A Programming Approach to Some Agriculture Policy Problems in West Pakistan

by

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INTRODUCTION

Planners attempting to influence the course of a country's agricultural development can expect to confront a wide variety of problems which are difficult, perhaps impossible, to formalize. Many of these will involve the most significant decisions in determining an effective sectoral growth strategy. Examples that come readily to mind for agriculture include the asessment of the optimal level of resources to be devoted to research and extension activities, the development of viable credit and marketing institutions, provisions for productive land tenure arrangements, *etc.*

There is, in addition, however, an important class of problems for which formal computational tools can be a significant aid to policy planning. As one might expect, these have to do primarily with problems of pricing and resource allocation. In the field of agriculture, for example, most developing countries engage in the manipulation of commodity prices. What is the proper relative price structure for securing the desired crop mix? Or, in the same vein, what are the effects of subsidies on the optimal level of input use? Such allocation models can also be used to assess the impact of changed input-output coefficients on optimal resource use. It is to issues of this type that the present essay on programming as a policy tool is addressed.

I.1 The Linear Programming Approach

Optimal solutions are undoubtedly of interest to planners. In recent years, however, it has become rather widely appreciated that the usefulness of

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*The author is currently Assistant Professor at Harvard University. This paper was presented at the Development Advisory Service Sorrento Conference in September 1967. In addition to the general discussion at the Conference, acknowledgements are due to Walter Falcon, Gustav Papanek and Bart Duff for specific comments. Remaining errors are the author's alone.

Portions of this research were supported by the Project for Quantitative Research in Economic Development and the Development Advisory Service through funds provided by the Agency for International Development under Contract CSD-1543.

economic models in analyzing policy issues lies more often in the systematic exploration of alternative parameter assumptions than in the results obtained with any particular set of parameters. This attitude is desired from two reasons: (1) decision makers are not about to take seriously results that are not supported by a thorough understanding of the sensitivity of a particular solution to small changes in the parameters, and (2) by varying the parameters over wide ranges, schedules and curves can be constructed that permit policy makers to engage in a number of revealing, yet much less demanding, partial analyses.

The opportunity to derive interesting and useful information by varying parameter values systematically is clearly demonstrated in the variable price and variable resource programming potential of the standard linear programming format[1]. Variable price programming, sometimes called" price-mapping", involves the derivation of a series of price-quantity relationships for a particular activity by parametrically varying the weight of that activity in the objective function of the model. Where the activity represents, say, a crop, the price-quantity curve may be interpreted as a normative, static supply curve for that crop. In the case of activities denoting inputs of one kind or another, systematic variation of the cost of operating the activity produces a normative demand curve for the input.

Other useful parametric programming exercises can be carried out by varying the availability of the fixed resources. As is well known, the implicit prices associated with each constraint represent the value of the marginal product of that particular "resource". Hence, systematically changing the magnitude of an element in the constraint vector can be used to produce a VMP curve (demand curve) for that resource.

In the present paper the properties of the programming models mentioned above are used to explore a series of agricultural policy questions for West Pakistan. Part II provides a brief outline of the model's structure and specification. Part III describes the different experiments and discusses the relevance of each for certain planning and policy-making purposes. In Section III.1, the effect of an additional, flexible, supply of irrigation water on the normative supply curves for various crops is developed. Section III.2 takes up the demand for supplementary water and the implications of farmer response to the price of water as a means of decentralized groundwater management. Some comments are also offered on the general problems of water pricing in West Pakistan. An experiment similar to that conducted in III.2 for water is carried out for labour in Section III.3. The effects on employment of water resource development are estimated and an integrated approach for increasing rural employment is suggested. A final section develops the possibilities for

[1]Heady and Chandler [8, Chapters 7 and 8].

using the programming model as a device to aid in the planning of an agricultural research strategy.

II. THE MODEL

The programming model presented in the following section was developed for the north central part of the Former Punjab. This area is one of the most rapidly growing agricultural areas in West Pakistan, averaging, since 1957/58 a 5.5-per-cent per annum increase in the gross value of production[2]. Most of the increased output was due to an expansion in rice acreage and a shift from low-quality coarse rice to a type of high-valued fine rice suitable for export. The rapid increase in the value of rice output has been due primarily to increased availability of irrigation water supplies. For although it receives more rain than most parts of the Punjab, the fortunes of the Gujranwala-Sheikhupura area are still dependent on surface canal flows and the amount of water withdrawn from the underground aquifer. With regard to the latter alternative, it is significant that over the 1957/58 — 1965/66 period, over 6,000 tubewells were installed by local individuals in Gujranwala district alone [12]. Assuming a one-cusec discharge and approximately 2,000 working hours per year, these tubewells by 1965/66 added nearly 95 per cent to the district's previously available water supply[3]. In view of this unusually rapid increase in irrigation supplies and the role of water in promoting agricultural growth in the area, the tract is particularly appropriate for a study whose emphasis is on problems of changing technology, water pricing and water allocation.

II.1 Structure of the Model

The objective of the following programming model is to maximize:

$$R = \sum_{i=1}^{k} c_i X_i - \sum_{i=k+1}^{m} d_i X_i - \sum_{i=m+1}^{n} e_i X_i \qquad (1)$$

where:

c_i = the per acre net revenue obtained from the i-*th* crop activity (gross revenue minus seed, fertilizer, pesticides, *etc.*)

d_i = the variable cost of the i-*th* water pumping activity.

e_i = the wages paid to the i-*th* labour-hiring activity.

Equation (1) is maximized subject to a series of constraints

$$\sum_{i=1}^{n} a_{ij} X_i \leq b_j \qquad j = 1, \ldots, z \qquad (2)$$

[2]This includes a correction for the shift from coarse rice to high-valued fine rice which is not accounted for in a constant price growth calculation.

[3]Calculations based on Tipton and Kalmbach [14] and Gotsch [5].

where:

a_{ij} = the input-output coefficient of the j-*th* resource for one unit of the i-*th* activity[4].

b_j = a vector of resource availability.

Water Constraints: In the Pakistan model, the first group of restrictions describes the role of irrigation. Water use and water availability are divided into 12 time periods assumed to be one month in length. Such a breakdown of the annual water useage is important since the extent to which the moisture needs of plants are met through time is, within bounds, as important to plant growth as the degree to which they receive their total water requirements. An obvious example is the limited usefulness of a downpour that provides one-tenth of the season's precipitation within a twenty-four hour period. (As the water a_{ij}'s are at the heart of the model, their estimation is discussed in some detail in Appendix A).

Land Constraints: In addition to the water needs, land requirements were estimated by crop. The resulting coefficients are simply a description of the periods during which a particular crop "occupies" the land. They are not strictly synonymous with the plant's growing season, however, since some time must be allotted for seedbed preparation and the removal of crop residues. Total land availability is assumed to be ten acres — about the size of an average farm worked by one pair of bullocks.

Bullock Constraints: A third group of constraints describes the animal power needed in the production of various crops, again by month. Bullock services are treated as a fixed resource because they represent a highly indivisible input for which virtually no rental market exists. As a consequence, nearly all farmers own at least one pair of bullocks regardless of the size of the farm. From several farm management studies, it appears that the animals can be worked about 6 hours per day for a 24-day month. This gives a limit of 144 hours of bullock pair labour as the appropriate monthly animal power constraint. No provision is made in the model for the possibility that the animals could work for longer days during peak periods.

Human Labour Constraints: Human labour requirements were also calculated by crop for each month of the growing season. The fixed nature of this resource stems from its interpretation as the labour of the tenant or owner and his family. Again based on farm management data collected in the Punjab, it appears that a farm of 10 acres would have about one and one-half mandays of family labour associated with it. Assuming eight-hour day for 25 days per

[4]All a_{ij}'s have been standardized to reflect requirements per acre of crop.

month, a total of about 300 hours per month would normally be available for use on the typical 10-acre farm.

Resource-Augmenting Constraints/Activities: In addition to the processes that use resources, two types of resource-augmenting activities are included. The first of these makes it possible to add to the fixed amount of available surface water. Physically, these activities represent the operation of tubewells that tap the underground water reservoir of the Indus Plain. The second set of augmenting activities permits the hiring of additional labour beyond that supplied by the family.

Activities that supply inputs may also be constrained to operate within certain limits. In the case of a tubewell, if capacity is given, the amount of additional water that can be produced by it is limited by the number of hours it can run per day. An absolute maximum, of course, would be twenty-four, but when maintenance requirements and down time are considered, available running time may be considerably less.

Capacity constraints for the model were developed from farm management data in the Gujranwala area[5]. In that region, the average one-cusec tubewell commands approximately eighty acres. Assuming a maximum operating time of 23 hours, the well could deliver a total of about 690 inches per month or 86 inches to the 10-acre farm assumed in the model.

In the case of hired labour, it was assumed that the farmer could hire as much additional labour as necessary at the going wage rate. There is no provision in the model — even in its regional version — for the documented phenomena that the wages of labour do vary by season.

