AN INTEGRATED VIEW OF ENVIRONMENTAL PROBLEMS OF AGRICULTURE

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PREFACE

The interactions between agriculture and the environment have emerged as important factors linking the concerns of the agriculturist, the economist, and the systems analyst. Recognition of their importance has led to the establishment of a task at IIASA to study the environmental problems of agriculture. This task has looked at environmental problems at the field level and at the regional and national levels. In addition, it has attempted to provide a framework which can allow the insights made at one level to become meaningful to others as well.

This paper summarizes the framework linking the field-level and regional/national-level phenomena. It outlines a mechanism for following the implications of public policy, farmers' decision-making, and environmental phenomena throughout the farming system and creating a unified qualitative picture of that system. It has already served as a useful organizing tool for other research done within the task (e.g. WP-79-79), and it is hoped that it will assist in other systems analyses of environmental problems of agriculture as well.

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PART I: THE STRUCTURE OF AGRICULTURAL SYSTEMS

It is not surprising that agriculture should show environmental problems in all regions of all nations: It represents environmental management of an intensity and intimacy much greater than most other human activities (Kovda, 1979). Environmental problems of agriculture are most clearly defined and most significant in developing countries in the tropical and subtropical zones which are either wetter than or dryer than average. These countries are vulnerable not only to disruptions in the agricultural supply system but also to fluctuations in world markets for all goods, primary and manufactured. They tend to be the countries with the highest illiteracy and demographic fertility rates, as well as the highest rates of morbidity and mortality. They tend also to be the countries for which agriculture constitutes the highest portion of the Gross National Product (GNP), and for which agriculture productivity is the key to overall national development (Myrdal, 1968). Nevertheless, environmental problems characterize all agricultural systems to one degree or another. Whereas they may be quite apparent in developing countries, they are present in developed countries as well, and their impact may be no less pernicious. If they are not as obvious, it is because of the organization of the agricultural production system rather than any innate characteristics of the environment or of its associated problems.

It is not easy to describe or define environmental problems of agriculture in a general sense. At a task meeting at IIASA in April, 1977, a list of 26 specific problems was drawn up (Golubev et al., 1978), and the relationships between them was touched on (Clapham and Pestel, 1978b). But because agriculture is inherently a form of environmental management in which the farmer must intentionally manipulate the ecosystem, it is seldom sufficient to confine an analysis to phenomena which can be labeled either as "environmental" or as "problems."

If the analyst is seriously interested in solutions of real-world problems, he must include the behavior of people and the reasons they manage agro-ecosystem as they do. He must explicitly consider farmers, herders, and production-oriented actors. What problems exist do so because of their actions. Potential solutions to problems are feasible only if they are appropriate to producers' mind sets. At the same time, the producers are the primary victims of ecological dysfunction, generally in the form of altered production, at least in the long run, or in various forms of externalities. The farmer does not act in a vacuum. He or she is stimulated or constrained by economies, policies, and institutions whose analogues can be found in all countries. To a degree at least, individual actions can be affected by policy signals or changes in institutional viewpoints. But this is not automatic, and people do not always respond as they are "supposed" to.

Most analyses of problems and their solutions tend to be oriented toward policy and institutions acting on national levels, or on the environmental problem *per se* in the field or watershed. Less often do we look toward the immediate individual farmer-herder level. But environmental problems of agriculture touch all of these domains, and it is often useful or even necessary to include all of them in a practical analysis if they are to make sense. They are not simply physical-biological phenomena which can be viewed in such terms as soil losses, salinization, crop loss, and so forth. They are also people-problems that can be viewed in terms such as death, morbidity, and wasted lives, as well as the practical decisions made daily by farmers all over the world. They are also institutional phenomena to be viewed in terms of policy. To ignore any of these considerations may distort the view of the system giving rise to the problem and make it appear that agricultural systems are simpler than they appear and that they are capable of easier and more abstract solutions than in fact is the case.

KNOWLEDGE, QUESTIONS, POLICY, AND FORM OF AN ANALYSIS

Scientific research is often equated with hypothesis testing and the addition of new understanding to the world's treasury of knowledge. But such considerations are only a small part of policy analysis of scientific phenomena, and of environmental problems in particular. At their best, policy analyses have a well-defined role in the policy design process, and their purpose is to help shape the responses of people and governments to problems rather than to provide a deeper understanding of the scientific phenomena comprising them. It is not sufficient to understand the dynamics of environmental processes in some deep sense. Nor is it always sufficient to design or build a device designed to control such a process. The outlines of an analysis are not determined by biogeochemical processes, and they are seldom set by specific devices to be built to serve specific functions. Rather they are set by the needs of the policy maker to understand the interactions among people, on one hand, and the environment on the other. This is a very fuzzy concept, and we have few guidelines to follow. It is often useful, therefore, to create an overview of the agricultural production system to help point out what matters are important and to channel the analysis to its proper place within the overall policy design process.

Regional Analysis vs. Project Appraisal

There are major differences between analyses designed to probe existing patterns of environmental problems in a region and assessment of the impact of some project designed to change these patterns. These projects may be physical structures such as a dam or a highway, or they may be policies such as educational or taxing strategies.

The former case focuses on environmental problems as abstractions. They are known and perhaps understood to a degree. The role of the environment and the most appropriate sort of analysis can be defined on the basis of known behavior. Regional analysis in this sense can be regarded as an attempt to solve a problem whose empirical data base is sound, at least in principle, and where one need not prejudge something to be imposed on the system. But the essence of project appraisal is that a specific structure is to be imposed on the agricultural production system which is different from what was there before. The reason for the appraisal is almost invariably a prejudgement of the impact and appropriateness of the project. We have no *a priori* reason to assume that the problems and system behavior which have held for the past few years will continue to hold. Even if the primary impacts of a project can be extrapolated from experiences in other places, there is no empirical basis upon which to gauge the secondary reverberations through the system. These indirect effects are likely to be more significant than the primary impacts, and they may be site-specific for the ecological and cultural state of an area. The best documented of these indirect effects are in the reservoirs formed by the big dams of the world (e.g. Kassas, 1972; Starkey and Alpers, 1975; Biswas, 1978).

The extremes of regional and project analysis are extremes on a gradient. The dynamics of development mean that even traditional cultures which do not have large projects imposed on them show evolutionary changes which lead to new problems. Many large projects are carried out in the context of fairly well known ways for doing things, so that the most obvious problems can be anticipated before implementation. Whether the gradient is continuous or uniform is not important. What is, is that most or all analyses of environmental problems of society must direct attention to configurations of the environment which have not yet occurred and even toward problems which may never have been problems before. This is especially important in developing countries which are being forced to rapid proliferation of new technologies by population pressure, but it is true of developed countries as well.

Analyses must provide appropriate answers to important questions. Thus the framework for the analysis must be able to allow the analyst to ask questions in a meaningful way. It is not a trivial statement to note that a question which is not asked cannot be answered. It is clearly essential that an analyst be able to raise insightful questions about the future in the earliest problem-definition stages. Indeed raising the right questions is likely to be more significant than getting the right answers to the questions which are asked.

The reality of the agricultural ecosystem must be understood in the context of the country. It is not to be understood in the general rules of behavior of which economists or social scientists would like to apply (although these may be good first-cut approximations which allow them to realize and begin to overcome their own biases), and it is not described by the abstract models of the ecologist who defines a steady-state or successional system in which man does not play a role. The role of man and the natural environment are linked in ways which may be region-specific. A meaningful analysis must specify the region- specificities and portray the linkages between man and the environment in a way which allows an explication of the problems and insights into their solutions.

Domains of Agricultural Production Systems

This is perhaps easiest if the agricultural production system is viewed in terms of several domains (Clapham, 1980b). This is technically a multilevel hierarchical view (Mesarovic *et al.*, 1970; Clapham and Pestel, 1978a,b,c), but for our purposes here it is more important that we can treat the system in terms of separate domains rather than that there is a particular term in the systems-science jargon which applies to them. Let us think in terms of three domains, as shown in Figure 1. As we shall show, each has a structure and a significance of its own, and the domains are connected by a systematic information flow characterized by a strong assymetry. Information flowing between domains in a "downward" direction represents control; an actor on the "higher" domain is attempting to influence or control a process on the lower. Information flowing "upward" represents process-monitoring; an actor in the "higher" domain monitors the behavior of particular processes in the lower, of which at least a part is a response of the system to his control inputs. He may then adapt his control strategy if needed. This is a pattern of adaptive control, as shown in Figure 2.

Each domain comprises a series of linked processes. There are several ways of defining them, and to do so is one of the arts of the craft of systems analysis. For our purposes, it seems most useful to identify the process corresponding to the specific manipulations of the problems under consideration, as well as certain other issue areas which facilitate the linkage of problems; this is discussed in

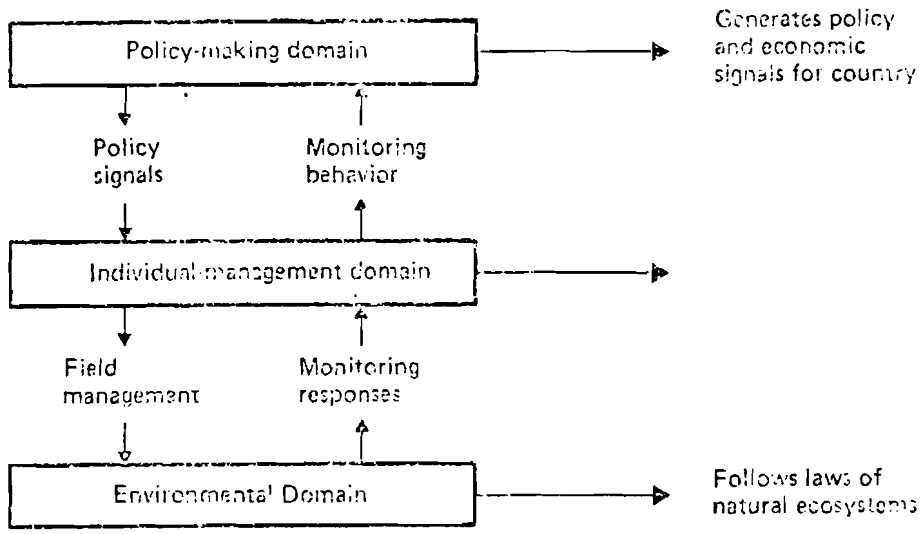

Figure 1 Domains Within the Agricultural Production System

greater detail by Clapham and Pestel (1978b). But it should be noted that different forms and purposes of analysis may require different decompositions of processes within strata.

It is useful to visualize environmental problems as parts of so-called "problem chains." These are defined as branched chains of processes centering on the issues of greatest interest. Each process has certain inputs which affect its behavior. These may come from other processes within the domain or from control exerted by actors in other domains. In the same way, the behavior of each process may influence other processes within the domain, or it may be monitored by (and affect the behavior of) actors or phenomena in others. So the problem chain links the issues and control inputs comprising direct and indirect inputs for the processes of greatest concern, as well as all issues and monitored outputs comprising their direct and indirect outputs (Clapham and Pestel, 1978b).

The problem chain must be long enough to include all of the significant information which enters the domain in question from other domains, as well as all of the significant outputs to other domains. This provides an unambiguous picture of the behavior of the domain, the signals to which it responds, and the signals generated by it to which other domains react. Treating complex systems in this way insures both that the complexity of the system within a domain can be

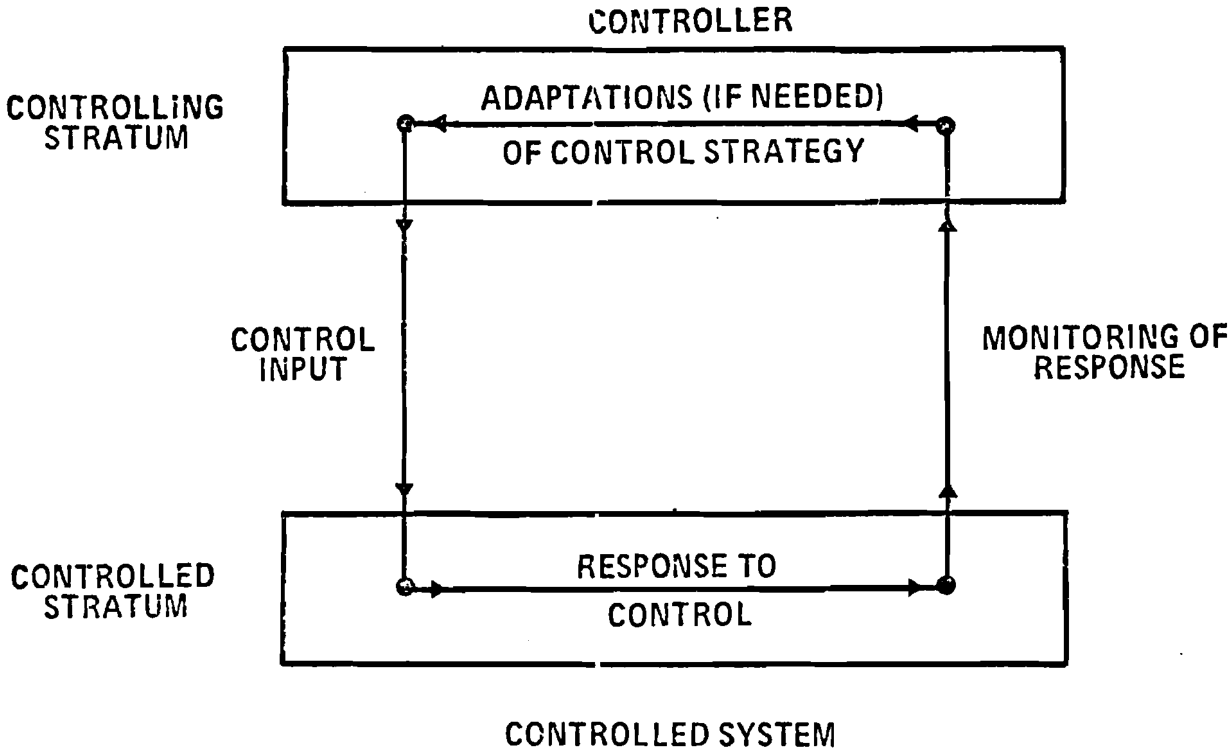

Figure 2 Patterns of Adaptive Control in a Multidimensional System

preserved, and that the dynamics of control and system response can be captured. In addition, the interactions among domains can be understood as information flows closely related to but separate from the processes occurring in each domain. In this way, the entire system can be grasped with a minimum of confusion even if the processes in different domains are understood in rather different disciplinary terms at different spatial or temporal scales.

The environmental domain is the base of the system. It is characterized by those processes which obey the laws of the natural ecosystem, and it includes those aspects of the system commonly assumed to be "ecological" in some sense or which have a "natural science" aspect to them.

The individual-management domain comprises the behavior of the farmer, the herder, and the other individual operators with direct influence on the environmental domain. It can probably be regarded as a set of processes by which individual actors respond both to the behavior of the environmental domain and to the stimuli and constraints imposed by society to adopt the techniques by which they carry out their livelihood. They are limited by the technologies and resources at their disposal, and they can be expected to act in a way by which they will best meet their needs. The decisions of actors in the individual-management domain are directed internally, toward their own actions.

The reverse is true of the decisions made by actors in the policy-making domain. They are explicitly intended to affect or regulate the actions of others. In general, the actors on the policy-making domain monitor the behavior of the individual actors and act to control them in a way which meets the needs of the larger society.

To a degree, the domains can be identified with disciplinary bounds (Table 1), but this is not terribly important. Such comparisons are useful mainly for reference purposes. Much more important are the linkages among phenomena and what they say about interdisciplinary and cross-disciplinary needs. A design for a realistic analysis of environmental problems of agriculture must define a network of subsystems so that not only is the description of each feasible and appropriate to the analysis, but also that subsystems are linked in a way which is feasible, realistic, and instructive. This is a difficult task, and yet it is basic to an adequate policy planning analysis of environmental problems of agriculture.

Table 1 Disciplinary Identifications with Domains of Agricultural Production Systems

	Environmental	*Individual-management*	*Policy-making*
Phenomena	Crop growth Nutrient movement Hydrology Soil movement	Cropping planning Land-use decisions Farm capital Formation Market decisions	Taxation, subsidies Coordination of different sectors Market management Education policy R&D, Extension policy
Disciplines or background of practitioners	Ecology Agronomy Soil Science Hydrology	Microeconomics Rural Sociology	Macroeconomics Business Law policy

Communication Between Domains

The information passing between domains comprises the signals that hold the system together. But if each domain has a quasi-disciplinary significance, as suggested in Table 1, then communication between domains also represents the truly interdisciplinary elements of our interpretation of the system. It also represents, to some degree, the aggregation problem inherent in analyses of this sort. One of the practical reasons for the analytical difficulty of dealing with environmental problems of agriculture is that the environmental domain is commonly viewed as a set of field-level phenomenona, and the policy-making domain is commonly viewed as a national (or at least regional) phenomenon. The individual- management domain is something in the middle. The different geographic disaggregations make it difficult to visualize them as components of a single meaningful system.

Yet there can be no question that the domains defined above exist in the real world and that information does travel between the processes they represent. The difficulties in visualization are due to the disciplinary backgrounds of most analysts and do not reflect the real system. The key to analyzing an agricultural production system with a multi-domain view is to identify the information signals linking domains in such a way that they are meaningful and compatible with the relevant processes throughout.

This is not a trivial statement. What passes from domain to domain is information, and not a process. If the domains are viewed at different levels of specificity or geographic disaggregation, the translation or aggregation must be made within the domains. As an example, a "macro" view of environmental problems of agriculture would probably choose to view farmers in a regional aggregate, but it would have to consider field phenomena at a lower level of aggregation. The significance of the interactions between farmers and fields is different if the communicating information is a regional notion or a field notion, and the "proper" level of aggregation is that which is most useful for the analysis. But regardless of the level of aggregation of the information transfer, it must be absolutely clear how the regional notion of the farmer is an aggregate of the farmers who tend individual fields. In the same way, the field is a subset of the land area of the region. This and other problems of the compatibility of information transfer in agricultural production systems are discussed by Clapham and Pestel (1978a; pp. 12-20).

Four blocks of information are transferred between domains, as shown in Figure 3. Control information is transferred from the individual-management domain to the environmental domain: This represents the actual manipulation of the environment by the farmer or appropriate individual actor. The transfer of information from the environmental domain to the individual-management domain represents those facets of the environment which are actually monitored by the farmer These may, in certain situations, include the direct manifestations of the environmental problems of greatest concern. But they are more likely to be restricted to phenomena more directly related to agricultural production or, perhaps, to public health. The typical farmer's planning horizon is too short, especially in developing countries, to spend much time monitoring developments which do not affect him yet. Indeed the conscious consideration of environmental phenomena whose negative impact lies in the future but which have few short-term consequences is a very sophisticated activity that is probably practiced by a minority of farmers in developed countries (For a strongly- stated, early, and very insightful exposition of this idea in the context of the American Midwest, see Leopold, 1945).

The policy-making domain generates signals to affect or control the decisions made within the individual-management domain. These may be policies directed toward the farmer himself or indirect economic signals which have a pronounced effect on his decision-making calculus. Finally, many of the decisions made by individual actors are monitored by policy-makers to assess the effectiveness of policy design.

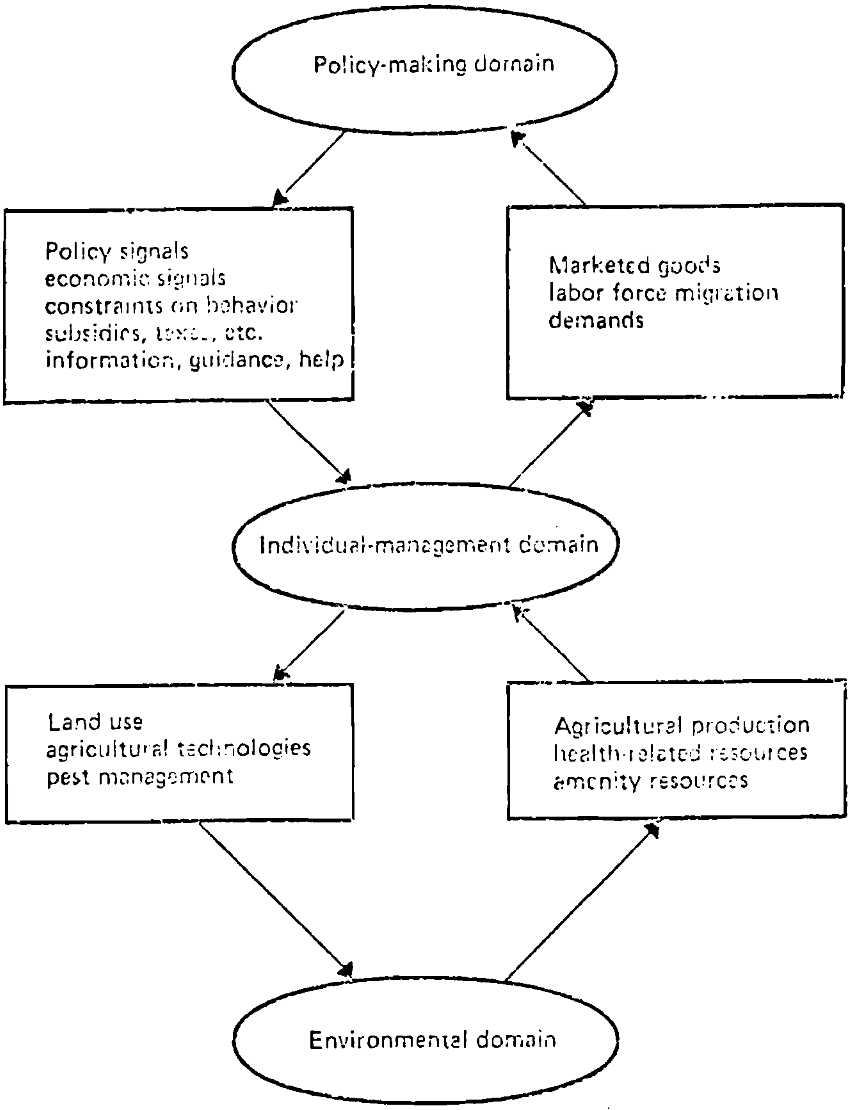

Figure 3 Schema of Information Transfers Between Domains

PART II: A GENERAL VIEW OF AGRICULTURAL SYSTEMS

Let us consider a general view of the agricultural production system in what might be called a "typical" country. Actually, "typical" is this context means very little, as there are no typical countries. But the lists of issue areas considered here can be used on a first-cut basis for most areas. Those which are not important can be deleted and others can be added. The treatment of the lists and the generation of problem chains and their use in pre-analysis can be taken as general. Our purpose in this is to establish a prototypic approach which can then be made specific fairly readily.

I should emphasize that the view presented here is a conceptual model. As such, it is simplistic in places, while other parts present material of great complexity which is not very well understood. Its purpose is to draw together a framework which is useful for understanding the interconnectedness of different parts of agricultural systems and to present a qualitative way of synthesizing a realistic assessment of the responses of the agricultural environment to change. This can in principle be transformed directly into a set of equations. But to do so operationally would be a task of extreme difficulty; I doubt that a mathematical model of the whole system is likely, and it may not even be desirable.

