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A DEMONSTRATION OF SYSTEMS ANALYSIS FOR DEVELOPMENT PLANNING

Final Report on a Week-Long Workshop to Develop a Computer Model of a Typical, Large USAID Project, Based upon a Portion of the Accelerated Mahaweli Project in Sri Lanka

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A DEMONSTRATION OF SYSTEMS ANALYSIS FOR DEVELOPMENT PLANNING:

The Integration and Optimization of Agricultural Enterprise with its Environment

1.0 INTRODUCTION

Natural resource development projects in developing countries have to deal with many complex and interacting factors. An irrigation project, for example, may have to contend with such diverse considerations as conversion of forest to farmland, preservation of rangeland and forests, preservation of wildlife habitat, planning for schools, hospitals, transportation, even whole villages, towns, and cities. These plans must also take demographics, culture, energy and water requirements, markets for crops and manufactured products, and micro and macro-economics into account.

How can planners deal with such complexity? How can planners have a degree of confidence that their plans are feasible? How can they be sure that they have considered the most important aspects of the project without neglecting one or more key issues? How can planners better formulate their objectives? How can planners test alternative scenarios to help them evaluate the relative importance of various options to project elements and interactions?

A plan for any large project can raise these questions. Because human and natural systems are so complex, they are difficult to understand and even more difficult to predict. One need not look far to find examples of plans gone awry, the appearance of unanticipated problems, and simply failures to consider important aspects of a system. These problems can be costly.

While there is no single panacea that can be applied to all planning problems, one tool that can be used is systems analysis. Systems analysis is the process of trying to identify all the important components of a system and determining how they interact to produce a set of behaviors.

Done properly, systems analysis has been shown to be a cost-effective method of addressing the complexity of systems, making predictions about aggregate system behavior, and perhaps most important, teaching planners and others how the various sectors of a bioresource system can interact to alter the expected results of a plan or project. Sometimes these results can be surprising, even counter-intuitive.

There are several levels of AID's Development Program Planning and Implementation Cycle where systems analysis could be applied: where demonstrations of linkages among sectors, cause and effect, and scenario simulation might be of most benefit. Three levels where systems analysis might be most useful are (1) at the CDSS policy and strategy planning step, (2) at the PID project-level design stage; (3) Mid-term evaluation.

To illustrate the utility of the process and to provide a check on the costs and level of effort involved, USAID ASIA/TR (initiated by Robert C. Ichord and Michael Philley) sponsored a week-long modeling workshop in

Washington in April, 1984. The objectives of the workshop were to develop a model of a typical, large AID project, and document the process with a report and a video tape production.

It was decided to demonstrate the systems approach on a "typical" USAID project in a developing country. Drs. Kenneth L. Reed and Stephen H. Berwick were requested to organize the demonstration. This workshop is documented in this paper. Berwick is responsible for the scope of the project, and the continuing development of the model. All inquiries should be directed to him at IIED (address on front page).

2.0 SYSTEMS ANALYSIS

We attempted to use a systems analytic approach to this study. This approach consists of careful definition of the goals and objectives of the analysis, a description of the components of the system, and finally a model of the system. This model can be conceptual, graphical, verbal, or mathematical.

Systems analysis has been around for many years and, especially in engineering contexts, the approach has been successful. During the late 1960's and 1970's, there were many attempts to extend the systems approach to natural and human systems. These attempts met with mixed success as various approaches were tried. In general, several rules of thumb have emerged: a clear-cut set of goals and objectives must be defined, the models themselves must be relatively simple, the system should be defined from the top down (that is, don't get immersed in complexity, start with a holistic overview of the problem), the model should be constrained to descriptions of the behaviors of interest, and finally, the models themselves should be viewed as imperfect but useful abstractions of the object system. A systems model cannot be as complex as the object system and necessarily must be a simplification.

Let us consider another type of model to help us understand the concepts discussed above. Figure 1 is a common roadmap. A map is a model of a system, in this case, it is a road map of the United States. Notice that it does not contain roads in Mexico. Likewise, there are no topographic contours on the map. Why is that? Because the planners who designed the map decided that the system would be bounded by the United States borders, and that they were interested in roads, not topographic information. Is this a good model? Yes, if you are interested in finding your way from Los Angeles to Salt Lake City. No, if you want to know where the Wasatch Mountains are. Is it a good model of the roads? Yes, if you are interested only in major highways. No, if you are interested in ferreting out interesting little side roads. They are not even depicted on the map.

This brings us to the concept of model resolution. Because a model can theoretically be infinitely complex, just as can nature, the modelers must make decisions as to the degree of detail they can encompass. There is a trade-off in modeling that must be respected: greater detail means more complexity, more cost, and more uncertainty about error. Studies have shown that error propagates through mathematical models in non-additive fashion and

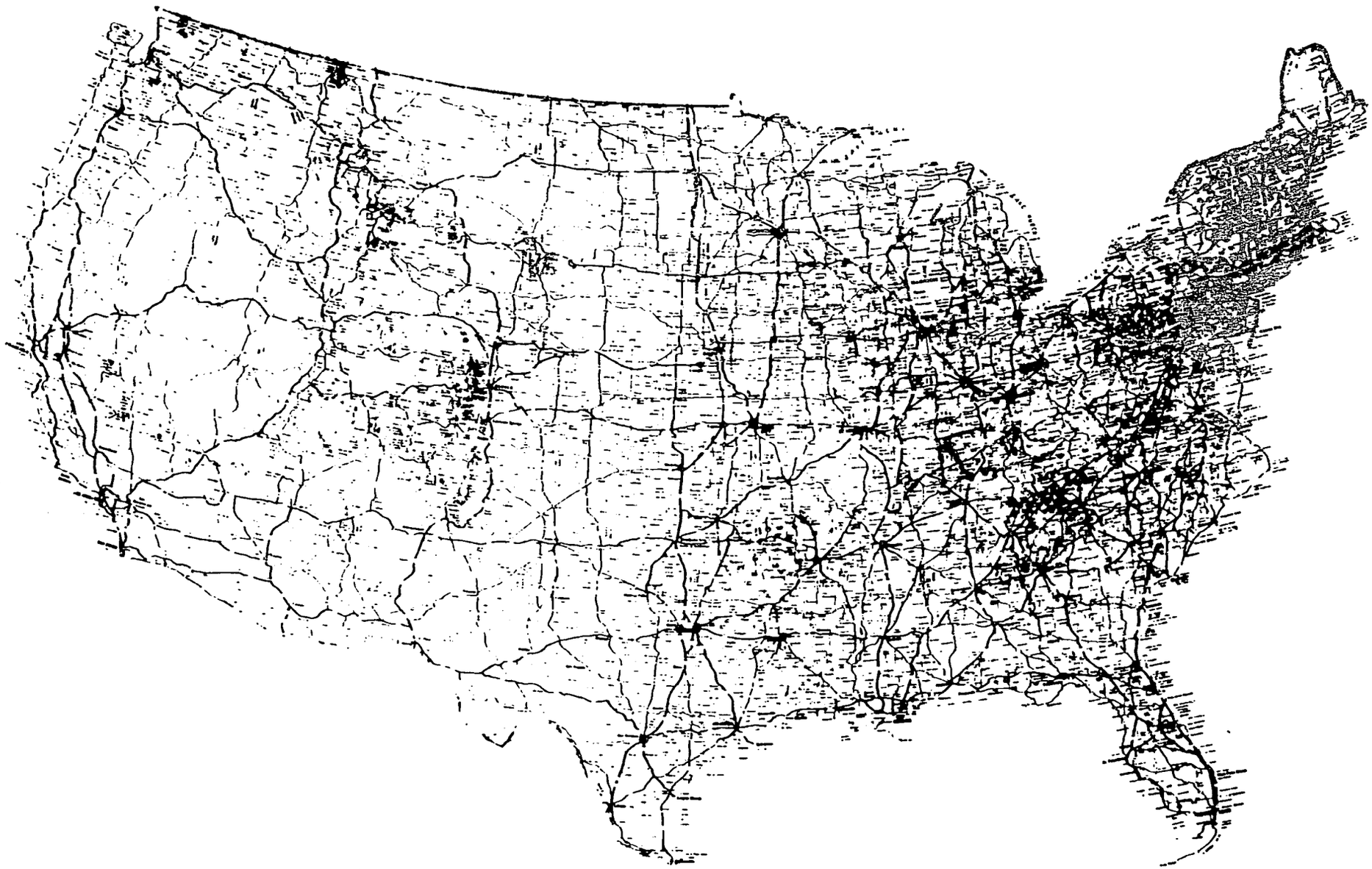


FIGURE 1. Hiway map of United States.

is influenced by the complexity of the model. On the other hand, the model must contain enough information to satisfy the needs of the users. The freeway map must show all the cities and interchanges. However, it might not show all the little towns and features.

This last point is important. The model cannot be expected to provide accurate answers to the last decimal point. It will only be as good as the information used to develop it and must be judged on the basis of its applicability to the purposes for which it was designed. Because the model produces results that appear to be of high precision (lots of decimal points), there is a tendency to over-emphasize accuracy in systems models. This can be naive and can obscure the true utility of the model. A Systems model can be exercised for any given length of time. In the case demonstrated here, the model simulates a 60-year time horizon. No one would expect, say, an economic model to be accurate over that period; we know that economic predictions are among the most difficult to make. Yet, people tend to expect systems model predictions to be accurate and precise.

The map analogy above is a good example of resolution tradeoffs, but misleading with respect to accuracy. Cartographic features tend to change slowly, and with modern technology, maps are very accurate. The components of natural resource models often cannot be measured at all, or if measurable, are prohibitively expensive. Further, it is usually the case that the model will require information about some process or object that no one has even considered measuring. Consequently, the actual formulation of the model will contain a vast amount of postulated information, guesses, and hunches. Some data will be accurate and precise, others will be fuzzy with no known degree of precision or accuracy.

Further, even simple systems can be difficult to visualize. A revealing exercise demonstrated this difficulty. Four scientists were asked to predict the human population trends of the project given a mortality and recruitment scenario. Population could be affected by nutrition. Each scientist predicted a different response to the factors, and this was a simple example. Obviously, complex real-world systems are even more difficult to understand and predict.

If the models are not accurate (and they seldom are), then what good are they? If the models are complex (and they usually are), then how can we know whether the simulated behavior is due to the correct behavior of the model or results from bugs in the program? How should we use the model? We hope to provide insight to these questions as the discussion of this model unfolds.

Because bioresource systems are big and complex, no single person is likely to understand it well enough to be able to develop a good model. A good way to put a model together is in the workshop format. Here, a group of experts in the system to be modeled are assembled with a couple of modelers and a coordinator. The experts and the modelers work together to develop the system structure and insure that their needs are met. This process is often more useful than the model itself as the various specialists gain insight into the interrelations of their specialities with others.

A good example of systems methodology has been developed at MIT. This approach, called System Dynamics, is a well-defined and clear-cut approach to systems analysis. In system dynamics, the objective is to model the dynamics of a system at a level that describes the causal mechanisms that interact to produce a problem, or behavior, over time. This approach contrasts with other modeling approaches which are essentially static models, such as prediction from regression or econometric equations.

System dynamicists attempt to identify the key system processes and their dependence upon the behavior of other processes. These dependencies, expressed as causal loops, can be described by mathematical or graphical functions, and evaluated by computer. If the causal loops are correct and well-defined, the resultant model behavior will mimic observed system behavior within the limits of the model and our ability to perceive and measure the real system behavior.

2.1 Steps of System Dynamics

Practitioners of system dynamics have broken the process down into a series of steps, that if followed, help to insure that a workable model will be developed. These steps are introduced below, then restated in more detail with examples in the next section of this report.

2.1.1 Definition of Goals and Objectives

As pointed out above, the systems analysis approach involves the identification and clear specification of the goals and objects of the analysis. If those goals and objectives are not clearly specified and enumerated, then the analysis will not be sufficiently focussed to provide the answers and insights needed. These goals must include (1) a listing of the goals and objectives of the project itself; and (2) a list of the specific goals of the systems analysis.

2.1.2 Definition of the Problem Statement

Next, the Problem Statement must be formulated. The problem statement is a general expression of the problem to which the model is to address.

