

Improving Irrigated Agriculture
Institutional Reform and the Small Farmer

Daniel W. Bromley

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ABSTRACT OF THE STUDY

Irrigation is a technological and institutional innovation which permits cultivation of lands otherwise ill-suited to agriculture. The institutional environment in which irrigation takes place is critical to the successful operation of any system. This institutional environment has received little analytical attention by those concerned with irrigation.

A model of farmer interdependence is developed and is related to the concept of farmers as cautious optimizers. This allows a focus on institutional uncertainty as a major impediment to creating irrigation systems which meet both efficiency and equity goals.

Suggestions for improving existing irrigation systems—and for designing new ones—are derived from the framework.

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PREFACE

i. This represents an early attempt to develop a conceptual model of farmer behavior in irrigated agriculture for the purpose of then deducing logical programs for improving the economic situation of small-scale irrigators. I have relied on three major sources for ideas. The first is my own experience in working with small-scale irrigators in the Philippines and the Dominican Republic, and in talking with irrigation administrators in Thailand and Malaysia. Additionally, my own research efforts concerning irrigation problems in Pakistan were valuable.

ii. The second source is the published literature listed at the end of this report. The section entitled "Literature Cited" contains that material directly referred to here; the section entitled "Additional References" contains material surveyed during earlier work on irrigation.

iii. The third source of ideas---and usually the most **helpful--is** the personal interviews and discussions with a number of individuals knowledgeable about irrigated agriculture in the developing countries. These discussions have occurred over the past 5 years in 7-8 developing countries, and more recently (during the period May-July 1979) involved researchers and irrigation administrators in England, India, Malaysia and Thailand. In this regard I am grateful to Tony Barnett and John C. Harriss of the School of Development Studies at the University of East Anglia, Norwich, England; Anthony Bottrall of the Overseas Development Institute, London; Vira Chankong, Pradit **Normongkol**, Suruvuth Pradisthananda and Sacha Sethaputra of Khon Kaen University, Thailand; Walt Coward of Cornell University; K. Gopalakrishnaya, Waheeduddin Khan, M. N. Kulkarni and K. K. Singh of the Administrative Staff College, Hyderabad, India; Yujiro Hayami, Tokyo Metropolitan University; Don Parker, University of Denver; P. C. Sun, Kunio Takase and S. C. Hsieh of the Asian Development Bank, Manila; Frances and David Korten of the Ford Foundation, Manila; Roberto Lenton and David Seckler of the Ford Foundation, New Delhi; Donald Taylor, South Dakota State University; Sam Johnson of the Ford Foundation, Bangkok; and at the World Bank, H. Binswanger, P. Ljung, J. Olivares, F. **Hotes**, A. Sfeir-Younis and I.J. Singh.

SUMMARY

- i. Irrigation is a technological and institutional innovation which permits cultivation of lands otherwise ill-suited for agriculture. The institutional environment in which irrigation takes place is critical to the successful operation of any system. This institutional environment has received little analytical attention by those concerned with irrigation.
- ii. Irrigated agriculture is characterized by physical interdependence which links farmers via the watercourse. (One's control over water availability is known to be a function of the number of other irrigators located along the watercourse.) On watercourses where all farmers are of similar political and economic power, those located some distance from the head of the system still find themselves vulnerable to the water schedule of those upstream.
- iii. Three dominant themes prevail throughout the paper. First, an irrigation system implies a physical linkage among farmers along a watercourse. This linkage introduces interdependence among economic units that is referred to as a technological externality. Such influence does not carry with it compensation. In irrigated agriculture, we have a situation in which a downstream irrigator receives water at the discretion of those upstream on the watercourse. With this sort of physical interdependence among farmers along the watercourse, independent economic activity leads to both inefficiency and inequity. One implication for project planning relates to the issue of homogeneity among farmers on a watercourse. In areas where there is a degree of socioeconomic difference among farmers to be served by a new watercourse, we simply compound those differences over the long run if the engineering works and the institutional arrangements over water allocation are not designed very carefully. Where the problem is one of improving existing irrigation systems, we have less flexibility in rearranging physical facilities to meet socioeconomic realities. In these cases, the only solution is to make up for heterogeneity along a watercourse with a more forceful institutional arrangement.
- iv. Second, institutional uncertainty. A society operates with the aid of indispensable rules and conventions which are collectively referred to as institutions. Property rights are the essence of predictability in these rules and conventions. Irrigation systems are characterized by Institutional uncertainty in that the rules and conventions for water allocation are more often than not ignored by some of the Irrigators. Some farmers on the system receive little water, or only at random intervals, and so are left with a most uncertain environment within which to make managerial decisions.
- v. Third, cautious optimization by farmers. Farming is characterized as adaptive behavior, based upon feedback from prior experiences. On an irrigation system, where institutional uncertainty is often pronounced, caution shows up as an unwillingness to adopt more productive cultural practices (e.g., HYVs) because of an inability to count on the necessary water receipts when they are most needed.

vi. A model of farmers interdependence is developed and is related to the concept of farmers as cautious optimizers- This allows a focus on institutional uncertainty as a major impediment to creating irrigation systems which meet both efficiency and equity goals.

vii. Several case studies are presented in the paper to highlight the sorts of institutional problems found on irrigation schemes around the world. The purpose of these regional illustrations is simply to show several ways in which current management of irrigation water is inimical to the objectives of both efficiency and equity* The salient lesson is that there is either the wrong type of control or no control at all.

viii. The paper concludes that physical interdependence brought on by irrigation requires an administrative system cognizant of this interdependence and structured in such a way that the interests of the small farmer are given protection. This general process is referred to as intensification^{cm}. The intent is to establish a relationship between productive agriculture and the application of management to the total agricultural enterprise (which must include water). The countries in which poor water management occurs are precisely those in which a minimal effort is expended toward the intensification of agriculture. On the other hand, countries in which such careful attention has been paid to water management also seem to be those countries with extremely high yields.

ix. The paper emphasizes that in irrigation projects not only technical, economic and financial aspects should be appraised. The project cycle should also consider a careful assessment of institutional arrangements. This would include principles regarding water allocation, maintenance schedules and responsibilities, fee payments, and the like. Part of this appraisal would concern with the likely viability of water users organizations; another part would concern the existing irrigation bureaucracy. Finally, with regard to the economic analysis, farm budgeting analysis should distinguish farmers depending on their location on the watercourse and ensure that monetary benefits received by small and low-income farms are given proper weight.

IMPROVED IRRIGATED AGRICULTURE:
INSTITUTIONAL REFORM AND THE SMALL FARMERS

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I. INTRODUCTION

1.01 Irrigation is a cultural adaptation to situations in which nature provides rainfall in too meager quantities for cultivation of certain valuable **crops**. The shortage may have a seasonal component, or it may be too arid **through** the full year. Whatever the case, the manipulation of surface and groundwater has become a dominant part of man's relentless pursuit of enough to **eat**. In Table 1 we see a tabulation of the cultivated and irrigated land, by region of the world in 1975. While irrigated lands accounted for only 12% of the total cultivated area, the majority of this land is devoted to high-valued and/or crucial food crops. The regions of the world of interest in **this** report—Asia, Latin America and Africa—contained (in 1975) approximately 77% of the world's cropped lands and approximately 75% of the irrigated lands. **Within these** three regions, Asia contained 42% of the cropped land and 95% of the irrigated land. While irrigation is locally important in several countries of Latin America and Africa, it is the dominant form of agriculture in most of the countries of Southeast Asia. Before continuing, it is important to recall **that the** term "irrigated" must be interpreted with some caution. It is often **difficult** to determine the extent of irrigation from published reports. There is considerable variation among sources in reporting irrigation, and it can **mean that** a unit of land receives water at some time during the crop season or **that the** land is regularly irrigated. Hence, the data in Table 1 should be **viewed as** suggestive rather than as definitive.

1.02 Our interest in this report is with irrigated agriculture and small **farmers—the** farmers who depend on water within those systems, especially small **farmers**. It is our intent to develop a theoretical framework which allows us to analyze the current behavior of small irrigators and to relate that behavior to **the** way in which their irrigation supply system operates. We will argue **that** their behavior in certain important respects is directly related to the **way that** an irrigation system functions (or fails to function). This model will provide the conceptual rationale for programs to alter the operation of **irrigation systems**. That is, we are not interested in improving irrigation **systems**, merely to make them more "efficient" in their use of water from an agronomic or engineering point of view. Our interest here is one of working on an important element in the decision structure of a small farmer; we seek to **improve the** operation of irrigation systems because that will improve the **operation** of small farmers, because that will provide more food for them and **for their country**, and because that will provide them a better diet and an **increased** level of income. Improvement in the irrigation system becomes a **proximate** goal—an instrumental variable—which is to be manipulated for the **benefit** of the farmer and the nation.

1.03 Any discussion of irrigated agriculture must commence with a discussion of the nature of the relevant decision unit. In conventional economics, **the concept of** a firm denotes a decision unit over which fixed and variable **factors of** production are manipulated for the benefit of the "owners" of the **firm**. The presumption being that the owners are in full control of the **relevant variables** such as fertilizer, water, seeds, labor use, planting dates, **harvest dates**, sales decisions and so on. This does not mean that each firm **must have absolute** control over **all** variables. What it does mean is that firms **in similar** industries have similar control over the same general variables.

Table 1A: LAND USE, BY REGION

REGION	AREA CROPPED ^{1/} (million ha)					IDLE ARABLE LAND ^{1/} (million ha)			TOTAL ARABLE LAND	PROPORTION of IRRIGATED LAND (%) ^{4/}
	RAINFED ONLY	IRRIGATED ^{2/}			TOTAL	RAINFED LAND	ARID ^{3/} LAND	TOTAL		
		RAINFED	ARID	TOTAL						
1. East Africa	62.3	1.3	0	1.3	63.7	297.5	*	297.6	361.2	2.0
2. West Africa	119.5	0.5	*	0.5	120.0	173.3	*	173.3	293.3	0.4
3. East Asia & Pacific ^{5/}	48.7	12.5	0	12.5	61.2	44.2	0	44.2	105.3	20.4
4. South Asia	155.7	37.1	10.3	47.4	203.1	23.3	3.7	27.0	230.0	23.3
5. EMENA	105.5	19.2	5.4	24.6	130.1	50.6	3.1	53.7	183.8	18.9
6. LAC	160.8	9.0	3.0	12.0	172.8	516.9	3.2	520.0	692.9	6.9
TOTAL	652.5	79.7	18.8	98.4	750.9	1,105.7	10.0	1,115.7	1,866.7	13.1

^{1/} Columns and rows may not add due to rounding of figures.

^{2/} Includes partially irrigated areas needing rehabilitation, upgrading or reconstruction.

^{3/} Area considered irrigable.

^{4/} Hectares irrigated expressed as a percentage of total area cropped in 1975.

^{5/} Does not include data for China, which has 99.5 million ha of arable land, 47.0 million ha of which are irrigated.

* Less than 50,000 hectares.

Table 1B: POTENTIAL FOR IRRIGATION EXPANSION

REGION	POTENTIAL EXPANSION IN CROPPED AREA ^{1/} (million ha)					TOTAL POTENTIAL CROPPED LAND ^{2/} (million ha)					POTENTIAL FOR EXPANSION ^{3/} (%)	
	RAINFED ONLY	IRRIGATED			TOTAL	RAINFED ONLY	IRRIGATED			TOTAL	RAINFED AGRIC.	IRRIG. LAND
		RAINFED	ARID	TOTAL			RAINFED	ARID	TOTAL			
1. East Africa	291.8	5.7	*	5.7	297.6	354.2	7.0	*	7.1	361.2	470.0	440.0
2. West Africa	166.8	6.4	*	6.4	173.3	286.3	7.0	*	7.0	293.3	140.0	130.0
3. East Asia & Pacific ^{4/}	30.6	13.6	0	13.6	44.2	79.3	26.1	0	26.1	105.3	60.0	110.0
4. South Asia	-117.8	141.1	3.7	144.9	27.0	37.8	178.2	14.0	192.2	230.0	-80.0	310.0
5. EMENA ^{5/}	40.9	9.7	3.1	12.8	53.7	146.4	28.9	8.5	37.4	183.8	40.0	50.0
6. LAC	486.5	30.5	3.2	33.7	520.0	647.2	39.5	6.2	45.7	692.9	300.0	280.0
TOTAL	898.7	207.0	10.0	217.0	1,115.7	1,551.2	286.6	28.7	315.5	1,866.7	140.0	220.0

^{1/} Columns and rows may not add due to rounding of figures.

^{2/} Area cropped in 1975 plus potential expansion in cropped area.

^{3/} Potential expansion in cropped area expressed as a percentage of 1975 levels.

^{4/} Data for China are not available.

^{5/} Data for potential expansion in Yugoslavia were not available and were assumed to be zero.

* Less than 50,000 hectares.

Source: Data for Romania (1980), Portugal (1978), Yugoslavia (1976) and China (1980) are from World Bank sources. Data for all other countries are from FAO for 1975.

1.04 Our conventional agricultural assistance holds this picture of the farm firm, even when we deal with tenant farmers who operate at the mercy of a powerful landlord. In these cases we are concerned with ways in which that control exerted by the landlord influences the decision making of the tenant farmer* While there is an extensive theoretical literature on landlord-tenant relations, we do not have anything comparable-in irrigated agriculture. Those writers who deal with irrigation are aware of the special problems, but there has been little integration of this irrigation literature with the conventional agricultural development literature. The irrigation literature is largely concerned with illustrating the poor water management practices in effect around the worlds and with suggesting organizational solutions to these problems. The agricultural development literature generally treats irrigation water as just another input along with labor and fertilizer. There is rarely any recognition of the special nature of irrigated agriculture.

1.05 Three dominant themes will prevail throughout the following discussion. First, an irrigation system implies a physical linkage among farmers along a watercourse.. This linkage introduces interdependence among economic units that is referred to as a technological externality. Such externalities are present whenever an individual's production or utility function includes real (i.e., nonmonetary) variables which are influenced by other economic units. Additionally, such influence does not carry with it compensation for these values which are chosen by others. In irrigated agriculture we have a situation in which a downstream irrigator receives water at the discretion of those upstream on the watercourse. With this sort of physical interdependence among farmers along the watercourse, independent economic activity leads to both inefficiency and inequity.

1.06 The second theme concerns institutional uncertainty. A society--and an economic system--operates with the aid of indispensable rules and conventions which are collectively referred to as institutions. An essential element in the creative activity of entrepreneurs is some degree of predictability over these institutional arrangements--property rights are the essence of predictability in these rules and conventions. When such rules are only selectively followed--or are changed in an arbitrary manner--the best plans of entrepreneurs are confounded. Irrigation systems are characterized by institutional uncertainty in that the rules and conventions for water, allocation are more often than not ignored by some of the irrigators. When this persists with impunity, those able to manipulate the rules--or simply ignore them--acquire a form of property right (even if it is only presumptuous) over the income stream which water can create. Other farmers on the system receive little water, or only at random intervals, and so are left with a most uncertain environment within which to make managerial decisions. The advent of rather sophisticated irrigation technology in the form of concrete ditches, pumps, control gates, and so on, appears to promise improved agriculture for all of those fortunate enough to be located on an irrigation system. However, the presence of institutional uncertainty means that, in the majority of cases', the new benefits are available to only a subset of farmers--those able to take advantage of the loose institutional structure which characterizes many irrigation systems in the developing countries.

1.07 The third theme concerns cautious optimization by farmers. Farming is characterized as adaptive behavior, based upon feedback from prior experiences. On an Irrigation system, where institutional uncertainty is often pronounced, caution shows up as an unwillingness to adopt more productive cultural practices (HYVs) because of an inability to count on the necessary water receipts when they are most needed.

1.08 Cautious optimization is not necessarily bad in and of itself. But in irrigated agriculture our concern lies with the reasons for its persistence. The physical interdependence among irrigators, the pervasiveness of institutional uncertainty, and cautious optimization combine to create a situation in which more productive farming practices are avoided by farmers.

1.09 The purpose of the discussion which follows is to bring together concepts of physical Interdependence (technological externalities), institutional uncertainty and cautious optimization to explain the behavior of farmers on an Irrigation system—but especially small farmers. Out of this integration will come some specific policy recommendations for improving the economic environment of such farmers in the developing countries.

II. IRRIGATION AND THE SMALL FARMER

2.01 In this chapter we will be concerned with the economic environment of the small irrigation farmer. The presentation will focus on the essential economic fact of irrigation—that of the physical interdependence of farmers linked by an irrigation canal and their joint use of the scarce water.

A. Model of Farmer Interdependence

2.02 We will build upon the concept of externalities to develop a model of physical interdependence among farmers situated on an irrigation system or project. ^{1/} This physical interdependence is in contrast to the normal type of market interdependence we take for granted. In the usual notion of interdependence, all farmers are linked together in certain input and output markets by virtue of the fact that they all bid for the same factors of production or must sell their output in the same markets. If the supply of seeds or fertilizers is less than perfectly elastic, then one's purchases reduce the quantity available for others—and this may drive up the price that subsequent buyers must pay. Similarly, in output markets the increased production by several farmers will drive down the product price such that other producers are made to suffer an income loss. Of course in our theory, we usually assume away these interdependencies. Or, if we do not assume them away, we label them pecuniary externalities. A pecuniary externality is a price-or cost--manifested change in the economic environment of firm i because of the actions taken by other firms in the same factor or product markets as i.

2.03 Pecuniary externalities are said to be of no economic interest—in a policy sense—because they merely reflect the workings of the market, and because they represent transfers of income instead of efficiency gains or losses. In the above example of factor price changes, the induced price increase arising from greater competition for a limited supply of factors merely transfers income from buyers of factors to suppliers of factors. These new rents to factor owners supposedly signal a greater interest in the production of said factors and will—in theory—eventually result in their increased availability. Once this occurs, their price will supposedly drop.

^{1/} Throughout, the term "project" or "system" will refer to a group of farmers located along a watercourse when all of them are served by one major outlet. That is, if a large canal carries water from a river and along that canal there are four major outlets to secondary canals, then we will refer to each of the four groups as separate projects.. Interdependence between or among projects will thus refer to reliance of several of the groups of farmers on the quantity of water in the major canal.

2.04 On the marketing side, if more farmers grow wheat than previously, thereby lowering its price, the gainers are consumers of wheat. If previous wheat growers suffer an income loss because of the new lower price, this is offset by the income gain of the consumers of wheat. The efficiency of the economic system has not changed, but the income released from its previous commitment to wheat may now be spent on other items.

2.05 But the sort of interdependence we have in mind here--and the foundation of the model of farmer interdependence--is referred to as technological externalities. The term to be used for the remainder of the paper is physical interdependence, and it should be understood that the interdependence refers to that created by the joint use of water resources as factors of production. We will elaborate on this interdependence by presenting a taxonomy of ways in which irrigators are physically linked.

2.06 The typical factors of production in irrigated agriculture are land, seed, fertilizer, pest control, labor, capital, rainfall, temperature, solar energy and irrigation. Of these, rainfall, temperature and solar energy are beyond the control of the farmer. Land is a fixed factor in most planning horizons, leaving the farmer to control the nature and the levels of seed, fertilizer, pest control, labor, capital and irrigation water. Of these factors, only two--pest control and irrigation water--are of a nature that physical interdependence among farmers will arise.

2.07 The example of pest control is obvious; if farmer A sprays for leaf hoppers, neighbors may reap some of the benefits from these efforts. But our interest here is in the physical interdependencies arising from irrigation. There are two types of interdependence in irrigated agriculture, those based on drainage of irrigation water and those "based on supply considerations." First consider drainage.

2.08 In those irrigated agriculture situations where water supply relative to the demand is not scarce, there can still be interdependencies arising from the fact that tail water from farm A will be carried to "downstream" farmers. The impacts could be several. Such tail water might carry toxic compounds and hence poison downstream drinking water. The tail water could be saline, thereby ruining downstream water quality for agriculture. Or, the tail water may simply not be wanted when it arrives and thus represents flooding. Another aspect of this interdependence would arise when a drainage ditch has limited capacity to remove water, and its use by farmer A means that the tail water from farmer B's field cannot be carried away.

2.09 It is important to recognize the interdependencies which can arise quite aside from water supply issues. But it is the supply interdependencies which attract the most attention. There are four major categories of supply interdependence: (1) individual pumps; (2) individual diversion; (3) joint pumps; and (4) joint diversion. Each will be discussed in turn.

Individual Pumps

2.10 There is a general impression that when farmers have their own pumps the supply interdependencies disappear. This is only true when the supply of

water is adequate given the demands for its use; in this sense then, we have a similar situation to surface water. It emphasizes the point that interdependence among farmers for water is a function of supply and demand rather than the fact that the water is below the ground or above it.

2.11 When farmers have their own pumps there are three possible situations. They pump from groundwater aquifers, directly from a river, or from a canal. When groundwater is being utilized, the extent of the interdependence is the most difficult to discern. Only with very precise monitoring of aquifer recharge and drawdown is it possible to know whether or not there is policy-relevant interdependence among farmers pumping from the aquifer. This interdependence would show up in terms of higher pumping costs as the water table recedes and in periodic requirements that wells be deepened.

2.12 When farmers pump directly from canals or rivers, the nature and extent of interdependence is more apparent. However, as before, if water supply is adequate vis-à-vis the demand placed on the water, there will be no policy problem.,

Individual Diversion

2.13 When individual farmers divert water directly from a river--a rare event except in small-scale mountain valley agriculture--there is an opportunity for water scarcity among farmers.

2.14 The more common situation is where individual farmers divert water from a canal--where "canal" here can mean a major watercourse, a secondary canal or a tertiary canal (ditch). When each farmer has a turnout from the water source, the sort of interdependencies which arise are the type that have received the bulk of the attention in the literature on irrigated agriculture. Here, inter-farmer conflict over scarce supplies is the major problem.

Joint Pump

2.15 When we turn our attention to joint pumping arrangements, we add an additional dimension for conflict among farmers arising from their interdependence. That is, not only do we have the types of interdependence discussed immediately above, but we also have the interdependence which arises from the jointness in supply at the pump set/stilling basin. This would be the same regardless of whether the source is groundwater, a river or a watercourse through a project.

Joint Diversion

2.16 The final category of farmer interdependence concerns the joint diversion of water from rivers or a canal. By joint **diversion**, we mean a situation in which water is diverted from its source and then shared among a number of farmers. The most obvious example is found in rice culture where water moves from paddy to paddy over some considerable distance. Here each farmer does not withdraw from a canal or ditch but instead depends upon the movement of water from an "upstream" paddy being farmed by another person.

2.17 Hence we find that the scarcity of water is a necessary condition for policy-relevant interdependence, and that such interdependence is the basis of inter-farmer conflict over water. Our interest here is confined to those situations in which conflict exists. For where water is adequate vis-à-vis the demand for water, we do not have an irrigation policy problem. We may need better seeds, more fertilizer, better pest management, improved crop production practices and the like. But it is not--by definition--an irrigation problem.

2.18 How might one express a basic interdependence among farmers in more formal terms? One way is through the specification of production functions for two or more farmers. In what follows, we will detail the case for two interdependent farmers; it should be kept in mind that this can be generalized to n farmers.

2.19 Start by considering two farmers mutually reliant upon limited water for irrigation. We can write the production function for farmer A as:

$$Y^A = Y(S^A, F^A, P^A, L^A, W^A, K^A, T^A) \quad (1)$$

where S^A is the seed varieties used

F^A is the application rate and timing of fertilizers

P^A is the pest management strategy of the farmer

L^A is the labor input

W^A is the quantity and timing of irrigation water received

K^A is the capital input

T^A is the land base of the farm

Likewise for farmer B we have a production function given by:

$$Y^B = Y(S^B, F^B, P^B, L^B, W^B, K^B, T^B) \quad (2)$$

where the symbols are as defined for farmer A.

2.20 However, this formulation fails to recognize the basic interdependence which exists between the two farmers over the scarce commodity, water. For we know that the water use by the "upstream" farmer (A in this case) has important implications for water availability to farmer B. We would thus need to reformulate the two production functions as:

$$Y^A = Y(S^A, F^A, P^A, L^A, W^A, K^A, T^A) \quad (3)$$

$$Y^B = Y(S^B, F^B, P^B, L^B, h(W^A), K^B, T^B) \quad (4)$$

where W^B has now been replaced by the expression $h(W^A)$.

2.21 This indicates that water use by B is a function of water use by A (and all other "upstream" farmers). If we consider only the two-farmers case, then it is possible to express water receipts for farmer B as:

$$W^B = \bar{W} - W^A \quad (5)$$

where $W^A + W^B = \bar{W}$, and \bar{W} represents the total available water per season, net of seepage and evaporation losses.

