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CONTROL OF WATERLOGGING AND SALINITY IN WEST PAKISTAN[1]

Introduction

WITHIN the Indus basin of West Pakistan lies the largest stretch of irrigated land in the world with 33 million acres under command of various irrigation systems. The productivity of this area is threatened by rising water-tables and the spread of salinity which are annually forcing many thousands of acres of land out of production. It was estimated in 1953–4 that 11·3 million acres were either poorly drained or predominantly waterlogged, 4·8 million acres were predominantly severely saline, and that saline patches were common in a further 11·2 million acres.[2] This indicates the extent which the problem has already reached. With a population increasing at about 2 per cent. annually and with home-produced food supplies already insufficient to feed the existing population the country faces a national disaster unless this twin menace can be overcome.

This problem is of comparatively recent origin and has arisen only because of the increasing intensification of irrigation in Pakistan. Irrigation developed at first by utilizing only the annual summer floods of the Indus and its tributaries. It was extended gradually by the construction of inundation canals which received water only in the summer when the rivers rose above the level of the canal inlets and took it to lands above natural flood level. Irrigation was extended again by building barrages across the river to enable use to be made of water even in the season of low river flows. Most of the old inundation canal systems, which naturally suffered from fluctuating river levels, have now been converted to perennial (irrigating throughout

[1] The author wishes to express his gratitude to Mr. Sayyid Hamid, Chief Engineer, Project Director, Ground and Water Reclamation Division of the West Pakistan Water and Power Development Authority, for his kind permission to use all the information on which this article was based. He would also like to acknowledge his debt to his colleagues in Hunting Technical Services and in particular to Dr. T. N. Jewitt, and Sir Murdoch MacDonald & Partners on whose work he has drawn extensively, and for the kind permission of the latter to use their data on drain and tube-well costing. The author emphasizes that the views expressed in the article are his own responsibility and are not necessarily those either of the Water and Power Development Authority or of Hunting Technical Services Limited or Sir Murdoch MacDonald & Partners.

[2] *Land Forms and Land Use of the Irrigated Plains of West Pakistan.* Canadian Columbo Plan Resources Survey.

the year) or non-perennial (irrigating only during the season of high flow) canals receiving assured supplies. The first barrage was built in 1859. Today there are fourteen barrages in West Pakistan and when the recently completed Gudu barrage on the Indus becomes operational virtually all the major canal systems will be barrage controlled.

So long as summer irrigation from inundation canals was the main form of irrigation no general waterlogging problem existed. Close to the rivers the water-table was near the surface but its depth increased with distance from the river, and over the greater part of the Indus plain groundwater-tables were at considerable depths. The infiltration of water from the rivers together with deep percolation of rainfall and the seasonal additions to the water-table from irrigation approximately balanced the discharge of groundwater by evapotranspiration and by movement towards the sea.

This dynamic equilibrium was destroyed by the advent of barrage-controlled irrigation. The rate at which water could be discharged from the aquifer was too slow to remove the additional deep percolation resulting from seepage from the new canals and from the water used to irrigate the new lands. As a result water-tables have risen ever since the barrage-controlled irrigation systems began to operate.

Until 1954 only a piecemeal approach had been adopted to finding ways of preventing and curing this waterlogging and salinity. Some small-scale drainage works had been constructed but no comprehensive plan to tackle the problem on a national scale had been drawn up. In that year investigations were initiated over a greater part of the former Punjab province to determine the causes responsible for the growth of salinity and waterlogging and to devise suitable measures for this control. But it was not until 1958, when the Water and Power Development Authority (WAPDA) of West Pakistan was created, that the means of dealing with the problem on a national scale became available. This body was set up to develop West Pakistan's water and power resources on a unified and multipurpose basis and one of its principal functions was the prevention of waterlogging and the reclamation of waterlogged and salted lands. Since then a large number of investigational projects have been started, the first complete drainage network (in the Rechna Doab) installed, and a number of other drainage projects are in an advanced state of planning.

