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IRRIGATION PROJECT DE-
SIGN IN EAST PAKISTAN

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Economic Aspects of Irrigation Project Design in East Pakistan

In East Pakistan as in most of the less developed countries there is a pressing need to reduce the capital-intensity of development programs and projects, in irrigation and other fields. Two major approaches can reduce investment costs for each unit of benefits; first by accepting the risk occasionally of lower returns in return for much lower capital costs, second by advancing the time stream of benefits, with little change in capital costs. Adoption of these changes in project design would result in considerable savings. Such savings are possible despite the large professional staff in EPWAPDA (East Pakistan Water and Power Development Authority, the executive body), largely because of the undue dichotomy between project design and project evaluation, which roughly corresponds to the gulf between engineer and economist. It has also to do with the role of economic planning agencies in the process of project formulation, which is generally not that of Director nor even that of Player, but rather that of the Critic who reviews the finished performance. These general problems are discussed in the concluding section.

Statement of Problem One

Irrigation systems are usually designed after detailed surveys have identified the agricultural developments which would be feasible in the project area after the development of available water resources, given soil, climactic and market conditions. Typically, the result of such surveys is

a preliminary cropping pattern "proposed" or forecast for the project area after development. From this proposed pattern is derived an estimate of total crop water requirements in the area in each period, usually in time units of ten days to one month. Then, irrigation water requirements at the field in each time interval are calculated by subtracting the amount of usable rainfall considered "reliable" for the period, with perhaps an allowance for available stored soil moisture. The largest calculated irrigation water requirement in any time interval within the cropping year basically determines the size of the irrigation system required, with due consideration for water losses in distribution. Thus, should the maximum gap between total crop water requirements and reliable rainfall occur in the second half of October, the irrigation system would be designed on the basis of these peak water requirements, with excess capacity in other time intervals. Although in a well done study, there may be several reconsiderations of the proposed cropping pattern in the light of the implied irrigation water requirements, the basic procedures remain the same.

The concept of "reliable" rainfall is obviously related to the probability or statistical frequency of rainfall levels in each time interval, which can usually be well established from historical rainfall records extending over many years. The choice of the amount of rainfall considered "reliable" for purposes of irrigation system design is basically a choice between lower and higher probabilities that at least so much rainfall will actually occur. If a high probability or reliability factor is chosen, the associated level of rainfall will be small, and the size of the irrigation system will have to be relatively large. If a lower probability factor is

chosen, the size of the irrigation system can be smaller, but there is a greater chance that in some year the available irrigation water plus rainfall will fall short of full crop water requirements.

The problem is then the choice of the probability or reliability factor to be used in establishing the amount of rainfall assumed available in each time interval within the year, for purposes of calculating the size of the irrigation system needed to meet peak water demands. Should a very low probability factor be adopted, then water shortages in critical periods would occur very frequently, and drought losses would be nearly as severe as in the absence of any project. Moreover, since cultivators would remain inhibited by the risk of severe drought from investing in fertilizers and pesticides, in land levelling and field channels, and from adopting high-yielding but less drought-resistant seed varieties, little agricultural development would take place.

On the other hand, should a very high probability factor be adopted, the assumed rainfall level would be exceeded in most years, so that much of the installed irrigation capacity would be infrequently utilized. A good part of the total resources available for irrigation would be used up building in extra irrigation capacity to meet improbable and infrequent contingencies in some project areas, rather than in extending basic facilities to additional areas. Again, little agricultural development would be promoted with the available investment funds. Between these two extremes lies a reasonable balance.

For optimal allocation of resources within the water sector, each project's supply capacity should ideally be expanded up to the point at

which the expected marginal rate of return on investment is equal to the sectoral cut-off rate. The optimisation process is quite complex, however. On the benefit side, one would assume each cultivator to be fully informed about the frequency distribution of rainfall, about the production functions of all relevant crops, and about the operating procedures of the project under all circumstances. For each level of irrigation capacity, there would be in each time period a probability distribution of total water availability at the field. The cultivator would be presumed to maximise his objective function (which might or might not be his expected net income), given these conditions, with respect to the decision variables under his control. The relevant variables include the cropping pattern to be adopted in each season, the allotment of irrigation water in each time period to each crop, the degree of complementary investment in water control and conservancy fieldworks (e.g. to store water in off-peak periods) and the use of other agricultural inputs like fertiliser. The project designer would then decide, having estimated cultivators' responses to each of his possible choices, how far it would be economic to extend irrigation capacity in each project area.

This formulation highlights the need for a great deal of knowledge, if the ideal approach were to be taken. This knowledge is unavailable in East Pakistan. Even for major crops, like rice and jute, little local research into yield responses to water deficiencies at different points of the growing seasons or with various fertilisation programmes, has been carried out. Data on crop water "requirements" in the agronomist's sense is scanty enough. Knowledge about cultivators' cropping decisions is also

very fragmentary. In most project studies, cropping patterns are treated as if they were decision variables of the project designers, and adjusted "optimally" to the proposed water supply conditions. In fact, neither irrigation nor extension specialists now have significant influence over farmers' cropping decisions. What little information is available indicates that farmers adopt very slowly any radical departure from their traditional practices.

There are other areas of ambiguity and uncertainty. How much can society afford to pay to protect cultivators within a project area from the infrequent but ruinous drought which involves extraordinary hardship? What is the effect of greater or lesser risk on cultivators' willingness to invest in modern agricultural inputs and methods? For lack of answers to such questions, it was decided to forego the attempt to discover the optimal solution to the reliability problem, and seek to find a good solution instead. In the pages which follow, the decision rule used in the past is compared with another which was thought to be readily applicable, relatively simple, and a considerable improvement in economic terms over the incumbent.

At present, all irrigation projects in East Pakistan are designed on the basis of "90% dry year rainfall". This is the amount of rainfall which is equalled or exceeded, on the average, nine years out of ten. It was not subjected to economic scrutiny, but was rationalised as "common engineering practice", and by the general notion that a cultivator can afford to lose a crop only one year in ten. In practice, the required irrigation capacity under this criterion is calculated by (1) subtracting from total crop water requirements in each time period the amount of rainfall

corresponding to the 10% frequency level for that time period, as estimated from historical rainfall records; and (2) adopting the maximum rainfall deficit in any time period as the peak irrigation requirement. This procedure leads to project designs featuring very low levels of average capacity utilisation, and low rates of return on investment at the margin.

Cost Benefit Analysis of the Dacca Southwest Project (DSW) with
Alternative Degrees of Risk.

To test the criterion of project design it is desirable to study first a particular project, drawing on data and analysis generated in the course of a feasibility study. The project selected, the Dacca Southwest Project (DSW), is still in the planning stage. It is to empolder a total area of almost 500,000 acres just north of the Ganges-Brahmaputra confluence against seasonal inundation. Large pumps are to pump water into the empoldered area from rivers in the dry season, and to pump rainfall run-off out during the monsoons. Natural drains and channels are to be used for both irrigation and drainage, by providing secondary pumping capacity to lift water out of the main irrigation channels into the secondary distribution system.