2.1.3 Definition of the Key Questions

Specific Key Questions must now be defined. These questions are those which are to be specifically answered by the model. If the model is decomposed into submodels, then a set of key questions must be developed for each submodel.

2.1.4 Development of Reference Modes

It is often useful to provide a set of Reference Modes. These are simply predictions of the model's results before the model has been built and run. They usually take the form of simple plots showing the expected behavior of important variables over a prescribed time period. This exercise helps to

focus our thinking on the problem and to demonstrate the mental model that we had in mind at the time. It is often interesting and instructive to compare the model's results with the reference modes.

2.1.5 Formulation of the Dynamic Hypothesis

This is a verbal statement that describes the project and what is expected of it, and what we expect the model to address. It is, in a sense, a verbalization of the behavior set forth in the reference modes. This is a verbal statement of feedback relationships underlying the reference modes.

2.1.6 Specification of the Model Structure

At this point, the flow diagrams are developed. It is helpful to make a list of the inputs and outputs affecting each model component. The structure should begin with an overall view and be decomposed into subsystems for more detailed development. Specifying the model structure is guided by the key questions related to the sector under consideration. This is the phase of model development where concensus on the important material, energy, and information flows in the system is reached.

2.1.7 Construction of the Computer Model

Finally, the flow models are converted to equations and coded into a computer language for solution. System dynamicists usually use a simulation language called Dynamo. The equations can take any algebraic form, but are usually very simple. Nonlinear behavior is represented as tables from which interpolation is used to provide estimates of the function value for use in the simulation. These shortcuts greatly speed model development and have the additional advantage of eliminating the necessity to derive functional forms for all behaviors, estimating their parameters, and testing the equations. The equations can be easily updated, and modified. New equations can be easily inserted into the model. Finally, the simulation results can be plotted or printed out.

After the equations are written, the model must be tested and evaluated. Depending on funds and requirements, studies of the relative sensitivity of the model to various of its components can be performed. These studies, called sensitivity analysis, identifies those sectors that are contributing most of the behavior. That information is helpful in deciding which component of the natural system is most important, and where additional study and or planning might be most beneficial.

2.1.8 Use of the Model

The model can be used to test ideas, run experiments and provide alternative scenarios. These exercises can provide valuable information to the planning team.

The steps outlined above go far toward insuring that the model will be developed to address the specific questions required of it. The System Dynamics methodology is sufficiently well defined as to ensure that a model will

be developed and not be a black hole into which unlimited time and money can be poured.

3.0 THE DEMONSTRATION PROJECT

The consulting scientists and AID personnel examined a number of potential projects for the demonstration and chose to model a portion of the Accelerated Mahaweli Project in Sri Lanka (Figure 2). This project was chosen because (1) it was an important large-scale project involving several disciplinary sectors; and (2) several environmental assessments and feasibility studies were available as data sources.

It should be noted that the model that was developed reflects information available from published sources, and do not necessarily reflect current conditions. The model we will describe is a demonstration model only. To emphasize this fact, the model will henceforth be referred to as the "Project X" model.

A miniworkshop was convened in January, 1984, to make several final decisions: (1) decide exactly which portion of Project X was to be modeled; (2) define the scope of the model with respect to the major components, a rough-cut of the problem statement, and to iron out several other details, not the least of which were questions of venue and development of a list of participants and a budget.

A team of three modelers, David van Wie, Robert Chamberlin, and Paul Faeth were assigned responsibility for the forestry-wildlife-energy sector, socio-economic sector, and agricultural sectors respectively. These three scientists were trained in systems dynamics at Dartmouth College. Additional expertise in the agricultural sector was provided by Dr. Laren Robison of Brigham Young University, the developer of a small-scale agricultural system for LDC applications, and Dr. Ronald Stinner of North Carolina State University, a specialist in agricultural pest modeling. Dr. Donald Hertzmark of the Asian Institute of Technology was called in to provide expertise in economics and energy modeling, and Dr. Stephen Berwick of the International Institute for Environment and Development provided special assistance with the wildlife and forestry sectors. Special expertise was provided by Dr. Michael Sobczek of TAMS, who was the project director of the Mahaweli Environmental Assessment and who spent a great deal of time in the region. The workshop was directed by Dr. Kenneth L. Reed of HDR Systems.

AID personnel were asked to take part in the workshop. AID participation was crucial for setting the direction of the workshop, helping to specify and identify the workshop and model directives and to assist in building the model itself. They also identified those Agency activities which could most profit from the systems analysis process.

Computer services and other valuable assistance was rendered by Richard Collins of USAID, who arranged for the use of AID training facilities and the AID IBM 370 computer system.

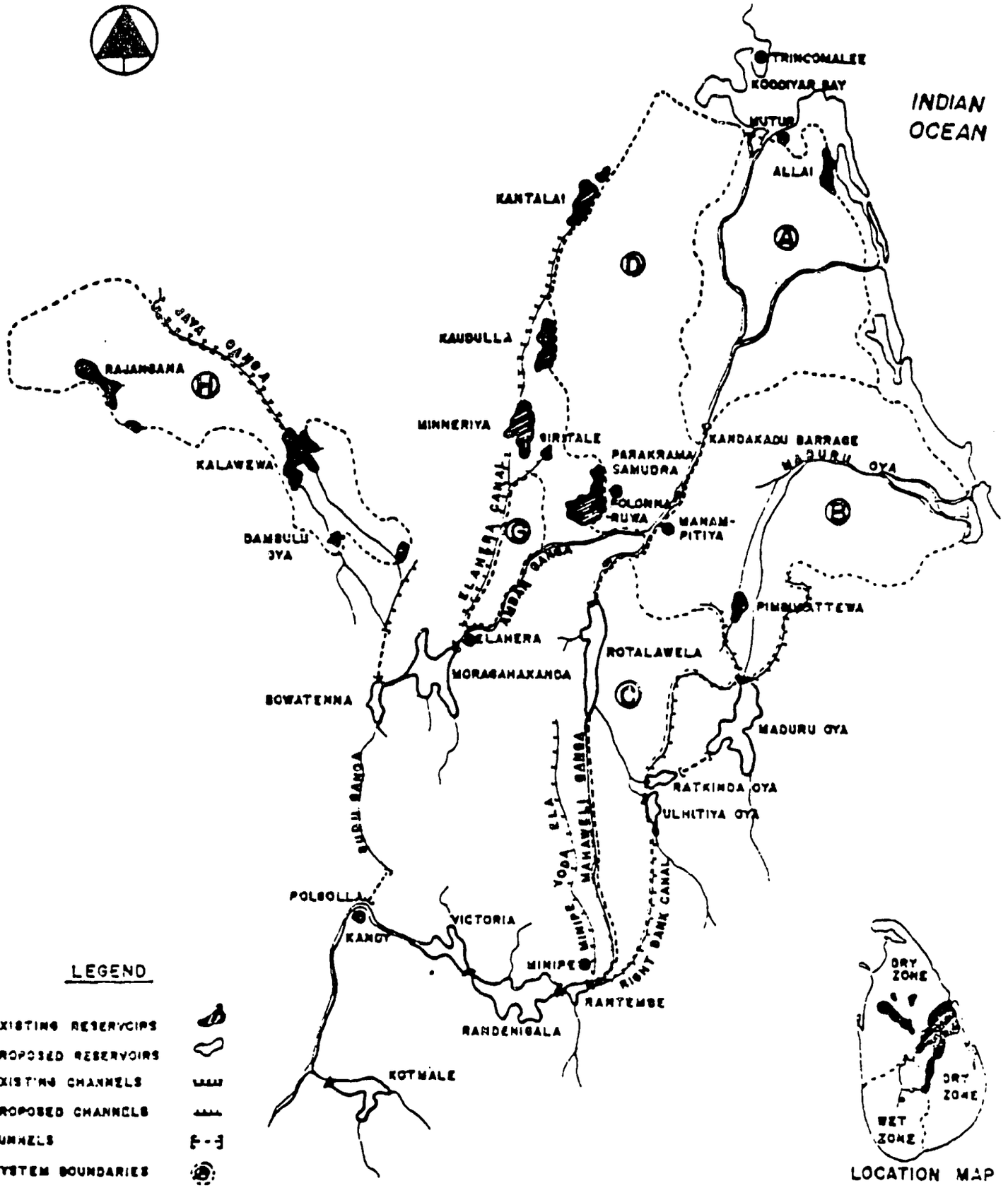


FIGURE 2. Map of Sri Lanka, showing location of project area.

3.1 Goals and Objectives

The first day's session consisted of defining the goals and objectives of the workshop, the model and the modeling context. This involved considerable discussion, included some tutorial material on the systems dynamic method, and separating into working groups. In the group discussions, it was resolved that the workshop goals were to:

(1) Develop a bioresource systems concept of a project

(2) Teach systems thinking

(3) Develop a tool for defining and testing project design and assumptions

(4) Develop a methodology to aid in both the design and evaluation of proposed developments with regard to their effect on individual and joint behaviors of multiple resource systems:

   (a) Assess the productivity of multiple resource systems;

   (b) Evaluate the effect of proposed developments on the sustainability of multiple resource productivity; and

   (c) Develop alternative intervention strategies and illustrate how such strategies affect the system.

(5) Define the boundary determination process and its implications.

(6) Demonstrate the modeling process.

(7) Determine the modeling resource requirements.

(8) Define the policy implications of sustainable as opposed to non-sustainable systems.

While it may seem that this step is of dubious value, it was vital in defining the context of the workshop, defining the workshop goals and objectives and to get each of the participants working on the same wavelength. Even then, it was difficult to reach unanimity and full understanding of the workshop goals. This initial discussion and formulation stage requires patience and the faith that the more substantive parts (e.g. model building) will soon follow. It is mainly in hindsight that the importance of these early steps can be appreciated.

Next was the task of defining the context of the model. This was in the form of a series of questions:

"Developing countries are dependent upon indigenous renewable energy resources. What are the long-term implications of development projects that affect their renewable resource base? Can systems analysis be of assistance in helping to understand the interactions of a multiple resource system, and can that additional insight be useful in planning for

optimal productivity and sustainability of the system? By describing sectoral resource interactions in a specific LDC project context, can a well-constructed systems model be useful as an analytic approach to natural resource planning and management? Can the model be used directly as a project design and evaluation tool? Can a transportable methodology be developed using the workshop format and the systems dynamics approach for use on-site in LDCs for project design and evaluation and for training AID personnel and host-country counterparts?"

This statement sets the context of the workshop and the model and defines a set of criteria by which the effort can be evaluated. Next, it was necessary to discover and enumerate the goals of Project X. This discussion was led by AID personnel with direct experience in the project. The list of Project X goals was determined to include:

(1) Construction of dams and canals to bring 117,000 hectares of undeveloped land under irrigated cultivation;

(2) Resettlement of 500,000 people from populated areas to small farms (of about 1.5 hectares per family) in the area;

(3) Double the national electric generating capacity;

(4) Increase food production by 550,000 tonnes annually;

(5) Store enough water to irrigate an additional 121,000 hectares; and

(6) Create employment opportunities through construction work, farming activities, and off-farm employment.

Sub-goals were defined by the participants:

(1) Maintenance of natural systems;

(2) Reforestation/Forest management;

(3) Provision of adequate fuelwood and building materials; and

(4) Management of wildlife resources.

This enumeration of both the workshop modeling goals and the project goals insofar as they are understood by the participants helps to frame the development of the model. As in the road map analogy, the goals to which the model is to be addressed is a key step in model development. It is a common fault of model building efforts that this step is often neglected. It can be tedious and difficult, but modeling without clear specification of goals will result in a model with incorrect or insufficient focus. Since we have already demonstrated that a model cannot do everything, it is vital that the model at least be able to do something. These goals help define that something.

3.2 Problem Statement and Key Questions

Now the workshop was ready to begin defining specific goals and objectives for the model and its sectors. First, the general problem statement was proposed: Is Project X sustainable?

This general statement is not unambiguous, but generally, the question is whether Project X will be sustainable over the long term or will the people find themselves worse off and leave? The focus of the model becomes more specific as we define the key questions. The workshop produced the following key questions:

(1) Will Project X meet its intended objectives?

(2) Will crop production targets be met and sustained?

(3) Will net income targets be met and sustained?