The vulnerability of the last farmer on the watercourse is emphasized by writing that farmer's water receipts as:

$$W^n = \bar{W} - W^A - W^B - \dots - W^{n-1} \quad (6)$$

where there are n farmers on the watercourse.

2.22 It is readily apparent in equation (4) that $h(W^A)$ is not a variable under the control of farmer B. This violates conventional economic theory where a firm is defined by a set of economic variables over which it has exclusive control. In a sense then, farmer B (and all other farmers who do not control the quantity or the timing of their water receipts) does not fit the classical notion of a firm. Indeed, it goes beyond this simple case. If we introduce the fact that seed varieties, fertilizer applications and the use of labor are functions of the expected water receipts for farmer B, we could write the production function as:

$$Y^B = Y(f(W^A), g(W^A), P^B, L^B, h(W^A), K^B, T^B), \quad (7)$$

where $S^B = f(W^A)$

and $F^B = g(W^A)$.

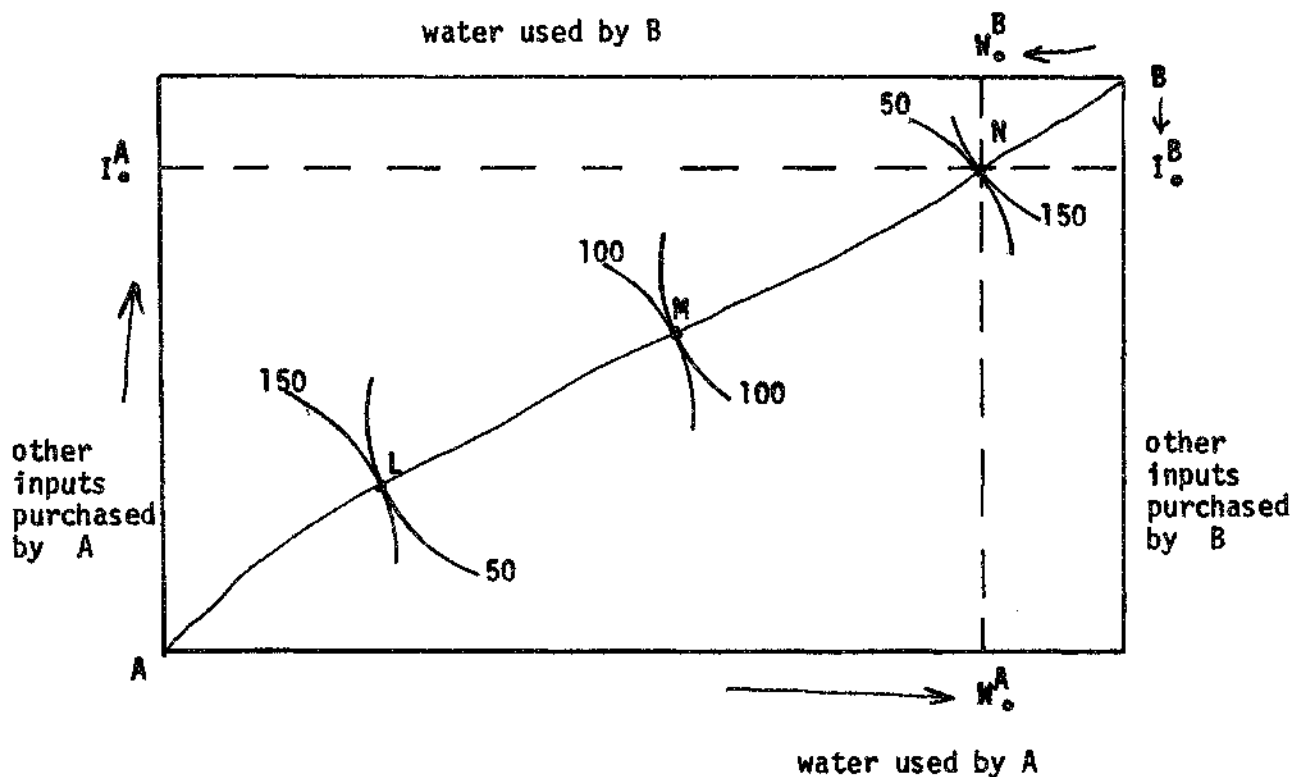
2.23 Before moving on to an elaboration of the above interdependence model, it warrants mention that water control comprehends quantity, timeliness and reliability of water receipts. The above formulation lends rigor to the notion of quantity but ignores timeliness and reliability. This omission is necessitated by the desire to keep the formulation simple. However, the issue

of reliability is sufficiently important that some brief discussion is necessary. We can differentiate reliability from timeliness by noting that the latter concept is a function of the crop needs of the farmer. **When** plants are stressed, it is important that water be applied before harm occurs. If water is not received at the exact time., the quantity or quality of the yield **can be** seriously jeopardized.

2.24 Reliability of water receipts is more concerned with the planning of the farm operation, and the expectations on the part of the farmer with respect to the ability to obtain water when the plants require it. Given the need for timeliness of water receipts of a certain quantity, the expected reliability of the system to deliver that requirement becomes the dominant factor in the farmer's choice of enterprises and seed varieties. With rice, the newer varieties are less forgiving than the more rustic varieties of bad timing in water and fertilizer applications.

2.25 The nature of the **inter-farmer** conflict over limited irrigation water can be illustrated using the conventional Edgeworth diagram of Figure 1. If we assume that both farmers are efficient, and that farmer A is the upstream farmer, then farmer B must take what water is left after A's use and also adjust other farm inputs accordingly; a failure to adjust other inputs would mean that B is wasting seed and fertilizer when there is no water with which to gain maximum advantage from these other inputs.

Figure 1. EFFICIENT WATER ALLOCATION



2.26 Under these assumptions, we would find ourselves at point N in the figure. Here, of the \bar{W} of water available to A and B, farmer A is using W_O^A and farmer B must be content with W_O^B . Assuming efficiency on the part of both farmers, A would use I_O^A of other inputs (some composite of seed, fertilizer, pest control and labor) while farmer B would use I_O^B . The absolute limit on water availability at \bar{W} means that B can only get more water if A gets less. 1/ The locus of points L-M-N is referred to as the contract curve, implying that once resource allocation is such that productive efficiency has been attained--as evidenced by tangency of the two farmers' isoquants--further movements can only come about because of contracting between the two parties. When the inputs move in conventional markets, this notion of contracting is perhaps a satisfactory one; after all, one party might very easily approach the other and seek to acquire some of the latter's factors of production.

2.27 However, irrigation water in the developing countries is quite another matter. Rarely is it traded in markets analogous to those for fertilizer and seeds; indeed, in most countries, water markets are prohibited. The standard practice is to allocate water--in a formal sense--on the basis of land to be irrigated. The de facto allocation may be quite different from the de jure allocation. The allocation depicted in Figure 1 is de facto rather than de jure, and hence it is more appropriate to refer to the locus L-M-N as the conflict curve rather than the contract curve.

2.28 Reference to a conflict curve raises immediate questions about the location of the two farmers along the locus L-M-N. In conventional analysis, relative prices between inputs will determine their mix in the production process. But irrigation water is not priced on a per unit basis, and because of the difficulties in accurately measuring water on irrigation projects, it is probably unreasonable to expect that it could be so priced, except in special circumstances. The de facto position along the conflict curve is--in simplest terms--a function of the relative power of farmers A and B. 2/ When power is introduced into the analysis, the term conflict curve becomes more understandable. While we have difficulty treating power in a rigorous fashion in our economic theory, there is little doubt that the exercise of power in irrigated agriculture is pertinent to water allocation.

1/ The vertical dimension on the Edgeworth Box imposes an upper limit on the quantity of other inputs available to farmers A and B. Unlike water, this is not a realistic situation, since A and B should be restrained only by their respective budgets rather than by some absolute physical quantity. However, in Figure 1 it is possible to imagine the vertical dimension as representing the maximum quantity of other inputs which A and B would purchase, constrained by their fixed land base and by the aggregate quantity of water available to them (\bar{W}). Hence the horizontal dimension of the box is given by physical availability of water, while the vertical dimension is given by the technological relationships among land, water and other inputs.

2/ This has been emphasized in Bromley, Taylor and Parker [1980].

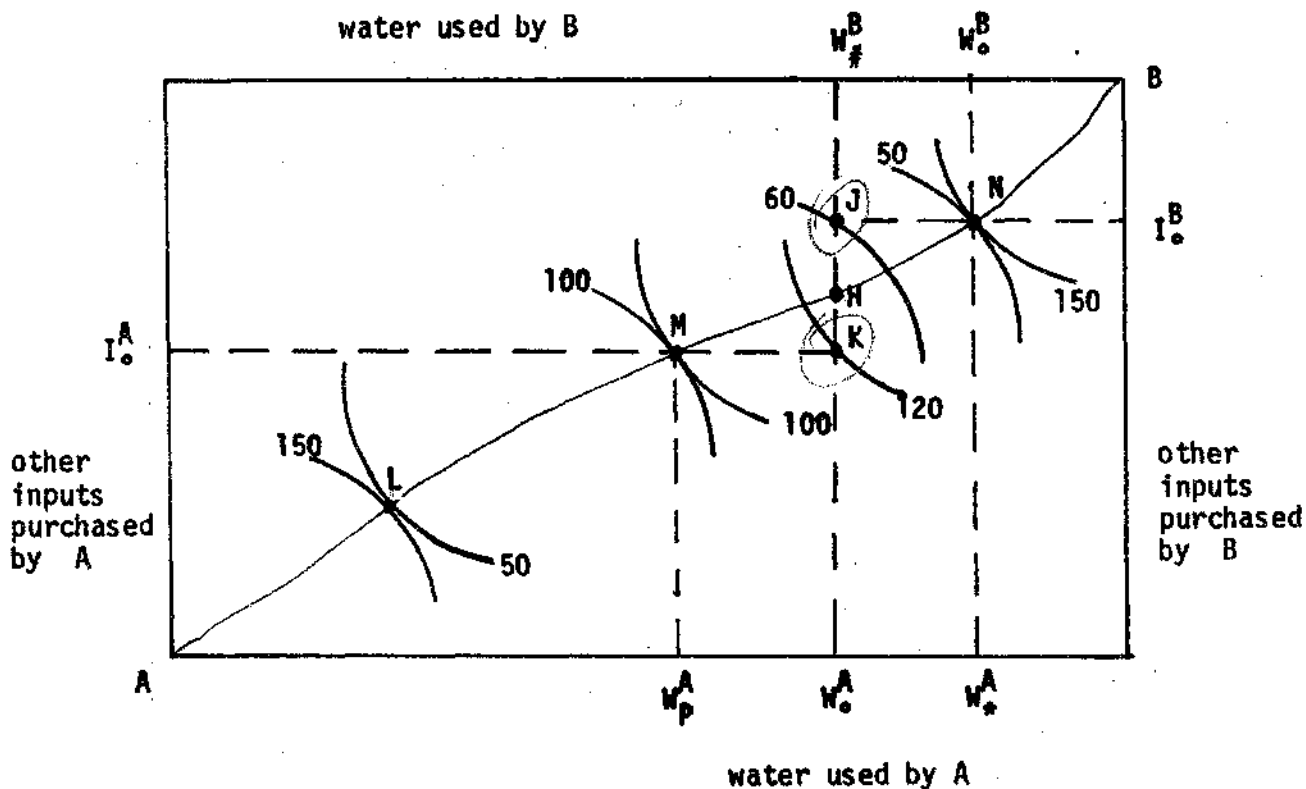
2.29 By power it is not necessary to have reference to brute strength or massive landholdings—though both surely do not hinder those so endowed. In irrigated agriculture, "power" can be something as innocent as position along the main canal or a tributary. Recall from equation (6) that any farmer's water receipts (quantity and timeliness) depend upon the number of irrigators upstream from the farmer in question, and their actions. They may not exercise great power at any one moment, but the downstream farmer is exposed to their exercise of discretion which comes from their more favorable position vis-à-vis the water source. In the language of John R. Commons, the upstream farmer has liberty which the downstream farmer does not have. What the downstream farmer has is exposure to the actions taken by the upstream farmer(s). If they do not hoard water, then the downstream farmer is not harmed. If they do take extra water, then the downstream farmer is harmed. The downstream farmer is vulnerable to the water management whims of those upstream, and for the tail-end farmer this can introduce great uncertainty. We have elsewhere referred to such a farmer as the least-advantaged farmer on a system [Bromley, Taylor and Parker, 1980].

2.30 The foregoing discussion has focused on farmer interdependence and the notion that some farmers are at the mercy of their upstream neighbors. By assuming efficiency in production on the "project," one was left with a problem of fairness or equity or justice among (or between) farmers. Economists are often reluctant to say that farmer B should get more water than at present, since it will require that farmer A gets less. Without knowing which farmer "deserves" more water—that is, without revelation of the prevailing social welfare function—we are at an analytical cul-de-sac. This makes it easy to dismiss the problem as one of politics and outside the domain of economics. However, such a conclusion is a mere artifact of the assumptions in the foregoing model. For it is rather more plausible to argue that the type of water problem under discussion creates important inefficiencies as well as equity problems. To locate inefficiencies is always to be assured of gaining the attention of an economist.

2.31 Consider Figure 2. Here we do not assume that both farmers are located on the efficiency locus L-M-N (the conflict curve). Indeed we assume that they are not on it, and that they will likely never attain it. Why might that be? To understand fully the inefficiencies inherent in the prevailing irrigated agriculture of the developing countries we must remind ourselves of the basic fact of agricultural production—it is spread over a considerable period of time, it is sequential, and with few exceptions there is "no going back." Add to this the fact that each decision is made on the basis of certain assumptions about the state of nature when the next decision must be made, and the foundation for an important problem has been laid.

2.32 When decisions are made about the amount of land to be cultivated during the coming season, or the particular crops to be planted, or the purchase of fertilizer, likely water availability and the probable timing of water receipts are crucial factors in these decisions. Now, when this sort of planning is undertaken by our upstream farmer (A), there is one set of expectations about each of these important issues. When the same questions are pondered by our downstream farmer (B), there is another set of expectations.

Figure 2. INEFFICIENT WATER ALLOCATION AND AGRICULTURAL PRODUCTION



We are quite safe in stating that the variances associated with the estimates for farmer B are greater than the variances associated with A's estimates. We are also safe in asserting that the variances of these estimates are an increasing function of the number of farmers upstream from the particular farmer under discussion.

2.33 Such variance in the above critical variables pertaining to water quantity and timeliness will have a chilling effect on certain farming practices of the "downstream" farmers. This has been extensively documented in the literature. ^{1/} How might this uncertainty show up in terms of economic efficiency?

2.34 The inefficiency arises because of the different degrees of control over requisite inputs on the part of A and B. If farmer A is the upstream farmer, we assume that he/she can plan the use of other inputs and water on the basis of previous experience and cropping desires for the coining

^{1/} This literature is reviewed extensively in Bromley, Taylor and Parker [1977], and is discussed briefly in Bromley, Taylor and Parker [1980].

season. Assume that this input combination would place farmer A at point M in Figure 2. Assume that A indeed purchases I_o^A of other inputs during the cropping season. However, instead of using W_o^A of irrigation water which is the correct amount given the level of other inputs being used, farmer A falls into the predictable pattern of taking a little more than necessary, just "to be sure." Assume that farmer A actually takes W_o^A of irrigation water.

2.35 Now what about farmer B? We can assume that history has taught B to be cautious in the purchase of water-dependent inputs because of the great unreliability of water receipts. Assume that B therefore uses I_o^B of other inputs during the course of the cropping season on the assumption that farmer A will use W_o^A , leaving only W_o^B for farmer B. However, we see that B was overly cautious since A took only W_o^A , leaving W_o^B for B to use. We can reasonably assume that B will take what water is available.

2.36 Thus we see that farmer A ends up at point K in Figure 2, using I_o^A of other inputs, and W_o^A of water. Farmer B ends up at point J in the figure, using I_o^B of other inputs, and W_o^B of water. Notice that neither farmer is on the efficiency locus L-M-N, and that total production between the two is less than it could be if they were at point H (180 from J and K versus 200 from H).

2.37 While the example here has depicted a one-period situation, it is not difficult to imagine that this sort of process occurs annually, as the interdependent farmers attempt to plan their own agricultural enterprise and anticipate the actions of other farmers with whom they are tied via irrigation water. As indicated previously, given this type of interdependence and uncertainty, it seems reasonable to suppose that only by accident would the two farmers be found on the efficiency locus. When the situation is generalized to a large number of farmers on a watercourse, the accidental nature of productive efficiency is underscored.

2.38 Of course a related problem arises when farmer B underestimates the amount of water to be taken by A and purchases complementary inputs (I_o^B) in a greater quantity than is optimal for the amount of water that will in fact be available. Either situation is detrimental to B and sufficient cause for B to remain off of the conflict curve. We are not so concerned whether downstream farmers overestimate or underestimate the amount of water to be used upstream. The crucial issue is that downstream farmers face an added degree of uncertainty in farm enterprise planning which introduces an important element of productive inefficiency into the agricultural sector. In the face of continued population pressure in the productive capacity of most of the developing countries, such inefficiencies are extremely costly.

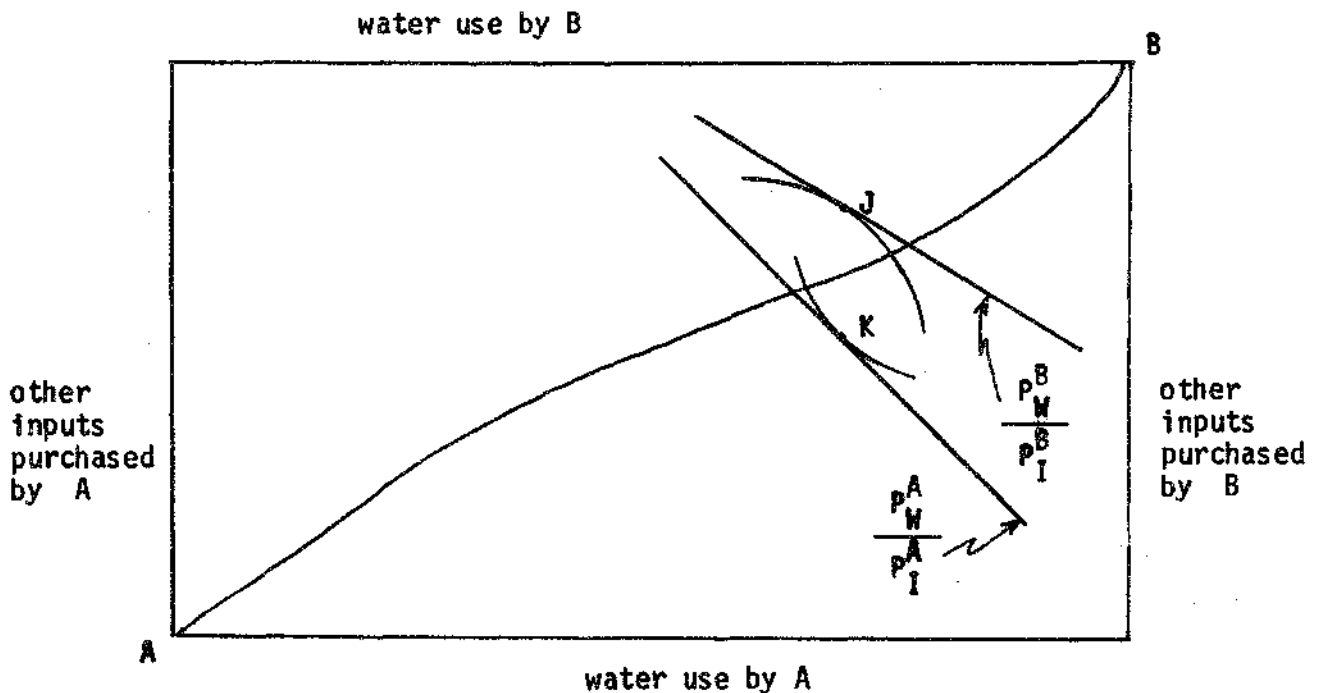
2.39 The obvious question now is how can it be possible for this sort of obvious disequilibrium to be sustained? For our theory tells us that a stable equilibrium is one in which relative factor prices are brought into equality with relative marginal rates of technical substitution between inputs (in this case, water and the composite of other inputs). The disequilibrium inherent in Figure 2 is sustained by differential factor prices paid by farmer A and farmer B. There is increasing recognition that all farmers do not purchase

inputs for identical factor prices as our theory would indicate, and some of this literature will be mentioned momentarily. For now let us consider what would happen if there is a difference between the types of farmers located at the head of an irrigation system and those located at the tail. That is, assume for the moment that those located at the head of a system are larger and more influential in the local economy, and that they therefore are able to obtain certain inputs at a lower price than those with less influence. If we assume that these latter (smaller) farmers happen also to be concentrated at the tail end of irrigation systems, it is possible to see how the sort of "disequilibrium" discussed above could persist.

2.40 Hence, not only are the tail-end farmers (B) exposed to the water-use whims of the upstream farmers (A), but they pay somewhat more for the same agricultural inputs. It is this difference in factor prices which permits a stable "disequilibrium" to exist. In Figure 3 we see the relevant price lines for A and B relating the unit cost of water with the unit cost of the composite "other inputs." The two relative prices are given by:

$$\frac{P_W^A}{P_I^A} > \frac{P_W^B}{P_I^B} \quad (8)$$

Figure 3. A SUSTAINABLE DISEQUILIBRIUM IN IRRIGATED AGRICULTURE



2.41 We can assume that the unit cost of water as between the two farmers is equal--and quite low. This would be the case in the vast majority of the developing countries where water is sold in large "blocks" depending upon the land area to be irrigated. With equation (8) and the condition that

$$P_W^A = P_W^B, \quad (9)$$

it follows immediately that

$$P_I^A < P_I^B. \quad (10)$$

2.42 A different sort of stable "disequilibrium" is possible from a situation in which both A and B pay the same unit price for other inputs, but different unit prices for water. This may be the more prevalent case for the simple reason that water is not priced on a per unit basis. That is, both A and B purchase water on a lump-sum basis per unit of land. However, if A receives much more water than B, then his/her per unit price is less. This would compound the situation depicted in Figure 3 and would move A and B farther from the conflict curve.

2.43 In point of fact, we should not assume that $P_W^A = P_W^B$. While the fee paid by A and B to the water agency may indeed be equal, the situation will normally be one wherein the additional costs to the downstream farmer (B) are higher than for the upstream farmer (A). We refer to these extra costs as transaction costs. Such costs would include the extra time and effort necessary to insure delivery to the turnout, the extra "policing" of the ditch for illegal turnouts, water stealing and poor maintenance, plus the likely need to devote more time to ditch maintenance. In sum, the downstream farmer usually pays more for an equal quantity of water when costs are understood to include both cash and noncash elements. Moreover, to the extent that there is a discrepancy between the amount of water paid for, and the amount actually received by, the downstream farmer, the per unit cost difference between upstream and downstream farmer is further exacerbated.

2.44 In the foregoing we have discussed two different pricing assumptions. The first was that small farmers are often found to pay higher per unit costs for the same inputs than are larger farmers. We then discussed the fact that farmers near the tail of an irrigation system can be expected to pay more per unit of water received for two reasons. Firstly, water pricing is usually on a lump-sum basis before the season starts and is based on the quantity of land to be irrigated. When water receipts are finally reckoned, because of the losses which downstream farmers incur in those receipts, we would find that the actual price per unit is considerably higher than it was for those at the head of the system. Secondly, the increased burden of transaction costs which fall on those near the tail of a system mean that water is even more expensive on a per unit basis.

2.45 On an irrigation system where all the farms are considered "small", we have the possibility that those near the tail of the system are in even more difficult conditions than those near the head, although both groups may be paying more for their purchased inputs than larger farmers. When there is a mixture of large and small farmers on an irrigation system, the possibility exists for equity and efficiency problems among this limited set of irrigators. It is not necessary that the small farmers be located at the tail of the system and the large ones at the head. The small farmers can be randomly scattered along the watercourse and still experience large variability in water receipts. One cannot separate the irrigation aspects of agriculture from the larger social/political climate which exists at the village level. Small farmers are very often tenants (of the larger farmers) and may in fact be located among the same watercourse. It is idealistic to assume that these factors do not matter when it comes to reliability and quantity of water receipts.

