide the minimum phosphate required for the entire 32 million cultivated acres in West Pakistan, it is estimated that it would be necessary to use 160,000 tons of phosphate (P_2O_5) or 335,000 tons of triple superphosphate annually. For this purpose 5 plants, each capable of producing 100 tons of phosphate per day, are recommended.

The total capital cost of fertilizer factories is estimated at Rs. 112 crores. The total annual operating cost when all of the 25 factories are in operation would be Rs. 57 crores. Repayment of principal and interest on loan would amount to about Rs. 10.5 crores, raising the ultimate annual cost to Rs. 67.5 crores a year.

Plant-Protection Measures and Improved Seeds

Plant-protection measures and improved seeds are proposed to be supplied to an area of about 1.08 million acres of crops out of the gross cropped area of 1.35 million acres in each project area. The annual cost of these measures is estimated to be Rs. 1.1 crores and the increase in gross value of crops will be Rs. 7 crores.

Staffing

The estimates by the Panel regarding staff required for each project area are given in Table I.

TABLE I

STAFF REQUIRED FOR EACH PROJECT AREA

	Senior staff	Junior Staff	Foremen, technicians, clerks and labourers
Directors and associate directors	10	—	—
Engineering	5	15	1,200
Agriculture	22	194	300
Administration	7	38	300
Research	11	23	60
Total	**55**	**270**	**1,860**

A gross increase of Rs. 27.4 crores over the existing crop value of Rs. 15.1 crores is expected in each project area in the Northern Zone. Each one-million-acre tract has 780,000 acres under cultivation; the net gain would thus be equal to Rs. 260 per acre. For 14 million acres of canal-irrigated land in the former Punjab and Bahawalpur, a minimum net increase of Rs. 360 crores a year would be obtained.

For former Sind area, the details of benefits are not presented. However, on the basis of reports by Hunting Technical Services, it is stated that agricultural production would be doubled. The present value of crops in former Sind is estimated at Rs. 118 per acre. The minimum increase in 7.3 million acres of presently sown area is estimated at Rs. 86 crores per year.

Total increase in production of crop would, thus, be Rs. 360+86=446 crores annually.

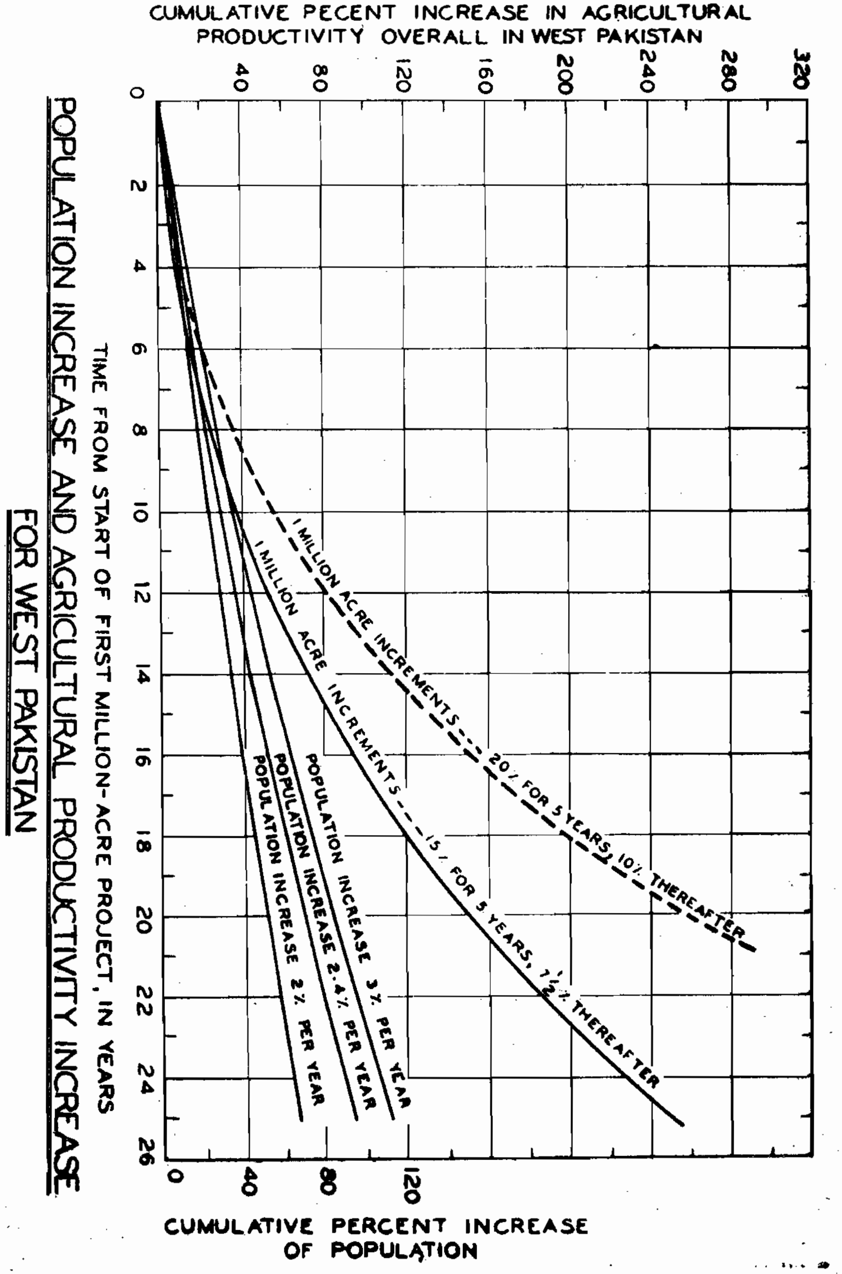
Cumulative increases in agricultural production as estimated by the Panel, based upon starting one project every year, are shown in Figure I, together with curves for estimated population for West Pakistan for the next 25 years.

