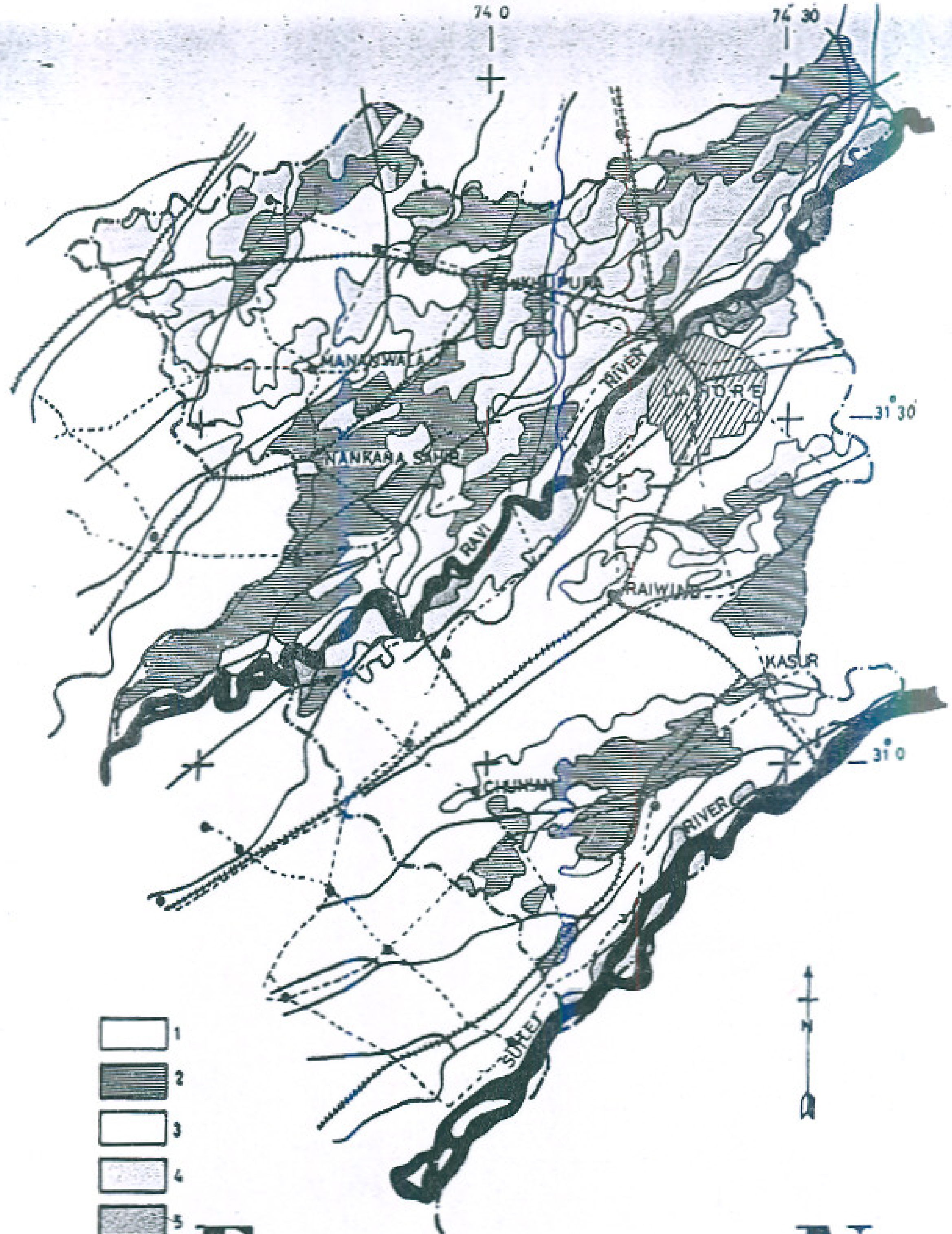

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In this issue

TITLE COVER

Lahore and Sheikhupura Districts, Generalized Land Development Possibilities.

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PEOPLE'S WORKS PROGRAMME : DEMOCRACY IN DEVELOPMENT

The Engineer Finance Minister of the Government of Pakistan Dr. Mubashir Hasan has demonstrated recognition of the contemporary reality by announcing a new concept of development at the base level. So far the development has been taken to be a bureaucratic function. The planning was carried on in the sanctuaries of Planning Commission carefully insulated from the thinking of the people at large. The implementation of such plans was entirely the responsibility of bureaucratic machinery designed and devised to work in the strait grooves of sanctions and procedures. The state machinery was to function on the turnkey system to produce the finished goods and this was the development system that held sway in the national life. It was never realised that as a new nation we have to carve out our own institutions of development as also we were to build our own political, social and economic institutions. It was never realised that the national existence was not merely dependent upon physical and material resources but also required, in addition, an organic unity and social cohesion based on which the developmental institutions should be fashioned. It is this deficiency which seems to have been recognized in full in announcing the People's Works Programme.

The press has recently carried some details of the philosophy guiding the People's Works Programme. The specific objectives have been defined as :—

(1) To combat unemployment and underemployment by significantly enlarging opportunities for gainful work.

(2) To undertake, within the framework of

the country's overall development plan, such productive projects as will build up the economy through the provision of basic capacities and amenities. The projects undertaken will be split into comparatively small units and will materialise quickly.

(3) To mobilise local resources and to motivate the people for a massive productive effort so that the process of development gets institutionalised and is associated with a large segment of the population.

(4) To provide opportunities for constructive leadership and draw upon local initiative to the maximum extent.

(5) To generate confidence and self-reliance among the masses through proper training and skill formation so that they become worthwhile productive assets for the country.

The organisational set up envisages to have parallel hierarchy of the people's organisations and Government officials. It is proposed that People's Village Committees will be set up at village level and will be linked up with the People's District Councils through certain intermediary committees. The basic unit of operation will be the village in the rural areas and a Ward in the urban area. The community living in the village or the Ward will elect its own representatives to act as implementing agencies for the execution and supervision of such work as the community, as a whole, will decide to undertake. This is what can be called taking the democracy to the gross route for the purposes of planning and execution of the development schemes to provide for the basic amenities and the felt needs of the community. The basic ingredient in such a scheme of things is of course political motivation. The people have to be given a sense of confidence and self-reliance that through their own organisations they can become productive assets of the nation. It is precisely from this point of view that a very significant departure has been made from the past concepts of development in asking the socially coherent small groups to convert themselves into institutions of development. It will not be the bureaucracy that will determine the needs of the village. The community itself will enunciate its felt needs, plan within the allocated resources and also supervise its implementation. It will look towards the administrative machinery only for seeking technical guidance. The bureaucracy will thus be there only to assist the village community as a friend and co-worker and not to sit in judgement over their requirements.

The engineers in this country have a very significant and effective role to play. The village community is living in conditions completely devoid of basic amenities. The felt needs of the community centre around such necessities as require engineering skill. The engineering community will be largely called upon to guide the fellow brethren in planning and implementing such schemes. The country now requires a group of engineers who are motivated by a missionary zeal to serve the hitherto unprivileged. Let the engineering community throw out a dedicated group, howsoever small, that can turn its face away from prestigeous and grand construction and identify itself with such humble works as may not require elaborate concepts and design formulae but perhaps will carry greater moral grandeur as those humble works will directly serve the suffering humanity. The castles built in the hearts of human beings carry greater grandeur than those constructed on the earth.

Irrigation and Power Section

Economics of Water Use in the Irrigated Plains of West Pakistan

M. ASHRAF ALI, ROBERT BRINKMAN
AND CH. MOHAMMAD RAFIQ*

A simple model has been constructed to show what contribution can be made by new Soil Survey data in the planning of water allocation on the basis of economic considerations. For all canal commands of Chaj, Rechna and Bari doabs, response curves have been prepared showing how the returns to irrigation water vary with increase in water supply. Separate figures are given for kharif (summer) and rabi (winter) seasons.

The model is an example only, since some variables like cropping intensity or crop prices have been kept constant in the calculations. Some of the new data used in the construction of the figures may be of use for incorporation into a proper decision-making model.

The results show that it is economic to allocate water from any source (canal, tubewell or storage) to Class I and Class II land to at least 150 per cent cropping intensity, and probably higher. It is economic to develop Class III land wherever fresh ground water is available after satisfying the needs of Class I and II land, but generally not where water would have to be supplied by canal remodelling or from storage. Development of Class IV land is not economic or marginal even where tubewell water is available.

For large areas (Chaj, Rechna and Bari doabs) for which comparative data are now available, World Bank figures and the present results for projected total water requirement are very close, mainly due to compensating differences in estimates. The present results show higher water requirements per acre than the World Bank figures, but lower acreages economically usable within different canal commands. No major changes in policy or emphasis on an Indus basin scale are suggested at present therefor. On a smaller scale, however, highly economic changes can be made in water allocation policy and practices.

The response curves show how much water could be economically applied in a canal command. Wherever a limited quantity of water could be applied to more than one command, each having insufficient supply, the water can now be directed to the command with the highest net returns not satisfied by previous allocations.

*Assistant Soil Survey Research Officer, Technical Officer, Soil Survey Interpretation (FAO), and Deputy Director, respectively, Soil Survey Project of Pakistan, Lahore.

For example, the lower Chenab command would need more than one MAF beyond its envisage supply to maximize economic returns, concentrating development on good land; while Sidhnai and Mailsi commands would need about one and a half MAF less than the eventual (not present) supply envisaged by the World Bank.

Also, the data show how high are the benefits of concentrating available water on the better land within each canal command, rather than spreading it evenly over land of different quality. For efficient planning of water allocations at this level of detail, however, the regular Soil Survey Reports with maps are needed, or the reports on Agricultural Development Possibilities derived from them which are under preparation.

Scope and Objectives

To date, development and allocation of irrigation water have been planned on the basis of availability and production costs for delivery to specified areas and of benefit from projected average cropping intensities and average yields for whole canal commands or other large areas. This has resulted in reasonable estimates of total amounts required and, particularly by emphasis on development of relatively low-cost water resources (tubewells in fresh ground water areas), is a reasonable indication of broad priorities. Without more data, however, it was not yet possible to indicate the optimum economic sequence and distribution of irrigation water supplies within and between canal commands, particularly during the period when only a part of the projected water supplies have been developed.

The plain parts of West Pakistan which it would be possible to supply with water from the Indus and tributaries and their associated ground water exceed some 30 million acres in extent (Lieftinck et al. 1969, Vol. 1, p. 109). The plans for irrigation water development (Lieftinck *et al.* 1969) envisage a total supply of some 135 million acre-feet (MAF) at watercourse head in thirty years' time, and quote a figure of 75 MAF as supplies available in 1970. This would work out to an average of 2.5 acre-feet per acre per year in 1970 and 4.5 acre-feet per acre per year thirty years later. This would imply average cropping intensities of about 70 per cent in 1970 and about 130 per cent thirty years later, assuming no under-watering.* Since farmers commonly achieve cropping intensities of 150 per cent, and locally more than 180 per cent in places where ample irrigation water is available, it is obvious that the irrigation water supply is the minimum factor to be used in economic calculations, and that objective like 'more land under the plough' may not be economically relevant at this stage of planning.

Some areas within the Indus plains, for example dune land, have traditionally been excluded from irrigation planning since it was obvious that they could not yield any net benefits. Other areas have been provided with some irrigation supplies since the last eighty years or so, and have proved their sustained productivity. Even within old and well established canal commands, however, there are certain patches where all attempts at irrigated farming have failed, or where the returns are consistently lower than elsewhere

*Lieftinck *et al.* quote an average cropping intensity of 145 per cent for the year 2000. This is based either on under-watering or on prevalence of cropping patterns using less water than our estimates.

Except in a general and qualitative way, these differences could not until now be incorporated in a planning model, and in particular for new irrigation development the location and extent of problem areas could not be accurately indicated.

The systematic soil surveys by the Soil Survey Project of Pakistan have now resulted in land capability information to a uniform standard for large areas of the Indus plains (Ashraf, Brinkman and Alim 1970).

Land capability tables have been prepared for all canal commands in the three eastern doabs of the Punjab (the area between the Jhelum and the Sutlej rivers), and for the canal commands in Peshawar vale. The tables show the gross extent, in thousands of acres, of each defined land capability sub-class (each "kind of land") within each canal command, subdivided by ground-water quality zone and main climate. They are available from the Soil Survey Project of Pakistan, Lahore.

A coherent set of estimates was prepared for cropping patterns, crop yields, prices and production costs, and irrigation water requirements for each kind of land within each main climatic zone. These estimates together with the acreage figures derived from soil survey and land capability classification, were used to construct response curves showing the net returns per acre-foot to increments of irrigation water used within each canal command.

The response curves immediately answer the question how much water can be applied in a canal command with positive economic returns. Wherever a limited quantity of water is available that can be allocated to more than one command, the highest benefits can be arrived at by serial allocation of quantities of irrigation water to the commands with the highest returns not yet satisfied by previous allocations. Ideally, for every decision concerning water allocation within the Indus plains the whole system should be considered, within the constraints, that only part of the water can be economically moved from its place of production (canal water), and that only part can be produced at will in different seasons (tubewell water). The use of quantitative data on the extent of different kinds of land, as produced by the Soil Survey Project of Pakistan, will considerably increase the precision of any decision-making model.

The present response curves have been constructed to illustrate some possibilities of such a model, but there are definite limits to their use for planning. Many variables have been represented only by reasonable estimates. These will need to be replaced by functional relationships or at least a set of estimates for sensitivity analysis, before sound decisions can be calculated. Such analysis can only be performed in a reasonable time with the aid of more computing facilities than the electric calculator at present available to us.

The assumptions made are discussed in a later section. Two examples are given here to illustrate the limitations of the present calculations and the further possibilities of the method. The cropping intensity has been fixed at 150 per cent, a figure achieved today by many advanced farmers where sufficient water is available. Intensities of 180 per cent or more are, however, possible and have locally been achieved with certain cropping patterns, and their more wide-spread use would require some twenty per cent more water on the good and very good land. It is most likely that the break-even point between use of Class III land and intensification on Class I and II land lies at cropping intensities higher than 150 per cent on the latter. Estimates for crop prices would also need to be made variable in a computing model, in order to test the sensitivity to price changes of cropping patterns and efficiencies of water use. The need for this can be seen, for example, by the recent price rise of cotton due to a Government export incentive, from about 35 to between 40 and 45 rupees per maund at the farm gate. On certain kinds of land this will cause a shift from rice to cotton. On others there will be no or a negligible change.

It is to be hoped that this study will assist in optimum economic allocations of water within, and between, canal commands and larger areas. Its main strength does not lie in the absolute Rupee figures that have been calculated, but in the fact that it is now possible to compare estimated net benefits of irrigation water used for different lands in different commands on the basis of one standard.