The control of waterlogging and salinity is now being treated as a task of urgent national importance and a national Master Plan has recently been drawn up detailing the order of priority of the works required and the annual investment involved in order to get this waterlogging and salinity under control.

In this Master Plan the Indus basin was divided into a northern and southern zone and for each of these areas a reclamation programme was drawn up. The programme for the northern zone, which covers a gross commanded area of 22·4 million acres, envisages the construction of some 30,700 tube-wells, producing some 24·5 million acre feet of pumped water annually, and of over 5,600 miles of open drains. The total capital cost of this programme is estimated to be 2,210 million rupees (£166 million sterling)[1] and the total annual cost, including depreciation, operation, maintenance and power, is estimated to be 291 million rupees (£22 million). This drainage programme is expected to raise the annual value of agricultural production from its present level of 2,666 million rupees to 5,058 million rupees (from £200 million to £380 million) and taking into account the expected increase in the costs of agricultural production it should result in a benefit:cost ratio of 2·1:1.

The southern zone covers a gross commanded area of 13·4 million acres. The Master Plan did not propose to rely to any great extent on tube-wells for drainage in this area because of the generally higher salinity of the groundwater and the differing systems of cultivation. The programme envisages the construction of about 400 tube-wells and approximately 27,000 miles of main and supplemental drains at an estimated capital cost of 1,206 million rupees (£90 million). Since the Master Plan was written the emphasis in the southern zone has shifted and more tube-wells than were originally envisaged are likely to be constructed. The total annual cost, including depreciation, operation, maintenance and power is estimated at 103 million rupees (£8 million). The drainage programme in this area is expected to raise the value of agricultural production from 1,320 million rupees at present to 2,403 million rupees at the end of the reclamation period (from £89 million to £180 million) and, taking into account the increased costs of producing the additional output, the benefit:cost ratio will be 2·6:1.

Since the Master Plan was written the majority of the cost estimates have been revised sharply upwards and the resulting benefit:cost ratios reduced.

The first tube-well project (Project Number One) to be completed

[1] 13·33 rupees to £1 sterling.

in West Pakistan in the northern zone was in the Rechna Doab. Here 2,047 tube-wells have been installed to control a gross area of 1·4 million acres. A second project for the Chaj Doab in which more than 2,000 tube-wells will be installed is now in an advanced stage of study (see Fig. 1).

In the southern zone two further projects are also in an advanced stage of study: one in the Khairpur Command of the Sukkur barrage area and the other in the Gaja command of the Ghulam Mohammed barrage area. General investigations are also in progress in the Right Bank Command of the Sukkur barrage, in the rest of the Ghulam Mohammed barrage area and in the Gudu barrage area also. The project planning report for the Khairpur Command has recently been completed and it is proposed to present in this article a brief review of the different methods of drainage considered for this project and a comparison of their cost.

Khairpur project: physical setting

The Khairpur area has been perennially irrigated for the past thirty years, ever since the Sukkur barrage was opened in 1932. Prior to the barrage the area was seasonally irrigated and even at that date the water-table was much higher than in most of the Punjab. During this thirty-year period the water-table has risen 11 feet, from a mean annual depth of 16 feet in 1933 to 7 feet in 1959, and it is still rising. There is relatively little seasonal fluctuation, but the depth varies greatly from the northern part of the area where the water-tables are mostly higher than 7 feet, to the southern part where they are as deep as 15 feet or more. Since surface drains are ineffective where the water-table is more than 6 to 7 feet deep, and since tube-wells can be used to draw the water-table to increasing depths only with increasing cost, the limit of the area requiring drainage has been taken as the 7-foot water-table contour. This gives a total gross drainage area of 355,000 acres.

The intensity of irrigation water application has been steadily increasing since perennial irrigation began. At the start this intensity was equivalent to 1·6 cubic feet per second (cusec) per square mile in winter and 2·4 in summer. At the present day it is 2·4 cusec per square mile in winter and 2·7 in summer. This compares with the supply prior to the barrage of approximately 1·4 cusec per square mile in the summer alone. Broadly speaking it is this increase which has caused the rise in the level of the water-table.