(4) Will resettlement and employment targets be met and sustained?

(5) Will viable populations of indigenous species be maintained?

(6) For how long will Project X meet its intended objectives?

At this point, the participants are ready to adjourn to disciplinary sections to identify specific key questions they were to address. They returned with the following:

Agriculture Key Questions:

(1) Will rice (crop) production targets be met and sustained?

(2) Will total rice (crop) production achieve both nutritional and economic self-sufficiency for the nation as a whole?

(3) Will total rice (crop) production achieve both nutritional and economic self-sufficiency for the farmer family?

(4) What are the trade-offs to total rice production as opposed to alternative crops?

Socio-Economic Key Questions:

(1) Does sufficient infrastructure currently exist for the first group of migrants?

(2) Will population growth exceed carrying capacity with respect to infrastructure and natural resources?

(3) Will a change in the economic well-being of migrants compensate for that of the indigenous population?

(4) Will the project deliver on income per capita goals?

(5) How will the new population be assimilated/accommodated with regard to both land tenure and industry?

Natural Resources Key Questions:

(1) Is there sufficient energy for the population over time?

(2) How are agricultural goals going to interact with natural resources?

(3) Will the project lead to local extinction of valued species?

(4) Are the management capabilities adequate for sustaining natural resources?

(5) Will water quality degrade to a level which will compromise other resource values?

These key questions have specifically defined the set of problems that the model must address. They are sufficiently specific as to guide the development of the model. During model construction, constant reference to the key questions is a good idea in order to be sure that the questions will be addressed and that the model retains its focus.

3.3 Reference Modes

After the key questions were defined, the group was asked to predict what they expected to see happen with respect to the key questions. These graphic predictions serve to illustrate the mental models of the participants and to provide a check on the model's performance. A few examples of reference modes generated by the workshop group are presented in Figure 3.

3.4 Dynamic Hypothesis

After the generation of a set of reference modes, the group discussed what they believed to be the set of factors that would interact to produce the reference modes. This verbal statement is termed the dynamic hypothesis. This is like the context statement; a prose statement of the project and potential behaviors:

"A large reservoir has been constructed to provide irrigation for rice cultivation in an area that had previously been used for subsistence agriculture. One half million rural people will be resettled on small farms in the development area. The planners expect that they will be able to support themselves and export rice to meet the country's food needs or generate foreign exchange. With one off-farm family supported by one farm family, and with no provision made for the second generation, the potential exists for an unplanned high population that could exceed the carrying capacity of the land. The planners assumed that second genera-

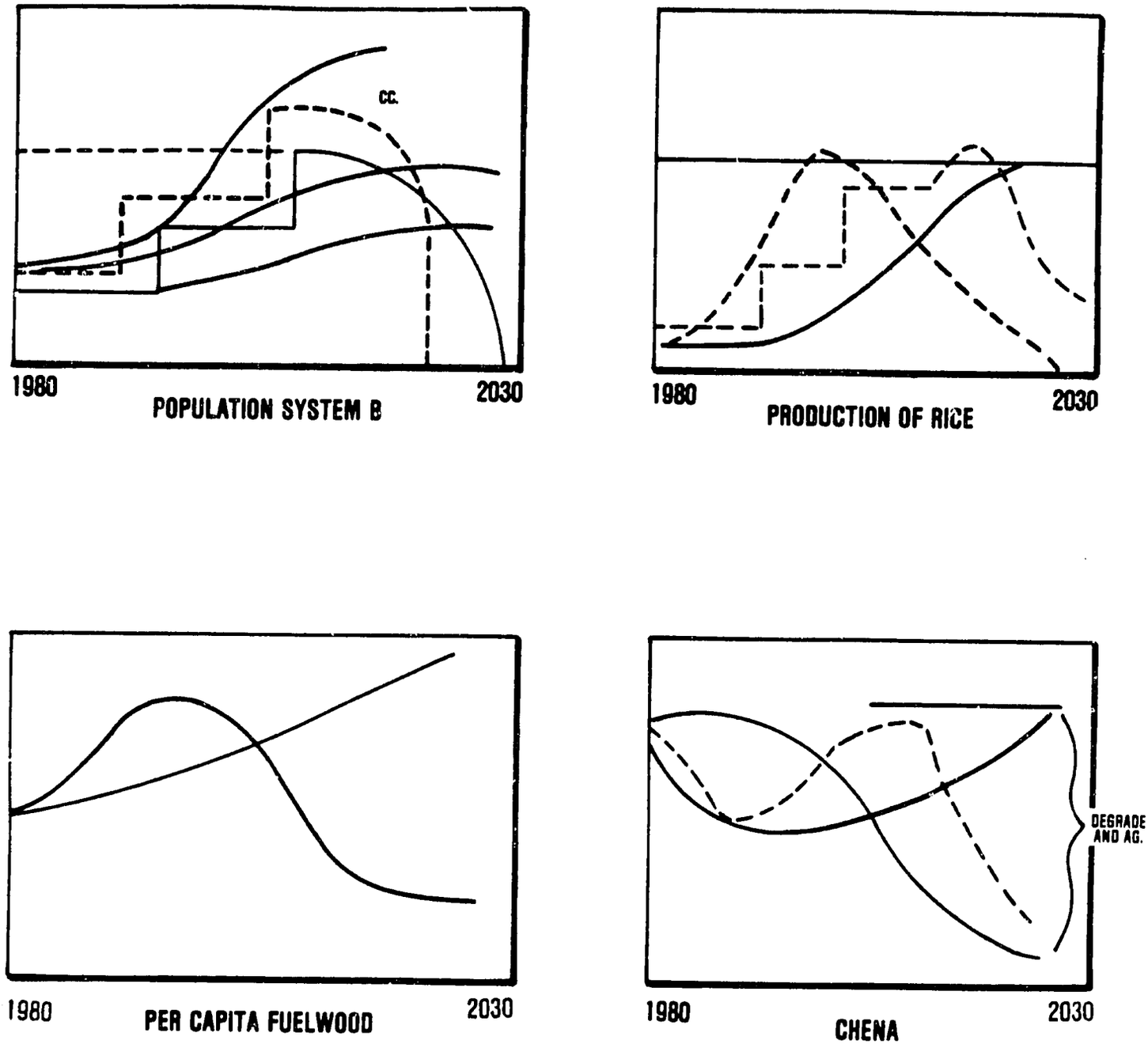


FIGURE 3. Examples of reference modes suggested by workshop participants prior to model construction.

tion support will be provided by new off-farm employment opportunities, but overpopulation could result in increased pressure to expand agricultural areas into adjacent forests. This would reduce wildlife habitat and available fuel and pulp-wood resources. Externally, some indications suggest that the world market for rice will decline, causing reduced profitability in rice production, hence a reduction in supply. Erosion of rice paddies coupled with elimination of fuelwood sources will result in a lower quality of life for the residents. These possibilities singly or in concert would trigger substantial out-migration from the project, thereby defeating the objectives of the planners and indicating that the project was indeed not sustainable."

3.5 The Model

At this point, the modeling objectives and a set of questions to which the model is to be directed have been well defined. Now the model can be built. The system boundaries were defined, corresponding to the physical and administrative boundaries of the project. The project is bounded by a large river and natural watershed limits. Boundary definition is important because it determines which behavior must be modeled explicitly or what is passed into the model as external variables. Boundary constraints focus the modeling to things immediately within control. For example, foreign exchange has to be exogenous to our model because while it may influence some of the model behavior, the project that we are modeling has an unknown impact on foreign exchange. We would have to expand the boundaries of our model to include the dynamics of foreign exchange. In another sense, the boundary determination also greatly affects the resolution of the model. The larger the system (as in the hiway map of Figure 1), the less fine detail can be included. For this model, the system boundary corresponded to the natural watershed boundary, a natural and easy boundary determination.

Because the dams are upstream from the system, we did not model the dams, the heights of the reservoirs, their electricity production, etc. These values are input as exogenous variables when needed. Likewise, since this project is a transmigration project, population influx into the model is exogenous; we did not model the conditions in the neighboring cities that led to the population flux into the system area. Features and behavior within the system boundaries must be modeled as they respond to external variables as well as the internal behavior of the system.

The model was designed as a six-sector model (Figure 4). The participants were divided into small working groups. A working group was assigned to each sector of the model, and participants were assigned according to their interests and expertise. With the aid of the modeler, each group developed the structure characteristic of their sector. They defined the variables and interactions and determined what information they needed from the other sectors. This information is what ties the model together.

There were no constraints on the discussion except that the developing models must be responsive to the goal, objectives and key questions defined above. The final model consisted of many more components than can be discussed here. Full model documentation is presented in Appendix A.

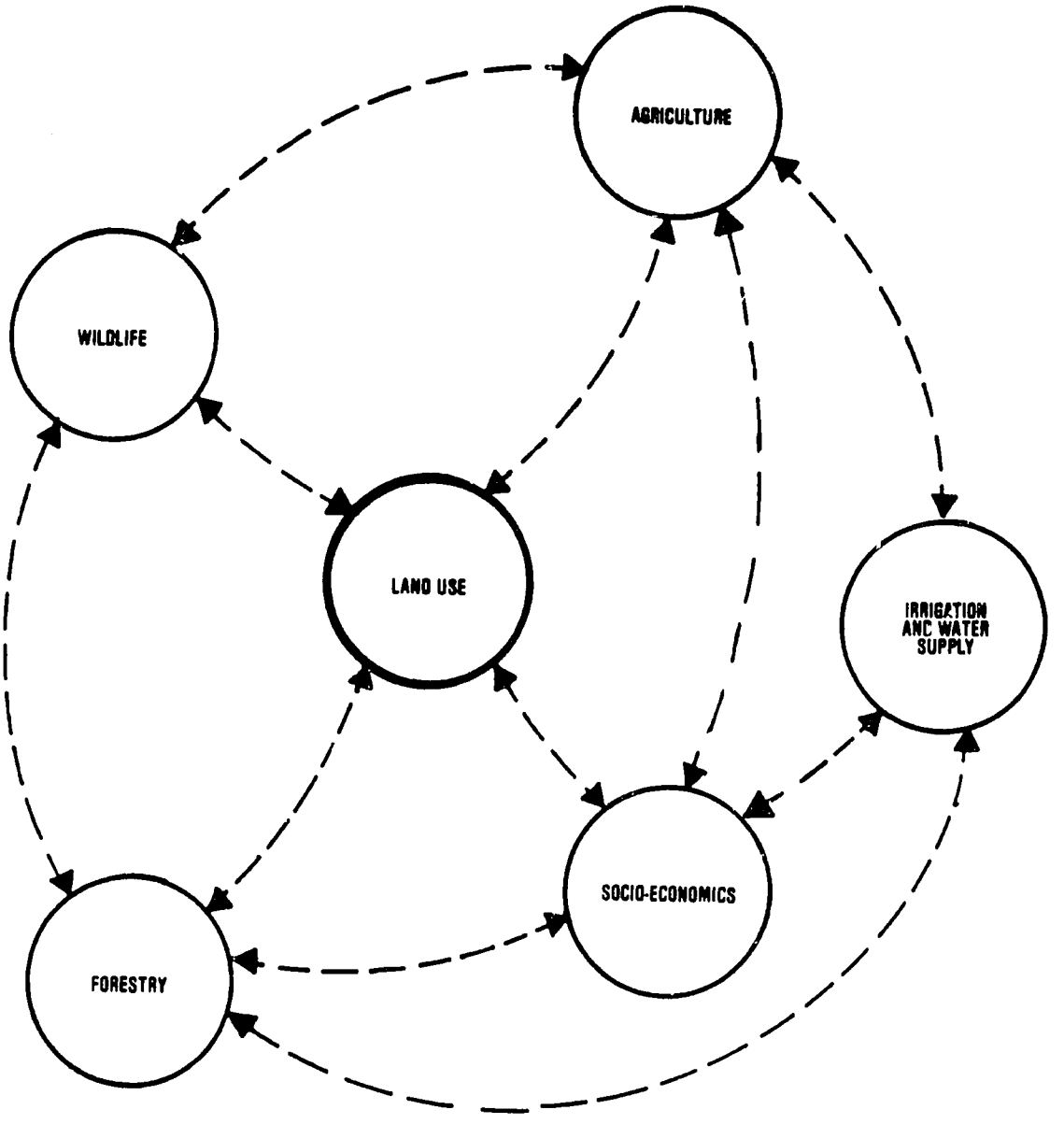


FIGURE 4. Holistic overview of the model, showing the main subsystems and their linkages.