Incorporation of data and estimates like the ones used in this study into a computer model would make it possible to run sensitivity analyses on the different estimates to identify which ones require better definition most urgently. It would also make possible rapid incorporation into the calculation model of increasingly accurate estimates or data for new commands becoming available. Basic land capability data for about fifteen more canal commands, are available at present and it is planned to calculate economies of water use for these in 1972.

MAIN RESULTS

Canal commands and economically irrigable areas

The net canal command areas quoted in table 1 from Lieftinck *et al.* 1967 (World Bank estimates) correspond closely but not perfectly with the culturable commanded areas quoted from Tipton and Kalmbach 1967. They are probably both derived from Irrigation Department records. The Soil Survey Project has prepared independent estimates based upon Survey of Pakistan topographic data and Soil Survey field information for gross area, from which a blanket ten per cent was deducted for infrastructure (roads, villages, canals, bunds etc.) to arrive at net canal command areas. These net areas (table 1) correspond closely with the World Bank figures when whole doabs are considered : generally within some two per cent. For individual commands the differences are greater : the maximum being more than 0.3 million acres in the Lower Chenab command. This is largely compensated when adjoining commands are considered and may reflect different boundary estimates by the Survey of Pakistan and by the Irrigation Department.

Out of the net areas, however, part is not economically irrigable. The proportion economically irrigable land ranges from 52 to over 90 per cent in the canal commands of Chaj, Rechna and Bari doabs (table 1). On the average, one sixth of the land in these doabs is not economically irrigable. Recent data suggest that generally similar percentages of land are not economically irrigable in Sind. Two large canal commands are of considerable lower general potential than the remainder : Thal and Ghulam Mohammad.

Cropping patterns and economics of irrigation water use

For each land capability subclass (each "kind of land") within each main climate a

TABLE 1

Estimates of canal command areas.

Canal command	Million acres net area					
	Soil Survey Project[1]			Other Agencies		
	Total	Irrigable	Economically irrigable	World Bank[2]	Tipton and CCA	Kalmbach[3] reclamation area
Upper Jhelum ..	0.604	0.561	0.498	0.543	0.541	0.647
Lower Jhelum ..	1.423	1.262	1.200	1.500	1.500	1.560
Chaj Doab ..	2.027	1.823	1.698	2.043	2.041	2.207
Marala-Ravi ..	0.130	0.071	0.067	0.105[4]	0.107	0.162
B.R.B.D. ..	0.474	0.459	0.325	0.427[5]	0.427	0.427
Upper Chenab ..	0.731	0.684	0.532	1.018	1.044	1.210
Lower Chenab ..	3.360	3.124	2.888	2.981	2.923	3.116
Haveli ..	0.177	0.168	0.141	0.143	0.158	0.158
Rechna Doab ..	4.873	4.506	3.953	4.729	4.659	5.073
Upper Dipalpur ..	0.382	0.344	0.340	0.372	0.323	0.330
Lower Dipalpur ..	0.517	0.472	0.456	0.611	0.660	0.699
Central Bari Doab ..	0.615	0.607	0.571	0.595[6]	0.581	0.736
Lower Bari Doab ..	1.540	1.416	1.286	1.575	1.526	1.552
Sidhnai ..	0.511	0.501	0.465	0.754	0.797	0.797
Pakpattan ..	1.291	1.142	1.093	1.273[7]	1.394[8]	1.361[8]
Mailsi ..	0.649	0.595	0.533	0.677[7]	0.650	0.678
Bari Doab ..	5.504	5.077	4.744	5.857	5.931	6.153
Three Doabs ..	12.404	11.406	10.395	12.629	12.631	13.433

1. *Total :* total net area, calculated as gross area minus ten per cent for infrastructure. Gross area measured using Survey of Pakistan topographic information and soil survey field data.

Irrigable : net area of all land in land capability classes I to IV inclusive plus VIIa and VIIIa.

Economically irrigable : net area of all land in land capability classes I to III inclusive.

2. Lieftinck *et al.* 1967. Economic annex, Appendix 6 : The area units used in the linear programming analysis.

3. Tipton and Kalmbach Inc. 1967, Vol. I.

CCA : culturable commanded area, p. 151 (table 8).

Reclamation : reclamation area, p. 40 (table 18). Includes CCA.

4. 0.158 million acres quoted in IACA 1966, Vol. 5, Annexure 7, p. 64 (table 6.1).

5. In Lienftinck et al. 1967, B. R. B. D. is included in Upper Chenab. We have listed it separately using Tipton and Kalmbach's area figure.

6. Excludes Wagah area, 0.047 millin acres.

7. The small area (0.015 million acres) of upper Mailsi is included in Pakpattan.

8. Something wrong with the figure.

Table 2

Irrigation water use[9] of croppnig patterns by climate and land capability subclass.

Climate / land cap. subclass	AF[10] per acre CCA, in kharif and in rabi										
	I	IIw	IIs sandy	IIs clayey	IIa	IIIw	IIIs	IIIa	IVw	IVs	IVa
Subhumid											
kharif	.. 2.8	4.5	2.6	5.0	2.7	4.6	3.5	5.0	—	5.0	5.0
rabi	.. 1.5	1.0	1.5	1.0	1.5	1.0	1.0	1.0	—	1.5	1.0
Main semiarid[11]											
kharif	.. 2.4	2.3	2.6	5.0/ 3.7	2.7	4.6/ 3.3	3.5	5.0/ 3.8	—	5.0	5.0/ 3.8
rabi	.. 1.5	1.5	1.5	1.0/ 1.5	1.5	1.0/ 1.5	1.5	1.0/ 1.5	—	1.5	1.0 1.5
Dry semiarid											
kharif	.. 3.0	2.9	3.0	3.6	3.3	4.1	3.0	4.1	—	4.2	4.1
rabi	.. 1.7	1.7	1.4	1.9	1.9	1.9	1.1	1.9	—	1.3	1.9
Main arid											
kharif	.. 3.4	3.4	3.4	3.9	3.7	4.5	3.4	4.5	6.0	4.5	4.5
rabi	.. 1.6	1.5	1.5	1.9	2.2	2.2	1.2	2.1	1.4	1.5	2.1

Table 3

Net value[12] of cropping patterns in terms of irrigation water use by climate and land capability subclass under modern management.

Climate / land cap. subclass	Rs per AF in kharif and rabi										
	I	IIw	IIs sandy	IIs clayey	IIa	IIIw	IIIs	IIIa	IVw	IVs	IVa
Subhumid											
kharif	.. 136	94	97	95	94	66	68	62	—	27	14
rabi	.. 235	193	161	193	185	128	105	110	—	11	—42
Main semiarid											
kharif	.. 158	103	94	95	109	66	68	62	—	27	14
rabi	.. 235	195	161	194	185	128	105	110	—	11	—12
Dry semiarid											
kharif	.. 148	109	96	104	121	64	59	60	—	25	11
rabi	.. 203	156	183	153	145	100	180	86	—	91	—21
Main arid	..										
kharif	.. 167	140	113	120	135	72	52	70	29	22	21
rabi	.. 213	152	182	103	81	50	202	36	—54	105	—39

9. Under-watering (a traditional practice to spread available water over more land) has not been considered in this study. It may have short-term advantages only under traditional management in subhumid and semi-arid areas. Under modern management this practice is expected to be uneconomic due to the higher fixed production costs (*e.g.* for fertilizers) and the necessity to use part of the water on less productive land. In addition, under-watering gradually increases salinity.

10. At watercourse head.

11. Double figures refer to land in fresh and saline ground water areas respectively.

12. Not counting water cost.

simple cropping pattern has been assumed, based upon the experience and practice of the most modern farmers as found during reconnaissance soil survey field operations. For each crop-land-climate combination, yields and irrigation water requirements were also estimated, on the basis of field information obtained during soil survey. Crop prices and production costs for each crop-land-climate combination were derived from published data and field information. Calculations from these data resulted in tables showing the irrigation water use by season for each cropping pattern and the economies of the use of this water : the net returns in rupees per acre-foot of irrigation water applied to each cropping pattern by land capability subclass and climate.

The tables of basic data, calculations and results are presented separately in a mimeographed 76-page paper "Appendix tables to Economics of water use in the irrigated plains of West Pakistan" available from the Soil Survey Project of Pakistan, Lahore. Tables 2 and 3 summarize the irrigation water use and net value per acre-foot of the cropping patterns for each land-climate combination under modern management.

The cost of current canal water is less than about Rs. 5 per acre-foot in kharif and less than Rs. 10 in rabi. Tubewell water costs about Rs. 25 per acre-foot wherever fresh ground water is available. Canal remodelling and drainage, the only way to increase kharif supplies in saline ground water areas, cost roughly Rs. 50 per acre-foot, and storage plus drainage, to increase rabi supplies in saline ground water areas, between Rs. 90 and 120. These figures, and other estimates used in the calculations, are discussed in a later section.

From table 3 it is clear that, with modern management, irrigation water costing up to some Rs. 50 per acre-foot in kharif and up to some Rs. 90 to 120 in rabi can be economically used on Class I and II land, and would give generally marginal returns on Class III land. On Class IV land its use would be highly uneconomic. With a traditional or intermediate level of management (development estimate), use of water at such high cost would not be economic even on Class III land. Tubewell water can be economically used on land Classes I, II and III, and its use on Class IV land is marginal or uneconomic in almost all cases, even with modern management. Only the use of current canal supplies would be economic or marginal on most of the Class IV land under modern management, but these supplies are already fully committed to better land.

On the basis of water cost and net value of cropping patterns, development priorities appear to be : First, tubewell installation to increase the cropping intensity on Class I and II land in fresh ground water areas to at least 150 per cent. Second, canal remodelling, construction of storage and drainage to achieve the same object in saline ground water areas, and further tubewell installation in fresh ground water areas to increase the cropping intensity on Class III land as far as ground water is available without resorting to mining. Third, if more water is available from storage or ground water : increasing the cropping intensity on Class I and Class II land beyond 150 per cent. With present water costs development of Class IV land, and of Class III land with saline ground water, should have a very low priority for economic reasons.

Water economically usable by canal commands

For each canal command between the Jhelum and Sutlej rivers, the net areas of each land capability subclass (subdivided by main climate) have been multiplied with the water requirement in kharif and in rabi of the appropriate cropping pattern, to arrive at the amount of water usable at a specific return per acre-foot (net except for water costs). These amounts were plotted on a horizontal scale in order of decreasing returns, and the returns in Rs. per acre-foot for two levels of management were plotted vertically above the horizontal scale. This resulted in response curves to increments of irrigation water in the kharif and rabi seasons for each canal command. A figure showing these curves for one canal command is included in this paper to serve as an example.

The appropriate production costs other than water costs were plotted downward from the horizontal scale for the two levels of management considered. Costs tend to be relatively high in the left-hand part of the figure, due to the emphasis on high-value crops requiring more inputs on the best land, and to the higher harvest costs associated with higher yields. After a decrease on Class II and III land, production costs increase again on the poor land, mainly due to high expenditure during the years of reclamation.

Water cost per acre-foot is indicated in the figures by the distance between the horizontal scale and the dotted line above it (oblique hatching). The left-hand part represents traditional, low-cost canal supplies; the next section additional supplies from tubewells in fresh ground water areas at a higher cost; and the third part represents water made available at still higher cost by canal remodelling or storage with necessary drainage.

The green areas in the graphs indicate the net economic returns to increasing water supplies, and the red areas indicate the net loss due to the use of irrigation water beyond the economic requirements of the command (on Class IV, or in a few cases Class III land, giving returns lower than the sum of the marginal water cost plus the other costs of production). Dark green indicates the net return under the assumptions of the development estimates, and light green indicates the improvement in net returns that can be expected once almost all farmers shift to modern management. In most figures the width of the dark green band decreases to the right, indicating that irrigation of more land tends to be somewhat less profitable than irrigation of the best land only in the command. At a certain point the green stops and a red area starts, indicating that with water supplies increasing beyond this point the returns from agriculture do not pay for the total production costs including the water cost. The total red area indicates the economic loss under conditions of development expected to prevail in the next ten years or so (development estimate) and the light red area the (lesser) loss under modern management.

The total amounts of water economically usable per year in each canal command between the Jhelum and Sutlej rivers have been summarized in table 4, and compared with the historic mean canal supplies and the water requirement estimates by the World Bank (IACA) and Tipton and Kalmbach. The grand totals for all the commands are remarkably close : less than one per cent difference between our estimate for modern management and the World Bank figure for the year 2000, and zero to two per cent

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RETURNS AND COSTS PER ACRE-FOOT OF IRRIGATION WATER

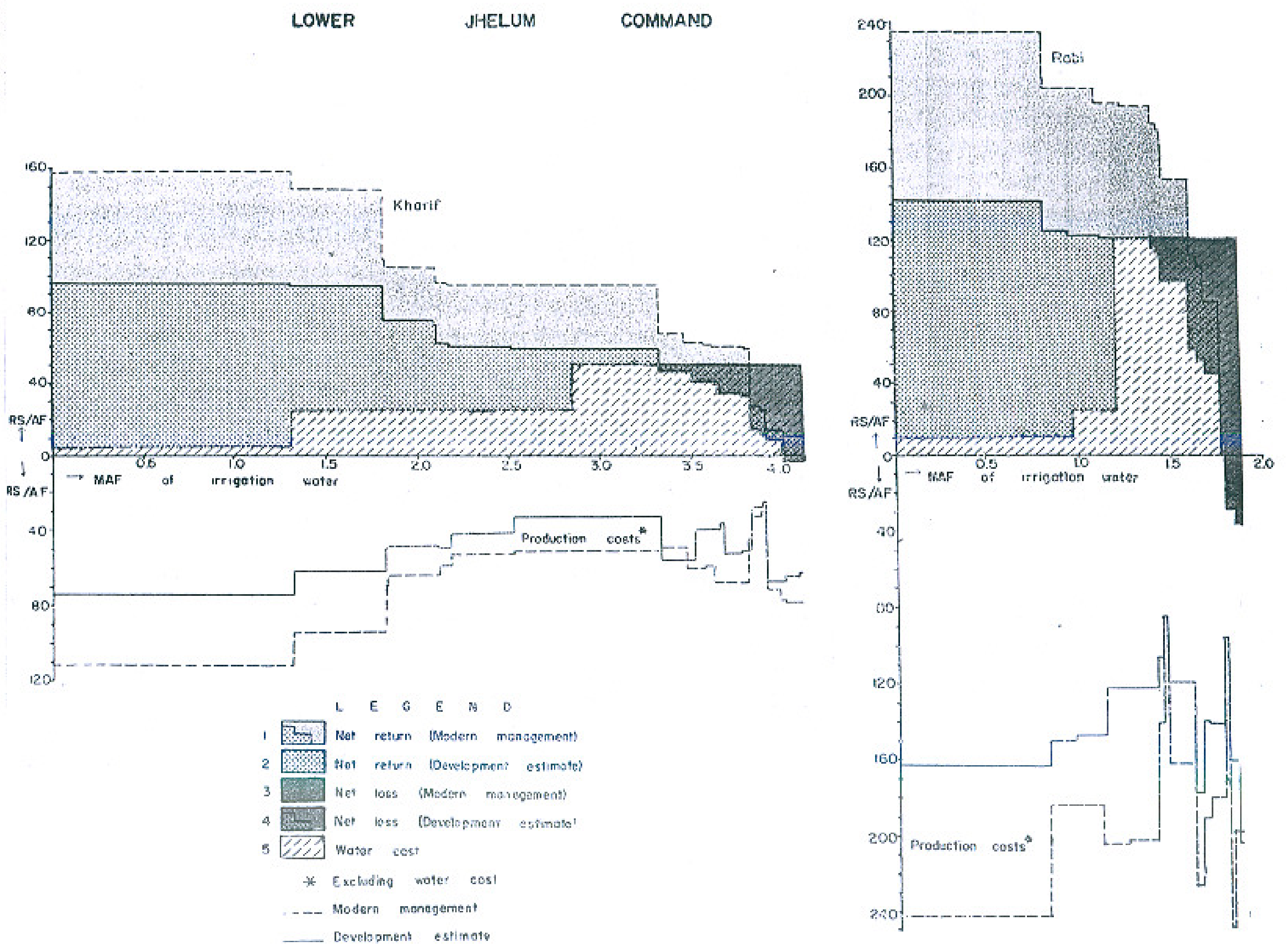

TABLE 4

Annual water supplies and estimated requirements.