The DSW scheme is thus a multipurpose project for irrigation, drainage of excess monsoon rainfall, and protection against overland flooding from the large adjacent rivers. This would appear to change the fundamental nature of the problem: the size of the system is not determined solely by estimated irrigation water needs, but jointly by irrigation, drainage, and flood control capabilities. Similarly, benefits are attributable to the joint

effects of irrigation, drainage, and flood control. The problem of choice among probability criteria extends to the frequency distribution of river stages and to the frequency distribution of rainstorms of given intensities over the project area, as well as to the distribution of rainfall levels within given time intervals.

These considerations do not, in fact, complicate the analysis unduly, for the following reasons. First, the criteria applied to the design of surrounding polders were unquestioned: losses from overtopments or breaches of these dikes once unprotected settlements had been established behind them might not be appropriately measured by narrow economic calculations. In more practical terms, the designers were forced in any case to provide ample freeboard above design flood levels, due to the possible future construction of other projects involving embankment upstream or downstream which would confine flood discharges and raise peak river levels. Therefore, the probability criterion adopted in polder construction mattered little.

Second, careful studies by the project consultants generated convincing evidence that the benefits from pumping run-off from monsoon rains out of the polders cannot by themselves justify the capital and recurring costs of the pumping and distribution system. Drainage pumping within feasible limits cannot prevent the accumulation of water on low-lying ground after severe rainfalls, but merely accelerate its removal. Since after a short time - say, a week at most - the length of time a crop is submerged has little further bearing on the extent of damage, there are strongly diminishing returns to faster rates of drainage pumping. Over the relevant range, the incremental benefits are quite small. For this reason, drainage requirements

never determine the size of the system, but drainage pumping proceeds at the fastest possible rate, given the system capacity determined by irrigation requirements. The net drainage benefits can be treated as an addition to irrigation benefits, and will operate to encourage the adoption of higher irrigation reliability factors, since capacity established to meet peak irrigation requirements can inevitably be used by removing water more rapidly than otherwise during the monsoons. However, if peak irrigation capacity cannot be justified economically in such multi-purpose schemes, where it can also generate supplementary drainage benefits at low marginal cost, then it certainly could not be justified if for irrigation purposes alone.

In other respects, the DSW project area is quite suitable as a subject for this pilot study. Present cropping intensity is 148%, comparable to the provincial average of 135%. About 55% of gross cropped area is under some paddy crop or paddy mixture, again comparable to the provincial average. Average annual rainfall is 74 inches, and 81 inches for East Pakistan as a whole. Average crop yields and size of agricultural holdings are also broadly comparable. Therefore, while it might be rash to generalize unduly from the results of a single pilot study, it is possible to feel sure the DSW area is not a very special case. At the least, it is representative of the broad central belt bordering the major rivers. In this belt there are at least two million acres whose development can probably be analysed in very much the same way.

Much light is shed on the fundamental choice of design in this problem by simple examination of the rainfall frequencies involved. The monthly frequencies plotted in Figure I reveal the distribution to be expected of

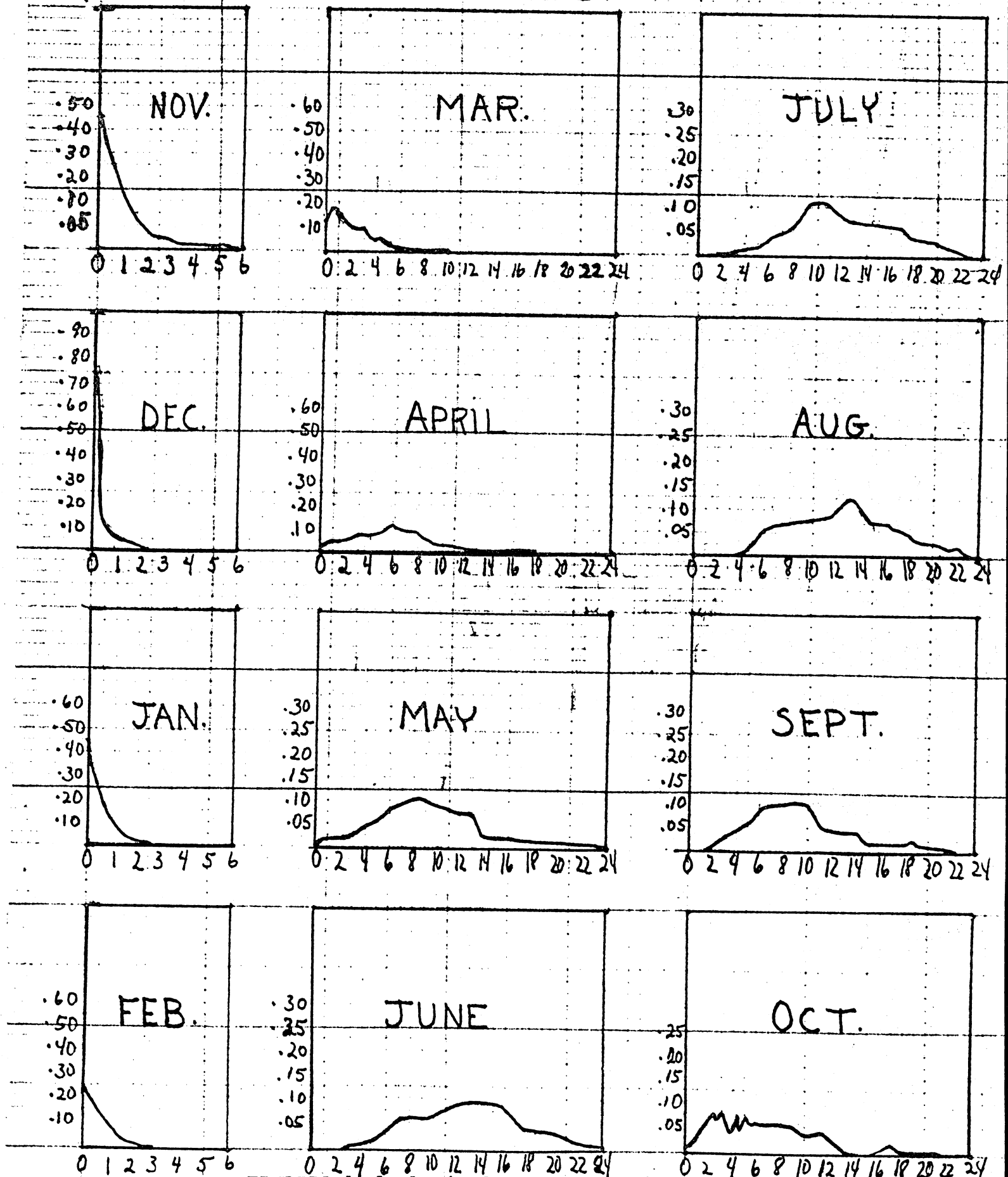
natural phenomena constrained to be non-negative: with increasing values of the mean, as in the summer months, the distributions approach normality; with decreasing values of the mean, the distributions become increasingly skewed and ultimately J-shaped, as in the winter months. This is the overall pattern in East Pakistan, with inter-regional differences primarily in the mean monsoon rainfall: the monsoon is heavier in the South and East than in the North and West.