3.5.1 Flow Diagrams

Each group drew up a series of flow diagrams representing the dynamics of their sectors. There are far too many of these to discuss in this report; refer to Appendix A for all the flow diagrams. A sample flow diagram is given in Figure 5.

Each sector consists of a number of variable types. These variable types are categorized as Levels, Rates, Auxilliary Variables, Flows and Constants. In the diagrams, each of these are represented by a specific type of symbol. Levels (represented by boxes or rectangles) are the state variables of the model. Levels represent quantities that can be measured at a single point in time. Population, forest volume, number of elephants are all examples of levels.

A rate is a variable that modulates the flow of information or material from one level to another. Rates are symbolized by valves on the flow arrows. Just as the amount of water in a bucket is a level, the amount of water per unit time that escapes from the hole in the bottom is a rate. The water level in the bucket at any time depends on the size of the hole (the rate of water loss). Since the rate also depends upon the amount of water in the bucket (the head), this influence would be represented by a dashed arrow from the level to the rate. Thus, there are two kinds of flows: material or energy flows and information flows. Flows are always represented by arrows: solid for material or energy flows, dashed for information flows.

Auxiliary variables influence rates and can be in turn influenced by levels or other auxiliary variables. Auxiliary variables are represented by circles and are always connected by information flows from levels (or other auxiliary variables) to rates.

It is important to pause here to interject an important modeling convention: Levels determine Rates and Rates feed back to determine Levels. The level of water in the bucket is determined by the rate that is poured in and the rate at which it leaks out. The level of water in the puddle under the bucket depends on the rate that leaks out of the bucket and the rate of evaporation and soaking into the ground. The amount of water in the bucket does not directly determine the size of the puddle. Because auxiliary variables are functions of levels, they can legitimately be used to determine rates.

Two more symbols are used: the "cloud" and the constant. The cloud represents a source (if the flow comes from the cloud) or a sink (if the flow enters a cloud). A cloud is used to represent transfer beyond the system boundaries or into another sector. Constants are represented by a small circle bisected by a line. These are values which do not change over the time frame of the simulation.

These concepts are illustrated in Figure 5. There is one level: Non-Farm Money Balance. The units of this level is Rupees. There are two rates affecting the level, each of which is affected by several auxiliary variables. Two constants can be used to modify the rates. These constants can be changed by the user before each run. This allows testing of policy variables and other experiments with the model.

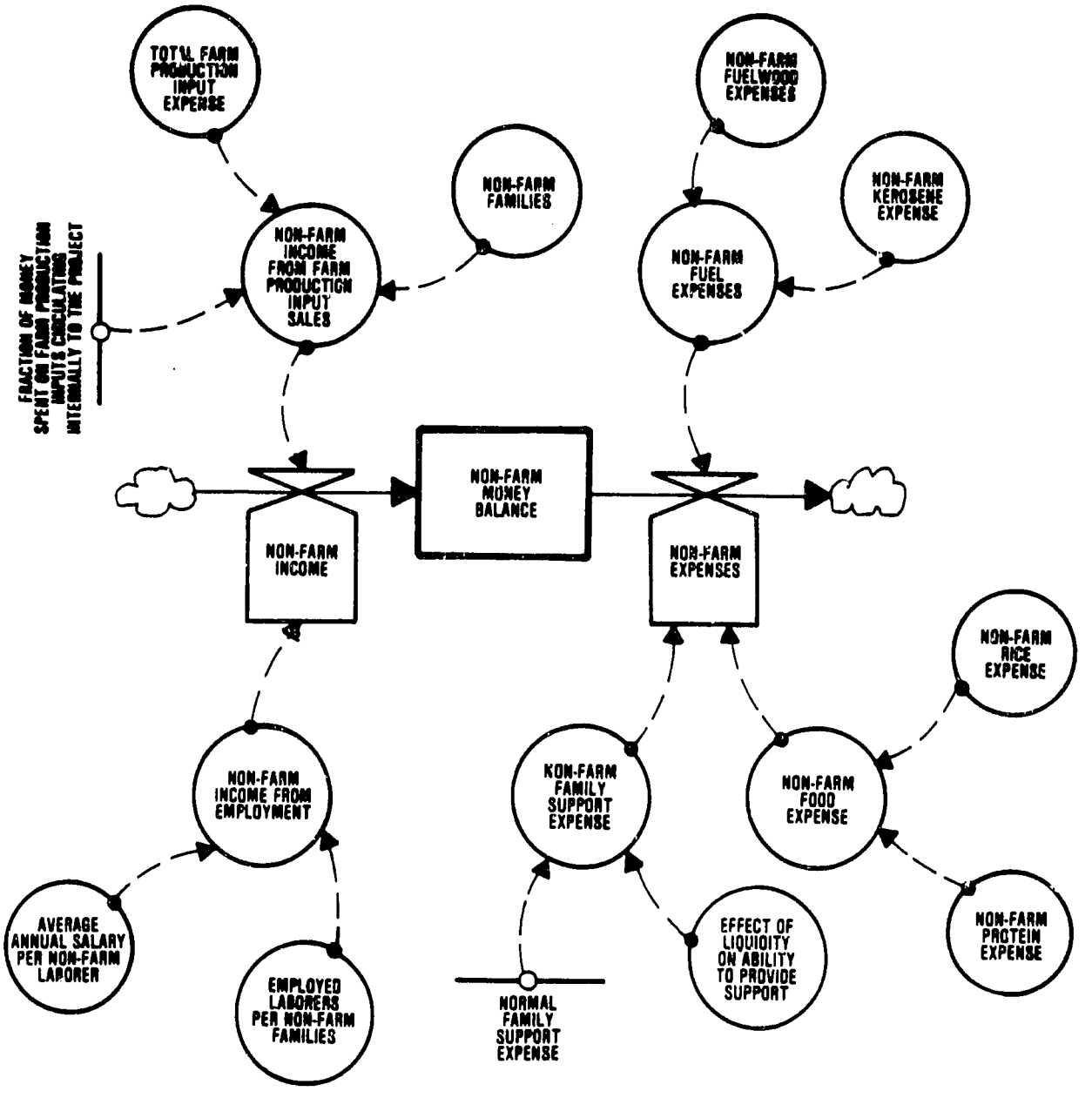


FIGURE 5. Sample flow diagram of a portion of the model (this is an earlier version of the formulation).

It is at this stage that even those participants most intimately familiar with the system have new insights and are provoked into asking questions that they possibly would have overlooked. This is probably this single greatest justification of the modeling exercise: it expands the horizons of the participants and makes them more sensitive to the complexity of the real-world object system with which they deal. Further, the exercise often identifies critical experiments and field tests. Since field tests are much more expensive than model building, a method of identifying the most important research targets is highly cost-effective.

3.5.2 Major Components of the Model

The quantities that were deemed important by the groups are, by sector:

AGRICULTURE

- Production:
  - Current Rice Yield, Tonnes per Hectare per Year
  - Draft Livestock, Head
- Nutrition:
  - Protein Consumption per Person, Kg per Person per Year
  - Calorie Consumption per Person, Megacalories per Person per Year
- Water Supply:
  - Volume of Maduru Oya Reservoir, Cubic Meters
- Subsistence Agriculture:
  - Chena, Hectares
- Grain Storage:
  - Government and Family Rice/Grain Inventory, Tonnes
- Land Allocation:
  - Cash Crop, Hectares per Family
  - Rice Paddy, Hectares per Family
  - Subsistence Agriculture, Hectares per Family
- Economics:
  - Market Price of Rice, Rs per Tonne

SOCIO-ECONOMICS

- Population:
  - Farm Population, People
  - Non-Farm Population, People
- Economics:
  - Farm Money Balance, Rs
  - Non-Farm Money Balance, Rs
  - Debt, Rs
  - Employment Opportunity, Number of Jobs
  - Capital Services, Dimensionless Units
- Infrastructure:
  - Public/Private Infrastructure, Dimensionless Units
- Legitimacy and Acceptability:
  - Participation/Equity, 0 - 1 Index

NATURAL RESOURCES

Wood:
- Area in Native Forest, Hectares
- Volume in Native Forest, Cubic Meters
- Area in Fuelwood Plantation, Hectares
- Volume in Fuelwood Plantation, Cubic Meters

Forage:
- Livestock Carrying Capacity, Animal Unit Years

Energy:
- Non-Farm Fuelwood, (Cubic Meters per Year) and Kerosene Purchase, Liters per Year
- Farm Fuelwood Use, Cubic Meters per Year
- Agro-fuel Use, Cubic Meter Equivalents per Year

Wildlife:
- Elephant Population, Head
- Langur Population, Head
- Leopard Population, Head
- Axis Deer Population, Head
- Resource Management Expertise, 0 - 1 Index

LAND USE

- Hectares of Paddy
- Hectares of Settlement
- Hectares of Native Forest
- Hectares of Chena
- Hectares of Park Land
- Hectares of Native Forest Chena
- Hectares of Degraded Land

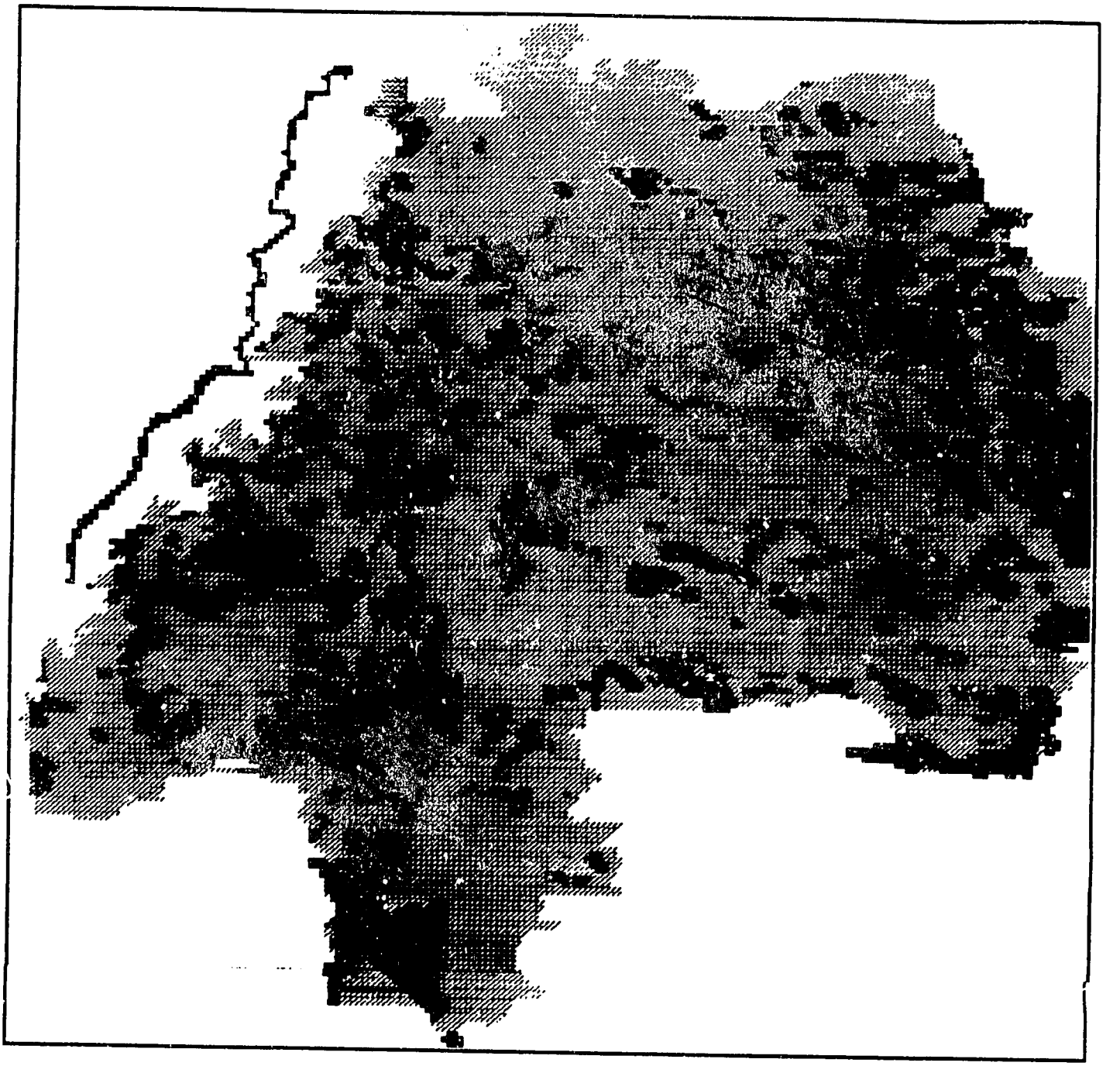
A map analysis of land use of the project area at project start-up and after 60 years is shown in Figure 6-7.