Canal command	MAF at watercourse head.							
	Historic mean[13] supplies	Total economically usable water[14]		Water requirements estimates for 1985		for 2000		
		Modern management	Development estimate	IACA 1966[15]	1967[16]	Tipton[17] and Kalmbach	IACA	Extra calculated by SSP[18]
Upper Jhelum ..	0.90	2.62	2.60	1.74	1.76	1.99	1.77	0.85
Lower Jhelum ..	2.28	5.43	4.54	5.61	5.61	5.17	5.83	−0.40
Chaj Doab ..	3.18	8.05	7.14	7.35	7.37	7.16	7.60	0.45
Marala-Ravi ..	0.16	0.35	0.35	0.38	0.56	0.53	0.39	0.04
B.R.B.D. ..	0.22	1.86	1.86	2.08[19]	2.08	1.36	2.08	−0.22
Upper Chenab ..	1.01	3.65	2.59	3.43	3.61	3.89	3.57	0.08
Lower Chenab ..	4.78	12.94	11.57	9.01	9.80	10.75	11.74	1.20
Haveli ..	0.27	0.76	0.68	0.63	0.63	0.56	0.63	0.13
Rechna Doab ..	6.44	19.56	17.05	16.53	16.68	17.09	18.41	1.15
Upper Dipalpur ..	0.36	1.62	1.62	1.46	1.46	1.18	1.53	0.09
Lower Dipalpur ..	0.73	2.40	2.36	2.39	2.39	2.74	2.52	−0.12
Central Bari Doab ..	0.69	2.29	2.29	2.08	2.08	2.54	2.13	0.16
Lower Bari Doab ..	3.30	6.96	6.64	6.75	6.75	6.40	7.13	−0.17
Sidhnai ..	1.36	2.79	2.60	3.51	3.55	3.32	3.73	−0.94
Pakpattan ..	1.96	6.21	5.88	4.77	4.61	5.61	5.91	0.30
Mailsi ..	0.88	2.72	2.21	2.80	3.63	2.78	3.22	−0.50
Bari Doab ..	9.28	24.99	23.60	23.76	24.47	24.57	26.17	−1.18
Three Doabs ..	18.90	52.60	48.52	47.64	48.52	48.82	52.18	0.42

13. Tipton and Kalmbach Inc. 1967, Vol. 1, p. 40 (table 18).

14. Soil Survey Project calculations.

15. Comprehensive report, Vol., 5, pp. 72, 73 (tables 6.5 and 6.6).

16. Lieftinck *et al.* 1967, Vol. II, 3.2 Sequential analysis, Appendix A, A11. This is a more refined analysis than 15.

17. Tipton and Kalmbach Inc. 1967, p. 115 (table 61).

18. Soil Survey Project estimates for modern management compared with IACA estimates for 2000, both for 150 per cent cropping intensity.

19. Included in Upper Chenab in IACA 1966. We have listed it separately using figures for 1985 given in 16.

difference between our drevelopment estimate (a level of management expected to prevail in the next ten years) and the three earlier estimates for the year 1985. The differences in individual canal commands (listed in the last column) represent much larger percentages in some cases. This is to be expected since our estimates are independent in almost all factors from the World Bank and Tipton and Kalmbach estimates. The main new aspect of the present results is not, however, the shifts in estimated total water requirements by canal commands, but the concept of the response curves that enable planners to allocate new water supplies to those commands where they would give the highest net returns per acre-foot at any stage of present water supplies. If the data on which this study is based would be incorporated in an appropriate decision-making model, the sequence of water development and allocation between as well as within canal commands could be optimized (within the constraints of the model). Without these data, the allocation of new water within canal commands would have to be uniform rather than optimal, and the economic optimum of water allocation to different canal commands could not be determined with as much precision.

From the emphasis in this paper on the variable : "net return per acre-foot of irrigation water", it might be assumed that we assign all of the net return to the irrigation water, not to other inputs like management, fertilizer, labour etc. This is not intended. However, this variable sets an upper limit to the net value of the irrigation water. Where this becomes small with respect to the water cost, or even negative, the use of such water is not economic and, in consequence, the use of other inputs is not economic either. Where this variable is large compared with the water cost, the benefits of the combination of water and the appropriate other inputs tend to be high.

ASSUMPTIONS AND ESTIMATES USED IN THE CALCULATIONS

General

A number of assumptions and estimates have been used in the calculations. All are based upon the best data available to us at the time of writing, but doubtless they are not the best possible. Some variables have been approximated by fixed values in this study to minimize the calculation work. It would be useful to build the present data into a computing model, which would make it possible to do quick re-runs of the calculations either when better estimates become available or in order to do a sensitivity analysis on certain variables. Especially if cropping patterns and intensities on the different kinds of land could be varied in response to, for example, changes in prices and markets, such a computing model could become a very powerful planning tool.

Management levels

For *modern management*, the estimates for yields as well as costs of production are based upon use of good varieties; adequate doses of fertilizers in proportions as currently recommended; adequate amounts of irrigation water; crop protection in case of cotton; and proper land preparation and crop management, either by bullock power or by tractor power, whichever is more economic to the farmer. These cost differences are small. They are listed in the Appendix tables which are available separately.

The *development estimate* is a level of management intermediate between the present (above traditional) and modern management levels. It is close, we hope, to the average of the next ten years or so, and has been calculated as follows.

Present average fertilizer consumption has been estimated at half the recommended doses (a somewhat high estimate), and present yields at half the optima assumed for modern management. No crop protection was assumed for cotton. Water requirements were estimated at the same level as for modern management, the same for the cultural operations except harvesting and fertilizer application labour, which were decreased proportionately to the yields and fertilizer doses respectively.

We have further assumed that on the average, the farmer will attain a modern management level as described above in some ten years or so, from the present level. On this basis we have postulated linearly increasing yields, fertilizer applications (and plant protection where indicated) to the level of modern management. *Equivalent annual figures* were then calculated from the annually variable figures by the method described below.

Equivalent annual figures. Part of the activities considered in this study can be taken as constant year after year : for example, a farming sequence (cropping pattern) under our assumptions for modern management and on land not requiring reclamation. Other activities are different in different years. For example, the cost of gypsum application is high in the first years of reclaiming saline-alkali soils, and low in later years. For efficient farming, the whole specified sequence of applications is necessary, hence the reclamation together with production and followed by regular cropping can be considered as one activity. The assumptions of the "development estimate" are another example of an activity changing with time.

In order to compare the value of irrigation water used in activities that are constant each year with the value of water used in activities that vary with time, we need to specify two variables : the length of time considered and the discount rate. We have taken a ten per cent annual discount rate and a ten-year period. The current cost of capital in West Pakistan ranges between eight and eleven per cent for industrial and large agricultural borrowers, and tends to be higher for small agricultural borrowers. The ten-year period has been taken as a compromise between the periods generally considered by individuals planning investments and by institutional (Government) planners. The (constant) equivalent annual figure (the annuity) equivalent to the sequence of the individual figures for each of the ten years considered is that figure which, discounted to the present for each of the ten years and added, yields the same total as the individual figures discounted to the present and added.

Yields, cropping patterns and intensity

The basic *yield and estimates* used are those common on the best land in advanced rural parts of, for example, Lyallpur district, or the best ten per cent yields on the best land in other climatic zones. They are based upon extensive information both by field estimates and local information obtained during reconnaissance soil survey, supplemented with data kindly provided by the Lyallpur Agricultural Experimental Station and the Rapid Soil Fertility and Soil Testing

Scheme. It is expected that these yields will be common on the best land in most areas in another ten years or so. For specific kinds of land with lower potential due to different limitations, lower yields have been estimated, and in some cases extra cost factors included, *e.g.* for reclamation, the figures again being based upon field information.

Cropping patterns. If the set of assumptions used in this study to arrive at costs and returns for individual crops would be used to calculate cropping patterns with maximum net returns to water or net returns per acre, in most cases patterns would emerge with one summer and one winter crop only. In reality a number of constraints prevent this : *e.g.* peak labour and peak water available ; limited absorption of the produce by local markets; uncertainty about price and weather fluctuations; and the need for at least a partial local self-sufficiency. On the other hand, if revenue records are used to estimate cropping patterns, only an average would emerge, mixing the patterns adopted by the advanced and traditional farmers on all kinds of land. Moreover, this average would pertain to the past years, not the present.

The most economic cropping patterns for each land capability subclass, climate and ground water zone could be calculated if all variables and constraints were known quantitatively. In the absence of this quantitative information, considerably simplified patterns have been assumed on the basis of field information from the best farmers on different land capability subclasses in different climates, obtained during reconnaissance soil survey. The estimates take into account *e.g.* the different crop suitabilities on different kinds of land; the tendency to concentrate high-value special crops on the best land; and some decrease in acreage under fodders due to mechanization and increasing productivity per acre, not completely offset by increase in milk production. The cropping patterns used are listed in Table 5.

Sugarcane has not been considered in the cropping patterns for two main reasons : the great differences in value of the crop depending upon the distance from a sugar mill; and the serious disagreements about the economic value of the crop.

The *cropping intensity* has been taken as 150 per cent per year in this study. Field observations in advanced areas with sufficient fresh ground water have shown that this can easily be exceeded. Intensities of 180 per cent are widespread, and even 200 per cent has been attained locally by a number of good farmers. Even with the assumptions of 150 per cent intensity and of no irrigation on marginal or non-irrigable land, the total water requirements calculated in this paper correspond closely with the attainable total supplies estimated by the World Bank (table 4). If irrigation water were freely movable and marketable, the irrigation intensity on Class I and II land would probably increase to some 180 per cent at the expense of the cropping intensity on Class III land. The technical and social factors preventing or delaying this process or minimizing its extent have led us to use a uniform, moderately high cropping intensity.

Water availability and cost

The total *available water* in the Indus plains is determined by the rainfall plus the inflow. Ground water cannot be used permanently in excess of the recharge from

TABLE 5

Simplified cropping patterns under irrigation by climate and land capability subclass

All intensities 150 per cent[20]

	I		IIw		IIs sandy		IIs clayey		IIa		IIIw	
Subhumid	special[21] fodders[21] maize Basmati wheat	10 5 40 20 60	fodders Basmati maize wheat	5 70 25 45	fodders gr. nuts maize wheat	5 50 20 70	fodders Basmati wheat	5 95 45	fodders maize Basmati wheat	5 50 20 70	fodders Basmati maize wheat	5 75 20 45
Main[22] semiarid	special fodders cotton maize wheat	10 5 40 20 60	fodders maize cotton wheat	5 50 20 70	fodders gr. nuts cotton wheat	5 50 20 70	fodders Basmati wheat	5 90/70 45/70	fodders cotton Basmati maize wheat	5 30 20 20 70	fodders Basmati maize wheat	5 75/50 20 45/70
Dry semiarid	special fodders cotton maize wheat gram	10 5 50 10 40 20	fodders cotton maize wheat gram	5 50 20 50 20	fodders cotton gr. nuts gram wheat	5 40 30 40 30	fodders IRRI cotton wheat	5 40 30 70	fodders cotton IRRI wheat	5 50 20 70	fodders IRRI wheat	5 70 70
Main arid[23]	special fodders cotton gram wheat	10 5 60 40 20	fodders cotton gram wheat	5 70 50 20	fodders cotton gr. nuts gram wheat	5 60 10 50 20	fodders cotton IRRI wheat gram	5 40 30 50 20	fodders cotton IRRI wheat	5 50 20 70	fodders IRRI wheat	5 70 70

	IIIs		IIIa		IVw		IVs		IVa	
Subhumid	fodders gr. nuts wheat	5 95 45	Basmati wheat	100 50		— —	gr. nuts wheat	100 50	Basmati wheat	100 50
Main[22] semiarid	fodders gr. nuts wheat	5 95 45	Basmati wheat	100/75 50/75		— —	gr. nuts wheat	100 50	Basmati wheat	100/75 50/75
Dry semiarid	fodders gr. nuts gram	5 70 70	IRRI wheat	75 75		— —	gr. nuts gram	75 75	IRRI wheat	75 75
Main arid[23]	fodders gr. nuts gram	5 70 70	IRRI wheat	75 75	IRRI wheat	100 50	gr. nuts gram	75 75	IRRI wheat	75 75

20. Intensities 100 per cent in Kharif, 50 in Rabi on very wet land and in areas with good ground water and clayey, wet, or saline-alkali soils; 75 per cent in Kharif and 75 in Rabi in other cases.

21. Special includes perennial or annual cash crops with a very high value per acre. Percentages given for special and fodders apply both in Kharif and Rabi, and should be doubled for calculation of intensity.

22. Double figures refer to land in fresh and saline ground water areas respectively.

23. Excludes coastal arid and frost-free arid climates, roughly from Hyderabad south.

rivers, irrigation systems and rainfall : only for short periods to compensate for the variation of demands and supplies within and between years. The traditional annual canal supplies for each canal command are listed in table 4. The figures by season used in response curves were taken from Tipton and Kalmbach 1967, I, Table 18.

Detailed data on the annual total ground water available within each canal command were not available to us. We have assumed that in all areas underlain by usable deep ground water (less than 2000 parts per million total salts, an optimistic limit of usability), ground water could provide the difference between the traditional canal supplies and the supplies required for 150 per cent cropping intensity, but no more. We have not considered possible transfer of canal water to other commands after its replacement by tubewell water therefor.

The water required to bring the areas underlain by saline ground water to 150 per cent cropping intensity (as far as economic, considering land capability) has been assumed to come from storage (rabi water) or canal remodelling (kharif water). Use of this water has been constrained in this study by its cost (including cost of necessary drainage), rather than by a limit on its availability.