Let us first identify a set of processes or issue areas which characterize each domain, as well as the instruments available to actors in each domain to control phenomena in others. We must also identify the information they use to monitor the behavior of the issue areas which concern them. These can be listed for each domain. Lists of the relevant issue areas and information flows will be presented in the discussion of each domain. But they are very general, and they are not intended as definitive for all places; other issue areas can be added or subtracted from these lists very easily, as can types of information flow.

These lists will then be used as the basis for a set of contingency matrices, one for each domain. These matrices are essentially cross-impact matrices for the various domains (Helmer, 1978). I have termed them "contingency matrices" in this paper only to underscore the fact that their analytical purpose is to explicate qualitative interactions rather than necessarily to form the basis of a formal cross-impact model. The matrices document which issue areas and inputs influence which issue areas and outputs. These influences must be specified in some detail, so that their construction allows an immediate qualitative view of the complexities of the system. The contingency matrices are formed from the entire list of issue areas, inputs, and outputs for each domain. As such, they give a maximal view of the interrelatedness of the system, and the picture they provide is intentionally broad. In principle, the complexity of the picture given by each matrix is mind-boggling. For example, if a domain possessed some 15 issue areas, there might be over 200 separate interactions that would have to be understood. Of course the real world is a complex place, and there might be that many interactions that were important for some questions.

But the point of the contingency matrices is not to organize confusion that cannot be further dealt with. Rather it is to provide a maximal view from which the most important can be picked out efficiently. If the purpose of systems analysis of environmental problems of agriculture is to answer significant questions, there must be some way of insuring that the most important questions are asked in the first place. The contingency matrices allow the analyst to cast his net widely over the issues which may be important for his particular case and assess their importance within his context. He can simplify the picture quickly by eliminating the unimportant or less important issues from the analysis on the basis of his own experience and prior knowledge. This progressive simplification forces him to look at potentially important relationships, however, and it makes it much more difficult for him to ignore important ones than the more normal from-scratch approaches which concentrate on particular problems. Analyses which begin with a close focus on the main problem are often based on traditional or disciplinary forms of analysis which ignore factors which may be extraordinarily important in the real-world dynamics of the system, and it is very difficult to begin with a tightly defined analysis and add to it by accretion and end up with anything but an unworkable monster. Progressive simplification, on the other hand, provides one means to tailor an analysis to particular instances where the traditional approaches may not be ideal.

ENVIRONMENTAL DOMAIN

The environmental domain of the human ecosystem includes those factors whose behavior corresponds to the laws of the natural ecosystem. This is not to say that agricultural production systems are natural; indeed they are commonly human creations which would collapse immediately were they not continually propped up by human management. But they are governed by the laws of natural ecosystems, and these laws do not change, even as the system is modified by human intervention. The phenomena of the environmental domain include interaction among species, crop and livestock responses to various inputs, soil, water, and nutrient balances, and the interacting dynamics of animals, plants, soil, water, and nutrients.

The environmental domain is at once the most and least general of strata in the agricultural production system. Because the laws of the environmental domain are those of the natural ecosystem, it is general in the sense that the phenomena of the environmental domain transcend national boundaries and may not be very different even under very different political or economic conditions. On the other hand, they are quite site-specific, with important details being limited to relatively small areas. The generality of the natural domain means that models which have been elaborated for one kind of system in one place may be rather broadly applicable to other systems with a similar general kind of make-up in different places and different controlling cultural, political, or economic regimes. Considering the complexity of most ecosystems, this is very useful, and it may even be an essential factor if human ecosystems are to be studied using mathematical models. On the other hand, the fact that there are real differences between different areas may cause a combinatorial problem due to the multiplicity of subregions which may necessarily be included in a realistic analysis.

Let us first describe the environmental domain in terms of the phenomena characterizing it and then by the information flows entering and leaving it.

Issue Areas

Climate refers to the development of weather patterns over several years or over the term of an analysis. It can generally be regarded as removed from conscious human control so that it represents a source of indigenous system variability. In general, we can assume average levels of temperature and precipitation, so that the problems engendered by climatic conditions are due to deviations from these and changes in them (Biswas, in press).

Biocide resistance is the genetic resistance engendered in target populations when pesticides are use against them. As a result, pest populations become less susceptible to biocide applications, so that higher levels or different formulations must be used. For a pest management system which is dependent on chemical biocides, resistance is one of the most damaging and negative of phenomena.

The effects of biocides on *non- target organisms* is one of the clearest negative environmental impacts of pesticide use. These were brought to the public eye by Rachael Carson in her book, *The Silent Spring*, although several other books showing the toxic effects of pesticides on birds and fish have also been published. But the most important non-target organisms killed by biocides are probably the beneficial insects which are capable of controlling economic pests under normal conditions but which are killed by the pesticides in such numbers that they lose their ability to control the pest.

Perhaps one of the best examples of biocide-based pest management having negative repercussions because of its impact on non-target organisms is the well-documented cottony cushion scale insect of the citrus groves of California (Doutt, 1964). This insect was introduced accidently into California around 1870, where it quickly decimated the California citrus groves. In 1886 and 1888, the main predators on the scale insect were introduced into California, and the pest was under control by 1890. With the availability of chemical insecticides after World War II, the decision was made to eradicate the cottony cushion scale insect altogether. DDT and Parathion were the main insecticides sprayed on the citrus crop. The scale is not terribly sensitive to these insecticides. But mortality of the natural enemies was so great that the scale population rose to outbreak levels and became an economically important problem for the first time in over 50 years. This is not an isolated example. deBach (1974) cites several examples in which it is easier to raise pests by spraying with insecticide than by raising them in the laboratory.

Pests and weeds represent predators on and competitors with, respectively, crop plants. As such, they are responsible for the losses of great quantities of potential production. They may be exceedingly important sources of waste, especially in the developing world. Pimentel *et al.*, (1978) cite numerous studies to estimate that the losses of crops to pest, weeds, and disease averages about 33% in developed countries and that it is higher for some crops. Likewise, it may be considerably higher in developing countries.

The role of pests and weeds in any agricultural situation is particularly significant in assessing environmental problems of agriculture. Virtually all ecosystems contain predation and competition, and the existence of pests and weeds is simply an expression of the fact that agricultural fields are ecosystems which are subject to many of the same tendencies as natural ecosystems. But one way to increase crop production is to reduce losses to pests and weeds, and pest control has long been one of the main elements of agricultural management.

Vegetation cover refers to the vegetation found in an area. It may be crops, pasture, weeds, or natural vegetation. The growth and dynamics of vegetation is one of the key variables in any human ecosystem, as plants have so many functions in all ecosystems. Depending on the particular phenomena it affects, vegetation cover can be measured in terms of root volume, leaf area index, vegetation diversity, and so forth.

Human disease includes a broad range of ailments within the human population. Most of these are caused by pathogenic microorganisms which lead to acute or chronic problems, often of considerable magnitude. Many diseases are dormant or free-living outside of their human hosts. These include the airborne viruses and the waterborne viruses, bacteria, and protozoa which cause such diseases as influenza, tuberculosis, typhoid, typhus, and dysentery. But some of the most significant diseases of the rural scene are those which are carried by animal vectors. The disease organisms range from viruses to protozoa to worms of various sorts. The vectors include insects, rats, snails, and myriad other organisms. In some cases, the diseases are highly contagious and dangerous, as in the case of bubonic plague; they may be debilitating over very wide ranges of the population, such as river blindness and schistosomiasis.

The status of *soil water* can be measured by a number of parameters, including saturation water deficit and percentage of field capacity. The notion also includes distribution throughout the soil. Regardless of how it is measured, it represents the water which is available to plants for their growth, but which also displaces oxygen from the air spaces in the soil under extreme conditions, as with waterlogging, thus depriving roots of air needed for their respiration.

Soil chemistry in this context refers to the kinds of chemical reactions which go on within the soil. The soil is a fantastic "reaction vessel" for all types of chemical reactions. Some of these are found in all ecosystems as part of the soil-forming process (see Brady, 1974, for a good discussion of soil chemistry), while other reactions involve anthropogenic chemicals. These include those governing nutrient dynamics, pesticide breakdown, and the oxidation or change of organic particles.

Waterlogging and salinization are common results of irrigation. Waterlogging occurs when there is so much water in the soil that it is no longer aerated. This is generally due to increased height of water table in irrigated soils. Indeed, the water table may reach the surface in some cases, and plant mortality may be very high. Waterlogging is also characterized by a suite of soil-chemistry phenomena, most of which involve the precipitation of toxic reduced forms of common chemical species (see, for example, Balls, 1953). Salinization, on the other hand, is caused by "too much" evapotranspiration so that the salts which entered the system with irrigation waters stay there after the water itself has evaporated. The salt content of a soil can build up to a point where it too becomes toxic to plants.

Soil erosion is the removal of soil by wind and moving water. It is a major problem in many parts of the world, as the rate of soil erosion may be considerably faster than the rate of soil formation. Furthermore, soil erosion can proceed so far even in a richly vegetated area that one is left with but bare rock after a relatively short period of time. But erosion need not be so complete to be significant. Erosion of topsoil has taken place in many parts of the world, so that crops must be grown in subsoil, which is inherently less fertile.

The *miscellanous soil problems* as defined here include soil compaction, soil oxidation, laterization, and related phenomena. These are relatively specialized problems which may be very significant locally but are not as widespread as phenomena such as erosion, waterlogging, or salinization. Soil compaction is caused mainly by the use of heavy machines without understanding their impact on the soil. Soil oxidation is the oxidation of materials in acid sulfate and mangrove soils. Laterization is the process by which certain highly weathered soils can dry out and harden irreversably if the vegetation is cut from them.

Soil fertility refers to the value of the soil for purposes of growing crops. It is a very complex notion, involving ion exchage capacity, available nutrient content, water status, aeration, and soil biota. In fact, it would be difficult to define at all rigorously, and its main value in a conceptual model is as an aggregate index of a number of other phenomena which are easier to specify but whose role in crop productivity is not as clear to the non-specialist.

Flooding and siltation are among the most dangerous and feared phenomena in the natural world. They can do tremensous damage, although the silt deposited by floods in agricultural areas may be rich alluvial soils which include some of the world's richest soils. The erosive power of a flood may be very great, and floods have no respect for property, social class, or life.

Soil structure refers to the physical makeup of the soil, notably its physical character and the nature of its aggregate particles. Its evolution is a long-term phenomenon, and its impact on other factors within the system are subtle, but potentially very important. Soil structure is a function of many things, including the natural ecologic conditions under which it is found, as well as all aspects of management (Brady, 1974)

Agricultural chemical runoff refers to the removal of agricultural chemicals from the land and their incorporation into surface waters. These are most important if they lead to eutrophication or if they have poisonous effects on the watercourse. Like most other processes in the human ecosystem, agricultural chemical runoff is not a simple matter of materials dissolving in runoff water and being carried to surface waters. It is closely dependent on the chemical processes in the soil which determine precisely what chemicals are available to run off as well as the dynamics of soil erosion. Many of the most important agricultural chemicals are, in fact, quite insoluble in water and are carried into waterways adsorbed onto soil particles. This is especially true of biocides and phosphorus, which is the nutrient most responsible for eutrophication.

The *quality of water* refers to factors such as its nutrient content and attendent level of eutrophication, its toxin content and its turbidity. Precisely what is used to indicate water quality depends, of course, on the purpose of the particular analysis. The waterway in question may be subject to stream standards, in which case quality refers to the deviation from the standards. On the other hand, the waterway may be used as a water supply, in which case quality refers to its appropriateness for the intended use.

The *genetic resources of crop plants* are important for the stability of crop varieties, as genes once lost are difficult to impossible to replace. Higher intensities of cropping depend on high-yielding varieties derived from inbred genetic lines. But selection is not omniscient. The plant-breeder can only select lineages for well-defined reasons, and he chooses properties which appear to answer certain questions or meet certain needs. Other potential needs which are not apparent are not selected for. It is possible to maintain crop genetic diversity in germ plasm banks, but these are commonly maintained at relatively low levels inadequate to preserve wide genetic diversity (Miller, 1973). A too-narrow genetic base for crops has been the basis of a number of crop failures, with significant impact on human populations. The most dramatic of these was the Irish potato famine of the 1840's, but the problem is not only historical. The

North American blight of the 1970's was also due to the very high degree of genetic uniformity of the crop line (Horsfall *et al*, 1972).

Crop and livestock productivity describe the responses of crops and livestock lines to all forms of management and to the particular details of the ecosystem comprising the agricultural system in which they are grown. Production is commonly measured per unit of one or more factors, such as land, labor, unit input of fertilizer, or cost.

The *habitat for natural populations* refers to the area which is available for natural populations to live. In some cases these may be end-of-succession terrestrial environments, most of which are quite vulnerable. Other cases may have early successional habitats which are heavily favored by certain species of game and which are quite easily created during land conversion and related processes. In the same way, aquatic habitats are characterized by different communities. In general, most natural populations require certain minimum sizes in order to maintain a viable complement of genetic diversity. The size of the population that can be maintained is a function to a degree of the size and appropriateness of the habitat available to the population. Most populations have a critical habitat size above which survival and genetic variability is assured, below which the genetic variability is likely to be lost quite quickly until extinction is the most likely result.

Signals from Individual- Management Domain

Land use refers to the committments made by individuals (and this includes all actors who are capable of committing land to specific uses, not just farmers), as well as to the specific uses to which land is put. It may refer to the particular crops that are grown in specific fields, or to the fundamental land-use patterns of an area.

Labor quality is one of the most important characteristics of the individual actor which is transferred to the environmental domain. But it is not the result of their decisions. It provides an "all-other-things-being-equal" assessment of what a given worker is capable of. This is closely related to the concept of human capital (Schultz, 1964), and it is a function of the state of health of the individual, his level of education, and so forth. It has long been recognized as a significant factor in capital-intensive activities, and some employers have made great efforts to screen potential laborers for health and capabilities and then to try to maintain them. This is true even in very primitive or isolated areas, if enough is at stake Webster (1975) documents the efforts to maintain labor quality in the Kariba Dam project of southern Africa, and one of the key reasons for the failures of the first (1880-1888) efforts to construct the Panama Canal was the inability of the Canal Company to maintain labor quality in the face of malaria and yellow fever (Waddy, 1975). But if the capabilities of workers are important in capital-intensive activities, they are no less important in dispersed activities such as agriculture. Indeed one of the great tragedies of modern times lies in the vicious circle of poverty and ill health. This has been well stated by Myrdal (1952): "Men and women were sick because they were poor; they became poorer because they were sick, and sicker because they were poorer." Both poverty and sickness breed ignorance and physical problems which reduce workers' capabilities in agriculture, often leading to malnutrition or even death.

Pest management techniques include a vast range of phenomena, from the use of chemical insecticides to biological control to integrated pest management. The most common of these is chemical pest management. We often think of biocides and pesticides as being almost synonomous, but the uses of herbicides, fungicides, nematicides, rodenticides, etc. are growing rapidly. In order to characterize biocide use, it is necessary to specify the particular mix of biocides being uses, as well as their patterns of use, both geographically and in time.

Biological control commonly refers to pest control in the absence of chemical biocides. Pests are controlled simply by the use of parasites and predators. This approach has had some astonishing successes, some of which are described by deBach (1974). Integrated pest management, on the other hand, is a very poorly defined set of approaches which includes chemicals, tillage and cultivation methods, parasites and predators, timing of planting, and so forth. It represents, in many ways, a compromise or a cross between chemical and biological control which minimizes the introduction of toxic materials into the environment but retains the option of their use under certain conditions. A general discussion of integrated control is given by CEQ (1972). Other mechanisms of pest control include the spreading of sterilized males of the pest into the environment. These need only be able to mate with females and deliver viable sperm to disrupt reproduction of the pest species. The greatest success of this method is the eradication of the screwworm, a severe livestock pest, from the United States.

Sanitation refers to the separation of human and animal wastes, plant debris, etc. from places where they can cause damage. For our purposes, these places are either where they can have direct contact with the human population or with watercourses. The importance of sanitation lies in its role in combatting disease and water pollution.

Water and flood management includes a rather broad range of topics, the most notable of which are flood control works and irrigation and drainage technologies and devices.

Agricultural technology decisions made by farmers include a broad range of affairs. The most obvious include the techniques of mechanical treatment of soil and the genetic structure of the crop. The farmer is constrained by the implements he has available to him, as well as the information upon which he can base his plans. But within the limitations imposed by his capital abilities, the farmer may show rather wide variations in his agricultural technology from year to year, and change may be rather rapid if the conditions are right. The best known example of technological change in agriculture is probably the widespread adoption of hybrid corn in the 1940's and 1950's in most developed countries. Hybrid wheats, corn, and rice have also been widely adopted in developing countries by farmers who were rich enough to purchase the inputs needed to grow them properly, but they have not been adopted by farmers who did not have the capital base to grow them effectively. In the same vein, the ability of poor farmers to change with appropriate signals is shown by the responses of peasants in upper Egypt when water from the High Dam at Aswan became available. The growing season for practically all of the corn grown in the country changed from the fall, as it had been for many years, to a summer crop (El-Tobgy, 1976).

One of the greatest unknowns in agricultural project assessment is the responses of farmers to change. Farmers -- especially poor farmers -- are among the most conservative of people, as their ability to assure adequate production of food for themselves and their families may be marginal at best. They cannot afford to change the technologies they understand and trust unless they are totally convinced that they will not starve as a result. Demonstrations of the new approaches in the next district may not be convincing, unless trusted people in the village have actually seen them. Yet when the farmer believes that he will benefit from change, he can do it very quickly, as shown by the examples above. It is not always possible to gauge when people will decide to change and when they will not, as the decision-making processes involved are very complex and may include a large number of institutions, including family, village elders, etc. (Todaro, 1977). But how different institutions affect decision-making is often very unclear. For example, Mayfield (1976) cites an example from the Egyptian delta in which one of the most important instruments for transferring information to the village and getting responses was a savings bank. The reasons in this case were clear, but it is hardly something that would normally have been considered in an assessment of technological development in the area.

Signals to the Individual- Management Domain

Agricultural production is the total production of crop and livestock commodities from the environmental domain.

The *fishery resources* refer to the state of the fisheries in surface waters and/or adjacent areas of the sea. In principle, this could be defined in terms of fish catch, fish biomass, or effort per landing. It makes rather little difference. In essence, this is a variable which measures the availability of fish to those who want them.

The *health- related resources* are health, assured supplies of drinking water, and the other phenomena which are often considered necessary to the proper functioning of individuals in a modern society.

The *amenity resources* are those attributes of the natural ecosystem and which people value highly, even if it is difficult to ascribe monetary values to them and if their function in their lives is not clear. Examples include beauty, the presence of birds, fish, or other animals of no direct economic or health benefit, and so forth.

Externality phenomena comprise those problems which are monitored by actors not active in agriculture but who are affected in some way by agricultural activity. The most common externalities are the negative ones, in which people are injured by the activity. Externalities significant because they engender actions which feed back into agriculture in a significant way. For a very interesting and literate discussion of externalities and their significance for environmental problems, the reader is referred to Mishan (1970).

The relationships between the information and issue areas are shown in the contingency matrix of Figure 4. This matrix is set up so that a notation within the table means that the phenomenon corresponding to the row of the matrix (indicated at the left of the table) has a significant influence on the phenomenon corresponding to the column (indicated by the code at the top). The numbers refer to specific interactions which will be described below. The columns refer to the inputs to the environmental domain from the individual-management domain, as well as all issue areas occurring within the domain. Thus, the phenomena listed on the left margin are those which represent potential inputs to any issue area within the domain. The rows represent total set of responses of the domain, whether these be those of particular issue areas or outputs to the individual-management domain. The order in which issue areas appear in the matrix is significant. Issue areas are grouped, for the most part, into blocks which can be understood together, but they are also ordered so that behavior of one part of the system which is contingent on that of others can be considered in order. Inputs, issue areas, and outputs are ordered so that priority in contingency matters is retained if one reads from left to right, top to bottom. There is some lattitude in the order, since the matrix is relatively sparse, but it is not complete. Priority is assured if the number in the matrix indicating a potentially significant

		CC	BR	NT	PA	VC	DI	SW	CS	WS	SE	SC	SF	FL	SS	AC	WQ	CG	CP	NH	AP	FI	HR	AR	EP
Land Use	LU					1	2				3						4	5			6				
Labor Quality	LQ																		1						
Pest Management	CB		1	2	3		4		5																
Sanitation	SA						1										2								
Water/Flood Mgmt.	WF						1	2	3	4			5	6	7		8					9			
Crop Technology	CT				1	2		3	4			5	6		7	8		9	10						
Climatic Cond.	CC	-			1	2	3	4			5			6											
Biocide Resist.	BR		-		1		2																		3
Non-Target Orgs.	NT			-	1		2												3	4		5			6
Pest Weed Attack	PA				-	1													2						
Vegetation Cover	VC				1	-		2	3		4				5										
Human Disease	DI						-																1		
Soil Water Status	SW							-	1		2		3		4										
Chemistry of Soil	CS								-				1			2									
Waterlog, Saliniz	WS									-			1			2									
Soil Erosion	SE					1					-			2	3	4	5		6	7		8			9
Misc Soil Probs.	SC											-			1										
Soil Fertility	SF					1							-						2					3	
Flooding & Silt.	FL							1			2			-	3		4		5	6		7	8	9	
Soil Structure	SS								1		2		3		-										
Ag. Chem. Runoff	AC															-	1								2
Water Quality	WQ						1										-		2	3		4	5	6	7
Crop Genetic	CG				1													-	2						
Crop Productivity	CP					1													-		2				
Natural Habitat	NH																			-				1	2

Figure 4 Contingency Matrix for the Environmental Domain

interaction appears to the right of the diagonal line splitting the square matrix of issue areas. If all contingencies are of this sort, or if all relationships to the left of that line can be assumed to be driven by prior behavior of the phenomenon in question (i.e. lagged inputs), then the consideration of each issue area can be handled *seriatim*, in the order presented in the matrix, and the analytical feasibility, or "computability" of the system is assured. There may also be simultaneous interactions, in which the order of presentation in the matrix is not so important. But it is generally easier to treat processes as being characterized by contingent interactions rather than by simultaneity, and this is generally more realistic for the phenomena found in the environmental domain (Clapham *et al.*, 1980). There are no direct interactions among inputs or among outputs except as described explicitly by a process within the domain. Let us now describe the interactions shown in Figure 4 to demonstrate the rationality of the picture it describes. In the following discussion, we shall proceed row by row within the matrix, from left to right. Each interaction is keyed to the number shown in Figure 4.

Patterns of Interaction Within the Environmental Domain

Land Use

1. Land use - vegetation cover. One of the basic aspects of the agricultural environment is the pattern of crops. What crops are grown, where, and in what rotation? For land which is not in crops, how is it managed? Woodlots and forests may be allowed to retain their natural vegetation, or they may be managed to increase wood production by trimming out young trees and bushes from the understory. The use of land for pastures fixes them in a grass-herb vegetation whose precise balance is most closely related to the intensity of livestock pressure.

2. Land use - human disease. Many human diseases are closely associated with particular land uses, most of which reflect the way of life of the people living there. Irrigated agriculture is characterized by the largest number of lifestyle-related diseases, most of which are vector-borne diseases whose vectors live in the water associated with the irrigation system. Perhaps the most widespread of these diseases in the world today is schistosomiasis. This is caused by a liver fluke that has a snail as an alternate host. These snails can be found in stagnant waters such as irrigation canals and ditches. Another disease associated with irrigation is malaria, whose mosquito vectors occupy a wide number of habitats. Malarial vector control is difficult, as each vector species must be treated differently, and measures which might be successful against one would actually promote another.