On the basis of these benefits and costs it is possible to work out a benefit-cost ratio, if not for the entire programme then at least for an individual project in the Northern Zone. For each million-acre project in the Northern Zone, the following constants have been suggested by the Panel[19]:

Capital cost (K)	=	26 crores
Annual benefits (B)	=	27.4 crores *minus* 1.8 crores (associated costs)
Annual operation & maintenance costs (O)	=	5.5 crores

[19]For a detailed analysis of the benefit-cost criterion, *see*, Otto Eckstein, *Economics of Water Resources Development*, (Cambridge: Harvard University Press, 1958), pp. 56-57.

FIGURE I


POPULATION INCREASE AND AGRICULTURAL PRODUCTIVITY INCREASE
FOR WEST PAKISTAN
CUMULATIVE PECENT INCREASE IN AGRICULTURAL PRODUCTIVITY OVERALL IN WEST PAKISTAN
40
80
120
160
200
240
280
320
TIME FROM START OF FIRST MILLION-ACRE PROJECT, IN YEARS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
1 MILLION ACRE INCREMENTS -- 20% FOR 5 YEARS, 10% THEREAFTER
1 MILLION ACRE INCREMENTS -- 15% FOR 5 YEARS, 7½% THEREAFTER
POPULATION INCREASE 3% PER YEAR
POPULATION INCREASE 2.4% PER YEAR
POPULATION INCREASE 2% PER YEAR
0
40
80
120
CUMULATIVE PERCENT INCREASE OF POPULATION

Estimated life of the project (T) = 25 years

Rate of interest (i) = 4%

$$a_{it} = \sum_{T=1}^{25} \left(\frac{1}{1 + .04} \right)^{-1}$$

Then $$\frac{B}{C} = \frac{B}{O + a_{it}K} = \frac{25.6}{5.5 + (.0640)\,(26)} = 3.57$$

Since the capital costs in this project are a relatively small part of total cost, even a much higher interest rate than the one assumed by the Panel would not materially reduce the benefit-cost ratio. Also, a reduction in the assumed life of the project from 25 to, say, 15 years would not change the ratio very much for the same reason. With an interest rate of 8 per cent and an expected project life of 15 years, the project would still have a benefit-cost ratio of 3.00. Even if we assume that the Panel has been too liberal in its assumptions about possible increase in output and we postulate that annual benefits are only ½ of what has been suggested, the benefit-cost ratio would still be above 1.5.

It should be emphasized, however, that this benefit-cost ratio applies only to projects in the Northern Zone. The ratio for the entire programme would be considerably lower because the projects in Sind are much more marginal regarding the increase in output that can be expected.

REVELLE PLAN IN CONTEXT OF PAKISTAN'S ECONOMIC DEVELOPMENT EFFORT

The reviewer who tries to see the solution of the waterlogging and salinity problem in connection with the overall economic development in Pakistan naturally would like to know how the proposed programme fits into development plans under way and those proposed for the future. He would also like to know if the proposed investment is of a magnitude which can reasonably be expected to be carried out considering recent investment performances and the various constraints which are present in an underdeveloped economy. These topics were not considered by the Panel.

Given the country's limited access to development capital, it is particularly relevant to ask, for example, whether the same increase in food output as has been suggested could not be achieved in a different way and at a lower real cost, say, by developing new land areas in the West Wing, or by speeding up investment in the agricultural development of East Pakistan or by developing the country's export potential in the industrial sector so as to make it possible to import a larger proportion of the country's total food needs from abroad.

We have pointed out earlier that the *Report* does not give an estimate of total capital requirements but merely shows that projects in the Northern Zone will each require a capital outlay of $54.5 million and in the Southern Zone between $135-$165 million each. No mention is made as to how many projects are to be undertaken in each zone except that the total number of projects will be 25. Since there is such a wide divergence in the costs of projects in the Northern and Southern Zones it makes a great deal of difference which combination of projects we assume. On the basis of the present canal-irrigated area in the two zones, it seems most reasonable to assume 19 projects in the Northern and 6 in the Southern Zone. Assuming furthermore that it will take 4 years to construct each project and projects are to be brought in at the rate of one every year as suggested by the Panel, the total stream of capital outlay would be as shown in Table IV.