It is immediately apparent that the problem of choosing a rainfall reliability level is focussed almost entirely on the months of Spring and Autumn. In the winter months from November through February, it hardly ever rains. Therefore, whether the project be designed for the 90% dry year, the 80% dry year, or the 50% dry year, the design rainfall will be virtually nil. In the summer months from May or June to August or September, it almost always rains so much that irrigation is unnecessary or necessary in very small amounts. Therefore, the choice of reliability level can be a serious problem only in March or April, or in October, for which months it does make a difference which level is adopted. The difference between the 90% and the 70% rainfall levels in these months might be two or three inches of water over the entire area, which would imply a major difference in irrigation supply capacity.

This preliminary consideration simplified the search for a less capital-intensive alternative to the 90% dry year criterion, and the treatment of project studies conducted under it. If the cropping patterns proposed for the project area are reasonable and are likely to approximate those which cultivators will actually adopt, and if the peak water requirements determining

MONTHLY RAINFALL FREQUENCIES: DSW PROJECT AREAS

FIGURE I



Source: EPWAPDA hydrological data, covering about fifty years of experience

the size of the system fall in the winter months, then it should be unnecessary to re-examine the design criterion. Any other criterion would lead to very similar results, because the estimated winter rainfall would remain virtually zero. Only those projects for which peak requirements occur in the months of Spring and Autumn under the 90% dry year criterion need be re-examined. However, most projects are likely to fall in this latter category.

The alternative solution suggested by the above calls for irrigation capacity limited to the peak requirements during the winter months when rainfall is nil, with this capacity used as intensively as possible in other seasons to provide supplementary irrigation.¹ It should be recognised that this alternative contradicts an influential body of opinion which holds that surface water for irrigation is the scarcest resource, particularly in winter, and that projects should consequently be designed to make maximum use of the larger supplies available in the other seasons.²

Comparison of the alternatives begins with the basic data presented in Figure II, on the monthly irrigation requirements over the entire project area when all cultivators will have begun to use the irrigation

1 Although this alternative begs the question of determining crop water requirements in the winter crops, which is primarily the question of forecasting the winter cropping pattern when irrigation is available, there is evidence that cultivators will go for high-yielding rice varieties on much of their acreage under irrigation, unless deterred by high and permeable soils or market conditions especially favorable to the cultivation of vegetables, perennials, or other cash crops.

2 J. Th. Thijsse, Report on Hydrology of East Pakistan, Dacca, 1964; p. 18 ff.

supplies and adjusted their cropping patterns accordingly. Losses of water through seepage and evaporation between the primary and secondary pumps were estimated at 10%, 10% more between secondary pumps and farm outlets, and another 25% in the field channels. Because the soil is impermeable and evaporation rates relatively low much of the year, this is conservative. Moreover, peak irrigation discharge is never to be more than 90% of peak irrigation capacity. It is clear from Figure II that maximum irrigation demands for the project as a whole occur in October (199,052 acre-feet at the field), with lesser demands in March (165,209 acre-feet) and in December (150,906 acre-feet).³

Thus the October peak is about 30% over that required in the rainless winter months, and the secondary March peak about 10% over. For reasons explained above, calculated winter irrigation requirements are invariant under different probability criteria, and it can be safely assumed that if it is worthwhile to irrigate at all, it is worthwhile to provide water to grow a crop during the winter season. Therefore, an alternative criterion was explored, one which reduced irrigation requirements in October and March to the level given by crop needs in December.⁴

³ For the cropping pattern forecast for one of the smaller polders, March appears as the peak month. And actually, for the area as a whole, the last fortnight of October has been identified as the ultimate peak period, since rainfall is then less and the predominant aman paddy crops are then in the flowering stage.

⁴ It would undoubtedly be economic to provide less than the full agronomic crop water requirements, but insufficient data on the response function is available to determine the margin.

FIGURE II

IRRIGATION REQUIREMENT BY MONTH

I T E M	MONTHS OF YEAR											
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Total Acre-Feet Required	121,744	124,107	165,209	178,787	232,764	236,537	276,991	235,869	242,486	232,472	91,151	150,906
Total Irrigable Area-Acres	292,157	300,169	362,239	360,426	386,954	401,639	392,039	306,685	363,805	370,194	304,413	313,775
Net Irrigable Area (less improve)	287,780	295,670	356,800	355,020	381,150	395,620	386,160	302,080	356,350	364,640	299,250	309,060
Rainfall in inches-32% dry year	0	0	0	15	4.0	6.3	7.0	6.6	3.2	1.1	0	0
Rainfall in Acre Feet	0	0	0	44,360	127,200	207,500	225,400	166,000	113,400	33,420	0	0
Net Acre Feet Required	121,744	124,107	165,209	134,407	105,564	29,037	51,591	69,869	129,086	199,052	91,151	150,906
Days per Month	31	28	31	30	31	30	31	31	30	31	30	31
Discharge on Field - cfs	1,980	2,240	2,690	2,260	1,715	493	1,390	1,135	2,170	3,240	1,630	2,455
Discharge at Farm Outlet-cfs	2,475	2,800	3,360	2,825	2,145	615	1,740	1,420	2,715	4,060	1,915	3,070
Discharge at Secondary Pumps-cfs	2,745	3,110	3,730	3,135	2,380	680	1,930	1,575	3,015	4,470	2,125	3,410
Discharge at Primary Pumps-cfs	3,020	3,420	4,100	3,450	2,620	750	2,120	1,730	3,320	4,920	2,340	3,750
% of Maximum Discharge	55%	63%	75%	63%	48%	14%	39%	32%	61%	90%	43%	69%
Irrigation Requirements-cfs												
a) Primary Pumps-cfs	3,000	3,440	4,190	3,440	2,620	760	2,130	1,750	3,330	4,920	2,340	3,760
LOCATION	(1) MAXIMUM IRRIGATION CAPACITY					PEAK IRRIGATION REQUIREMENT				% OF MAXIMUM IRRIGATION REQUIREMENT		
At Field	3,560 cfs					3,240 cfs				91		
At Farm Outlet	4,462 cfs					4,060 cfs				91		
At Secondary Pumps	4,948 cfs					4,470 cfs				90		
At Primary Pumps	5,450 cfs					4,920 cfs				90		

(1) Does not include 30% reserve at Primary Pumps

Adoption of this alternative criterion would imply that peak irrigation requirements would be 3,750 cusecs at the primary pumps instead of 4,920 cusecs (from Figure II)⁵. Therefore, drainage pumping capabilities would be lowered, and the risk of some water shortage in exceptional drought years increased.

Despite the uncertainties surrounding the effects of flood waters on crop yields, it is actually necessary to consider the impact of the design change on drainage operations first, before considering its impact on irrigation. The reason is quite simple. The rapidity with which monsoon run-off can be removed from the land determines the area on which transplanted "aman" rice can be grown, rather than the lower yielding, but flood resistant, broadcast, "deepwater" aman. Since the seasonal crop water requirements of the former are approximately 40% more than those of the latter, each change in the cropping pattern will change the crop water requirements in October and the value of the crop on the ground then. For this reason, it is necessary first to find out the implications of the design change for drainage pumping.