B. Summary

2.46 Irrigated agriculture is characterized by physical interdependence which links farmers via the watercourse: the physical structure which brings them one of their most valuable inputs also ties them inextricably to their neighbors. One's control over water availability is known to be a function of the number of other irrigators located along the watercourse, and given differential power and economic influence, we find the small farmer on a system "with a mixture of large and small farmers in double jeopardy. That is, not only must this farmer contend with the usual problems of being on the edge of subsistence, but it is also necessary to contend with the exigencies of highly uncertain water receipts. On watercourses where all farmers are of similar political and economic power, those located some distance from the head of the system still find themselves vulnerable to the water schedule of those upstream.

2.47 This physical interdependence—a technological externality—introduces serious inefficiencies into irrigated agriculture, not to mention pervasive equity problems. When there is a mixture of powerful and subservient farmers on a watercourse, the inefficiencies can be stable because of different factor prices paid by the two classes of farmers. When this socioeconomic mixture is not present, it is still possible to have inefficiencies because of uncertain water receipts.

2.48 The recognition of different factor prices between the "commercial" sector and the subsistence sector is rather commonplace among economists. Grabowski cites evidence from work by Barbara Tuchman in Mexico, Keith Griffin in Indonesia, Joshi and Rao in India, and Robert Wade and Gunnar Myrdal [Grabowski, 1979]. A recent study by Berry and Cline [1979] indicates that borrowed capital for Indian farmers with holdings of less than 2 hectares is 17.3% per annum; for those with between 2 and 6 hectares, the per annum rate is 13.8%; for those with between 6 and 10 hectares, the per annum rate is 12.2%; and for those with over 10 hectares, the rate drops to 11.8% per annum.

2.49 In a test of Indian data, Surjit S. Bhalla (in an appendix to the Berry-Cline study) finds that the unit rental cost of land decreases by Rs 5-Rs 10 for each additional acre rented. His findings on capital markets are cited immediately above. In 1970-71, government, cooperatives and the commercial banks handled 30% of the total lending, compared to 19% in 1961-62 and only 7% in 1951-52. The private moneylenders' share declined over the same period from 75% to 50%; the remainder of credit is supplied by friends and relatives and by landlords. In 1974 the interest rates charged by commercial banks was 8.4%; it was 8.8% for government organizations and 8.9% for cooperatives. In contrast, the rate for moneylenders was 22.8%. Whereas the organizational lenders had fairly equal rates for the various farm sizes, moneylenders charged 22.5% for those farmers with less than 2 hectares, 20.9% for those with between 2 and 6 hectares, 23.3% for those with between 6 and 10 hectares, and only 16.3% for those with over 10 hectares. Finally, the imperfections in the labor market were found to be pervasive and greater than in either capital or land [Berry and Cline, Appendix A by S. S. Bhalla].

2.50 One implication for project planning relates to the issue of homogeneity among farmers on a watercourse. In areas where there is a degree of socioeconomic difference among farmers to be served by a new watercourse, we simply compound those differences over the long run if the engineering works and the institutional arrangements over water allocation are not designed very carefully. Through careful engineering, it might be possible to group rather similar classes of farmers on a watercourse. The danger here, however, is that one merely shifts the locus of conflict from the watercourse to the main canal serving several watercourses. However, if the irrigation bureaucracy is more powerful at the level of the main canal than at the watercourse—and this seems to be the general pattern—then we may have improved the situation.

2.51 Where the problem is one of improving existing irrigation systems, we have less flexibility in rearranging physical facilities to meet socioeconomic realities. In these cases, the only solution is to make up for heterogeneity along a watercourse with a more forceful institutional arrangement.

2.52 The basic problems associated with Irrigated agriculture arise because of the fact that the decision-making environment of the individual farmer is modified by others without compensation—this is the classic technological externality. While all farmers on an irrigation system face some uncertainty over the timing and quantity of water receipts, this uncertainty is removed from the head of the system.

For those near the end of the watercourse, uncertainty over water receipts introduces productive inefficiency and equity problems.

2.53 The essential problem for those wishing to assist in the improvement of irrigated agriculture is to understand the source of this uncertainty and how it differs from the usual uncertainty which is faced by all farmers. It is also important to understand the ways in which farmers respond to uncertainty. Once these aspects of the problem are well understood, we can turn our attention to the Improvement of Irrigated agriculture through various means to reduce this uncertainty.

III. THE ENVIRONMENT FOR CHOICE

3.01 In chapter II we were concerned with the physical linking which inevitably follows the joint use of a drainage ditch or a watercourse. This interdependence, when accompanied by persistent unreliability of water receipts, was seen to introduce productive inefficiencies into the agricultural sector. We now turn to a more definitive treatment of uncertainty within the context of adaptive behavior theory. 1/

A. Farming as Adaptive Behavior

3.02 The central element in the model of farmer interdependence in chapter II was the notion of farmer B's expectations about how much water would be available after A had taken a portion, and the timeliness of deliveries of that residual. This represents learned behavior on the part of B, for the situation has probably existed for as long as the two have been linked via the watercourse; B has learned through experience that A can be expected to take so much water and that there will thus be a certain quantity available once A is satisfied.

3.03 The essence of learned behavior is feedback—the receipt of information on the basis of certain behavior in the past. We assume that in the early days of the irrigation project, B might have had a presumption that all farmers would enjoy equal "access" to irrigation water—where access comprehends both quantity and timing. However, experience taught B that this was not to be. Early planning on the part of B was bound to be deficient because part of the economic environment was beyond his/her control. Along with the weather, disease and market prices, this new input (water) brought with it an element which introduced another stochastic constraint into daily economic planning. Not only must the farmer respond to—and anticipate—the normal vagaries of farming, but now the added vicissitudes introduced by one or several upstream irrigators must be reckoned with.

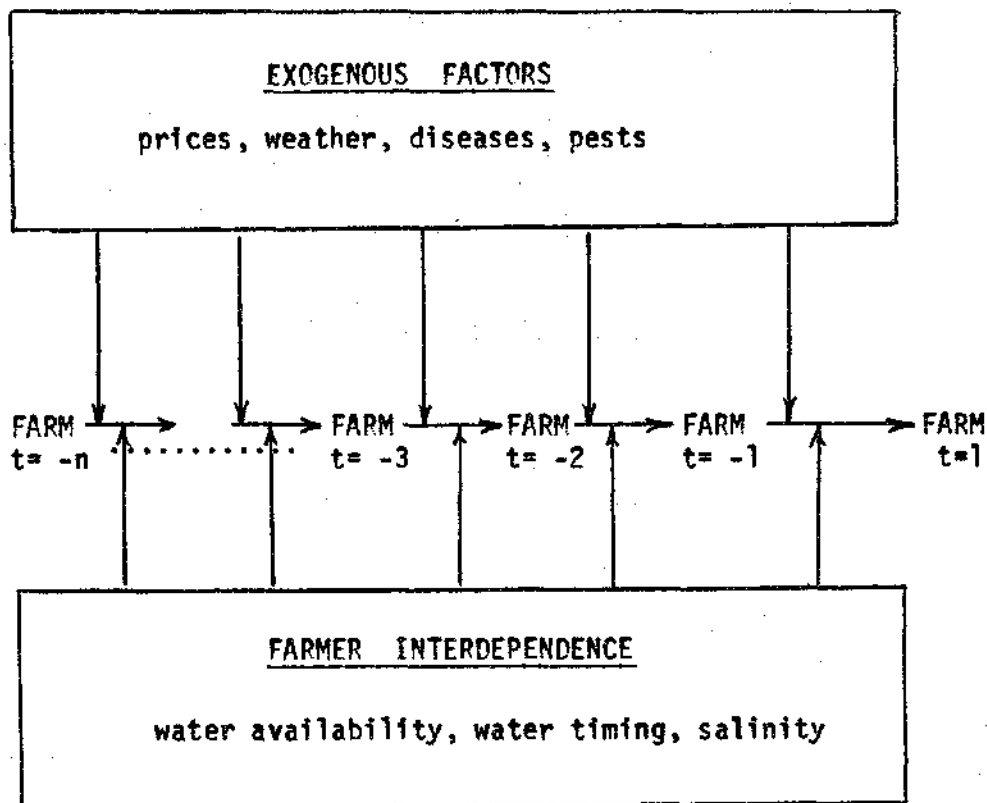
3.04 It requires no great wisdom to see that farming is—above all else—adaptive behavior. The central questions for development planning are, therefore, adaptation to what? What is the nature of that adaptation? How does adaptive behavior alter the choice set? How does adaptive behavior alter the goal set? And how can development activities incorporate these implications into the design of economic policy?

3.05 We have already talked about the forces to which the irrigation farmer must adapt—weather, crop diseases, uncertain supply of fertilizer, unknown prices for the product, the upstream farmers who have prior access

1/ This body of theory owes much of its development to Richard H. Day. A recent book represents an application to economic development: Economic Development as an Adaptive Process [Day and Singh, 1977].

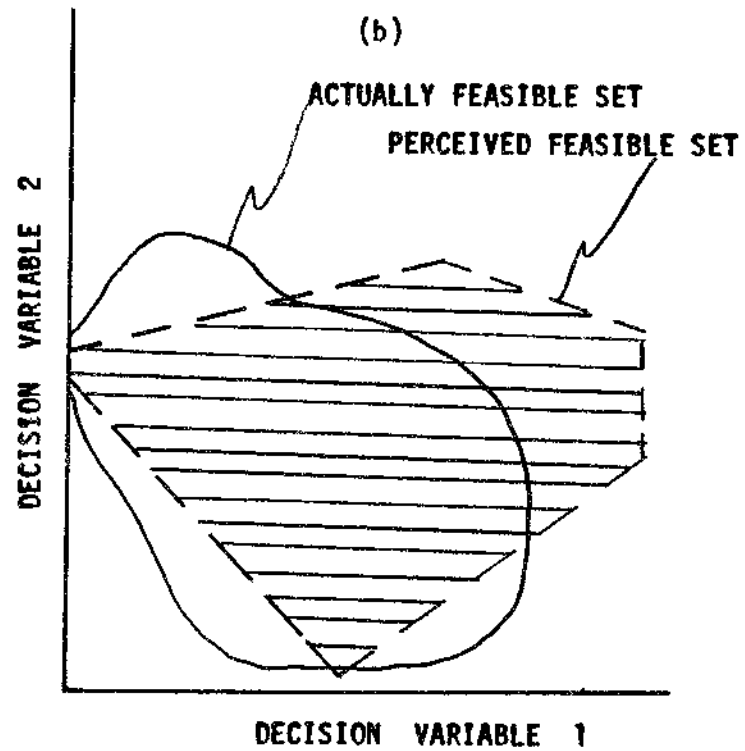
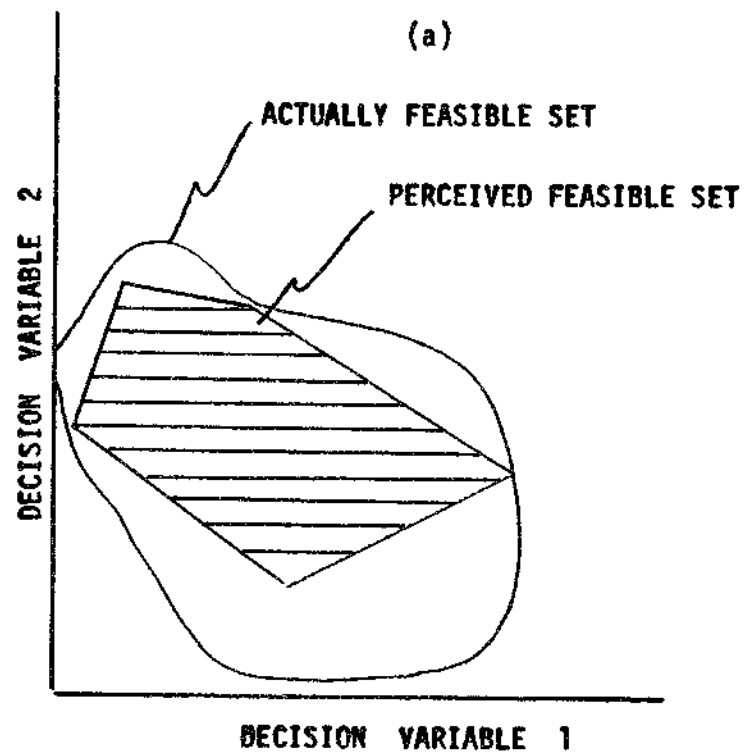
to scarce irrigation water. We can depict this feedback process by imagining two discrete time periods for the farmer: (i) the upcoming season, denoted by $t=1$; and (ii) the sum of recent experiences into which the array of exogenous forces have been incorporated: $t = (-1) + (-2) + \dots + (-n)$. This is depicted in Figure 4.

Figure 4. FEEDBACK INFLUENCES ON FARM DECISIONS IN $t=1$



3.06 The learned behavior of farmers can be thought of--in totality--as constituting a set of feasible management choices. The farmer knows, within certain bounds, what will "work" and what will not. Hence, the adaptation we have in mind here should not be thought of as a series of major adjustments. It is more correct to imagine them to be small changes from the normal pattern in light of experience, hunches, prognoses, extension-service advice, what the neighbors are thinking of doing, and even astrological indicators. With this input, the farmer is able to define what we would call a feasible set or a feasible range of enterprise and activity choices. Day and Singh draw attention to the important distinction between those choices which are perceived by the farmer to be feasible and those which are, in actuality, feasible. That it is important for the set of perceived feasible choices to lie completely inside of the set of actually feasible choices can be illustrated with Figure 5. In panel (a) of Figure 5, the actually feasible set contains the totality of the perceived feasible set. In panel (b), however,

Figure 5. ACTUAL AND PERCEIVED FEASIBLE SETS
(Adapted from Day and Singh, 1977)



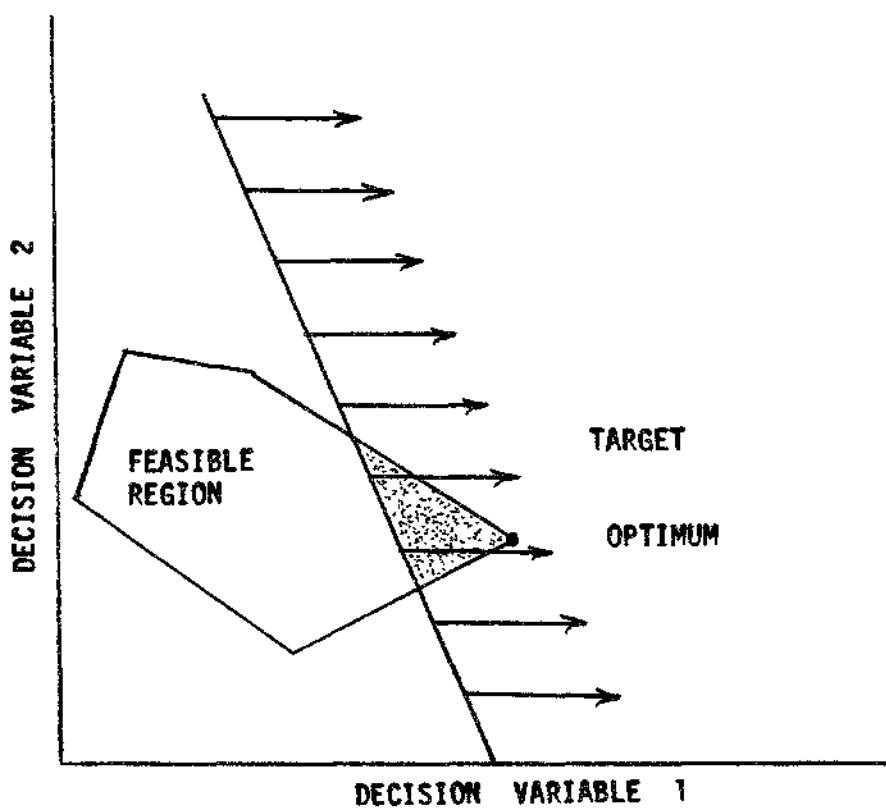
we see that the actually feasible set does not contain all of the set of choices perceived by the farmer. This means that the farmer is liable to make a choice with respect to one of the decision variables, which is not possible. An example might be the choice to plant 7.4 hectares but upon completion of land preparation discover that it is only possible to buy enough seed for 3.6 hectares. To go back to a previous example, the farmer may make an input purchase (say, fertilizer) on the assumption that water will be available at the critical time, only to apply the fertilizer and then discover that water is unavailable. The farmer avoids serious mistakes by avoiding situations in which the actually feasible set does not contain the totality of the perceived feasible set.

3.07 Day and Singh argue that when farmers are faced with extreme uncertainty, they will respond by behaving cautiously; this is the risk-aversion one sees in the literature. One aspect of cautious behavior is to restrict one's choice set to ensure that the perceived feasible set is totally contained in the actually feasible set. This would resemble panel (a) of Figure 5. Having altered the choice set in such a manner, the next question pertains to the nature of the goals of the farmer.

3.08 Much has been written on the nature of optimizing behavior, and we will spend little time on that here. The difference between optimizing and satisficing behavior, however, can be illustrated with the help of Figure 6. Optimizing behavior would focus the decision process on finding the optimum point and adjusting the decision variables under one's control so as to achieve this point; this is noted in the figure. Satisficing is being content with a larger target. In the figure it is more desirable to move to the northeast in terms of accomplishing the goals of the decision maker; the farther to the northeast, the better. However, satisficing behavior would indicate that some subset of the feasible region intersects the target region, and any outcome in this intersection is "good enough." This region is denoted in Figure 6 by the shading. There is no great preoccupation with finding the best solution--there are several which will do.

3.09 Day and Singh also introduce the concept of cautious optimizing. Here the farmer defines a region of safe-enough decisions, or what they call a zone of flexible response (ZFR). Here, rather than a target of moving in the general direction of the northeast, the farmer wishes to define a region in which serious mistakes might be avoided. This region is defined on the basis of feedback from prior experience. In panel (a) of Figure 7, some safe-enough solutions are also feasible. In panel (b) this is not the case; here the decision maker chooses that alternative which is closest to the set of safe-enough solutions (point M). Referring back to panel (a), once it is discovered that a safe-enough decision is also in the feasible set, it is possible to make the ultimate decision on the basis of some other criterion--say profit maximization. In this example, the safe-enough decision might be to assure a certain level of consumption in the farm household. This constraint defines a region as in panel (a). Then, within that set, the farmer may adjust variables 1 and 2 so as to maximize profit; this is constrained optimization where the constraint is some minimum diet for the family. It is also lexicographic decision making--once one dominant objective has been attained (food sufficiency), another can become relevant (profit maximization).

Figure 6. SATISFICING BEHAVIOR (Adapted from Day and Singh)



3.10 To summarize so far, adaptive economic behavior is said to be characterized by feedback from learned behavior and experiences to assist in the selection of decision variables for the next planning horizon. The decision goals are said to be cautious optimizing, or the selection of safe-enough outcomes. We must remember that feasible choice sets—or opportunity sets—differ across farmers. Some will have a rather large range of opportunities for decision making, while others will have a more restricted set. An example can be found in the capital market. A large farmer with secure land title has a greater choice of lending agencies than does the poor tenant farmer; this is an example of differential opportunity sets between the two. Likewise, the large farmer may have sufficient production that buyers will come to him/her and may actually bid for the crop. In contrast, the small farmer may be lucky to find one buyer for the small amount left over after the family's subsistence needs have been met. Finally, with respect to irrigation, the farmer at the end of the watercourse will have fewer options than the farmer located at the head of the system. Again, the one at the end of the ditch has a more restricted opportunity (choice) set than does the farmer at the head of the canal. We can use the previous examples of feasible regions to depict this phenomenon in Figure 8.

Figure 7. CAUTIOUS OPTIMIZING
(Adapted from Day and Singh)

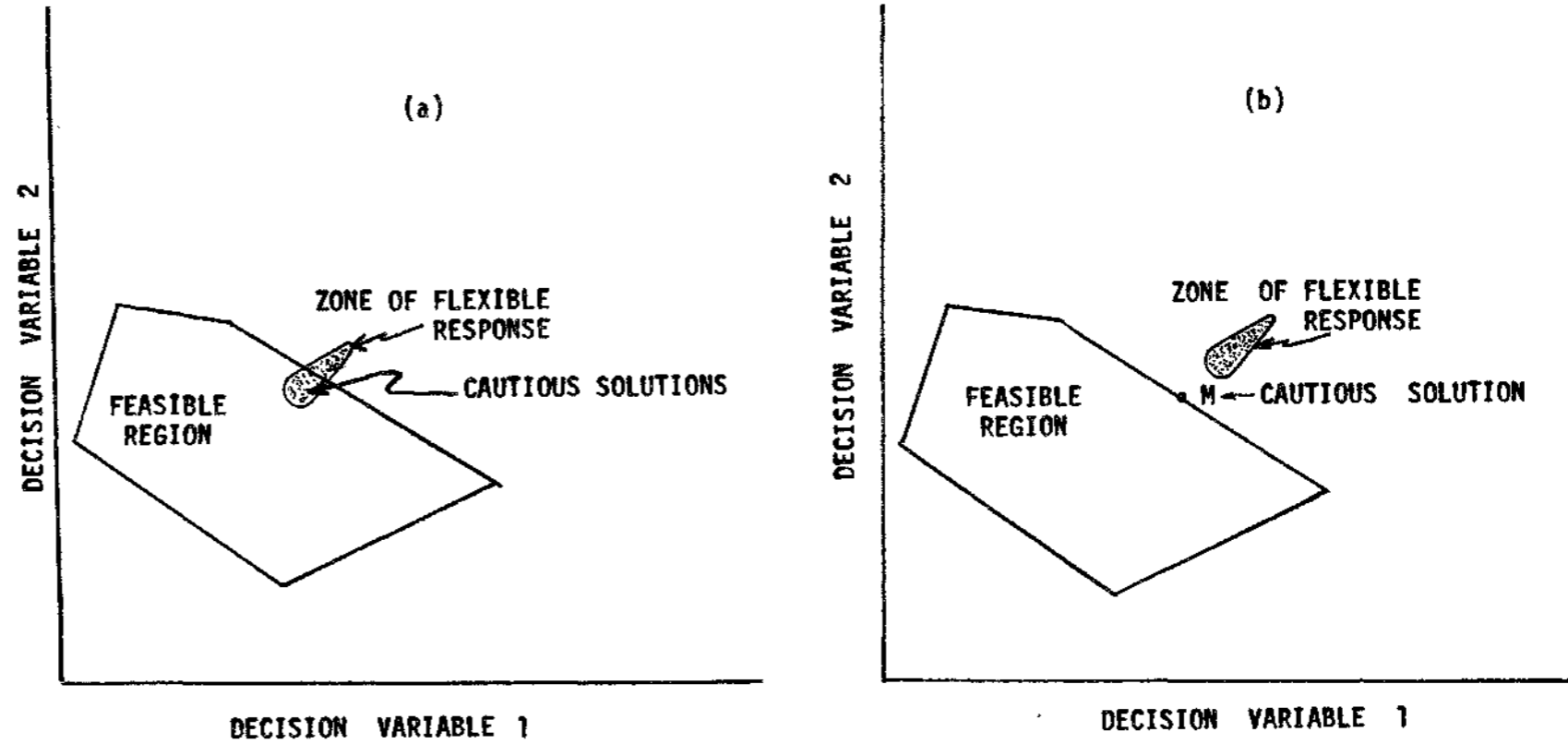
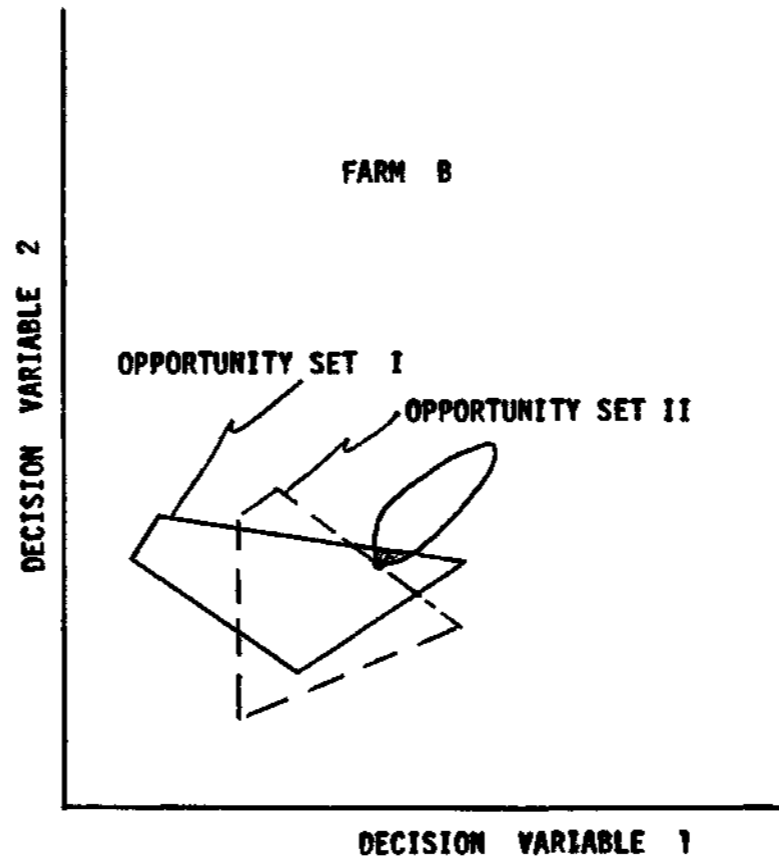
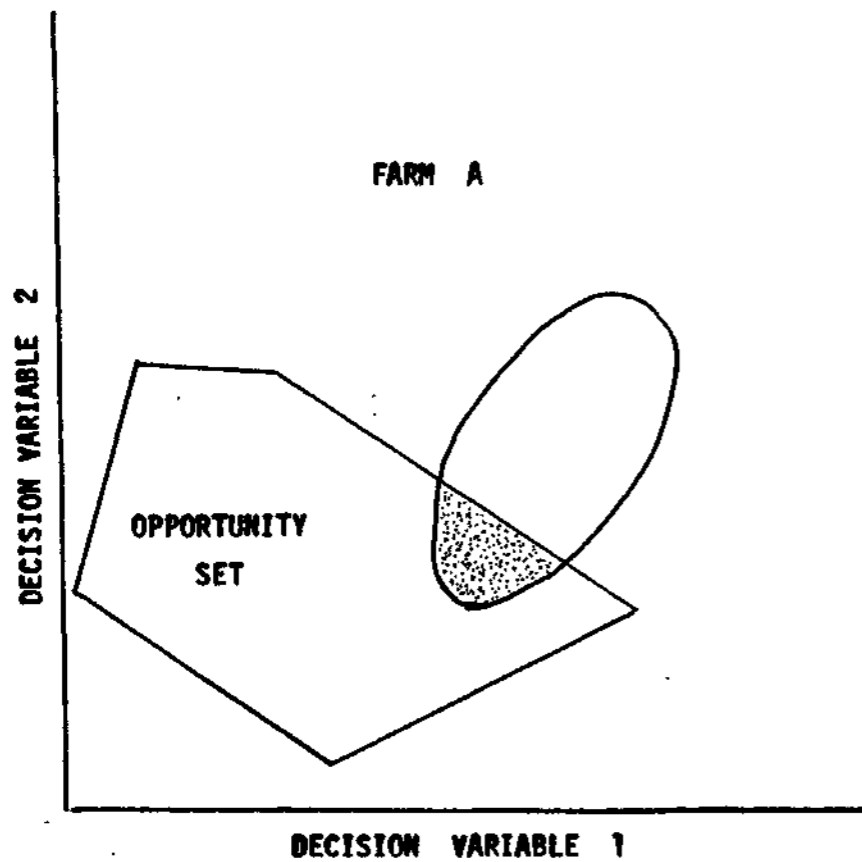


Figure 8. DIFFERENTIAL OPPORTUNITY SETS



3.11 Notice that there is more of interest here than the mere difference in the size of their respective opportunity sets. Most importantly we see that farmer B has a smaller zone of flexible response, as well as a feasible set which is subject to change during the course of the crop season (depicted as two sets). Farmer A can choose any combination within the feasible region or, if wishing to be cautious, can be confined to the set of cautious solutions.