Special Constraints: Lastly, the model contains a set of inequalities that restrict the range of feasible cropping patterns to ones that (1) provide sufficient fodder for the farmer's bullocks and (2) do not permit "unreasonably" large acreages for "unusually" high-valued perishable crops such as fruits and vegetables. As long as it is assumed that small farmers do not think of their own effort on the market, there is little theoretical justification for the latter constraints. Failure to include them, however, results in an optimal solution in which virtually the entire farm is devoted to vegetables. Without knowing a great deal more about the difficulties of marketing perishables under primitive conditions — not to mention problems of risk aversion, *etc.*, that appear to be among the real determinants of limited fruit and vegetable production — there is little more that one can do.

[5]A more complete treatment of the subject could have included capacity as a variable by expanding the model to include capital as an input into tubewells and limiting its availability or charging a price for its use.

II.2 A Schematic Representation of the Model

The structure of the programming model discussed above can perhaps be best appreciated schematically. Table I shows that there are 35 crops activities plus 12 water-producing activities plus 12 labour-hiring activities for 59 activities in all. There are 5 sets of 12 monthly constraints plus 5 special constraints for a total of 65 constraints.

II.3 The Basic Solution

As indicated earlier, the empirical estimates for the model's parameters were derived by constructing budgets for representative farms in the northern part of the Punjab. Material for these calculations was obtained from a variety of sources including the Indus Basin Special Survey undertaken by the World Bank, feasibility studies by Tipton and Kalmbach, a comparative study of tubewell and non-tubewell cultivators by Ghulam Mohammad, and a farm management survey by Harza Engineering and the author[6].

Table II shows the optimal solution of the model when water availability is limited to perennial canal supplies. As can be seen from a comparison with relevant empirical data, the model reproduced the historical situation in perennial areas with reasonable accuracy. Although the cropping intensity is somewhat less than that reported by Ghulam Mohammad, this can be explained in part by his definition of non-tubewell farmers as those receiving (purchasing) up to 25 per cent of their water from supplementary sources. Moreover, the Ghulam Mohammad study was done in the heart of the fine rice area which explains the somewhat greater proportion of rice in the cropping pattern.

The purpose in presenting the above solution is to show that the optimal solution of the programming model is consistent with what farmers have been doing in the area from which the parameters have been drawn. As such, it has not been a rigorous attempt to show that farmers allocate resources efficiently although the evidence clearly points in that direction. Rather it has been an attempt, in some sense, to "calibrate" the model. Needless to say, the demonstration that the model behaves reasonably well when faced with expected prices lends confidence to the results of the following sections in which the analysis is based on a parametric variation of prices.

[6]Indus Basin Special Study [9]; Tipton and Kalmbach [14]; Ghulam Mohammad [12]; and Harza-Gotsch [7].

TABLE I

SCHEMATIC REPRESENTATION OF THE MODEL

Constraints / Activities (Number)	(Number)	Crops (35)	Water pumping (12)	Labour hiring (12)	Resource availabilities
Water	(12)	Water (irrigation) requirements (acre inch/month)	Additional pumped water (acre inch/month)		Canal water available (acre inch/month)
Land	(12)	Land requirements (1)			Land available (acres/month)
Animal power	(12)	Animal power requirements (hours/acre/month)			Animal power available (hours/month)
Labour	(12)	Labour requirements (hours/acre/month)		Additional hired labour (hours/month)	Operator's labour available (hours/month)
Tubewell capacity	(12)		Tubewell capacity requirements (1)		Tubewell capacity available (acre inch/month)
Special	(5)	Land requirements for specific crops (1)			Land available for specific crops (acres)
Objective function		Rs. (net) revenue/acre	Rs./acre inch	Rs./hour	

TABLE II

CROPPING PATTERNS AND CROPPING INTENSITIES RECHNA DOAB, PERENNIAL CANAL ONLY[b]

(Based on 10 cultivated acres)

	Model	District data (Central Rechna)	Ghulam Mohammad (Upper Rechna)
Winter Crops			
Wheat	2.80	3.70	3.23
Barley	—	.14	—
Oilseeds	.86	.10	.21
Gram	.82	.70	.35
Fodder	1.44	.91	1.41
Fruits, vegetables & misc.	.16	—	.35
Sub Total	**6.08**	**5.55**	**5.44**
Summer Crops			
Rice	1.78	1.73	3.60
Cotton	—	.72	.27
Maize	.64	.29	.25
Fodder	.64	.66	1.07
Sugarcane	.80	.26	.58
Fruits, vegetables & misc.	.24	—	.27
Sub Total	**4.10**	**3.66**	**6.04**
Grand Total	**10.10 acres**	**9.21 acres**	**11.48 acres**
Cropping intensity[a]	101.00 per cent	92.10 per cent	114.80 per cent

[a]Cropping intensity is defined as the ratio of cropped to cultivated acreage.

[b]The model approximates most closely data from the central part of the Punjab (Rechna Doab). Column (2) shows the cropping pattern of Sheikhupura district in 1950/51 before the implementation of SCARP I. The lower intensity is due in part to the non-perennial areas located in the northern part of the district.

TABLE III

CROPPING PATTERNS AND CROPPING INTENSITIES FOR AREAS IN RECHNA DOAB RECEIVING SUPPLEMENTARY TUBEWELL WATER

(Based on 100 cultivated acres)

	Model	SCARP I[b] (Central Rechna)	Ghulam Mohammad (Upper Rechna)	Bureau of Statistics[c]
Winter Crops				
Wheat	50.4	34.4	31.7	39.6
Barley	—	.7	—	—
Oilseeds	8.0	4.0	1.2	2.0
Gram	—	3.3	2.2	5.9
Fodder	12.8	16.8	13.8	14.8
Fruits, Vegetables & Misc.	4.0	6.1	5.1	1.8
Sub Total	**75.2**	**65.3**	**54.0**	**64.1**
Summer Crops				
Rice	51.0	16.6	62.2	41.2
Cotton	—	8.9	—	2.1
Maize	—	5.9	.8	7.4
Fodder	6.4	13.3	10.8	9.4
Sugarcane	8.0	8.3	6.5	13.4
Fruits, Vegetables & Misc.	3.2	7.4	4.9	1.8
Sub Total	**68.6**	**60.1**	**85.2**	**75.3**
Grand Total (Cropping Intensity)[a]	**143.8**	**125.4**	**139.2**	**139.4**

[a]Cropping intensity is defined as the ratio of cropped to cultivated acreage.

[b]Salinity and Reclamation Project No. 1 cultivated acreage assumed to equal 1 million acres. (Total project area is slightly larger.)

[c]Calculated from Bureau of Statistics compilations on acreage by type of irrigation.

III. EXPERIMENTS WITH THE PROGRAMMING MODEL AND THEIR POLICY IMPLICATIONS

III.1 Groundwater Development and the Supply Response of Crops

Much has been written in recent years about the extent to which farmers respond to changes in the relative prices of crops. The results of various attempts to estimate "positive" supply models have provided convincing evidence that, by and large, farmers in developing countries employ the same economic logic as their brothers in more highly developed areas[7].

What is frequently overlooked, however, is that insofar as farmers employ a calculus of profit maximization, their response is not to relative prices but to relative net revenues. This distinction is of some significance in a number of developing countries where a major effort to promote growth by introducing rapid technological change has had significant differential effects on crop costs. In the section that follows, an attempt is made to show, using the model developed in Part II, that many of the previous calculations on supply elasticities in West Pakistan may be irrelevant as a result of the widespread groundwater development being undertaken there. This issue is of some importance since commodity price elasticities enter into a number of policy calculations including support prices and buffer stock operations, the utilization of surplus U.S. commodities under P.L. 480, *etc.* In the following section, static supply curves are developed for "with" and "without" tubewell conditions to examine the effect of an increased, highly flexible water source on the likely reactions of farmers to changing price-quantity relationships. They can easily be derived from the programming model by varying the price for a given crop, computing the net revenue associated with each price and then resolving the model for each variation. The linear programming model is, of course, an optimizing model, and hence, the supply curves derived by parametrically varying prices are normative in nature. That is, they describe what farmers *should do* at varying prices in order to maximize profits, and thus they differ conceptually from the supply response estimated from time-series data which show what farmers *have done.* Nevertheless, the conclusion that the new tubewell technology can be expected to exert a profound influence on (1) the optimal *level* of output at current prices (shifts in the supply curve) and (2) the *elasticity* of farmer price responses appears unmistakable.

The two effects described above are readily discernible in Figure 1. The equilibrium level of sugarcane output at current prices has more than doubled under the impact of a flexible supply of supplementary water. Moreover, over the relevant range, Curve II is much more elastic than Curve I. This comparative increase in price elasticity is significant in that Curve I is in some

[7]For estimates of supply elasticities in the Punjab, *see* Falcon [2], Falcon and Gotsch [3], Krishna [10], and Ghulam Mohammad [13].

sense analogous to the long-run supply elasticities derived from time-series estimates[8]. The link is that the latter estimates assume a time lapse sufficient for farmers to have made all the adjustments implied in the normative curve.

The choice of sugarcane as an example is not without reason. Present cane prices to growers are substantially above world market prices and are held there by factory price guarantees and a restrictive government import policy.