For this pilot study, some sensible analysis carried out by the project consultants can be brought to bear on this question. They had been moved by the problem of maintenance in East Pakistan to include a 30% reserve over peak irrigation capacity at the primary pumping plants. They considered the costs and benefits associated with drainage rates of 1/2 inch per day,

⁵ The 30% reserve pumping capacity at primary pumps proposed by the consultants is ignored for the moment.

1/3 inch, 1/4 inch, and with no drainage pumping whatever. The method employed in making these benefit comparisons involved firstly estimation of the depth, duration, and area affected by flooding from the run-off of a design storm, at various rates of drainage pumping. (The design storm is a thirty-day storm of ten-year recurrence frequency, with a geometric rate of daily decay after the initial storm burst.) From these calculations it was possible to estimate the area in which transplanted aman could be grown, rather than lower-yielding broadcast aman, at each drainage pumping rate, and the consequent differences in benefits. Table I presents summary results from the Feasibility Report.

TABLE I

Direct Benefits and Costs Associated with Several Rates of Drainage Pumping with Unchanged Irrigation Capacity.

<u>Cost and Benefits</u>	<u>Daily Rate of Drainage Pumping</u>			
	<u>None</u>	<u>1/4 inch</u>	<u>1/3 inch</u>	<u>1/2 inch</u>
1. Net Annual Benefits Rupees per Acre	423	513	521	525
2. Capital Costs, Rupees per Acre	1,040	1,057	1,152	1,343
3. Operating Costs, millions of Rupees	12.33	16.16	17.73	20.90

Source: Figure III and DSW Feasibility Report.

This data is graphed in index form in Figure III below. It is clear that pumping storm water from the land at faster rates brings strongly diminishing returns. This follows primarily from the fact that it makes no

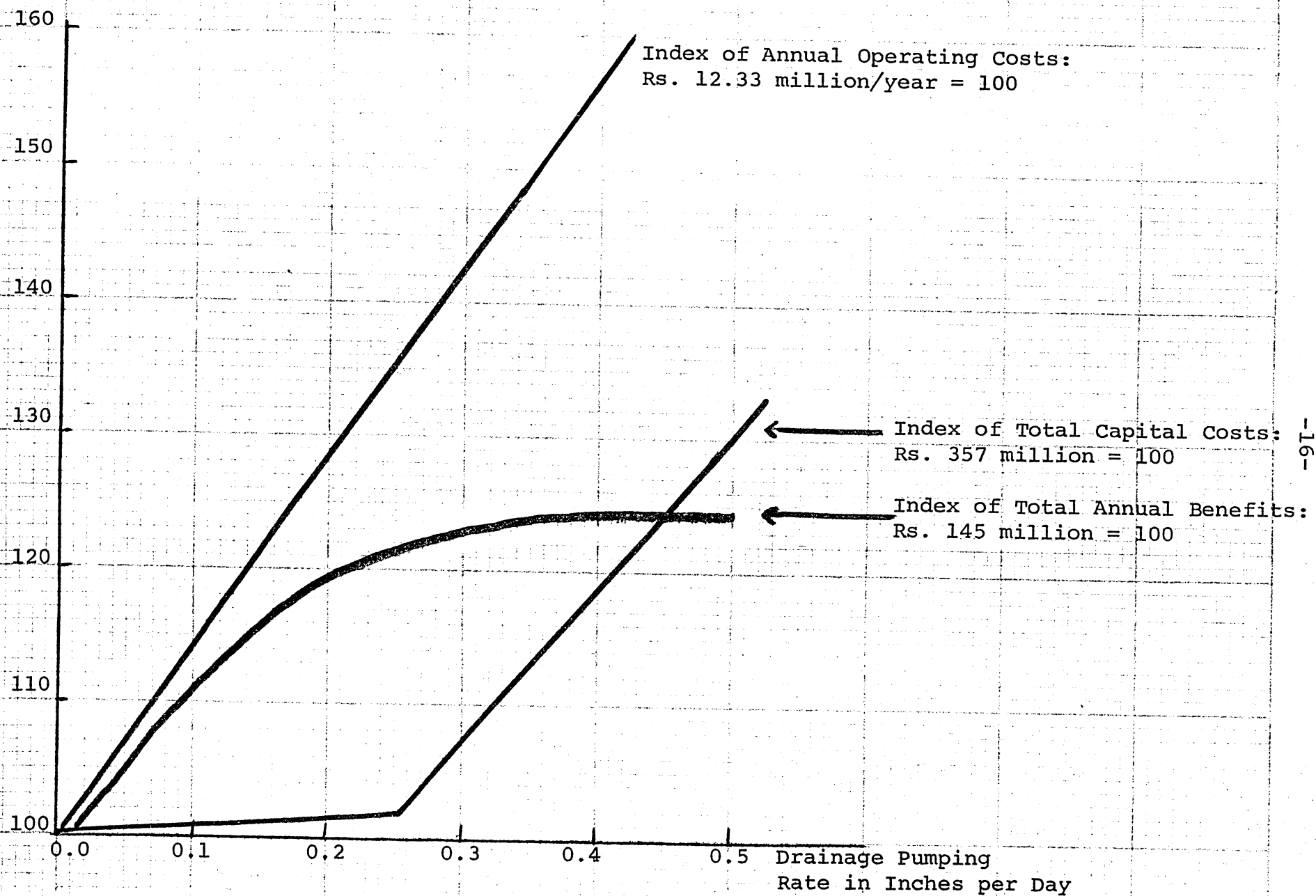


FIGURE III

difference whether transplanted aman paddy is submerged for twelve weeks or only for two weeks; the crop is lost in either case.

The pump capacity determined by December's irrigation requirements would be capable of draining the project area at the rate of approximately 1/5 inch per day. From Figure III the difference between pumping 1/5 inch per day and pumping 1/3 inch per day is evidently Rs. 17 per cultivated acre, or Rs. 6.8 million per year for the project area as a whole. The corresponding difference in operating costs would be Rs. 2.3 million per year. Therefore, the loss of annual net benefits from drainage pumping if capacity were reduced from 1/3 inch per day to 1/5 inch per day would be Rs. 4.5 million, or Rs. 11 per cultivated acre.

However, the consultant's calculations just described happen to have been carried out with reference to the design storm, of ten-year recurrence frequency. Since this storm is considerably more severe than any experienced under average conditions, the extent of flooding and consequent adjustment of the cropping pattern, in the average year, are significantly overestimated. The design storm rainfall (24.33 inches) is about twice that of the average thirty-day storm over the project area (12.54 inches). Since the maximum water losses from run-off through evapo-transpiration, infiltration, and entrapment in bunded fields and other irregularities were estimated at a maximum of about 15 inches per month, it is clear that run-off from the storm of average size would depend critically on the distribution of the rainfall within the thirty day period. From historical evidence the consultants have concluded that this run-off would be about 45% of that under the design storm. For the broad purposes of this study the same factor can be applied

to the net agricultural benefit calculations, which would imply that in an average year the difference between drainage at 1/3 inch per day and 1/5 inch per day would be Rs. 5 per acre or Rs. 2 million over the whole cultivated area, due to a reduction of area under transplanted aman and an increase in area under broadcast aman.