TABLE IV

STREAM OF CAPITAL OUTLAYS NECESSARY TO IMPLEMENT THE PROGRAMME WITHIN A PERIOD OF 28 YEARS

Year	Annual capital outlay		Projects initiated and under construction
	In millions dollars	In crores rupees	
1	14	6.65	1 (North)
2	28	13.30	1 and 2 (North)
3	42	19.95	1, 2 and 3 (North)
4	79	37.50	1, 2 and 3 (North); 1 (South)
5	79	37.50	2, 3 and 4 (North); 1 (South)
..	..	..	..
..	..	..	..
25	79	37.50	17, 18, 19 (North): 6 (South)
26	65	30.85	18, 19 (North); 6 (South)
27	51	24.20	19 (North); 6 (South)
28	14	6.65	19 (North)
Total	**1,952**	**926.55**	

According to our assumptions, the entire programme will call for a total capital expenditure of $1.95 billion or Rs. 925 crores over the entire 28-year period. For each 5-year plan this would mean on the average an expenditure of $390 million or Rs. 185 crores. Since total planned development expenditure for the Second Five Year Plan in the government sector is Rs. 1,462 crores, the waterlogging and salinity programme would require approximately 12 per cent of total currently planned development outlays. Measured by the development allocations for West Pakistan alone, the programme requirements are of course more substantial, that is about 23 per cent. Table V shows the sectorwise breakup of development expenditure for West Pakistan in relation to the required expenditure for the waterlogging and salinity programme.

TABLE V

SECTORWISE BREAKUP OF EXPENDITURE ON WATERLOGGING AND SALINITY AND TOTAL PLANNED DEVELOPMENT EXPENDITURE IN THE PUBLIC SECTOR (WEST PAKISTAN), SECOND FIVE YEAR PLAN (1960-65)

(in crores of rupees)

Sector	West Pakistan allocation[a]	Five-year expenditure on waterlogging[b] and salinity	Col. (2) as a per cent of Col. (1)
	(1)	(2)	(3)
Agriculture	134	17	13
Water and power	233	127	55
Industry	59	34	58[c]
Education and training	50	7	14
All other sectors	312	—	—
Total	**788**	**185**	**23**

a) *Cf.* Government of Pakistan, Planning Commission, *Revised List of Schemes Included in the Second Five Year Plan: 1960-65*. Karachi, November 1961, Table III, p. 3.

b) Percentage distribution based on Table II above.

c) This figure is not too meaningful since most of the industrial investment is carried out in the private sector.

It is apparent that only a relatively small percentage of agriculture's development budget would be committed to waterlogging and salinity but more than half of the present allocation in the water and power sector would have to be used for this purpose. The present allocation to drainage, reclamation and tubewells, including expenditure on electrification, is only about 27 per cent of the total water and power budget. If the waterlogging and salinity plan were to be carried out as envisaged by the Revelle Panel either additional funds would have to be provided to the water and power sector or some of the projects presently contemplated in the overall water and power programme could not be undertaken. From a practical point of view, it is very unlikely that the waterlogging and salinity programme would start on a large scale before the beginning of the third-plan period. The size of the Third Plan is likely to be much larger than the Second Plan; and by then it can be expected that some of the budgetary items in the water and power sector which are now still very important (*e.g.*, allocations for construction of new irrigation canals) will become smaller. Whatever budgetary adjustments will be necessary, the analysis of investment requirements carried out above suggests that the Revelle Plan is well within the reach of the people of Pakistan without jeopardizing growth in other sectors and regions of the economy.

DEVELOPING NEW LANDS AS AN ALTERNATIVE TO TUBEWELL RECLAMATION

The question is frequently asked: why not abandon the areas which are most severely affected by waterlogging and salinity and use the funds to extend irrigation development into virgin lands. Indeed out of some 51 million[20] acres classified as agricultural land in the Indus Plains, only 26 million acres (50 per cent) are presently perennially or seasonally canal irrigated.

Several factors speak against this approach as a solution to Pakistan's agricultural problem. First, there is strong evidence that the benefit-cost ratios of irrigation projects which were developed during the last part of the last century and beginning of this century were much higher than projects initiated in more recent years[21]. The reason is that the quality of land in the more recent project areas is far below that found earlier. If the most recently undertaken projects are indicative, it is doubtful that much additional land can be found in West Pakistan where under present prices for food products an irrigation project would show a benefit-cost ratio much greater than one.

Secondly, a major part of the land in the affected districts is still capable of producing good crops and it would be impossible to abandon this good land for social and political reasons. If only the affected part of the area is abandoned and the people are alloted land in some new project areas the existing canal-water supplies would be spread even more thinly over the entire area, new and old, than is the case at present. The amount of water avail-

[20]West Pakistan, Bureau of Statistics, *Statistics of West Pakistan Agricultural Data by Divisions and Districts, 1947-48 through 1959-60,* Lahore, 1960, pp. 9-15.