This increase in water supplies has been accompanied by an increase in the annual area cultivated from less than 200,000 acres in the Khairpur area as a whole just after the barrage was opened to nearly 600,000 acres today. Within the 355,000 gross acres of the drainage project 318,000 acres are classed as cultivable and the average cropping for the five years ending 1959/60 is shown in Table 1.

TABLE 1. *Khairpur drainage area cropping (thousand acres)*

Winter crops		*Summer crops*	
Wheat	75·7	Cotton	40·7
Fodders	35·6	Sorghum	35·4
Pulses	17·2	Rice	15·3
Oilseeds	14·7	Fodders	13·5
Others	2·3	Others	1·8
Perennial crops	15·9	Perennial crops	15·9
Winter total	161·4	Summer total	122·6

Wheat, cotton, sorghum and fodder crops are the main crops grown in the region, with perennial areas of fruit orchards and sugar-cane also of some importance. The fodder crops support a large population of working bullocks and breeding cows. Buffaloes are kept for producing ghee and milk. Agriculture is largely for subsistence though with the land owned in farms of up to 500 acres, much of it farmed through share-croppers, a proportion of the crop is marketed. Cotton and oilseeds are the main cash crops.

The present intensity of cropping (the proportion of the cultivable area cropped in a single season) is 51 per cent. in winter and 39 per cent. in summer. This is above the original summer design cropping intensity of 32 per cent. and above the winter design of 48 per cent. These are average figures and conceal the fact that 18 per cent. of the gross area is not used at all, having been abandoned as a result of salinity or never even brought under cultivation. On the area which is in use the average intensities are 60 per cent. in winter and 48 per cent. in summer. Much higher intensities even than these are obtained on limited areas with a favourable water supply.

The very low design intensity of this project, in common with all the Indus basin projects, resulted partly from the need to spread the expense of bringing irrigation water over as wide an area as possible and partly from the fear that high rates of water application would result in rapidly rising water-tables. The effect of this design has been, by spreading water too thinly, to speed up the rate of soil salinization without eliminating a rising water-table. Given the prospect that drainage will be installed, the necessity for such low intensities is removed. In view of the expense of drainage it also becomes essential to raise the productivity of the land in order to cover the cost of drainage. Higher intensities become a necessary accompaniment to drainage. One of the major recommendations of this report therefore is that the design intensity be raised to 75 per cent. in winter and 60 per cent. in summer, a total of 135 per cent. overall against the present design of 80 per cent.

In order, however, to raise the intensity of cultivation additional supplies of irrigation water will be needed. Under present methods of farming a considerably greater area of winter crops could be grown with the present available water supplies but already increases in the summer-crop area are limited by canal capacities. Additional summer supplies can only be obtained either by enlarging the canals or by exploiting the groundwater.

In areas where the groundwater is of good enough quality to use for irrigation a tube-well drainage scheme can serve the dual purpose both of lowering the water-table and of increasing irrigation supplies. This is the situation in the Project Number One tube-well area in the Punjab. In Khairpur, however, this is only possible over a limited area, because most of the groundwaters are highly saline. In the project plan for Khairpur water from wells with less than 1,000 parts per million of dissolved salts has been taken as available for direct re-use for irrigation while water from wells with more than 1,000 p.p.m. has been assumed to be suitable for irrigation only if mixed with canal water and if above 2,000 p.p.m. not suitable even if mixed. These are arbitrary limits and may be varied when experience of the scheme indicates that this is necessary. On this basis it is estimated only 26 per cent. of the wells which would be needed for drainage would be suitable for direct re-use, 20 per cent. more would be suitable if mixed with canal water and 54 per cent. would be entirely unsuitable. Those wells which are suitable for re-use form a well-defined region thus simplifying the problem of integrating the supply of well water with canal water. Over a large part of the area which required drainage, however, increased intensities can only be achieved by remodelling the canalization and bringing more water from the river.