Some data on *canal water costs* (and charges) have been summarized in table 6, from unpublished data kindly provided by the Department of Irrigation and Power, Government of Punjab 1970. They have been averaged from data covering the years 1964-65, 1965-66 and 1966-67 for all the canals in Punjab except Rangpur and Thal canals. These two were excluded for lack of complete information for the three consecutive years. The expenditure figure given below represents the sum of average annual capital outlay (largely incurred on replacements) and maintenance costs including personnel expenses. Because almost all the expenditure on the system is independent of the quantity of water going through the canals, expenditure (and revenue) have been assigned to kharif and rabi cropping seasons in equal proportions.

TABLE 6

Average cost of canal water supplies, Punjab 1964-1967.

Annual expenditure, million rupees ..		66.93
Annual revenues, million rupees ..		119.19
Kharif water utilized, MAF		23.63
Rabi water utilized, MAF		10.33
	kharif	rabi
Water cost, Rs/AF ..	1.42	3.23
Water charges, Rs/AF ..	2.52	5.76

The cost estimates are very crude approximations to economic costs, since some true capital costs have been included in the total, and since imports, like vehicles, have not been shadow priced. Average water charges have been included in the table for comparison.

In the seven years since about 1965, costs have risen considerably, and (high) estimates of Rs. 5 per acre-foot for kharif water and Rs. 10/AF for rabi water have been used in the response curves. The conclusions drawn would not be significantly affected even if these cost estimates were halved. The cost of tubewell water in fresh ground water areas has been estimated at Rs. 25/AF on the basis of Finney 1969. This does not include the cost of amendment (gypsum) which may have to be added to part of the water to prevent soil damage.

Extra kharif water from canal remodelling in saline ground water areas has been estimated at Rs. 50 per acre-foot : Rs. 5/AF for running costs plus Rs. 25/AF for canal remodelling costs and Rs. 20 for drainage (see below, Cost of drainage in saline ground water areas). The World Bank (Lieftinck *et al.* 1967, Vol. I, p. 33) estimates the economic costs of canal remodelling at Rs. 19/AF and of tubewell at Rs. 16/AF. Latest figures for cost of tubewell water (Finney 1969) are about Rs. 25, and a slightly smaller rise has been assumed here for the cost of canal remodelling, also bringing this to Rs. 25/AF.

Cost of rabi water from storage. Tarbela water at the dam costs Rs. 54 per acre-foot of total live storage and about Rs. 65 per acre-foot of usable water*. With the assumption of one third loss between dam and watercourse head, the cost of Tarbela water would be about Rs. 100/AF at watercourse head.

This estimate may be on the high side as can be seen from the following quotations.

"The cost of water from Tarbela reservoir delivered at the watercourse would be about Rs. 93 per acre-foot...." (Lieftinck *et al.* 1969, Vol. I, 40), and "Attribution of three-quarters of the cost of Tarbela dam to its irrigation function would mean that the average cost of stored water delivered to the watercourse would be about Rs. 70 per acre-foot...." (*ibid.*, p. 46).

However, as can be seen from the figures in this paper, decreasing the cost of the rabi water from storage by some Rs. 20/AF would add relatively little to the economic demand.

To the estimate of Rs. 100/AF we have added Rs. 20/AF for drainage, since a proportion of all extra irrigation water used in saline ground water areas will have to be drained out again to maintain the water-table at sufficient depth. The drainage estimate is discussed below.

Cost of drainage in saline ground water areas. It is assumed that about 40 per cent of increased supplies at watercourse head will have to be taken out as drainage in saline ground water areas (field, watercourse and distributary losses plus part of canal losses). The cost of drainage has been estimated to be roughly Rs. 20 per acre-foot of increased supply at watercourse head. This cost has been worked out on the basis explained in the following paragraphs. In general no drainage is required with traditional water supplies. However, in areas where traditional supplies already cause waterlogging, a similar figure for drainage cost would have to be added to the traditional water cost.

Tubewell water for irrigation costs about Rs. 25/AF (Finney 1969), on the assumption that distribution costs are negligible. Drainage water from tubewells could be expected to cost somewhat more, due to the shorter life of certain parts in contact with saline water : say, Rs. 30/AF. To this cost should be added the cost of some widely spaced main drains to take the water to the river : say, Rs. 20/AF (see below).

We have no direct figures available for surface drainage of ground water, but have taken the Sukh Beas storm water drainage scheme as an example for costs, and made some assumptions about the efficiency of a similar system in evacuating ground water. The design capacity of the Sukh Beas Scheme (Lieftinck *et al.* 1967) is about 2250 cusecs or 4500 AF/day. Assuming that such a scheme

*Lieftinck *et al.* 1967, Vol. II, page 5.2, table 5 interpolated at 10 per cent discount rate and page C. 8, table C. 6 showing usable water at about 80 per cent of total.

could evacuate ground water at an average rate of one third to one fourth of its design capacity, its effective capacity would be 0.45 MAF/year. The capital cost of the scheme is about Rs. 190 million, and the annual operations and maintenance cost Rs. 2.2 million. At discount rate of ten per cent and an estimated life of more than 30 years the total annual cost will be some Rs. 22 million including maintenance, that is Rs. 50 per AF of drain water, the same as with tubewells.

These calculations are very rough, but will have to serve until more precise data are available to us.

Canal lining in saline ground water areas has not been considered here as a possible source of water, for reasons of simplicity only. This, however, would be a valid alternative of supplement to other sources. In saline zones the cost of irrigation water obtained (saved) by canal lining would be about Rs. 65 per acre-foot, because there canal lining would not only reduce seepage losses but also the related drainage pumping (last sentence summarized from Lieftinck *et al.* 1969, Vol. I, 51).

Reclamation of saline-alkali land

The reclamation costs of saline-alkali land have been converted into an equivalent annual cost (annuity) at a 10 per cent discount rate and over a ten year period. Gypsum has been estimated at Rs. 80 per ton including application. Its present cost is about Rs. 80 per ton at Lahore (crushed unnecessarily fine and with a limited supply) but the price is expected to fall considerably with increase in crushing capacity. The raw material is abundantly available in surface deposits in West Pakistan.

In order to attain the sequence of yields used for the calculations most of the moderate saline-alkali land (irIIIa) would probably require about 2½ tons of gypsum annually for four years. Marginal (irIVa) land would require roughly five tons of gypsum annually for four years, probably followed by one ton annually for another four years or so. Equivalent annual costs over a ten-year period (10 per cent discount rate) are Rs. 106 per acre for irIIIa land and Rs. 240 per acre for irIVa land. These amounts have been debited half to the kharif and half to the rabi crops. For this purpose a 200 per cent intensity (no fallow) has been assumed, since this would give best results in reclamation. However, after calculating the reclamation costs per crop on this favourable basis, for the sake of uniformity with other land capability subclasses we have reverted to a "standard" 150 per cent cropping intensity.

The extra irrigation water needed for reclamation of saline-alkali soils has been converted into an equivalent annual application and debited to the crops by a similar calculation.

Production costs other than water cost

Costs of labour and power for bullock-powered land preparation and other cultural operations are on the basis of Gill *et al.* 1966, adjusted upward by about 20 per cent to account for the increase in wages between 1961-64 (Gill's reporting period) and 1971 and adjusted to exclude harvesting costs, which are listed separately. The costs of mechanical cultivation and sowing are contract rates current in advanced rural areas of Lyallpur district, by local information. Probably this approach has underestimated the true economic costs, because tractor prices are on the basis of the official rate of exchange (in 1971) and this is not completely compensated by the duties on diesel fuel.

Fertilizer costs have been taken as Rs. 0.75 per lb. N, Rs. 0.75 per lb. P_2O_5 and Rs. 0.50 per lb. K_2O. The subsidized prices of N and P_2O_5 are about a third lower.

Other costs. Harvesting costs have been taken as a percentage of the yield since contract harvesting is relatively widespread. Water application costs have been included in the crop production costs and calculated at usual labour rates. Plant-protection costs for cotton were estimated on the basis of Finney 1969.

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Reconnaissance Soil Surveys in Pakistan

Ey MUHAMMAD ALIM MIAN*

The Soil Survey Project of Pakistan was set up in 1961. The primary objective of the Project is to make a comprehensive inventory of the soil resources of the country through reconnaissance soil survey and to prepare soil survey reports and maps. The Project has so far surveyed about, 90,000 square miles of agriculturally important areas of West Pakistan. The findings and recommendations of this survey have been presented in thirty reconnaissance soil survey reports which include maps of soils, land forms, land capability and land use. These reports are designed to be of practical use in agricultural development planning at various levels. They provide information of fundamental value for land development and improvement projects, schemes of land settlements, irrigation, drainage, soil conservation and afforestation; all requiring accurate soils information for their effective planning. The soil, land capability and crop suitability information contained in these reports could also be of great assistance to agricultural extension staff at tehsil, district level and to irrigation planners for preparing projects for the individual main canal commands or part thereof. The soils information can be interpreted for many different purposes. It can also be utilized for town and regional planning. The map appearing on the cover of this issue depicts potential of Lahore and Sheikhupura districts for agricultural and urban/industrial development. The different units shown on the map (title) are explained below.

DEVELOPMENT POSSIBILITIES

		Agricultural	Urban and Industrial
1.	Light green	Intensive vegetables/ fruits/ milk/fodders for urban use. Green belt.	Possible but wasteful.
2.	Dark green	Intensive horticulture/ agriculture. Green belt.	Possible but wasteful.
3.	Brown	Reclamation for general agriculture.	Urban development. Suited for parks after reclamation.
4.	Blue	Fodders /milk (winter only)	Not practical for buildings. Source of sand.
5.	Red	Not practical	Not practical for buildings. Good source of sand.
6.	Purple	Not economic	Industrial development. Good foundation if covered, and provided with minor surface drains. Not suited for parks except after excavating about 3 feet.
7.	Hatched	Urban land	

*Soil Chemist, Soil Survey Project of Pakistan.

Development of Water Resources in the Punjab*

By S. M. H. BOKHARI, PSE-I,
Chief, Water & Power,
Planning and Development Department,
Government of the Punjab.

Present Irrigation System

In this land of five rivers, summer irrigation has been practised for hundreds of years. Permanent canals, both perennial and non-perenial, were, however, introduced about 120 years ago. Gradually, the irrigation network has grown into a single integrated gravity flow system, which is almost unique in the world. It contains 14 main barrages, diverting water supply into 24,000 miles long irrigation channels. There are about 3,500 miles of complementary surface drains and 9,470 irrigation-*cum*-drainage public tubewells. Small dams, private tubewells and persian-wheels also contribute their bit as sources of artificial irrigation.

Restricted Growth of the System

2. Although the system is very impressive in dimensions, but it is inadequate even to meet the scientific water requirements of the area already served by it, let alone any scope for future development. Due to some past events, land and water potentials have contracted permanently with the result that as time passed on, the pressure on the agricultural land kept on building up and the gap between the availability of water and demand went on widening. Some of these events are mentioned below :

(*i*) The menace of waterlogging, which became noticeable within a few years of commissioning the permanent canal system, took a heavy toll of good irrigated land every year because the application of remedial measures at a limited scale only did not prove effective. As a result of combined attack by the rising water table, incidence of salinity/alkalinity and vast spills from the repeated floods during the wet cycle of 1950s, means of communications were disrupted, canals and other irrigation works damaged and many abadis were deserted by the inhabitants because of insufferable living conditions.

(*ii*) Signing of the Water Treaty with India meant a perpetual loss of 24 MAF flowing into Punjab from three eastern rivers

*The views expressed in this paper are of the author in his personal capacity and Govt. of Punjab is not responsible for any of the statement made.

and its replacement burden on the three western rivers by transfer through inter-river links was far greater due to transmission losses. Moreover the source of replacement in the form of Mangla and Tarbela storages has only limited life as compared to almost infinite life of the diversion weirs, feeding the canal systems on the three eastern rivers. Besides these losses of water potential about 16 lac acres of sailaba area have gone dry due to the construction of dams on the western rivers and total diversion of eastern rivers by India. Another over 3 lac acres has been permanently occupied by the replacement works and a sizeable area along the link canals is going out of commission due to waterlogging.

3. Coupled with these events seasonal variations in river discharges have made it difficult to generate more irrigation supplies so badly needed for further development, in the absence of additional storages, which could conserve huge monsoon discharges flowing into sea. One such storage site is at Kalabagh, where site explorations have reached an advanced stage and it is high time that finances for its execution were lined up. In addition to this dam, work must also continue for finding out more and more storage sites, so that most economical ones were eventually selected both for the replacement of Mangla and Tarbela reservoirs after they have outlived their economic life and to conserve every drop of water that is wasted into sea now. Unless we move quickly in this direction, we may never match with the growing needs of food and fibre for the expanding population.

Existing Water Availability

4. According to the available statistics, out of a total of 42.1 million acres reported area, about 27.1 million acres are brought under cultivation annually. Artificial irrigation both from the public and privately owned sources reaches a maximum of 21 million acres, leaving the rest about 6 million acres to be fed from the natural precipitation. About half of the area irrigated from the gravity flow system gets perennial supply and the other half is non-perennial. Both in the perennial and non-perennial sectors, existing water allowance is far below the optimum level, but due to extreme pressure on land, the farmer is forced to apply shallow irrigation, which is mainly responsible for the wide-spread incidence of salinity/alkalinity in the irrigated areas.

5. Even if the long range target of agricultural development was restricted to 27.1 million acres, the corresponding annual water requirements at the canal head, work out to about 189 MAF, for the existing cropping pattern at an intensity of 150%. Allowing for the 30% transmission losses, the water requirements, at the head of the water courses, come to about 132 MAF. Compared to this, the existing canal diversions reached a maximum of 54.15 MAF during 1968-69, which correspond to a discharge of 37.8 MAF at the watercourse head. Thus the gap between the maximum water availability in the canal system and optimum irrigation requirement measures up to 94 MAF at the head of watercourses. Some relief was available through public and private tubewells, but still this gap was too wide to be bridged within our limited water resources The position might slightly improve after Tarbela, but during the last three years, canal diversions reached a rock bottom figure of 41.72 MAF in 1971-72 (ending April 15, 1972).

6. Even for the existing culturable com-

manded area of about 21 million acres, the minimum scientific water requirements at the farm head, is about 63 MAF excluding additional supplies required for reclamation purposes. This figure will naturally go up proportionately, if the abandoned areas of Bahawalpur and area to be commanded by Greater Thal Project, Jalalpur Canal and Dajal Branch Extension are included. Keeping this requirement as the short-term target, planning efforts have to be organized within the available financial resources to generate more water supply and cut down as much of the transmission and farm losses as we possibly can, so that the actual deliveries to the farms could reach close to the crop requirements.