Since under full development the differences between these two crops in net income per acre is estimated from feasibility study survey data at Rs. 62, and the estimated total loss of direct benefits is only Rs. 5 per acre, it follows that about 8% of the project area must be assumed to switch crops with lower drainage capacity. In other words, if the entire project area switched from transplanted to broadcast aman cultivation, the loss would be Rs. 62 per acre. Since the estimated loss is only Rs. 5 per acre, an acreage shift of only 8% of the total is implied.

Similar reasoning results in a 3% reduction in peak October water requirements, due to the increased acreage assumed under broadcast aman paddy.

Under the design which reduces the capacity of the irrigation system to winter requirements, crop water requirements in October would be 226,272 acre-feet (7.44 inches) and irrigation capacity only 150,906 acre-feet (4.95 inches), so that design rainfall must become 75,366 acre-feet (2.49 inches) to make up the difference. Similarly, the design rainfall in March must increase from zero to 14,303 acre-feet, or 0.49 inches. From the rainfall frequency data underlying Figure I it is easily discovered that this alternative then implies approximately a 75% dry year reliability criterion for both October and March. By changing from a 90% to the 75% level, for two months only, the system could be reduced by 2,410 cusecs of pumping capacity,

and 25% of the designed channel capacity.

The implications of this choice can be made clear by concentrating first on the month of October, for which the larger absolute change is implied. With knowledge of the rainfall frequency function, it is possible to calculate the expected amount of water pumped, expected water availability from irrigation and rainfall, and the expected water deficiency in years of shortfall, for each of the alternative designs. The statistical formulae are relegated to Appendix One. The main results are given in Table II. The principle underlying the calculations is extremely simple; pumping will be at the maximum level so long as rainfall and pumped water together fall short of full requirements; otherwise, pumping will be just sufficient to make up any rainfall deficit (and zero if rainfall alone is greater than requirements).

Under the 90% dry year criterion proposed by the general consultant, even after irrigation has been fully extended to the entire project area, average utilization of design capacity would be only 41% even in the month of peak irrigation demands. In other months of the year, as Figure II indicates, irrigation demands would be substantially less. Under the alternative (75% dry year) criterion, the average level of utilization after full development would still be only 51%.

On the average, the provision of an additional 50,000 acre-feet of irrigation supply capability at the field would lead to an additional 5,700 acre-feet delivered to the field. This implies an average rate of utilization of the additional capacity of only twelve percent.

The maximum water shortfall, which would be expected only once every

TABLE II

Comparisons of October Irrigation Supply Under Two Alternative Designs

	<u>90% dry year Criterion</u>	<u>Alternative Criterion</u>
1. Expected Pump Delivery		
a. in acre-feet	82,800	77,100
b. as % of design capacity**	41%	51%
2. Expected Water Availability at the Field		
a. in acre-feet	292,400	286,700
b. as % of total crop water requirements	125%	123%
3. Maximum Water Shortage		
a. in inches	1.1"	2.5"
b. as % of total requirements	14%	33%
4. Frequency of Maximum Shortfall	one year in eighty	one year in eighty
5. Frequency of any Shortfall	one year in ten	one year in four
6. Average Shortfall in those Years		
a. in inches of water	0.64"	1.18"
b. as % of total requirements	8%	16%

** Excluding 30% reserve capacity at the primary pumps

eighty years, would be 14% of total consumptive use requirements in one case and 33% in the alternative. Taking just those years in which some shortfalls occur, the average shortage under the original criterion would be 8% of crop needs; while under the alternative criterion, the average shortfall would be 16% of crop needs. These shortages would occur one year in ten, and one year in four, respectively.

The obvious next question is the impact of these differences on agricultural yields and project benefits. Although empirical evidence on the effect of marginal water shortages on crop yields in East Pakistan is scarce, it is quite clear that the general consultants were mistaken in their planning assumption that to prevent the loss of a crop more frequently than one year in ten, it is necessary to adopt the 90% dry year design criterion. Although some water shortage occurs one year in ten under this criterion, it averages only 8% of crop requirements and is at most 14% of crop requirements - assuming full development of the project area. There would never be any significant drought damage under this criterion, let alone the loss of a crop.

While the shape of the response curve depends on crop, soil, climate, growth stage, fertilization program and other factors, one strongly suspects diminishing returns as water application approaches full consumptive use requirements.⁶ What little experimental data is available for East Pakistan

⁶ A functional relationship exhibiting strongly diminishing returns was suggested by R. Dorfman, Appendix 5, p. 419, Report on Land and Water Development in the Indus Plain. The White House, Department of Interior Panel on Water Logging and Salinity in West Pakistan; Washington, D. C. January 1964.

confirms this: Ghulam Mohammed cites results from a Government Experimental Farm.⁷ These are presented in Table III below. Nevertheless, due to lack of data a much more pessimistic assumption will be adopted: that the loss of income will be proportional to the shortage of water below full consumptive use requirements. This represents the maximum loss: the cultivator can always give full water requirements to a fraction of his acreage: then, even if the unirrigated part of his crop is lost altogether, the overall loss will be only proportional to the relative water shortfall. On this basis, Table III indicates the expected reduction in direct agricultural income under the alternative design criterion.

TABLE III

Agricultural Benefits in the Aman Season Under Alternative Criteria

	<u>90% Dry Year Criterion</u>	<u>Alternative Criterion</u>
1. Average Agricultural Incomes from the Aman Crops	Rs. 151/acre	Rs. 140/acre
2. Average Annual Loss of Income from Smaller Irrigation Supply	Rs. 6/acre
3. Maximum loss of Income Under Total Drought, One year in 80	Rs. 12/acre	Rs. 39/acre

Source: Table II and the assumption that income loss is proportional to water shortfall.

⁷ Ghulam Mohammed, "Development of Irrigated Agriculture in East Pakistan: Some Basic Considerations," Pakistan Development Review, Autumn 1966. Since the variable in this experiment was the total application of water during the growing season, rather than the application during just one critical period, the results are only approximately applicable to the present argument.

Under the alternative criterion, the value of the crop on the ground in October would be Rs. 146/acre after the shift in cropping patterns. Water shortage would average 16% one year in four, or 4% overall: so, under the pessimistic assumption, the expected loss in agricultural income would be Rs. 6/acre, or Rs. 2.4 million over the whole cultivable area.

The maximum loss the farmer would face, one year in eighty, would be Rs. 39/acre or 28% of the value of the crop. This risk would arise only after irrigation had been fully developed in the whole area. It does not seem this could be a serious deterrance to the use of modern inputs which return three or four rupees for each rupee invested.

A similar analysis of changes in irrigation performance during (spring) cropping season, and the associated changes in benefit levels, can be carried out. Without extended discussion, the results are presented in Table IV.