3.12 On the other hand, B might start the season under the impression that Opportunity Set I will exist throughout, only to find later on that now Opportunity Set II exists. Instead of several cautious optimizing solutions, there is, in fact, only one possible decision.

3.13 Adaptive behavior, then, can be combined with notions from chapter II about farmer interdependence and disadvantaged (powerless) small farmers to illustrate the essence of subsistence farmers in the developing countries. The learned response is one of cautious optimizing in response to constantly changing opportunity sets. The range of choice for the farmer is limited by the economic environment, as well as by the influence exerted by more powerful neighbors. As seen previously, not only are there important equity implications from this situation, but productive inefficiencies are also present. Economic development policy directed to the small irrigator must address both of these issues.

B. The Uncertain Environment

3.14 There are two general categories of uncertainty which will interest us in the matter of irrigated agriculture. The first will be referred to as technical uncertainty, and the second as institutional uncertainty. Technical uncertainty comprehends those stochastic outcomes where drought, an outbreak of disease or other random events alter the economic environment of the farmer. In technical uncertainty we have a situation in which future states are the result of stochastic variability in physical parameters such as rainfall, disease vectors, and so on, but which affects are unrelated to the actions of other individuals in the economic system.

3.15 In institutional uncertainty we have a situation in which the institutional arrangements which define opportunity sets are altered by the actions of others. Here, revenue or cost functions are influenced by the actions of others, with such actions generally traceable to the desire for monetary gain at the expense of some other economic entity. Institutional uncertainty will be discussed in greater detail in the following section. For now we want to turn our attention to the matter of uncertainty as it effects choice among farmers.

3.16 The literature on farmer decision making contains frequent reference to the risk-averse nature of farmers, especially the small farmer. This is said to be more pronounced since the advent of the high-yielding varieties. With these new species, we say that the farmer faces a more risky crop

environment, but one in which the payoffs from adoption are considerably increased. This conjunction of increased payoff, but also increased risk, is said to be worrisome to farmers who remain with the traditional varieties because they are "risk averse."

3.17 But it is necessary to draw a distinction between gains and losses. In risky situations the utility of a project is equal to the expected utility of its outcomes. This is obtained by weighting the utility of each possible outcome by the probability of its occurrence. However, people have shown patterns of preference which appear to be inconsistent with expected utility theory, Tversky and Kahneman are working in a branch of decision analysis known as prospect theory; this represents a modification of decision theory by dividing a choice problem along two lines: (i) the framing of the problem; and (ii) the evaluation of choice. In prospect theory, outcomes are expressed as positive or negative deviations (gains or losses) from a neutral reference outcome (which has a zero value). The value function of prospect theory is shown in Figure 9. Notice two important properties of the value function. First, the difference in subjective value between gains of, say, \$10 and \$20 is greater than the subjective difference between gains of \$110 and \$120, even though the magnitude of the absolute gain is identical. This gives the value function its S-shape. Second, the response to losses is more extreme than the response to gains; this is shown by the steep slope of the function over the loss domain.

3.18 Consider the following pair of concurrent decisions. The respondent is told to examine both decisions, and then indicate the preferred options.

Decision (i), choose between:

- (a) a sure gain of \$240
- (b) 25% chance to gain \$1,000 and 75% chance to gain nothing

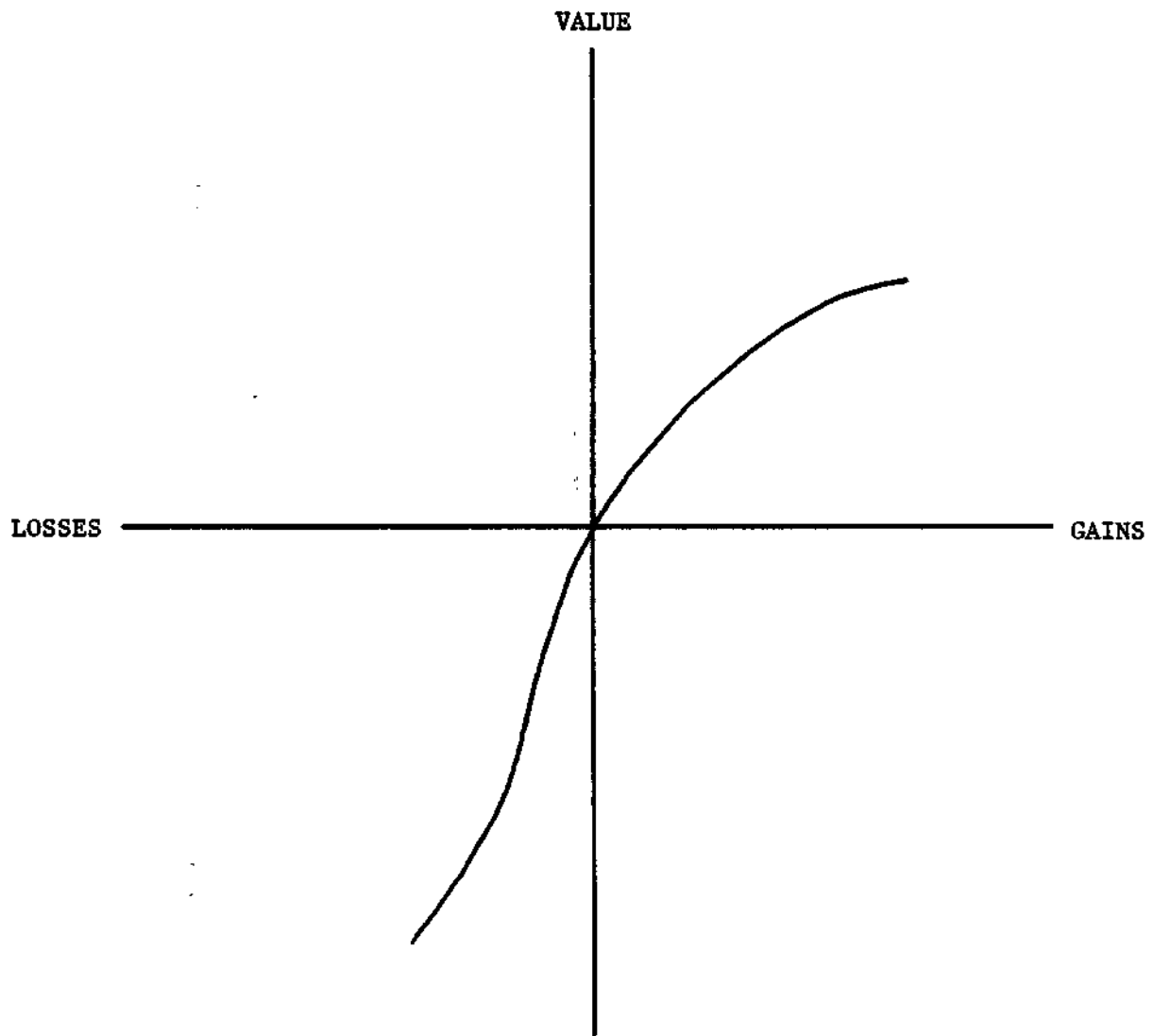
Decision (ii), choose between:

- (c) a sure loss of \$750
- (d) 75% chance to lose \$1,000, and 25% chance to lose nothing

3.19 In decision (i), Tversky and Kahneman found that 84% of the respondents favored (a) and only 16% favored (b). In decision (ii), only 13% of the respondents favored (c), while 87% favored (d). The majority choice in (i) is risk averse; a riskless prospect is preferred over one of higher expected utility. In decision (ii), the majority choice is risk taking (d). This pattern of risk aversion in prospects for gains, and risk seeking in choices involving losses is due to the properties of the value function and a weighting function which will not be discussed here.

3.20 Because the two decisions were presented together, the respondents had to choose one prospect from the set (a,c), (b,c), (a,d), (b,d). The pair

Figure 9. VALUE FUNCTION OF PROSPECT



(a,d) was the most common one chosen in their study (74%), while the pair (b,c) was the least popular (3%). However, the pair (b,c) is clearly superior to the others as is obvious when the question is framed as:

Choose between: (a) 25% chance to win \$240, and 75% chance to lose \$760.

(b) 25% chance to win \$250, and 75% chance to lose \$750.

3.21 Here, choice (a) is equivalent to (a,d) from the previous problem and has an expected value of -\$510. However, choice (b) is equivalent to (b,c) from before and has an expected value of -\$500. Phrased this way, their sample had little difficulty in identifying choice (b) as the preferred outcome (all respondents favored it). The popularity of the inferior option from the first decision problem is attributable to the fact that it was framed as a pair of concurrent choices.

3.22 The environment of choice facing a small farmer in the developing countries will be of considerable importance in determining the actions to be taken. If an action is perceived as a linked sequence, we will observe behavior which seems quite at odds with our expectations. When those sequences become only slightly complicated, the departure from "rationality" could be even more pronounced.

3.23 The operation of an irrigation system introduces another aspect of uncertainty into the farmer's choice milieu. In the most obvious sense, irrigation reduces one major source of uncertainty--adequate water. But, as outlined in the previous chapter, an additional source of uncertainty is introduced--will I obtain water when it will be needed by my crops?

3.24 In the absence of irrigation we might assume that certain rain-fed cultivation would be carried on. Here, the farmer faces what we have called technical uncertainty; the probability of rainfall or other outcomes is the result of events beyond the control of any agent. However, not all events are so removed from human involvement. If an irrigation system has been created, human negligence could contribute to the overtopping of a ditch which resulted in destruction of the bank and eventual interruption of water deliveries. Another example might be that failure to maintain the control gates in good repair renders them inoperable, and the system loses control over water deliveries.

3.25 The access to irrigation water--while removing the farmer from one form of technical uncertainty--replaces that uncertainty with a multi-faceted domain of uncertainty largely resulting from human action--or inaction. This is not to say that control structures cannot break even with good maintenance, nor is it to argue that rain-fed agriculture is not subject to cases where human action alters the farmer's opportunity set. However, it is to point out that when economic enterprises become more linked, the chances for external actions influencing opportunity sets have been increased. Every time we remove man from dependence on nature, it seems that we make him more dependent on his fellows.

3.26 When early farmers relied upon their own livestock for manure, there was little possibility for supply disruption due to a strike by railroad workers. The uncertainty was there in the form of the probable death of an animal, or its running away, but the uncertainty from other exogenous events related to manure supply simply did not exist. When farmers kept their own seedstock, there was a similar situation; just as they are now dependent on external suppliers.

3.27 This should not be interpreted as an indictment of certain changes in the agricultural economy in the developing countries. It does remind us, however, that in trading away the more traditional mode of production, we may have introduced more technical as well as institutional uncertainty into agriculture. The technical uncertainty has been discussed previously; high-yielding varieties require more judicious application of fertilizer and water than do the traditional varieties. Translated into the terms of our current discussion, that means yields will be higher if fertilizer is applied at the correct time and in the correct amounts, and if water is then available in the correct amounts. However, the availability of fertilizer and water are not only dependent upon technical (physical) events, but upon institutional events as well.

3.28 The increased susceptibility to institutional uncertainty among farmers introduces a new dimension into their environment of choice. Now, in addition to considering outcomes as purely random, or as acts of some deity, it becomes obvious that certain outcomes are the result of acts by their neighbors, or of the rural credit officer, or of the landlord. This is not to deny that farmers have always been at the mercy of landlords and rural credit officials. But when irrigation systems link them together with a number of others from the surrounding area—some of whom they do not trust—the resulting uncertainty takes on an added dimension.

3.29 Irrigated agriculture, then, trades one form of uncertainty for another. Rainfall (a technical uncertainty) is no longer crucial to success, but adequate water receipts at the proper time are. This realization of water deliveries is, however, less dependent upon pure randomness than it is on the actions of other farmers along the watercourse. In the absence of operational (and respected) institutional arrangements which secure the water deliveries of all farmers on a system, many of them will be in a more uncertain environment than they were prior to irrigation. Let us consider institutional uncertainty in more detail.

3.30 An institution is a socially sanctioned set of ordered relationships among people which defines an individual's rights, duties, obligations and exposures vis-à-vis others. A rental contract is an institution, so is a job contract, an agreement among apartment dwellers over stereo noise after 10 p.m., and speed limits. All of these "rules" define rights, duties, obligations and exposure. If I exceed the speed limit, I am exposed to the force of law; if I play loud music at midnight, I am exposed to the sanctions of my community of apartment dwellers. Likewise, I have the right to be free of stereo noise after 10 p.m.

3.31 For something to be an institution, it is not necessary that it be codified or even written down. What is vital is that individuals be able to operate with the presumption and expectation that codified rules will be enforced, and that noncodified rules will be honored. This simple fact introduces predictability into social interaction and produces a measure of order out of chaos.

3.32 Predictability of rights, duties, obligations and exposure are necessary conditions for a dynamic society. Uncertainty over institutional arrangements creates stochastic shifts in opportunity sets and, to an important degree, can stifle innovative behavior which might contribute to the improvement of small farmers. This is the essence of what Spengler called the fundamental "problem of order," or "... the necessity for a continuing reconciliation of freedom with control, change with continuity, and hierarchy with equality" [Samuels and Mercurio, 1981, p. 221].

3.33 The institutional economist interested in development would be inclined to look at technology and institutions as equally important factors in economic change. Others may be more inclined to view technology as the engine of economic change, and institutions as mere constraints on the adoption of new technology.

3.34 Irrigated agriculture is an example of this preoccupation with technological solutions to economic development. The presumption has been that the construction of dams, canals and control structures was sufficient to create a bounteous agriculture. In point of fact, the weight of evidence runs to the contrary, with a large number of irrigation systems around the world plagued by excessive water loss, maldistribution of water, poorly maintained drainage facilities, increasing salinity and water theft.

3.35 The concept of rural stagnation will here be used to describe a situation in which many farmers in the developing countries adhere to traditional agricultural practices. The conventional wisdom in economic development—indeed the *raison d'etre* of the scientific revolution in agriculture—is that farmers need to have access to the improved technologies and to forswear their traditional practices. The basis of this approach to economic development is the quality of the productive factors at the disposal of the cultivator—the seeds, the fertilizer, the land, the water control, the pest control, and so on. The argument goes: give the farmer better factors of production, and agriculture will produce a surplus of both food and income; the former to feed the rural and urban masses—if not to export—and the latter to supply the demand for investment funds for the rest of the economy. Agriculture can be an engine of economic development, and that engine runs best on high-quality "fuel" (the factors of production). We can refer to this as the factor-quality hypothesis.

3.36 There is a second hypothesis which would place greater emphasis on the nature of the economic environment in which the subsistence farmer operates. This hypothesis would suggest that rural stagnation arises for two related reasons—the inability of subsistence farmers to: (i) accumulate an economic surplus, and (ii) plan on accumulating a surplus. It is the presence

of this surplus which cushions the perils of change and which holds the reward for abandoning traditional practices. At first thought it appears that this is nothing more than a problem in "agricultural policy" broadly defined. That is, there is a need to adjust relative factor and product prices so that subsistence farmers might accumulate a surplus which could then be used for economic development. However, the issue runs deeper than that and arises for different reasons. We might refer to this as the institutional-uncertainty hypothesis.

3.37 This difference of opinion about the conditions which will lead to agricultural development are central to any discussion of irrigation and the small farmer. If the factor-quality hypothesis is correct, then the way to deal with small-scale irrigation is simply to build better water transportation and control facilities and leave the farmers to their own devices. On the other hand if institutional aspects dominate, then better irrigation facilities are insufficient to enhance small-scale irrigated agriculture. In the following, each of the two hypotheses is discussed.

The Factor-Quality Hypothesis

3.38 Farming based wholly upon the kinds of factors of production that have been used by farmers for generations can be called traditional agriculture. A country dependent upon traditional agriculture is inevitably poor, and because it is poor it spends much of its income for food [Schultz, p. 4].

Theodore Schultz is perhaps the most articulate spokesman of the school which blames rural stagnation on low-quality factors. The Schultzian peasant is small, poor, tradition-bound but efficient. That is, given the resources at the disposal of the farmer, given the prevailing institutional environment and given the objectives of the farm enterprise, it is impossible to reallocate factors of production and improve upon the prevailing situation. Schultz states:

The presumption is that when farmers are limited to traditional factors of production they reach a point after which they can make little or no contribution to economic growth because there are few significant inefficiencies in the allocation of factors, the removal of which would increase current production, and because investment made to increase the stock of traditional factors would be a costly source of economic growth [p. 24].

3.39 The Schultzian farmer is situated on a production-possibility frontier. From this, Schultz draws the conclusion that subsistence agriculture cannot be an engine for economic growth since there are "few significant inefficiencies in the allocation of factors." As we know, Schultz uses this model to advocate the investment in human capital and in modern (nontraditional) agricultural inputs. He would say that rural stagnation arises because no one

is investing in new "income streams." To transform traditional agriculture, it is necessary to invest in the modern inputs which create these new income streams.

3.40 Indeed the legacy of agricultural assistance is consistent with this notion. We have seen decades of investment in new seeds, fertilizer plants, pest control, farmer training, and the like. We have seen most of the developing nations keep even in their race to produce enough food. But we also know that there are grave concerns about the continued ability of many countries to continue to keep pace.

3.41 The problem of increased yields from currently cultivated land is essentially a problem of the failure of farmers to adopt new agricultural practices such as the high-yield cereals—a failure caused, no doubt, by a number of factors. But central to the decision of whether or not to try new (more risky) practices is the nature of expectations concerning the economic environment. For this we need to explore the issue of secure expectations and the institutional structure which provides that security.

The Institutional-Uncertainty Hypothesis

3.42 The Schultzian world is one of wise and efficient farmers doing the best they can with a poor resource endowment, and with inadequate purchased factors. It is a world of rural stagnation brought about by efficiency, and the lack of good investment opportunities. But it is a curious world, for much of the blame for stagnation rests with the fact that farmers are already efficient. While it is true that there are instances of development arising out of the elimination of inefficiencies, it seems safer to conclude that economic development is more commonly induced by the accumulation of an economic surplus by entrepreneurs—such surplus then forms the wherewithal for new investment and a cushion for risk taking.

3.43 Institutional uncertainty creates an environment in which otherwise willing farmers are reluctant to invest in (adopt) new more productive practices because of the absence of secure expectations over possible gains. Added to the technical uncertainty of more fickle high-yielding varieties, we have institutional uncertainty.

3.44 Institutional uncertainty exists because of the pervasiveness of what Myrdal calls the "soft state."

When we characterize the countries of South Asia as "soft states" we mean that, throughout the region, national governments require extraordinarily little of their citizens. Even those obligations that do exist are inadequately enforced. This low level of social discipline is one of the most fundamental differences between the South Asian countries today and the Western countries at the beginning of their development [p. 182].

3.45 The "soft state" is not confined to South Asia, and its reference in the above quote arises simply because Myrdal was writing about poverty in that part of the world. But the existence of a "soft state" is rather common in the developing countries—even those nations we would normally think of as military dictatorships. For there is an important difference between the nature of the government (dictatorship, democracy) and the social discipline in daily economic life. A "soft state" is here defined as one in which: (i) formal institutional arrangements are merely "suggestive"; and (ii) these rules are often changed at will such as to confound the investment plans of certain economic agents.

3.46 Economists are inclined to assume away the issue of rule (or institution) adherence or enforcement, dismissing it as a legal or sociological problem. Similarly, the second aspect of the soft state (arbitrary rule changes) is considered a problem for the political scientist. However, few can deny the important chilling effect on entrepreneurial activity which flows from the manifestations of a soft state.

3.47 What can be said about the problem of institutional uncertainty? The obvious place to start is that institutional change in any country is not simply a random event; nothing is done without a purpose. That purpose may be noble and democratic, or it may be selfish and strongly selective in its ultimate effect. Landlords have been known to be selective in their dealings with tenants and wage laborers. Rural credit sources of the informal variety have been known to be less than noble. Rural cooperative managers have been found who take advantage of less astute peasants. Indeed, the nearly universal interest in government-run supply and marketing organizations can perhaps be traced to the distrust of less-than-pure motives of private-sector alternatives. This is not to deny "softness" in public-sector arrangements, but it does speak to a recognized concern that small (and often not-so-small) farmers may be at the mercy of avaricious entrepreneurs.

3.48 One reaction to the notion of a soft state is to scoff and dismiss it as a misdirected "conspiracy theory." Another is to argue that "yes, these interests may manipulate the environment for their own gains, but they certainly are not out to get the poor." We have here two important assumptions. The first is that as long as these manipulative interests are "not out to get the poor," their manipulation is sufficiently innocent as not to require further consideration. Good intentions, it would seem, or at least the absence of bad intentions, are all that is necessary to condone manipulation of a nation's economic environment.

3.49 The second assumption is more serious; it seems to imply that there is a gamut of Pareto-better worlds out there which can be attained through manipulation of the economic environment by those so situated as to be capable of having their interests protected by government. This sanctioning of institutional change on the grounds that some can be made better off without making anyone worse off is convenient to those unwilling to address the fundamental problems inherent in the soft state. But it is naive to assume that one interest in a society can be made better off without making others worse off—relatively, if not absolutely. When we address matters of irrigation policy

in the developing countries, particularly as it impacts small farmers, notions of Pareto safety must be discarded; there are very few Pareto-safe options.