Limited Financial Resources

7. In most of the developing countries like ours, financial resources are the biggest constraint for the optimum development of the natural resources and consequently a sustained growth rate of economy. This makes the process of allocating funds to various sectors and within a sector to many equally important competing projects, highly complicated. Various criteria have been adopted in the past, and opinions differ about the development strategies, but one thing is certain that inadequate provision of funds for development programmes is as serious a hazard to the economy as shallow irrigation application to the agricultural land. This may help in taking up more and more of new development projects every year, but ultimately the cost of development is increased manifold depending upon the extension of the execution and gestation periods, without any improvement in the financial/economical/social benefits of the projects. This is clearly borne out by the post-project monitoring of completed projects.

8. In the planning procedures followed so far, the portfolio of schemes in the water sector is seemingly drawn up without keeping the target of ultimate development of irrigated agriculture in sight, and there is apparently no guarantee about the availability of adequate funds for their execution according to an optimum schedule of construction included in the P.C.I. forms of these projects. Most of these are conceived, planned, prepared and pushed up by the departmental functionaries on their own initiative and may or may not reflect the needs of the majority of the population of the area, and may or may not fit aptly into the integrated development of the area. In fact, this tendency of independent sectoral development exists in more or less all the sectors, whether physical infra-structural, social or productive.

9. This position is likely to remain unchanged, unless the emphasis was shifted from central and provincial Development plans to comprehensive Regional Plans, drawn up at Tehsil and District level. These plans should project estimates of manpower and material resources available within the region, short-term and long-term needs of the community, portfolio of development projects from various sectors duly integrated, to fulfil these needs, priorities for execution of various schemes and the corresponding requirements of funds. From the lower formation, these plans would travel up to a district and get integrated into a multi-sectorical district Development Plan and similar plans from all the districts would be merged into a provincial plan. However, to achieve this objective, local Planning Cells may have to be established at the corresponding levels who would draw up these plans in consultation with the elected representatives of these areas.

10. Another visible snag is, the adoption of a common PC I proforma for project costs and feasibility for schemes from all the sectors. Usually the compilation of these proformae in the departments is done at a level where the significance of transferring various elements of cost and benefits into economic indices cannot be appreciated. In this way, meaningful scrutiny of these projects at the level of Provincial and Central Development Working Parties becomes difficult. Another tendency has also been noticed that once a PC I proforma is approved, the physical phasing of the work as well as demand for the funds during a particular year for the execution of the projects are made quite independently of the approved provisions of the PC I proforma. Partly this situation has arisen because of the inadequacy of resources, so the demand is tailored according to the possible availability of funds. Nevertheless there was need to do something about it, because all the ongoing projects in the water sector are lingering on for years together beyond their projected dates of completion and in some projects, such as tubewells for instance, the economic life of the project facilities is considerably reduced by long delays in energization of the completed tubewells. This not only upsets the ultimate cost-benefit ratios but invariably increases the recurring and non-recurring annual charges which totally tarnish the economic picture of the completed projects.

Development Programme in the Punjab

11. Between 1960 to 1970, all meaningful development in the province almost came to a halt as the resources of money, men and material were committed to the completion of replacement works under Water Treaty. Only a few reclamation and drainage projects were started and the pace of ongoing projects such as Thal and Taunsa Barrage was appreciably retarded.

12. During the Third Plan period, it was estimated that after 1970, when all the replacement works except Tarbela would have been completed, more funds might become available for system addition and improvement. Accordingly a minimum requirement of Rs. 35 crore were worked out for the execution of irrigation schemes by the provincial Irrigation Department during 1970-1975. Due to abnormal circumstances and unforeseen calamities, however, the actual availability of funds was far too less. Against an average annual requirement of Rs. 7 crore, hardly Rs. 5.6 crore became available during the first two years of the current Plan period and hence the planning activity in the Province was restricted to apply repeated cuts to the ADP size and to find out the barest minimum requirement of funds for various ongoing projects.

13. During 1972-73, Department proposed an optimum programme for about Rs. 9 crore, which was reduced to Rs. 5.6 crore on no other consideration than the non-availability of adequate financial resources. The break-up of the ADP 1972-73 for various sub-sectors is given below :—

Name of the Sub-Sector		Allocation (in million)
1. Surveys and Investigation	..	2.00
2. Irrigation Schemes	..	31.50
3. Drainage and Reclamation	..	17.10
4. Flood Regulation	..	3.00
5. Miscellaneous	..	2.40
Total	..	56.00

14. The above provisions have been made in the light of the following strategy for development during 1972-73.

I. To ensure maximum conservation and optimum use of scarce water resources, investigations have to be carried out/completed for projects particularly those in the comparatively more backward areas.

II. Completion of ongoing schemes particularly those in the relatively backward areas. Maximum emphasis is being laid on the completion of badly delayed tubewell projects and energization of almost all the tubewells installed so far during 1972-73.

III. The tubewell development in the sweet water zone would not be undertaken in the public sector and farmers would be encouraged to instal their own private tubewells through subsidies and other incentives.

IV. Backward areas to receive special consideration both in case of ongoing as well as new programme. More and more emphasis is to be laid on the development of these areas in future and therefore concerted efforts have to be made, not only to execute the schemes already in hand but also more and more schemes have to be investigated and planned for these areas.

V. A reasonable provision has been made for the execution of ongoing surface drainage projects.

VI. Maximum use of local talents, machinery and labour will be ensured and external elements in any form or manner to be kept, if highly essential, to the barest minimum.

15. Major schemes included in the development programme for 1972-73 in various sub-sectors are briefly described as under :—

(*i*) *Surveys and Investigation.* A provision of Rs. two million is meant to cover the expenditure on surveys and investigation for schemes in the backward area, basic and applied research and channel regime observation. If this provision falls short, more money has to be diverted by readjustment. In addition to the programme already in hand new avenues pointed out by the elected representatives from backward areas have also to be explored.

(*ii*) Provision of Rs. 31.5 million for irrigation schemes is meant to cover expenditure on the following schemes:

Name of Scheme	ADP Provision 1972-73	Estimated cost (Rs. in million)	State of completion	Area to benefit on completion/ Remarks. [Estimate only]
1	2	3	4	5
Thal Project	3.00	154.5	96%	1.85 million acres in Mianwali, Muzaffargarh and Tehsil Khushab of Sargodha District.
Taunsa Project, Units I, II & III.	3.00	258.3	88%	1.8 million acres in D. G. Khan and Muzaffargarh District.
Bakht Extension projects	1.00	4.9	55%	0.1 million acres in the district of Mianwali.
Reopening of abandoned areas on Sadiqia Bahawal and Eastern Sadiqia Canal.	1.5	13.9	Ground, breaking during 1971-72	0.185 million acres in Bahawalpur Division.
Greater Thal Projects	3.6	143.2	...	1.57 million acres in the districts of Sargodha, Mianwali and Muzaffargarh.

Name of Scheme	ADP Provision 1972-73	Estimated cost (Rs. in million)	State of completion	Area to benefit on completion/ Remarks. [Estimate only]
1	2	3	4	5
Silt Ejector on D. G. Khan Canal	2.67	2.67	To be completed during 1972-73	The entire command of D. G. Khan canal would benefit because the silt entry will be reduced and carrying capacity of the channel restored to its original design.
Dajal Branch Extension	1.00	68.6	..	An additional area of 0.4 million acres in D. G. Khan would benefit on the completion of this project.
15-R Distributary on Upper Jhelum Canal	0.5	1.3	Completed	The scheme was completed long ago. Provision has been made to pay land compensation for the area acquired for this project.
Lift Irrigation scheme on former Grey Canal-Eastern Sadiqia Canal	1.5	4.8	Ground breaking during 1971-72	0.640 million acres in Bahawalpur Region.
Mianwali Lift Irrigation Schemes	0.5	5.6	85%	5,790 acres.
For completing/installation of 128 tubewells	3.4		..	Provision of Rs. 3.4 million has been made to complete all the ongoing tubewell projects. The number of tubewells involved is about 128.
Energization of 216 completed tubewells	4.00	4.00		216 tubewells would serve an an area of about 60,000 acres, out of which 20,000 acres lie in Bahawalpur Region.
Other small schemes	5.80			
Total	31.5			

(*iii*) *Drainage and Reclamation.* A provision of Rs. 17.1 million has been made for drainage and reclamation projects which on completion would provide drainage facilities to about 1.8 million acres. Major schemes of this sub-sector are as under :—

Name of the scheme	Allocation (in million)
1. Satiana-Samundri Drain ..	3.40
2. Raiwind Drain ..	2.00
3. Sukrawa Drain ..	1.50
4. Rechna Outfall Drain ..	1.00
5. Hudiara Drain ..	0.80
6. Chakbandi Drain ..	0.80
7. Pandoki Drain ..	0.70
8. Satto-Kotla Drain ..	0.65
9. Thal Area Drain ..	0.6C
10. Construction of link watercourses in Scarp-II area ..	2.18
11. Repair equipment ..	0.35
12. Subsidy on private tubewell sinking ..	1.50
13. Miscellaneous ..	1.62
Total ..	17.10

(*iv*) *Flood Regulation.* A provision of Rs. 3 million has been made in this sub-sector to cover the cost of reconstructing damaged syphon on B.S. Link, protection of Rohri bund etc.

(*v*) *Miscellaneous.* A provision of Rs. 2.4 million has been made for miscellaneous items essentially required to improve the operational aspects of the irrigation system. During the current year, major activities under this sub-sector include the reorganization of Irrigation Research Institute and construction of residential non-residential buildings throughout the irrigation system.

WAPDA's Water Programme for Punjab

16. Due to paucity of funds, no new development projects could be taken up in the Province of Punjab in the Wapda programme and adequate provisions could not be made even for the completion of badly delayed on-going SCARP programme. This programme was drawn up by WAPDA during 1959, following preliminary investigations and surveys of the menace of water-logging and salinity, which had assumed an alarming dimensions by then. Initially this programme included the construction of some 27,000 tubewells for irrigation-*cum*-drainage purposes and about 3,500 tubewells purely for drainage, in addition to about 6,000 miles of surface drains at a total cost of Rs. 2210 million. The first major project under this programme namely SCARP I was commissioned in March. 1963 with 2,041 tubewells to serve a total area of 1.21 million acres and to reclaim an area of 0.425 million acres. Subsequently, SCARPS II, III and IV were also taken up in Chaj, Lower Thal and Rechna Doab. In view of the high capital investment into these projects, the Government of West Pakistan and later Government of Punjab kept these projects under constant review and evaluation. As a result of this, the following tentative findings have been thrown up :—

(1) Public tubewells, though claimed to be superior in technical specification, are much costlier than private tubewells on comparable basis. Much of the extra cost arose from the possibly avoidable use of expensive foreign consultants, contractors and material.

(2) Public tubewells involve huge recurring and non-recurring subsidy since receipts from the reclamation fee and water rates cover only a small proportion of non-recurring and recurring costs.

(3) A large number of operational problems have been created by SCARP tubewells, which make the optimum utilization of the installed capacity very difficult, if not impossible.

(4) Large sized SCARP tubewells have been over-efficient in lowering the water table too quickly; if the present rate of pumping is maintained, water table may drop so low as to affect the working of private tubewells adversely.

(5) Cropping intensity was anticipated to rise to an average of 150% from the pre-project average of about 75%; actually it rose to 108.9% only in SCARP I; on the whole 120% is considered attainable in the SCARP areas. Contrary to this, the cropping intensity already achieved in the areas of private tubewells concentration is about 150% according to a report made by M/s T & K of WAPDA.

(6) The operational life of SCARP projects was over-estimated to be 40 years; actually it has turned out to be only 10 to 12 years.

(7) Salinity/alkalinity hazards were under-estimated in the project areas during planning as well as execution stages. Therefore,

for a large number of tubewells, canal water was not available in adequate quantity for mixing purposes, with the result that either these tubewells had to be totally abandoned or operated for restricted time or converted into purely drainage wells.

(8) The rate of salt intrusion into the so-called sweet water zone has been faster than anticipated. This is so, as either the tube-wells are located in the sweet water zones only to the exclusion of saline areas, or the tube-wells located in the saline areas have been abandoned. This has led to sharp gradients from saline water table to that in the sweet water zone causing rapid salt intrusion.

(9) Due to excessive delays in the completion of these projects caused by a time lag of 3 to 5 years between the installation of tubewells and their energization, these projects have not only been over-capitalized, but even the life of project facilities has been reduced. Within 10 years between 1962 to 1972, only 4,775 tubewells were installed in SCARPs II, III & IV. Out of these, hardly 3200 tubewells have been energized giving an average of 320 tubewells per annum and the remaining about 1600 tubewells are proposed to be energized during 1972-73. Against this meagre average of 320 tubewells, the number of private tubewells, both diesel and electric, commissioned annually have exceeded even 10,000 in some years. Thus large public funds remain locked up in these public tubewells for years together without any productive gains.

ANNUAL DEVELOPMENT PROGRAMME, 1972-73 (WAPDA)

17. An amount of Rs. 100 million has been allocated to cover WAPDA's Water Programme for the Punjab, which has the following features :—

Name of the Scheme	ADP Provision (in million)	Remarks
1	2	3
1. General Investigation	4.00	Continuation of surveys and investigations on the schemes such as Chashma Right Bank Canal, Sailaba area, Tarbela Left Bank Canal, Post-Tarbela works, dam/diversion weir over Sangha Nullah in D. G. Khan and usual water and soil investigation studies throughout the Province of Punjab.
2. SCARP-II	42.2	The provision will cater for the energization of 560 tubewells.
3. SCARP-III	34.3	The provision will cater for energization of 810 tubewells.
4. SCARP-IV	18.7	The provision will cater for the energization of 150 tubewells.
MONA	0.8	This is an ongoing project and it would continue experimental research for the benefits of reclamation projects being executed all over West Pakistan.
Total ..	100.0	

Looking into Future

18. Following sources can be tapped to augment irrigation supplies in future :—

(*a*) A series of big and small dams. Ample provision must be made not only to undertake surveys and investigation for new dam sites and detailed exploration of already known potential sites, and construction of the same but for extensive research to find out ways and means other than already known methods of watershed management, to prolong the effective life of the dams under conditions obtainable in our country also.

(*b*) Encouragement of private, diesel/electric wells by granting subsidy and liberal credit facilities, in the sweet water zones not exploited so far, particularly to the small landholders who group up into co-operative units. All components of the tubewells being manufactured in Pakistan should be standardized so that their specifications are at par with International standards.

(*c*) Deficiencies in the supply of electric supply/diesel should be removed effectively and permanently. A series of Tubewell repair/rehabilitation workshops should also be set up throughout the province to help tubewell owners.

(*d*) Proper education and encouragement of the private farmers to level their lands, straighten their water-courses and in sandy reaches where conveyance losses are high, to line their watercourse, particularly when the sub-soil water was brackish. Through People Works Programme, proper motivation can be provided to the farmer for utilizing his surplus resources of labour and material for his own as well as national good.

(*e*) By way of research, to find out the exact amount of seepage losses in the water courses/channels, efficiency, cost and economic life of various types of lining under our field conditions; about 100 watercourses should be lined in the sandy areas with brackish water table during 1972-73.