Land uses other than irrigation may retain the habitats for diseases which would normally occur in the area, and other farm activities may make them more or less common. As an example, certain types of grazing can promote habitats for ticks that carry encephalitis or spotted fever. Use of land for dumps provides a habitat for rats whose fleas carry plague. Disease is seldom inherent in particular land uses, as disease control can always be a part of intelligent land use. But one of the chief goals of the evolution of land use strategies should be to destroy the habitat for disease hosts as well as to promote the production of economically productive resources.

3. Land use - soil erosion. Just as a given land use has a characteristic vegetation cover, it also has a characteristic erosion potential. Part of this is due to the vegetation cover and the soil-holding abilities of living plants. But another part is due directly to the way in which the land itself is managed. For example, a given crop may be able to survive in a steep field or a terraced field. But the amount of soil lost from the latter is far less than that from the former. Also, many land uses result in unvegetated land for at least part of the year, and the amount of soil lost from such areas is precisely related to the way the soil is managed for erosion control.

4. *Land use - water quality.* Certain aspects of water quality are automatically important in an assessment of environmental problems of agriculture. Many of these are controlled directly by land use or by other processes for which land use is a particularly effective proxy variable. It is often easier, for example, to visualize point-source pollution problems as land-use-related as to concentrate on the dynamics of the particular point sources. This is true both of agricultural point sources such as cattle feedlots or poultry farms and of industrial sources such as factories. In such cases, the policy question is less often whether to build a particular point-source as where to locate it. That is, the decision to build is an economic one; the policy decision is a land use decision. But the most important environmental impact of such point sources is the effect of pollution on water quality.

5. *Land use - crop genetics.* There are two aspects of the impact of land use on the genetic state of crop varieties. The first concerns the diversity of the crop genome within a given area and is largely a matter of the mixture of crop varieties grown there. The second concerns the concentration of cropland within the cleared base. Crop genetic erosion has recently become a problem of some note in many parts of the world, especially those in which high yielding varieties and intensive use of certain varieties is practiced. The genetic diversity of the crop in such areas is very low, as only a few particular genotypes which meet certain criteria are planted. Such low genetic diversity may have substantial negative impacts on both the short-term and long-term stability of the crop (Horsfall *et al*, 1972). Land uses which foster a multiplicity of varieties within a given area tend to be much more resilient.

Genes which might be useful to the crop in the future can be saved in several ways. The most obvious is in gene banks maintained by governments or plant breeders to retain diversity in available form. As shown by Miller (1973), these banks can be found all over the world, but their levels of funding are generally inadequate to insure that the gene pools of even the most important crop varieties can be retained at high levels. Genes can also be stored in volunteer crop plants or weedy varieties of crop species which have reverted to a more natural habit. If land-use patterns allow the existence of areas around fields which are not actually cropped and in which weeds are allowed to survive, this may also insure the retention of important genes that have been bred out of the planted crop varieties. Indeed some of the important discoveries on the origin of corn have come from plants which have reverted to weedy growth in just such refuges in Mexico.

6. *Land use - agricultural production.* Agricultural production is most meaningfully represented as commodity production. But the most useful way of looking at the ecological phenomenon of crop production is in terms of productivity, or production per unit area. This is converted into commodity production by multiplying by the harvested land area in each crop.

Labor Quality

1. Labor quality - crop and livestock production. The quality of labor has a clear and pronounced impact on the productivity of field crops and livestock. A knowledgeable farmer or a well trained farmer is a better farmer than one who has no training at all. Likewise a motivated or healthy farmer is a better and more effective farmer than one whose motivational state or health is poor. The same is true for the rural support population of trained agricultural professionals, veterinarians, certified seed growers, and so forth. If they are well trained and motivated, they can do a much better job than if they are not. The ability of these supporting professionals to extend the productivity of the farmer is directly reflected in his agricultural production.

Pest Management

1. Pest management - biocide resistance. Biocides are designed to kill. To the degree that any given population includes genes which confer resistance to biocide action, then the very use of biocides insures that these genes will be selected for, and so biocide-resistant genes will increase in frequency, and resistance will build within the population. The result is that the impact on intended target populations will necessarily decrease with continuing use. The literature is replete with examples of biocide resistance in pest species, and it can probably be regarded as an integral part of pest management via biocides.

2. Pest management - non-target organisms The impact of pest management on non-target organisms may be positive or negative, but current practices render it almost exclusively negative. Biocides kill, and most biocides are relatively broad in their killing spectrum. Thus it is virtually impossible for a pesticide program directed against a particular insect not to kill other species as well. As shown by deBach (1974), this non-target killing may lead to outbreak levels of the pest as it frees the pest population from control by natural enemies. On the other hand, biological or integrated pest management relies on non-pest species for all or part of the control, and these species are monitored closely in the design of the control scheme. As a result, this sort of pest management encourages non-target populations.

3. Pest management - pest and weed attack. In principle, this relationship is a relatively simple one. The purpose of pest management schemes is to rid the field of unwanted pests or weeds. An empirical relationship between biocide application or dose and mortality in the pest population can be derived for any given biocide use strategy. Such relationships occupy much of the literature of applied entomology. But the real world is seldom quite so simple. All pest management schemes have at least some effect on populations which act antagonistically or synergistically with the target population. In order to be sure about the effectiveness of any pest management approach, these factors must be thoroughly understood, including the responses of the pest population to all changes in the crop ecosystem. These include the plant/ animal environment as well as the chemical.

4. Pest management - human disease. Not all pests are undesirable because of their effect on crops or livestock. Others are vectors for human diseases. Everything that one can say about the management of crop pests can equally well be said about disease vectors. Some can be controlled reasonably well by chemical means and some past successes have bordered on the spectacular. Indeed the single act that probably gave the greatest boost to chemical control of insect pests occurred in Italy at the end of World War II. When the U.S. Army entered Naples in 1944, the city was thoroughly defeated, and there was imminent danger of a louse-borne Typhus epidemic. DDT was used to control the vector, and the epidemic was nipped in the bud. Most of the vectors for the most common diseases are insects, so that insecticide application has long been considered a satisfactory approach to their control. However, disease vectors show the same biocide resistance as crop pests, and the second-order effects involving non-target populations may also be significant.

5. Pest management - soil chemistry. Few pesticides are permanent. Especially those which are organic chemicals break down naturally in the soil to simpler residues. These pesticide residues are commonly thought to be harmless, although they need not be, and the exact impact of different species of pesticide residue on the biota of the given field is not very well understood. But populations of both biocide-target species and other species respond to the total chemical environment, not simply the most recent addition by the farmer. And if the residues of one kind of biocide remain in the soil for some period of time, they can exert a selective pressure on the populations that come in contact with those soils for years after application of the chemical has stopped.

Sanitation

1. Sanitation - human disease. The separation of human and animal wastes from places where they can come into contact with humans is not a trivial thing. It is not uncommon for people to defecate or urinate along rivers where the wastes can be washed away, or in relatively private, but numerically restricted, places like under bridges or behind bushes frequented by others. Direct evacuation into waterways can be found even in relatively sophisticated countries. As an example, I once saw several hundred privies built out over the Elk River in West Virginia, U.S.A. It is not surprising that similar patterns should be followed in developing countries. Human excrement is often used as a fertilizer on food crops. Urine and feces, regardless of where they are deposited, contain the propagules of whatever parasites the host is plagued with. If the wastes end up in a place where the eggs can hatch and the larvae survive, the cycle can be completed.

Soil-living worms such as hookworms are favored by the use of excrement as a fertilizer, and some of the schistosomes are aided by waste deposition in water inhabited by the right species of snail. Construction of latrines can go a long way toward controlling some parasitic diseases, and other sanitation methods can control still others. This is not to say that sanitation or measures such as latrine construction will solve all of the problems in a given area. For example, *Schistosoma mansoni* and *S. japonicum* inhabit the gut, and their eggs are passed with feces. Latrine construction is an important tool in the control of these two schistosomes. But *S. haemotobium* lays its eggs in the wall of the urinary bladder and passes its eggs in urine. The main mechanism for spreading this disease is micturation of children swimming in the rivers. Latrine construction would be virtually useless against this parasite, even though it causes schistosomiasis just as the others (Ansari, 1973)

2. Sanitation - water quality. Organic wastes deposited in water do more than release the propogules of the parasites back into waterways. They also provide nutrients and fixed energy which may be instrumental in local eutrophication. Eutrophication may reduce the quality of surface waters for various uses, but it may also create the habitat for disease vectors themselves.

This will be discussed below under the section, "water quality - disease."

Water and Flood Management

1. Water and flood management - human disease. Many waterborne diseases are closely related to the presence or absence of suitable habitat for disease vectors. It may be useful to visualize the scope of the vector habitat on the local field level or on the central water-resources project level. Perhaps the best example of the former is schistosomiasis, whose vector is a snail which is strongly favored by the existence of slowly-moving or stagnant water such as can be found in irrigation systems and drains. One of the chief methods of control of this disease is to design and manage the irrigation system to deny a suitable habitat to the snail for long enough that it cannot thrive.

Two excellent examples of the problems of designing irrigation schemes at the national or regional level are malaria and onchocerciasis, or river blindness. In the former case, it is necessary to make a complete assessment of all of the malaria-carrying mosquitoes that are endemic to an area and then minimize the habitat suitable for them. As pointed out by Waddy (1975), this has been done successfully in a number of locations. But the measures which work in one case might spell disaster in another. The vector in the southeastern part of North America, for example, is *Anopheles quadrimaculatus*. The Tennessee Valley Authority was able to reduce malaria in the area while providing hydroelectric power by varying the height of the water in the reservoirs. It was suggested that a similar technique should be used in west Africa, until it was pointed out that this would create conditions even more ideal for the most important local malaria vector than were found previously.

In the case of river blindness, the vector is the black-fly, *Simulium*, which grows in rapidly moving aerated water such as found in rapids or in the spillways of dams. The design of large water projects in areas where river blindness is endemic must be careful not to create habitat for the black-fly while meeting some of the other goals of society.

2. Water and flood management - soil water status. There are two effects which may be important here. The first regards the mass balance of water within an irrigated or drained soil. This is a significant factor in all irrigated lands, especially those of arid and semiarid regions. But no less important is the distribution of water, either with regard to the surface or vertically within the soil column. Some irrigation technologies (e.g. drip irrigation and ditch irrigation) result in highly nonuniform coverage of the surface, while others (e.g. flood or spray) have more nearly uniform coverage. The movement patterns of water in the soil may result in unusual vertical distribution of water.

3. Water and flood management - soil chemistry. Water is a basic component of most chemical reactions in the soil, and irrigation has two effects. One of them is the simple role of water in chemical processes; this is considered in this typology as the influence of soil water status on soil chemistry. However the chemical makeup of the irrigation water may have an effect of its own. The concentrations of various ions in solution may change the pattern of ion exchange reactions, as can the pH. Other chemical properties of irrigation water may also affect the colloidal movements of soil particles.

4. Water and flood management - waterlogging and salinization. Waterlogging and salinization are two of the more important facts of life in irrigated lands, especially in poor countries in arid zones. The first is a phenomenon caused by the raising of water tables by the addition of irrigation water is soils which do not drain properly. Water added by irrigation which is not lost through evapotranspiration must either run off on the surface or percolate into the soil. Unless there is natural drainage within the soil so that it moves laterally to the surface, or to a deeper aquifer, water builds up in the soil until the root zone is saturated. In many areas, this is a significant phenomenon, so that irrigation must be coupled with drainage if it is to be effective. The growth of plants is related, among other things, to the aeration of the soil and the resulting capability of roots to breathe. If all of the air space is taken up by water because of waterlogging, then crop production is generally affected adversely.

Salinization of soils, on the other hand, refers to the buildup of salts in the soil because of evapotranspiration. As salts accumulate, the salinity of the interstitial water rises, perhaps to a point above which the active transport mechanisms of plants for nutrient unput can function. Salinization can be controlled by flushing of salts from soils by adding more water than is needed for evapotransiration. This, however, runs the risk of waterlogging for inadequately drained soils. Waterlogging and salinization can thus be considered extreme conditions along a gradient of irrigation water use; the first represents too much water for soil conditions, the second represents too little. In principle, there is a middle ground which minimizes the deleterious effects of both. For undrained soils, however, the middle ground may show the manifestations of both.

5. *Water and flood management - soil fertility.* Soil fertility is a rather fuzzy concept. Basically, it refers to the amount of nutrients in the soil and their availability. In general, the dynamics of nutrient availability is controlled by the colloidal and ion exchange behavior of the soil. One of the factors implicit in any irrigation system is that there is a net movement of water into soil. Depending on the chemistry of the moving water, there may or may not be a stripping of nutrients through ion exchange. Likewise, there may or may not be a movement of the colloidal particles within or even out of the root zone of crop plants. Either can lead to a reduction in soil fertility.

6. *Water and flood management - flooding and siltation.* One can do many things to control flooding. One is flood control works. These are relatively well understood engineering devices and rather little needs to be said about them here.

But formal flood control devices are not the only means of controlling floods or limiting flood-related siltation. Often the most effective methods are land-use control which maintains flood-prone land in a configuration for which flooding is not particularly damaging or through which downstream effects of floods can be mitigated. Figure 4 shows no direct influence of land use on flooding. This is because the effect, even though very important, is an indirect one. Land use allows the maintenance of types of vegetation which can buffer the environment by absorbing great quantities of water. This, in turn, allows for the mitigation of flood effects, both in situ and downstream.

7. *Water and flood management - soil structure.* Soil structure can be changed by many different forces, including the movement of water within irrigated soil and the effects of floods.

8. *Water and flood management - water quality.* One of the characteristics of any irrigation system is the chemical properties of the irrigation return water. Not all of the water delivered to the field is actually used through transpiration. Some of it is used to flush out the soils to lower the salinity, and this water is returned to the surface waters or ground waters. If the return water is discharged into surface waters such as rivers or lakes, its salinity is likely to be considerably higher than the water removed from the surface waters to be used

for irrigation: The amount of water is less, while the amount of salt is the same or higher. The resulting increase in salinity of surface water may have important consequences. In addition, return water may include fertilizer and pesticide residues which can also promote eutrophication or poison fish or other aquatic life.

It is not always clear that return water cannot be used successfully or that surface waters are the only waterways affected by return waters. In Egypt, the water from the Nile is of such high quality when it is abstracted for use as irrigation water that it would be possible to use drain water for irrigation if there were pumps to bring it to the fields (Abul-Atta, n.d.). In the Indus valley of Pakistan, on the other hand, there is relatively little salinization problem at the surface. But the water which percolates into the ground water system is so saline that there has been a dangerous rise in salinity of the ground water underlying the irrigated croplands of the Indus.

9. Water and flood management - fishery resources. Water and flood management schemes influence fish production resources in many ways, but most of these are indirect. Fishery responses are directly affected by changes in salinity, eutrophication, and other aspects of water quality. But the physical effects of the engineering devices used in irrigation and flood control schemes may in themselves have a significant impact on fishery resources. Perhaps the best known of these is the effect of dams on anadromous fishery populations. Many anadromous fish populations have been adversely affected because a flood control, hydropower, or irrigation dam was built without fish ladders. Passage of spawning fish to spawning areas is prevented even if the dam caused little change in the water quality. Fish have also been known to get lost and swim into irrigation channels where they were caught between irrigation events.

Agricultural Technology Decisions

1. Agricultural technology decisions - pest and weed attack. The density and variety of pests and weeds are a function of the community within which they are found. What pests are present and the degree to which they are held in check by natural enemies or competitors are due to many factors, including the concentration of the planted crop and whether the cropping system includes intercropping which might offer refugia for enemies or competitors for certain vital resources. Eggs of a pest or weed seeds may remain in a field and be available for germination during a following cropping season. To some degree, these problems can be alleviated by cultivation, plowing, burning off, and so forth. But precisely how this is done may have a considerable impact on the type and intensity of pest and weed attacks.

Other aspects of rural lifestyle and its allied technology may also have significant effects on pest control. It may be impossible, for example, to adopt agricultural technologies which would probably be very successful in controlling pests because of economic or cultural limitations of the farmer. One example of this is the Egyptian cotton leafworm, as discussed by Clapham (1980). Simple poverty may obviate the potential for what would be standard practice in a developed country. A particularly telling example of this is the inability of the *fellahin* in much of rural Egypt to control the Pink Bollworm by the simple expedient of destroying infected bolls before the next growing season. The reason is that these bolls and their associated stalks are required as household fuel and must be stored in villages as an important resource, even though this practice guarantees at least some infestation by the bollworm.

2. Agricultural technology decisions - vegetation cover. Crops are vegetation. However one describes vegetation cover in a particular analysis, a crop population can be described in the same terms as any other population or plant community. Indeed, this description should be easier, as the crop population is much more highly managed and therefore should be much better known.

Also significant are the effects of livestock on their forage. Some varieties of domestic animals are browsers; others are grazers. All have specific preferences and ranges of plants on which they will feed. Browsing and grazing cause losses of foliage, and they may alter the competitive balance between plants very substantially if plant consumption is extensive. Even under the best-managed conditions, the effect of livestock on the flora of a pasture must be monitored quite closely. In vulnerable areas, it may be the main factor in widespread vegetational changes or even desertification.

3. Agricultural technology decisions - soil water status. The soil water status can be regarded as a function of the amount of water in the soil at any one time, additions of water, and subractions of water through evaporation and transpiration. Both evaporation and transpiration are affected by the variety of crop and efforts made to increase its luxuriance and the depth of root penetration. Evaporation from the soil surface can also be affected by the type of mechanical soil treatment.

4. Agricultural technology decisions - soil chemistry. The most important chemical reactions in the soil are probably those governing breakdowns of pesticides, changes in the form of fertilizer nutrients and livestock feces, and changes in the ion exchange capacity of the soil. All of these can be influenced by the way farming is carried out. Pesticide degradation may be photchemical or metabolic, and the amount of light penetration and rate of bacterial metabolism can both be altered, generally positively, by cultivation. Oxygenation of the soil is also a key factor both in inorganic soil chemistry and also in bacterial metabolism of organic soil constituents. Soil aeration can be either increased or decreased by the type and intensity of cultivation. If it is increased, bacterial metabolism of organic micelles may have the rather detrimental effect of reducing organic content of the soil and thereby lowering the soil's ion exchange capacity and ability to form stable aggregates.

5. Agricultural technology decisions - miscellaneous soil problems. The use of machinery or heavy implements can cause soil compaction. The types of machines and the way they are used are obviously a basic aspect of the cropping technologies employed. Likewise, the techniques which result in soil oxidation, laterization, or related phenomena are the results of decisions made by the farmer.

6. Agricultural technology decisions - soil fertility. Agricultural technologies, especially those influencing yield, can affect soil fertility by the degree to which crop residues provide inputs of organic material into the soil. But these effects are not simple. On one hand, technology changes which lead to increased yield make a greater demand for available nutrients by the crop. One must increase the rates of fertilization in such cases in order to maintain the same level of available nutrient. This is especially true when stable extensive agriculture systems evolve into or are replaced by intensive systems requiring inputs of chemical fertilizers.

But yield-increasing technologies may also increase the soil fertility by increasing plant biomass production, both above and below ground, so that at least the below-ground biomass is left in place at harvest and is incorporated into the soil as organic humus. These organic materials are the main sources of ion exchange sites within the soil, and an increase in organic material can only be beneficial to soil fertility. Of course how much crop residue is actually incorporated into the soil depends on how the soil is treated after harvest, whether residues are plowed in, whether there is a green-manure phase to the rotation, and so forth. And excessive cultivation may oxidize more organic material than is added during the cultivation process, even with improved below-ground biomass production.

7. *Agricultural technology decisions - soil structure.* Soil structure results from the aggregate impact of many factors, cultivation and tillage, and the crops grown. The key role of agricultural technology is shown in the well known difference in structure of the surface layer between agricultural and forest soils (Brady, 1974). Agricultural soil aggregates tend to be much smaller and less ordered than those of a natural ecosystem.

8. *Agricultural technology decisions - agricultural chemical runoff.* Tilling, cultivating, use of animals for draft, methods of spreading fertilizers and manures, and similar factors are all important inputs to the dynamics of nutrient and chemical ions in agricultural soils. To a large degree, these factors determine the distribution of agricultural and agriculture- related chemicals within the soil column. This is clearly a key factor in the dynamics of those types of agricultural chemical runoff which are carried adsorbed onto soil particles or which are dissolved in water flowing horizontally at the surface.

9. *Agricultural technology decisions - crop genetics.* The genetic diversity and characteristics of a crop population are a direct result of the way in which genetic lines are selected for planting. In developed countries and developing countries which have been able to adopt a green-revolution agricultural strategy, it is common to plant relatively uniform populations of high-yielding varieties which have been developed after extensive inbreeding. Such populations are much less well buffered against climatic fluctuations or evolutionary developments in disease populations. But they tend to be much more responsive to purchased inputs such as fertilizers, and they may be resistant to important pests. Thus there is a very close and dynamic relationship between agricultural technology and the genetic status of the crop population.

10. *Agricultural technology decisions - crop and livestock productivity.* Agricultural technology is nothing less than the basis by which crop and livestock productivity is realized in the real world. It is not uncommon for production to be calculated in models by a mathematical production function in which inputs are transformed to yields under the assumption of a given mix of machinery, agricultural practices, and related technological factors. Efforts to improve crop productivity in developed or developing countries commonly includes changes in crops, agricultural practices, and the role of purchased inputs. In other words, technological change is commonly seen as the mechanism by which agricultural productivity can be increased. Of course there is much more to it than this. Technology cannot always be transferred directly and simply from one place to another, and the ability of technology to be adopted in a particular place is largely a function of the culture of the people living there. But it is nevertheless true that the agricultural technology as it is actually practiced in the field is probably the best available indicator of agricultural productivity.

Climatic Conditions

1. Climatic conditions - pest and weed attack. Pests and weeds are organisms, and they respond to the abiotic environment around them. Furthermore, they tend to be opportunistic species which show very rapid growth under certain conditions and relatively little expression under others. The precise balance of weeds and pests is a function of temperature and of water balance conditions. Indeed climate is probably the single most important "trigger" to a pest outbreak.

2. Climatic conditons - vegetation cover. Plants tend to be somewhat less opportunistic than animals, but they do respond to both temperature and rainfall, and the luxuriance and extent of vegetation, as well as its species composition is obviously closely related to temperature and precipitation patterns.

3. Climatic conditions - human diseases. Disease vectors tend also to be opportunistic species, for much the same reasons as crop pests. They are "human pests," if you will, and their ecological role relative to man is quite analogous to that of crop pests to crops. Thus their responses to climate and climatic fluctuations is very similar to those of pests.

4. Climatic conditions - soil water status. The losses of water from soil takes place through evaporation and transpiration. Both are closely related to the temperature of the air. Likewise the addition of water in nature is via rainfall, which is explicitly a climatic variable.

5. Climatic conditions - soil erosion. Overland soil erosion can best be considered the function of the amount of water which runs over the surface and the distribution of the intensity of runoff. Both of these are related to the ability of the system to buffer the runoff of water from a given rainfall event. But given a particular rainfall-runoff relationship for a particular ecosystem, the amount and intensity of runoff which actually occur depend on the characteristics of the precipitation event. In the same way, wind erosion rates are closely related to the speed of the wind-storm which is doing the eroding.