Drainage possibilities

Two types of drainage have been considered for Khairpur: tube-wells and open drains. The costs of drainage by either method are largely determined by three sets of factors: (1) the physical conditions of climate, geology and soil, (2) the technical factors of engineering design and (3) the costs of construction in the country concerned. We are here largely concerned with the first.

The two major physical factors which are common to both tube-wells and open drains are the depth at which the water-table is to be maintained and the amount of water to be drained. In perennially irrigated areas like Khairpur growing deep-rooted crops such as cotton, the main purpose of drainage is to provide a sufficient depth of soil above the level of the groundwater in order (1) to give the crop roots adequate aeration, (2) to provide a channel for the removal of salts from the upper zone of the soil. The minimum permissible depth varies from crop to crop. For open drains in this area a depth of 4 feet was chosen for the point midway between drains, with 6 feet in the drains and slightly more in the drain bed. This is probably still not deep enough to prevent upward capillary movement of salts on fallow land, and for tube-wells a depth of 7 feet was chosen.

The calculation of the amount of water to be drained is based on a consideration of the regional water balance. Numerous items in this are not subject to accurate measurement and since the drainable surplus is a residual its calculation is subject to a wide margin of error. For Khairpur, calculations showed that less than 40 per cent. of the incoming water was actually required by crops for consumptive use and less than 2 per cent. was being added to the water-table annually yet was responsible for the annual rise of 0·3 feet. The remainder is mostly returned to the atmosphere by evapo-transpiration from uncropped land. This latter amount will decrease as cropping intensity increases and the final estimate of the surplus requiring removal by drainage was 0·9 cusec per square mile for tube-wells (equivalent to 26 per cent. of incoming water) and 0·6 cusec per square mile with open drains (equivalent to 19 per cent. of incoming water). The greater surplus with tube-wells results from the greater depth at which the water-table is maintained and the lower evapo-transpiration losses. Once the magnitude of these factors has been decided upon the number of tube-wells required for drainage depends upon the discharge per well which is determined by the hydraulic characteristics of the aquifer, in particular the soil permeability or the rate at which water moves through the aquifer. The number of open drains likewise depends upon the soil permeability though in this case it is the permeability of the upper 6 feet of soil, not of the deep aquifer, which is considered. All these factors can be measured by detailed field studies and the resultant well or drain spacing required for the given degree of drainage can be calculated. For Khairpur the results of these field studies showed that one well 200 feet deep of 3 cusec capacity pumping for 70 per cent. of the year would be able to drain 1·4 square miles or almost 900 acres to a depth of 7 feet midway between wells. Where the aquifer is shallow it will be necessary to have shallower smaller-capacity wells at a closer spacing. The comparison with open drains has been made on the basis of an average drain spacing of 1,000 feet, giving 5·28 miles of drain per square mile. This is the best available calculation, based on measurements of soil permeability, of the spacing required to lower the water-table to 4 feet midway between drains. In practice, spacing should vary between areas at different permeability if any given degree of drainage is required.

The comparison of cost

In making the comparison between tube-wells and open drains it should be remembered that the comparison is not purely economic. Tube-wells have a number of advantages over open drains which cannot be put in economic terms. For one thing they are more flexible. The depth to the water-table with open drains, once dug, is fixed by the bed level of the drains and by their spacing, but with tube-wells it can be varied within wide limits, in particular it can be lowered to much greater depths than is economic with open drains, thus providing a greater soil area above the groundwater for deep-rooted crops and reducing the capillary rise of salts. In addition, where water-table depths are in excess of 6 feet, tube-wells can give a measure of control before the groundwater rises higher, which open drains 6 feet deep can never do. And again tube-wells, with their relatively small disposal channels, have little effect upon the existing irrigation layout. Deep drains, on the other hand, absorb some 10 per cent. of the gross surface area, interfere with the existing irrigation system and create great social problems of resettlement and land redistribution. Apart from the cost of expropriating the land this cannot be measured in economic terms but it is a major factor in favour of tube-wells, apart from the cost differences.