Historically, the distortion of cane prices has been minimized by the extremely high water requirements of sugarcane. In fact, many areas served by non-perennial canals grow virtually no cane at all. As Figure 1 indicates, however, and as evidence from SCARP I and other high tubewell density areas corroborates, large-scale groundwater development has substantially altered the relative profitability of the cane crop. Hence, if the government does not want further inroads into land which might be devoted to export crops such as rice and cotton, or into food crops, some adjustment will be required in its present sugar policy. A failure to make these alterations may prove quite costly, both in terms of budget expenditure and national income foregone. Quantitatively, it would appear that maintenance of the *status quo* in sugarcane output in the face of a widespread increase in water availability would require a decrease in the guaranteed mill price (2.0 rupees per maund) of 25-30 per cent — or at least in the Central Rechna area for which the tableau is *apropos*.

Additional experiments along these lines for other crops have been reported elsewhere and will not be repeated here[9]. However, the general conclusion appears to be that the degree to which farmers can be expected to respond to changes in the relative profitability has increased considerably upon the installation of tubewells. Such a finding suggests, of course, that agricultural prices will become an increasingly powerful policy tool as the water development programme accelerates.

The next sub-section shifts the focus of the investigation from agricultural outputs to inputs—in this case, water. Although the approach is again that of parametric price variation, the policy issues raised are substantially different from those discussed in the preceding paragraphs.

III.2 Water Pricing, the Demand for Supplementary Water and Groundwater Development Policy

As indicated in Part II and the foregoing section of Part III, a separate set of activities was included in the model to simulate the introduction of a new technology whose function was to provide additional water deliveries to the

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[8]Indeed, for sugarcane, the relationship is remarkable. A crude calculation of the elasticity of Curve I gives a value of approximately 2.7. The long-run estimate based on time-series data is slightly greater than 3 (*see*, Falcon and Gotsch [3]).

[9]Falcon and Gotsch [3].

water-using rows. Operation of these pumping activities, of course, entailed a penalty, namely the variable cost of operating a tubewell. In this section, pumping costs were varied parametrically to trace out seasonal and annual demand curves for supplementary water. The derived schedules are used, in

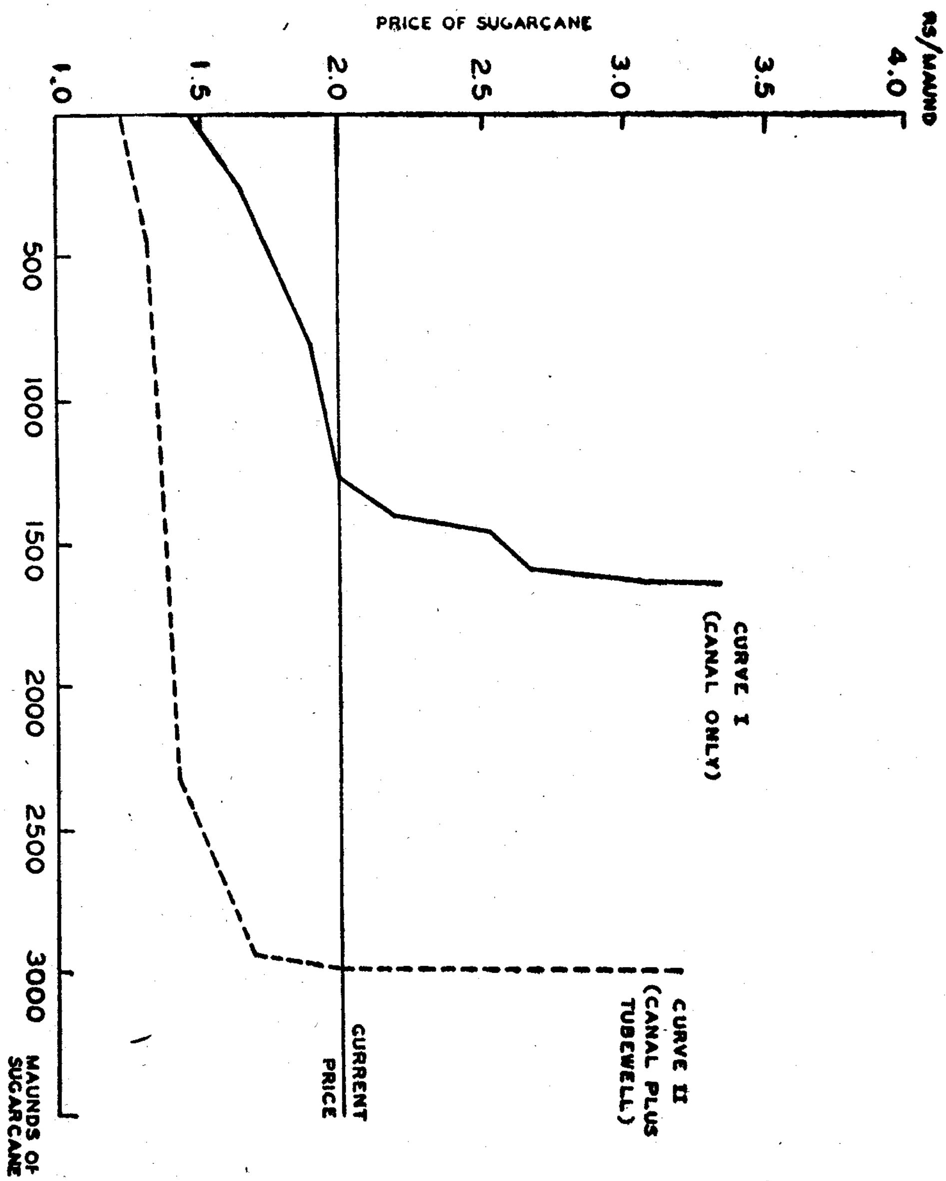

Figure 1. Normative Supply Curves for Sugarcane (10.0 acre farm, Central Rechna Area)

turn, as the basis for a discussion of certain aspects of groundwater development policy in West Pakistan.

Figure 2 shows the demand curve for supplementary water on a representative farm of 10 cultivated acres. According to the schedule, diesel tubewell owners with costs of approximately 1.2 rupees per acre-inch should have pumped of the order of 230 inches of supplementary water per annum if they equated the value of the marginal product of water with its marginal cost. Electric tubewell owners with variable costs of 0.8 rupee should have pumped about 320 inches or approximately 40 per cent more. If a weighted average price were assumed (2/3 diesel, 1/3 electric), Figure 2 indicates that private entrepreneurs should have pumped of the order of 270 acre-inches of supplementary water per annum.

The results of the exercise based on representative farms can be compared, albeit a bit crudely, with the actual withdrawals of a large public tubewell project located in the area from which the model's parameters were drawn. By invoking the proportionality assumption of linear models and multiplying the entire vector of resource constraints (b_j 's) by 10^5, the ten-acre farm becomes a one-million acre farm with surface water availability measured in million acre-inches, animal power in million bullock-hours, *etc.* solutions to the problem must then also be multiplied by 10^5. (For example, the demand for supplementary water at 0.8 rupee per acre-inch would be interpreted as 32 million acre-inches.)

Multiplying the "right hand side" of the representative farm model by 10 results in an area roughly equivalent in size to Salinity Control and Reclamation Project No. I[10]. Comparison of the optimal withdrawals suggested by the model with the current pumping rate in SCARP I (28 million acre-inches) indicates that if the same area were covered with private diesel tubewells, profit-maximizing cultivaters would probably pump less than is presently being withdrawn; if all farmers owned electric wells, they would probably pump more.

Comparison of quantity alone, however, is of little direct value since actual farmer payments for water from public projects are considerably less than the cost to private tubewell owners of operating their own pumps. Although several difficulties arise in attempting to assess the cost of supplementary water in SCARP I in a way that is compatible with the assumptions underlying Figure 2, a crude estimate of the cost of water can be obtained by comparing the revenue obtained by the government before and after the installation of

[10]Lee [11] shows that there is probably no more bias in this approach to aggregation than in one in which programming models are developed for a series of different farm sizes and then aggregated. Nevertheless, the assumption that all crops are planted as though on a single farm clearly violates reality and is responsible for part of the peaking in Figure 4.

tubewells and dividing the difference by the total water pumped[11]. Harza Engineering, in their evaluation of SCARP I, supply the numerator for the