6. Climatic conditons - flooding and siltation. The main input of water into an ecosystem is via precipitation, either as rainfall or snowfall. Depending on the location, the rapid runoff of rain or rapid melting of snowfall is the source of the water in floods.

Biocide Resistance

1. Biocide resistance - pest and weed attack. The more resistant a pest is to the biocides used against it, the more virulent will its attack be and/or the more biocide will have to be used against it to control it to essentially the same degree. Biocide resistance can be found in virtually all pest populations subject to chemical pest management schemes, regardless of whether they are crop pests, livestock pests, or human disease vectors. Indeed some of the most important of these animals are resistant to so many things that they represent much more serious threats than they used to be in the earlier days of chemical pest control. This is particularly true of mosquito populations in parts of the humid tropics.

2. Biocide resistance - human diseases. Disease vectors show biocide resistance just as agricultural pests. Indeed the mosquito populations cited above are carriers of malaria, and the prevalence of malaria is rising in several parts of the world.

3. Biocide resistance - externality phenomena. Biocide resistance can be viewed as an externality which may be considered in the reckoning of sophisticated non-agricultural users of the environmental domain.

Non-Target Organisms

1. Non- target organisms - Pest and weed attack. Many of the non-target organisms that are killed by pesticides are beneficial to the farmer. Many, in fact, are natural enemies to the particular pest the farmer is trying to control. Their death releases the pest from at least partial control, so that the pest problem may become worse than it was previously. Some of the most egregious examples of this response of pests to mortality of natural enemies killed by pesticides are given by deBach (1974).

1. Non- target organisms - human disease. The behavior of disease vectors to the mortality of their natural enemies is exactly equivalent to that of crop or livestock pests.

3. Non- target organisms - crop productivity. Not only natural enemies of pests are effected by pesticide spraying. So are animals which benefit the farmer in other ways. One clear case in point is bees which are needed to fertilize many fruit trees and certain other crops. They are very susceptible to most pesticides now in use, and some fruit crops have suffered because of decreased pollenation rates. Indeed fruits must be fertilized by hand in some parts of Japan because the available bee populations are too small to do the job.

4. Non- target organisms - natural habitat. Birds are also victims of pesticides, and the reproduction of many species has suffered as a result. The best-known examples are the large raptorial birds of North America and Europe, such as the Peregrine Falcon and certain eagles. But several fish-eating birds are also in danger. The particular problem with the large raptors is that chlorinated hydrocarbon insecticides tend to interfere with calcium metabolism, so that egg shells are much thinner than normal (Ratcliffe, 1967, 1970). These birds are relatively noticeable, so that their problems can come quickly to public attention. But ironically, many of them are also quite long-lived, so that the declines in numbers follows the collapse of reproduction by several years, and the severity of the problem is muted a bit. Other organisms which are not so prominent in natural ecosystems may also be affected negatively by pesticides. But these are much less well understood.

5. Non- target organisms - fishery resources. Many fish are sensitive to pesticides, and fish-kills in conjunction with pesticide usage are not uncommon. These can be documented in the national fish-kill reports published annually by the U.S. Environmental Protection Agency. In addition, the reproduction of several commercially important fish populations has been disrupted by pesticide use. DDT metabolites in the eggs of lake trout in Lake George, New York, caused nearly complete collapse of reproduction of this species for several years (Burdick *et al.*, 1964), and pesticides in the flesh of salmon in the U.S. Great Lakes is above the maximum limit allowed for their sale, thus destroying a commercial fishery if not the fish population.

6. Non- target organisms - externality phenomena. The negative impacts of pesticides on non-target populations are so widespread and varied that they comprise a large number of externalities which are taken very seriously by serious people outside of agriculture. It was the realization of the breadth of these non-target effects that provided the main stimulus to Rachael Carson's *The*

Silent Spring, which can be regarded as one of the first expressions of the worldwide environmental movement.

Pest and Weed Attack

1. Pest and weed attack - vegetation cover. Pests can attack crops and cause substantial defoliation, weakening of the crop, and so forth. All of these reduce the vegetation cover so that the crop is no longer as efficient a guard against erosion or excessive oxidation of the soil. In the cases of weeds, weeds may contribute to the vegetation cover, if the net effect of a weedy field is more plants than simply the crop, and it will always increase vegetation diversity. Alternatively, the weeds may be less dense than the crop, in which case the vegetation cover can be reduced by weed growth.

2. Pest and weed attack - crop productivity. Because pests and weeds represent predators and competitors, they almost invariably cause a reduction in crop productivity. There are some exceptions, in which the plant may be able to compensate for some degree of pest defoliation, but in this case the pest would probably not be considered a pest, and we probably would not worry about it. Even if vegetative growth of the plant is not significantly affected by pests or weeds, the fruit or part of greatest value may be adversely affected.

Vegetation Cover

1. Vegetation cover - pest and weed attack. As with pest and weed attack on crops, the effects of pests and weeds on non-crop vegetation are a function of the health and species makeup of that vegetation. Thus the "attractiveness" of vegetation to pests at any point in time is closely related to the state of the vegetation as it has developed during previous periods.

2. Vegetation cover - soil water status. The transpiration of water from the soil via vegetation is the main mechanism for soil-water losses. It is generally much more significant than direct evaporation. The amount of water transpired is a function of the energy available to evaporate the water (i.e. the temperature) and also the depth and distribution pattern of the root system of the vegetation.

3. Vegetation cover - soil chemistry. Nutrients are mobilized in soils by vegetation through the exudation of acids from plant roots. In addition, vegetation may secrete other chemicals which collect in the soil and enhance or inhibit other vegetation. The best known examples of this latter phenomenon are the negative interactions of allelopathy, which have been documented quite extensively (Sondheimer and Simeone, 1970). It is most important in arid and semiarid regions, as the breakdown of the allelopathic chemicals is slowest in these regions.

4. Vegetation cover - soil erosion. No single barrier to erosion is more successful than extensive vegetation. The effectiveness of wind erosion is a function of the shear forces at the surface of the ground. The friction that is generated by even a thin ground cover is sufficient to reduce these forces to very low levels in the case of wind erosion, and a full root system can hold soil very effectively. Likewise with water erosion, a well developed root system is able to hold soil particles against even rapidly moving water. Soil erosion losses from forests and grassland, with vegetation covering virtually the entire soil surface, are typically much less than from bare land or agricultural land, where vegetation covers only a small percentage.

5. *Vegetation cover - soil structure*. Vegetation cover affects soil structure in two ways. One is insofar as a healthy vegetation cover can incorporate large amounts of organic material in the soil through sloughing of root materials and the death of roots, if not of whole plants. These materials are broken down by detritus organisms, leaving only the refractory organic materials in tiny organic micelles which are capable of bonding readily with water. The humic micelles comprise the most effective binder for the soil and are critical for the formation of stable aggregates. In addition, the growth of plants and their associated soil biota comprise a mechanical process whereby the aeration of the soil is improved and the structure is actually built by the coaction of plant growth and animal movement within the soil.

Human Disease

1. *Human disease - health-related resources*. Disease as a class of environmental processes leaves its mark very heavily on the human population. Acute disease implies direct suffering and often death, often with important behavioral responses from the human population. Attitudes toward desired family size and the structure of the rural labor force are often based on the assumption that a family will lose a significant proportion of its young to disease. The acute diseases that have been most important in this regard are the so-called childhood diseases, smallpox, and plague. Chronic diseases, on the other hand, do not kill (or at least take their time about it), but rather leave their victim in a state of pain or lethargy so that he still consumes the resources of the community, but his contribution is less than it might otherwise be. Such diseases include schistosomiasis, onchocerciasis, some forms of malaria, and so forth.

Soil-Water Status

1. *Soil-water status - soil chemistry*. The soil is the "reaction vessel" for myriad kinds of chemical reactions. Most of these take place in solution or are solid state reactions catalyzed by water. In either case, the water in the soil and its relationship to soil particles is critical to soil chemistry. It is also important for its role in movement of chemicals through the soil in solution or in colloidal dispersions.

2. *Soil-water status - soil erosion*. The amount of erosion by wind or water is related to the erodability of the soil. Very dry soils tend to be more crumbly than moist soils, as the latter are held together by hydrogen bonds between the water molecules and the organic and clay micelles. Soil water thus contributes not only to soil fertility but also to the resistance of soils to erosion, particularly by wind.

3. *Soil-water status - soil fertility*. No plant can grow without water. And the presence of nutrients and the ability of the ion exchange system of the soil to make them available is not sufficient to ensure soil fertility without sufficient water. Soil-water status is thus one of the most important contributing factors in soil fertility.

4. *Soil-water status - soil structure*. Like the vulnerability of soil to erosion, soil structure is a function of hydrogen bonds binding soil particles. Thus the presence and amount of water in the soil has a great deal to do with the

structural coherence, and hence the structure, of the soil.

Soil Chemistry

1. Soil chemistry - soil fertility. The chemical dynamics of the soil can affect soil fertility both positively and negatively. On the positive side, nutrients may become available by mineralization of organic materials, breakdowns of chemical fertilizers, and the like. On the negative side, certain minerals, notably phosphorus, may become permanently attached to soil particles so that they are no longer available by plants, and the exchange capacity of the soil may be lost by oxidation of the organic micelles. The soil chemistry is also affected by pH, degree of aeration, and numerous other factors. It is virtually impossible to generalize about the effect of soil chemistry on soil fertility beyond the fact that it is basic and that the analytical capability to understand and measure it is well developed. For a further treatment of this theme, the reader is referred to Brady (1974).

2. Soil chemistry - agricultural chemical runoff. Agricultural chemical runoff is a major problem in many agricultural watersheds. But what runs off is not always the same as what the farmer put on. For example, biocides break down in time, and it is their metabolites rather than the raw biocide that run off. These may be less toxic, but they need not be, and the metabolites of several insecticides are more toxic than the original insecticide itself. Fertilizer nutrients also change their form. They may be oxidized or reduced, mineralized into a soluble form, or rendered insoluble by incorporation into an inorganic soil particle. In all cases, however, what runs off is what is available in the soil at the time of the runoff event. Depending on the time lapse between application of the chemical in question and the runoff event, there may be considerable alteration in the form of the chemical species.

Waterlogging and Salinization

1. Waterlogging and salinization - soil fertility. Whether it is due to reduction in soil aeration or an increase in salt content to a point of toxicity, waterlogging and salinization are both highly detrimental to soil fertility. Indeed, they may render the soil totally infertile, even if its nutrient content is relatively high.

2. Waterlogging and salinization - agricultural chemical runoff. When salinization is found in a region, the agricultural chemical runoff may become considerably more saline itself than would otherwise be the case. The reason for this obviously is that a saline soil, as it erodes, contains more soluble salt than a normal soil. Since agricultural runoff is at least largely a function of soil erosion, any fellow-travellers with erosion may be significant.

Soil Erosion

1. Soil erosion - vegetation cover. Severe erosion can damage vegetation cover either by uprooting it or by covering it. Most of the damage from water-erosion comes from uprooting plants or undercutting the soil in areas of moderate or high relief. Uprooting plants during erosion episodes is especially pronounced during floods, and undercutting of soil to form rills or even valleys is most common in semi-arid regions or areas of high relief. Both phenomena are so well known as to need no documentation, and illustrations can be found in practically any book on soil conservation.

Damage by wind erosion is especially important in arid and semi-arid areas, where the soil is naturally more vulnerable to erosion. Roots may be exposed during erosion events in areas undergoing active erosion, and vegetation may be damaged or killed in the process. But equally important is that vegetation may be covered in areas of deposition. This is likely to be especially true of areas in which the vegetation is relatively healthy and can hold the soil effectively. But the very health of such vegetation will also mean that it presents an effective trap for wind-blown dust. Perhaps the best-known example of the dynamics of wind erosion and vegetation cover is the 1930's dust bowl of the American southwest. But the phenomenon is much more widely distributed and is the basis of desertification in many areas (Eckholm, 1976).

2. Soil erosion - flooding and siltation. As mentioned above, soil erosion by water is most pronounced in many areas during periods of flood. But soil which is eroded from one place must be deposited somewhere. This may be in lakes, in reservoirs, in streams, or along flood plains. Such deposition almost always represents a total loss of the value of the soil; not only is it not useful as soil, it causes a deterioration of the value of the ecosystem in which it is deposited.

The only major exception is the alluvial soils deposited on flood plains during periods of flood. These are commonly very good soils which can often support more intensive agriculture than the more mature soils adjacent to them. Indeed in very arid or very wet areas, these alluvial soils may be the only soils capable of supporting agriculture. This is most obvious in the long-established arid-zone agricultural areas such as the Nile valley of Egypt or the Indus valley of Pakistan, where the intensively cropped alluvial soils abut the desert directly. But it is also true of the tropical rainforest areas such as the Amazon, the Congo, and the Mekong, where agriculture is practiced only in the alluvial soils. The other soils of the area cannot support agriculture and are more likely to be inhabited by hunter-gatherers.

3. Soil erosion - soil structure. Soil erosion implies that soil is removed from one place and deposited in another. In both cases, the soil structure is affected. In general, the top layers of soils are stripped off by wind or water. Especially with wind, the lightest fractions tend to be preferentially removed; these tend to be rich in clay minerals and organic micelles. This may have some effect on the ion exchange capacity and the ability of the soil to retain its structural coherence. For the region of deposition, the result may be a loess soil, which has considerable structural coherence and even relatively high fertility. It may also be relatively low-fertility dust or sand.

4. Soil erosion - agricultural chemical runoff. In general, the most important chemicals comprising agricultural chemical runoff are biocides, as well as nutrients such as phosphate. Such compounds and ions tend to be almost insoluble and cannot move by the percolation of water through the soil. The only important exception is nitrogen, which is quite soluble. The insoluble materials tend to be found adsorbed to soil particles, and they are released through ion-exchange reactions in the soil. They move physically when the soil particles to which they are adsorbed are eroded. Therefore soil erosion and the resulting mass movement of soils represents the most important factor in generating agricultural chemical runoff.

5. Soil erosion - water quality. Soil introduced into watercourses is commonly suspended in the water for awhile. Whatever adsorbed nutrients it contains can easily be released by ion exchange in the water and be made available to aquatic life. Thus the erosion of soil into surface waters often leads to an increase in the dissolved or available nutrient content of the water, as well as its turbidity. Both of these effects represent significant declines in water quality.

6. Soil erosion - crop productivity. Soil erosion can damage crop production by mechanically abrading leaves or by altering the soil structure and soil fertility to a point where the soil is no longer as capable of yielding good crops. Roots may be bared or torn out, and entire crops can be undermined. These direct effects of soil erosion can cause rapid death or substantial destruction of the crop. The effects on soil structure are more indirect and more long-term. Once again, the U.S. dust bowl of the 1930's or the Sahel drought of the 1970's provide dramatic examples of this interaction, and are discussed by Eckholm (1976).

7. Soil erosion - natural habitat. Soil erosion can cause damage to natural habitats just as it can to vegetation and crops. This can be especially pronounced in vulnerable areas where management shares the land with natural populations. This is typical of nomadic cultures, and overgrazing in such areas has been a major factor in ecosystem deterioriation throughout the arid and semi-arid portions of Africa.

8. Soil erosion - fishery resources. The presence of unusual amounts of silt, clay, and fine soil particles in streams and lakes may have a pronounced direct effect on fish populations, as well as several indirect ones. Many fishes experience gill abrasion or clogging by excess particulate matter in the water, and the eggs of fish laid in bottom gravels can be asphyxiated if soil erosion leads to too rapid deposition of silt on the gravel bottoms. The fish most vulnerable to asphyxiation of this sort are the highly desirable salmonids (salmon and trout).

9. Soil erosion - externality phenomena. Soil erosion has numerous causes, many of which are under the control of man. Therefore the degree of erosion which stems from these causes represents an externality of management patterns which may be brought into the calculus of other users of the environmental domain.

Miscellaneous Soil Problems

1. Miscellaneous soil problems - soil structure. Oxidation of acid sulfate soils, laterization, and compaction of productive soils all involve direct and relatively simple changes in soil structure.

Soil Fertility

1. Soil fertility - vegetation cover. In all soils, both agricultural and nonagricultural, there is a strong positive correlation between soil fertility and luxuriance of the vegetation cover, all other things being equal.

2. Soil fertility - crop productivity. In an agricultural soil, the luxuriance of vegetation is commonly reflected in crop productivity, with fertile soils producing more crop biomass (and therefore more crop yield) than poor soils. There are some exceptions, but they are a minority.

3. Soil fertility - amenity resources. The amenity resources affected by soil fertility include all of those for which the health of the biological community represents an amenity resource for the human population. This amenity may be agricultural, with a pronounced desire by many people to retain farms in particular places for the "green belts" they provide. Indeed the tax laws of many places in the United States and other countries have been modified recently to support the maintenance of farms around cities for just this reason. Non-agricultural amenity resources include forest, game habitats, picnic areas, parks, etc. These areas depend to a large extent on maintenance of soil fertility. If the fertility of the soil is maintained, then the resource itself can be maintained. If it is lost through erosion or pollution, the amenity resource may be lost.

Flooding and Siltation

1. *Flooding and siltation - soil- water status.* One of the results of a flood is that the soil is saturated with water after the flood has passed.

2. *Flooding and siltation - soil erosion.* The immense power of a flood is capable of eroding soil even when the soil would not normally be very vulnerable to erosion. The erosion potential of a flood must be taken as a qualitatively different matter than the erosion by water under more normal rill- or sheet-erosion regimes.

3. *Flooding and siltation - soil structure.* When water is eroded in one place, it must be deposited somewhere else. One of the results of flooding is massive deposition of sediment in those parts of the flood plain in which water velocities are low and competence of the moving water is correspondingly reduced. In some cases, the deposited silt may be extraordinarily useful. Alluvial soils have already been pointed out as often being much better than those of surrounding areas. If there were no floods in such areas, there would be no deposition of alluvial soil. Indeed this problem is surfacing in Egypt now, where fertility of the Nile valley must be retained by artificial means, and it is also implicit in any development scheme in a wet tropical area which would treat flood control as an objective of developmental schemes. In such cases, it may be easier to learn to live with floods than to try to make up for the lack of alluvial soils.

4. *Flooding and siltation - water quality.* Flooding and siltation affect water quality in several ways. Large quantities of particulate matter are introduced into surface waters during times of flood, with the deleterious effects discussed above under "Soil erosion - water quality." Conversely, as siltation takes place, particulate matter is deposited on the bottom of the watercourse, so that the turbidity of the water decreases. Even though this generally reduces the rate of release of soluble sorbed materials, nutrients can be withdrawn from bottom silt by rooted plants if the environment of deposition is such that rooted plants can thrive. These may be able to pump nutrients into the overlying water course which can have a detrimental impact on water quality. The precise balance of impacts depends, obviously, on the specific system, and overall results may be beneficial or detrimental.

5. *Flooding and siltation - crop productivity.* If crops are flooded, they are generally destroyed.

6. *Flooding and siltation - natural habitat.* Siltation on top of a natural habitat, whether it is terrestrial or aquatic, is commonly deleterious. On the other hand, there are many marginal habitats such as mangrove islands, very low-lying deltaic areas, and areas of natural alluvial soils, which depend on periodic flooding and siltation and in which there is a dynamic balance between them. In such cases, these habitats require both in order to survive. Even some forests, such as the Pacific Coast Redwoods in California depend on periodic floods to snuff out competing species which are not flood-adapted (Stone and Vasey, 1968).

7. Flooding and siltation - fishery resources. The direct impacts of flooding and siltation on fish are likely to be via washing out breeding areas or habitat for other stages of the life cycle of the fish or their food sources, asphyxiation of adults through gill clogging or of eggs by siltation. Floods are commonly accompanied by high mortality of fish. But fish populations tend to be adapted to the conditions found in the watercourses in which they are found. So unless there are extreme conditions or the fishery is poorly managed, the effects of floods on fish populations should have only marginal impact on fishery resources.

8. Flooding and siltation - health-related resources. Floods take a heavy toll in life and property. Water supplies can be damaged by floods, and disease can follow them. Anybody who has ever lived through a flood can speak of the psychological destruction and the loss of life which generally accompanies them. In some cases, such as the tidal-wave floods of Bangladesh, hundreds of thousands of people may be killed. In other cases, homes, families, and whole communities may be destroyed.

9. Flooding and siltation - amenity resources. Just as floods can destroy the basic resources needed for human life and health, they can destroy the amenity resources which make it pleasant.

Soil Structure

1. Soil structure - soil chemistry. The types and dynamics of chemical reactions in the soil are a function of many things, including the coherence and aggregate nature of the soil.

2. Soil structure - soil erosion. Proneness to erosion depends on many things. The coherence of the soil is not as powerful a barrier to erosion as a thick vegetational cover. But it is nevertheless true that a soil whose structure is very good is much less likely to erode than an amorphous soil or one with a small crumb structure.

3. Soil structure - soil fertility. The physical makeup of the soil is an important factor in its tilth, its suitability as a rooting medium for crops, and other key aspects of soil fertility.

Agricultural Chemical Runoff

1. Agricultural chemical runoff - water quality. The impact of agricultural chemicals on water quality is almost inevitably negative. Runoff of nutrients is a major cause of eutrophication. Runoff of pesticides or other toxins can kill vertebrate or invertebrate life in the watercourse and thoroughly disrupt the community. While agricultural runoff is not generally as much of a problem as industrial or municipal point-source pollution at this time, area-wide runoff is inherently more difficult to control The trends in point-source pollution control will lead to area sources such as agriculture being the major source of nutrients in surface waters in many areas in the foreseeable future.

2. Agricultural chemical runoff - externality phenomena. Agricultural chemical runoff is a factor of some concern to sectors of the society other than agriculture. The pollution effects of agricultural runoff are most closely associated with feedlots for livestock, as well as biocide runoff.

Water Quality

1. Water quality - human disease. The most disabling diseases of the agricultural population are either waterborne (e.g. Typhoid, Typhus, etc.) or have waterborne vectors (e.g. malaria, schistosomiasis, onchocerciasis, etc.). To be sure, not all of these thrive under polluted-water conditions; for example, the vector of onchocerciasis (river blindness) is *Simulium*, the black fly, which lives in highly oxygenated fast-flowing water. But pollution favors more of the disease organisms than not. Polution also favors the vectors. As examples, the gnat, *Culex pipiens fatigans* breeds extensively in polluted water and is a carrier of elephantiasis and encephalitis. The same is true of the mosquito *Anopheles quadrimaculatus*, formerly the prime carrier of malaria in the Tennessee valley of the U.S.A. (Waddy, 1975).

2. Water quality - crop productivity. The quality of the water used for irrigation may affect the response of the crop either to the water itself or to the fertilizers or cultivation techniques used on them.

3. Water quality - natural habitat. The best-known example of progressive deterioration of water quality is eutrophication. In such cases (but in others as well), aquatic habitats may be substantially damaged as the water quality changes. Changes in water quality seldom have significant impact on terrestrial habitats but aquatic habitats are often very useful and are often quite important. This is especially true of reservoirs and other bodies of water in arid zones.

4. Water quality - fishery resources. Fish, like all animals, have relatively restricted ranges of tolerance for concentration of different chemicals found in the water. If the water quality is not appropriate for their survival, they will not survive.