The cost of the tube-well drainage scheme, once the number of tube-wells required has been determined, is made up of the capital cost of the individual well, the capital cost of the disposal works and the running costs of the total scheme. The cost of the well is determined by a number of engineering design factors and may vary within wide limits even in the same area. In Khairpur the cost per well is expected to range from Rs. 60,000 to Rs. 86,000 (approximately £4,750 to £6,500). The major factor causing this variation is the salinity of the groundwater.

The salinity of the groundwater also has a major influence on the cost of disposal works. Where salinity is low and the pumped water can be re-used, no disposal may be required. Where salinity is high complete disposal may be necessary, and this may involve complex disposal problems as the present dispute between Mexico and the United States over the disposal of saline drainage waters in the north-western Mexicali Valley indicates.

The total cost of these items, and including the provision of electrical power, is estimated to amount to Rs. 389 (£29) per gross acre drained. The capital cost of the open-drain alternative is estimated to be Rs. 959 (£72) per gross acre drained. Although this latter figure is not of the same accuracy as the tube-well cost estimate, the difference between the two indicates the striking difference in the comparative costs of the two methods of drainage. The operation and maintenance costs of the tube-wells are also lower than the operation and maintenance costs of open drains and thus the total annual costs of tube-wells, including amortization of capital and provision for replacement, are much lower than the annual costs of open drains. Per gross acre drained, tube-wells are estimated to cost Rs. 43 annually, open drains Rs. 82.

The benefits of drainage

The tables in the report show that tube-wells under Khairpur conditions are decisively cheaper than open drains. This does not necessarily mean that tube-well drainage is economic. It will only be so if the benefits of drainage exceed these costs.

The calculation of the benefits of drainage in such an area as this has many difficulties. On the one hand, the prevailing economy of peasant subsistence farming with static yields has been resistant to change for many years. On the other hand, the modern scientific revolution has opened up the way for change on a scale and at a speed which could be dramatic. The government is in fact endeavouring already to bring to the farmers the knowledge of modern farming techniques but this attempt is still in too early a stage to estimate what effects it may produce. The continued rise of the water-table and the spread of salinity, however, will remain a barrier to any attempts to raise crop yields and improve farming standards. Only with drainage can the full possibilities of modern farming techniques be released; certainly only with drainage can any intensification of the farming system become permanent.

Since definite information on the effects of drainage is lacking, the general assumptions made in calculating the benefits of drainage were that drainage alone would raise crop yields by 25 per cent., that improved farming and the use of fertilizers would raise them by 50 per cent., but that the interacting effects of both would raise them by 100 per cent. These are very broad assumptions but considering the very low yields at present obtained in the area the actual increases are comparatively small. For instance, cotton, sorghum, oilseeds and pulses all yield about 500 lb. per acre at present, wheat about 800 lb. and rice 1,000 lb. For livestock an increased milk yield per head of 50 per cent. was assumed. Total livestock output would increase greatly because of the enhanced yields of fodder crops.

Table 2 summarizes the calculations of farm output and costs on the above assumptions for four different situations:

(1) Present conditions.

(2) Future conditions with improved farming but no drainage.

(3) Future conditions with improved farming and drainage but without additional water.

(4) Future conditions with improved farming, drainage and water.

It can be seen that the largest benefit occurs with drainage and with additional water. Since tube-well costs are lower and fewer disposal works are needed when the drainage water is usable for irrigation, this type of drainage yields the highest benefit:cost ratio. When no additional water is available and the time lag before the benefits have fully materialized is taken into account, the benefit:cost ratio becomes less than one. Benefits are taken here as the difference between the level of output as it would be without the project (column 2 of Table 2) and as it would be with the project (columns 3 and 4). In the case of this project the benefit:cost ratio with additional water is 2·9:1, without water 0·8:1, and the ratio for the whole project 2·0:1. The two ratios have to be considered as a whole since it would not in fact be very practicable to drain one part without draining the other.