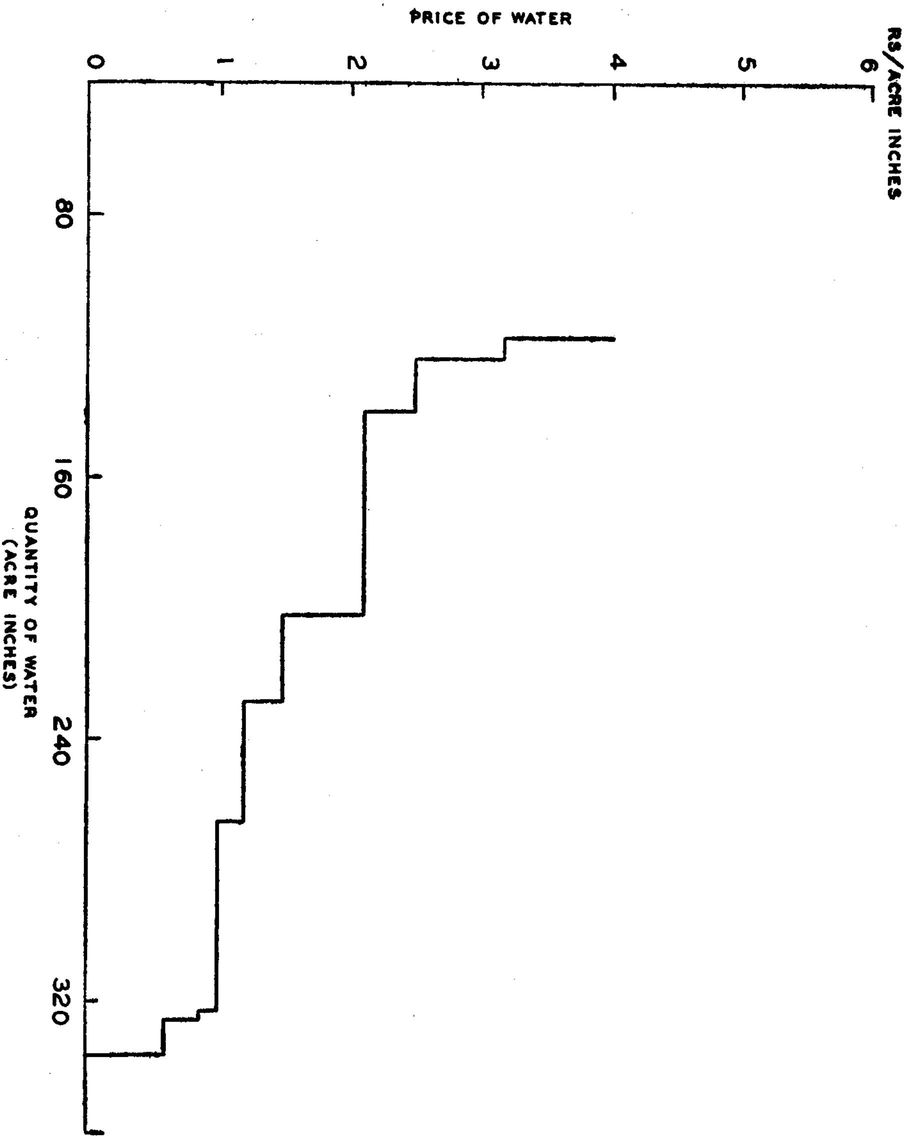

Figure 2. Annual Demand for Supplementary Water at Various Pumping Costs

[11]The problem arises primarily because water charges are currently on an acreage-irrigated and not on a volumetric basis. Operationally, this means that farmers decide once for all at the beginning of the growing season how much of a crop they are going to plant, and hence, what their water costs are going to be. Once this decision has been made, water may quite legitimately be treated by them as a fixed cost and used to the point where the value of its marginal product is zero.

above computation[12]. In 1959/60, the government recovered from the project area 14.5 million rupees from water rates, land revenue and other taxes assessed on a cropped-acre basis; in 1964/65, this figure had risen to 29.4 million rupees. Dividing the difference by the water pumped yields a figure of 0.5 rupee per acre-inch as payment, direct and indirect, for the supplementary groundwater. Substitution of this result in Figure 2 gives an estimate of water demanded of 34 million acre-inches, an amount significantly above the 28 million acre-inches actually being pumped.

One source of the discrepancy between the cost of water and the withdrawals and cropping intensities predicted by the model seems to be related to the installed tubewell capacity.

The per acre pumping capacity assumed in the model was based on the findings of the farm management studies alluded to earlier. For the central part of Rechna Doab, this proved to be approximately 1 cusec for 80 acres. For SCARP I, on the other hand, there is an installed capacity of only 1 cusec per 150 acres. Consequently, there are substantial limitations on the ability of the operating organization of the project to respond to the seasonality of water demands. This restriction in turn leads to a *lower* overall application rate than would be desirable given the extremely low-water rates but probably a *higher* rate than is optimal for meeting the requirements of the current cropping intensity.

Figures 3 and 4 illustrate monthly water demands at different pumping costs and the difference between current pumping practices and the optimal pattern suggested by the model under comparable monthly surface water flow constraints. Caution should be used in interpreting these results since it must be kept in mind that in the case of the model, SCARP I has been treated as a gigantic farm subject to a single decision-maker[13]. Nevertheless, when the comparisons of pumping patterns in Figure 4 are considered in conjunction with the attained intensities in Table III, (SCRAP I = 125; Model = 143), the evidence points strongly to the conclusion that flexibility is an extremely important element in efficient water use.

To reiterate, under present conditions in SCARP I, farmers do not have the opportunity of pumping as much water as the price of water would warrant since tubewell capacities are too low to meet seasonal demands. At the same time, much water is wasted because once the acres that can be planted have been sown, additional water may be applied to the point where the marginal

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[12]Harza Engineering [15].

[13]This undoubtedly has the effect of overstating the variance in the optimal time distribution of supplementary water. The fact that farmers typically spread their planting dates as a result of labour constraints tends to mitigate the extremes shown in Figure 4.

product is zero. For certain plants, such as rice and berseem (Egyptian clover), this can lead to unusually high applications per acre[14].

It could be argued in rebuttal to the implied case for individually owned tubewells made by this finding, that the result is simply a function of a poorly designed public project. If water were sold on a volumetric basis and sufficient capacity were installed, the needed flexibility could be attained[15]. Unfortunately, the regime-type distribution system in West Pakistan allocates water to farmers in rotation. Since groundwater and surface water are mixed at the head of the water course, both are subject to the same rotational scheme. It is difficult to see how this system can be modified to provide the flexibility of individual water control implied in Figure 4.

The foregoing paragraphs offer a number of comments on water pricing and the demand for supplementary water. This discussion suggests a further use of the experiment in clarifying certain aspects of the current debate over an appropriate groundwater development strategy for West Pakistan.

Some participants in the discussions over groundwater policy allege that the development programme must be in public hands. This is the only way, it is held, that the surface and groundwater resources of the province can be used most effectively. Specific arguments include the need to coordinate surface flows and groundwater withdrawals, the importance of overall control of the aquifer, the necessity of evening out interseasonal variation in groundwater availability, the need to insure applications of water sufficient to insure that the tendency of harmful salts to collect in the root zone is reversed, and the importance of equity in distributing the benefits of groundwater development.

Private development proponents counter by pointing out that another, and possibly overriding set of considerations have been ignored, namely, that investments in tubewells by private farmers add net resources to the country's development programme. Moreover, individual farmers, controlling their own water supplies, will use scarce water resources more efficiently. Lastly, profit-motivated cultivators, spurred by the returns on private tubewells, have become a modernizing segment within the agricultural sector that is impossible to value.

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[14]Corroboration of this explanation is given in the Indus Basin Special Study[9]. On the watercourse studied in SCARP I, the following amounts of water were applied per acre: (consumptive use requirements at the same point of measurement are given in parantheses) rice 72.6 (46.1); fodder 92.8 (38.3); cotton 30.8 (34.5); wheat 22.8 (23.9). Cultivator awareness of water response curves is implied by the deltas they have used. Rice grows in standing water and hence there is no negative marginal product for water. Berseem is also tremendously tolerant of high applications. On the other hand, both wheat and cotton can be drowned by overirrigation. Moreover, one could argue that the deltas supplied on rice and berseem had some greater than zero value which compensated for the labour involved in irrigation in that the leaching process was accelerated by the additional water.

[15]Additional capacity in public projects also has, of course, a cost. But this diminishes sharply as tubewell sizes increase.