3.50 The presence of a "soft state" makes it rather likely that the small farmer will bear the brunt of the incessant manipulations by the fortunate to further enhance their economic position. The issue of risk aversion is usually discussed in terms of the inability of the farmer to survive one bad year with the more fickle, modern varieties. But there is another aspect which rarely receives the attention it deserves. This involves such things as uncertainty over the price and availability of requisite fertilizers and insecticides, and the uncertainty of product price at harvest time. The advantage of subsistence agriculture is that the small farmer is minimally dependent upon the outside world; a world he suspects of wanting to keep him subservient. By turning to cash crops, he increases his dependence upon input markets as well as product markets.

3.51 It is pervasive institutional uncertainty which causes rural stagnation: an inability to know what the rules of the game will be, and thus an inability to become a dynamic economic agent. The farmer is sure that if the crop promises to be a good one, prices will be low. If farm income goes up too much, the landlord may notice and modify the rental arrangement, or agricultural price policy will surely change next year under pressure from urban consumers. The farmer is concerned that any economic surplus which appears in the subsistence sector will quickly be transferred to the urban sector, to the agricultural inputs sector or to the product market sector.

3.52 Small farmers in the developing countries find themselves in an economic environment which is often not conducive to the types of practices which development planning traditionally advocates. The essence of "modernized" agriculture is to become more involved in the various markets--for inputs, outputs, information, and the like. By way of contrast, the essence of subsistence agriculture is to operate with a minimal involvement in such transactions. In a world of institutional uncertainty--and pervasive powerful interests--the subsistence farmer has little incentive to break out of the rather secure (but impoverished) existence of the past. By "secure", I do not mean to imply that the farmer is happy and comfortable. I mean, instead, that at least the subsistence farmer is not overly dependent upon a host of external markets and agents over which there can be little control. True, the farmer may be at the mercy of the landlord, but there is little interest in also becoming dependent upon the fertilizer dealer, the tractor repairman, the chemical supplier and others. This disinterest stems not from a rejection of the benefits which "modernization" might bring, but rather from the costs that come with modernization. Those costs are the increased dependence on a world which the subsistence farmer does not trust and which the farmer may only imperfectly understand.

3.53 When irrigation is introduced into the picture, it becomes even more complex. The interdependence discussed in chapter II has already forced the small farmer into an economic environment where individual control is reduced. The essence of developing irrigated agriculture in a way that helps--rather than hurts--the small farmer is to ensure that the institutional arrangements

governing water allocation and system maintenance do not exacerbate the already uncertain economic environment of the small farmer.

3.54 When new technology in the form of ditches and control structures enters an area where irrigation has not been practiced, it creates the opportunity for some farmers to reap new income streams. When the institutional arrangements are not well established at the time the new technology creates these new income streams, a basis for conflict and division has been established. That is, when irrigation comes to an area, some farmers will be able to expropriate for themselves some of the income streams made possible by this innovation. If this is allowed to continue for several crop seasons, those fortunate few who were able to appropriate the new income will come to think upon their good fortune as "legitimate." Then, it will become difficult—if not impossible—to rectify the situation.

3.55 It is for this simple reason that the traditional approach to irrigated agriculture has created a number of unsuccessful projects. It is not sufficient to construct the engineering works and "get the water flowing" with only vague and general rules governing water allocation and maintenance of the system. The general conditions of system operation (allocation and maintenance) must be specifically defined before water moves through the system. These conditions need not be overly precise, but they must represent a "constitution" in the following sense. Before any ditch is built, it is important to have general agreement about how water ought to be allocated prior to any one farmer knowing precisely where the watercourse will be located vis-à-vis his/her farm. That is, general rules must be articulated behind the Rawlsian "veil of ignorance." ^{1/} For in the absence of specific knowledge about who will be "head end" farmers and who will be "tail end" farmers, it is easy to imagine that all farmers will agree on a general principle of equity in water receipts and in system maintenance.

3.56 Having such agreement then provides a basis for enforcement once the system is in operation. The argument always advanced in opposition to this formulation is that farmers will not even sit down to discuss irrigation principles until they see the water flowing. While it may indeed be difficult to exact an understanding that each farmer ought to have, say, four hours of water every five days, it is not difficult to get general agreement on the sort of "constitution" implied here.

3.57 For existing irrigation systems in which there is an interest in rehabilitation, the problem of institutional uncertainty is not so readily solved. Here, where there are existing patterns of water allocation and system maintenance, it will be more difficult to bring about change. As mentioned previously, those well served by the existing arrangement will consider it legitimate and will fight any efforts toward reform. To the extent that they are the more powerful members of the local community, their wishes will carry some weight. However difficult it may be, the interests of small

1/ This approach is spelled out in greater detail in Bromley, Taylor and Parker [1980].

farmers are badly served by a world in which they are at the mercy of a number of economic agents. The goal of improving small-farmer irrigation must recognize that the central issue is one of institutional uncertainty. Once understood, the policy instruments will be more easily identified.

C. Reducing Uncertainty

3.58 We have talked of rural stagnation and of the adaptive behavior of farmers in the developing countries. This was given specific content by talking about the problems of small-scale irrigators. The solutions to irrigation problems in the developing countries cannot be talked about in isolation from the normal concerns with economic development. In the present context, economic development will be taken to mean a succession of changes within the subsistence agricultural sector which alter the basic structural and technological aspects of economic life. It must be clear that development is thus the result of some logically prior changes—changes which permit structural and technological change. This prior condition is the retention within the subsistence sector of an economic surplus with which to finance the technological change. It should also be clear that technological change fed by the existence of an economic surplus cannot be expected to operate independently of the economic infrastructure in the subsistence sector. What is this structure? It is factor and product markets—the means whereby subsistence farmers have access to such inputs as credit, machinery, seeds, fertilizer, extension advice and markets for their products.

3.59 Development must begin with a recognition of the hierarchical nature of farmer decision making. Drawing upon the earlier discussion, we recall that there is a hierarchy of goals:

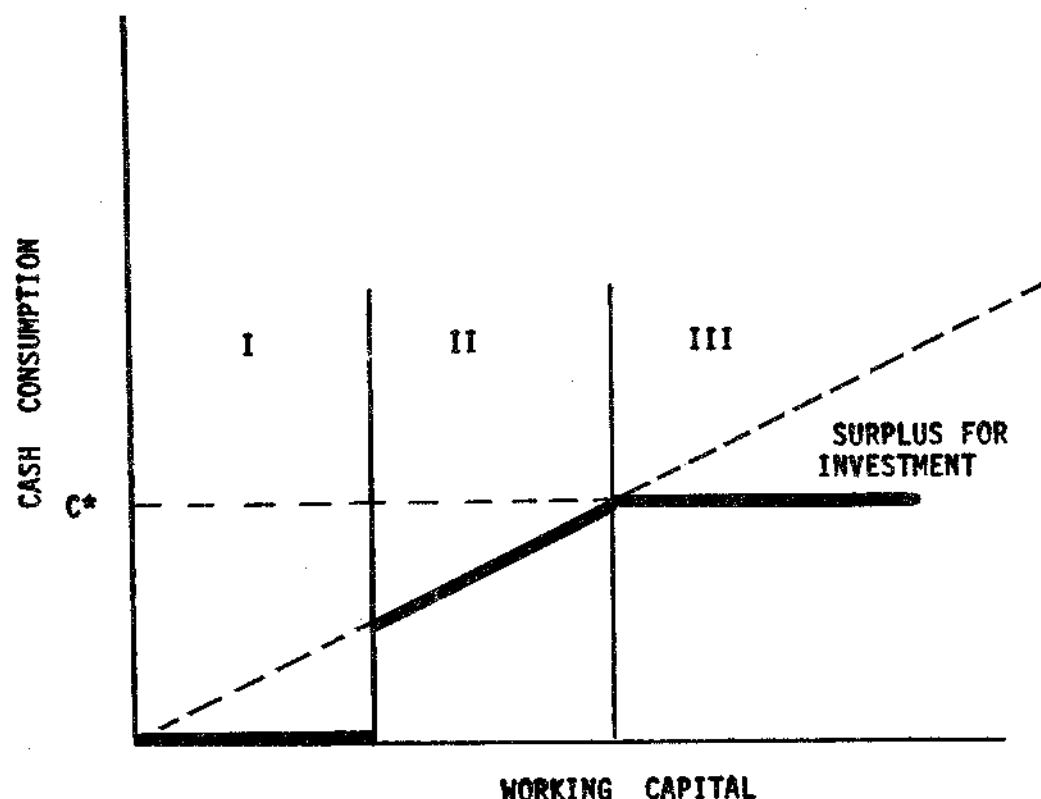
- (a) assure survival—the subsistence goal
- (b) cautious optimizing—the safety goal
- (c) acquire cash for consumption and savings—the surplus goal
- (d) profit maximization—the speculative goal.

3.60 These goals are lexicographic: the safety goal is not considered until the subsistence goal has been attained; the surplus goal is not considered until the safety goal is attained; and the speculative goal is not considered until the surplus goal is attained.

3.61 The nature of the lexicographic problem can be illustrated by reference to a diagram from Day and Singh. In Figure 10 we have farmers' working capital plotted against cash consumption. In stage I of the figure, all of the working capital of the enterprise is required merely to meet the subsistence needs of the farm family, plus the safety goal. In stage II the farm has generated sufficient income in this period to allow some consumption beyond subsistence and safety needs. In stage III we finally reach a situation

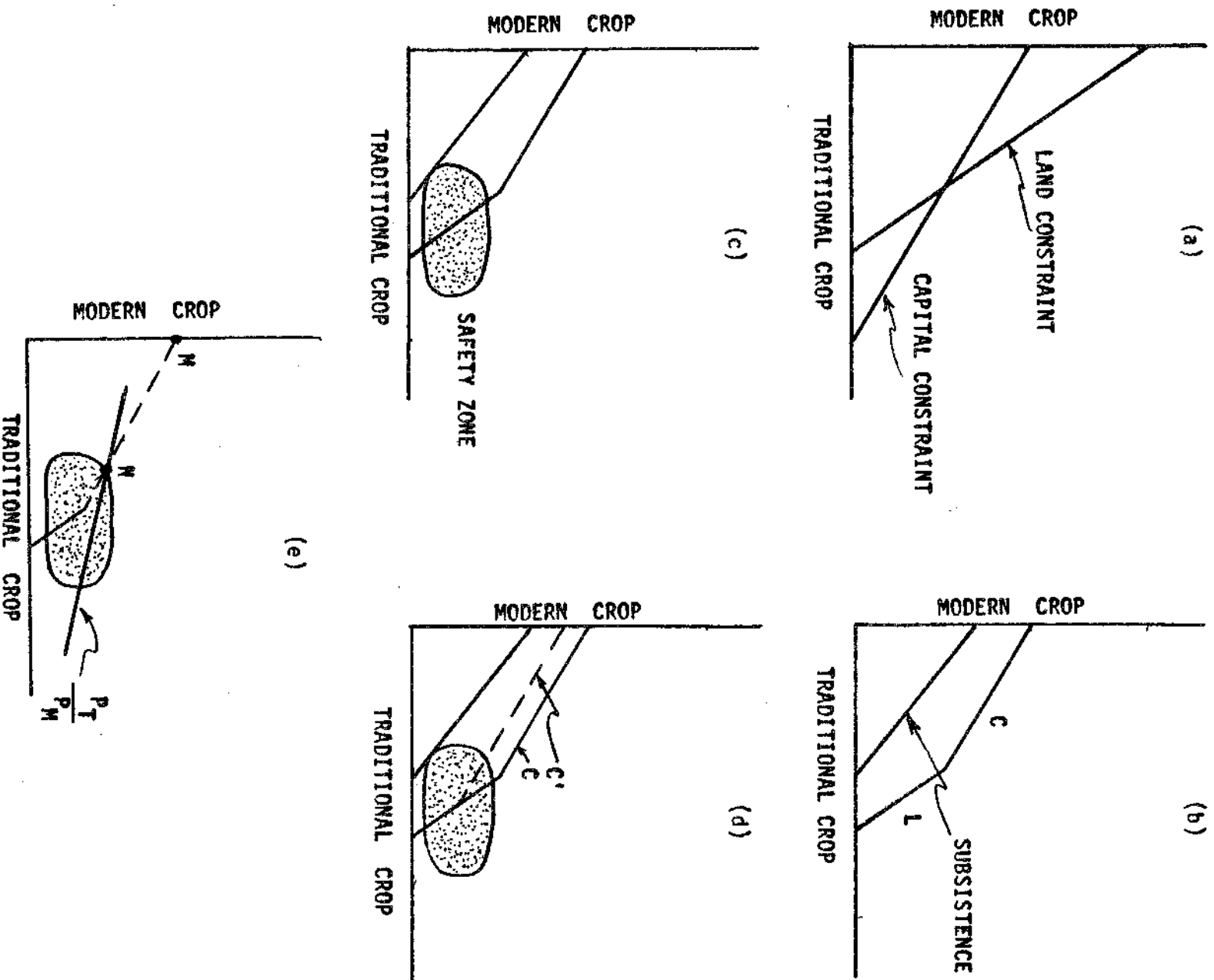
in which the farm family has sufficient working capital to allocate some to noncurrent consumption items (investments). It is this investable surplus which was said to be missing in instances of rural stagnation. Here, with an investable surplus a variety of technological options can be pursued. The advent of these choices will then begin to ripple through the rural economy altering its structural characteristics.

Figure 10. THE DEMANDS UPON WORKING CAPITAL
(Adapted from Day and Singh)



3.62 Figure 11 is also an adaptation from Day and Singh, and its purpose is to present another illustration of the lexicographic choice process of the farmer. In panel (a) we see the traditional crop plotted along the horizontal axis and the modern alternative along the vertical axis. Implicit in the output of each is a "technological package" that includes the nature and level of fertilizer, seed, pesticides, machinery; clearly, the implicit package for the traditional crop differs from the implicit package for the modern crop. In this diagram we will consider only two constraints--land and capital; in the subsequent discussion we will introduce irrigation water. The constraint lines delimit the zone of feasible outputs of both in a variety of combinations.

Figure 11. LEXICOGRAPHIC DECISION MAKING
(Adapted from Day and Singh)



3.63 Recall that the first-order goal of the farmer is subsistence which can be met through consumption or sale of either crop, though it is more likely that the traditional crop will be consumed while the modern crop would be sold on the cash market. Whichever option is chosen, it is possible to plot a "subsistence-opportunity-income line" as in panel (b). This line depicts the production of the two crops required in order to cover subsistence needs (either through direct consumption in which case there is an opportunity cost computed, or through sale in which case income is generated which can then be allocated to the purchase of food stuffs and necessary material needs).

3.64 Once subsistence is assured, safety becomes the relevant goal. We can depict safety, as we did in Figure 7, as a zone of flexible response which can either intersect or be removed from the zone of feasible combinations and the zone of flexible response. This is shown in panel (c) of Figure 11.

3.65 With safety and subsistence adequately considered, it is now possible to turn attention to a surplus for cash consumption and savings. This can be depicted as a shift of the capital constraint to C in panel (d). Finally, in panel (e) it is possible to depict the profit-maximizing choice where relative prices for the traditional and modern crop become the dominant decision variable. Notice that until this time relative prices were of no significance—except implicitly in the calculation of the "subsistence-opportunity-income line." In panel (e) only the relevant aspects are shown to highlight the profit-maximizing combination of outputs, previously circumscribed by the subsistence goal, the safety goal and the surplus goal. Now, the total revenue line reflects the relative prices of the traditional and the modern crops, and it is that parameter which will determine the ultimate combination from the safety zone. Indeed, given the discrete nature of the relevant zone of flexible response, the final output combination would be quite insensitive to several price ratios between the traditional and the modern crops. This is perhaps more realistic than our classical textbook case with all-around smoothness. Notice that it is only the safety goal which prevents the farmer from specializing exclusively in the modern crop. With the relative prices being what they are, a corner solution at M would be more profitable than the indicated solution at N.

3.66 As long as the farmer is constrained from the profit-maximizing combination of outputs by a restrictive safety zone, economic development programs must concentrate on expanding the safety zone. This will require at least two special aspects: 1/

- (a) institutional arrangements to lower the farmer's private costs of a mistake; and
- (b) institutional arrangements which are predictable and dependable both within and between planning horizons.

1/ The safety zone is dependent upon past behavior and experience; it is a subjective concept which resides in the mind of the decision maker. The safety zone is expanded as a function of decreased institutional uncertainty.

3.67 What does each of these entail? With respect to the first, there are several things which governments can do to reduce the costs of a mistake. Partial contracting for output is one possibility. Programs to assure availability of seeds, fertilizer, irrigation water and other inputs will reduce the chance that the farmer will make a commitment to modern crops only to find that necessary inputs are not available. Guaranteed "loans", as found in US agriculture, are a possibility for reducing price uncertainty.

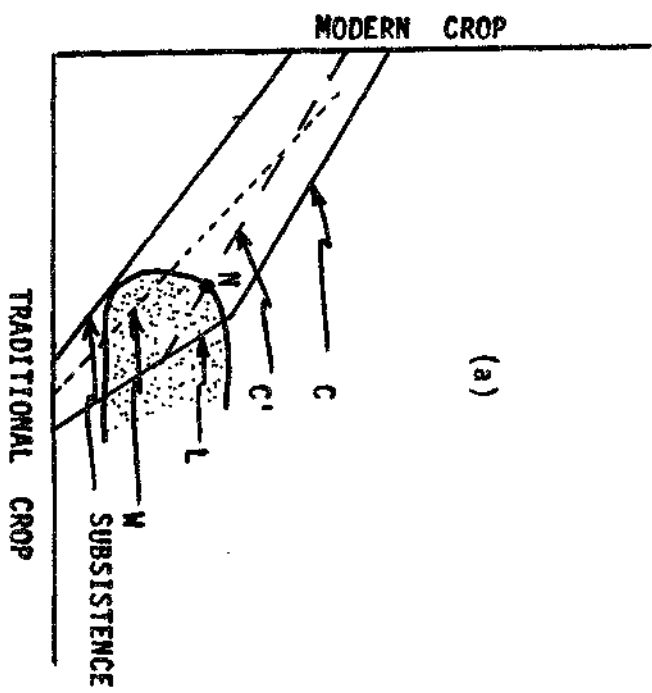
3.68 But the major changes will come in the creation of institutional arrangements which are dependable. By this, one should not infer that institutional arrangements must never change, nor does it mean that the farmer should expect a perfectly predictable world. But it does mean that institutional "tinkering" and continual "adjustments" must be minimized. The subsistence farmer is constantly forced to second-guess the nature of the economic environment--and while all farmers must do likewise, the limited safety zone of the subsistence farmer renders this cautious behavior particularly stifling.

3.69 In essence then, economic development is the process of creating the conditions in which subsistence farmers can depend upon a small economic surplus in excess of subsistence, safety and consumption requirements. This surplus can then be used to undertake technological change at the farm level. Such modifications in traditional practices then create a demand for infra-structural changes in the wider rural economy.

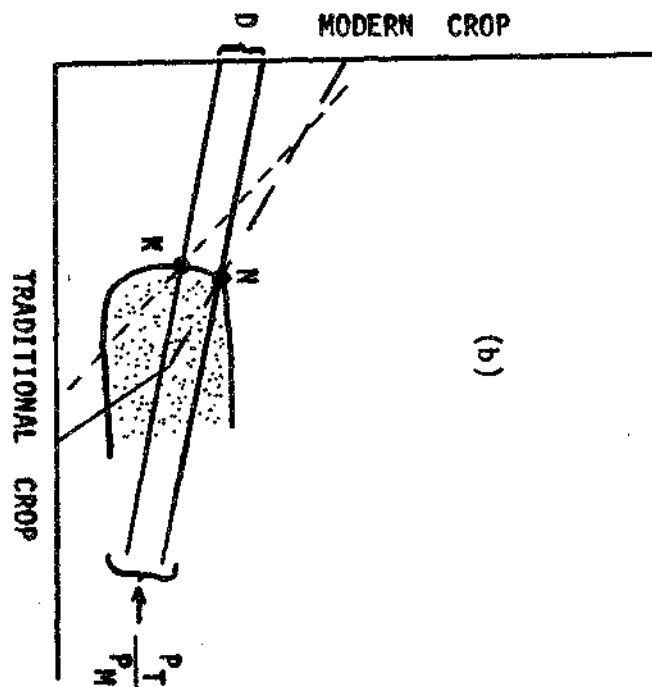
3.70 The discussions of uncertainty and adaptive behavior can now be related to the problems of irrigation. We are interested in the farmer located somewhere along a watercourse other than at its head, and we assume that this farmer is susceptible to the influence of at least one upstream farmer. As outlined in chapter II this will usually result in reduced water receipts over that possible if all irrigators received the amount implicit in project design for their area to be irrigated. This can be depicted in panel (a) of Figure 12 as a new constraint in output space--a constraint which takes precedence over the previously binding land constraint. For the small irrigator, land is no longer one of the binding constraint in crop choice and output. Instead, it is the quantity and timeliness of water for the crops; especially is this the case in Asian rice culture. Because modern crops are less forgiving of imprecise water application, there is no need for this constraint to be parallel to the now irrelevant land constraint. Indeed there is good reason to assume that it departs from the slope of the land constraints as shown in panel (a).

3.71 When the same safety zone is superimposed, the full impact of uncertain water receipts is highlighted. Now the small farmer is further away from the capital constraint, indicating that capital is being underutilized even on the very smallest farms. Additionally, total revenue has fallen by the magnitude $(P_M)(D)_0$ as shown in panel (b).

3.72 The position of the water constraint warrants some further comment. The traditional pattern in irrigation project development is to strive for a situation in which land and water availability are such that "normal" crop practices can be followed on each farm located on the project.



(a)



(b)

Figure 12. IRRIGATION AS THE BINDING CONSTRAINT
(Adapted from Day and Singh)

3.73 This "lump sum" allocation of water to a given area of land means that neither should—in theory—be more constraining than the other. When water receipts exceed that needed for the production of a crop, land becomes the binding constraint of increased production. When water is received in quantity less than that required, it—and not land—becomes the binding constraint. This is the situation shown in Figure 12. In light of this, one possible policy objective might be to insure that land and water are coincidental constraints on crop production.

3.74 This discussion has been cast in terms of lowland rice production where a (dry-season) crop may be impossible without irrigation or where supplemental irrigation is the difference between average and exceptional yields. Where crops can be grown in the absence of irrigation, the farmer may choose to apply more water to only part of a field. Still, over the total area farmed, yields will be less. It is the prospect for this event which often discourages farmers from switching to the high-yielding varieties. While traditional varieties will be more forgiving of failure to receive water, this is not always the case with the HYVs.

D. Summary

3.75 Economic development of small-scale irrigation will require the explicit recognition of three conditions; programs conceived and implemented in ignorance of these conditions are destined to failure. With an abundant supply of unsuccessful development programs world-wide, there seems little reason to create more.

3.76 The first condition is the physical interdependence of farmers along a watercourse. The second condition is institutional uncertainty. The third condition is lexicographic decision making by small farmers, with subsistence and safety goals dominating profit maximization.

3.77 Physical interdependence is an unavoidable fact in irrigated agriculture. There is no way to provide water to more than one farmer—even with groundwater pumping—that does not result in this physical linkage. Development programs for small-scale irrigation can only hope to make the best of this situation.

3.78 Institutional uncertainty is a fact in the developing countries because of the existence of the soft state. However, in contrast to the physical laws which produce the interdependence among farmers on a watercourse, there is nothing immutable about the soft state and institutional uncertainty; they exist because of an unwillingness to eliminate them.

3.79 Institutional uncertainty creates a decision environment in which subsistence and safety decisions predominate. While it is true that farmers everywhere are cautious maximizers, the existence of the soft state compounds the usual uncertainties of agriculture. This uncertainty, coupled with the marginal existence of the majority of small farmers, makes subsistence and

safety dominant. When institutional uncertainty is reduced, subsistence farmers will be able to become less safety conscious.

3.80 Of course none of this should be taken to imply that small farmers are not interested in innovation or that they do not innovate. We have all seen indications to the contrary. But certainty over irrigation receipts introduces yet another degree of uncertainty into an already unpredictable world. It is, however, a pernicious form of uncertainty in that the farmer can often see the reason for his difficulties. Unlike crop failures, unlike the inability to obtain fertilizer and unlike unpredictable price behavior, inequitable water allocation on an irrigation system can often be attributed to dishonest water masters, overly zealous upstream irrigators, or both. The tail-end farmer is not ignorant of the causes of his inability to obtain reliable water receipts. Hence, the physical interdependence introduced by irrigation introduces a very special element into the adaptive mode of behavior.