It is clear that utilization of pump capacity in March, on the average, would actually be greater than that in October, because there is less variation in the former month in the level of rainfall. More importantly, it is clear that even under the 75% dry year criterion, there would be only a nominal shortage of water: 0.18 inch on the average, once every four years. Since crop water requirements cannot be calculated within a range of error of 3% in either direction, this can be considered a negligible shortfall. Therefore, it is unnecessary to consider the loss of agricultural benefits during the (spring) season from restricted irrigation operations.

In summary, total losses associated with the smaller size of the system

under the alternative criterion could not be more than Rs. 11 per acre in the average year, or Rs. 4.3 million annually. These are separable into Rs. 5 per acre from flooding, and Rs. 6 per acre from additional drought damage. This amounts to about 2% of the total annual benefits expected to flow from the project under full development, despite the reduction of the irrigation and drainage system's size by about 25%.

TABLE IV
Comparisons of March Irrigation Supply Under Two
Alternative Designs

	<u>90% Dry Year</u>	<u>75% Dry Year</u>
1. Expected Pump Delivery		
a. in acre-feet	107,600	106,450
b. as % of design capacity	54%	70%
2. Maximum Water Shortage		
a. in inches	<u>0.00</u>	<u>0.48"</u>
b. as % of total requirement	0.00	8.7%
3. Frequency of Maximum Shortfall		one year in twelve
4. Frequency of any Shortage		one year in four
5. Average Shortfall in those Years		
a. in inches		0.18"
b. as % of total requirement		3.2%

Source: Calculated from rainfall frequencies and data in Figure II, by the method explained in Appendix I.

Before deciding to base the DSW project largely on a system of secondary irrigation pumping from natural channels and drains, the project consultants also considered an alternative distribution system based on gravity canals branching from appropriately located primary pumping stations. The latter is the most common solution to the distribution problem in East Pakistan. By using the preliminary cost information generated by this comparison, it was possible to calculate the order of magnitude of cost savings not only for the actual project design, but also for the rejected design based on gravity flow distribution.

As actually designed according to the 90% dry year criterion, with secondary pumping from natural drains and with 30% excess reserve at the primary pumps, estimated project costs are Rs. 395 million, or Rs. 1150 per cultivated acre. Of this, the field costs associated with flood embankments and a proportionate share of the overheads amount to Rs. 141 million. So, the costs attributable to irrigation and drainage are estimated at Rs. 254 million.

The cost reductions which would actually be realized if capacity were reduced by 20% as suggested were estimated directly by the design engineer of the project consultant's organization. Savings were estimated under the most conservative possible assumption, that no field costs would change except the costs of the pumps themselves. That is, it was assumed that earthwork and field structures and pumphouse facilities would be entirely unaffected by a 20% reduction in design capacity. This assumption is justified by the special nature of the distribution system, which minimises the need for gravity canals. On this basis, the estimated reduction in

capital costs is Rs. 30 million, of which Rs. 23 million represent field costs and the remainder overhead, interest during construction, and the like.⁸ This amounts to about 12% of the costs attributable to irrigation and drainage.

From the calculation of the previous section, the most pessimistic estimate of the expected annual loss after full development proved to be Rs. 4.3 million. For comparison, estimated total annual benefits from the project after full development were Rs. 447 per acre or Rs. 175 million overall.

The undiscounted benefit-cost ratio on the whole project would thus be about 2.3 times that on the final 50,000 acre-feet of capacity, even under the most unfavorable assumptions. It is evident that these last additions to capacity bring a greatly reduced return on the extra investment, while contributing little meaningful extra reduction of cultivators' risks. It would seem much more profitable to use that last 3940 cusecs of pump capacity (7,010 less 4,170 at the primary pumps; 4,950 less 3,850 at the secondary pumps) to provide a basic level of winter irrigation and supplementary summer irrigation to an additional 100,000 net acres, and generate several times larger benefits.⁹

8 The cost of pumps is all in foreign exchange. At a more realistic exchange rate, total capital cost savings might be not Rs. 30 million but Rs. 50 million.

9 In the particular case of the DSW project, the argument is even stronger than stated so far. The project consultants recently discovered an error in their initial calculation of the lift, or "head" required at the primary pumps to bring water into the polders from the river. On revision, since the discharge of a given pump is inversely related to the "head" at which it operates relative to the design lift, it appears that October peak irrigation requirements appear only at the secondary pumps. Consequently,

In order to estimate the cost savings under the hypothetical alternative distribution system based on gravity canals, it was necessary to employ some rather crude costing methods. In accordance with an empirical generalization contained in an IBRD report on water economics,¹⁰ an exponential scaling factor of 0.75 was applied to the costs of pumps, irrigation channels, and land acquisition for the irrigation system. Again, no cost reductions were assumed for flood embankments, drainage channels or transmission lines and facilities. It appears as a result that the capital cost savings under this system would be about Rs. 65 million, or 25% of the project costs attributable to irrigation and drainage.¹¹ In this case, the undiscounted benefit-cost ratio on the project as a whole would be 6.5 times that on the last 50,000 acre-feet, which indicates an even steeper descent on the marginal productivity curve. Since organized irrigation has been extended to only 400,000 acres out of 21,000,000 net cultivated acres, including both large and small-scale irrigation, it is undoubtedly mistaken to pursue such diminishing returns in limited project areas.

This conclusion is considerably strengthened by the fact that irrigation demands will never in East Pakistan materialize on 100% of the theoretical

the peak capacity at the primary pumps can be justified only by drainage benefits, which are only half the total. Therefore, the benefit-cost ratio in the whole project would be more like five times that on the final 50,000 feet of capacity. In the more general case, under single-lift pumping into gravity canals, for example, the analysis and results presented above continue to apply without modification.

10 H. G. van der Tak, Economic Aspects of Water Utilisation in Irrigation Projects, IBRD, January 22, 1965; p. 28.

11 And more with a higher foreign exchange price as before.

command area. The small average farm size and serious fragmentation of holdings make it inevitable that many cultivators will find it impossible or unprofitable to convey water to all their theoretically irrigable plots, due to minor topographical irregularities and the trouble of creating the labyrinthine field channels required. Indeed, the pace of development of water use within a command area must be expected to be relatively slow in East Pakistan, despite the striking innovations in the organization of small cultivators for cooperative irrigation which have been evolved. Under such circumstances, it is naturally preferable to under-design the system initially, especially since it is so easy to expand capacity later by adding more pumps. By phasing construction and installation to keep pace with organisational development and the growth of effective demand for irrigation, major capital savings can be realised.

Although the foregoing analysis pertains to an area of 500,000 acres in the centre of the province, it is doubtful whether the conclusion would be different elsewhere in East Pakistan. In the North and West, where summer rainfall is lighter and summer water requirements more dependent on irrigation, the case for a winter-oriented design might be somewhat weaker. However, in those same areas, the need for drainage pumping would also be less in the summer months, and the scope for more intensive utilization by this means diminished. Furthermore, seed research has so far favored the winter season with dwarf wheats and IRRI rice varieties, which will become increasingly popular over the coming years and increase the relative value of rabi season crops.

Capital Cost and Construction Periods

The DSW project illuminates another critical design choice in irrigation projects in East Pakistan, one with considerable bearing on the gestation period of projects and thus on the capital-intensity. This question was resolved appropriately, but the weight of practice and opinion remains on the side of the alternative rejected in the DSW feasibility study.