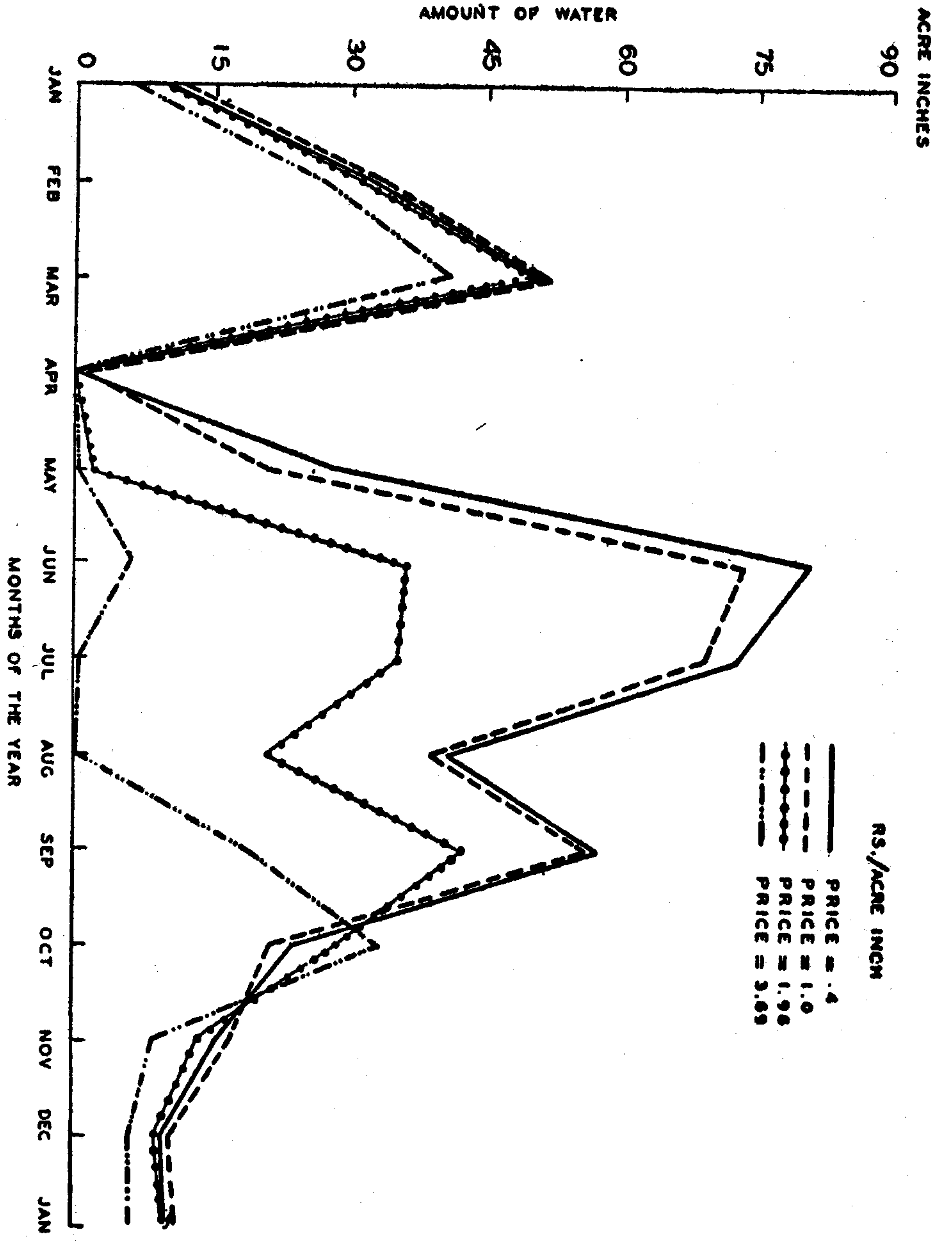

Figure 3. Monthly Demands for Supplementary Water at Various Pumping Costs

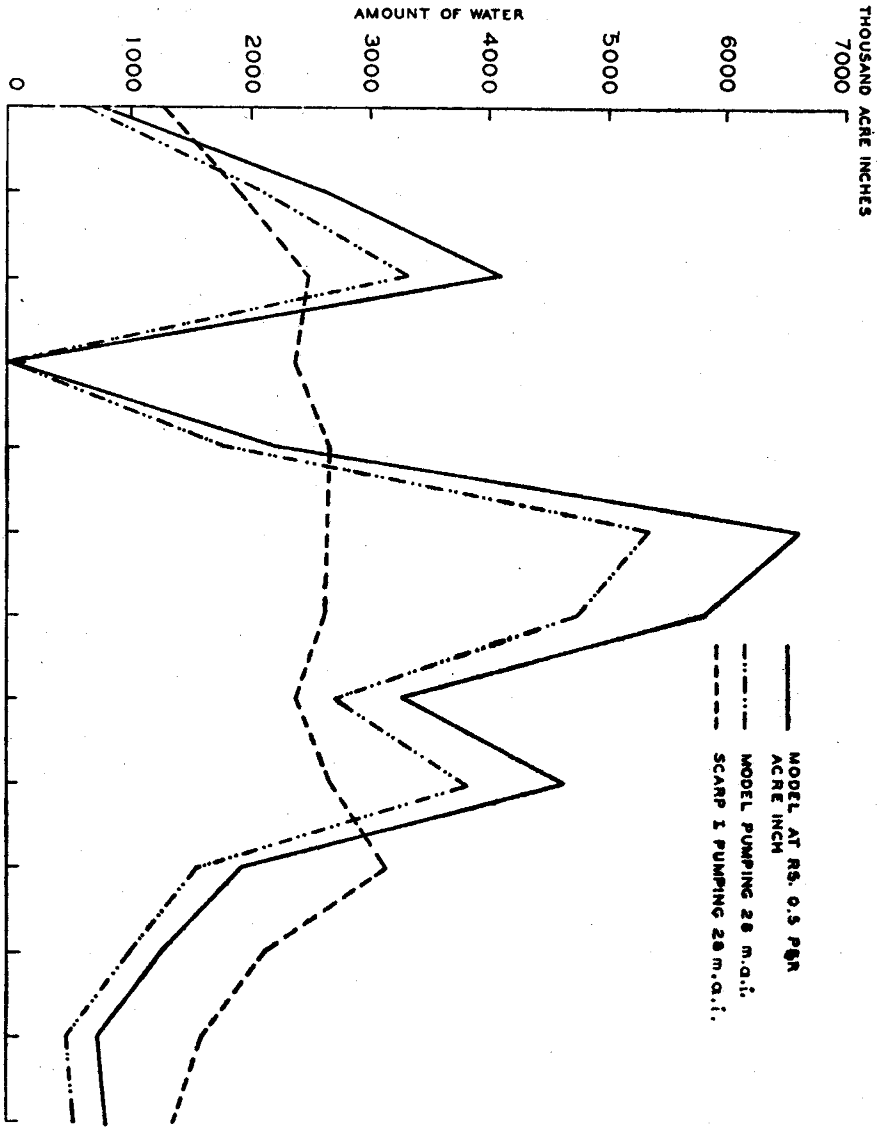

Figure 4. Seasonal Distribution of Pumping

In some cases, the arguments hinge on differences in opinion regarding the appropriate time horizon to use in evaluating development proposals. If the long-run, aggregate water management problems are deemed to be of overwhelming importance, then a predominantly public programme appears to be attractive. If, on the other hand, one feels that growth in a developing country has a very high rate of discount, the unavoidable conclusion is that, with present resource availabilities, everything possible must be done to encourage private development.

The nature of the conflicting objectives between public and private development outlined in the paragraph above leads naturally to a search for policies which might alter certain aspects of either one or the other. In particular, since the resource constraint appears to be the most significant constraint currently operating in Pakistan, policies that would make private development an acceptable long-run alternative to public projects need careful exploration. As the analysis makes clear, objections to private development can by no means be removed entirely, but at least the choice between alternative can subsequently be based on differences that cannot be remedied by relatively simple changes in public policy.

The basic question to be addressed is the allegation that public projects are needed for proper management of the underground aquifer. Concern on this point originates as much from the rather disastrous United States experience as anything else. Developments in the south-western part of the United States of America have confirmed that individuals trying to maximize profits will *i*) expand irrigated agricultural areas well beyond the long-run yield of the aquifer on which they are dependent, and *ii*) permit even the destruction of an aquifer by seawater through the failure to deal adequately with the commonality problem.

The commonality problem as it exists in the United States and as it exists in the Indus Basin has important differences, however. Perhaps of greatest significance for this study is the fact that the pricing of energy is largely under government control. Electricity generation is almost wholly under the semi-autonomous provincial Water and Power Development Authority. Currently, farmers are being supplied power at 0.08 rupee per KWH which is approximately half its real cost. On the other hand, excise taxes on diesel oil have also set a precedent that could easily be used as a tool of public policy.

Given the power to control energy costs — and hence the cost of pumping water — it appears that the government could, by *indirect* means, influence substantially groundwater withdrawals. For example, suppose that the recharge of the aquifer in SCARP I were approximately 26 m.a.i. From Figure 2, this would mean a price per acre inch of about 1.0 rupee. Using Ghulam Mohammad's figure for variable costs of private tubewells, this could be achieved by setting the cost of electricity at 0.09 rupee per KWH; diesel at 53 rupees per barrel. In other words, by increasing electricity prices by 15 per cent if pumping were done with electricity, and subsidizing the price of diesel by 30 per cent if pumping were done with diesel, withdrawals could be brought in to balance with recharge[16].

Conversely, the pricing mechanism might be used to increase withdrawals in the interest of promoting reclamation and salinity control. The principal cause of soil salinity is inadequate "deltas" to leach the accumulated salts through the root zone. However, as cropping intensities approach 125-130, land becomes a binding constraint and applications per acre can be expected to rise. The extent to which such increases will occur is, of course, a function of the price of the additional water[17].

It might be argued that the policy suggested above would be less sensitive in year-to-year fluctuations than direct government operation. While this is true, it is unlikely that highly sensitive annual adjustments between surface water inputs and groundwater withdrawals are necessary. What is needed is a long-run equilibrium between inflow and outflow and for this, an appropriate energy pricing system would appear to be valid.

The foregoing argument has been centred on countering objections to private water development put forth on water management grounds. It has not tried to add yet another variant to the proposals for an optimal public-private strategy, but has shown that certain technical arguments, thought by many to be central to the problem, are amenable to public policy. Hopefully, greater attention can now be focused on the opportunity cost of the resources involved, on the rapidity with which water resources can be developed, and on considerations of equity, which appear to be more fruitful focal points for the public-private debate.

III.3 Tubewell Technology, the Demand for Agricultural Labour and Alternative Uses of the Rural Labour Force

In developing countries with high birth rates and large agrarian populations, there is little doubt that the agricultural sector must continue to provide

[16]This is not to argue that such a balance is an appropriate public policy. For an interesting discussion of the complexity of determining optimum rates of groundwater withdrawal, *see* Burt [1].