5. Water quality - health- related resources. People use water to drink, to wash, and for water supply for various functions of society. These functions may be limited by factors such as poisons, bacteria, and suspended solids in the water. A large majority of the people in rural areas of developing countries do not have access to adequate water supplies, and they suffer from diseases that have long been brought under control in developed countries. One of the key needs identified by the U.N. Habitat conference in Vancouver, Canada, and the water conference in Mar del Plata, Argentina, was to provide people with potable water of adequate quantity and quality to insure a high standard of health (W.H.O., 1977).

6. Water quality - amenity resources. The amenity resources of recreational fishing, water sports, etc. depend on the maintenance of minimum levels of water quality. If the water quality changes because of agricultural or point-source pollution, then the amenity resources suffer as well.

7. Water quality - externality phenomena. Water quality is perhaps one of the most important factors for non-agricultural users of the natural ecosystem, and therefore must necessarily form part of the externality phenomena vector which they observe.

Crop Genetic Resources

1. Crop genetic resources - pest and weed attack. Perhaps the best known responses of the system to decreasing genetic variability are with respect to plant diseases, such as rusts and blights. The Irish potato famine was caused by a fungus which was able to flourish in the completely inbred Irish potato population. The 1970's corn blight of North America was able to flourish in a population which was spread almost throughout a continent and which contained almost universally a particular genetic characteristic which rendered it vulnerable to the particular race of *Helminthosporium maydis*.

Developing countries seldom show the same degree of genetic uniformity of crops as developed countries, but the trend is in that direction, with the increasing importance of higher yielding varieties of crops. So far, the results have not been as dramatic or as negative, but the history is much, much shorter and the probability of diseases or pest infestations which can flourish because of genetic uniformity is quite likely. An excellent summary of the relationship between genetic uniformity of crops and disease and pest problems is given by Horsfall *et al.*, (1972).

2. Crop genetic resources - crop productivity. The relationship between these two factors is a complex and important one. On one hand, particular patterns of inbreeding have been followed because the resulting low-genetic-variability population is able to be more productive, and therefore to return more to the farmer. On the other hand, if a genetically based problem does happen, it is likely to be much more damaging and to lower productivity much more. Both of these effects occur in developing as well as developed countries, and there is an implicit tradeoff which should be recalled at each step of the development process.

Crop Productivity

1. Crop productivity - vegetation cover. The vegetational characteristics of a cultivated crop change substantially throughout a growing season as the crop matures under the farmer's management. The change in a cultivated crop may be somewhat greater than that of a natural vegetation community, as it is typically much simpler. In any case, whatever measure of vegetation cover is most important is strongly correlated with the productivity of the crop.

2. Crop productivity - agricultural production. Agricultural production is equal to crop productivity times land base area.

Natural Habitat

1. Natural habitat - amenity resources. Natural habitat is itself an amenity resource which is often highly prized. It may be retained as a relatively wild and trackless area through which even low density impacts such as hiking are not permitted, or it may involve relatively high density hiking such as is common in European forest parks. Its simple existence provides a respite from much of the confusion and stress of modern life.

2. Natural habitat - externality phenomena. The availability of natural habitat can be included in the vector of externalities which are considered by the individual-management domain.

INDIVIDUAL- MANAGEMENT DOMAIN

The individual-management domain comprises those actors who interact directly with the environmental domain. They provide certain inputs to the environmental domain in an effort to control it. In return, they monitor it and use the differences between the expected and actual output to adapt and change their management strategies. At the same time, they respond to controlling inputs from the policy-making domain, and their behavior is monitored by that domain so that the latter can adapt its efforts at control accordingly. It is probably reasonable to view the individual-management domain as a series of local decision-makers whose function is to create a mix of actions designed to manipulate the environment for specific purposes, given the constraints and the opportunities under which they operate, and given the nature of the adjacent domains.

These decision-makers are individual actors whose decisions determine what they themselves do. If they affect others, it is through indirect effects. For an agricultural study, the most important individual actors are farmers and related individuals such as herders or farm-support personnel. Also important are public water authorities, the public health worker, and the non-agricultural users of the environmental domain. The first categories are all actors directly involved in agriculture. The last is an aggregate of all others: It might include the sport fisherman or the city dweller who enjoyed walking in the woods. Even though they are not engaged in agricultural production, their attitudes may have a great effect on the behavior of government on the direction or control of farmers' activities. This is especially true in developed countries, where the concerns of non-farmers have resulted in severe limitations on farm practices (mainly related to pesticide applications) as well as substantial reductions in the rates at which farmland is taxed. As with the environmental domain, we can summarize the interactions of the various information flow types and issue areas by a contingency matrix such as that in Figure 5. The organization of this matrix is the same as that of Figure 4.

The notion of scale in the individual-management domain is of some importance. As mentioned earlier in this report, one of the main difficulties in understandng environmental problems of agriculture is that one must link policy matters, which tend to be broad in scope, with ecological phenomena, whose scale tends to be the field. The key to this linkage is the way in which the individual-management domain is understood. As the farmer carries out his management functions, his behavior is at a field level, and it can be most easily understood if the decisions themselves are viewed relative to agricultural fields. But policy is directed toward all farmers (or at least to large numbers of them), and the adaptations of the policy-maker are with regard to the aggregate of individual actors. As a result, the policy signals impinge on all actors in a general sense as they manage their fields, so that decisions oriented toward particular pieces of land reflect these signals, and the policy-making domain responds to the aggregate of all of the decisions made on the individual-management domain without necessarily reflecting on the mosaic of environmental signals considered by the farmers. There is thus no translation problem from the field-level to the national-level if one is willing to take seriously the role of the individual actor and the way he undertakes the management of his farm or role in the system. This would appear to be essential for analysis of environmental problems of agriculture in any case. Not to consider the individual actor and his behavior neglects the process by which agricultural systems are managed in the real

		NU	WD	FC	MD	TP	PH	HC	LU	LQ	CB	SA	WF	CT	CM	PM	LF	RS	EG
Ag. Production	AP			1	2	3													
Fishery Resources	FI	1																	
Health Resources	HR	1					2	3											
Amenity Resources	AR	1																	
Externalities	EP	1					2												
Subsidies & Taxes	SU	1	2	3	4	5	6												
Commodity Prices	CO		1	2	3	4													
Land Reform	LR		1	2	3	4													
Urban Conversion	UC	1				2													
Extension, R&D	EX		1	2	3		4												
Infrastructure	IS	1	2	3	4	5													
Constraints Legis	CL	1	2			3	4												
Nonag. Users	NU	-					1		2				3					4	5
Public Water Auth.	WD	1	-	2		3	4	5					6				7		
Farm Capital Form	FC			-		1							2					3	4
Marketing Decis.	MD				-	1									3				
Agric. Tech. Plans	TP			1		-			2		3		4	5		6	7	8	9
Public Health Dec.	PH						-				1		2						
Human Capital Fm.	HC							-		1							2	3	

Figure 5 Contingency Matrix for the Individual-Management Domain

world, as well as the target of virtually all agricultural policy in most countries.

Issue Areas

There are many *non- agricultural users of the environmental domain.* These include sportsmen's groups, people who are interested in rural-urban conversion, mining concerns, and myriad others. What they all have in common is that they make some use of the environmental domain as part of their livelihood or leisure activities, and they depend to a degree on specific characteristics of that domain for these uses.

The behavior of the *public water authority* is an important factor for agriculture in irrigated areas. These bodies are responsible for making decisions for managing the regional and local distribution of water within a preexisting system of water and flood control. They may be closely tied to governmental bodies such as ministries of irrigation, or they may be quasi-independent. Regardless of their status within the government, the management functions of the water authority are necessarily decentralized, and the manager must work closely with individual farmers or farmers' organizations.

Farm capital formation covers many facets, including purchase or construction of buildings and machinery, and level of development of land.

The *marketing decisions* are those which the farmer makes regarding the disposition of his produce. He may have several options. He can let it rot in the fields without harvesting it, or he may harvest it. If he harvests it, he may eat it himself, he may feed it to livestock, he may store it for later sale, or he may sell it immediately. In the case of livestock, he may slaughter them or not slaughter them. In many countries, farmers are regulated so that government policy attempts to reduce the options available to the farmer. In such cases, however, farmers are often able to circumvent the intent of the regulation. In other countries, cooperatives or landlords tie the farmer's hands by lending him money at the beginning of the season which must be repaid at harvest. Unless the farmer has a very large surplus, he must sell his harvest in order to repay his loan. But it is rare except under conditions of very great poverty that farmers have no options in marketing their produce.

Agricultural technology decisions include all of the decisions made by a farmer as to the mix of his crops and livestock for a particular growing season and his allocation of hired labor, variable inputs, capital, land, and whatever other resources are available to him to realize his production. It also includes whatever decisions are appropriate to renting land from or to his colleagues, sharing resources, or requesting assistance from cooperatives or extension services.

The *public health* establishment in most countries is devoted to improving the health of the people.

Human capital formation refers to the process by which the productivity of individuals rises. Human capital is a term used by Schultz (1964), among others, to indicate a measure of the innate productive capacity of human beings as a function of their culture, education, health, etc. This is analogous to material capital as a productive asset, but it is oriented to the relatively intangible aspects of humans and what they are rather than what they have.

It is an important, but rather "fuzzy" concept with a dynamic experiential component. Individuals must "pick up" a very large degree of what they are. If information or facilities are readily available, then the process is easier, and people can more easily develop the capacity to do things better for themselves. It should be noted that the concept of human capital is a collective term as well as a characteristic of an individual. Just as education and health can make an individual more effective, the presence of highly trained and specialized practitioners within the agricultural community can make the larger population more effective. There are farm-oriented individuals who may not be everyday farmers, but whose prime purpose is to supplement farmers and amplify their efforts in some way. These specialized elements of the agricultural population include veterinarians, trained mechanics, and other specialized farm service people. They represent a human support system that may be quite separate from -- and more important than -- the material capital support system of the agricultural production system.

Signals from the Environmental Domain

These are discussed above, p. 16.

Signals from the Policy- Making Domain

Subsidies are a form of information which come down to the individual-management domain from the policy-making domain in many guises. They may be direct cash subsidies for specific purposes, they may be tax loopholes, provisions of the tax law which are designed to foster certain activities, and so forth. In all cases, the subsidy represents a transfer of money or provision of a service to influence the behavior of the farmer. That is, it is a financial means of altering the market to get people to do what they otherwise would not do.

Commodity prices are formed on the policy-making level as the market clears and as they are modified by tax policies and overt or covert manipulation by various institutions adjacent to the market. The information available in the form of commodity prices thus is a control in the sense that it represents perhaps one of the most significant inputs into the farmer's decision-making process.

Land reform refers to policy information formed at the policy-making level regarding changes in land tenure. These are most likely to be reflected in changes in land use. But in some circumstances and in some countries, the actual changes may range from very dramatic to quite subtle.

Urban conversion consists of taking agricultural land and replacing it with urban development such as residential areas, parking lots, commercial developments, and so forth.

The patterns of change in agriculture can be modified to some degree by the availability and quality of *extension services*. These are provided by central governments, cooperating governments, international agencies and multinational foundations. They may work directly with farmers, or they may develop new kinds of technologies which can then be made available to farmers. Technological development and diffusion are the keys to agricultural change in all countries, as well as the environmental impact of this change. The services offered by governments to expedite these changes represent one of the most individualistic, subtle, and probably most important ways in which the policies and workings of central governments are brought to bear on agriculture in general and specifically on the environmental problems of agriculture.

Infrastructure refers to the systems of dispersed support services to the country. These include communications and transport facilities like roads, railroads, canals, telephone and telegraphic communications, radio and television facilities, inc. Infrastructure also includes large public works such as large reservoirs and irrigation systems, as well as power plants and nationalized energy processing facilities. They are built by the central government for many reasons, including transportation of goods and people, communication, improvement of services, development of better marketing systems, and so forth.

We often think of the impact of central governments or of societies in general on farmers in terms of *constraints on permissible actions*. These may be established through legislation or promulgated by regulatory agencies. In fact, such constraints are a favorite way of controlling environmental problems and will probably continue to be so as long as the environmental impacts of agriculture are externalities in the decision-making process.

Signals to the Environmental Domain

These are described above, p. 14.

Signals to the Policy- Making Domain

The *commodities brought to market* represent the aggregate of the agricultural commodities that farmers decide to market. That is, it is the total supply of each commodity brought to market and for which the market must clear.

The agricultural sector must make a number of characteristic *purchases from the market*. Some of these are consumer goods designed to maintain the farm population; others are raw materials which serve as particular inputs to production. As such, the purchases from the market represent a demand for non-agricultural goods whose function is to encourage agricultural productivity.

The state of the *labor force and its migration* represent volatile and significant factors in many countries. This is especially so in developing countries where rapid increases in the labor force resulting from a youthful age distribution bring needs for job-development capital, the attendant markets for products, and so forth.

Requirements for services are generated by all economic sectors at the individual-management level. The services being required include provision of aid, tax relief, joint-venture formation, patent protection, etc. The way in which these requirements are carried to the policy-making domain is via the political process in force in the country in question. This may be elected representative, village head-man, etc. If the policy-making domain is to be able to perform an effective job of monitoring the individual actors, then there must be information channels from the individual-management domain to the policy-making domain. These requirements for services are an important type of information passed along these channels.

Externalities generation information represents a different type of requirement for service sent from the individual-management to the policy-making domain. Instead of requirements for services designed to expedite the agricultural production process, it represents a vector of factors stemming from agricultural production which various actors at the individual-management level would like to see changed or corrected. Some of these are direct external costs of the decisions made by farmers; some are indirect phenomena which arise because of the dynamic behavior of the environmental domain. An example of the first includes changes in farm land use which affects non-farmers; Examples of the second include pollution and habitat erosion.

Patterns of Interaction within the Individual- Management Domain

Agricultural Production

1. *Agricultural production - farm capital formation.* Farmers are rational in some way when they allocate resources between capital and consumption goods. This does not mean that they are profit-maximizers or that they are necessarily well-informed. But they can be expected to act in some way which will best meet their perceived needs, based on their expectations of production, problems, and needs. Investment into farm capital is one of the most important factors in increasing production in the future. But the amount and type of investment is a rational decision by the farmer. One of his most important information sources is his own experience with the technologies he has used in the past and the production levels that have resulted from those technologies. Given this, he can make a rational decision as to the capital formation strategy he wishes to follow.

2. *Agricultural production - marketing decisions.* Once a farmer has produced his product, he must decide what to market and what not to market. Typical options for a plant crop are to market it, eat it, let it rot, or feed it to his animals. To the degree that he is free to act and that these are to his advantage, he can be expected to act accordingly.

3. *Agricultural production - agricultural technology decisions.* Agricultural technology plans can be regarded as a summary of all techniques that a farmer will utilize during the season, as well as his land uses and the uses of his livestock resources. He may decide to convert noncrop land to cropland or to change the mix of crops on the land he owns. He may decide to change the mix of his livestock or to use them differently. As the farmer decides on the particular mix of machinery, labor, ideas, and so forth, he will once again compare his knowledge of past agricultural production with his expectations of changes that might be possible with more basic revisions in cropping technology.

Fishery Resources

1. *Fishery resources - non- agricultural users of environmental domain.* Fishermen, either commercial fishermen or sport fishermen, are non-agricultural users of the environmental domain. They behave in ways which are not likely to be considered paramount in an analysis of environmental problems of agriculture. But their behavior may be important for agriculture if it results in information passed to the policy-making level which in turn results in constraints being placed on the activities of farmers.

Health-Related Resources

1. *Health- related resources - non- agricultural users of the environmental domain.* As with fisheries, the deterioration of health-related resources is likely to be noticed by non-farmers (as well as farmers) and be translated into some form of response or demand. In principle, this response can be in the form of a control on the environmental domain by individual actors or a request to the

policy-making domain for relief in the form of regulation or legislation.

2. Health-related resources - public health activities. Every society includes a cadre of people whose responsibility is public health. They deal with health problems of all sorts, including those related to agriculture. Examples of such problems include methemoglobinemia resulting from fertilizer-nitrate pollution of ground water used for drinking, waterborne diseases which are spread by inadequate drinking water supplies for the rural population, and vector diseases such as malaria or schistosomiasis. As with other non-agriculture users of the environmental domain, they may exert their influence by their activities in the environmental domain or by requests for services from the policy-making level.

3. Health-related resources - human capital formation. One of the most important factors in the productivity of the individual farmer is his health. This is especially true of debilitating parasitic diseases which do not kill, or at least do not kill immediately, but rather render the diseased person less capable than he otherwise would have been. Such people simply cannot work as hard as healthy individuals, and they cannot be as productive in the field. There can be no question that a healthy farmer is a better farmer than a sick farmer.

It is difficult to justify just how much better he is, but an order-of-magnitude estimate for schistosomiasis in Egypt is given by Wright (1951), who estimates that schistosomiasis infection cost the country some 20 million Egyptian pounds per year and decreased labor productivity by a factor of about 1/3. He points out that 22% of the army recruits from the schistosomiasis-infested delta area of lower Egypt were rejected for physical defects during one period of observation, while this was true for only 3% of the recruits from upper Egypt, where schistosomiasis was rare. During the same period, most of the country's heavy labor was carried out by people from upper Egypt. Note that this is for but one disease in one country. Jordan (1975) cites other examples for schistosomiasis, and Waddy (1975) cites statistics for malaria which are almost more gruesome than these. The most serious diseases affecting the human capital within agricultural populations are the chronic parasitic diseases with arthropod, molluscine, or vertebrate vectors. Public health measures can often result in a dramatic reduction in disease, through control of either the disease agent itself or the vector.

Amenity Resources

1. Amenity resources - non-agricultural users of the environmental domain. Changes in the quality of amenity resources can evince some very powerful responses from the non-agricultural users of the environmental domain. As with other similar conditions, these may be directed toward control of various sorts, or they may be directed toward requirements for action from higher levels.

Externality Phenomena

1. Externality phenomena - non-agricultural users of the environmental domain. This relationship is a very simple one defining the fact that people other than farmers do monitor externalities of agricultural management.

Subsidies and Taxes

1. Subsidies and taxes - non- agricultural users of the environmental domain. In principle, subsidies are available to all actors in the system, farmers and non-farmers alike. They are taken into the decision-making process by those non-agricultural users of the environmental domain who respond to fishing resources, health-related resources, amenity resources, and the various externality phenomena. The goals of these actors may be advanced or frustrated by the subsidies available. The effectiveness and goals of the subsidies can be considered only on a country-by-country basis, and sometimes only on a region-by-region basis within the country. But the use of the taxing system in the form of subsidies is a very powerful mechanism by which certain social goals can be realized.

2. Subsidies and taxes - public water authority. Perhaps the most capital-intensive aspect of agriculture is irrigation and related water control devices. These are commonly constructed by national governments. Where and how they are constructed, over what time frame, and the style of interaction between the irrigation authority on one hand and the farmer on the other, are all decisions of the central government which can have a terrific impact on the effectiveness of an irrigation project and its ability to provide water and related assistance to the farmer.

3. Subsidies and taxes - farm capital formation. Governments can provide numerous means of supporting investment in agricultural capital. These include tax deductions or credits, government-supported bank credits, etc. These devices may be directed toward specific kinds of farm capital, such as machinery and buildings, or the farmer may be free to choose his own course of investment. Once again, this is a very policy-dependent matter which differs in type and in effectiveness from country to country.

Perhaps the most significant of these, however, is credit. This may be long term or short term, and it may be either granted outright and managed by the appropriate branch of the government, or the government may guarantee credit managed by the private sector. Both of these devices represent a strong involvement of the policy-making domain in farm capital formation, and one or the other is to be found in almost all countries. The form of credit is especially important in developing countries. It is commonly understood that governments do not provide services evenly, but rather concentrate on those who can accept them most easily -- specifically the large farmers. The small farmer is left either without credit or forced to borrow from the village money-lender, whose rates are likely to be excessive and his demands severe. As the World Bank (1975) has shown, the most effective development of the small farmer (and hence his capability for understanding and solving his environmental problems) may require a level and style of credit far different from normal. There are many alternatives. Mayfield (1976) documents a private banking system in Egypt based on a German model which seems to have overcome most of the disadvantages both of the village money-lender and the existing government credit bureaucracy. Regardless of the particular mechanism, it is one way of allowing the farmer to invest in permanent stock, be these animals, tractors, buildings, or land.

4. Subsidies and taxes - marketing decisions. The marketing decisions that the farmer must make concern the disposition of his production. Should he sell it, and if so how much? Conversely, should he feed it to his animals or not harvest it at all? Several kinds of subsidies can affect these decisions. First, if the government controls prices, then hoarding to capitalize on within-year cycles is unlikely, but too-low a price may lead to hoarding to keep food from market.

Likewise, the government can provide storage facilities free or at low cost to encourage farmers to market produce. Marketing boards are another way of encouraging farmers.

5. *Subsidies and taxes - agricultural technology decisions.* Anything which changes the actual cost of the use of a variable input to a farmer will affect his decision structure in using these inputs. These may be in the form of credits for fertilizer use, subsidy of the chemical industry so that fertilizers can be made available more cheaply, provision of extension services which counsel in the use of different kinds of variable inputs, and so forth. Likewise, they may be relative tax rates for different uses of land, free advice on soil conservation, and policies directed toward the use of animals, machinery, etc.

6. *Subsidies and taxes - public health: disease responses.* Most public health schemes are subsidized by the central government and also by international agencies such as WHO, UNICEF, or the World Bank. The success of public health schemes depends in large part on the effectiveness of field people. The support given such people, the facilities available to them, and their contact wth similar people in other countries can have a great impact on the style and effectiveness of public health programs.

Commodity Prices

1. *Commodity prices - public water authority.* In order to use irrigation systems, a farmer must generally build part of his system himself. Whether he does this or the degree to which he maintains his irrigation system will depend on (among other things) the price of the products which he is capable of growing as well as the cost of labor and machinery for building and maintaining the irrigation system. But these facilities provide the demand for water to the water authority, once they are constructed.

2. *Commodity prices - farm capital formation.* A farmer who has money to spend on inputs always has the choice of making those inputs consumables such as fertilizers, pesticides, other farm chemicals, or labor. He may choose to invest in capital goods such as machinery and buildings. Many inputs are associated with modern agricultural techniques and assume the presence of a certain amount of capital in the form of machines or other kinds of capabilities. The trends in the relative prices of the commodities in which the farmer deals, as well as those of capital vs. consumable inputs are key factors in making the tradeoffs between the various options.

3. *Commodity prices - marketing decisions.* When a farmer decides what percentage of his produce to market, he must assess the relative value of selling it immediately or of transferring it into potentially more profitable form by storing it or by feeding it into livestock. There may be other options as well. The relative prices of various commodities (as well as the relative costs of the options) are the key factors in his decision strategy.

4. *Commodity prices - agricultural technology decisions.* In the same way, the investment into variable inputs is a function of the relative prices of the commodities which he is capable of growing as well as the relative prices of the variable inputs which he is able to purchase. Among these decisions are whether to market plant produce or feed it to animals, as well as when to slaughter

animals or whether to use them for milk, eggs, blood, or breeding stock.