It was mentioned that two-stage pumping has been proposed for the DSW irrigation system: during dry periods, water would be first pumped into the natural drains, depressions, and low-lying channels. A system of smaller pumps would lift water out of these low channels into the laterals and ditches of the distribution network. The conventional method pumps water only once, into major canals running along the high ground within the project area, so that water will flow by gravity into smaller canals, ultimately down to the farmers' fields.

This conventional method has several disadvantages in East Pakistan: the land is so flat that water flows very slowly under the force of gravity, so the major canals need a large cross-section to transport the necessary water. This increases the land required. The local topography is quite irregular, so that extensive filling up of low spots with earthwork is required along the path of canals. Also the process of siltation has concentrated the sandier and more permeable soils along the high ground, so that seepage losses and the danger of waterlogging adjoining areas are high and more new structures across the canals are required.

The major disadvantage to the conventional solution, however, is that it involves acquisition of a great deal of land with which the local

inhabitants are very reluctant to part. Major canals must occupy the high ground, in order to command the great expanse of the project area. However, in order to keep out of the floods, people also occupy the high ground. Consequently, a network of canals almost inevitably runs afoul of every densely populated patch of ground in the region, impinging on roadways, gardens and orchards, sometimes even houses and schoolyards.

The alternative solution, by contrast, minimizes land acquisition: existing drains, and natural channels abound in most areas, because of the tremendous wash of water over the terrain each year, and these are used for distribution. The slope of the land is so gradual that a moderate improvement permits reversal of the natural flow for irrigation by pumping water into the lower end of natural drains. Since these channels are lower than the surrounding land and at the level of the groundwater table much of the year, there is little problem of seepage or waterlogging. Little valuable arable land has to be acquired.

This is a tremendous practical advantage. Land acquisition is painful everywhere in the subcontinent, but especially so in East Pakistan, where the average farm consists of three acres split up into five or six distinct plots. The identification of plots and the establishment of title is difficult and time-consuming. Conflicting or contested titles are a serious problem when land is to change hands. The work of assessment is also difficult. Dispossession of unauthorized occupants is a problem; mosques, graveyards and other holy places spring up overnight so that land cannot be condemned. The Deputy Commissioner, on whom responsibility for acquisition rests, is over-burdened with other work and is reluctant to antagonize local interests

on behalf of a distant Authority. Owners consider the Government's assessments inadequate, and experience has taught that recalcitrance has its reward. It is almost impossible for the Government to avoid appeals to the Court by those who would try to show cause why their holdings should be exempted: once on the Court calendar, which is a long one, proceedings can be dragged on and on. Reform of land acquisition legislation and procedure has been a matter of considerable discussion and study, but no satisfactory solution to this complex problem has been devised as yet, except to avoid it.

In other EPWAPDA undertakings, land acquisition problems have been an important, although certainly not the only, source of delay in project completion. These schedule overruns have been substantial, as Table V indicates.

TABLE V

Initial and Actual Gestation Periods for Major Water Schemes

<u>Name of Project</u>	<u>Commencement Date: Date of Sanction</u>	<u>Comple- tion Target</u>	<u>Actual Date of Completion</u>
Ganges-Kobadak: Kushtia Unit	1954	1962-63	1970-71
Faridpur Drainage	1956	1965-66	1968
Feni Flood Prevention	1957	1960	1968
Coastal Embankments	1960	1965	1971
Groundwater Pump Irrigation Project	1959	1965	1968
Dacca-Demra Project (revised)	1962	1967-68	1967-68

Such long gestation periods as these are largely responsible for the high capital-intensity of major irrigation projects, in other areas as well as in East Pakistan, since over the critical early years there is no output or benefit whatever.

Analysis of the relative costs of single-lift and two-stage pumping, while considerably better than no analysis whatever, largely misses the point: two-stage pumping is not so much cheaper, but by minimizing delays from land acquisition problems, it shortens the gestation period and advances the time-stream of benefits. The differences in capital costs are minor: two-stage pumping saves money on land acquisition and the canal system, but involves more spending on pumps and transmission lines. Since the water authority is not a revenue-receiving body one might expect them to be somewhat sensitive to variations in project costs, but much less sensitive to variations in the time stream of benefits. Fortunately, since cost considerations proved insufficient for a decision, the project consultants were swayed by the reduced land acquisition problem with double pumping.

It is quite easy to demonstrate that the choice in favor of double-pumping, where possible, is pronounced. If it prevents a delay of a single year in project completion the overall present value of the savings from two-stage pumping will be approximately 30% of the total capital costs attributable to irrigation and drainage. This is indicated by Table VI, in which annual capital costs and net agricultural benefits are discounted at 8%.

TABLE VI ¹²

Comparison of Phased Costs & Benefits Under Single

<u>and Double Pumping</u>				(Rs. mil)		
<u>Year</u>	<u>Capital Cost</u>	<u>Single Pumping</u>		<u>Capital Cost</u>	<u>Double Pumping</u>	
		<u>Net Benefit</u>	<u>Discounted Difference</u>		<u>Net Benefit</u>	<u>Discounted Difference</u>
1.	8.9	0	-8.2	10.8	0	-10.2
2.	32.0	0	-27.4	32.7	0	-28.0
3.	60.5	0	-48.2	62.2	1.8	-47.9
4.	81.8	1.8	-58.8	87.6	6.8	-59.5
5.	64.0	6.8	-38.9	71.2	16.7	-37.0
6.	58.6	16.7	-26.4	63.3	26.5	-23.2
7.	28.4	26.5	-1.1	25.6	61.7	+21.0
8.	21.5	61.7	+21.7	-	95.0	+51.4
9.	-	95.0	+47.5	-	125.1	+62.5
10.	-	125.1	+56.6	-	150.4	+69.5
11.	-	150.4	+64.5	-	175.8	827.0
12.-30.	-	175.8	<u>753.0</u>			
			734.3			825.6

12 The phasing of capital costs and agricultural net benefits under two-stage pumping was adjusted from polder-by-polder, item-by-item data given in the project feasibility report. In essence, a year was added to the construction schedule of all polders and internal works, because the estimated schedule seemed optimistic in the light of past experience. The phasing of agricultural benefits was correspondingly retarded. The figure of Rs. 825.6 million also includes an adjustment for replacement of all secondary pumps in year fifteen, which is not shown in Table VI.

The advantages of two-stage pumping, Rs. 91 million, are all in the form of faster realization of benefits. It goes almost without saying that in the face of future uncertainty and a severe shortage of development funds, measures such as this to shorten the pay-out period are very important.

Moreover, the flexibility introduced by double-pumping distribution system is conducive to faster development and better discipline among the water users. Under a gravity flow system there is little scope for selective distribution of water: either a branch operates or it doesn't; either a branch is constructed or it isn't. In the past, this has exacerbated problems of revenue collection, since cultivators see capacity irrevocably installed whether any money is paid or not. With small pumps, installation can proceed in step with effective demand, and pumps can be removed, if necessary, for non-payment of charges. This flexibility is very valuable in East Pakistan, where organization is a critical constraint on water resource development.