[17]Some consultants have suggested a 10-15 per cent increase in application above the evapo-transpiration (maximum yield) requirement is needed for leaching purposes. If the production function in Figure 1 is generally valid, this would prove difficult to bring about without a direct acreage control system. One could envisage payments for the use of water beyond the point where short-run MC=VMP but it would appear that a more convincing solution would be a programme of cultivator education about the long-run gains from applying the additional 10-15 per cent. Unfortunately, this area of investigation is still clouded by a lack of agreement among irrigation engineers regarding the physical requirement of the leaching process.

a large amount of incremental employment. Recognition of this problem has led to suggestions by a number of economists and administrators that off-season labour be used to create rural infrastructure such as roads, drainage works, schools, minor irrigation channels, *etc.* Successful efforts to implement such a programme for underemployed labour have, in fact, been carried out under the Rural Works Programme in both East and West Pakistan[18].

While the instruments suggested above have an important place in creating additional employment, it is likely that a more massive impact on the demand for labour will come from the water development programme mentioned earlier. In the following section, an attempt was made to estimate quantitatively the magnitude of the increase. In addition, an integration of the two alternatives is suggested as a goal for provincial employment policy.

As Figures 5 and 6 make clear, the demand for labour generated by the model was indeed altered significantly by a simulated water resource development programme. Total labour use was increased by over 40 per cent; of this increase, nearly 28 per cent was due to the hiring of additional workers on a monthly basis.

The seasonal distribution of agricultural employment, particularly of hired workers, was also altered rather significantly. As Figure 6 shows, not only is there the usual peak in labour demand for the harvesting of winter crops and the planting of summer crops, but a second peak has arisen because of the opposite phenomena. The latter case, in which rice is being harvested and the land preparation and seeding of winter crops is underway, is not of the magnitude of the spring peak, but it is a singular departure from the historical pattern.

These findings provide some guide to the planning of public expenditures aimed at increasing employment in agriculture. First of all, it is obvious that the most massive increase can be brought about by developing water resources. The 40-per-cent increase mentioned earlier is undoubtedly a substantial understatement since it results only from increased acreage and changed cropping patterns. The increase in labour required for intensifying agriculture, *i.e.* increasing yields, has not been included. As the Indus Basin Special Studies have shown, this may be substantial, particularly in the fodder crops, and in rice and cotton.

A second important factor not included in the 40 per cent is the increased activity in the livestock sector, especially dairying, which is often associated with areas where extensive water development has taken place.

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[18] *See* especially Gilbert [4].

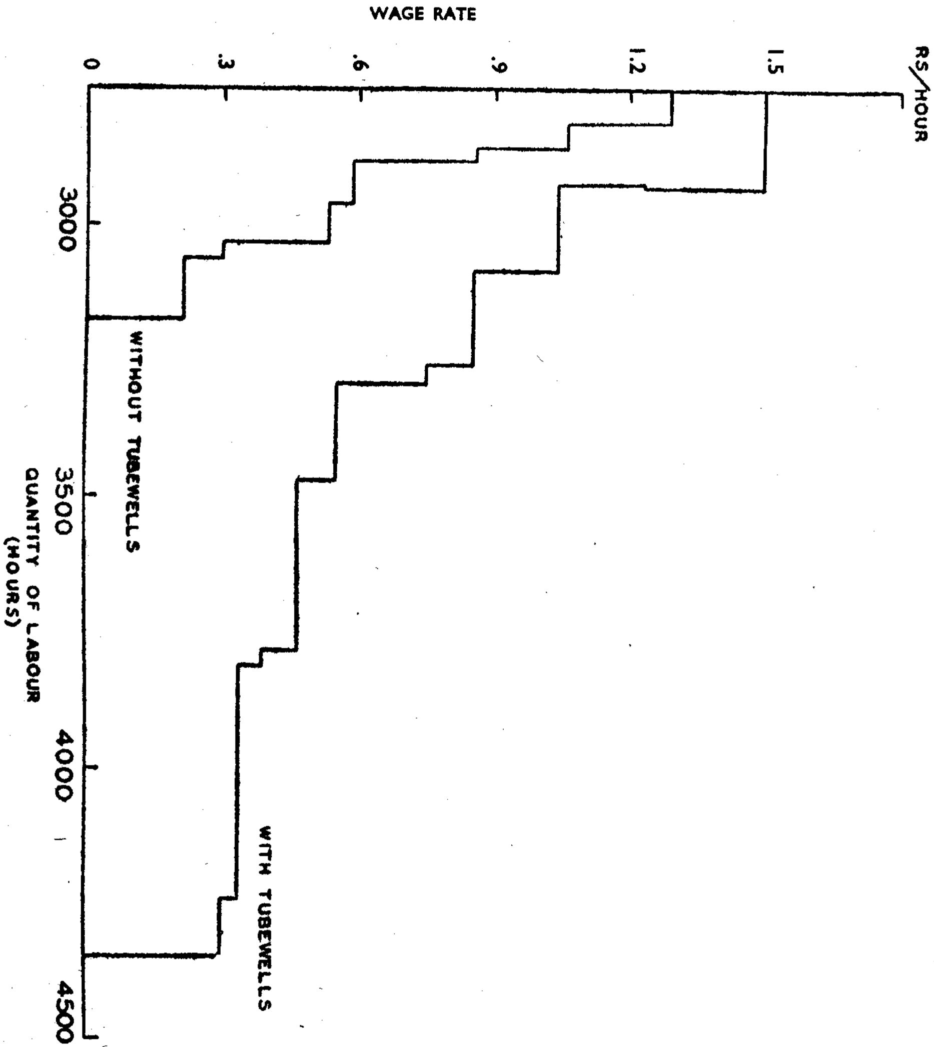

Figure 5. Total Labour Used in Tubewell and Non-tubewell Farms

Addition of the omissions mentioned would probably place the increased demand for labour in irrigated areas at closer to 55 per cent, some 30 to 35 per cent of which is likely to be hired.

The increased demand for labour in areas where water resources are being developed suggests that a substantial migration of labourers from less fortunate areas can be expected. While this labour transfer should be welcomed, past experience teaches that such population movements are sometimes carried out under trying conditions which could be mitigated through appro-

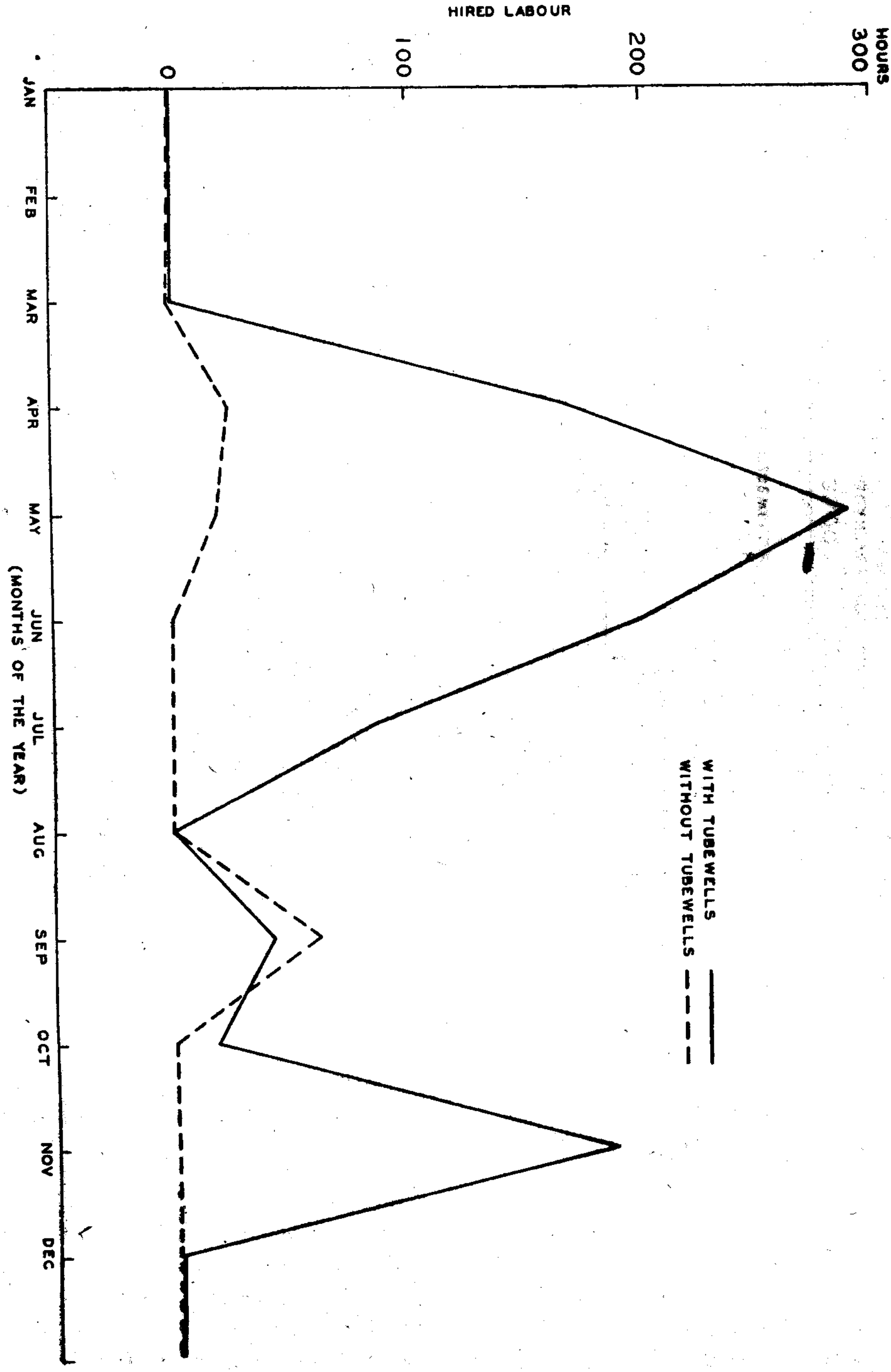

Figure 6. Seasonal Distribution of Hired Labour on Tubewell and Non-tubewell Farms

priate relocation policies. Obviously such policies are double-edged in that they relieve the pressure of unemployment in areas where additional water supplies are unavailable, as well as adding to the labour force in areas experiencing rapid agricultural growth.