3.5.3 Model Linkages

Prior to encoding the flow charts, workshop participants, by examining and summarizing the sector flow diagrams, determined the most likely variables with intersectoral linkages. The initial model linkages are listed below. For example, nutritional output from the agricultural model would serve as input to the socio-economic model. Additional linkages emerge during the programming and testing stages. The units of some of the linkages are given with the variable name.

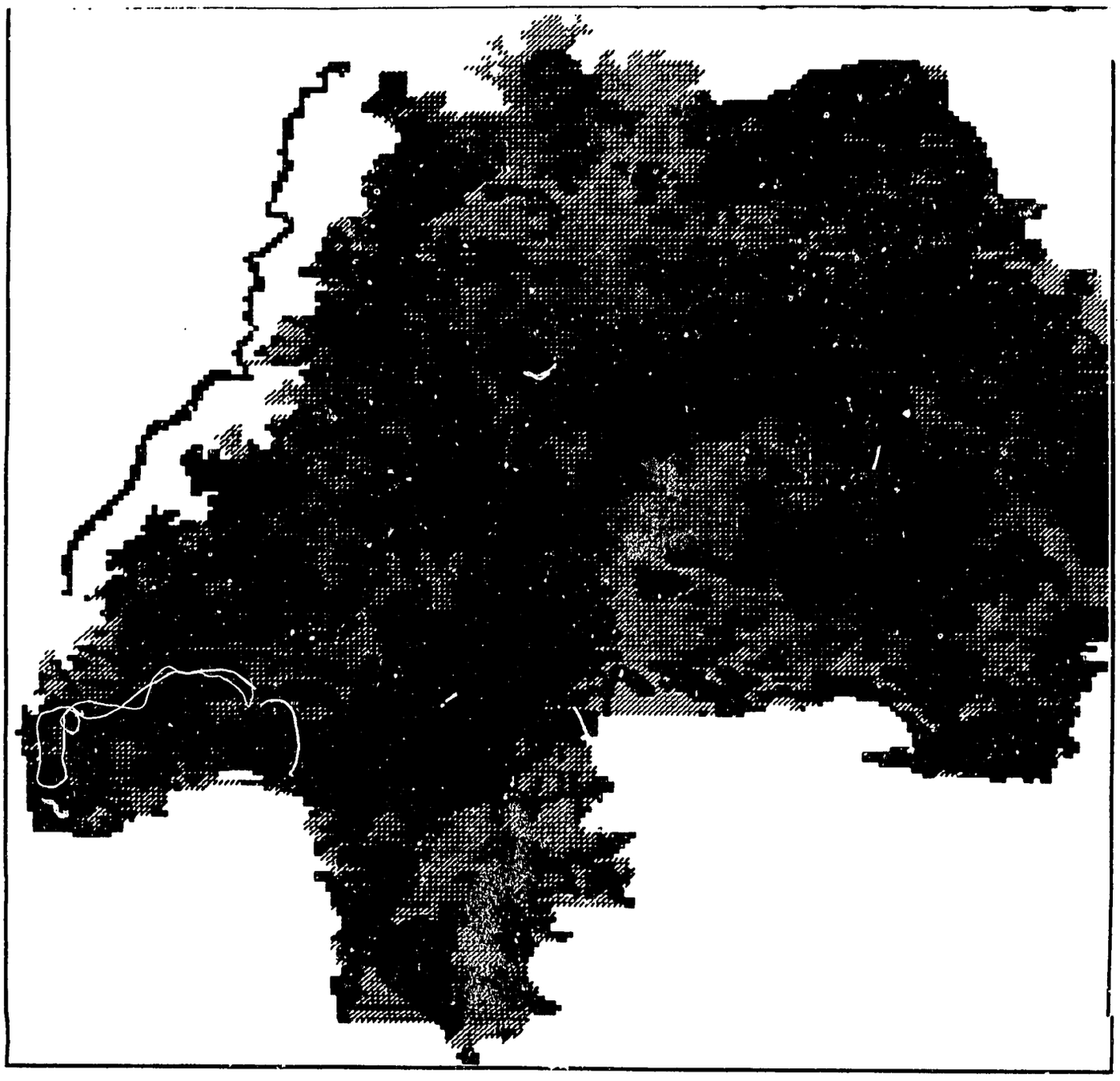
Socio-Economics -- Agriculture

- Farm Liquidity, Rs available/required Rs
- Farmer Knowledge, 0.0 to 1.0 Index
- Farm Population
- Non-Farm Population
- Average Family Size, Persons per Family



LAND USE MAP OF PROJECT X

- PADDY LANDS, 16868.7 Hectares
- TANKS AND WATERCOURSES, 5711.3 Hectares
- ROCK OUTCROPPINGS, 5310.8 Hectares
- DENSE FOREST, 1837.5 Hectares
- MEDIUM FOREST AND CHENA, 9336.8 Hectares
- SETTLEMENTS, 3706.3 Hectares
- GOVT. FARMS, 1410.7 Hectares
- FOREST PLANTATIONS, 4790.8 Hectares
- PARKLAND, 13212.5 Hectares



LAND-USE MAP OF PROJECT X IN 2030

- PADDY LANDS, 66050.0 Hectares
- TANKS AND WATERCOURSES, 5701.3 Hectares
- ROCK OUTCROPPINGS, 5918.0 Hectares
- DENSE FOREST, 607.5 Hectares
- MEDIUM FOREST AND CHENA, 40975.0 Hectares
- SETTLEMENTS, [illegible]
- [illegible]
- FOREST PLANTATION, [illegible]
- [illegible]

Agriculture -- Socio-Economics

Family Nutrition/Consumption
Caloric Intake
Protein Intake
Crop Allocation per Hectare
Tons of Cash Crop per Family
All Farm Inputs: Fertilizers, Pesticides, Seed, etc.

Socio-Economics -- Natural Resources

Farm Population
Participation/Equity, 0 to 1 (acceptance)
Farm Liquidity
Extension, Number of Agents per Farm Family
(optimum assumed to be 1:2000)
Family Size
Demand for Land: Clearance, Agriculture, etc. Hectares per Year

Natural Resources -- Socio-Economics

Fuel Stocks, Cubic Meter Equivalent
Employment Demand, Total Pool per Jobs Available

Agriculture -- Natural Resources

Land Use Transfer, Hectares per Year
Livestock, Head

Natural Resources -- Agriculture

Conversion, Hectares

This list of variables is formidable and the model was in fact larger and more complex than the modelers had bargained for. This was partly a result of the desire of the workshop participants to ensure that the model really contained the factors that they felt were important. It was a constant battle to constrain the model enough to be manageable and an important trade-off was discovered: technical manageability vs. client satisfaction. While it has been stated that the model should be as simple as possible, oversimplification results in client dissatisfaction and accusations of unreality.

One determinant of model size is the ability to explain model behavior on the basis of the structure. It can be difficult to discern whether unexpected behavior is the result of bugs in the program or from faulty model structure. This problem is enhanced in large models. A feel for this compromise can come only from experience; naive participants want as much structure as possible. These concepts were the focus of many discussions throughout the workshop.

In the end, the resultant model was a compromise and all participants (the modelers included) felt that they benefited greatly from the exchanges. However, the large model could not be fully implemented on schedule. Preliminary

runs were made during the workshop, but the debugging, refining and reformulation of components continued through June, 1984. A model is never finished, but the June 1984 version is presented here.

The model was coded in Dynamo on the AID computer system, then transferred to the Dartmouth system for further work. Once the model was developed, the scenarios suggested by the key questions can be run. A few scenarios are discussed below.

USING THE MODEL TO SIMULATE POLICY INTERVENTIONS: A FEW SELECTED SCENARIOS

4.0 SIMULATING A DEVELOPMENT PROJECT

In its current stage of development, the systems model contains over 800 variables. Of these, about 50 are level, or state variables. A model of this complexity is capable of generating a rich repertoire of behaviors. This section will focus on a set of model-generated time series plots that suggest both the detail and the comprehensiveness of the model.

The first series of plots show model results for land use, farm family fuel use, and rice yield compared across four scenarios. The four scenarios are:

1. No Project -- this scenario allows us to pose the question: What would happen in the project area, over the time frame of interest, if no project were to occur? This is a "business as usual" scenario. It is labeled "No Project".

2. Project Scenario "A" -- this scenario simulates the project at an inmigration rate of 34,560 families over the 5-year time interval, 1983-1988. Land transfers from native forest and slash and burn lands to paddy and settlement areas also occur within this time frame. The simulation is run without any special policy interventions beyond those currently planned.

3. No Forest Management -- this scenario simulates the same population and land transfer dynamics of the previous case without the benefit of forest or natural resource management. In essence, this allows us to ask: What would happen in the project area, over the time frame of interest, if the forest sector were overlooked by the planners? This scenario examines the possible consequences of not considering other resource sectors when planning such a large project. It reflects in fact, the omission of forestry in Mahaweli planning until nearly 1980 (Sobeczak, personal comm.) as well as the continued simulated omission through the life of project.

4. Complete Forest Management -- this scenario simulates the Scenario "A" population and land transfer plans with a major policy intervention into the forestry sector. These policies include: a

reforestation program that establishes fuelwood plantations on degraded land every five years; a vigorous recruitment of natural resource managers, and an explicit policy to keep these managers working in the project area; and, a national park policy that aims to protect and manage 75% of the native forest that remains after the planned conversions from native forest. It reflects an attempt to link forestry to other sectors such as agriculture in an interdisciplinary way.

The second set of plots unfolds the story of the relative fate of the farm and non-farm populations in the project area. There are five plots in all: farm and non-farm population numbers, life expectancies, births per thousand population, average family sizes, and percent of family fuel needs left unsatisfied for each population type. As simulated, the model indicates that the project benefits the farm sector relative to the non-farm sector.

4.1 Land Use: Paddy, Native Forest, and Degraded Land

Figures 8-11 show the model-generated plots for land use under the four scenarios described above. Each of the four plots shows the changes in paddy, native forest, and degraded land. For the sake of brevity, the other land use categories -- settlements, slash and burn lands, savannah-parkland, and forest plantations -- are not shown although they could have been included. The dynamics of these land categories do, of course, influence the use and management of the land types plotted. Appendix Figure A-6 is the flow diagram for the land use sector. The following descriptions and explorations are derived by examining the plots and then analyzing relevant flow chart(s).

4.1.1 Land Use in the No Project Scenario

Figure 8 shows the trends in paddy, degraded land, and native forest under the "No Project" scenario. Paddy changes very little over the course of the simulation. Growth in the hectarage allocated to paddy is constrained by proximity to existing irrigation tanks. Paddy does degrade somewhat, however. This is due to the heavy traffic and resultant soil compaction that occurs on the paddy plots most proximate to settlements.

Native forest lands decline gradually during the latter parts of the simulation. Forests are claimed for two reasons. First encroachers seeking land for subsistence agriculture, slash and burn the most accessible forest lands. The pressures for this type of forest intrusion begin around 1995. The 32,000 hectares of slash and burn land that exists in the project area is sufficient to supply the needs of all encroachers up to that time. When these lands become occupied, or degrade due to shortened cropping rotations, pressure on the native forest for cropland commences.

Native forest areas are also targets for fuelwood gatherers. Excessive fuelwood harvesting on the forest perimeter by both farm and non-farm families causes long-term degradation of those lands.