The results achieved must be honestly compared with the existing conditions, to publicize the use of the most economical type of lining by the irrigators in future for their watercourses.

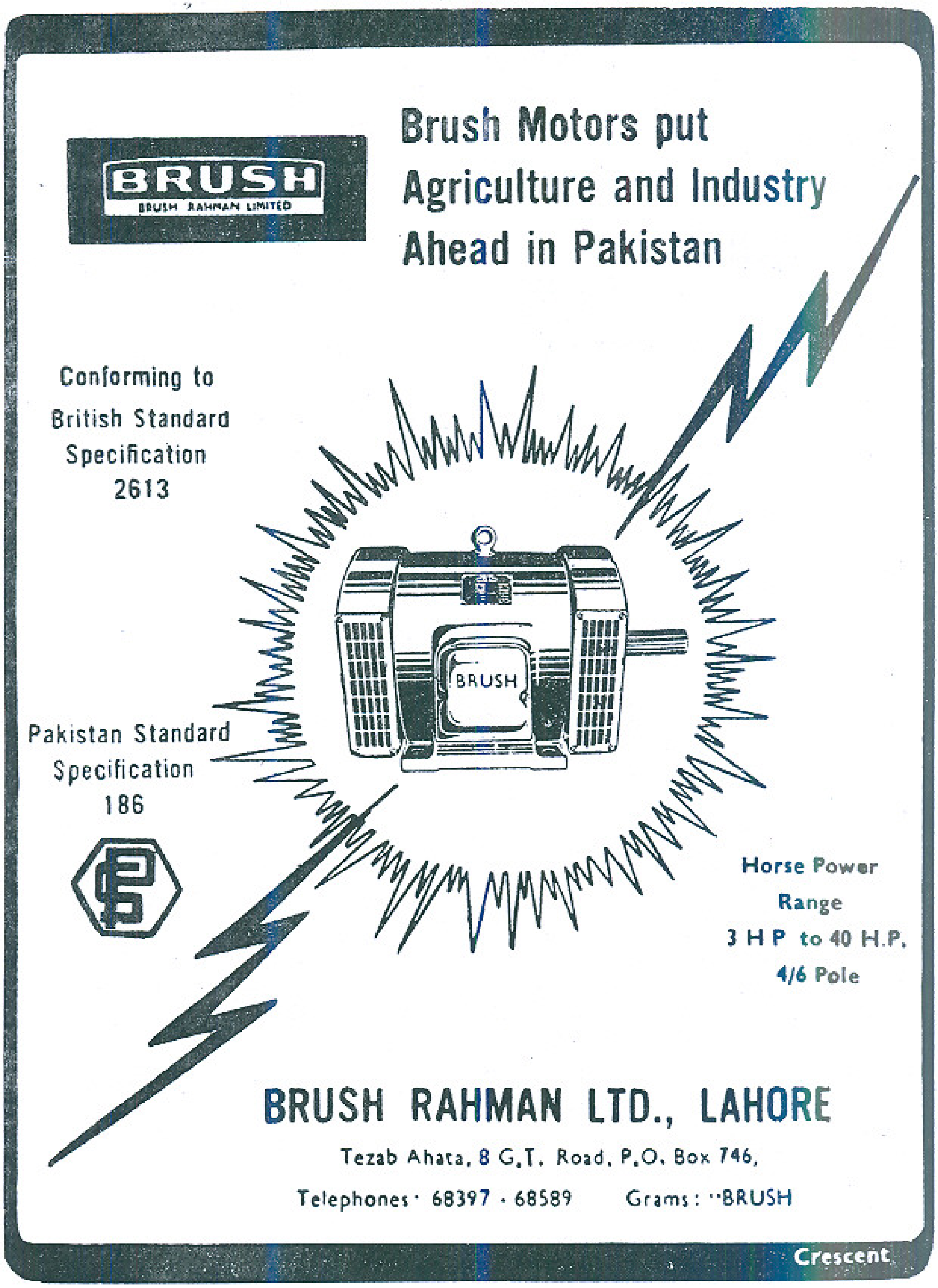
(*f*) The process of land consolidation and settlement are time consuming. Some arrangements must be designed to expedite the completion of these operations within the shortest possible time. Consolidation of holdings and its rectagulation are quite helpful in economical water managements.

(*g*) Drainage in the saline areas must be taken up through vertical/horizontal drains depending upon the conditions of each location. This is extremely essential to avert the hazards of salt intrusion into sweet water zone, accelerated by the operation of scarp tubewells in the so-called sweet water zones.

(*h*) More Indus water should be diverted to Saline/Alkaline areas by the construction of Trans-Punjab Link and remodelling the existing irrigation network as and where essential, so that adequate water of good quality was available for leaching and Reclamation purposes in these areas.

(*i*) To undertake arid zone research and research on the crop seasons, with a view to shorten their length and stagger the peak water demand periods of main Kharif and Rabi Crops by changing their sowing as well as maturing time schedules, without affecting their yield/acre.

(*j*) Serious efforts have to be made to rehabilitate fertile lands badly eroded in the districts of Jhelum, Rawalpindi and Campbellpur, through latest soil conservation techniques and levelling of the heaps and mounds through a combined effort by man-power and machinery.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Sedimentation in Rawal Dam

By S. M. AYOOB

Water Resources and its proper utilization is of paramount importance for Pakistan's Agricultural based economy. Storage of surface water is being done and utilized even in the form of small dams of varying capacities. The main problem in storages is the deposition of silt, which progressively decreases the live capacity. Determination of underwater topography by utilizing Echo sounding techniques after regular intervals gives the actual deposition and actual trends in reducing the capacity of Dam can be interpreted and actual life can be very well correlated with the theoretical computations.

This technique can be successfully utilized for all storages.

INTRODUCTION

Rawal Dam was constructed across Korang River to supplement the irrigation and domestic requirements of the Rawalpindi area. The shifting of capital of Pakistan to Islamabad has enhanced its importance. The storage of water was commenced in 1960 and the Dam was formally inaugurated in May, 1962. It is a well known saying that the death of reservoir starts the very first day it is born, as the sedimentation starts immediately with the inflow. A hydrographic and sedimentation survey was conducted in 1966 to estimate the magnitude of sediment deposition during the first six years of storage. Sediment deposition appeared to be significant and recommendations were made to conduct such surveys after every three years. The second survey was carried out in 1969 and the third survey was conducted in March, 1972. Echo sounding technique was utilized to determine underwater topography during the last two surveys.

The results of the third survey conducted in March, 1972 have been utilized in this paper. It gives an appraisal of annual rate of sediment deposition, nature of deposits and the capacity depleted at various elevations during the 12 years of impounding.

Run off of the Catchment Area and Inflow of the Rivers

Rains are the main source of the discharge of Korang river which is the main distributary of the reservoir. With the advent of summer the snow from the higher altitudes begin to melt and some discharge is contri-

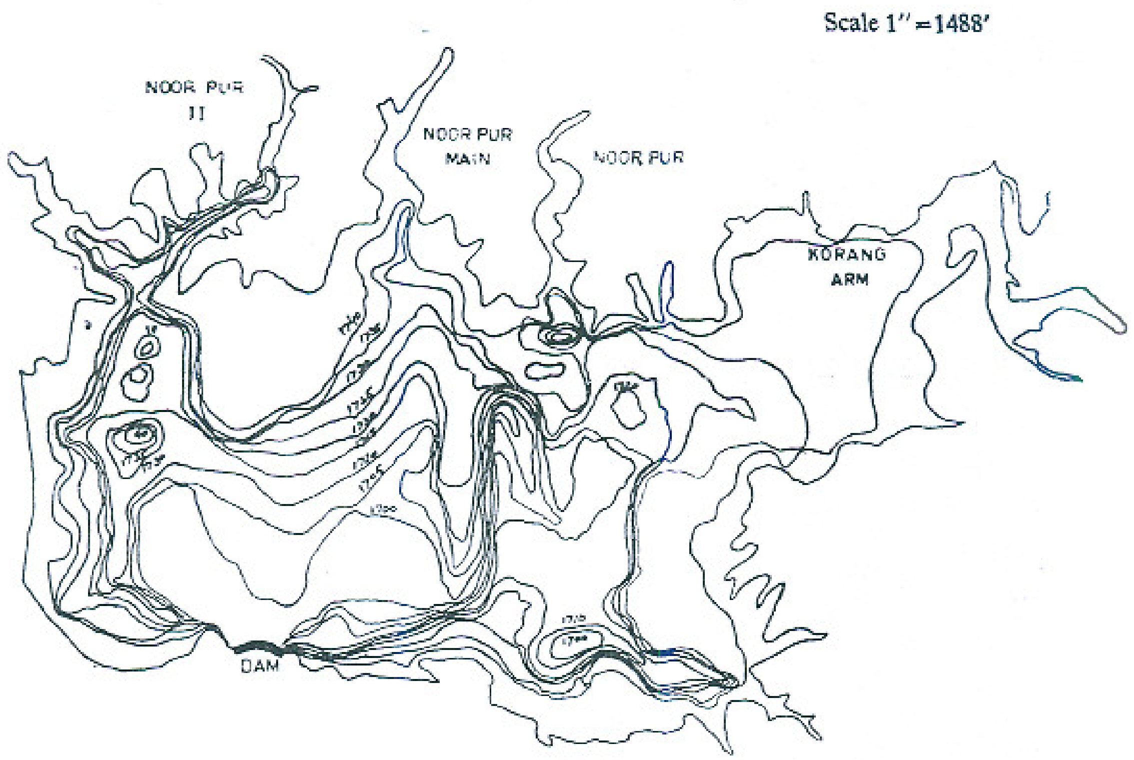

Fig. I. Rawal Lake surface area 3.2 sq. miles bed contours in March, 1972.

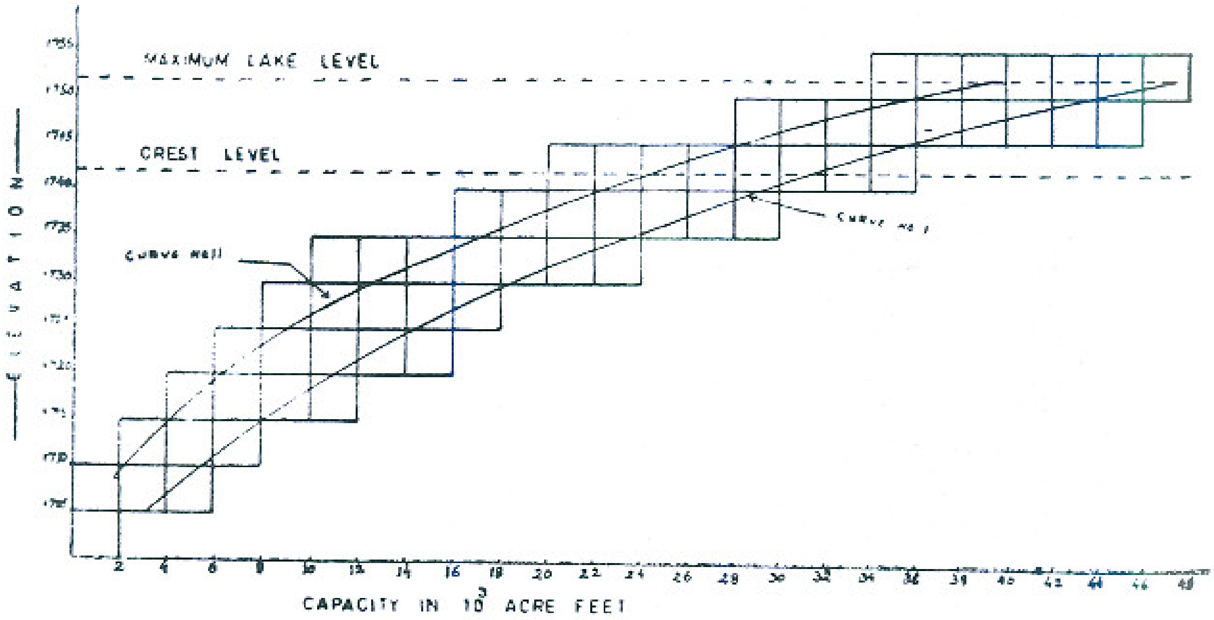

Fig. II. Reservoir capacity curves-curve No. I. Pre-storage curve No. II. March, 1972.

buted. The major rainfalls contribute more than half the yearly flow which is stored for use during the other months. The supplies from the other distributary—Nurpur Shah Nullahs are mainly of the rainy season. The perennial flow of the Korang is only 3 to 6 cusecs. The winter flow is mainly due to seepage. Efficient recording of the lake elevations is maintained from the gauge fixed with the main Dam.

The slope of both the streams is very steep. They are flashy in nature. Discharge measurements have never been undertaken. Even for the feasibility study of the project, the estimate of run-off had to be made from rainfall records from the year 1927 to 1958 of Murree and Rawalpindi. The total average yearly discharge was estimated as 84,000 A. Ft. During 1957 actual measurements were made and the run-off was found to be 70,322 A. Ft. Discharge observations at suitable sites is very essential.

Sedimentation

The useful life of the reservoir depends on the rate at which silting takes place and the mode of its operation. The storage capacity is lost because of the deposition of sediment brought by the streams.

Reservoir sedimentation is a complex process and depends on many factors. In estimating the capacity of a reservoir, it is not only the quantity of sediment deposition that is important but also the mode and place of its deposition. Major factors that influence the mode of sediment deposition in a reservoir are shape of the reservoir, reservoir operation and sediment-reservoir volume ratio. As a result of these various factors, sediment deposits reduce the capacity of the reservoir at all levels.

The beds of the Korang and Noorpur Nullahs are predominantly composed of sand, gravel and boulders in the upper reaches while sand and gravel are found in the lower reaches. At the entrance of these streams in the lake and at the main lake the bed material is composed of clay, silt and sand. The finer material is deposited near the spillway. To determine the quantity of the deposited sediment, bed samples were collected with the help B. M. H-60 sampler from all over the bed of the lake. The samples were analysed in the laboratory and the proportion of sand, silt and clay were determined. The analysis of the samples along with location of sampling is given in Table No. I.

The samples were collected from the main dam at all the range lines. The results show that near the spillway the percentage of clay is about 60 and this percentage decreases as we proceed upstream and the percentage of silt and sand increases.

The bed samples collected from the Korang show that the proportion of coarse material further increases as we proceed upstream from the periphery of the main lake. This condition exists up to the range line 130-115 and beyond it is all gravel.

The conditions in Noorpur Nullahs are different. The percentages of clay, silt and sand range between 10-50%, 9-72% and 5-80% respectively. This shows that Noorpur Nullah brings more fine material than the Korang. In general it is evident that fine material is being deposited in the main lake and the coarse material is dropped at Korang Arm. Since Noorpur Nullah as mentioned above brings greater quantity of fine material, the Noorpur triple arms show deposition of fine material as well as coarse material.