Although the overall benefit cost ratio for the whole project is favourable the evidence above indicates that where no additional water can be made available the cultivators will be unable to bear the full cost of the drainage and part of it will have to be borne by the government. Calculations of the cultivators' payment capacity without additional water indicate that the most the government can raise from them, and still leave them with a reasonable living standard, is some Rs. 12 per acre. Under present conditions most cultivators rent their

TABLE 2. *Agricultural output of Khairpur drainage area and associated costs*

(*Rupees per gross acre*)

		Future conditions		
	Present conditions	*Improved farming, no drainage, no extra water*	*Improved farming and drainage, no extra water*	*Improved farming, drainage, and extra water*
OUTPUT				
Winter crops	39·5	58·6	75·6	116·8
Summer crops	45·6	70·5	101·1	153·5
Livestock	29·9	52·4	68·8	114·2
Total output	115·0	181·5	245·5	384·5
COSTS				
Seeds	4·5	5·2	4·3	6·6
Feeds	10·0	14·0	20·2	31·0
Livestock	5·6	6·0	13·0	15·9
Fertilizers, &c.	..	9·7	18·5	21·6
Miscellaneous	10·1	13·8	21·5	27·8
Taxes	10·8	12·7	11·1	17·1
Total costs	41·0	61·4	88·6	120·0
Net output*	74·0	120·1	156·9	264·5
Benefit over present conditions	..	46·1	82·9	190·5

* Net output is equivalent to the return to family labour plus profit.

land from the owner for a share of the crop, and the total family income on an average holding of 11 acres after paying this share and covering cash expenses is about Rs. 530 (£40). The owner's share yields about 3 per cent. on capital invested. After drainage with improved farming but without additional water it is expected that the share-cropper's income will rise to Rs. 1,100 (£82. 10*s.*) and the owner's to 6 per cent. on capital invested. Since Rs. 1,200 is regarded as a minimum reasonable subsistence income the government cannot take any part of the cultivators' increased income if they wish to create a prosperous peasant society. The most that they can reasonably expect is one half of the owner's increased share or about Rs. 12 per acre per annum. In addition the government will receive additional income as a result of the higher intensity of farming made possible by the additional water supplies from tube-wells, which amounts to another Rs. 4 per acre, leaving Rs. 27 per acre to be borne by the government. There may be considerable indirect increases in government revenue resulting from the increased incomes of traders and merchants, processors and carriers, but these are unlikely to be large enough to cover this Rs. 27 per acre.

The general conclusion can be drawn from this examination of the economics of drainage in agricultural conditions such as those of Khairpur that where no additional water can be made available drainage is likely to be uneconomic. Where it can be made available, particularly where the drainage system itself can produce the additional water, the intensification of agriculture that can result will cover the cost of drainage. If yield increases larger than 100 per cent. can be obtained, these conclusions must be modified. It would be unsafe to predict that such increases will be obtained, however, in the present state of the knowledge of the process of change. In so far as Khairpur is in the na[illegible]re of a trial drainage project the high proportion of its costs that wi[illegible] to be borne by the government may be justified. But such i[illegible]nt cannot be repeated on a national scale particularly if the in[illegible] funds have to come from outside. The only long-term solut[illegible]agricultural improvement lies in a change in the structure of fa[illegible]ng away from its present reliance on peasant hand-labour towards a more capital intensive high-yielding type of farming which will [illegible] able to bear the high costs of drainage. In the short run even to ra[illegible]e the level of yields to those assumed to result from improved farm[illegible]g and drainage will require a massive effort of farmer education and extension far wider in scope than anything yet tried in similar conditions. But unless these far-reaching changes are adopted and drainage installed, the continued deterioration of crop yields and the reduction of the area cultivated will lead to even greater poverty and hardship than at present.