IV. REGIONAL ILLUSTRATIONS

4.01 In searching for illustrations which would highlight the sorts of institutional problems found on irrigation schemes around the world, one faces the difficult task of ignoring some very important projects with serious institutional problems while at the same time discussing projects which--on a global scale--would not be considered very significant. We must recall that the purpose for the illustrations is simply to show several ways in which current management of irrigation water is inimical to the objectives of both efficiency and equity. There is no presumption that the projects discussed here can be considered perfect examples of irrigation situations in the regions from which they are drawn. However, there is the expectation that the types of issues discussed here can be found on a sufficiently large number of irrigation settings that they warrant our careful consideration.

4.02 Here we will discuss irrigated agriculture in four regions of the world: (1) Mexico, (2) North Africa, (3) South Asia, and (4) Southeast Asia. The literature to be utilized in the discussion represents but a small fraction of the extant writing, and also a small fraction of that reviewed in the preparation of this report. However, it was selected for special notice because of the issues it treats and the problems it identifies.

A. An Example from Mexico

4.03 In a carefully documented study entitled "Irrigation, Conflict, and Politics: A Mexican Case," Eva and Robert Hunt [1978] present a detailed picture of irrigation in a small Mexican town (San Juan in the State of Oaxaca). This is arid country in which irrigation is absolutely essential for the production of corn, tomatoes, rice, mangoes, chicozapotes and sugarcane. Several major feeder canals serve the fields and orchards which surround San Juan, with minor ditches spread over the outlying irrigated land of the municipio. In the town of San Juan there are two town canals using water from the Chiquito River; one canal serves the house orchards and land around the town, the other serves the "Grasslands" where most of the small landowners are located. In theory every resident can have water from the town canals, though only some avail themselves of this particular source. Irrigation is under control of the town water commission (La Junta de Aguas). This is a most unwanted position since commissioners receive inordinate pressure for favors in water allocations. When the poor are on the commission, they suffer from the intreaties of the powerful landlords to whom they are otherwise indebted. The rich do not want to serve, since it is not necessary in order to obtain their water needs.

4.04 There are two "water masters" who make the everyday decisions, but instead of one master per canal as intended, they work together to discourage attack from irate irrigators. They are, however, rewarded for the hazards of their job; their bribe income during the dry season is sufficient to allow a

relatively comfortable existence. Even after having paid the bribe, an aspiring irrigator must stand on the ditch to ensure that the bribed water masters indeed give him his water. Even though evaporation losses are low during the night, few farmers choose to irrigate then, for this is to invite widespread water stealing. The earlier discussions of the "soft state" refer to just this phenomenon.

4.05 Maintenance work is derived from the amount of water received by an irrigator; however, in practice only the lower classes perform any maintenance. The wealthy hire laborers to perform their share of maintenance.

4.06 A second irrigation network in the municipio is represented by two privately owned canals which serve the land of the wealthy sugar farmers. There is some selling of water from these two canals, though the bulk of it is used by the landowners whom it is intended to serve.

4.07 The third system is the "ejido" canal which serves the land of the poorest members of the community. In contrast to the other systems, the officers in charge of water allocations, conflict resolution and ditch cleaning are not separated from the other roles central to ejido life.

4.08 The social organization of San Juan is as one would expect of a small rural town. Approximately 10% of the 2,500 residents belong to the elite class (la clase alta), another 10% belong to the "middle" class (la clase media), while the remaining 80% are the poor residual (los peones). The elite own the bulk of the land and the commercial enterprises, as well as the best irrigated land. The middle class derives income primarily from white-collar service jobs and in the retail establishments owned by the elite. This group owns a small amount of irrigated land but disdains agricultural pursuits. The peones own little and derive their income from wage labor. There is a small amount of irrigated land owned by this group, but it is largely insignificant.

4.09 Hence, we have a situation which the Hunts maintain is rather typical of Mexico in which landownership—and hence water control—is in the hands of approximately 10% of the local population. The elite own all of the commercial establishments in town, which together with their agricultural wealth probably account for 90-95% of all income earned in the local economy. To imagine that the small farmer has any meaningful control over irrigation water in times of scarcity is difficult, if not impossible.

B. Irrigation in North Africa

4.10 The discussion in chapter III about subsistence farmers may have left an impression that innovation among this group of farmers is a rare phenomenon. However, it is necessary to point out that innovation is not inconsistent with subsistence agriculture as long as that innovation is perceived as improving the chances of the small farmer. A recent study in

the Sudan by Barnett [1979] concentrates on the innovative tendencies of the subsistence farmers and the unwillingness of bureaucrats to change. There is an important lesson for irrigation in this case study as well.

4.11 The Gezira Scheme covers approximately 800,000 hectares between the Blue and White Niles in the Sudan. This is an old system, with the original irrigators coming from the ranks of the pastoralists. Given their unfamiliarity with irrigated agriculture, there evolved a detailed set of procedures and a hierarchical administrative structure which was also quite authoritarian. This control extended both to crop selection and practices and to water allocation.

4.12 Barnett points out that engineers—not agriculturalists—dominated early decision making, and hence irrigation procedures tended to be more responsive to physical aspects of the system than to agronomic requirements. These precise engineering objectives gave way to bureaucratically inspired and enforced "rules of thumb." One of the open conflicts revolves around the bureaucratic interest in cotton production and farmer interest in dura production for fodder.

4.13 What has transpired in the Gezira Scheme is that the tenant farmers have innovated significantly in irrigation matters, while the bureaucrats have stuck to the traditional methods—and apparently refuse to recognize that irrigation practices now differ markedly from what is articulated in the "rule books." Specifically, night watering is now prevalent. Additionally, the fixed rotation schedule has been altered to permit watering when water requirements dictate rather than on a fixed rotation which failed to recognize seasonal and age differences in plant water needs. Finally, the farmers have developed an irrigation method which economizes on the scarcest factor of production—labor; this too was in spite of official rules to the contrary.

4.14 Barnett argues that these innovations have been a major factor in contributing to the intensification and diversification of local irrigated agriculture, even though the official irrigation bureaucracy refuses to admit that farmers are not following the rules. The drive for innovation came from the tenant farmers who are in a perpetual state of indebtedness and cash-flow deficiencies. Moreover, the irrigation scheme has weakened the extended family such that labor is the scarcest factor at several critical stages of agricultural production. The farmers, in their efforts to economize on the most limiting factor, have innovated in several important respects. The government requirement that they grow cotton has constrained them somewhat, but they then managed to innovate within the confines of this constraint. It is the bureaucrats who lag behind.

4.15 When water is scarce, the farmers ignore the requirements to use it on cotton and instead irrigate their own dura first. As a result the prescribed 14-day rotation for cotton irrigation is sometimes extended to 20 days, and even to 25 days. Barnett indicates that "paradoxically they seem to achieve better yield results with this practice ... [p. 66]."

4.16 The only remaining puzzle is how this abuse of official irrigation practices and priorities can continue. Apparently, according to Barnett, the news never reaches the top of the very centralized irrigation bureaucracy; the reports prepared at several levels below the top fail to transmit this departure from authorized practices. In this example, the usual bureaucratic "information loss" is turned upside down. The standard situation is one in which irrigation management is seriously deficient, and hence system production is greatly inferior to what is possible; but the top of the irrigation hierarchy somehow never seems to find this out. On the contrary, Tiarnett tells of a system in which the production and income of the system are probably quite good, and the top of the bureaucracy is not told that it is because their guidelines have been contravened.

C. Irrigation in South Asia

4.17 A team from Colorado State University has been studying irrigation practices and problems in the Punjab and Sind zones of Pakistan. Data collection took place in 1975-76 from a sample of 387 farmers in 16 villages on 40 watercourses. The sample was stratified along the watercourses so that there are head, middle, and tail irrigators in the sample. The findings of that extensive research effort will be summarized here [Lowdermilk et al., 1978].

4.18 The dominant aspect of Pakistan irrigation is revealed by reference to major water losses in watercourses between the turnout from the main canal (the mogha) and the entry point to the farmer's field (the nakka). The research found losses ranging from 33% to 65%, with an average loss rate of 47%. The average losses per 1,000 feet of watercourse were 26%, or slightly over one-third cubic foot per second. Water losses were found to be greatest in those watercourses with the most water; where public tubewells augment watercourse supplies the losses are greatest, while on those watercourses with private tubewells, the losses drop significantly.

4.19 The research reveals a high correlation between ample irrigation water and overirrigation. Field application efficiency—an index of the proportion of water entering the farmer's field which is stored in the crop root zone—was highest for tail-end farmers where water was less available. Low field-application efficiencies result in excessive tail water which can contribute to both salinity and drainage problems. Field-application efficiencies were found to be correlated with farm size: those farmers with over 10 hectares averaged 64% efficiency, while those with less than 10 hectares averaged 80% efficiency at the field level. The larger farmers tend to have access to tubewell supplies which contributes to overirrigation.

4.20 Yields of wheat, rice and cotton were greater on those watercourses with access to tubewells. It was also found that cropping intensities were greater when tubewell water was available. Both of these differences are attributed to the fact that tubewells permit greater water control—and hence reliability. The research reveals that timing of water receipts is usually more important than the quantity of water received. Cropping intensity was

found to be a decreasing function of a farmer's distance along the watercourse (from the head).

4.21 About 70% of the 387 sample farmers reported that they did not receive word from the irrigation bureaucracy in advance of closing canals for maintenance. Agricultural extension workers were found—in this, the world's largest contiguous irrigation system—to be untrained in water management.

4.22 The soft state exists in Pakistan water management. The research revealed that required watercourse improvements and procedures are ignored. As with the Gezira Scheme, official sanctions against certain behavior—such as water trading, water purchasing, modifications of moghas—are ignored with impunity. Ironically, it is through such evasion that the system is as productive as it is.

4.23 In a sample of 354 farmers, the following question was asked: "What do you presently perceive to be the major constraint to obtaining increased per acre yields in your farm operation?" The responses to that question are shown in Table 1. The importance of irrigation could not be more vividly portrayed. Middle and tail-end farmers identified water problems as serious about twice as often as did head farmers.

Table 1: Allocation of Farmer Response in Answer to Question: "What do you presently perceive to be the major constraint to obtaining increased per acre yields in your farm operation?" (Sind and Punjab regions of Pakistan.)

(n = 354)

<u>Major Constraint</u>	<u>Percent of Reports</u>
Insufficient supplies of irrigation water	73.0
Lack of fertilizer and improved seed	9.3
Improved implements and farm machinery	6.0
Lack of land	2.8
Lack of capital or credit	2.0
Lack of insecticides	1.7
Lack of extension services and improved road	1.7
Seasonal labor shortages	0.9
No major constraint	<u>2.6</u>
	100.0

Source: Max K. Lowdermilk, Alan C. Early and David M. Freeman. Farm Irrigation Constraints and Farmer's Responses: Comprehensive Field Survey in Pakistan. Fort Collins, Colorado: Water Management Research Project, Technical Report No. 48-A, Vol. 1, September 1978.

4.24 The bulk of the farmers in the research sample receive no information on plant water requirements, stages of plant growth or importance of plant maturity for water requirements. Sixty-one percent were found to believe that wheat requires more water than cotton—or responded that they did not know. Of 378 farmers, 47% reported that they stopped irrigating when water reached the far border, and 33% stopped irrigating when all of the "high spots were covered." Farmers share a common notion that crop roots penetrate only a few inches into the soil and that 5 inches of water applied will infiltrate to a depth of only 12-24 inches.

4.25 Eighty-five percent of the farmers reported no contact with either an agricultural assistant or a field assistant from the extension service over the previous three months. It is not surprising, therefore, that Lowdermilk *et al.* are at great pains to emphasize the need for improved extension efforts in agricultural water management. The other obvious deficiency is in farmer and bureaucrat discipline with respect to compliance with established rules concerning water allocation, watercourse maintenance and dealing with instances of water stealing, bribery and ditch cutting.

4.26 In a second major study in the Pakistan Punjab, Parker [1979] was concerned with the institutional environment along a watercourse, as well as farmer water receipts (quantity as well as timeliness) as a function of physical location along the watercourse. Parker utilized a three-tiered model which depicted, as the first tier, farmer water control as a function of laws and regulations, watercourse transport losses, location along the watercourse, the farmer's economic status and several sociological factors. The second tier considered the adoption of high-yielding varieties as a function of water control (from tier one), input availability, knowledge of proper techniques and willingness to change. In the third tier, crop yield was a function of technology used (from tier two), soil characteristics, actual water received and exogenous factors such as weather, disease, etc.

4.27 Parker selected two sections of the Punjab province—Khanewal Tehsil in Multan District and Lyallpur Tehsil in Lyallpur District. The primary crops in Khanewal are wheat in the winter (rabi) and cotton in the summer (kharif). The primary crops in Lyallpur are wheat in the winter and sugarcane in the summer. Sample villages were chosen at random from the command areas of single major canals within each of the two regions. Individual farmer respondents were chosen using a stratified random sample from the head, middle, and tail sections of each watercourse associated with each sample village. Ten respondents were chosen from each watercourse, allocated to head, middle and tail in the same proportions as the total population of irrigators on the watercourse.

4.28 Parker's findings reaffirm the general picture concerning the important variables in the ability of farmers to exercise reasonable control over water receipts (farm size, farm location). Additionally, the results attach special significance to variables concerning the total number of farmers on a watercourse and the number of farmers upstream from the respondent; this is also modified by the number of farmers on the watercourse deemed to be "uncooperative." It was found that the number of uncooperative farmers increased as the number of other farmers with whom the respondent must deal

over water receipts increased. The proportion of uncooperative farmers had a negative effect upon water receipts and satisfaction of watercourse cleaning.

4.29 In the second tier of the model, Parker found that the adoption of modern agricultural practices was greatly influenced by the quantity of water received. However, the timing, reliability and security of water receipts were instrumental in the choice of fertilizer use. In the crop production aspect of the model, the findings reaffirm the importance of water control and of water-dependent technological variables. That is, greater water control enhances the farmer's opportunity set.

4.30 Parker concludes by stating:

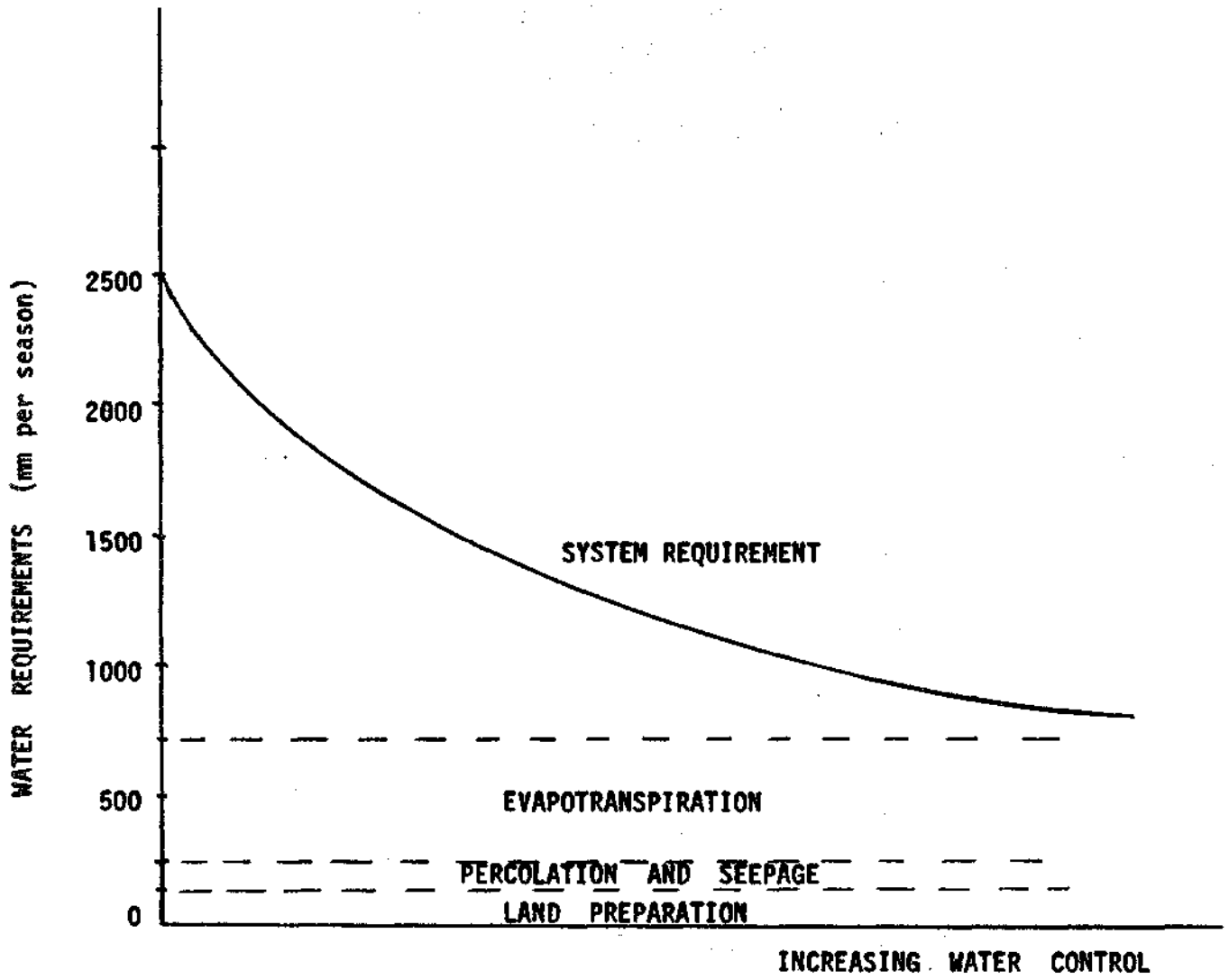
... Farmers who are advantaged by size of land holding, by social status, or by watercourse location (both in terms of physical aspects of location as well as in relation to other farmers) tend to have much better water control than do other farmers. This superior water control, by boosting the yield levels of the privileged large cultivators, tends to exacerbate farm income differentials. Efforts to equalize water control between farmers could be a promising method of improving income distribution in rural areas [p. 184].

D. Irrigation in Southeast Asia

4.31 When compared with the rest of the world, Southeast Asian rice irrigation is usually considered to be the most efficient, the most rational and the least subject to the sorts of problems just described for Pakistan. While it is true that there are outstanding irrigation projects in Asia, it would be a fallacy of composition to generalize.

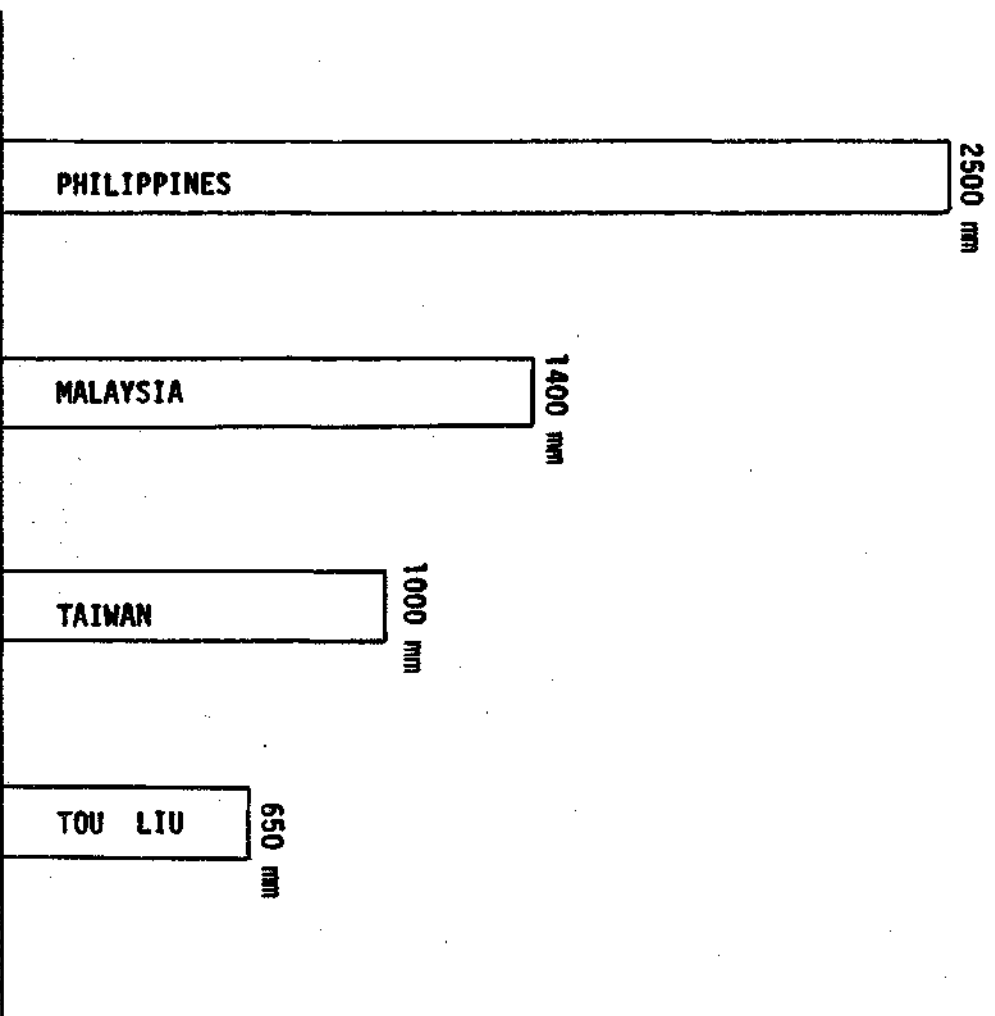
4.32 A recent paper by Levine [1977] illustrates the differences which exist in Asian irrigation. The basic model of Asian irrigation is presented in Figure 13, with system water requirements plotted against the degree of water control. Under climatic conditions present in most of Southeast Asia, it is generally considered necessary to provide between 600 and 750 mm of water per season of rice (between 95 and 110 days depending upon the variety). With near-"perfect" water control, it is possible to provide just this amount of water to the system. However, as water control diminishes along the watercourse, it becomes necessary to provide increasing quantities to the system so that what remains at the farm turnout is adequate to meet crop requirements, evaporations percolation and seepage, and other requirements. To highlight the differences among Asian countries, Levine also includes a diagram upon which Figure 14 is based. Here it can be seen that the Tòu Liu project in Taiwan is the epitome of good water control, but that the average for Taiwan is somewhat inferior. However, Taiwan is still superior to Malaysia and especially to the Philippines. That is, the efficiency of Philippine irrigation is estimated to be on the order of 20-25%, for Malaysia, it is estimated at 40%, while in Taiwan the average is over 60%. Recall that efficiency

Figure 13. SYSTEM WATER REQUIREMENTS AND WATER CONTROL



Source: Levine [1977].

Figure 14. TYPICAL ASIAN IRRIGATION SYSTEM WATER REQUIREMENTS



Source: Levine [1977].

pertains to the percentage of water reaching the farmers field as a percentage of that turned into the system which is "allotted" to that field.

4.33 The obvious question then becomes to determine why the Tou Liu system is so efficient. Levine provides part of the answer in terms of rotational irrigation within 50 hectare units according to a strict plan. Other aspects of the Tou Liu project include some of the laterals being concrete lined, control gates and Parshall flumes at each 50 hectare turnout, extensive networks of farm ditches, and 24-hour irrigation schedules. In contrast, the Malaysian system is based upon continuous irrigation, but control only within the primary and secondary canals. Beyond the canals, water distribution is in the hands of the farmers, and few farm ditches exist. Finally, the Philippines systems are also based upon continuous irrigation; however, there are few effective controls in the channels and the turnouts, channels are not well maintained, there are few measuring devices, control over water is only exercised five days per week (for eight hours each day), and farmer cooperation is minimal at best.

4.34 Although these observations describe a situation, they are mere symptoms of something else—and Levine correctly identifies that other element as the country's perception of the scarcity of water. There are two aspects of scarcity which are relevant to water use in agriculture. The first is the scarcity of water to the individual farmer and to the broader society, while the second is the security of water receipts to those who "ordinarily" use **water**. Each will be discussed in turn.