[21]The declining productivity of new irrigation projects in the subcontinent is brought out clearly in:

Kanwer Sain, "Historical Development of Criteria for Justification of Irrigation Projects in India" in *Proceedings of the Regional Technical Conference on Water Resources Development in Asia and the Far East,* United Nations Flood Control Series, No. 9, September 1956, pp. 69 ff.

able per acre is already far below normal consumptive use requirements of crops[22]. It is also generally conceded that the low-water applications per acre have in themselves contributed to aggravate the salinity problem by not allowing salts to be washed down below the root zone.

Rather than bringing new land under canal irrigation it would be desirable, therefore, to concentrate the available water resources on a smaller area thereby allowing more intensive cropping, increased use of fertilizer and other inputs. There can be little disagreement, therefore, with the Panel's overall recommendation, namely, to concentrate capital inputs on reclamation works on the area presently irrigated so as to bring about a better balance between all the inputs required in the agricultural-production process.

COMMENTS ON THE TECHNICAL ASSUMPTIONS MADE BY THE PANEL

The degree of success of the programme recommended by the Panel will depend to a large extent upon the soundness of the technical assumptions made.

Regarding the quantity and quality of additional water to be derived from tubewell pumping, the available evidence is unfortunately not conclusive. The Panel assumes that 46 million acre feet of water can be pumped annually in the former Punjab and Bahawalpur as shown in Appendix Table I. Out of this about 20 MAF will be from fresh water recharge due to seepage from canal distribution system, rivers and rainfall and 26 MAF from mining of groundwater.

With regard to the recovery of seepage from the existing canal distribution system and new link canals, the Panel has assumed 100 per cent recovery over 19 million acres of land which has nonsaline groundwaters. Since the culturable area commanded by the canals is only 13.6 million acres out of the total 19 million acres, it is unlikely that 100 per cent of the fresh recharge can be recovered. The West Pakistan WAPDA, I.C.A. and F.A.O. experts suggest that it would be preferable to assume only 85 per cent of this as recoverable[23]. Water available from this source would thus be less.

The proposed rate of mining of underground water of 26 MAF a year, which would lower the water table to 100 feet in 30 years, is based on the key

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[22] *See*, Harry F. Blaney and Wayn D. Criddle, *Report on Irrigation Water Requirements for West Pakistan*. Internal Report submitted to Tipton and Kalmbach, consulting engineers to WAPDA, April 1957, p. 5.

[23] WAPDA, West Pakistan, *Salinity Control and Reclamation Project, Investigations and Background Information, Project Number One, op. cit.*, p. 73.

assumption that 1,900 MAF of water is stored in the aquifer underlying 19 million acres of land upto a depth of 400 feet. This implies a storage coefficient[24] of 0.25 which was suggested by Tipton and Kalmbach in their review of Salinity Control Project Number One[25] and their feasibility report on Project Number Two[26].

There is conflicting evidence regarding the magnitude of the specific yield or storage coefficient applicable in the Indus Basin. Hunting Technical Services working in Sind use a coefficient of 0.1 or 10 per cent[27]. A comprehensive survey of the groundwater resources of West Pakistan undertaken by the Irrigation Department, Punjab (later West Pakistan, WAPDA) with the help of ICA and FAO experts also determined the coefficient of specific yield to be 10 per cent[28]. There is no discussion in the *Report* of the Panel which would indicate on which basis the available evidence was weighed and why the higher figure for specific yield was adopted.

Most of the available evidence in Pakistan as well as abroad[29] indicates that the storage coefficient or specific yield is likely to be nearer to 0.1 or 10 per cent instead of 0.25 or 25 per cent as assumed by the Panel. The quantity of water available for pumping is, therefore, likely to be much less than that estimated by the Panel but not necessarily insufficient to put their plan into operation.

Factors Determining Pumping Depth

Regarding the pumping depth, the Panel has suggested that the water table should be lowered to 100 feet in the first 30 years after which the rate of mining of water should be reduced by 50 per cent to avoid excessive cost.

Two considerations are relevant here: the first relates to the cost of pumping from different depths; the second has to do with the quality of water.

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[24]The term storage coefficient refers to the volume of freely available water that can be stored in, and pumped from, a given volume of subsoil.

[25]WAPDA, West Pakistan, *A Review of Project No. 1, Salinity Control Programme in West Pakistan, op. cit.*, p. 11.

[26]WAPDA, West Pakistan, *Feasibility Report on Salinity Control and Reclamation Project No. 2 (Chaj Doab), op. cit.*, p. 45.

[27]WAPDA, West Pakistan, *Sukkur-Guddu-Ghulam Mohammad Drainage and Salinity Control Project*, Report No. 5, Vol. 3, *op. cit.*, pp. 119-120.

[28]WAPDA, West Pakistan, *Salinity Control and Reclamation Project, Investigations and Background Information, Project Number One, op. cit.*, p. 73.

[29]*See*, J. F. Pland and others, "Groundwater Storage Capacity of Sacramento Valley, California" in *Water Resources of California*, Bull. 1, California Water Resources Board, Sacramento, 1949, pp. 617-32, quoted by David K. Todd in *Groundwater Hydrology*, (New York: John Wiley and Sons, 1959), p. 25.