TABLE No. I.—*Mechanical Analysis of Bed Samples.*

S. No.	Range Line	Description	% Sand Coarse & Medium	% Fine Sand	% Silt	% Clay
1	2	3	4	5	6	7
1	3—25	Main Dam	9.4	2.8	31.9	55.9
2	2—27	,,	0.8	12.7	25.4	61.1
3	1—54	,,	6.6	15.4	18.0	60.0
4	0—56	,,	3.6	16.5	19.3	60.6
5	58—159	,,	0.6	21.5	26.0	51.9
6	63—158	,,	3.2	20.1	32.3	44.4
7	77—157	,,	5.8	18.0	31.3	44.9
8	80—156	,,	0.8	5.4	48.8	45.0
9	82—155	,,	0.3	15.9	56.0	27.8
10	84—153	,,	0.6	3.4	52.8	43.2
11	85—152	,,	9.8	8.3	52.2	29.7
12	92—151	,,	10.5	7.9	55.7	25.9
13	94—148	,,	10.3	26.9	42.9	19.9
14	96—147	,,	5.7	20.1	54.2	20.0
15	98—145	Korang	3.1	29.8	47.7	19.4
16	101—143	,,	1.2	16.9	56.1	25.8
17	103—141	,,	8.7	31.9	42.7	16.7
18	105—139	,,	76.1	13.2	3.2	7.5
19	106—136	,,	70.4	13.9	9.7	6.0
20	107—134	,,	92.3	0.3	2.4	5.0
21	108—133	,,	26.1	17.7	48.8	7.4
22	109—132	,,	20.4	18.4	43.7	17.5
23	110—131	,,	23.8	20.5	42.9	12.8

1	2	3	4	5	6	7
24	111—130	Korang	80.8	10.7	4.0	4.5
25	130—112	,,	91.9	4.1	1.8	2.2
26	130—112	,,	88.7	5.1	4.0	2.2
27	130—115	,,	68.0	0.9	14.6	16.5
28	121—122	,,	GRAVEL			
29	17—53	Nurpur-2	0.6	15.4	40.3	43.7
30	18—52	,,	8.7	3.1	30.7	57.5
31	18—22	,,	7.0	2.2	41.8	49.0
32	19—26	,,	13.3	11.8	28.9	46.0
33	20—25	,,	1.4	8.8	35.3	54.5
34	28—51	,,	0.2	5.1	46.5	48.2
35	29—30	,,	0.5	6.1	40.4	53.0
36	31—50	,,	0.8	25.6	33.6	40.0
37	31—49	,,	0.4	13.5	43.6	42.5
38	35—48	,,	1.5	35.1	32.6	30.8
39	36—47	,,	0.7	36.8	30.6	31.9
40	37—46	,,	17.2	31.6	12.6	38.6
41	59—82	Nurpur-Main	4.2	7.1	64.9	23.8
42	60—81	,,	5.1	33.2	42.9	18.8
43	61—80	,,	29.2	36.6	22.9	11.3
44	63—79	,,	50.7	30.3	9.0	10.0
45	65—77	,,	3.5	37.5	40.2	18.8
46	67—76	,,	17.2	30.3	36.8	15.7
47	68—75	,,	59.2	18.1	12.0	19.7
48	85—92	Nurpur-1	0.2	5.0	72.7	22.1
49	86—91	,,	1.0	17.8	58.9	22.3
50	87—90	,,	0.5	14.2	62.8	22.5

Suspended sediment samples were also collected from various levels in the lake up to 2-5 ft. from bed with a special type of sampler designed for taking samples at required depth from a reservoir. These were analysed in the laboratory, to determine the following sizes:

1. Above .177 mm.
2. Between .177 mm and .062 mm.
3. Between .062 mm and .005 mm.
4. Below .005 mm.

The results are given in Table No. II. The proportions are expressed in parts per million.

Two samples were taken from the middle of the main lake at range lines 158-63 and 159-58 from a depth of 40 ft. below the surface of the lake. The depth was recorded by depthometer. The total sediment concentration is 108 PPM and 112 PPM respectively.

The total concentration of the samples collected from the range line 132-109 is 140 PPM. This range line is at the entrance of the Korang into the lake. The sample was taken when practically there was no flow in Korang. This is the maximum concentration found in the samples collected

TABLE No. II—*Analysis of Suspended Sediment Samples.*

S. No.	Range Line	Location	Depth in ft.	Sediment in PPM. Above .177 mm	Between .177 & .062mm	Between .062 & .005mm	Below .005mm	Total	Dissolved Contents PPM.
1	158—63	Main Lake	40	Nil.	Nil.	30	70	100	200
2	159—58	,,	40	,,	,,	40	72	112	200
3	2—22	Main Dam	25	,,	,,	29	77	106	200
4	130—112	Kurrang	5	,,	,,	30	73	103	200
5	132—109	,,	5	15	50	28	47	140	300
6	105—137	,,	8	Nil	Nil.	26	52	78	250
7	95—92	Noorpur Main	15	,,	,,	24	57	81	250
8	63—79	,,	8	,,	,,	24	52	76	200
9	68—75	,,	..	,,	,,	24	47	71	250
10	65—77	,,	..	,,	,,	23	60	83	200
11	37—46	,,	8	,,	,,	23	68	91	200
12	59—82	,,	4	,,	,,	26	60	86	200
13	86—91	Noorpur-1	15	,,	,,	24	52	76	200
14	17—53	Noorpur-2	25	,,	,,	25	63	88	200
15	29—30	,,	15	,,	,,	26	69	95	200
16	35—48	,,	12	,,	,,	28	67	95	200
17	18—22	,,	12	,,	,,	22	68	90	200
18	Left bank canal			,,	,,	21	42	63	200
19	Right bank canal			,,	,,	26	42	68	200

at different points. The total concentration at other sites range between 71 and 112 PPM. The detailed analysis is given in Table No. II.

The results show that the quantity of suspended sediment is quite low and that all the sediment is deposited in the lake. Although there is no data of sediment concentration in the water flowing into the lake yet from analysis of samples collected from the bed of the reservoir and the rate of silting, it is evident that the total concentration must be quite high.

One sample each was collected from the two canals offtaking from the reservoir at R. L. 1708. Total concentration in the right canal is 68 PPM and in the left canal it is 63 PPM. It means at this time of the year suspended when there is no inflow sediment concentration in the reservoir is very low and negligible quantity of sediment is carried by the two canals.

At present there are no arrangements of silt sampling of the tributaries and without this data it is difficult to arrive at some accurate estimation of sediment transport in the reservoir. Arrangements must be made to collect samples especially during Monsoon period. If the suspended sediment is known from the data collected, the bed load can also be computed from it.

HYDROGRAPHIC SURVEY

Under water topography was determined by detailed sounding of the lake bottom by utilizing Echo Sounding Techniques. The echo sounder used is a transistorised portable type Ray Jafferson Depthometer with two ranges 0-12′ and 0 to 120′. It operates at a fixed accoustic frequency of 185 killocycles.

A 16 ft. long 5 ft. wide aluminium boat equipped with a suitable out board engine was used for the survey. The boat was moved at a constant speed from one end of the range line to the opposite end. Each range line is provided with concrete pillars at ends. The water level in the reservoir at the time of observations was lower than the maximum level and so the dry portion from each pillar to water edge was measured. The difference between the total distance and the dry portion gave the length for which recording was made. The Echo Sounding recorder graph data was plotted for each range line.

Contour Map

The reservoir has 71 fixed cross-sections which are about 1000 ft. apart in the main lake and 500 ft. apart in the remaining zones. At the site 4″×4″ concrete pillars have been constructed along the periphery of the lake to mark the ends of the range lines.

The data from the recording graphs was used to draw the contours of the bed of the lake with 5 ft. interval, starting from the lowest contour of 1700 up to the contour of 1740. The contour map is shown in Fig. I.

The contour map shows that small depressions and ridges exist in the bottom of reservoir. The bed of the lake seems to be regularly sloping.

Area and Capacity

To compute the capacity of reservoir, areas lying between the contours was found with the help of planimeter. The capacity for each 5 ft. contour interval was calculated starting from the contour of 1700 up to R. L. 1740. The total capacity at each contour interval was determined by adding capacities at the lower contours. The present capacity (March, 1972) was determined up to R. L. 1740 as water level of the reservoir at the time of survey was at R. L. 1741. The capacity above R. L. 1740 was taken from the results of survey conducted in 1969 and the pre-storage capacity determined by topographic survey. Thus the capacity up to maximum lake level R. L. 1752 was estimated by adding the pre-storage and 1969 capacity above R. L. 1740. The capacity above the water level should have been determined by ground survey. Since this was not within the scope of the Echo Sounding survey the only alternative was to resort to pre-storage capacity. The deposition takes place at all elevations when the lake level is at the maximum elevation and therefore deposition above R. L. 1740 may be estimated and the total storage capacity above this elevation corrected. The integrated capacity at each elevation is given in Table No. III. Pre-storage capacity is also given in the Table. Fig. II shows the two elevation capacity curves for the pre-storage and the present capacity.

The pre-storage capacity of the reservoir up to R. L. 1710 was 5355 A. Ft. and up to R. L. 1740 was 29699 A. Ft. The pre-storage capacity at the crest of the dam at R. L. 1742 was 32120 A. Ft. with 10 ft. high gates installed on the top of spillway crest the gross-storage capacity increased to 47500 A. Ft. This capacity is at R. L. 1752.

The present capacity at R. L. 1710 is 2198 A. Ft. which means a total sediment deposition of 3157 A. Ft. in about 12 years. It is equal to about 265 A. Ft. per year. Dead-storage of 5355 A. Ft. has been provided upto R. L. 1710.

The capacity up to the crest of the dam at R. L. 1742 has reduced from 32120 A. Ft. to 24440 A. Ft. The pre-storage capacity of full reservoir *i.e.* at R. L. 1752 was 47500 A. Ft. and the new capacity on the basis of present survey is computed as 39475 A. Ft.

TABLE No. III

Elevation Capacity Table.

Elevation	Pre-Storage Capacity in acre ft.	Present Capacity in acre ft.
1705	3325	..
1710	5355	2198
1711	5750	2480
1712	6250	2800
1713	6750	3200
1714	7250	3600
1715	7815	3890
1716	8375	4250
1717	8945	4650
1718	9625	5180
1719	10250	5610
1720	10805	6040
1721	11500	6580
1722	12167	7080
1723	12875	7620
1724	13667	8200
1725	14355	8925
1726	15000	9560
1727	15875	10200
1728	16667	11000
1729	17500	11790
1730	18435	12750
1731	19250	13400
1732	20250	14400
1733	21325	15200
1734	22509	16180
1735	23780	17335
1736	24688	18200
1737	25875	19200
1738	27250	20300
1739	28625	21400
1740	29699	22325
1741	30970	23400
1742	32120	24440
1743	33500	25700
1744	34813	26380
1745	36258	28515
1746	37875	29700
1747	39500	31000
1748	41250	32540
1749	42750	34200
1750	40224	36445
1751	45875	38500
1752	47500	39475

i.e. about 8025 A. Ft. of sediment has accumulated in the reservoir at the rate of 670 A. Ft. per year during the last 12 years.

Progressive deposition of sediment reduces the trap efficiency of the reservoir. The rate of silting decreases as the bed rises. This is evident from the results of the survey conducted so far. Gross, dead and live storage capacities determined at different times along with existing capacities are given in Table IV.

TABLE IV—*Rawal Lake Storage Capacities.*

	Dead Storage		Live Storage	Gross Storage
Original Capacity 1960	R. L. 1708 R. L. 1710	4500 A. ft. 5355 ,,	R. L. 1752-1710 42145 A. ft.	47500 A. ft.
Capacity on 1st Survey 1966 ..	R. L. 1710	2454 A. ft.	38933 A. ft.	41387 A. ft.
Capacity on 2nd Survey 1969 ..	R. L. 1710	2237 A. ft.	37993 A. ft.	40230 A. ft.
Capacity on 3rd Survey 1972 ..	R. L. 1710	2198 A. ft.	37277 A. ft.	39475 A. ft.
% loss detected on 1st Survey ..	54		8	13
% loss detected on 2nd Survey ..	58		11	15
% loss detected on 3rd Survey ..	59		12	17

Suggestions

1. Daily discharge at suitable sites on the river Korang and Noorpur Shah Nullahs be observed and the flood flows may be specially recorded. It will be better if automatic gauge recorders are set up on these streams.

2. Arrangements may be made for occasional silt sampling to determine the sediment load transported by the streams. Sediment observations during flood flows should be made regularly. This will help in estimating the sediment deposition directly.

3. Ground survey may be conducted of the area above the water level so that estimate of sediment deposit at these elevations may be made.

4. The management of the water shed may be undertaken to improve the land cover and to increase the afforestation. Various water shed improvement projects in operation may be given serious attention, so that the purpose for which they were undertaken is achieved to the maximum extent.

5. There should be maximum co-ordination between the various departments responsible for one aspect or the other of the above project. For example the Irrigation Department maintains and operates the reservoir, the Forest Department is responsible for the aforestation in the catchment

area, and the Agriculture Department is responsible for the Agricultural activities and land conservation measures. The co-operation of these departments can lead to greater benefits and help in enhancing the life of the Rawal Reservoir.

6. Measures for reducing of evaporation losses from the surface of the lake may also be undertaken.

ACKNOWLEDGEMENT

The author is thankful to Rese rch Team of Hydrology and Groundwater Section for successfully carrying out the fall and laboratory work.

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Buildings and Highways Section

Vertical Media-Slow Sand Filter

SAEED MEHTAB BUTT,
M.Sc. (Civil Engg.) USA.

In places where nature has blessed human being with potable water, either on the surface or under the sub-soil, the community is prosperous, contented and healthy. But it does not mean that if nature has deprived any part of the world of potable water, the area there is doomed. The man with observation and experiment has developed methods, for filtration of muddy water and even for desalination of sea-water. This paper is an introduction towards another economical process of filtering the raw water into clear and usable.

The filtration of the raw water has been done by two methods, *i.e.*, conventional type and Russian type. The conventional method has been adopted and developed in Europe for the filtration of muddy water by subjecting the water on the top of the filtring media which is generally sand of different grades and stones, as shown in Figure No. 1. On the contrary, the Russian way of filtration differs in a way of supplying raw water from the bottom of the filtring media, as shown in Figure No. 2, and getting clear water from surface of the filtring media. In either case, sedimentation is the primary requirement of filteration, without which not only the efficiency of filtration bed is affected but it becomes almost impossible to get any yield. Therefore, the system becomes expensive and subsequently less beneficial for the small community.

The author has, therefore, put some research on a new way of filtering raw water without any sedimentation. A prototype vertical media filtration bed, as shown in Figure No. 3, was constructed at Lyallpur. Perpetual experiments were performed and quite favourable results for the filtration of the raw water of Rakh Branch Canal, Lyallpur, have been obtained.