Degraded lands increase noticeably throughout the simulation. Degraded land comes from six sources: paddy and native forest (as discussed above);

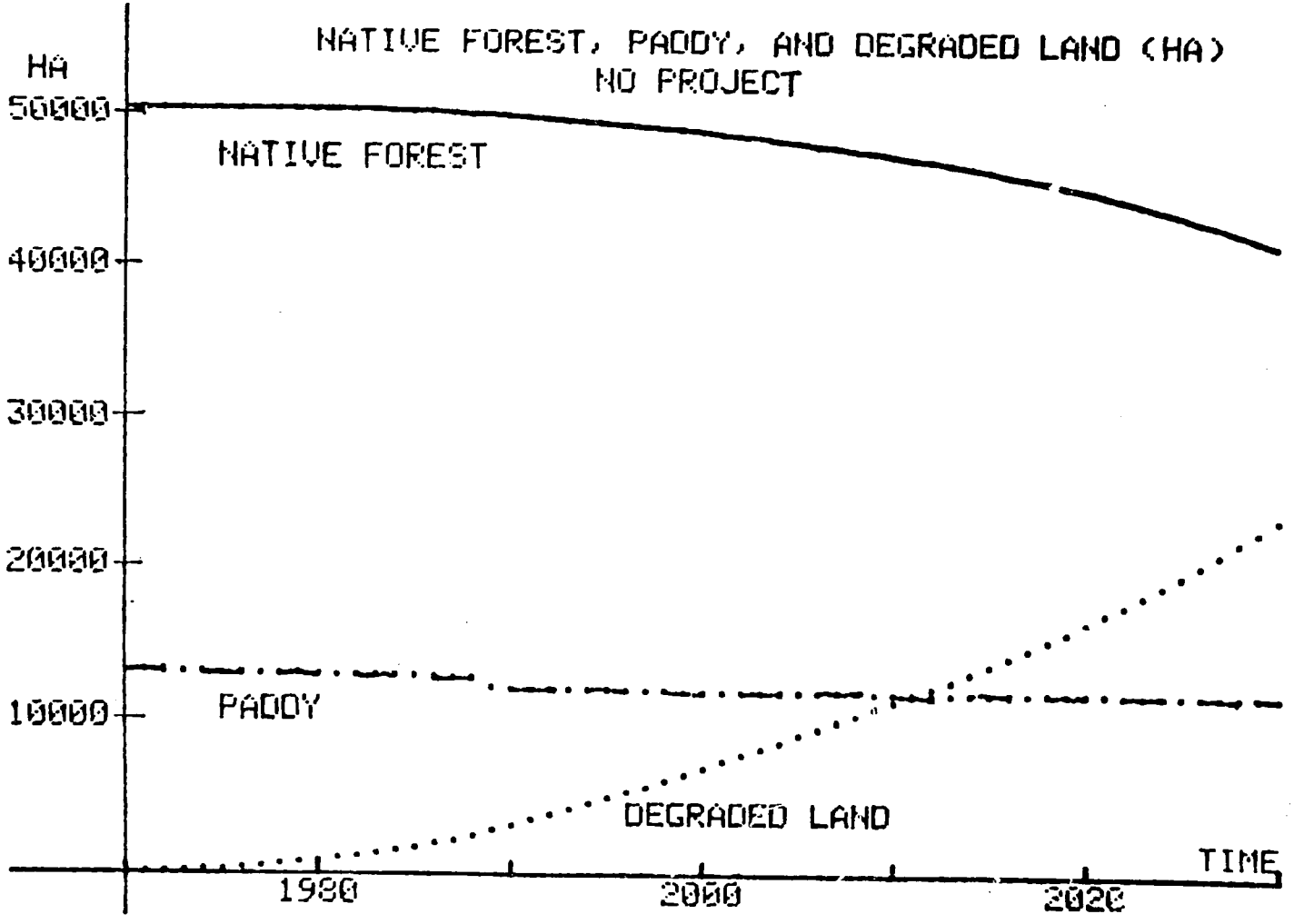

NATIVE FOREST, PADDY, AND DEGRADED LAND (HA)
NO PROJECT
HA
50000
40000
30000
20000
10000
NATIVE FOREST
PADDY
DEGRADED LAND
TIME
1980
2000
2020

Figure 8.

slash and burn lands under compressed cropping rotations; overgrazed savannah-parkland; and mismanaged fuelwood plantations. The primary contributions to degraded land have come from native forest and savannah-parkland (not plotted here).

4.1.2 Land Use in Project Scenario "A"

Figure 9 shows the trends in paddy, native forest, and degraded land under project scenario "A" -- roughly the current project as planned. Beginning with project start-up in 1980, approximately 30,000 hectares of native forest and slash and burn land is converted to paddy. Ninety percent of all planned land conversions are accomplished in the five years, 1980-1985. In 1988, five percent of the existing paddy is planted with bund shelterbelts. This accounts for the slight dip in paddy that occurs at that time. These shelterbelts, if managed properly, will provide a large share of the farm family's fuel needs. As in the previous scenario, there is some degradation of the paddy most proximate to settlements toward the latter stages of the simulation.

At project start-up, approximately 25,000 hectares of native forest are cleared and converted to paddy or settlements. As shown, the decline in forest area does not stop there, however. Nearly one-half the remaining forests are lost between 1990 and the end of the simulation. Population pressures, particularly from a growing landless, unemployed non-farm population, are claiming large amounts of forest land for slash and burn farming. In addition, widespread fuel scarcities for both farm and non-farm families are causing excessive harvesting of trees on the most accessible forest edge. Degradation of these lands result.

Degraded lands increase to around 30,000 hectares by the end of the simulation. They also show no sign of leveling off. As with the earlier example, shortened slash and burn rotations, overgrazing of the savannah-parkland and lands adjacent to the increasing village areas are contributing to this increase.

4.1.3 Land Use Under No Forest Management

If the project planners had not consulted with foresters during project design and management, the results would have been predictably dismal. Figure 10 shows a possible outcome.

The major difference relating to paddy, is that no fuelwood shelterbelts are established on paddy bunds. This translates into less fuelwood for farm families in the future and, hence, more pressure on the unmanaged and unguarded native forests to supply those needs.

Intense competition between fuelwood marketeers and poachers for the most accessible fuelwood results in accelerated degradation of nearby forest areas. By 1990, there is no orderly fuelwood market to speak of -- poaching is rampant. Extreme mismanagement of the forest plantations that did exist at project start-up (4500 ha), results in degradation of the plantations and deprives farm families of their fuel of choice. Farm families join the largely impoverished urban unemployed in marauding the remaining forest

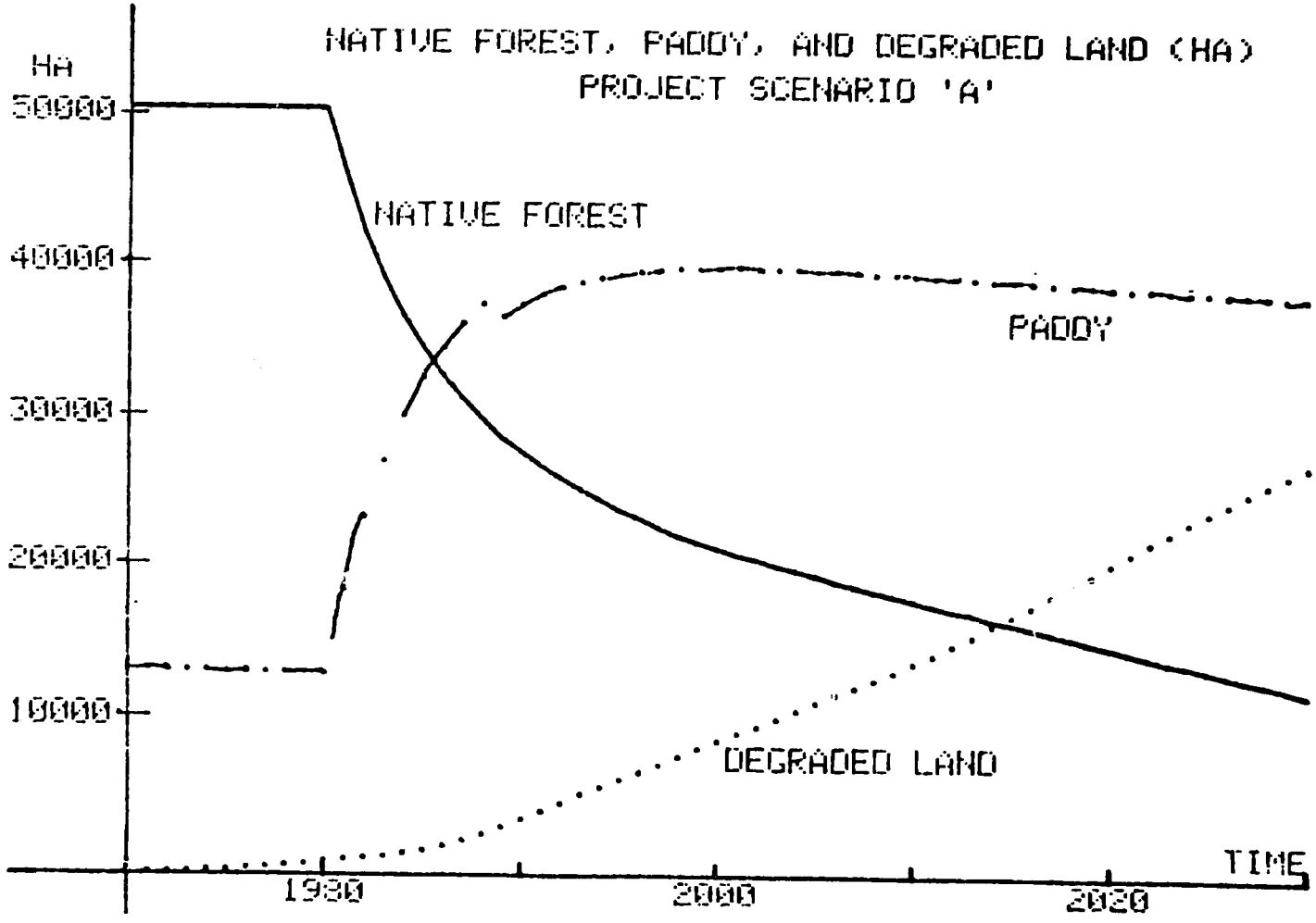

NATIVE FOREST, PADDY, AND DEGRADED LAND (HA)
PROJECT SCENARIO 'A'
HA
50000
40000
30000
20000
10000
NATIVE FOREST
PADDY
DEGRADED LAND
TIME
1980
2000
2020

Figure 9.