4.35 Dealing first with water scarcity, we begin by exploring the conditions whereby water might be considered scarce by individual farmers; here it is necessary to discuss the operation of the current irrigations systems in the various countries. Consider three types of farmers: (i) those on an irrigation system who regularly receive water; (ii) those on a system who only sometimes receive water; and (iii) those near a system with irrigable land who receive no water. Clearly, for the latter two groups water is indeed scarce. However, we need to distinguish between nominal scarcity and real scarcity. And this is where we need to look at water use by farmers in the first group. Agronomic research has determined—for a variety of climatic conditions—water "requirements" for virtually all irrigated crops. While an economist might be interested in the optimal application of water vis-a-vis other inputs, we must recognize that plant stress gives some lower limit on water application. Once some reasonable level of water has been provided to the irrigated crop, it is possible to begin to explore the extent to which farmers apply more than this amount.

4.36 However, as part of that determination, it is necessary to bear in mind other aspects of the production process. For example, an effective method of weed control on rice is flooding—here water is applied in excess of direct plant requirements but it serves as a substitute for other inputs such as herbicides or manual weeding. Or consider the issue of leveling fields for rice; it is possible to imagine an array of "minimum water applications" under various assumptions regarding field leveling. Here, "extra" water is a substitute input for the time and resources necessary to bring

individual paddies to a perfect (or near-perfect) plane. The same applies to ditches that are ill-designed, or badly maintained. If water is cheap to the individual farmer, it becomes a viable substitute for other inputs. This will be referred to as nominally scarce water. That is., an irrigation system is operated such that cheap water to those fortunate enough to receive it regularly replaces the use of other inputs. The price paid by other farmers is one of no water for lands that are irrigable, or infrequent water for those on land served by distribution network. To the extent that water is scarce to these latter two groups of farmers, they adopt crops and/or cultural practices where it is possible to survive without water; the private cost of this situation is the foregone income to the individuals from the lack of water.

4.37 But there is a social cost as well. Consider first the situation where an irrigation system is designed and constructed to serve a certain area and a specified number of irrigators. In any system design there is a presumption of efficiency of water delivery over the system, and of field leveling. If, in practice these conditions differ from the design assumptions, there will be less water for those at the end of the system; this is compounded by a water allocation scheme which allows those near the head of the system to assure themselves of their water "needs." The upshot is an investment which has been undertaken on one set of production possibilities and realized on an entirely different set. That this is serious to the agricultural planning of a developing country should require little elaboration here; to the extent that the investment was financed by external debt, it should also be obvious that serious foreign exchange implications attend such situations.

4.38 Another social cost worthy of discussion is the use of water to replace labor in leveling and weeding operations; if labor is abundant-- as is often the case--this substitution of a socially scarce factor for an often abundant factor may be serious.

4.39 Yet another aspect of social cost is the aggregate production foregone by those producers near an irrigation system who were not included in the system because of an apparent lack of water to serve their needs. This point relates to the set of design assumptions involved in determining the command area of the system. Or, it is possible that there is an abundance of irrigable land near an existing system which is now vacant because it will not support agriculture in the absence of water. If irrigated agriculture is a necessary ingredient to an agrarian reform program, this apparent lack of water may stifle efforts on this front. This aspect is even more serious if steep-slope agriculture is practiced. That is, if farmers are confined to steep slopes because of an apparent lack of irrigable land upon which they might be settled, they pay, and the country pays twice. The farmer is impoverished because of a poor resource base (and one which will--in all likelihood--get worse), the country is without the increased production which could result from production under irrigated conditions, and the erosion and resource depletion brought on by steep-slope agriculture not only make the nation's land base poorer, but siltation may speed up the demise of existing irrigation systems. This is a high price indeed for permitting a situation of nominal scarcity to continue.

4.40 Water is only scarce in a real sense if irrigation systems are designed and operated with a high degree of efficiency, and much attention is devoted by those organizations responsible for irrigated agriculture to assure an efficient allocation of water on lands with irrigation potential.

4.41 Throughout the foregoing we have not mentioned the matter of competition for water between agriculture and energy production. With hydroelectric production it is often possible that the use of water for one activity precludes its use for another. If water is used in abundance on some farms, that may also imply an additional social cost by precluding its use for the generation of electricity. Similarly, if it is used for the generation of electricity, it may preclude its use in irrigation. This issue confounds the determination of the real social cost of water use.

4.42 Yet another aspect of the social cost of water use is that of salinity and water logging of soils. For those farmers now receiving water, the excess application has a cost both to them and to others. Water logging and salinity reduce their yields, but they also influence the salinity of receiving waters. If others then utilize this saline water, their yields are reduced.

4.43 Thus, the issue of scarcity has both a private component and a social component; Nominal scarcity refers to those situations in which water is apparently scarce, yet that scarcity derives from the particular way in which water is currently managed or in which individual fields are leveled. Real scarcity refers to situations where "good" water management and irrigated agriculture are practiced, and yet there exists irrigable land which might be cultivated if more storage facilities were constructed.

4.44 Levine points out that as countries have begun to realize that good arable land is not in infinite supply, that genetically superior rice varieties are available and that water supplies are becoming more difficult to develop, they suddenly realize the scarcity of water--and the social costs of its current use. Once that is recognized, the effort to begin improved water management suddenly appears in a more favorable light. The difference between Taiwan and the other Asian countries studied (Malaysia and the Philippines) is that water has been recognized as a socially scarce input for approximately 50 years. Levine points out that it took the impetus of the 1954-55 drought in Taiwan to drive this point home definitively, but since that time there has been a relentless push to increase the efficiency of water use on the island.

4.45 It would take us beyond our purpose here to study in great detail the Taiwanese irrigation systems. However, there are some general principles which merit brief discussion. A recent publication by Abel will be helpful in this regard [1977]. Abel identifies four essential factors which contribute to the high degree of efficiency of Taiwanese irrigation. First is the explicit recognition that water is a scarce factor of production to be used as efficiently as possible. Second, the Government of Taiwan has evolved a system of centralized planning of irrigation investments but decentralized management of the systems. Third, within the irrigation associations,,

information systems have been developed which permit the ready exchange of agronomic and engineering information between farmers and the managers of the systems. Fourth, the irrigation associations utilize systems of incentives for managers of the system as well as for the users of the water.,

4.46 These four conditions combine to create an irrigation system in which there is quick and accurate information available to all participants, a shared recognition of the importance of good water management, and a recognition of the need for discipline, order, compliance and cooperation. Not all farmers receive all of the water they would like, nor necessarily when they want to receive it. However, they know that others are treated similarly, so there is less inducement to "break rank" and rationalize it with reference to others getting more. Allocating water among farmers is like dividing cake at a children's birthday party. Chaos is apt to prevail in the absence of mutual expectations of one's share.

4.47 In Taiwan the systems are essentially owned and managed by the farmers, and the water management personnel work directly for the farmers. The cooperative water-user organizations hire and fire managers of water, based on their performance. On the continuum of soft states, there can be little doubt that Taiwan is closer to the "hard" end. And it is this aspect which is necessary for a system to establish any expectation on the part of the users that water will appear at a predetermined time and in some relation to the planned-for quantity. Indeed, Abel points out that farmers know how much water they will receive before the planting decision is made. As indicated previously, there is an abundant literature on the response of farmers to insecure water receipts. The major findings indicate that water supply--which must include some notion of reliability and security--is the most important factor in determining which crops to grow and what areas will be planted. Moreover, water supply is often the dominant variable in determining yield differences among crops. Also, water supply is found to be a dominant factor in the adoption of new inputs--including high-yielding varieties. In addition to the production implications, there are serious equity concerns in water security; the least advantaged farmers are usually the ones to pay the highest price for insecure water. With a loose organization controlling water allocation, the poor and powerless are the least able to influence water distributions and they are also the ones least able to mobilize an imaginative response to the insecurity of water receipts.

4.48 As before, there is a private cost of an irrigation system which cannot insure secure deliveries, and there is a social cost. One of the private costs has already been discussed--that of the reduced production from those farmers who do not adopt improved technologies. But the aggregate cost of this failure to improve cultural practices is that total production is less than it could be with improved management of the systems. Given the risk aversity of poor farmers, the insecurity of water deliveries is all the excuse necessary to induce them to continue their traditional methods. If part of the agricultural strategy of a country is to spread improved technology among a large number of farmers, the degree of water security becomes an important limiting factor.

E. Summary and Implications

4.49 It is impossible to provide a comprehensive overview of world irrigated agriculture without the commitment of a great deal of time and space. The examples offered here cannot hope to present more than general impressions from a few scattered situations. Their inclusion is based on the fact that the common elements support the general theoretical issues developed in the earlier chapters. In the Mexico setting we see that the wealthy and influential farmers do not need irrigation associations in order to receive their water "needs." We see that when the poor farmers serve on the association, they are threatened by their powerful neighbors, We see some violence, bribery and a general lack of enforcement. We see a situation in which only the poor farmers spend time maintaining the irrigation system, with the rich hiring others to do their work. While not necessarily bad in itself, too much "absenteeism" can sometimes have a negative effect on the viability of the water users association. Finally, we see an extreme maldistribution of income in the local economy, and this implies a maldistribution of power and control. The management of the joint input cannot help but give rise to the sort of inefficiency discussed in chapter II.

4.50 In the Sudan we see an irrigation bureaucracy and a set of rules concerning the water allocation which are out of touch with the needs and priorities of the water users. Because of this, we find widespread disregard for the rules.

4.51 In Pakistan we find very low efficiency of water use, with extensive overirrigation in some fields and insufficient water for others. We see field efficiency—the proportion of water reaching the field which is stored in the root zone—decrease with greater water availability and with increased farm size. This measure of efficiency was lowest where farmers had access to tubewells. The latter finding indicates that the management of the system is grossly inadequate, since the availability of groundwater has not brought about a rational plan for conjunctive use of both surface and groundwater. Under ideal conditions, plans for conjunctive use would be developed so that each source is used to the greatest advantage. The results from Pakistan also indicate that the timing of water receipts is of much greater importance than is the quantity received. This point relates to the theoretical discussion in chapter II. There, although the diagrams are developed in terms of quantity, the underlying issue is one of reliable expectations concerning quantity and timing of water receipts.

4.52 The Pakistan example also highlights the fact that cropping intensity is a decreasing function of the distance from the head of the system. This, too, is a logical result from the uncertainty faced by those farmers near the tail-end of the system. They soon come to expect the worst with respect to water receipts and are unwilling to undertake the risks of a crop unless water is reasonably secure.

4.53 The Pakistan example also calls attention to the conditions which are present in the other settings. That is, there is little communication

between the irrigation bureaucracy and the farmers. Moreover, it was seen that there has been no training in water management for the agricultural extension workers. In light of this, there can be little doubt that water use is nonoptimal with respect to plant needs. Since this will usually mean overwatering, we see again a possible reason why those near the head of a system would be using more water than is necessary, and thereby depriving others less advantageously located of sufficient water.

4.54 Again focusing on the interdependence among system farmers, Parker's research--as well as that of the Colorado State team--found that water was a more crucial constraint to increased yields for those farmers at the middle and tail sections of irrigated systems.

4.55 Finally, in Asia, we find a very high degree of variability in rice yields from country to country. The hypothesized causal factor here--though we did not explore strict causality in this report--is the efficiency with which water is managed within the country: the degree of intensification of irrigated agriculture. As in the previous examples, the inefficiency of irrigation results from an institutional vacuum, which means that the joint input is not really managed but merely taken by those who have access to it.

4.56 The uncertainty so prevalent in the irrigation systems of the developing countries means that input usage among farmers is inefficient. When these inputs are extremely scarce both to the farmer as well as to the nation--as is the case with fertilizer, pesticides and modern seeds--the country and the farmer pay a dear price for this inefficiency. This not only means that individual yields are below what is possible, but aggregate production is less than what it could be for each country. With the bulk of the developing countries barely able to feed their expanding populations, this is a severe price to pay. This uncertainty shows up in farmer behavior by causing extreme caution and a preoccupation with safety-first decisions. The practical result of this is that experimentation--the very essence of a dynamic agricultural sector--is stifled. When that dampening affects the subsistence sector differentially--as it does--the very sector most in need of experimentation is held back.

4.57 In terms of the theoretical discussion of chapter II, the agricultural sector is interior to the production possibility frontier--or, to say the same thing, it is off of the conflict curve which is the locus of efficient points. Distributional issues enter as well, since it is the small farmer--or the one near the-tail of a system--who pays the greatest price for the current mismanagement of water. To the extent that small farmers comprise an important target constituency, irrigation is an important policy instrument.

V. IMPLICATIONS FOR SMALL FARM DEVELOPMENT

5.01 The small irrigation farmer is a cautious optimizer, which means that safety is placed ahead of profit maximization. Given the fickle and uncertain world in which the small farmer must operate, survival is enhanced by such lexicographic decision making. When situated on an irrigation canal with other farmers of equal socioeconomic status, the physical interdependence introduces an added degree of uncertainty—and a requisite burden of "transaction costs"—merely to obtain water in the needed quantities and at the appropriate times. When the small farmer is situated on a canal with farmers of higher socioeconomic status, this troublesome situation is exacerbated even further. Indeed, in many instances the powerless farmers simply do not receive irrigation water.

5.02 This aspect of irrigated agriculture in the developing countries introduces two costs to the economy. The first is an efficiency loss—aggregate production is less than it could be if the irrigation systems were not characterized by low-grade anarchy. The second is an equity cost in that the avowed objective of many governments to look after the interests of the small farmer is simply Ignored. In a world in which small farmers already pay higher per-unit costs for the same inputs than their larger and wealthier cohorts, this further burden from a technology that claims to promise scale-neutral benefits is a cruel joke.

5.03 Survival in subsistence agriculture is the result of adaptive behavior. It can take several forms, but caution is one manifestation, as is distrust of yet more government "assistance." Some of them can no longer afford to be "helped" by government.

5.04 The case studies illustrate—for a variety of situations--the problems faced by small irrigation farmers. The lesson is that there is either the wrong type of control (as in Gezira) or no control (in the others). The improvement of irrigated agriculture cannot proceed in this administrative vacuum. The physical interdependence wrought by irrigation requires an administrative system cognizant of this interdependence and structured in such a way that the interests of the small farmer are given protection. I will refer to this general process as intensification.

5.05 The process of agricultural intensification has been detailed by Boserup in her The Conditions of Agricultural Growth [1965], and Wilkinson elaborates on the theme in Poverty and Progress: An Ecological Perspective on Economic Development [1973]. In a sense, these two books build on the seminal work of Geertz in Agricultural Involution: The Processes of Ecological Change in Indonesia [1963], although Geertz is cited in neither study. Intensification is the increasing application of labor and capital to a given land base in response to population growth and the need to increase production of food. Boserup's thesis is that agricultural development is caused by population trends rather than the other way around, and that agricultural development is essentially the result of a process of intensification. We do not need to enter the dispute over the direction of causality to report on some

interesting correlations between yields per hectare, agricultural land per capita and the degree of intensive agriculture (as reflected in the degree to which irrigation water is carefully controlled).

5.06 The purpose in such a discussion will not be merely to advocate better water control. The intent is to establish a relationship between a productive agriculture—as reflected by yields per hectare—and the application of management to the total agricultural enterprise (which must include the management of water). For it is the proposition here that those countries in which poor water management is occurring are precisely those countries in which a minimal effort is expended toward the intensification of agriculture. And it seems safe to conclude that the only way these countries are to stay ahead of the growth in their population will be to increasingly intensify their agriculture. This does not rule out the bringing of new land into cultivation—though we must hypothesize that the best land for agriculture is already so used. But it does highlight the fact that these countries already have substantial area under cultivation, albeit with very low yields. Indeed, we will see that the "land-abundant countries" (vis-à-vis population) are currently experiencing rice yields per hectare of less than half the yields in the "land-scarce countries."

5.07 First consider Figure 15. Here we see a plot of rice yields in tons per hectare against the historic growth of rice yields in Japan; as a norm, few would doubt that Japan's agriculture is "productive" and highly "developed" and that the degree of intensification—including water management—is pronounced. It is also beyond dispute that Japan's agriculture has not always been so intensive. One reads Figure 15 by noting that Laos is where Japan was in 900 A.D., the Philippines is where Japan was in 1400 A.D., and Malaysia is where Japan was in 1900 A.D.

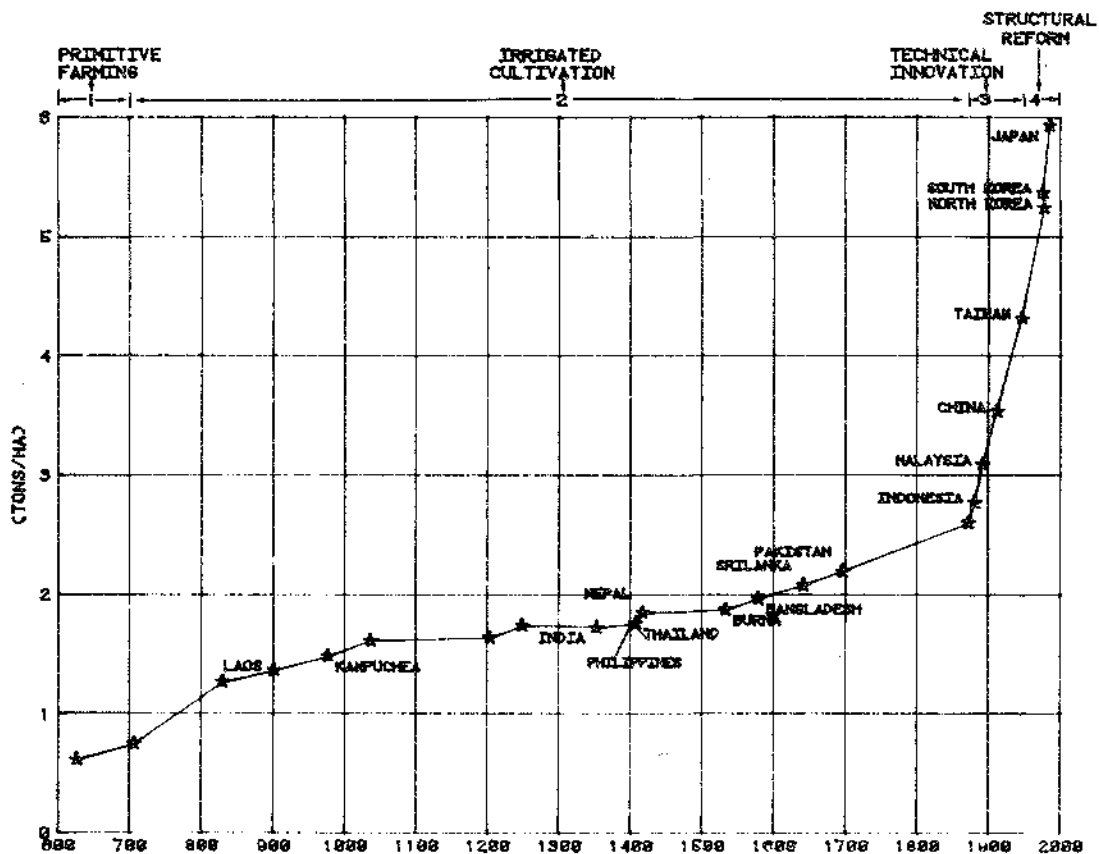
5.08 While it would be possible to marshal a variety of statistics to prove the degree of intensification in countries such as Japan, Taiwan, South Korea and China, our interest here is in water management. Recall from chapter IV that irrigation efficiency varied considerably, as between Taiwan, Malaysia and the Philippines. We might consider the efficiency of irrigation as an indication of the degree of intensification of a country's agriculture, and we find that rice yields in these three countries differ significantly. When plotted against Levine's estimates of irrigation efficiency, we obtain Figure 16. It should be emphasized that this discussion is not intended to establish causality in the statistical sense.

5.09 The point is that those countries in which such careful attention has been paid to water management also seem to be those countries with extremely high yields. To be sure, other things have gone along with better water management; one cannot consider water management in isolation from the total agricultural enterprise.

5.10 The recent report of the Trilateral Commission, Reducing Malnutrition in Developing Countries: Increasing Rice Production in South and South-east Asia [Colombo et al., 1978], placed intensification at center stage in a plan to reduce malnutrition in a part of the world containing the vast

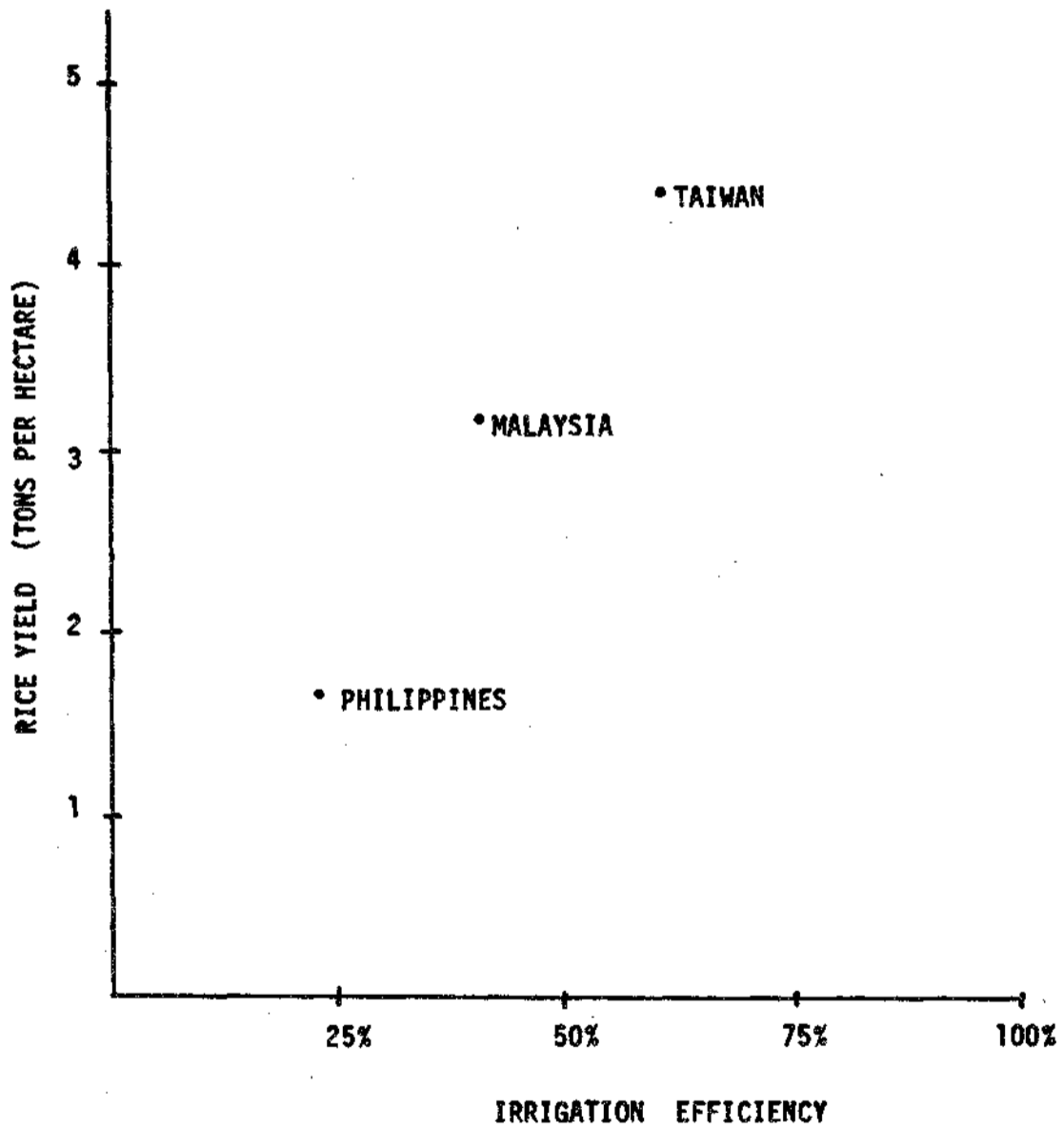
majority of the world's poorest citizens, and where almost three fourths of the world's food grains are consumed. An earlier table also shows that the bulk of the irrigated land is found in South and Southeast Asia. The cornerstone of the Commission's plans to improve food production was better control over irrigation water. Careful cost calculations were performed for several irrigation improvement options. These were: (i) change uncultivated land into adequately irrigated land; (ii) change rainfed cultivated land to adequately irrigated land; (iii) change inadequately irrigated land to adequately irrigated land; (iv) change uncultivated land into inadequately irrigated land; and (v) change rainfed cultivated land into inadequately irrigated land.

Figure 15. HISTORIC RICE YIELDS IN JAPAN AND CURRENT YIELDS IN SELECTED COUNTRIES



Source: W. David Hopper, "The Development of Agriculture in Developing Countries," Scientific American (Sept. 1976), p. 200.