Regarding the first question, no specific information is given by the Panel about pumping cost under conditions prevailing in Pakistan nor do we have any published data on the basis of which it would be possible for us to appraise the assumption made by the Panel.

The situation is different when we turn to the second question, namely, that relating to water quality.

The Panel assumes that, over 19 million acres in the former Punjab, water of good quality exists down to 400 feet. No detailed discussion of earlier research on this topic is given. Earlier studies by the Punjab Irrigation Engineers[30], the U.S. Bureau of Reclamation[31] and FAO experts[32] suggest that groundwaters of the Indus Plains are probably more saline than has been assumed by the Panel. These studies imply that the extent of the area having nonsaline groundwater may be less than 19 million acres and that therefore larger quantities of saline water will have to be exported out of the area. Similar conclusions can be drawn from the studies conducted by WASID[33] and other workers[34]. The brief experience available from the operation of SCARP 1 indicates that in more than 200,000 acres of the project (17 per cent of the area) water is unfit for irrigation even when mixed with existing canal water. Additional canal water supplies would have to be provided in this part of the project in order to use the tubewell water[35].

The Panel suggests that to maintain the salt balance at a satisfactory level for agriculture, about 10 per cent of the water will eventually have to be exported from the region. For the next 10 or 20 years the annual amount does not need to be more than one million acre feet. The "export" of saline

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[30]A.M.R. Montago, *Factors Affecting Irrigation in the Punjab from Tubewells*, Lahore, 1938, p. 32, quoted by F. M. Eaton in FAO Report No. 167 to the Government of Pakistan on *Certain Aspects of Salinity in Irrigated Soils*; Rome, September 1953, p. 14.

[31]C.E. Mairhofer, *Reconnaissance Report on Drainage, Waterlogging and Salinity Problems of West Pakistan*, U.S. Bureau of Reclamation, Denver, October 1952, p. 17.

[32]FAO Report No. 167 to the Government of Pakistan on *Certain Aspects of Salinity in Irrigated Soils*, Rome, September 1953, pp. 15-16.

[33]Water and Soils Investigation Division (WASID) of WAPDA in cooperation with ICA, "A Short Note on Potential Availability of Ground Water in the Former Punjab and Bahawalpur Areas", Appendix B to WAPDA Masterplan.

[34]A.V. Karpov and Ross Nebolsine, "Indus Valley, Key to West Pakistan's Future: Today & Tomorrow", *Indus*, Vol. 2, No. 10, November 1961, p. 31.

[35]West Pakistan Irrigation Department, *Report of Reclamation in Soil Reclamation Project No. 1*, by Chief Engineer, Irrigation, and Director, Land Reclamation, Lahore, November 1962.

groundwater from the Northern Zone will cause a 42-per-cent increase in the average salinity of Indus River water in the former Sind. Ultimately, when 10 per cent of the water pumped is exported, the salinity of Indus water entering Sind will be raised to about 835 parts per million or 280 per cent of what it is at present.

Water containing 835 parts of salts per million can be used for agriculture if the quantity of water applied for irrigation is in excess of the consumptive use by crops by about 15-20 per cent. However, according to the calculations of the Panel, Sind would get only 1.77 acre feet of water per acre per year if the 13 million acres commanded by canals were to be irrigated. This is obviously much less than the consumptive use requirements of crops; and the Panel, therefore, rightly suggests that the irrigated area in former Sind would have to be much smaller than 13 million acres. If the area is not reduced, water applied at this rate would make the former Sind soils highly saline with disastrous results for agriculture in the area. There is, therefore, a direct relationship between the depth to which water is pumped in the Northern Zone and the amount of water which has to be exported. As the quantity of saline water which has to be exported increases the area which can be profitably cropped in former Sind automatically decreases. This statement holds *a fortiori* if the groundwater salinity in the Northern Zone is a positive function of depth.

Another aspect insufficiently covered in the *Report* concerns the savings of foreign exchange for tubewells whose pumping depth is only 30-40 feet. For tubewells pumping up to 100 feet depth, at present only imported turbine pumps can be used. The foreign-exchange component of the latter type may be as much as three times higher than that for pumps produced domestically. Even if the quality of pumps produced in Pakistan should not be good enough at present to meet specifications, it would seem desirable to make a detailed investigation comparing the cost of improving domestic pumps with the savings from not having to import pumps from abroad.

During the last 10 years the cultivators have installed nearly 5,000 tubewells in the former Punjab and Bahawalpur in part with the help of the Agriculture Department. Nearly 4,000 of these have coir strainers and cost less than Rs. 7,000 each.

The Cropping Pattern

There is some indication that the assumptions made by the Panel with regard to the utilization of irrigation waters from canals and tubewells are too optimistic. Their estimates of the area sown as well as the present and future water use are summarized in Table VI.