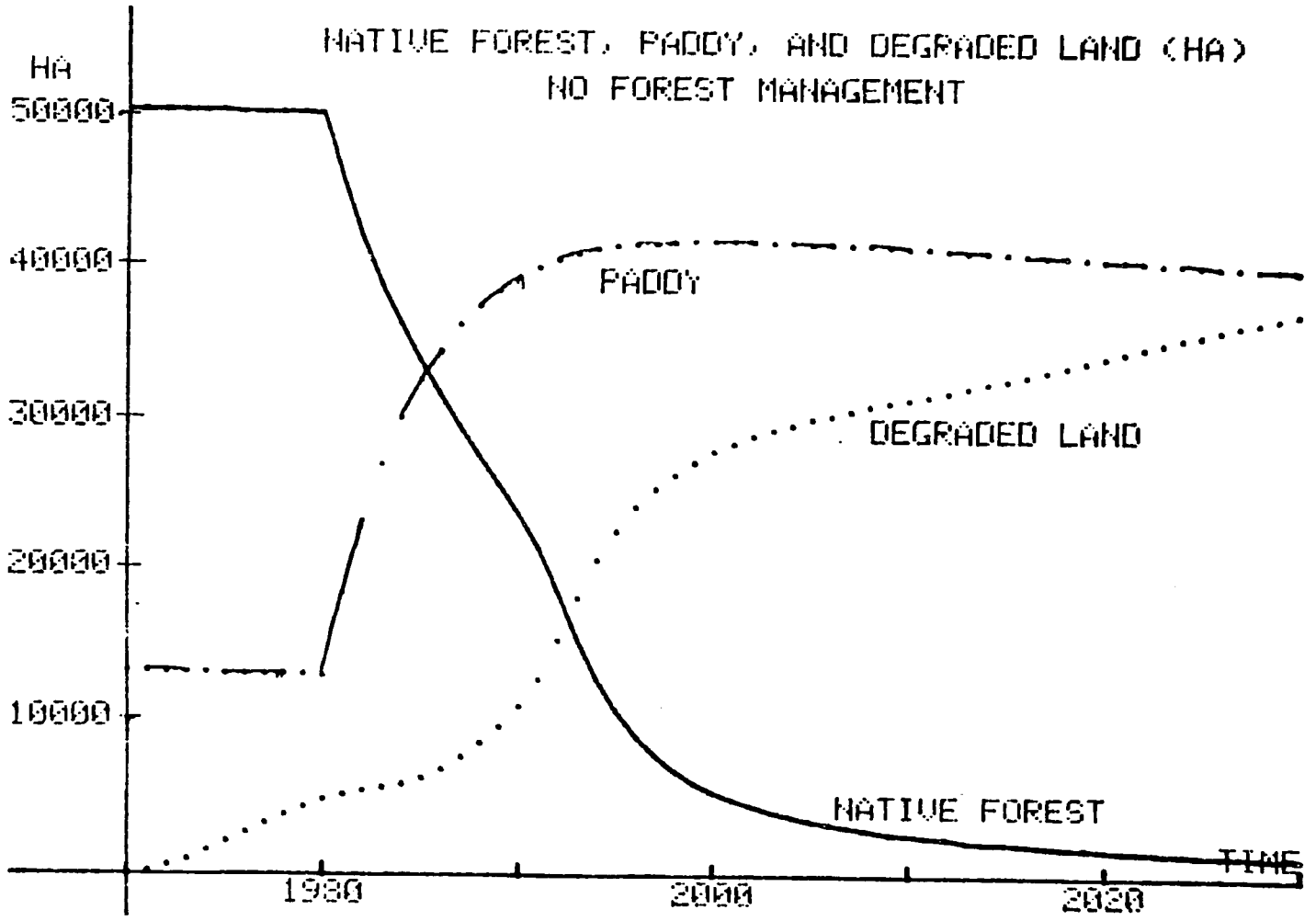

NATIVE FOREST, PADDY, AND DEGRADED LAND (HA)
NO FOREST MANAGEMENT
HA
50000
40000
30000
20000
10000
PADDY
DEGRADED LAND
NATIVE FOREST
TIME
1980
2000
2020

Figure 10.

areas. Accessible forest areas that are not cut for fuel are cleared for subsistence cultivation. Use of the forested lands for these two purposes only subsides when forests become so inaccessible as to be non-existent for project area residents.

Once again, degraded land accumulates noticeably. The most rapid increases occur from 1985-1995. This is the period during which the area experiences its greatest population growth rates. As in the previous two scenarios, overgrazing has also contributed its share in degrading the savannah-parkland and village-side "loafing" areas.

4.1.4 Land Use Under Complete Forest Management

Figure 11 shows the trends in paddy, native forests, and degraded land when a comprehensive forest management plan is administered. Under this plan, the paddy bunds are reforested in 1988. This slight dip in the amount of paddy increases forest plantation areas by 25%, to 6000 hectares.

Due to high quality management of fuelwood plantations and national parkland forest, pressures to intrude upon the forest for either slash and burn farming or fuelwood harvesting are successfully deflected. An aggressive degraded land reforestation effort provides a sustainable source of fuelwood for the farm family. Plantation harvests that exceed the fuel needs of the farm population augment the local marketable supply of fuelwood. Thus, non-farm families benefit also.

It is important to note that this policy does not avert pressures that are degrading land from other land types. The fact that degraded land continues to accumulate despite reforestation efforts suggests that overgrazing of savannah-parkland, village-sides, and overuse of existing slash and burn lands is persisting. Clearly, a consistent set of forest, rangeland, and industrial policies are required to mitigate the pressures underlying land degradation. This scenario suggests that an ongoing forestry program is one key element in limiting wholesale degradation of the land over the 60 year time frame.

4.2 Farm Family Fuel Use

Figures 12-15 show time series plots of farm family plantation fuelwood and agro-fuel use for the four scenarios. Fuel use is expressed as a percentage of total fuel requirements per family annually. Each person requires .57 cubic meters of fuelwood per year for cooking. A 5-member family, then, requires 2.85 cubic meters of fuelwood per year.

In the model, farm families consume fuel according to its availability and affordability along a preference structure. The preference structure, or hierarchy, is as follows:

1. Fuelwood harvested gratis from plantations.

2. Permitted collections from native forests.

3. Purchases of fuelwood on the market.

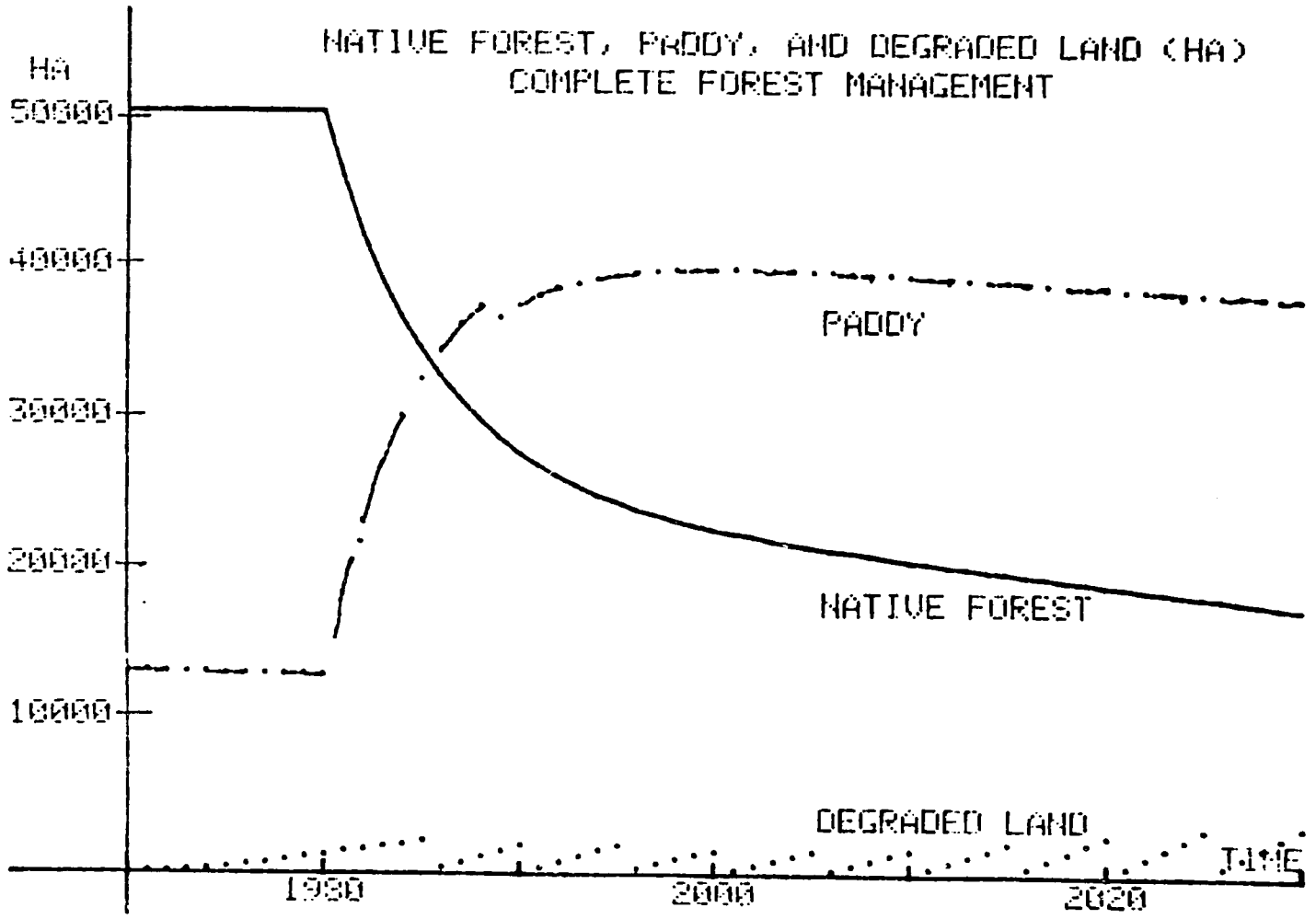

NATIVE FOREST, PADDY, AND DEGRADED LAND (HA)
COMPLETE FOREST MANAGEMENT
HA
50000
40000
30000
20000
10000
PADDY
NATIVE FOREST
DEGRADED LAND
TIME
1980
2000
2020

Figure 11.

4. Poaching of fuelwood from native forest areas.

5. Use of agro-fuels -- crop stubble and livestock dung.

6. Unsatisfied fuel needs.

The preference structure indicates that plantation fuelwood is the fuel of first choice for farm families; permitted collections is the fuel of second choice if plantation fuels are inadequate in supplying 100% of the family's fuel needs. In effect, families "get what they can" from the most preferred fuels before they move down the list to the least preferred fuels.

4.2.1 Farm Fuel Use in the No Project Scenario

Figure 12 shows the simulation of farm family fuel use under the No Project scenario. The plot indicates that the 4500 hectares of fuelwood plantation extant in 1980 are sufficient to supply all of the farm family's fuel needs for most of the simulation. Only in the latter years do plantation fuel sources become inadequate. Slight mismanagement of the plantations, coupled with an increased demand from a gradually growing farm population, create the plantation fuel shortfall. Faced with this shortfall of their most preferred fuel, farm families turn to the fuels of second, third, and fourth choice, although these uses are not plotted. Note that this occurs in concert with the gradual decline in native forest areas observed in the land use plot for this scenario. The native forest fuel sources are sufficient to obviate the need for burning agro-fuels for cooking, and the plot shows no use of agro-fuels.

4.2.2 Farm Fuel Use in Project Scenario "A"

Figure 13 shows the response of farm family fuel usage when the project is initiated. At project start-up, 34,560 families are brought in to the area. The ability of the currently existing plantations to accommodate this immense growth in demand is outstripped. By 1990, only 50% of farm fuel needs are met by plantation fuels. Reforested paddy bunds (1988) do make for some increase in the share met by plantation fuels. Yet, the shortfall persists. Due to this shortfall, farm families obtain fuel from their alternative sources -- permitted native forest harvests, fuelwood purchases, fuelwood poaching. For clarity in the graphics these have not been plotted (although they could have been). By 1990, however, these sources show signs of drying up. With limited fuelwood availability from all sources, farm families resort to the fuel of last choice, agro-fuels. As shown, use of agro-fuels rises steadily until 2020, at which time it levels off at a provision of 50% of total fuel needs. At this point, 25% of fuel needs are met by plantations. The remaining 25% is divided between the alternative native forest fuels. From 2025-2030, an increasing portion of farm fuel needs remain unmet.