Figure 16. RICE YIELDS AGAINST IRRIGATION EFFICIENCY
(Yields from Figure 15; irrigation efficiencies
from Levine)



5.11 The cost-effectiveness of the various plans was shown to vary considerably, with options (i) and (iv) being the least cost-effective. The lowest capital costs for increasing paddy production by 1 ton per hectare per year are through improving inadequately irrigated land to adequately irrigated land (iii), followed by improving rainfed cultivated land to adequately irrigated land (ii).

5.12 The investments called for under the two favored plans were not large-scale projects. Instead they consisted of digging out farm ditches and keeping them well maintained, and good management of water within each project (as well as among projects).

5.13 Donor agencies interested in assisting small farmers would be well advised to concentrate their efforts on intensifying irrigated agriculture. This intensification must recognize the difference between irrigation systems in which each farmer has an individual source of water--a pump from a river, a pump from groundwater or a diversion direct from a river--and those systems where several farmers are linked to a common source. In either system they will usually share a common drainage network. In the following discussion, this difference among systems must be kept in mind.

5.14 Another distinction which merits discussion is that between inundation irrigation prevalent in lowland rice culture and the intermittent irrigation of wheat, cotton and corn. While the specifics of any particular project would need to take these differences into account, the general discussion here will apply equally to both types of irrigation. More detailed suggestions will require development on a case-by-case basis.

A. Intensifying Irrigated Agriculture

5.15 We will disaggregate irrigated agriculture into six components:

1. the farmer
2. the water transportation and control network
3. the agricultural information system
4. the irrigation information system
5. the agricultural infrastructure
6. the irrigation infrastructure

The Farmer

5.16 When undertaking projects or programs to improve irrigation, the most important element is the ultimate user of the water. In the construction of new projects, it is essential that all farmers agree--in general terms--to

a "constitution" wherein principles are adopted regarding water turns, maintenance schedules and responsibilities, fee payments, and the like. It is not essential that every detail of the water allocation system be decided before the project becomes operable. But it is important that the general issues be resolved prior to any farmer receiving water.

5.17 In the identification stage of the project cycle, it will become necessary to insist upon this sort of process as a normal part of the general feasibility assessment. Also at this stage, it is necessary to pay special attention to the differences among farmers on a proposed system. Engineering studies have been optimistic in terms of the service area for a project, and this distorts the true aggregate production from a system. Water deliveries are never quite what we hope they will be, and the benefit-cost studies of proposed projects must be carried out more critically than they have in the past. In this regard, farm budget studies—which form the foundation of a project's benefit-cost analysis—should be conducted with an eye to a farmer's location within the system. It is unreasonable to assume that tail-end farmers will have the same yields as those near the head of a system, unless the uncertainty discussed earlier is eliminated. It is preferable to design sample farm budgets for three reaches of the watercourse: (i) head; (ii) middle; (iii) tail. With different assumptions about water losses along the system and about the degree of water control, it will be possible to derive a more reasonable set of expectations regarding project performance.

5.18 While the undertaking of entirely new irrigation projects will be continued, there is more opportunity for cost-effective yield improvements through the rehabilitation of existing projects. Consistent with the report of the Trilateral Commission, I consider the enhancement of existing irrigation systems to be a very rational policy for the next 5-10 years. This rehabilitation will have some construction activity in terms of adding laterals and farm ditches. It will also have some capital restoration components. Finally, it will involve careful work with groups of farmers and with the existing irrigation and agriculture bureaucracies. More will be said on this below. But it should be recognized that the same steps which are followed in the project cycle for new projects are relevant to the rehabilitation of existing projects. We still must pay attention, to the problems of identifying the best candidates for improvement; we still must offer special assistance in the preparation of project plans. Countries will need special help in terms of identifying objectives for their irrigation program and in assessing the role that irrigation can play in the overall agricultural picture.

5.19 In the project appraisal stage, the technical, institutional, economic and financial aspects will require careful assessment, just as if a new irrigation project were being undertaken. Part of this appraisal would concern the likely viability of water users organizations; another part would concern the adequacy of the existing irrigation bureaucracy.

5.20 The economic appraisal should ensure that monetary benefits received by small and low-income farmers are given proper weights. If countries are serious about benefiting small farmers, there is no reason why benefits received by rich farmers must be weighted the same as benefits received by the

small farmer. The benefit-cost literature reflects this differential shadow pricing of benefits, and it might be employed in benefit-cost studies of projects where small farmers are important target beneficiaries.

5.21 At the negotiation stage, the World Bank retains some ability to influence the nature of proposed projects. The loan documents can reflect the specifics of the project with respect to water management organizations in the government, the staffing of these organizations, the periodic training to be received by its staff, general salary guidelines of various levels within the organizations, 1/ the number and placement of water measurement devices, the number and location of water control structures, and rotation schedules. Also, maintenance and repair criteria can be negotiated and become part of the legal documents of the project.

5.22 It may turn out that the host countries will not require much persuasion to take steps which will enhance the operating efficiency of the proposed projects. If this becomes a problem, it can be minimized if the Bank were willing to share some of these costs.

The Water Transportation and Control Network

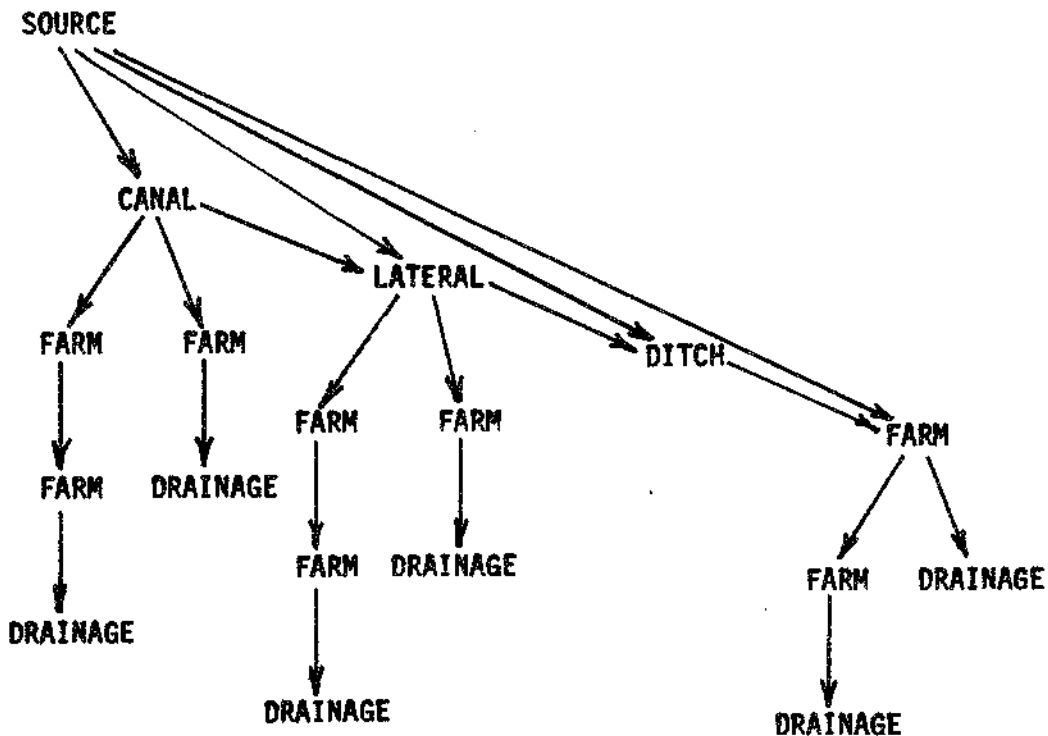
5.23 It is the existence of this network which links farmers together and thus introduces the physical interdependence outlined in chapter II. We may depict the basic options in water transportation networks by making reference to Figure 17. The source can be either a division from a river, a pump set which draws water from a river or a pump which draws underground water. The source can then go directly to either a canal, a lateral, a ditch or a farm. Water for irrigation can then move either from farm to farm (as in some Southeast Asian rice culture) or travel along a ditch to a number of farms and then become drain water.

5.24 What we have in the figure is the physical structure and its control mechanisms but not the way in which water is managed in that network. It is strictly the engineering works of an irrigation project. This would also include the engineering works at the source of the water, whether a diversion from a river or a pump.

5.25 In the existing systems it may be possible to improve this network in both an engineering sense and in a socioeconomic sense. If attention is paid to careful engineering works, it may be possible to "design out" some of the uncertainty in water receipts discussed in earlier chapters; technology would become a substitute for institutional aspects. However, it is not clear that this is a fail-safe strategy. While lined ditches reduce maintenance obligations and seepage, they do not prevent the upstream farmers from helping themselves when they feel as if they need a little more water. Engineering works can reduce technical (stochastic) uncertainty but cannot deal with institutional (strategic) uncertainty.

1/ A frequent problem is that ditch tenders are so low paid that they are easy targets for those wishing to influence water allocation by offering side-payments.

Figure 17. POSSIBLE WATER TRANSPORTATION ROUTES IN IRRIGATION



5.26 As for the latter, we might be able to construct new laterals in areas where water now moves from plot to plot, and we might construct better (or more frequent) control structures. If these are carefully placed so as to overcome current inequities in water allocation, the interests of the small farmers will be enhanced. ^{1/} Also if there exists factionalism within a system, the judicious placement of laterals, ditches and gates may be instrumental in ameliorating the problem.

5.27 In identifying sites for new irrigation projects, special attention should be given to the compatibility of engineering "imperatives" with socio-economic considerations. While water will, indeed, not flow uphill, there is no reason why canals, laterals and ditches cannot be located such that the currently poor farmers are not further disadvantaged once the system becomes operable. Sites in which the only feasible transportation network is one which places the already large and advantaged farmers near the head of laterals and ditches should be avoided when more agreeable locations exist.

5.28 A second factor should be to match up--as closely as possible--the basic physical subdivisions with existing sociological subdivisions. To

^{1/} See Easter [1977].

* have a lateral serve two "rival" villages is asking for problems. If it is not possible to engineer the system in such a way as to avoid obvious conflicts, it will become increasingly important that institutional mechanisms be started at the same time that the initial surveying is started. There should be meetings between farmers and the representatives from the water management organization. There should be initial efforts to establish farmer groups for managing the water once it arrives; it is essential that this institutional infrastructure exist before the water flows and behavioral patterns become established. That is, when the system is new, all farmers will have positive expectations about how the system will function and some general notion about how they will personally benefit. If, during the first season, actuality departs significantly from these expectations, then trouble is virtually assured.

5.29 Current benefit-cost procedures are insufficient in both scope and content to assess properly this mutual importance of engineering and sociological considerations. What will appear as a "good" project in our conventional view may indeed be a serious failure. This fact may require an input on project identification efforts of anthropologists or social psychologists with experience in the developing countries.

The Agricultural Information System

5.30 This includes the full array of information about agriculture which is provided to the farmer, plus the information flow from the farmer- back through the system. This system includes the accumulated knowledge about specific agricultural enterprises in a country and the network whereby that information is transmitted to the users. We generally refer to parts of the system as "extension," but the notion employed here comprehends more than the extension service in a country.

5.31 A program to enhance small-farmer irrigation should pay special attention to the informational needs of this group. Programs in which water and crop practices are integrated would be a necessity.

The Irrigation Information System

5.32 This represents a special class of information flows specifically about water in agriculture. It is more narrow than the previous category, and much more specific. Included here would be information about crop response to alternative timing and quantities of water at certain stages of plant growth, information concerning irrigation procedures to be used in conjunction with fertilizers and herbicides, plus information about good water management in general.

5.33 This information system-in conjunction with the agricultural information system-comprises the totality of information exchange in an irrigated agriculture setting.

The Agricultural Infrastructure

5.34 This represents the full array of agricultural services beyond the farm but not including the formal information system. Here we have the suppliers of agricultural inputs, the marketing channels, banks and informal moneylenders, and other commercial enterprises that are linked to farmers. The work on farmer cooperatives, on agricultural credit, on seed certification programs and on improved farm-market roads would be categorized here.

The Irrigation Infrastructure

5.35 The final element is the system of management and control over water beyond the farm level; we might think of this component as the irrigation "bureaucracy." In most countries this component represents an engineering organization whose primary functions are planning, designing, constructing and maintaining canals and laterals; the dams are often constructed by an energy agency, with the irrigation bureaucracy getting some water for irrigation. The irrigation infrastructure may also include a nominal staff for the "management" of irrigation water, though their functions only rarely extend down to the level of a ditch.

5.36 Improving the irrigation infrastructure can be discussed in both quantitative and qualitative terms. The quantitative dimension pertains to the simple lack of personnel in the developing countries to manage the shared input water. In part, this is the result of a frequent pattern of the failure for any one agency to have an interest in, and control over, irrigation water. Or, when that agency mandate does exist, we find a lack of people to carry out the required tasks.

5.37 A program in improved irrigation would, therefore, need to commence by ascertaining whether the problem is one of a bureaucratic vacuum or a problem of insufficient personnel.

5.38 Bureaucratic Vacuum. The types of irrigation problems discussed earlier for Mexico and the Philippines represent two aspects of a bureaucratic vacuum. In Mexico we find a local irrigation system in which ownership of canals/ditches is varied, while in the Philippines and in many other places we find national jurisdiction over construction of canals and laterals but little else.

5.39 An assistance model for situations such as we find in San Juan would probably need to focus on the use of indigenous rural development/religious/community organizations to provide some technical assistance to the small number of local irrigators and their elected or appointed water bureaucracy.

5.40 For larger (national) systems the model would probably call for the creation of a water management division which would contain subdivisions concerned with: (i) operation, which is essentially water control and distribution; (ii) maintenance, which is routine work on control structures, and ditch cleaning; and (iii) repair, which is the more significant overhaul of the physical facilities.

5.41 This division would need to be entirely separate from current divisions which are occupied with water planning, construction, and the like. There are even good arguments for why this type of a division ought not to be located in the "construction" agency at all, but instead located in the ministry of agriculture. This makes sense in certain countries, and this issue would need to be resolved on a country basis. There are no universal principles to guide us here.

5.42 This group of individuals works on the transportation network—that is, manages it—to do one thing and that is to move water from the source to the farmers as efficiently, as predictably and as equitably as possible. It is quite possible to imagine some bureaucratic performance criteria by which to evaluate the quality of the job being done by such a division. The information system is then capable of operating as a link between farmers and those who manage water. Farmers indicate desires about water receipts, the water managers indicate likely availability and timing; farmers communicate conveyance system maintenance problems, the managers indicate likely maintenance dates and work-detail needs; and the farmers indicate availability for work parties, etc. The mere existence of the management division can thus be seen to create a communication system about irrigation.

5.43 It is essential that each segment of an irrigation system/project in which 10-20 farmers are located have a water management person whose primary (if not sole) responsibility during the irrigation season is water control among those farmers. Depending upon the control structures, the extent to which those 10-20 farmers are spread out, and the degree of inherent cooperation among the farmers, it may be possible for this water management individual to work two such subdivisions of a project system. Thus, an irrigation project containing 80-100 farmers ought to have 3-4 such individuals, depending upon local conditions. These individuals should report to a "canal master" or some such analogue. If one canal serves 3-4 "clusters" of farmers served by laterals, then this canal master would be in charge of perhaps 10-15 water managers. The canal masters would report to supervisors in several possible patterns depending upon the extensiveness and complexity of the project.

5.44 What must be recognized is the need for visible water managers and canal masters on a daily basis during the irrigation season.

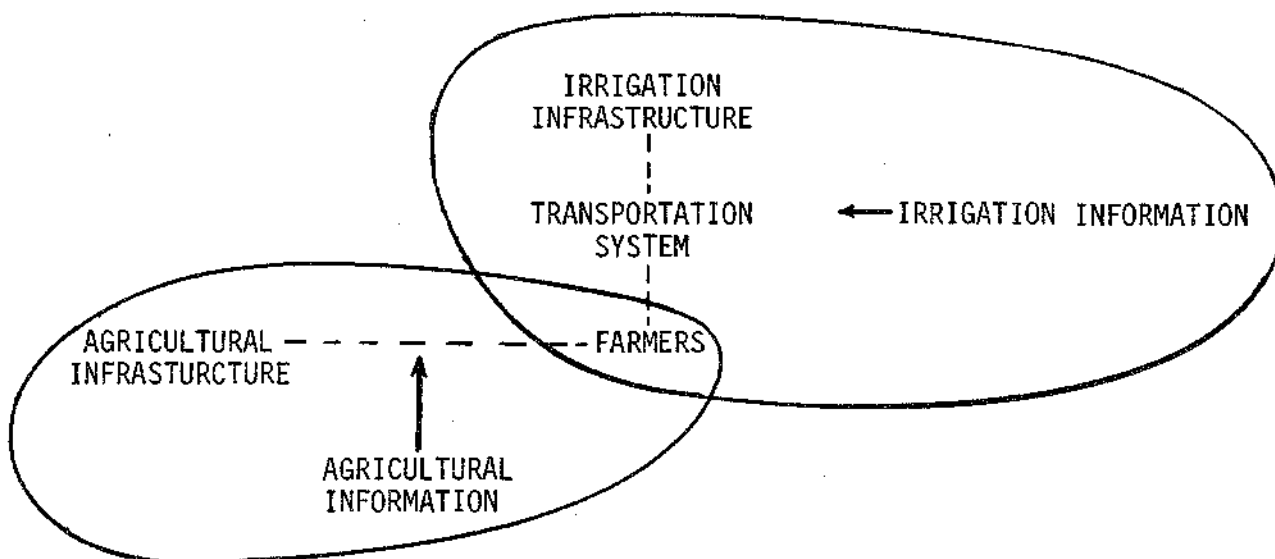
5.45 Insufficient Personnel. The second quantitative aspect arises when a water management agency exists but is inadequately staffed. The previous discussion can be recalled for some indication in minimal staffing needs. The usual situation may often find a weak canal master and one or two water managers (or ditch tenders) for a very large number of farmers.

5.46 Turning to the matter of quality, the basic issue is that there is a virtual dearth of qualified water managers in the developing countries. There can be no greater priority than the development of a qualified cadre of public servants to staff existing (or new) positions as described above. This training would need to be in agricultural areas, as well as in engineering concepts pertaining to water movement and losses within a system. It is difficult to define the ideal training program without making specific reference

to each country's (or region's) situation; this would require detailed diagnosis of each project/system by experts.

5.47 By way of summary, the six components of the irrigation system can be depicted as in Figure 18. Nonirrigated agriculture is depicted as a sphere involving the farmer, the agricultural infrastructure and the agricultural information system. This sphere is more developed in some countries than in others, and the levels of intensification will vary as well. The bulk of conventional agriculture assistance operates within-or upon-this sphere.

Figure 18. SIX COMPONENTS OF IRRIGATED AGRICULTURE



5.48 But irrigated agriculture interposes yet another sphere on the farmer and that is one containing both the transportation network and the irrigation bureaucracy. As before, information about irrigation is important to this sphere. However, in this instance the link between a water management organization and the farmer (via the transportation network) is weak, if it exists at all. Having introduced this second sphere, we can state that in most countries the intensification of agriculture continues to operate within the first sphere, often ignoring the irrigation sphere. Recall from above the discussion concerning Pakistani farmers and their knowledge about irrigation, and that 70% of the farmers in a sample of 387 received no word in advance of canal closings by the irrigation bureaucracy.

B. Conclusions

5.49 Irrigation is a technological innovation of unappreciated complexity. The common impression seems to be that one only provides the transportation system and the rest—meaning water management—will automatically follow. We know, of course, that this is not the case. When technology precedes the institutional arrangements which define who controls the new income streams made possible by that technology, those already in a position to enhance their economic and political advantage will move quickly to do so. Such is the history of irrigated agriculture in the developing countries.

5.50 In many instances, great wealth and considerable power are not necessary preconditions for gaining at the expense of others—all that is required is that one be fortunate enough to have a farm at the head of an irrigation system. With only this fortuitous accident, the conditions are set for a significant income gain vis-à-vis the more distant irrigators. Of course, on some systems, being at the head of the system is due to more than mere luck; it is not unheard of for influential farmers to have some role in the location of canals and laterals. But such overt influence is not necessary.

5.51 Irrigation creates new income streams, and the dominant fact of irrigation in the developing countries is that those income streams accrue to those fortunate enough to have some control over the application of water.

5.52 Programs to enhance the economic position of small irrigation farmers can consist either of the construction of new irrigation projects to serve small farmers, or the rehabilitation of existing projects. The hypothesis here—and one that is supported by the recent Trilateral Commission report—is that the most cost-effective policy would focus on improving water allocation on existing irrigation projects. This emphasis is here referred to as intensification. International assistance agencies have a special role in this process.

5.53 Through the provision of both advice and loan funds, there is a unique opportunity to encourage countries to devote more attention to intensification. Financial incentives can be offered but may prove to be unnecessary. The obvious payoff should be sufficient to elicit the required cooperation of recipient governments. But the demonstration of these payoffs will require careful attention. The network of international research centers under the Consultative Group provides one obvious mechanism. Many of these centers have programs concerned with improved cropping practices, of which irrigation is an integral part. There is now talk of the creation of a center concerned exclusively with water management. It is not clear that the institutional problems of water management lend themselves to the center approach in the same way that genetics and cropping systems do. Yet the center should be given serious consideration.

5.54 And yet, the major impetus for improved water management is surely to come from the international assistance agencies. Recipient governments have a long history of cooperation with such agencies, and this should enhance the potential for success.

5.55 The concepts developed here will hold for the vast majority of irrigation systems in the developing countries. What will require tailoring is the specific remedial action on a country-by-country, if not project-by-project, basis. The components of irrigation systems presented here would seem to offer a logical way in which to structure both diagnosis and treatment. But it must be emphasized that project-specific and country-specific programs must be developed. No sweeping generalizations will do when it comes to rectifying years of malallocation of water.

5.56 If the diagnosis is undertaken with the conceptual model offered here, both economic efficiency and distributional justice can be the policy objectives. One does not need to appeal to abstract notions of efficient water use in an agronomic or an engineering sense. While these are important, policymakers are more inclined to listen to arguments which emphasize the private and social costs of the current mismanagement. Few of them will want to improve the efficiency of water use unless we convince them that water is truly scarce. In the jargon of linear programming, they must be convinced that an extra cubic foot per second of water has an extremely high shadow price—both privately and socially.

5.57 This should be the primary mission of donor agencies. As that work progresses, it will become time to devote attention to remedial programs. These efforts will require as much agency attention as now goes into the planning and evaluation of new projects. But the payoff to the country and to the agencies is almost certainly greater.

5.58 In conclusion, small-farmer irrigation combines all of the elements currently fashionable in agricultural development. It is concerned with enhancing a country's ability to keep food production ahead of population growth. It is concerned with creating a more dynamic and innovative subsistence sector. It is concerned with distributional justice. And it is concerned with spending donor and host-country resources in a manner that is likely to yield high returns as compared to other program options. The era of massive capital infusion for dams, canals and control gates has yielded to an era of program performance and accountability. We are at the threshold. The urban masses of the developing countries—not to mention the rural landless—demand ever increasing quantities of basic foods. With rice, wheat and corn comprising a good share of the irrigated crops in the developing countries, there is little doubt that programs to enhance production will be popular with such governments. The subsistence sector comprises an important opportunity to meet that nutritional imperative. The intensification of agriculture at the small-farm level through better water management is not only a cost-effective policy, it is an ethically compelling one as well.

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Spanish: Presupuestos de fincas. Editorial Tecnos, 1982.

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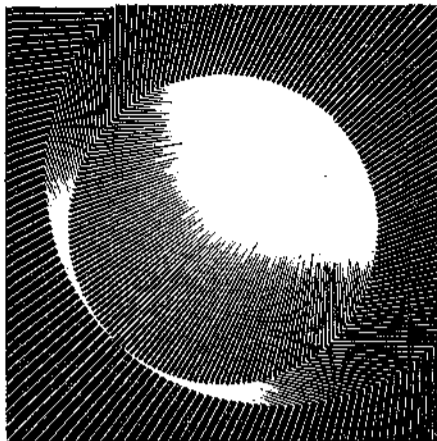
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Cambridge University Press, 32 East 57th Street, New York, N.Y. 10022, March 1982.

LC 81-12307. ISBN 0-521-24490-0, about \$40.00 hardcover.

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The Johns Hopkins University Press, April 1982. About 304 pages.

LC 81-15569. ISBN 0-8018-2359-5, \$30.00 hardcover; ISBN 0-8018-2360-9, \$12.95 paperback.

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