TABLE VI

EXISTING LAND AND WATER USE IN A PROJECT AREA IN THE FORMER PUNJAB AND BAHAWALPUR AND POSSIBLE USE WITH TUBEWELL WATER[a]

Crops	Existing use of canal water			Possible use of canal and tubewell water		
	Area	Total water supply	Per-acre water supply	Area	Total water supply	Per-acre water supply
Kharif[b]	320	8.5	27	818	19.7	24
Rabi[c]	535	9.2	17	536	9.2	17
Total	**855**	**17.7**	**21**	**1,354**	**28.9**	**21**

Note: 1 Area in '000' acres; total water supply in million acre inches: per-acre water supply in acre inches.

a) Details are shown in Appendix Tables II and III.

b) Summer crops harvested in autumn.

c) Winter crops harvested in spring.

There are several aspects of the old and the new cropping pattern which are insufficiently explained in the *Report*. Total *rabi* water supply at present is assumed to be larger than total *Kharif* water supply. This is surprising in view of the fact that 83 per cent of the annual river flow occurs during the summer months and more than 60 per cent of the annual canal water supply is diverted during the *Kharif* season. Secondly, the entire tubewell water supply seems to have been allocated to the *kharif* crops which implies that the tubewells must be either idle during the *rabi* season or they are used exclusively for leaching purposes. Thirdly, the *kharif* acreage under the new cropping pattern has been expanded to such an extent that the effective water application per acre during the *kharif* season will be actually lower than the existing water supply. It is repeatedly stated in the *Report*, and everyone else agrees, that present water applications per acre are insufficient. It is, therefore, puzzling, particularly in view of their fertilizer recommendations, that the Panel would recommend even lower water applications per acre than are presently available.

In addition several other assumptions which underly the proposed cropping pattern and the expected increase in output should be made explicit:

i) The Panel used the Lyallpur district as a representative area. This is one of the best agricultural districts of West Pakistan and does not really represent average Punjab and Bahawalpur conditions. The assumption that out of 1 million acres 1,354 thousand will be cropped seems, therefore, optimistic.

ii) The Panel proposes to treble the area under sugarcane and recommends exports. Compared to other sugar-producing countries, Pakistan is extremely inefficient: yield per acre and the quality of cane are both low. Unless yield and quality of sugarcane can be improved, it is doubtful that sugar can be exported without heavy government subsidies.

iii) The Panel does not propose any increase in cotton acreage. The area under cotton could be easily doubled in the former Punjab and Bahawalpur when the water table has been lowered and salts leached out of the soil. Pakistan cotton has a ready world market and there is likely to be no difficulty in exporting it.

iv) The Panel assumes that cultivable waste land of about 70 thousand acres in each project area (1.4 million acres in 20 project areas) can be brought under cultivation. As the existing water supplies are insufficient to provide for year-round cropping on the existing area, utilization of water on cultivable waste land in the former Punjab and Bahawalpur is not likely to be profitable.

Surface Drainage Works

No provision has been shown by the Panel in the annual cost for the maintenance of drainage works (*cf.* Table 4.3 of the *Report*), though a provision of $ 5.0 million is suggested in the capital cost. This provision would be low if more saline water is to be 'exported' from the project areas than that estimated by the Panel.

Fertilizer

The recommendation that 45 million pounds of nitrogen be used annually in each project area seems reasonable for the project areas in Northern Zone to which additional tubewell water is supplied. For the remaining irrigated areas the quantity of nitrogen which can be used profitably will be less. For unirrigated crop land still less fertilizer will be required. Total nitrogen requirements as assumed by the Panel may, therefore, be on the high side.

The Panel has recommended the use of 160,000 tons of phosphate for the entire cultivated area of 32 million acres of West Pakistan. However, phosphate fertilizer is required only for about one half of the West Pakistan soils and until more experiments have been conducted on phosphate requirements of soils of different regions a smaller phosphate capacity should be planned.

Education, Research and Extension

A sum of $2.5 million was suggested for education, research and extension in each project area, but this has not been taken into account in the annual cost. A minimum of Rs. 4 million a year would be required for this purpose for each project area. This is likely to be the crucial factor in the success of the whole programme and the extent to which cultivators succeed in making efficient use of the water resources and greatly expanded provision of fertilizer, plant-protection facilities, improved seed and improved implements will depend largely on how efficiently the education, research and extension programme is organized.

While the senior staff for the administration of the project will have to be provided by the universities and professional colleges, it may be desirable that a training institute for junior staff for the Agriculture Department and foremen and technicians for the Engineering Departments be opened somewhere in SCARP 1 in the Rechna *Doab*. This institute could train staff for subsequent projects to be opened in other parts of the former Punjab and Bahawalpur.

Former Sind Area

While the Panel has made an excellent analysis of the problem of the former Punjab and Bahawalpur, it has not done so as yet for the former Sind area. The Panel simply endorses the recommendations of Hunting Technical Services without going into details. Basing their conclusions on the Khairpur Project, they state that the value of agricultural production could at least be doubled through agricultural development.