One of the serious obstacles that such a relocation policy would encounter is that bane of all temporarily hired labour, namely, the seasonality of labour requirements. The result of incorporating tubewells into the model suggests that seasonal fluctuations may even be accentuated with additional water supplies as farmers tend to increase their specialization (Figure 6). Obviously, if this is true, then the seasonal underemployment about which so much has been written could be increased rather than diminished with labour migration.

It is at this point that additional government policies designed to absorb seasonally available labour could be brought into play. This is particularly feasible in irrigated areas where there are a significant number of small irrigation and drainage works that could undoubtedly be carried out economically using labour-intensive methods. Much-needed renovation of silted irrigation distributaries and minors comes immediately to mind. Moreover, the increased output in agricultural areas where rapid growth is anticipated will require a proportionate, perhaps exponential, increase in rural infrastructure. More and better roads will be required to bring the additional commodities to market, communications systems will need to be improved, schools built, *etc.*

A policy of providing substantial off-season employment as part of an overall employment policy will require a good deal of planning. For example, methods for supervising and administering labour-intensive methods must be revived, appropriate wage rates must be set by season in order to minimize the interference with agricultural employment, *etc.* But without some supplementary programme the unfortunate circumstances surrounding migrant labourers that have been experienced in so many parts of the world are likely to be repeated in Pakistan.

III.4 Devising a Strategy for Agricultural Research

As indicated earlier, the levels of the primal activities are often of less interest in a programming model than various by-products of the optimal solution. This is particularly true of the so-called "dual" solution from which can be read the implicit "shadow prices" of the various constraints imposed upon the model. In the following section, use is made of the implicit values of several constraints to suggest what might be termed a "bottleneck breaking" approach to agricultural strategy.

Table IV gives the "dual" of the optimal solution whose primal values are shown in Column (1) of Table III. In addition to "shadow prices" for various constraints, total availability of resources plus amounts used in the solution are shown.

The inclusion of tubewell or water-pumping activities has virtually removed the constraint imposed by insufficient water supplies. (The remaining "shadow prices" are merely the opportunity cost of pumping water.) Instead, land, at least during the months of September and October, is the principal binding resource. This results from the competition between the dominant summer crops that are not yet harvested and the demands of winter food crops for seedbed preparation and sowing. If it were possible to move summer crops ahead slightly in their planting dates — or alternatively, shorten the growing season — and if it were possible to move the winter planting dates slightly further into the year, substantial increases in cropping intensity could be achieved.

Armed with the results of the model which show the high returns to relaxing the land constraints in September and October, it is possible to begin a systematic exploration of means by which such "bottlenecks" could be relaxed. For example, upon inquiry, one finds that much of the rice crop is delayed in planting because of the infestation by the rice stem borer. It was discovered historically that, without modern plant control measures, about the only effective means of holding down infestations of this extremely damaging pest was to deny it the residues of rice plants for a period sufficiently long to break its life cycle. The result was an ordinance forbidding the planting of rice before June 15th. This in turn means a harvesting date which makes it extremely difficult to prepare the seedbed and plant winter crops.

Entomologists, examining the rice pest problem, have suggested that there are now plant-protection measures, such as systemics, which can virtually assure control of rice pests. Widespread adoption of these new techniques would seem to pave the way for a revision in harvesting and planting dates so that winter crops might be planted after rice.

Conversations with plant breeders indicate, however, that still other means are possible for opening up a gap between summer and winter crops. Work at the International Rice Research Institute is progressing on rice varieties that mature two to three weeks earlier than the present improved varieties. The initial impetus behind the work was to develop plants that would be less vulnerable to lack of moisture in shortened monsoon seasons, but their applicability to the situation in West Pakistan is obvious.

The possibilities suggested above, coupled perhaps with some improvement in seedbed preparation, could be used to decrease the amount of overlap between the two seasons. This can easily be expressed in the programming model by modifying the land requirements for the crops involved. In the following example, rice and wheat were assumed to be the principal crops to be

TABLE IV

DUAL OF THE PRIMAL MODEL SOLUTION GIVEN IN TABLE III FOR RECHNA DOAB

Resource		Amount available	Amount used	"Shadow price" (*in rupees*)
Water				
(acre-inches)	April	16.2	15.8	0
	May	19.3	19.3	1.0
	June	21.4	21.4	1.0
	July	21.0	21.0	1.0
	August	20.7	20.7	1.0
	September	21.4	21.4	1.0
	October	16.9	16.9	1.0
	November	11.5	11.5	1.0
	December	10.3	10.3	1.0
	January	10.7	10.7	1.0
	February	13.8	13.8	1.0
	March	16.6	16.6	1.0
Land				
(acres)	April	10.0	8.9	0
	May	10.0	5.6	0
	June	10.0	7.7	0
	July	10.0	7.7	0
	August	10.0	7.7	0
	September	10.0	9.7	0
	October	10.0	10.0	78.1
	November	10.0	10.0	20.8
	December	10.0	8.35	0
	January	10.0	7.96	0
	February	10.0	7.96	0
	March	10.0	8.36	0
Family labour				
(hours)	April	300.0	300.0	.3
	May	300.0	300.0	.3
	June	300.0	300.0	.3
	July	300.0	300.0	.3
	August	300.0	276.76	0
	September	300.0	300.0	.3
	October	300.0	300.0	.3
	November	300.0	300.0	.3
	December	300.0	239.4	0
	January	300.0	226.9	0
	February	300.0	273.9	0
	March	300.0	203.1	0

(Contd.)

TABLE IV—(*Concld.*)

Resource		Amount available	Amount used	"Shadow price" (*in rupees*)
Hired labour				
	April	Unlimited	165.0	0
	May	,,	0	0
	June	,,	201.0	0
	July	,,	132.8	0
	August	,,	0	0
	September	,,	44.6	0
	October	,,	17.7	0
	November	,,	185.7	0
	December	,,	0	0
	January	,,	0	0
	February	,,	0	0
	March	,,	52.7	0
Animal power (hours)	April	144.0	40.6	0
	May	144.0	144.0	.92
	June	144.0	144.0	.30
	July	144.0	107.2	0
	August	144.0	47.8	0
	September	144.0	55.8	0
	October	144.0	42.5	0
	November	144.0	82.9	0
	December	144.0	77.4	0
	January	144.0	38.0	0
	February	144.0	43.5	0
	March	144.0	54.6	0
Tubewell capacity (hours)	April	88.0	0	0
	May	88.0	16.8	0
	June	88.0	59.1	0
	July	88.0	55.4	0
	August	88.0	31.5	0
	September	88.0	45.5	0
	October	88.0	17.2	0
	November	88.0	13.0	0
	December	88.0	8.2	0
	January	88.0	8.1	0
	February	88.0	26.8	0
	March	88.0	42.2	0
Crop constraints (acres)	Sugarcane	1.0	1.0	356.6
	Fruit	.3	.3	350.2
	Winter vegetables	.2	.2	396.1
	Summer vegetables	.1	.1	247.8
	Winter fodder	1.6	1.6	161.6
	Summer fodder	.8	.8	95.0

affected. Rice planting dates were moved forward by one week and the growing season reduced from 5½ months to 5 months. It was also postulated that some improvements in bullock implements or some degree of mechanization had made it possible to delay the time of starting normal seedbed preparation for wheat and grain by one week. The new solution of the model is shown in Table V.

It is apparent from the results of the exercise that the modification of planting and harvesting dates had an improvement impact on cultivator productivity. Cropping intensities rose from 143 per cent to 166 per cent and net revenue increased by nearly 10 per cent. The magnitude of the benefits corroborates comments made earlier about the pay-off of research directed at "bottlenecks" in the agricultural production process.

TABLE V

PRIMAL SOLUTION TO THE MODEL WITH REVISED LAND CONSTRAINTS

(Based on 10 cultivated acres)

	Activity level (*acres*)	Yield (*maunds/acre*)	Delta (*inches/acre*)
Winter Crops			
Wheat	6.21	1.25	2.39
Fodder	1.28	45.00	3.40
Vegetables	0.16	—	1.93
Fruits	0.24	—	3.20
Sub total	**7.89**		
Summer Crops			
Rice	3.68	1.80	4.61
Fodder	0.64	25.00	2.06
Maize	3.28	1.50	2.96
Sugarcane	0.80	50.00	9.51
Vegetables	0.08	—	1.93
Fruit	0.24	—	3.20
Sub total	**8.72**		
Grand total	**16.61 acres**		
Cropping intensity[a]	166.1		

[a]Cropping intensity is defined as the ratio of cropped to cultivated acreage.