Conclusion: Project Design and the Planning Process

The problems with which the foregoing analyses have dealt fit a very common pattern, a subject of great concern and frustration to most planning agencies. Although capital is recognized as scarce, Ministries and Agencies continue to propose schemes which are needlessly capital-intensive, and to follow practices which prolong gestation periods. Planning bodies are continually faced with the unpleasant choice between poor projects and no projects at all. However, planning bodies bear a large share of the responsibility for the inappropriate design criteria, so often implicit in

development projects. They fail to realize that project design is too important to be left to design engineers. Because most officials in the planning agencies are either civil servants and generalists, or economists, they are apt to defer to the engineers on technical matters, with an exaggerated idea of what constitutes a technical matter. This deference is seldom discouraged by the engineers and technicians.

It is too seldom realized fully that, although all investment projects have necessarily a technical or engineering aspect by virtue of the physical tasks involved, the integration of the bits of technical knowledge is overwhelmingly an economic function. It can be done only by engineers who understand economics, or vice versa. Since this understanding is hard to locate in either camp, a wide gap evolves between project design and project evaluation. First the technical people design the project, then the economists and planners evaluate it. The technical agencies formulate the scheme according to their lights, and it ultimately returns to the planning authority as a finished project report. Then, the planners set about the work of evaluation. At this stage, they are virtually faced with a fait accompli. Few planning agencies are so well supplied with project studies that they can send back all the unsatisfactory ones, and wait another six or eight months for revision. Consequently, evaluation by the planning authority comes to be regarded by the technical people as one more minor obstacle between them and the money. Confronted with a summary of a lengthy project study, in which they have not participated, economists in the planning agency find it difficult to assess the evidence, pinpoint the critical assumptions and areas of weakness, or identify the key issues. Nobody knows

this better than the engineer in the agency, who knows exactly where the weaknesses are. Within the planning body, a tendency emerges to view with suspicion the schemes submitted by the agencies. The spirit of collaboration tends to decay into one of rather lop-sided contest.

Left largely to their own devices in project design, the technical agencies respond to the real forces apparent to them. Organizational considerations are strong: within each agency, there are drives toward greater employment, prestige and bounty which are an inducement to propose more and bigger projects. The more projects the agency can get approved or included in the Plan, the larger its claim on resources. The emphasis within the agency tends to be on establishing feasibility for as many schemes as possible, rather than on evolving an optimal investment programme. This emphasis quickly communicates itself to the agency's consultants. Although at the Centre, development funds may appear very sharply limited, to the agency the supply seems quite elastic at the actual cost of capital to them. At the Centre the need to reduce capital: output and capital: labor ratios may be obvious, but to the agency the safest course appears to lie in adherence to conventional designs and conventional engineering practice, although these conventions probably developed in labor-scarce and capital-abundant economies. There is little incentive to depart from "common engineering practice," and incur any personal risk of technical difficulty.

Two major conclusions emerge, neither one particularly novel. First, the best contribution the planning authority can make to the process of project formulation is at the beginning of the process, not at the end.

Planners operating in the project field need to put more faith in early studies of basic issues, relying even on very preliminary data, and less faith in lengthy and glossy feasibility reports which plump in the second chapter for one line of development, sweeping all the basic issues under the rug, and fill the rest of two volumes with peripheral data and engineering details which are completely irrelevant if the basic approach is wrong. One major function of such early studies would be, quite obviously, the identification of crucial questions or areas of uncertainty which need more study, more data collection, or a larger input of technical knowledge. The result would be much better feasibility and project reports, since consultants' terms of references could be sharpened and focussed on the really important aspects.

Second, there can be no direct and continuing presence of the planning authority in the process of project design. It is impossible to station a senior planning official in all design meetings to uphold the scarcity of capital against the claims of safety, convenience, ambition, and the sanctity of established procedure. In that case, project design can be integrated into the planning process only if priorities and scarcities are made manifest in policy measures which cause actual discomfort to a sufficient number of important people. The limitations of a fixed budget represents a powerful manifestation, felt even by those whose subjective time preference is conditioned by the fact that they expect a new posting after a few years. However, the practice of applying shadow prices in project evaluation work by the planning authority, which is currently the procedure in a number of countries including Pakistan, is doubly forlorn. Not only are these applied

at the wrong end of the process and by the wrong people, they are also explicitly being applied to projects designed under an entirely different set of prices, the real ones. Not unnaturally, it is too late to do much about it. Even if directives are issued to the various agencies instructing them to use shadow prices in project design, there will be little improvement. Scarcities still don't impinge on the agencies' proclivities.

The scarcity of investment capital for development in East Pakistan, as in most developing areas, dictates a determined effort to lower capital-intensities. As this study illustrates, the reduction of gestation periods, by whatever means, can be a most important source of savings. Moreover, the cost of insurance against small risks encountered in project design can easily be excessive. Should some communities be completely insured, there might be no funds left to provide other communities any insurance whatever.

APPENDIX ONE

CALCULATION OF EXPECTED OPERATION OF THE IRRIGATION SYSTEMS

The computations yielding estimates of expected levels of pumping, water availability, and water-shortage were based on the following statistical relationships:

U = total crop water requirements in the peak month.

K = design capacity of the system.

p = the designed system plant factor for that month: the designed supply of water to the field per unit of capacity.

R = the design rainfall level for the month.

f(r) = the rainfall frequency function for the month.

b = a pre-set probability level expressing the choice of the reliability factor.

$$\text{where } \int_0^R f(r)dr = b$$

$$1) \quad R + pK = U$$

This simply defines the system capacity which corresponds to the pre-determined probability factor. Then, if

w = the amount of irrigation water pumped during the month.

$$2) \quad w = \min(pk; U-r) \quad w \geq 0$$

That is, in the peak month enough water is pumped to make good the rainfall deficit or to fully use available capacity, whichever is the smaller.

$$3) \quad P(w = pK) = P(r \leq U - pK) = \int_0^{U-pK} f(r)dr$$

That is, pumping will be at the maximum so long as rainfall isn't greater than the gap between full consumptive use requirements and full irrigation supply.

$$4) \quad E(w) = pK \int_0^{U-pK} f(r)dr + \int_{U-pK}^U [(U-r)] f(r)dr$$

If rainfall is less than this gap, pumping will be at the maximum; if rainfall is greater than total crop requirements, pumping will naturally be nil; and for intermediate rainfall levels, pumping will make good the deficit. Expected total water availability is thus no more than the sum of expected pumping and expected rainfall.

If

x = total water availability during the month

$$5) \quad E(x) = E(w) + E(r).$$

The maximum water shortage which can occur is the difference $(U-pK)$ between full crop water requirements and the full irrigation supply level, and this would be experienced only if no rain fell during the month. The expected shortage in years of shortfall is, of course, much less than this, since some rain is likely to occur. Considering just those years in which shortages occur, the average shortfall is

$$6) \quad E(s) = \frac{\int_0^{U-pK} ((U-pK) - r)f(r)dr}{\int_0^{U-pK} f(r)dr}$$

Application of these statistical concepts to the particular problem at hand yields the results indicated in the text.