The salient features of the vertical media filter are as under :—

(*i*) The vertical type filter is different from conventional type in the sense that instead of settling raw water and then subjecting it to the filtring media, it is directly brought into contact with the filtering media resulting in the reduction of the water works area and subsequently in its capital cost.

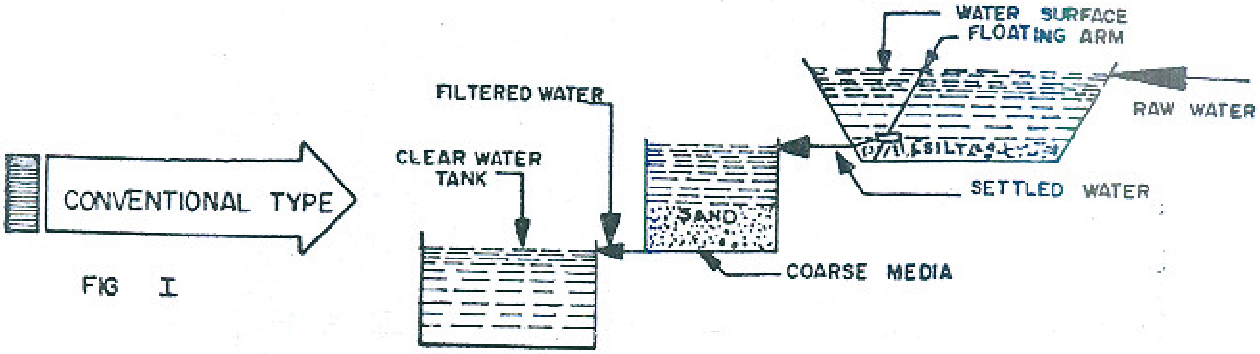

Fig. 1. Sand Stone Filter

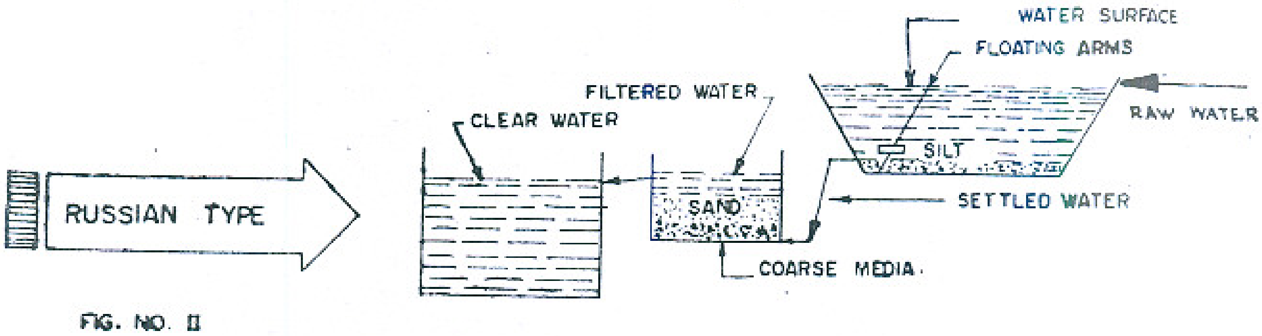

Fig. 2. Sand Filter.

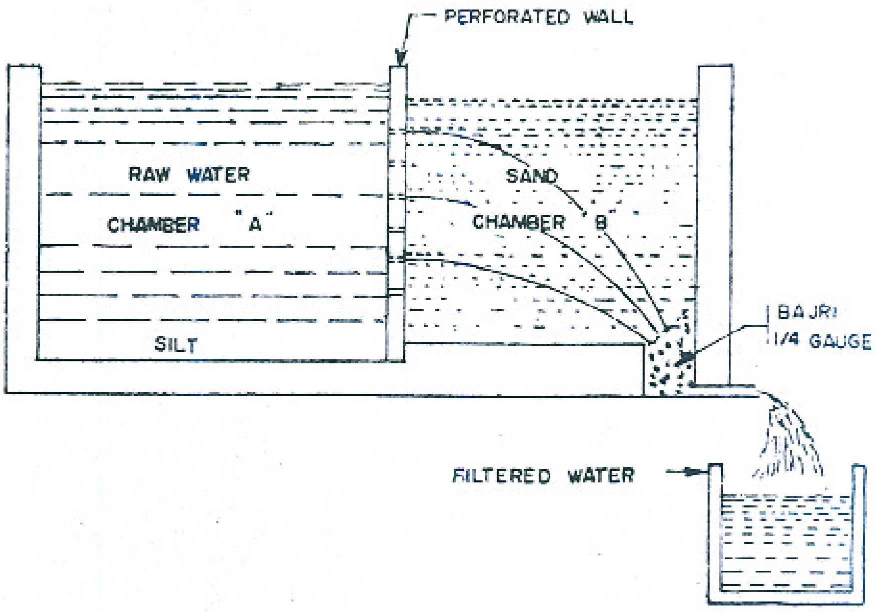

Fig. 3. Prototype Vertical Media Filter.

(*ii*) The filtering media is laid in the vertical layers and the flow of water is in horizontal direction, whereas in the conventional type the flow of water is in the vertical direction.

(*iii*) Since the flow in the vertical type filter follows parabola curve therefore the course media beyond the sand layer would be perpendicular to the line of flow, *i.e.*, it would be along horizontal axis but in the opposite direction of the line of flow.

(*iv*) The sand media is neither scraped nor washed regularly except gentle scrubbing of the perforated wall.

(*v*) Its operational cost is minimum.

(*vi*) Output is as good as that of slow sand filter.

So far as the material is concerned, it does not differ from the material required for the slow sand filter except that some material is required to keep the sand media in vertical layer with maximum area of contact for the raw water. Different materials like wire gauze, nylon mesh, jute bags were considered but finally the compressed bricks (perforated) were selected for constructing the middle wall of chamber A & B prototype (Fig. 3). While laying these bricks the vertical joint of 1/4" was not filled with the mortar in order to increase the area of contact further. In this way 10% of the open area was attained. But in tabulating the discharge of filtered water the entire area of the perforated wall is taken.

Chamber B (Fig. 3) was filled with sand (uniformity coefficient 2.5). Filtration was started after filling Chamber A with the raw water of Rakh Branch Canal. The bed started functioning and the discharge gradually began to improve and after running for a few minutes the turbidity was less than 3 units. The experiment was run for days without removing the silt deposited in Chamber A. The turbidity of the raw water increased with the continuous running of the bed.

The rate of filtration with the sand media depends upon the suspended solids of the raw water, head of water and extent of choking of the sand void. Therefore, the results (of almost same head of water) were recorded with an interval of every two days which are tabulated as below :—

Area of filtration	Time taken to fill 3 glns.	Rate of filtration/gln/hour/sq. ft.
1.732	11—30	9.05
1.73	12—20	8.42
1.78	21—45	4.65
1.845	22—0	4.43
1.68	26—0	4.17
1.795	25—0	4.0
1.72	25—0	4.18
1.89	17—0	5.16
1.67	21—0	5.14
1.72	25—0	4.18

In order to find the line of flow of water in the sand, peizometer tubes were fixed. The data plotted showed that it is a curve of 2nd degree (parabola).

After four weeks of experiment, the perforated wall of chamber was just brushed (not hardly) in order to renew the sand surface. The phenomenon was repeated. The rate of filtration on the 1st day was recorded as 8.8 gallons/hour/sq. ft. on the same head and after a week it was 4.17 gallons/hour/sq. ft.

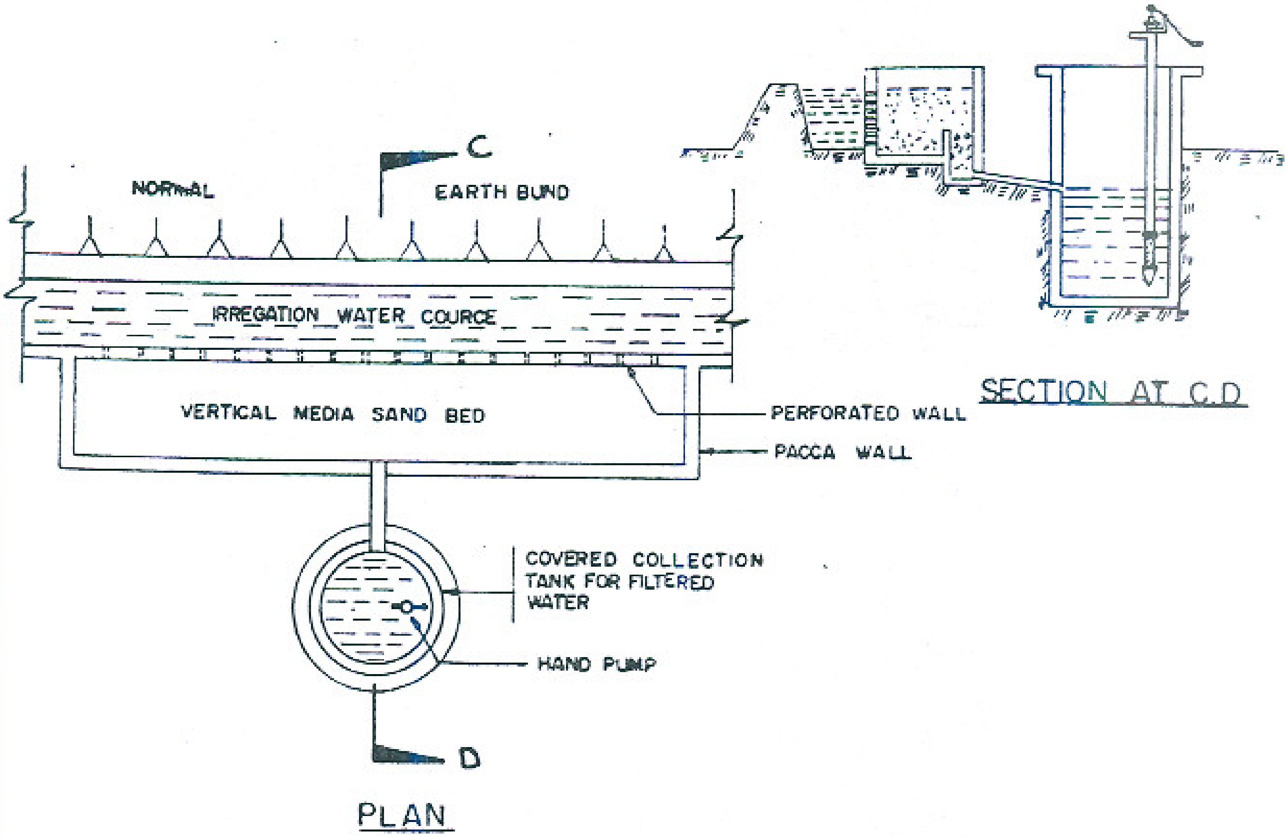

Fig. 4. Vertical Media Filter For Small Community of 100-200 Heads.

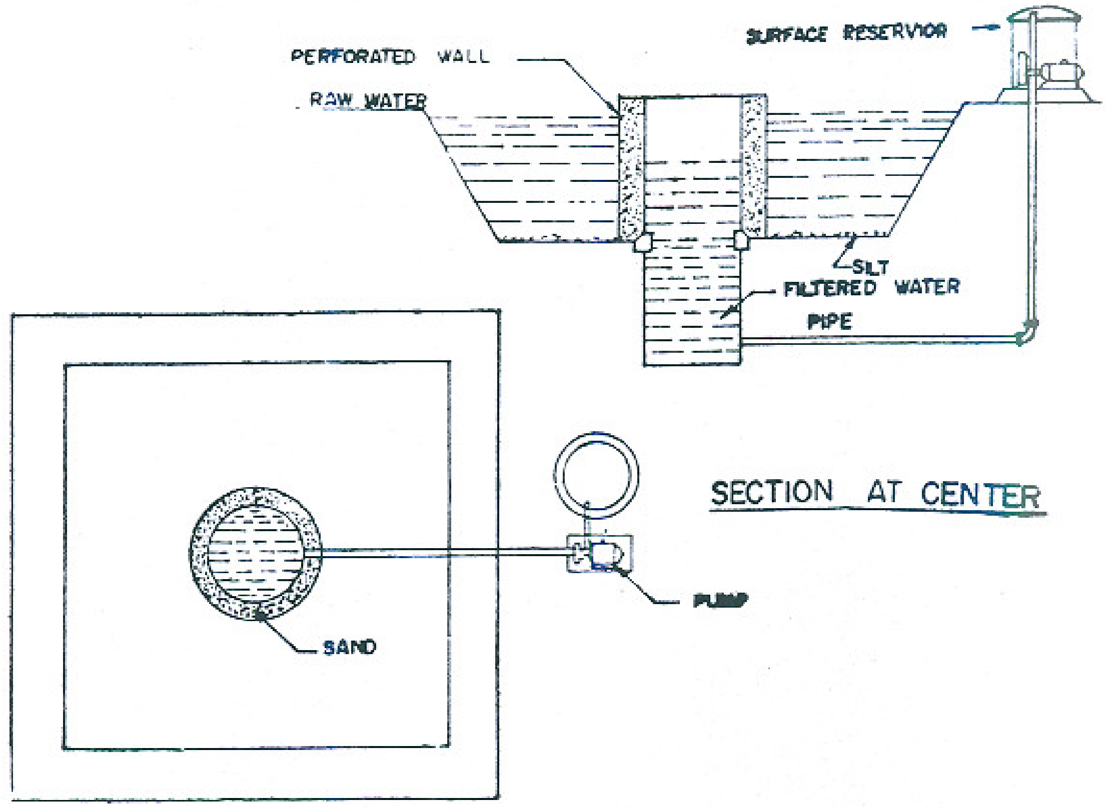

Fig. 5. Vertical Media Filter Community of 2000 Heads.

The sand media from different sources was replaced and experiments were run. It was observed that the results vary with the change of uniformity coefficient.

The media was replaced with finer sand (pit sand without screening and washing uniformity coefficient 3.6). The highest rate of filtration was 4.71 gallons/hour/sq. ft. and lowest was 2.14 gallons/hour/sq. ft. after a week. Therefore this was discarded.

Summarising all it is concluded that raw-water of our canals can be filtered through vertical media filter at a rate of 4 gallons/hour/Sq. ft. without any sedimentation. For practical purposes in the field, it is recommended to adopt a figure of 30 gallons/day/sq. ft. (for a sand of uniformity coefficient of 2.3), after allowing all factors which could hamper the rate of filtration.

This method of filtration has a direct application for the benefit of a small community of 100 heads or even smaller one. The vertical media filter can be constructed on one of the banks of a minor as shown in Figure No. 4. Its cost per capita comes to Rs. 6 to 7. The filtered water can be collected in a sump and lifted up by a hand-pump. Similarly, a bigger size of filter can be constructed for a larger community of 2000 heads, as shown in Fig. 5. Its cost per capita comes to Rs. 8 to 9.

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