IV. SUMMARY

The preceding exercises provide an example of the way in which a relatively simple linear programming model can be manipulated to yield quantitative policy prescriptions that are useful in certain types of agricultural situations. The basic approach is one of varying objective-function weights and resource constraints parametrically to generate a series of curves and schedules that can, in turn, be used as inputs into some broader policy discussion involving cropping patterns, groundwater control, employment, *etc.*

The first experiment undertaken with the model involved the generation of a normative supply curve for sugarcane by varying systematically the price of the crop, resolving the model, and recording the optimal acreage at each new price. This exercise assumed initially that only traditional water supplies were available for irrigation. A second curve was then developed from a model that incorporated tubewell activities and the possibility of providing supplementary water from underground sources. Comparison of the two curves indicates that the installation of wells results in both a shift of the supply curve of sugarcane to the right and an increase in the elasticity of supply response.

The outcome of the exercise suggests that, in view of the large-scale water development programme being undertaken in the Indus Basin, the government should re-examine its sugarcane price policy. While this is a complicated problem beyond the scope of this paper, it is clear that tariff and support price levels, set under the implicit assumption that certain constraints were limiting sugarcane acreage increases (water) must now be reviewed when those constraints are lifted. Failure to consider new price and fiscal policies is likely to result in large-scale diversion of resources from important export crops such as rice and cotton.

The second experiment demonstrated how an important problem of groundwater regulation under private tubewell development could be handled by an appropriate energy pricing policy. Parametric variation of pumping costs produced a series of quantitative estimates of withdrawals, assuming that cultivators equated the marginal cost of pumping with the value of the marginal product of water. When related to the SCARP I area, these estimates suggest that if electricity prices were raised by 15 per cent and if diesel oil prices were subsidized by 30 per cent, a relatively stable watertable would be insured. This approach does not, of course, dispose of a number of objections to the private programme (*e.g.*, equity), but it does question the validity of frequently expressed opinions regarding the need for direct public control of the aquifer.

A third example involved the demand for labour and the prospects for creating additional employment through a water resource development programme. Comparison of cases with and without tubewells indicated that the addition of a highly flexible source of supplementary water to the farm enterprise meant nearly a 55-per-cent increase in labour utilized. Nearly 35 per cent of this increase could be identified as incremental hired labour.

Because labour requirements were specified by time period, an optimal seasonal distribution of labour was part of the model's output. The resulting figures suggest that, if anything, additional water supplies tend to increase the variance of labour demands. Since substantial labour migrations can be expected into areas in which water resources are being developed, it would be highly desirable for policy makers to anticipate the seasonality problems of migrant labour by planning and providing for non-seasonal construction jobs in the fields of education, health, irrigation, *etc.*

The last section of the paper demonstrates the use of the "dual" of the programming model in defining strategic areas for agricultural research. For example, the "shadow price" that exists for land in September and October due to the competition between summer crops not yet harvested and seedbed preparation for winter crops, indicates the value of research programmes which would create a time gap between the two crops and hence permit double cropping. Returns to such a "bottleneck breaking" approach appear to be quite high.

As indicated earlier, the models presented here are simple and there is much room for improvement in both their structure and in the estimation of parameters. It would be useful, for example, to know more about the effects of drought at different points in the plant's growth curve. It would also be desirable to incorporate the demand side of the economy into the model. In spite of their relatively simple nature, however, the foregoing exercises demonstrate that the programming approach can incorporate a variety of complicated relationships between water, animal power, land and output — relationships that would have been difficult to analyze using ordinary budgeting techniques. Since a significant number of agricultural planning problems *do* involve price and resource allocation problems, it seems reasonable to assume that the techniques employed in this study can be expanded and multiplied to serve an ever-widening audience of policy makers.

Appendix A

Diminishing Returns To Water

Methods of estimating most of the parameters of the model may be found elsewhere[1]. However, the central role of the water coefficients in the constraint matrix suggests that at least a brief description of their derivation be given at this point.

Although the model described above is a straightforward application of the linear programming technique, an attempt was made in the case of water to permit some deviations from fixed input proportions. Such a modification was felt to be necessary in view of the widely demonstrated diminishing response of plant growth to increments in water availability. For example, a large number of field experiments have shown that the water response curve for wheat has the shape indicated in Figure 7.

For inclusion in the model, the curve in Figure 7 was *approximated by* a step function[2]. The linear segments so derived became the basis for the wheat activities in the programme. (For example, X_{20} through X_{23} all refer to wheat). A similar procedure was applied to the remaining crops.

Since one of the primary objectives of the model was to take into account the importance of intraseasonal competition for resources in a climate where continuous cropping is possible, the second step in developing the water coefficients for wheat activities was to break down the total "delta" reported in the agronomic experiments into monthly requirements[3]. This was done by assuming that, for a given amount of water, the time distribution that would maximize the output of wheat was proportional to the monthly net consumptive use requirements[4]. That is, if the net consumptive use requirements of the month

[1]Gotsch [6]. Estimates of manpower needs by crop were obtained from the Indus Basin Special Survey [9] and are not included in [6].

[2]For a discussion of the methodology involved in developing suitable curves from a large number of experiments, *see* Gotsch [6; Chapter 4]. Further justification of the methodology can be found in the highly competent study by Yaron [17].

[3]"Delta" is the usual engineering shorthand for the amount of water applied per acre.

[4]Net consumptive use refers to the total calculated requirements of the plant (closely related to the evapo-transpiration on the area) minus the effective precipitation. Meeting consumptive use requirements insures that the plant is not hindered in its growth by moisture deficiencies.

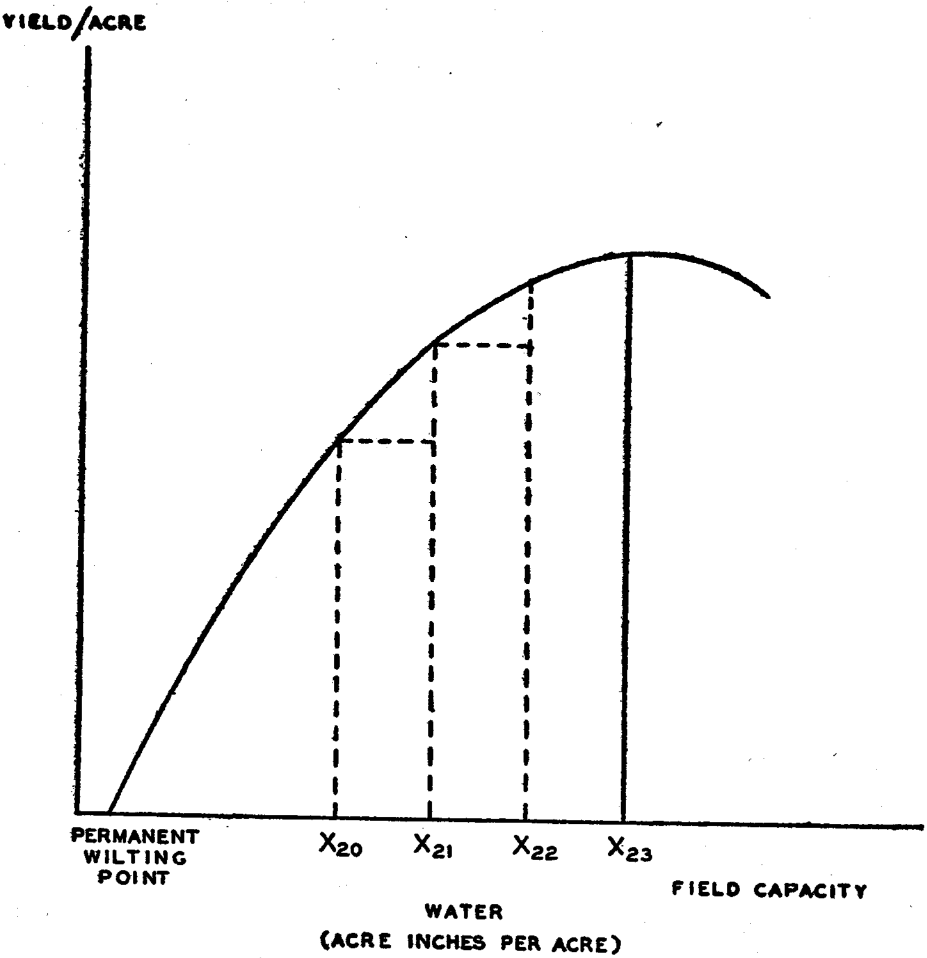

Figure 7. Approximated Water Response Curve for Wheat

of October was 20 per cent of the total requirement, water supplies which were less than the full requirements were also distributed so that 20 per cent of the available water was used in October.

The approach outlined above for obtaining monthly water coefficients for the constraint matrix, A, is clearly crude and does not include the recognition that optimal irrigation practices are essentially a sequential decision-making problem. The use of evapotranspiration estimates at point X_{23} in Figure 7 can be justified unambiguously. By definition there is no appreciable water shortage in any period and hence, the timing of water application is of marginal significance. But it is well known that in cases where the quantity of water available is less than that required for maximum yield, its distribution over the growing period of the plant is a significant determinant of the effect of moisture shortages. Nevertheless, until more empirical material on the effects of drought at various points on the plant's growth stage curve becomes available, the approximation suggested above permitted the inclusion in the model of a good deal of information on the timing of water requirements and water availability.

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