Inclusive of rainfall, water availability per acre for 13 million acres of cultivable canal-commanded area would be only 1.77 acre feet. It would be difficult to maintain the existing level of production, and there would be a decrease in total production if the available water was spread on all the 13 million acres. The most urgent problem for the former Sind area is to demarcate comparatively unproductive lands on the Guddu and G.M. Barrage projects and to take them out of the canal commands so that the available water can be used for better lands in other parts of former Sind. It may be desirable, therefore, to limit the maximum area to be brought under crops in former Sind to the best 7 or 8 million acres commanded by the three barrages.

One paradox of the situation in former Sind is the fact that although water available or likely to become available in the next 20 years is not sufficient for the 13 million acres of canal-commanded cultivable land, the water being used at present is so badly distributed that in some parts of former Sind it is causing a rise in the water table and consequent salinity of the soil. On account of this loss of surplus irrigation water from the fields, the value of crops, raised for each acre foot of water diverted at the canal head, is only Rs. 27 in Sind, compared with Rs. 49 per acre foot in the former Punjab and Bahawalpur.

CONCLUDING REMARKS

Our analysis has concentrated mostly on the technical assumptions made by the Panel with respect to the implementation of their proposed plan. The general conclusion has been that, in some of the key assumptions about groundwater availability and water quality, the Panel may have been too liberal. The storage coefficient or specific yield of 0.25 (25 per cent) used by the Panel to estimate the yield of water from tubewell pumping is not supported by experimental evidence available in Pakistan and this coefficient is likely to be more near 0.1 or 10 per cent; consequently, much less water is likely to be available. Furthermore, waters of the Indus Plains are probably more saline than has been assumed by the Panel and a larger part of the pumped water may have to be exported out of the area.

One of the conclusions of this review has been that the possibility of utilizing pumps, made in Pakistan, should be investigated more thoroughly because it would certainly conserve foreign exchange and utilize already existing industrial capacity. Using these pumps may, however, imply that the water table could be lowered to only 30-40 feet as against 100 feet or more recommended by the Panel.

The utilization of all the tubewell water on *kharif* crops only as proposed by the Panel implies that tubewells of double the capacity required will have to be installed. This will increase the capital cost as well as operating cost. It is suggested that a cropping pattern to utilize year-round water supply should be evolved to reduce the cost of pumped water.

Even if the Panel's assumption about water availability and increase in agricultural production should turn out to have been on the high side, it does not mean that their plan is not basically sound and feasible. Regarding the use of a given amount of water on the farm, one of the authors of this review has shown elsewhere[36] that apparently the same amount of water can produce quite different quantities of output depending on how it is used and distributed over the irrigation cycle. It is certain that present wateruse methodology on farms in Pakistan is still very wasteful and that much of the water which reaches the fields is lost through unproductive evaporation or seepage. This has also been brought out clearly in the reports of Hunting Technical Services for the former Sind[37] area. As water becomes more and more the limiting production factor compared with other inputs, ways will have to be found to increase the proportion of a given water quantity available for crop use.

The Panel emphasizes correctly that the waterlogging and salinity problem is also a general agricultural development problem; in describing the present relationship between the irrigation system and the existing farming methods they aptly remark that it is "like building a superhighway and travel on it with stage coaches." But the Panel nowhere analyses the institutional and economic reasons which have allowed this dichotomy to persist. For example, there is very little analysis of the existing water-rate structure. It is possible that extremely low water rates, levied on a per-acre basis, are among other things responsible for allowing farmers to stay with their antiquated farming methods and to use the water as if it were nature's free gift. Appropriate water-rate schedules, increasing over time as well as other tax measures may contribute to force farmers to adopt these new technologies.

In estimating possible aggregate increases in production due to additional water and fertilizer, one gets the impression that the Panel has used the limited available experimental evidence almost without qualification. Although provision for extension and education services is made in the capital budget (a capital cost of Rs. 25 and annual costs of Rs. 12 per acre) there is no careful analysis of present limitations on the available technical manpower and the rate at which additional manpower can be trained to accelerate the implementation of the programme. The brief experience with the Village AID Programme in Pakistan and the Intensive Agricultural Districts Development Programme in India suggests that the road from experiment station research results to village application under our conditions is long and tedious. In most cases it involves further on-the-spot research to determine water requirements along with the kind of fertilizer needed, the rates and proper timing of applications. It also involves adult education and extensive vocational training for young people.

[36]Christoph Beringer, *An Economic Model for Determining the Production Function for Water in Agriculture*, Berkely, Giannini Foundation Research Report No. 240, February 1961.

[37]WAPDA, West Pakistan, *Sukkur-Guddu-Ghulam Mohammad Drainage and Salinity Control Project*, Report No. 5, *op. cit.*, Vol. 1, p. 142.

Similarly much more careful analysis is required with regard to the problem of administration. The proposed 1-million-acre project areas will invariably cut across present *tehsil*, district and divisional boundaries. The project area authority on the other hand should have complete control over almost all administrative and technical departments with the exception of law enforcement. The administrative implications of the division of power implied in the Revelle recommendations need much more analysis than what has been provided.