Land Reform

1. Land reform - public water authority. The relationship between land reform and the farmer's interaction with the public water authority turns around the fact that a farmer is generally responsible for building certain parts of the overall system himself. On one hand, if the land is his, he is more likely to make the decision to do so. On the other hand, if he has a very small piece of land, he may feel that he will never have the economic resources to develop irrigation. Land reform in this case might hold back irrigation development. The probability is that the former effect would be more important than the latter, but both may be found.

2. Land reform - farm capital formation. In the same way, land reform may provide the opportunity for capitalization by the farmer, or it may deny an opportunity which had formerly existed. There may be a possibility for sharing of resources, or land reform may close options which had formerly existed. There are no general or straightforward relationships here, and the situation is an extremely complex one which must be worked out for each particular case.

3. Land reform - marketing decisions. Land reform or changes in land use may create new opportunities for farmers to store products, or to develop alternate uses for products, such as feeding them to livestock. Once again, depending on the type of land reform, the relationship can go in either direction to increase marketing percentages or to decrease them.

4. Land reform - agricultural technology decisions. Depending on whether a farmer has greater or lesser control over his own land after a land reform program, he may feel that a different kind of agriculture is appropriate. This may involve an intensification in cultivation, use of more or less purchased inputs, differences on land uses, and different roles of animals as these become owned by the peasant and may involve a tradeoff between meat and draft functions. So land reform may have a rather potent impact on at least the potential for intensification of agriculture and the concomitant increase in the use and the sophistication of the variable inputs.

Urban Conversion

1. Urban conversion - non- agricultural users of the environmental domain. The non-agricultural users within the typology presented here are likely to be most closely involved with the amenity resources or specific natural resources such as fisheries. They are likely not to have any involvement with the environmental domain of an urban ecosystem. Therefore urban conversion may make a substantial impact on the way that non-agricultural users of the environmental domain make decisions about the way they use land and the intensity with which they care about it.

2. Urban conversion - agricultural technology decisions. The biggest impact of urban conversion on agricultural technology decisions is in the way it forecloses options regarding land use. Once land is developed or even committed to urban purposes, it is not possible to use it for agriculture. Thus urban conversion represents a foreclosure of land utilization decisions which formerly would have been available.

Extension: R&D Diffusion

1. Extension: R&D diffusion - public water authority. Perhaps one of the most intricate kinds of technologies that is available to the farmer is that of irrigation and water control. Thus there is probably no sector in his decision structure which is more capable of influence by extension help and the diffusion of new technologies than water management in general. His interactions with the agencies which provide him with water are by no means static, and they may develop considerably as he is able to use water more effectively.

2. Extension: R&D diffusion - farm capital formation. In the same way, extension services may educate the farmer as how to use newer kinds of technologies and may even be able to provide him assistance in forming cooperatives which will allow the purchase of the associated machinery.

3. Extension: R&D diffusion - marketing decisions. New advice and new technology can do two things. First of all, they can enable the farmer to store his produce more effectively and cheaply, both so that he will be in a better position to take advantages of natural market fluctuations and also so that he is less vulnerable to the vagaries of middle men, lenders, and so forth. New technologies can also provide new ways of using farm produce for manufactured goods. Processing may be an additional on-farm option for the farmer, or it might be the basis for a new market for his products.

One of the main factors in determining whether and when a farmer will bring his produce to market is his knowledge of the price he will receive, and, if possible, some projection of the developments in price as time progresses. Accurate provision of price information to farmers can make a difference in the patterns of marketing production. This is especially true in market-oriented developed countries, but it may also be true in developing countries where production is sufficiently secure that farmers can respond strongly to price as well as to their perceptions of risk.

4. Extension: R&D diffusion - agricultural technology decisions. In principle, a farmer has a rather large "market basket" of variable inputs from which to choose. These include fertilizers of various formulations, pesticides of various sorts, and so forth. In order for him to decide reasonably what to buy and use, he must know which are available and at what price. In some countries, this information and assistance in the choice is provided by the estension service. In others, it is provided through different channels such as agricultural credit banks, cooperatives, etc. Many traditional farmers in developing countries do not know how to use variable inputs most effectively. They depend on information from various sources, including extension services, cooperatives, and the manufacturers themselves, in order to determine the ways in which variable inputs are used, the relative amounts of different agricultural chemicals in the mix, and the effectiveness of their use.

5. Extension: R&D diffusion - public health: disease responses. The same processes that go on in agriculture go on in the control of insect vector diseases. Just as extension and research with the development of new technology can aid in crop production, they can also aid in disease control.

6. Extension, R and D - human capital formation. There are many ways in which human capital of the farm population can be increased. One of the most effective is by providing information directed towards particular farm functions.

Most of these represent extension services. Indeed one can think of the extension service as a continuing-education function of the central government whose purpose is to bring useful developments to farmers and to improve their effectiveness as farmers.

Infrastructure

1. Infrastructure - non- agricultural users of the environmental domain. There are many non-agricultural users of the environmental domain whose decisions can be strongly influenced by infrastructure development. For those who are interested in the amenity resources of wilderness or rural areas, a good transportation system makes it much easier to get from the city into the countryside. For those involved in rural-urban conversion, industrial development, and so forth, the development of roads, railroads, and other kinds of transportation systems is also a strong stimulus. Infrastructural development in general makes things possible which had not been previously, but it also intensifies the differences between various sectors of the society in making decisions regarding common resources.

2. Infrastructure - public water authority. Water resources development and management involve more than the implacement of a dam and then allowing it to sit unmolested for the next 100 years. Water resources developments must be maintained, inspected, and used in various ways. They are among the most complex of developments, especially in the rural areas of developing countries. The level of infrastructure may be a significant factor in the degree to which complex water-related management schemes such as irrigation can be maintained.

3. Infrastructure - farm capital formation. One of the basic problems in developing a highly capitalized agricultural system is the so-called spare parts problem. Machines require spare parts and trained mechanics to keep them operative. An adequate infrastructure base is a requisite to maintaining machinery of even moderate complexity. Thus farm capital formation as machinery is likely to be significantly influenced by the infrastructural base of the country.

4. Infrastructure - marketing decisions. The farm-to-market road system is a key factor in the decisions regarding marketing of commodities. The development of a road may, for example, make it easier to market certain perishable goods rather than use them at home. Infrastructure may also involve state marketing boards which are able to assist farmers in their marketing decisions and handle some of the details.

5. Infrastructure - agricultural technology decisions. The availability of the variable inputs is probably as important as price in determining whether a farmer will plan to use them. If he is convinced that the inputs he needs will be available, he is much more likely to move to a more modern cropping system than if he is unsure or if he doubts their availability. The competence of the transportation and information networks comprise basic determinanta of whether the desired variable inputs will be considered available to the farmer.

6. Infrastructure - human capital formation. If extension has a direct impact on human capital, infrastructure has a much less direct, but probably no less important one. Infrastructure represents, among other things, the channels of communication between rural people and the rest of the country. This includes bilateral communication devices such as telephones, direct information conduits such as radio and television, and the capacity for movement of people and commodities such as railroads, roads, and waterways. The simple movement of things and information enables people to grow and to become able to do new things or to improve their previous abilities.

Constraints on Permissible Actions

1. *Constraints - non- agricultural users of the environmental domain.* Constraints are commonly directed toward specific target actors. Agriculturalists are the group of greatest concern to us in analyses of environmental problems of agriculture, and they are the obvious target of certain kinds of constraints. But any actors using the environmental domain may be constrained through legislation or regulation.

2. *Constraints - water and flood management.* The extent of irrigation and the related questions such as the strategy for soil flushing or amount of water per farmer are all things which can be legislated. Indeed there is probably no quicker way to influence irrigation development than by legislation.

3. *Constraints - agricultural technology decisions.* In some areas, the main agricultural problems are pesticide pollution and fertilizer runoff. In such cases, it may be possible or useful to regulate the use of fertilizers, either by application rates or by types, and it may be useful to regulate the use of pesticides either by banning certain types or by limiting their use to certain applications. In other areas, the problems of pollution are related to land use. Land use restrictions, zoning, and similar examples of active limitations on farmers' activities are practiced in many countries. Less obvious constraints include acreage allotments, production targets, and similar devices which effectively restrict the farmer's freedom of decision-making. These may be implemented directly by the government or by cooperative systems.

Non-Agricultural Users of the Environmental Domain

1. *Non- agricultural users of the environmental domain - public health, disease response.* The different users of the environmental domain have many different perspectives with regard to disease control. Most of them are agreed in the validity and importance of public health activities. But there may be profound differences in the preferred approaches to public health. As an example which is by no means unique, many such actors, for good reasons, are very much opposed to the use of pesticides, or at least to certain kinds of pesticides. The best known of these is DDT, which has been banned in most developed countries for agricultural uses because of its negative effects on non-target organisms. But it is often felt to be the most effective insecticide for use against arthropod disease vectors. There was a great deal of ill feeling generated when the United States Environmental Protection Agency banned DDT within the U.S.A., as the U.S. continued to export considerable quantities of the chemical to developing countries for use against malaria mosquitoes. There was a strong feeling that the U.S. was simply exporting pollution in an undesirable way. In this case, the U.S.E.P.A. was reflecting the values of constituencies which were oriented to neither agriculture nor public-health. This does not mean that the E.P.A. action or the values of the public to which it reacted were ill-founded or wrong. It is simply an example of the way in which feelings of one group can be brought to bear on public health activities.

2. *Non- agricultural users of the environmental domain - land use.* Land is a scarce commodity, and agriculture is not the only activity which makes use of land. For our purposes, the most important limitations involving land use are

those which remove land from agriculture. This includes road and infrastructure construction, rural factories, using topsoil for brick manufacture, etc., all in addition to the more massive withdrawals of land for urban conversion. Most such land uses are also related to population growth. As the population grows, the per-capita need for infrastructure, industry, building materials, etc. do not decline much, so that pressure on the land is built into the dynamic of growing societies.

3. *Non- agricultural users of the environmental domain - water and flood management.* Agriculture is the largest user of water in the world (e.g. White, 1968), but non-agricultural users also depend on water for many of their activities. Some of them, such as mining, electric power generation, and industrial users depend on water for their livlihoods and thus compete with agriculture for water. Much effort is given in water resources research to understanding the needs of various actual and potential water users for existing and proposed water resources and assessing the tradeoffs between them.

4. *Non- agricultural users of the environmental domain - requirements for services.* Throughout the rural landscape, all users require certain services from society. It may be that some of these are able to put their requirements as demands which will be met, and it is possible that some demands will be met more easily than others. But there are needs, and they will be communicated to the policy-making domain as effectively as the communication structure of the society allows.

5. *Non- agricultural users of the environmental domain - externalities generation.* This paper has already defined a number of phenomena which can be identified as externalities of agricultural production. These are viewed as particular instrument settings by agriculturists within the individual-management domain or agriculture-related outputs of the environmental domain which have an impact on the activities of actors outside of agriculture. That is, they are a vector of phenomena which have a significant impact on the non-agricultural users of the natural environment. These actors must assess the externalities and then generate a statement of some sort to the policy-making domain, commonly the government, that there are important externalities that must be considered and dealt with. This process of assessing the significance of the phenomena and generating the statement to the policy-making domain is the essence of the interaction

Public Water Authority

1. *Public water authority - non- agricultural users of the environmental domain.* The activities of all sectors of the economy are circumscribed by many factors, including the presence or absence of the raw materials for their activities. One of the most important for most sectors is water. Without water, for example, most industries cannot function. If a water authority is able to supply water to allow industry to flourish, then at least it is not limited by this factor. Likewise, the ability of water authorities to provide drinking water is an important factor in the commercial life of a village. Like so many other factors, water is critical to many aspects of life. But just how it affects people's decisions and behavior is not always clear, and there are probably no general rules regarding it.

2. *Public water authority - farm capital formation.* The particular type of farm capital that is most likely to be influenced by the behavior of public water authorities is on-farm irrigation and drainage works. There is commonly a sharing to irrigation development. The delegated authority constructs the

reservoir, the main canals, and perhaps even moderately small feeder canals, but the farmer must construct his own in-field distribution canals. There is no incentive whatsoever for him to do this if the public works projects to feed them do not exist. But if they do, it may be very much in his interest to invest in irrigation and make some rather profound changes in his overall way of operation.

3. *Public water authority - agricultural technology decisions*. Just as the development of water resources can influence farmers' decisions on development of farm capital in irrigation in the long run, the amount of water that can be supplied and on what terms is a key factor determining the extent and type of irrigation carried out by the farmer in the short run.

4. *Public water authority - public health activities*. The importance of the engineering design of water resources projects for the control of waterborne disease vectors is second only to the importance of the operation of the system. The spread of schistosomiasis, for example, has been vastly aided by the development of irrigation systems with slowly-flowing water in irrigation ditches or drainage canals which provide an ideal habitat for the alternate-host snails (Kassas, 1972; Biswas, 1978). Breeding grounds for malaria mosquitoes have formed around village standpipes which were designed to provide access to potable water for rural people for the first time. To a degree, at least, these problems can be short-circuited, and a water-resources system can be designed and run to minimize them. But it is by no means clear that constructing a water-resources system with the best of intent will not produce additional problems in its stead. A useful overview of the interactions between water resources development and public health is given by Starkey and Alpers (1975)

5. *Public water authority - Human capital formation*. Just as water is basic to agriculture and other sectors of the economy, water is an essential requisite of human life, and all societies take special efforts to provide water to their members. For some people in developing countries, however, getting water means walking hours to a water source and then walking back. If a public water authority can provide water to a village, it can cut hours off of the work of the women of the village and allow them to develop in other ways. Freeing people to develop in this way has been identified as a priority need for developing countries by the United Nations (WHO, 1977), and projects designed to implement it are being carried out by numerous development agencies, including the World Bank and some of the specialized agencies of the U.N.

6. *Public water authority - Water and flood management*. One of the main functions of water authorities is to manage water and flood control works, and to influence the ways that individual farmers manage their on-farm systems.

7. *Public water authority - Labor force and migration*. Cities were once places where life was shorter than in rural areas, for many reasons (Deevey, 1960). But this has changed, so that urban people live longer than rural people and often have higher standards of living. The perception of these differences is often quite clear, so that people may move to where they believe they will be better off. As pointed out by Todaro (1977), the perceptions of the people who are apt to move is the key to their migration, and these perceptions are often very subjective and inaccurate. Furthermore, cities in some countries are so overcrowded that they can scarcely accomodate the new arrivals from the countryside.

It is quite likely that key changes in the countryside which improved life in rural areas would do much to alter the perceptions of rural people about the advantages of the cities. One of the easiest of these key changes is the provision of water in villages so that people do not have to work so hard to get it and so that water- related diseases can be reduced. As mentioned above, this is a priority project of the United Nations and the World Bank, as well as several other international development agencies, and they have shown some success in this area (WHO, 1977). Whether success in community water supply provision has led or will lead to reduced rural-urban migration is conjectural at this time, but it is quite likely.

Farm Capital Formation

1. *Farm capital formation - agricultural technology decisions*. Certain technologies are not feasible until a certain level of capitalization can be maintained. Or conversely, they are no longer feasible after a certain level of capitalization has been reached. They require certain kinds of machinery or chemical inputs that are not feasible under changed conditions or are not economically justifiable. Perhaps one of the most interesting examples is in the Punjab of India, where gram and wheat are the most appropriate crops under rainfed condition. But if the same areas are irrigated, sugar tends to be the more profitable crop, even though it is much less nourishing. Similar kinds of changes can be expected whenever the farming changes from a lower level of capitalization to a higher level.

2. *Farm capital formation - water and flood management*. If a farmer is to maintain the irrigation and water management works under his control, he must be able to do it. In some cases, this may be possible on the basis of human labor alone, but this is unlikely in general. Some kind of motive power such as draft animals or small to large machinery are necessary.

3. *Farm capital formation - labor force: migration*. It is a common notion that with the modernization and improvement of agriculture, it is generally possible for farm yields to increase faster than the farm population. This means that one of the impacts of farm capital formation in most countries, including developing countries, is the production of a net labor surplus in the rural areas which is available for migration to the cities. This of course may cause substantial problems in the cities, but if it is possible to absorb them by an urban labor force, then it may be beneficial for the industrial plans of the country. Conversely, one of the goals of development programs of many countries is to modernize the agricultural sector in ways which do not displace labor from the farm. It is not always clear how to do this, but the crowded conditions in the cities make it critical.

4. *Farm capital formation - requirements for services*. It is implicit in the development of modern highly capitalized agriculture (among other highly capitalized enterprises) that the more complex a system, the more information and assistance it needs. One can expect a positive feedback between the level of mechanization in the rural areas and development of support services and infrastructures outside of the farms. If this feedback does not exist in fact, then the growth of modern agriculture is probably constrained by the infrastructural base. The form of the feedback is a demand for support expressed by individual actors which may or may not be supported by the policy-making structure.

Marketing Decisions

1. *Marketing decisions - agricultural technology decisions*. The marketing decisions of one year may have a pronounced effect on the agricultural technology decisions for the next. A farmer is not likely to want to concentrate on a crop which for one reason or another he cannot or does not wish to sell or

which is not of maximal benefit to him. He is more likely to shift to a crop which can be marketed readily or for which there are several alternative uses. Or he may increase the intensiveness of his more profitable crop and make whatever changes in technology he is capable of in order to realize an expected production which is most useful to him. This interaction also has an important effect on livestock. Livestock in many parts of the world depend on feed rather than pasturage. In this case, the amount of crop set aside for feed is translated directly into livestock biomass. This is doubly signifiant in that feed is an alternative disposition to food crops (notably grains) in situations whenever farmers have a surplus above their subsistance and contractual committments. Thus livestock represent a buffer for food markets in which the actual technology of livestock raising is a direct response of marketing decisions.

2. *Marketing decisions - commodities to market.* This is a very simple relationship. Once the farmer has decided how much of which commodity to market, he simply transfers it to market.

Agricultural Technology Decisions

1. *Agricultural technology decisions - farm capital formation.* Agricultural technology decisions are short-term decisions which are made by growing season. But they commonly have a certain amount of continuity, especially if the farmer is in a position to have a planning horizon that extends beyond a single season. In this case, decisions are made with an eye to capital development, and at least some of the expenditures made within a given year are likely to be toward the purchase of equipment or livestock designed to last considerably longer.

2. *Agricultural technology decisions - land use.* The allocation of land among all crops and other competing uses is a decision closely related to agricultural technology plans.

3. *Agricultural technology decisions - pest management.* The approaches to pest management represent an important subset of overall technology practice.

4. *Agricultural technology plans - water and flood management.* Like pest management, the approach to irrigation and flood control is a basic aspect of agricultural technology.

5. *Agricultural technology decisions - cropping technology.* The process of making decisions for agricultural technology results in a plan by which the farmer expects to carry out the subsequent year's activities. When this plan of cropping technology is implemented in the field, it represents a discrete information flow from the individual-management domain to the environmental domain.

6. *Agricultural technology decisions - purchases from market.* Many of the inputs which a farmer purchases are commodities such as fertilizers, pesticides, and so forth, which are purchased in the market. Therefore, the existence of a plan for utilization of a given set of inputs to realize a certain output also involves a demand on the market for the consumables or durable goods which form part of that plan.

7. *Agricultural technology decisions - labor force: migration.* In the same way the use of labor in the plan suggests a demand for labor on the rural labor market. To the degree that a surplus or deficit exists, there is a force for migration into or out of the rural area.

8. Agricultural technology decisions - requirements for services. Agriculture is not a self-contained phenomenon, and farmers are not perfect. Plans require assistance in the form of extension, R&D, infrastructure, etc. Thus the existence of a plan for using agricultural technology implies a demand to the policy-making domain for assistance in carrying out and refining those plans and for services that extend to all parts of the enterprise.

The decision to use particular variable inputs at certain levels requires a commitment of a certain amount of money, which the farmer may not have. An agricultural system which depends implicitly on chemical fertilizers, pesticides, and other purchased inputs requires credit. We often take it for granted that credit is a service of the central government and that interest rates are reasonable. But this is not the case for many, if not most, of the world's farmers. Even if they knew how to use fertilizer and wanted to do so, the interest rates charged by the village money-lenders is so high that they cannot afford to buy it. This has been described in a general way by the World Bank (1975), and Mayfield (1976) has outlined a particular and fascinating alternative provided by the "Local Savings Banks" in Egypt. There is a clear feedback between the provision of services by the government or other central authority, the incorporation of these services by the rural population, and the demand for still more. Indeed, one of the most difficult and important aspects of managing the dynamic development of the agricultural sector (or of any other sector, for that matter) is keeping the supply and the demand for services in balance.

9. Agricultural technology decisions - externalities generation. Environmental externalities related to agriculture are both direct and indirect. The indirect forms are those which originate in the environmental domain due to biogeochemical behavior of the soil and water. But some of the decisions made by farmers themselves represent costs to others. These involve factors like land use changes, etc.

Public Health

1. Public health - pest management. The weakest link in many chronic diseases is often the alternate host, which is most commonly an arthropod, mollusc, or vertebrate. Chemical biocides have been used widely against many of these vectors and have shown great successes, at least in the relatively short term. Due to their use, malaria is much less common than it used to be (Waddy, 1975), and molluscicides can be used successfully against some of the snail vectors of Schistosomiasis (World Bank, 1973). Biocides are likely to remain a key element of public health management for some time to come.

2. Public health - sanitation. Diseases, especially those caused by parasites, are spread by contact of susceptible individuals with infected persons or alternate hosts. The latter is infected with a mobile stage of the parasite which can be passed into the environment or directly to the susceptible person. These mobile stages are typically larvae of some sort which grow from eggs passed in feces or urine, or organisms passed through infection of blood-feeding arthropod vectors. Anything which facilitates either contact of humans with the excreta of infected compatriates or growth of the vector encourages spread of the disease. Sanitation is an important means of removing human excrement and garbage from places in which they can cause problems, and it is a key element in disease control. As a practical matter, it may consist of providing information or propaganda to constructing latrines, pure-water sources, and sewage treatment facilities.

3. Public health - water and flood management. The goals and outlooks of the public health community are rather different from those of the irrigation-water-using community. Water resource systems designed primarily for irrigation may encourage the growth of insect vectors. and effective public health measures may mandate changes in the way the system is run or in the way that the farmer carries out his own irrigation techniques. In some cases, there may be rather substantial changes in water and flood management to meet the public health goals of a society as well as its agricultural production goals.

Human Capital Formation

1. Human capital formation - labor quality. Human capital formation and the level of human capital are characteristic of individual actors. The intensity with which they can interact with the environmental domain is a direct function of the level of human capital, which is perhaps best indicated by the quality of their labor.

2. Human capital formation - labor force: migration. Like the state of health of a population, the level of human capital within the rural community can be an important factor in determining the attractiveness of the rural scene compared to the urban scene, and thereby one's proclivity to stay in the country or to move. As Todaro (1977) points out, education, sophisticated training, and similar aspects of human capital formation provide expectations for improved conditions in the cities. Whether these conditions actually exist or not is a different matter, and unemployment in rural-urban migrants in third-world cities is typically very high. As an example, education increases the likelihood of locating urban jobs at relatively high salaries, so that education generates expectations of obtaining such a job (or more likely, such a wage). This, in turn, generates increased migration of the most capable rural people to the city, where they are most likely to join the underemployed "informal service" sector.

3. Human capital formation - requirements for services. There is a very strong feedback between the abilities of people to use information and their requirements for services of various sorts. A sophisticated population can absorb new knowledge of various sorts, and remaining so requires additional knowledge and specialized services of many sorts. A given level of sophistication depends on maintaining the supply of the services, so that maintaining and increasing the level of human capital of the agricultural population implies necessarily an increased demand for services from the central government.