We believe that the main hurdle to the implementation of the Revelle Plan is likely to be the difficult problem of administration, education and extension and not the cost of pumps and fertilizer which, on balance, have received most of the emphasis in the *Report*.

The Panel's suggestion to concentrate all efforts on limited-project areas is certainly sound as a development strategy for agriculture. Spreading limited 'administrative and planning inputs' over too wide an area, as has been done in the past, is just as unprofitable as to spread other scarce physical inputs over an unlimited area.

It is to be hoped that the *Report* will be printed soon in its final form and that it will become available to those concerned with economic development in Pakistan.

Appendix

TABLE I

WATER TO BE PUMPED ANNUALLY IN FORMER PUNJAB AND BAHAWALPUR

(*in million acre feet*)

Pumping to recover	In total area of 28 million acres	In comparatively nonsaline groundwater area of 19 million acres	In saline groundwater area of 9 million acres
1) Leakage from canals and branches	13.9		
2) Recharge of groundwater by seepage from new link canals	3.1		
3) Seepage of rivers to the water table	2.0		
4) Rain input to groundwater	1.0		
5) Total fresh recharge	20.0	13.6	6.4
6) Mining of groundwater to lower the water table to 100 feet depth in nonsaline areas and to 50 feet depth in saline areas	19.5	15.8	3.7
7) Net rate of pumping	39.5	29.4	10.1
8) Gross rate of pumping assuming that 15 per cent of tubewell water will seep back to the water table	46.0	34.6	11.4
9) Gross rate of mining (row 8 *minus* row 5)	26.0	21.0	5.0

Source: Calculated from Chapter 6 of the *Revelle Report*.

TABLE II

LAND USE AND RELATED DATA FOR A TYPICAL MILLION ACRES SERVED BY THE LOWER CHENAB CANAL

Land use	Area	Yield	Price	Gross value	Apparent depth of water	Total water used	Total value of crops
Kharif crops							
Cotton	105	6.6	30.7	203	27	2,835	21.3
Sugarcane (gur)	65	30.3	15.9	482	43	2,795	31.3
Maize	50	11.9	11.7	139	17	850	7.0
Rice	10	11.6	15.1	175	27	270	1.7
Bajra	10	6.6	13.5	89	15	150	0.9
Fodder and misc.	80	—	—	120	20	1,600	9.6
Subtotal	**320**					**8,500**	**71.8**
Rabi crops							
Wheat	320	12.4	12.8	159	14	4,480	50.9
Gram	60	10.2	13.2	135	22	1,320	8.1
Oilseeds	32	7.0	22.9	160	13	416	5.1
Barley	6	10.1	10.1	101	14	84	0.6
Fodder and misc.	117	—	—	120	25	2,925	14.0
Subtotal	**525**					**9,225**	**78.7**
Gross cropped area	855				**Total**	**17,725**	**150.5**
Double cropped area	130						
Net cropped area	725						
Fallow	55						
Culturable waste	135						
Not arable	85						
Total	**1,000**						

Gross value produced Rs. 151 million.

Source: Calculated from Table 4.2 of the *Revelle Report*.

Notes: 1) Area in '000' acres. Yield in *maunds* per acre. Price in rupees per *maund*. Gross value in rupees per acre. Depth of water in acre inches per acre. Total water use in thousand acre inches. Total value in million rupees.

2) *Maund* (md) is equal to 82.3 pounds.

TABLE III

POSSIBLE SCHEME OF LAND USE WITH CANAL AND TUBEWELL WATER

Land use	Area	Yield	Price	Gross value	Assumed depth of water	Total water used	Total value of crops
Kharif crops							
Cotton	105	6.4	30.7	195	26	2,730	20.5
Sugarcane	209	30.3	15.9	482	43	8,987	100.7
Maize	404	11.0	11.7	128	15	6,060	51.7
Rice	10	9.7	15.1	147	22	220	1.5
Bajra	10	5.4	13.5	73	12	120	0.7
Fodder and Misc.	80			120	20	1,600	9.6
Subtotal	**818**					**19,717**	**184.7**
Rabi crops							
Wheat	321	12.6	12.8	159	14	4,494	51.0
Gram	60	10.2	13.2	135	22	1,320	8.1
Oilseeds	32	7.0	22.9	160	13	416	5.1
Barley	6	10.1	10.0	101	14	84	0.6
Fodder and Misc.	117			120	25	2,925	14.0
Subtotal	**536**					**9,239**	**78.8**
Gross area cropped	1,354				**Total**	**28,956**	**263.5**
Double cropped area	504						
Net cropped area	850						
Fallow	—						
Culturable waste	65						
Not arable	85						
Total	**1,000**						

Gross value produced Rs. 264 million

Source: Calculated from Table 4.3 of the *Revelle Report*.

Notes: 1) Area in '000' acres. Yield in *maunds* per acre. Price in rupees per *maund*. Gross value in rupees per acre. Depth of water in acre inches per acre. Total water used in thousand acre inches. Total value in million rupees.

2) *Maund* (md) is equal to 82.3 pounds.