POLICY- MAKING DOMAIN

The policy-making domain comprises the institutions which attempt to govern the overall behavior of the system. It is characterized by the most powerful actors, which tend to be "global" in that they exert control on the individual actors who actually perform the "work" of the system. This is true not only of the actors who interact with the environmental domain but also those who perform the other basic functions of the society. It is a particularly important domain in that policy represents the mechanism by which socety exerts direction over all of its disparate elements. It may not be entirely successful, but it is certainly the most powerful mechanism which exists. Policy is generated in vastly different ways in different countries. Power may be extremely concentrated in some, so that the decision-making authority is vested in a very small number of people. In other countries, it may be much more diffuse, where real authority is spread over a wide institutional base.

The policy-making domain is "where the action is" if one is interested in the driving forces of society as a whole. But it is only a relatively small part of the overall system, and it needs to be considered in the context of the individual-management and environmental domains in order to be understood adequately. The policy-making domain is constrained by the basic values and goals of the society which exist on the higher or normative domain.

Let us now summarize the phenomena characterizing the policy-making domain, as well as the information transfers between it and the adjacent domains. In order to simplify things and concentrate on the agricultural- production system, the non-agricultural sectors of the economy are treated as a "quasi-policy-making domain" at the same level. The overall agricultural production system is thus seen as a complex array of domains which interact continuously with a satellite subsystem. This satellite is perhaps best viewed in a simplified way as an extension of the policy-making domain which deals with phenomena that are not of direct significance to the agricultural system. They may be important or even critical in the long run to the behavior of the overall agricultural system, especially in economies dominated by the non-agricultural sectors. But they are not part of the cycle of adaptive control of the agricultural production system itself (Figure 2; Clapham and Pestel, 1978c).

Issue Areas

The *non- agricultural sectors* include all other sectors of the economy outside of agriculture. In some countries, this is most of the economy; it may be relatively small in others. Nevertheless, even if the non-agricultural sectors comprise a relatively small part of the economy, the interactions between non-agriculture and agriculture at the aggregate level may be quite important, and the activities of the non-agricultural sectors may provide opportunities and constraints for the agricultural sectors which may be significant.

Consumer Demand is the relationship between quantity of various commodities purchased and price.

The *dynamics of the market* may differ from one country to another, although the basic balancing of supply and demand is characteristic of all markets.

The *labor market* is an analog to the commodity market except that it balances supply and demand for labor instead of commodities. The analogue of price in the labor market is salaries and wages, while the "quantity" includes numbers of people, as well as their training, experience, etc. Its workings are more arcane than those of the commodities market, and it is not possible to talk in simple terms like the economist's supply and demand curves. But it is a useful notion in a qualitative sense.

The dynamics of *taxing and granting of subsidies represent the* behavior of the government towards generation of its own operating funds, as well as the disposition of these funds among the various activities of society supported by the government.

Research and Development are the way new technologies are developed and made available for use by people. To some degree, these may be indigenous to a country; They may also be supplied largely from outside. In the former case, the research and development is at all levels. In the latter case, the R&D efforts of greatest impact are those involved in translation of technology developed elsewhere to meet the particular requirements of indigenous problems. It should be noted that technology transfer is not a simple thing, and even well-developed technologies for developed countries cannot be transferred without considerable alteration to a developing country.

Education provides an informed electorate, a better trained labor force, etc. It is thus probably the key element in the improvement in productivity of any country, developed or developing.

Externality coordination is the process by which the policy-making domain attempts to coordinate the externalities implicit in the system through legislation or regulation.

We can summarize the interactions of the various parts of the system in the contingency table shown in Figure 6.

Signals from the Individual- Management Domain

These are discussed above, page 42.

Signals to the Individual- Management Domain

These are discussed above, page 41.

Patterns of Interactions within the Policy- Making Domain

Commodities to Market

1. Commodities to market - market clearance. The commodities which appear in the market represent the supply at which the market must clear.

Purchases from Market

1. Purchases from market - demand The market does not care where demand comes from. Commodities required for agricultural production represent demand just as those desired by consumers.

Labor Force: Migration

1. Labor force: migration - non- agricultural sectors. The movement of labor and the availability of labor in certain places provides a stimulus to industry to develop new plants and new markets. These may not be terribly important in developing countries in general, but they may be locally important. These are effects which enter into the business planning process and which precede the actual functioning of the labor market.

2. Labor force: migration - labor market. The supply side of the labor market is determined by the people who need jobs or who want to change their jobs. In a developing country, the largest block of potential workers are those who migrate into urban areas from the rural areas. They tend to be unskilled,

		NA	CD	MC	LM	TS	RD	ED	CE	SU	CO	LR	UC	EX	IS	CL
Commodity to Mkt.	CM			1												
Purchases	PM		1													
Labor Force; Mig.	LF	1			2											
Require. Services	RS	1			2	3	4	5								
Externality Gen.	EG					1			2							
Nonagric. Sectors	NA	-	1	2	3	4	5	6			7		8		9	
Cons. Demand	CD		-	1												
Market Clearance	MC		1	-	2	3	4	5			6					
Labor Market	LM	1	2		-	3	4	5								
Taxing & Subsidy	TS	1	2	3	4	-	5	6	7	8	9	10		11	12	
R&D Institutions	RD	1					-		2					3	4	
Educational Inst.	ED	1			2		3	-	4					5	6	
Coord. Externality	CE	1							-	2		3			4	5

Figure 6 Contingency Matrix for the Policy-Making Domain

particularly in those skills most useful for urban activities.

Requirements for Services

1. *Requirements for services - non- agricultural sectors.* The provision of services by the government may have a considerable impact on the ability of the non-agricultural sectors to produce and distribute their commodities. This creates a powerful incentive for managers to demand those services of the central government which will allow them to maximize their profits and/or to meet their production targets.

2. *Requirements for services - labor market.* The labor market must be regulated by many devices. Some of these operate in the general direction of communication between potential employers and potential employees; in other cases, the requirements for services actually generate jobs which exert a demand on the labor market per se.

3. *Requirements for services - taxing and subsidies institutions.* Services cost money. If there is a demand for services from some sector, it must be either denied or paid for. Therefore the competing demands for services from the various parts of the society must by met by some mechanism within the policy-making domain which can allocate expenditures and/or services among the various actors involved. This may be done via the taxing structure or the way in which subsidies are given or denied.

4. *Requirements for services - research and development institutions.* Of all of the services which are performed at the policy-making level, perhaps one of the most important is R&D and the targeting of research and development to specific needs.

5. *Requirements for services - educational institutions.* The prime institution within which people are trained to grant services and within which many services are carried out is educational systems. Provision of knowledge is one of the most important functions of any government. Especially in developing countries, basic literacy is one of the most powerful factors in development of both urban and rural areas.

Externalities Generation

1. *Externalities generation - taxing and subsidies institutions.* There are several ways of treating externalities. One is via the market. And it is often noticed that people do things because it is cheaper for them not to worry about certain problems than it would be to worry about them. Therefore, one can use the tax system as an *a posteriori* way of recognizing externalities and including them in the market decision process. This involves charging effluent or emission taxes or erecting similar devices which are designed to alter the price of a commodity.

2. *Externalities generation - coordination of externalities.* An alternative approach is to regulate without altering the price. This is an assertion by the government of the right to coordinate activities with the intent of reducing the various externalities generated within the system. Coordination may involve setting constraints, or it may involve the assumption of more direct control over

the individual decision-making process.

Non-Agricultural Sectors

1. Non- agricultural sectors - demand. The non-agricultural sectors exert considerable demand for all commodities in the economy. Many agricultural commodities have specific industrial uses; others may only be important as food for workers. This kind of relationship is sometimes expressed in an input-output matrix.

2. Non- agricultural sectors - market clearance. The behavior of the market is a function of many things. In the abstract, supply and demand (both being defined as relationships of quantity vs. price) define an equilibrium price-quantity pair. But real markets are seldom this perfect or abstract. Pure equilibrium implies atomistic behavior of all who enter it, as well as perfect information. But power and information are often concentrated in the non-agricultural sectors so that they may be able to influence the market and distort it to some degree from its expected behavior.

3. Non- agricultural sectors - labor markets. The non-agricultural sectors of the economy commonly control the demand side of the labor market, as they are the people who do the hiring. This is especially true in developing countries, where the greatest problem of the labor market is to absorb rural migrants to the cities.

4. Non- agricultural sectors - taxing and subsidies institutions. Two influences are implied in this particular pair. The first is the relatively simple one that the non-agricultural sectors contribute a certain amount of money into the national coffers through excise-tax, value-added tax, and income tax routes. But the non-agricultural sectors may also have enough political clout to distort taxing mechanisms away from the social goals for which they were intended.

5. Non- agricultural sectors - research and development institutions. Research and development are critical for countries where the diffusion of the results of research and development activities can have a significant impact. This is the case in all but the very poorest countries. The effect of the non-agricultural sectors on R&D institutions is twofold. First of all, industry may carry out R&D in its own laboratories, and some of this R&D may have an application to agriculture. On the other hand, the centralization of power characteristics of non-agricultural sectors may allow them to exert disproportionate influence on the goals and plans of R&D institutions, so that the research and development done on non-agricultural affairs is relatively more than the role of these sectors in the total economy.

6. Non- agricultural sectors - educational institutions. Education is one of the most important functions of a society if the goals of that society are furthered by an increasingly sophisticated and well-trained labor force. For agriculture, it is likely that whatever training is done at the individual-farmer level is done by governments or outside agencies. For the non- agricultural sectors, training may be by government or by the industries themselves. In-house training by industry has two effects. First, the quality of training is likely to be high, since there is a real incentive for the industry to do the job right. Secondly, if an industry trains people, the government does not have to do it. There is then a tradeoff of rather interesting and perhaps significant sorts between industry and the rest of society with regard to educational institutions. On one hand, if industries train people, then the national government may have more resources to train farmers. On the other hand, such non-centralized education may also act to increase productivity and attendent urban income, so that rural-urban income differentials are even greater than they would have been.

7. *Non-agricultural sectors - commodity prices.* Price is a function of supply as well as demand, and many non-agricultural activities are oriented toward providing agriculture with its requirements for production-related inputs. As an example, the development of a basic chemical industry commonly includes increases in supply for agricultural chemicals. A successful chemical industry is likely to result in decreases in input prices. On the other hand, an increasing share of the economy in industry may make labor more expensive in agriculture as well.

8. *Non-agricultural sectors - urban conversion.* The non-agricultural sectors of most societies are largely urban. Their economic growth is almost always parallelled by a growth in the urban area devoted to them.

9. *Non-agricultural sectors - infrastructure.* In the same way, non-agricultural sectors depend on roads and infrastructural development to provide them with basic resources, transportation of raw materials from port or fabricator to the plant, and transport of fabricated product back to the point of dispersion.

Consumer Demand

1. *Consumer demand - market clearance.* Demand is, along with supply, the input to the market. Market clearance can be defined as the balancing of supply and demand.

Market Clearance

1. *Market clearance - consumer demand.* The most common economic view of the market are that commodities trade at an equilibrium price determined jointly by supply and demand. The level at which the market clears in any one year, however, has a very strong influence on demand in subsequent years, as it determines the expectations of the consumer for what he can logically expect to find on the market.

2. *Market clearance - labor market.* The output of the market clearance mechanism is a series of prices and commodities traded. Depending on the relative importance of planning, relative price, and so forth, it then becomes possible for decision makers to project needs for different commodities and therefore needs for different kinds of skills. Once this can be done, they can calculate a demand for a different kind of labor for the labor market in the future.

3. *Market clearance - taxing and subsidies institutions.* In most countries, the greatest government income comes from value-added taxes, profit taxes and income taxes. All of these are based on incomes, prices, and expenditures. All of these are a function of the way the market clears.

4. *Market clearance - R&D institutions.* As with the labor market, the market clearance and the trends in markets over several years can give considerable insight to the desires of consumers. These can point the direction for needed research and development.

5. *Market clearance - educational institutions.* For countries with predominantly market economies, the trends shown by commodity passing through the market gives a very good indication of skill needs for the future. These influence educational institutions to adapt their training in response.

6. *Market clearance - commodity prices.* One of the basic characteristics of the market is the price at which supply and demand are equilibrated.

Labor Market

1. *Labor market - non- agricultural sectors.* A labor supply for the non-agricultural sectors of the economy is dependent on the labor market operating in the country. The amount and quality of the labor force are both significant factors in industrial production.

2. *Labor market - consumer demand.* One of the key characteristics of the labor market is compensation levels. More than anything else, this determines the disposable income of the population, which is then reflected in consumer demand.

3. *Labor market - taxing and subsidies institutions.* In the same way, compensation levels are directly related to government income through income taxes, at least in countries which tax income.

4. *Labor market - R&D institutions.* Research and development takes skilled people with certain qualifications. If they exist in sufficient numbers, research and development can go on readily. If they do not exist, or if there is an imbalance in available talent and ability to employ that talent at satisfactory levels of compensation, R&D activities may be inadequate.

5. *Labor market - educational institutions.* The operation of the labor market may have a very strong effect on the choices of students for education and in the kinds of curriculum that are made available to students. This is especially true for societies in which the educational institutions are free to respond to what they preceive as the needs of society for types of training.

Taxing and Subsidies Institutions

1. *Taxing and subsidies institutions - non- agricultural sectors.* There are many ways in which government taxation and expenditures are directed toward the non-agricultural sector, and there are many reasons why this is a critical direction of national policy. Taxation of different industries can be an important way of raising money, and differential taxation may be a significant way of directing investment into favored industries. Likewise, subsidies of particular industries, government ownership of plants, and establishment of joint ventures are all ways of stimulating expansion and production in particular areas.

2. *Taxing and subsidies institutions - demand.* Taxing a commodity or subsidizing its consumption almost always exerts a strong impact on demand for that commodity.

3. *Taxing and subsidies institutions - market clearance.* There are direct ways in which the government can intervene in the market through the tax structure to manipulate it for various reasons, some of them good. This may be done on the supply or the demand side, and it commonly involves purchases from the market or establishment of "fair-price" or regulated-price shops that coexist

with the market or the establishment of price floors or ceilings for particular commodities.

4. *Taxing and subsidies institutions - labor market.* Government can have great impact on hiring of people who would not otherwise be hired by subsidizing manufacturers to do so. They can also increase the salability of a worker by subsidizing his education.

5. *Taxing and subsidies institutions - R&D institutions.* A very large percentage of R&D in most countries is carried on by the government.

6. *Taxing and subsidies institutions - educational institutions.* Education is generally considered a government function.

7. *Taxing and subsidies institutions - coordination of externalities.* Regulation is not cheap, and a government which adopts the regulatory approach rather than the market-altering approach must pay for it. Also, depending on how funds are allocated for the regulatory agency, the government may be able to control the kinds of regulatory approaches and the focuses of the regulatory processes.

8. *Taxing and subsidies institutions - subsidies and taxes.* The subsidies to specific individuals on the individual-management domain can be identified.

9. *Taxing and subsidies institutions - commodity prices.* There are excise taxes, subsidies and support prices which may influence the price of various commodities.

10. *Taxing and subsidies institutions - land reform.* The notion of land reform can be looked at as a reasonably logical extension of the taxing function, except that in this case it is land ownership which is being "taxed" or "subsidized" rather than money.

11. *Taxing and subsidies institutions - extension: R&D diffusion.* The provision of extension services and the diffusion of research and development results are among the major avenues of government expenditures. Providing information and services to agriculture is expensive. While the overall costs may be less than for other parts of the economy, such as military or public works expenses, they may be viewed as "soft" inputs and appear as appropriate targets for budget-cutting. This is especially true if the impact of extension and R&D diffusion are not readily apparent or will not be felt until some time in the future. In many cases, these impacts are indirect and slow to develop, and it is difficult to assess the extent to which the dynamic development of a sector is due to information provided it, as opposed to more obvious direct inputs. The most vulnerable sorts of information to this short-term cost-benefit scrutiny are probably those which might be most successful at raising farmers' consciousness of long-term environmental problems and showing them how they could help combat them.

12. *Taxing and subsidies institutions - infrastructure.* The construction and maintenance of infrastructure in a country is likewise a major avenue of government expenditures. Those forms of infrastructure which are most important for agriculture are transport systems, energy systems, and water-resource systems.

Research and Development Institutions

1. R&D institutions - non- agricultural sectors. Research and development are as critical to non-agricultural sectors as they are to the agricultural sector. Indeed, as many countries see growth in industry as critical to their own development, research and development in non-agricultural sectors may at once carry along the overall economy and provide a strong competition for the best people who might have provided R&D in agriculture.

2. R&D institutions - coordination of externalities. The whole regulatory process is, at its best, one which involves creative solutions to emerging problems. Research and development may be able to provide better ways of dealing with problems and therefore of coordinating the externalities than existing technological approaches.

3. R&D institutions - extension: R&D diffusion. Once research and development are done, they can be diffused. But the development process and the translation of process developed elsewhere to meet local problems is an essential prerequisite to extension work and the diffusion of technology.

4. R&D institutions - infrastructure. As with public works, research may improve the capabilities of society to provide infrastructure at reduced cost.

Educational Institutions

1. Educational institutions - non- agricultural sectors. The level of sophistication of a population can affect the non-agricultural sectors of the economy in two ways. First, on the supply side, the quality of products is likely to be improved; on the demand side, the sophistication of demand is also likely to be increased by increasing levels of education. This can be seen in both developed and developing countries. For example, countries like Taiwan and South Korea have reached very high levels of literacy. In both countries, this fact has made it relatively easy to train people with few formal skills to work in modern factories making finished textiles and electronic goods (Rossmiller, 1979).

2. Educational institutions - labor market. The training available through the educational institutions is reflected in the productivity, abilities, and compensation levels of the labor force.

3. Educational institutions - R&D institutions. In the same way, the effectiveness of research activities is largely dependent on the preexisting capabilities of the educational institutions.

4. Educational institutions - coordination of externalities. The more educated the populus is, the more capable it is of understanding, dealing with, and accepting the regulations which are necessary in order to coordinate the externalities of a system.

5. Educational institutions - extension: R&D diffusion. Extension efforts do no good unless they are accepted by the farmers. The more educated a farmer is, the more likely he is to seek out and then accept extension assistance. In the same way, the better trained an extension agent is, all other things being equal, the more effective he will be.

6. *Educational institutions - infrastructure.* The better informed the populus, the more likely the infrastructural system is to be planned in a reasonable way and laid out and used in an optimal fashion.

Coordination of Externalities

1. *Coordination of externalities - non- agricultural sectors.* Some of the most important evironmental externalities are pollution of air and water by industry and other non-agricultural sectors of the economy. For this reason, the majority of the effort to coordinate externalities for the larger society are directed toward the regulation of these non-agricultural sectors.

2. *Coordination of externalities - subsidies and taxes.* In many cases, it is possible to subsidize people to do things in a way which is held to be socially acceptable. In some places this might be for the government to pay the operating expenses on certain kinds of wastewater treatment plants. There might be a subsidy for using land or variable inputs in certain ways, and so forth. The list is very broad. Alternatively, the government can impose a tax of some sort on specific activities it wishes to discourage.

3. *Coordination of externalities - land reform.* Mandated changes in land use or land ownership patterns may also be part of the regulatory process.

4. *Coordination of externalities - infrastructure.* In some countries, perhaps the most important way in which the policy-making domain coordinates the externalities of the system is to erect pollution control plants or to mandate private construction of treatment plants.

5. *Coordination of externalities - constraints legislation.* It is also possible to legislate constraints on what is or is not permissable regarding land uses, inputs, and practices in general.

ADAPTING AND MODIFYING THE CONTINGENCY MATRICES

The contingency matrices shown in Figures 4-6 represent a very compact way of looking at a great many interrelationships of extraordinary complexity. It is not entirely unfamiliar, however. Because each of the issue areas represents a process (or set of processes), and the interactions represent information flow which leads to responses within the various processes, the contingency matrix can be transformed easily into a flow chart, as demonstrated in Figure 7. Figure 7 shows only a rather small part of the system summarized in Figure 4, but to draw a flow chart of the whole system would be unnecessarily complicated. Nevertheless Figure 7 points out, perhaps better than Figures 4-6, that the system is really nothing more than a series of describable processes whose outputs are a function of their various inputs. The job of the analyst at this point is to verify that the picture shown in Figures 4 through 7 is sufficiently complete to allow a responsible simplification. The result should be an overview of the system that is comprehensive enough to be useful, as well as both tractible and consistent.

Perhaps the best use of the contingency matrix is as a qualitative means of sorting and ranking the relationships according to their importance. In a comprehensive analysis of a large region or a country as a whole, one must expect to spend a great deal of time trying to understand the problems in some depth before beginning to review the appropriate research methodologies, doing an intelligent job of gathering data, or even beginning to explore whether the needed

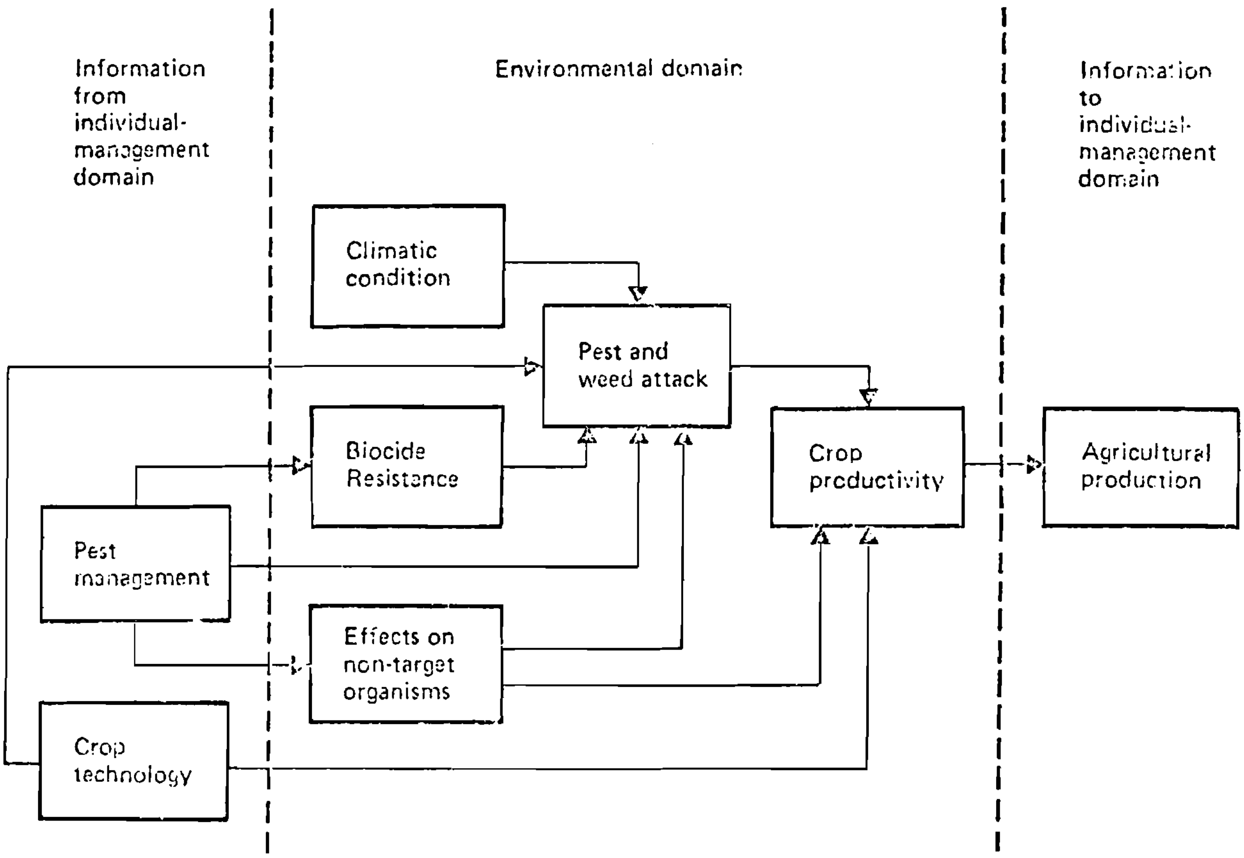

Figure 7 Flow Chart Exposition of a Portion of Contingency Matrix of Environmental Domain

information exists. A contingency matrix is an exceedingly useful way of organizing the analyst's prior knowledge of the system. Each point on the contingency matrix represents a directional influence of one issue area on another which can be defined explicitly as has been done above. The analyst can then ask, "Is this relationship important, or is it not?" If so, it can remain in the analysis. If not, then it can be eliminated. The contingency matrix can be expanded or contracted at any point in the analysis and the basic interactions summarized above can be modified as thought appropriate by the analyst or his client.

PART III: ANALYSIS OF ENVIRONMENTAL PROBLEMS OF AGRICULTURE

So far, we have concentrated on different "pieces" of the analysis of environmental problems of agriculture. This may be a useful device, but only if they can be put together into a coherent overall structure that provides information on the characteristics or behavior of the agricultural system in the real world. This structure is suggested by Figure 8. The issue areas are shown by domains, and they are linked by the flows of information. This is a very highly aggregated diagram, and it does not show how the issue areas are related within each domain; nor does it show how one would actually go about doing a multidimensional analysis. The first objection is not serious. As we have discussed above, one could construct the flow chart of the entire system if one wanted to. Likewise, one could work out a contingency matrix for the whole system if it were appropriate. This would be essentially a cascading of Figures 4-6. It is not such a difficult thing to retain a great deal of complexity within a simple graphical view of the system. But a flow chart or contingency matrix of the entire system would be so complex as to be of no practicable use. The much simpler diagram of Figure 8 and the contingency matrices of each domain provide a quite satisfactory overview of the system which is much less confusing.

It might be convenient under some circumstances to have a framework which allows a unified consideration of all of the domains of a system in formal mathematical terms. Indeed the contingency matrices can easily be collapsed into a set of functional equations, in the proper calculation order. If one wanted to model the entire complex system, the contingency matrices would provide a full check-list of the relationships which would have to enter the model. But most policy questions do not allow this kind of analysis; nor would it be appropriate.

The information available for different parts of any complex system have different characteristics. Some parameters can be measured to high levels of precision, while others exist only as informal judgements of practitioners. Some relationships can be expressed easily in numerical terms, while others cannot. Some numbers are meaningful only at specific instants in space and time; others inherently represent averages over a long term or a broad area. Nevertheless, an analysis must be made to answer various specific questions within a very short time frame, making the best possible use of all available information. We seldom have the luxury of doing "scientific" quantitative analyses where important environmental policy decisions must be made. And it is appropriate neither to delay decisions until "hard" data are available for rigorous parameter estimation (and this is often simply impossible because of the nature of the system), nor to ignore much of the available information and restrict the analysis to the "hardest" and most quantitative relationships. This seldom addresses the questions most relevant to the policy-maker. Indeed the most important matters tend to be those dealing with relationships which are most difficult to quantify, and it may even be difficult to pose meaningful questions which can be addressed by quantitative terms even in principle. This is one reason that many policy-makers doubt the usefulness of quantitative methods for policy design.

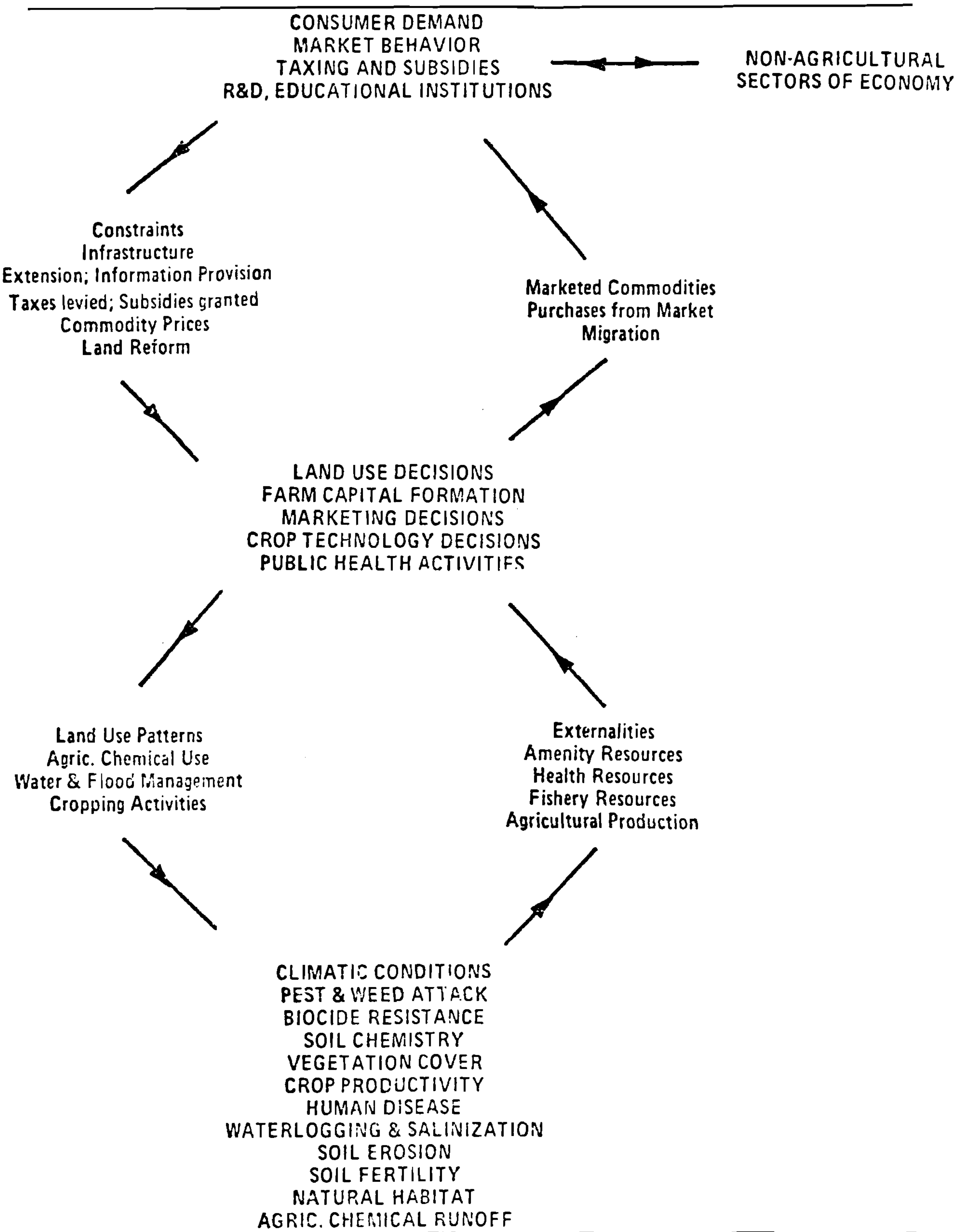

Figure 8 Schema for Integration of Domains in Agricultural Production System

The main advantage of the contingency matrices is that they provide a very simple way of ordering knowledge that people already have. They are neither prescriptive nor mathematical. They provide a framework within which the three domains can be linked in a simple graphic way that can be understood by systems scientist and layman alike. Preparing them requires no data beyond the informed judgement of what issues are clearly (or potentially) important in each domain, who are the various actors in the system, what signals do they perceive, which signals are they capable of responding to, and what signals are created through their decision-making activities.

It cannot be overemphasized that while these judgements need not require quantitative data, they represent extremely sophisticated judgements which are by no means trivial. The breadth of a set of contingency matrices might be far beyond the competence of a typical disciplinarily oriented scientist. But the view of the agricultural production system as a phenomenon this broad is second nature to the farmer, and it is likely also to be to the informed decision-maker. A completed set of contingency matrices provides a simple, logical framework to assess the relative importance of various relationships and a qualitative mechanism following their repercussions through the system. It is somewhat analogous to a "road map" of the agricultural system. As such, it can provide a framework for discussion between managers and analysts as to what effects should be quantified and which need not and whether quantification in this context implies detailed data-gathering and analysis or a full-fledged mathematical model.

Going from the real world to a meaningful representation of a complex system is neither a simple nor an automatic task. It requires retaining sufficient complexity to understand the indirect effects of the dynamics of change in the system without becoming confused by the complexity. The analyst must determine what is known about the system without foundering in a sea of detail or losing heart over the inscrutability of the patterns he is trying to represent. He must cast his net widely enough at first to enable him to be reasonably sure that the most important factors are included someplace within it. If his "net" is a qualitative framework which helps to organize relationships without needing a lot of detail to do so, then this is a feasible task. Simplification and problem definition can then proceed by eliminating relationships that are not important rather than by accretion of other problems that suddenly appear important.

Problem definition can be oriented toward the particular place and time rather than toward disciplinary framework. There is no insurance, of course, that the important paths will be identified, especially for indirect effects which span disciplines and must be considered for situations which are not well understood. But analysis of any sort must be oriented toward answering questions, and it is not possible to answer a question which is not asked. Starting with a broad qualitative framework which attempts to include all of the relevant domains of the production sytem maximizes the likelihood that the questions which are most essential for understanding the changes in a particular agricultural system will at least be asked.

But the qualitative framework does more than to allow questions to be asked. It is also a stylized representation of the system which can be viewed in several guises and at varying degrees of precision. As we have already seen, the contingency matrices are precisely equipped to flow charts, so that they comprise a graphic representation of the key relationships in the system. But they can be translated with equal ease into a set of functional equations with unambiguous calculation order.

Formalizing the functional equations into those with estimable parameters would allow a highly mathematical analysis. This approach requires tremendous amounts of data and knowledge, as well as a sound theoretical base. But it is potentially quite useful. Alternatively, functional equations can be connected to a cross-impact-type analysis in which deviations from expected values are allowed to ramify through the system (e.g. Helmer, 1978). This approach allows results to be available on the basis of rather little data; it is not a precise model, but it is an effective way of quickly assessing the sensitivity of a system to changes in key components. Still a different alternative would be to use the functional equations as a qualitative basis for determining which relationships are important and which are not and for doing a first-cut analysis of qualitative ramifications of changes in particular parts of the system.

Most clients for analysis of environmental problems of agriculture are managers who must make decisions within a relatively short time frame (Baskerville, 1979). There must obviously be close agreement between the analyst and his client on the nature of the analysis to be performed, so that it is appropriate to the decision which must be made both in timing and in degree. Constructing a framework like that described here provides a basis for checking whether the analyst is considering actors or pressure groups that the client knows to be important, and it provides one mechanism of deciding how good an answer is needed and by what time. This, in turn, determines the quality and quantity of data requirements and provides a sound rationale for justifying expenditures on data collection. It is probably typical of environmental policy analyses that some parts of the system can be quantified fairly successfully and to a good purpose, while other parts require an ordering of judgemental information and the establishment of meaningful scenarios (Rossmiller, 1979). The point is to meet the needs of the manager with as good an analysis as possible given the pressure of time and data availability (Clapham, Pestel, and Arnaszus, 1980).

IMPLEMENTING A MULTIDIMENSIONAL ANALYSIS OF ENVIRONMENTAL PROBLEMS OF AGRICULTURE

To implement an approach is to make it specific for a particular problem and a particular analytical purpose. This is quite different from demonstrating how something can be done in principle or describing the general relationships that are involved in a particular type of study. The analyst must specify precisely what he is talking about, state the questions that need to be answered, tailor a particular analysis to those questions, and point out precisely what data are needed and perhaps where they are available. Furthermore, his client must be able to agree that the approach will meet his needs. The test of a general approach is the degree to which it expedites the specific analyses.

Steps in Designing the Analytical Framework

The first step in constructing an integrated framework within which to view environmental problems of agricultural production systems is to verify and adapt the elements to the specific case involved. This is very important, and it is a straightforward qualitative procedure. The general view discussed so far includes an environmental domain and two levels of decision-making. The environmental domain is always present in agricultural systems, and it must be understood in more or less detail, depending on the kinds of problems involved. Likewise, there is always an individual-management domain which interacts directly with the environmental domain and which responds to inputs from above. In the same way, there are always policy-makers. These include the national government, as well as whatever other levels of authority have real power in the country in question. There are several federal countries in which a state, provincial, land, republic, or similar level of decisionmaking exists between the country-wide and individual actor levels. This decision level often behaves quite differently from the national level, and it can be very important. Other countries have delegated specific powers and responsibility for dealing with environment-related problems and regional development to regional authorities. Different regional authorities may have different goals and different strategies for reaching them. Indeed even the way in which they monitor individual actors, the lags involved in their decisionmaking process, and so forth, may be quite different from region to region. Other countries feel the presence of international groups or lending institutions quite strongly.

After the structure of the domains is verified or modified, the issue areas and information flows must be examined very carefully. It is inevitable that the list presented here will be useful only as a first approximation of the list of issues and information required for the particular case. The next, and perhaps the most important step in setting up the analysis is to verify and adapt the contingency tables for each domain. This is a relatively straightforward process, at least in the first step. One carries it out by asking the question, "Does this input/ issue area influence that issue area/output?" for each pair. The result of the "yes" answers is a contingency matrix such as Figures 4-6.

But simply filling out the contingency matrix is not sufficient. The particular relationships must be specified, as has been done in the bulk of this paper. Furthermore, the relative importance of each influence must be assessed. This is probably best done by rating them in some qualitative manner (e.g. critically important, very important, important, possibly significant, marginal, unimportant). In most cases, certain relationships will stand out as more important than others, and the important foci of the analysis for different places within the overall analytical framework will become clear. In general, it is possible to design a stepwise analysis where the most critical areas are tackled first, followed by those which are less so, and so forth until either all of those areas thought to some have relevance have been included or a structural sensitivity analysis shows that further inclusion of issue areas is not warranted.

An analysis intended to have an impact on the policy process is not a matter simply of designing and implementing a construct. It is a way of asking important questions and answering them in a way which is useful to the policy-maker. This must commonly be done within a time-frame that seems impossibly short. In complex areas such as environmental problems, it must focus on complexity in a creative and simplifying way. In order to make meaningful policy suggestions, the analyst must recognize that his analytical framework is a tool in a very broad set of tools used to assist the decision-maker (see Clapham, Pestel, and Arnaszus, 1980, for an expansion of this idea). But the craft of specifying the general construct means that the implementation and ways of using the tool must also be specific to the given use. Tools are appropriate only when they provide the desired results. For a policy analysis of environmental problems of agriculture, these results are meaningful answers to the most important questions.

It is useful therefore, to do a first analysis of the problem using the completed analytical framework to verify the range of questions which that framework can address, the kinds of answers which it can make available, and the kinds of recommendations that it can generate. This analysis can also identify problems of consistency and point out relationships which were ignored because they were thought to be less important, but which are synergistic with other factors to which the system is sensitive or which are closely tied to the implementation of some policy.

A useful qualitative analysis is a stepping-through of the contingency matrices within and between domains. When numerical relationships are available, they can be used, but the main intent is to carry out a rapid analysis using information readily at hand and without worrying about rigorous parameter-estimation procedures. In addition to the verification and error-checking functions discussed above, this analysis also provides a good opportunity relatively early in a study to discuss the system with the client and make sure that it is appropriate to his views of the policies available to him and that the nature of the system and its behavior correspond to his strategic and tactical inclinations. It is always much easier to make changes earlier rather than later, and it is often much easier to discuss conceptualization of a problem in qualitative or semi-quantitative, rather than in quantitative, terms. This is especially true if the analyst and his client are from very different backgrounds and their only common language for discussing the problem is fairly general and qualitative. Finally, a qualitative or semi-quantitative analysis probably goes far to demonstrate which parts of the analysis should be treated in a modeling fashion, and which should be of a judgmental sort. That is, it will help both to focus data gathering, should data be necessary, and to specify the intensity of quantitative expression of the final analysis.

REFERENCES

Abul-Atta, A.A., n.d. *The Water Policy of Egypt*. Cairo: Ministry of Irrigation, Arab Republic of Egypt, 1-19.

Ansari, N., ed., 1973. *Epidemiology and Control of Schistosomiasis (Bilharziasis)*. Basel: S. Karger, for the World Health Organization.

Balls, W.L. *The Yields of a Crop*. London: E. & F.N. Spon, Ltd.

Baskerville, G., 1979. Personal communication during visit to IIASA.

Biswas, A.K., 1978. Environmental implications of water development for developing countries. *Water Supply and Management* 2: 283-297.

Biswas, A.K., in press. Climate and economic and agricultural development. *Science*.

Brady, N.C., 1974. *The Nature and Properties of Soils, 8th ed.* New York: Macmillan Publishing Co.

Burdick, G.E., Harris, E.J., Dean, H.J., Walker, T.M., Skea, J., and Colby, D., 1964. The accumulation of DDT in lake trout and the effect on reproduction. *Trans. Am. Fish. Soc.* 93: 127-136.

Clapham, W.B., Jr., 1980a. Agricultural system structure and the Egyptian cotton leafworm. *Agriculture and Environment* 5:201-211.

Clapham, W.B., Jr., 1980b. Environmental, Behavioral, and Policy Dimensions of Agricultural production systems *Environmental Conservation* 7:145-152.

Clapham, W.B., Jr., and Pestel, R.F., 1978a A common framework for integrating the economic and ecologic dimensions of human ecosystems, I: General considerations. *IIASA Research Memorandum* RM-78-29: v+27.

Clapham, W.B., Jr., and Pestel, R.F., 1978b A common framework for integrating the economic and ecologic dimensions of human ecosystems, II: Problems and problem chains within the nautral stratum. *IIASA Research Memorandum* RM-78-30: v+52.

Clapham, W.B., Jr., and Pestel, R.F., 1978c A common framework for integrating the economic and ecologic dimensions of human ecosystems, III: Policy, analysis, and uncertainty. *IIASA Research Memorandum* RM-78-31: v+23.

Clapham, W.B., J., Pestel, R.F., and Arnaszus, H., 1980. On the scenario approach to simulation modeling for complex policy assessment and design. *Policy Sciences*, in press.

Council on Environmental Quality, 1972 *Integrated Pest Management*. Washington, U.S. Government Printing Office.

deBach, P., 1974. *Biological Control by Natural Enemies*. Cambridge: Cambridge Univ. Press, xi+323. Deevey, E.S., 1960. The Human Population. *Scientific American* 203 (3): 15-20.

Doutt, R.L., 1964. The historical development of biological control. in DeBach, P., *Biological Control of Insect Pests and Weeds*. New York: Reinhold Publishing Corporation, 21-42.

Eckholm, E.P., 1976. *Losing Ground*. New York: W.W. Norton & Co., Inc.

El Tobgy, H.A., 1976. *Contemporary Egyptian Agriculture*. Beirut: The Ford Foundation, x+228.

Golubev, G.N., Shvytov, I.A., and Vasiliev, O.F., 1978. Environmental problems of agriculture, I: Water-related environmental impacts of agriculture at the field level. *IIASA Research Memorandum* RM-78-32: v+24.

Helmer, O., 1978. Cross-Impact Gaming Applied to Global Resources. *IIASA Research Memorandum* RM-78-04

Horsfall, J.G. *et al.*, 1972 *Genetic Vulnerability of Major Crops*. Washington: National Academy of Sciences.

Jordan, P., 1975. Schistosomiasis -- epidemiology, clinical manifestations, and control. in Starkey, N.F., and Alpers, M.P., eds. *Man- Made Lakes and Human Health*. London: Academic Press: 35-50

Kassas, M., 1972. Ecological consequences of water development projects. in Polunin, N., ed. *The Environmental Future*. London: Macmillan, 215-246.

Kovda, V.A., 1979. Personal Commlunication.

Leopold, A., 1945 *A Sand County Almanac*. New York: Oxford University Press.

Mayfield, J.B., 1976. Local Government in Egypt: Some New Change Strategies and Training Opportunities. Mimeographed Technical Report, 142pp.

Mesarovic , M.D., Macko, D., and Takahara, Y., 1970. *Theory of Hierarchical, Multilevel Systems*. New York: Academic Press.

Mishan, E.J., 1970. *Technology and Growth: the Price We Pay*. New York: Praeger Publishers, Inc.

Myrdal, G., 1952. *Chron. World Health Org*. 6: 203.

Myrdal, G., 1968. *Asian Drama: An Inquiry into the Poverty of Nations* New York: Pantheon.

Pimentel, D., Krummel, J., Gallahan, D., Hough, J., Merrill, A., Schreiner, I., Vittum, P., Kozoil, F., Bachs, E., Yen, D., and Fiance, S., 1978. Benefits and costs of pesticide use in U.S. food production. *BioScience* 28: 772,778-784.

Ratcliffe, D.A., 1967. Decrease in eggshell weight in certain birds of prey. *Nature* 215: 208-210.

Ratcliffe, D.A., 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. *Jour. Appl. Ecol. 7: 67-115*.

Rossmiller, G.E., 1979. Personal Communication

Schultz, T.D., 1964. *Transforming Traditional Agriculture* New Haven: Yale University Press.

Sondheimer, E., and Simeone, J.B., 1970. *Chemical Ecology*. New York: Academic Press, Inc.

Starkey, N.F., and Alpers, M.P., eds., 1975. *Man- Made Lakes and Human Health*. London: Academic Press.

Stone, E.C. and Vasey, R.B., 1968. Preservation of Coast Redwoods on alluvial flats. *Science* 159: 157-161.

Todaro, M.P., 1977. *Economic Development in the Third World*. London: Longmans Group, Ltd., xxiv+445.

Waddy, B.B., 1975. Mosquitoes, malaria, and man. in Starkey, N.F., and Alpers, M.P., eds. *Man- Made Lakes and Human Health*. London: Academic Press: 7-20.

Webster, M.H., 1975. Medical aspects of the Kariba hydro-electric scheme. in Starkey, N.F., and Alpers, M.P., eds. *Man- Made Lakes and Human Health*. London: Academic Press: 69-88.

White, G.F., 1968. *Strategies of American Water Management*. Ann Arbor: Univ. Michigan Press.

World Bank, 1973. Appraisal of Upper Egypt Drainage Project. Report Number 80a-UAR

World Bank, 1975. Agricultural credit. Chap. 3 in *The Assault on World Poverty: Problems of Rural Development, Education, and Health*. Baltimore: Johns Hopkins University Press, 99-261.

World Health Organization, 1977. Report on Community Water Supplies. United Nations Water Conference, Mar del Plata, Argentina E/CONF.70.14.

Wright, C.H., 1951. Medical parasitology in a changing world: What of the future. *Jour. Parasitol.* 37: 1-12.