4.2.3 Farm Fuel Use Under No Forest Management

Figure 14 shows the response of the model under complete neglect of forest management policies. As shown, plantation fuelwood sources become totally inadequate by 1986. Plantations have suffered from mismanagement and have

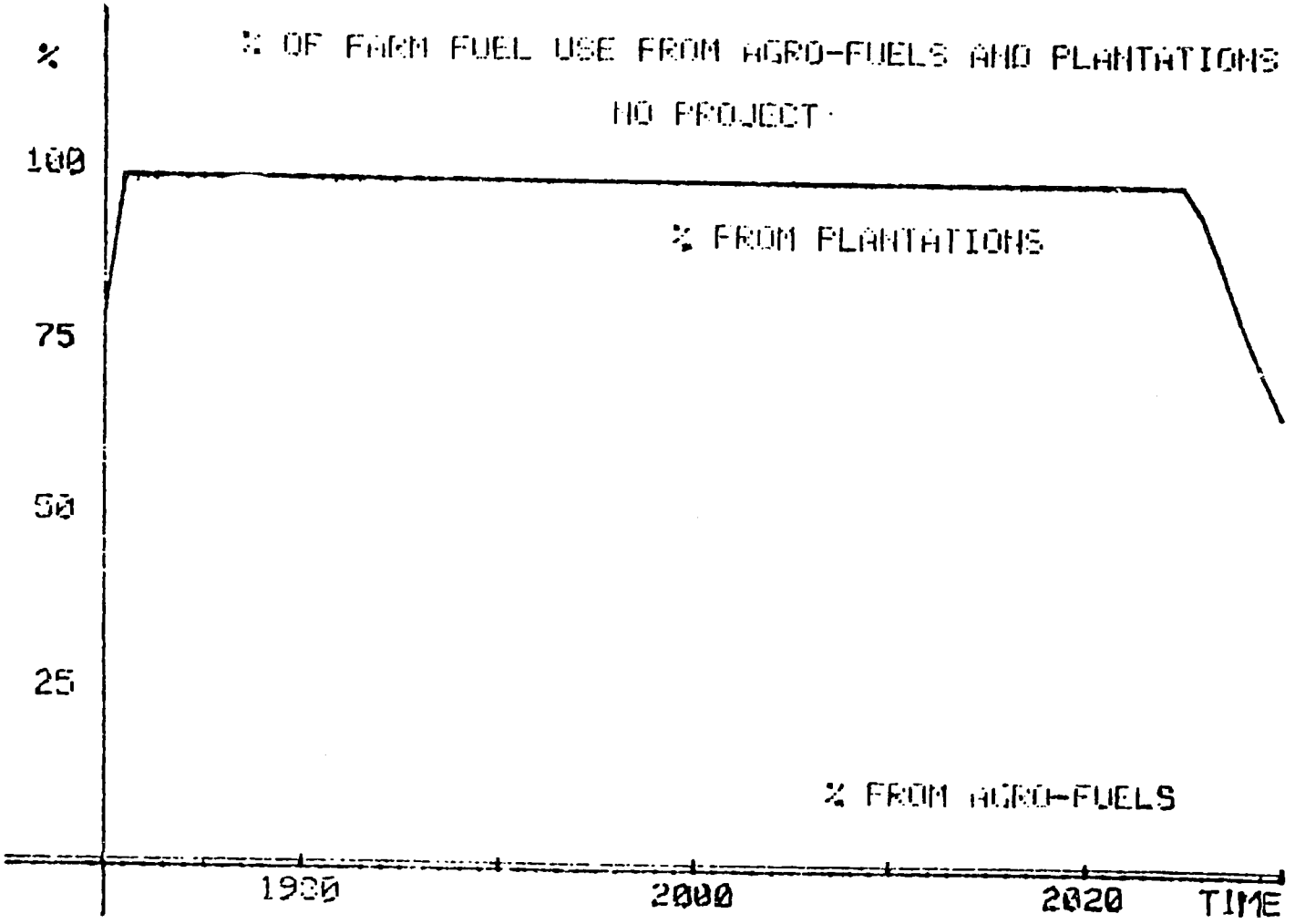

% OF FARM FUEL USE FROM AGRO-FUELS AND PLANTATIONS
NO PROJECT
%
100
75
50
25
% FROM PLANTATIONS
% FROM AGRO-FUELS
1980
2000
2020
TIME

Figure 12.

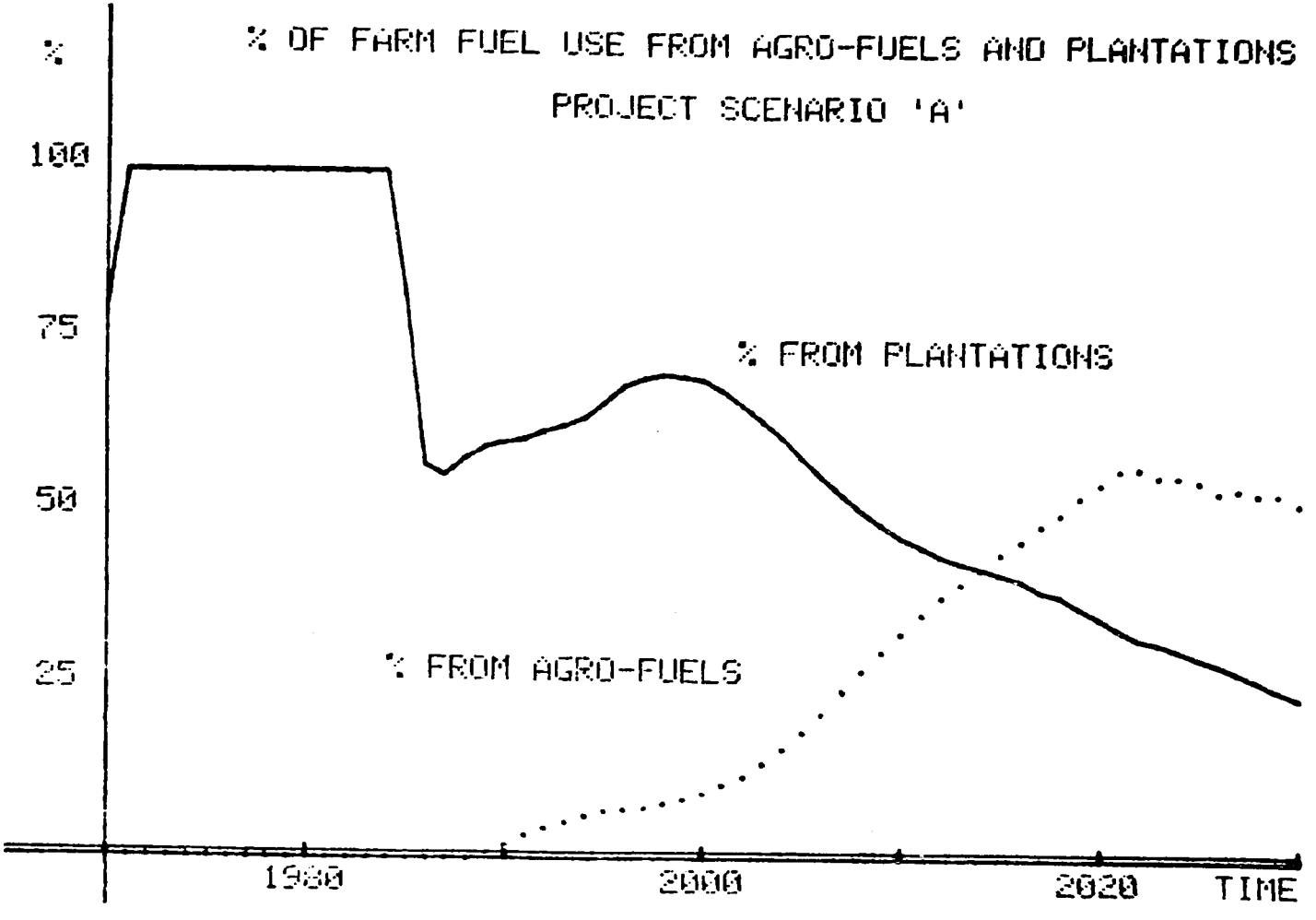

% OF FARM FUEL USE FROM AGRO-FUELS AND PLANTATIONS
PROJECT SCENARIO 'A'
%
100
75
50
25
% FROM PLANTATIONS
% FROM AGRO-FUELS
1980
2000
2020
TIME

Figure 13.

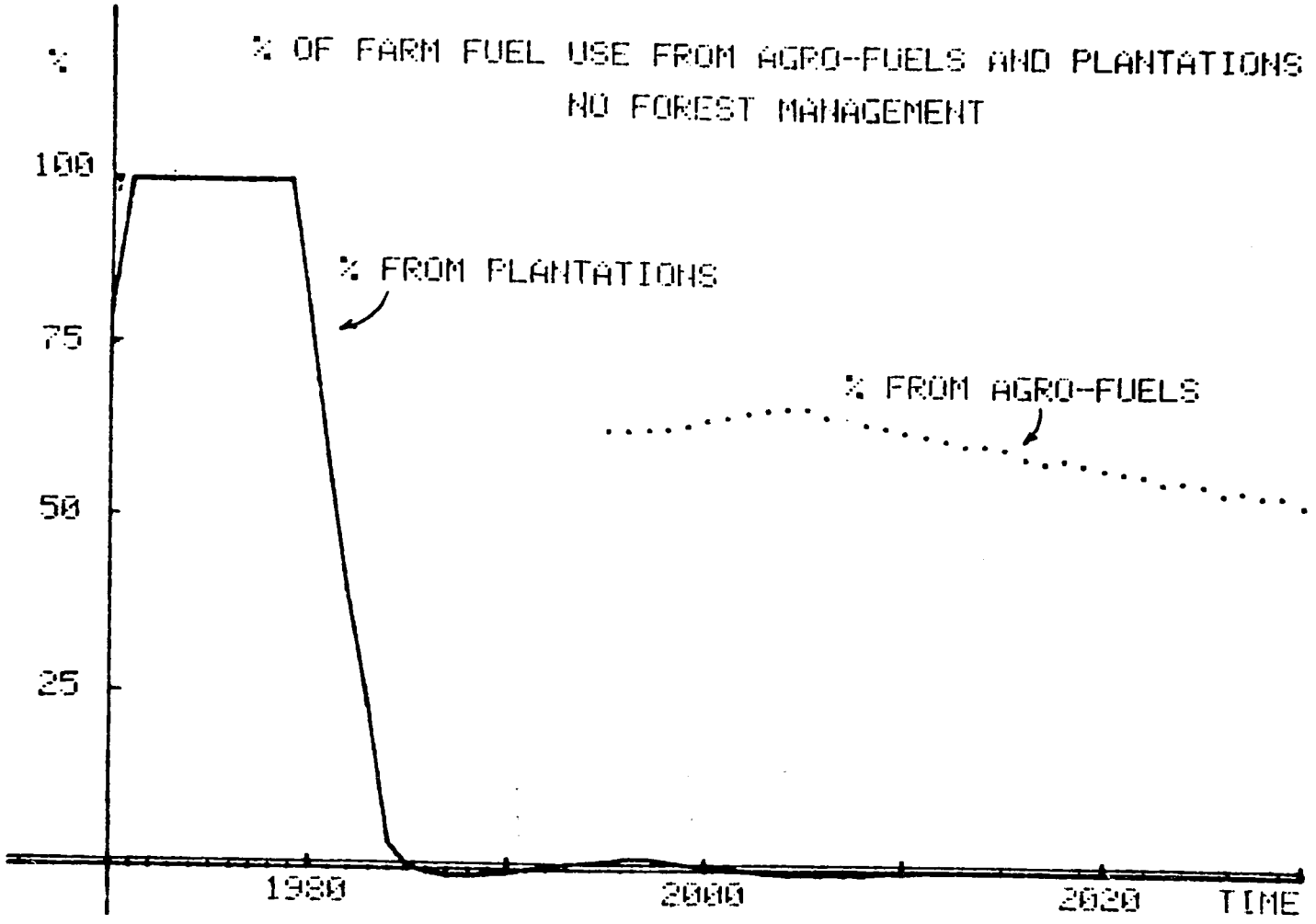

% OF FARM FUEL USE FROM AGRO-FUELS AND PLANTATIONS
NO FOREST MANAGEMENT
%
100
75
50
25
% FROM PLANTATIONS
% FROM AGRO-FUELS
1980
2000
2020
TIME

Figure 14.

degraded. The fuels supplied from native forest lands are exploited with equal access by both farm and non-farm populations. Heavy exploitation of the forests has created a forest resource so inaccessible as to forbid harvesting within a reasonable amount of time. The fuelwood market collapses. Agro-fuels become the fuel of choice for farm families. Between 50-60% of farm fuel needs are met through crop stubble and livestock dung in the latter 30 years of the simulation. Native forests supply only minimal amounts of fuel. A large fraction of farm fuel needs (30-40%) remain unsatisfied in this scenario.

4.2.4 Farm Fuel Use with Complete Forest Management

Figure 15 shows farm fuel use in the Complete Forest Management scene. Reforestation of degraded lands commences in 1985. After a 7-year maturation time, the first round of reforested plantations become harvestable. In the time gap, from 1985-1992, alternative fuels are consumed, including some agro-fuels. Due to the rigorous protection of national park native forest areas by natural resource managers, rangers, and forest guards, these forests are not the fuelwood "cornucopia" that they were in the earlier cases. This is a minor factor, however, as, by the turn of the century, reforested plantations provide 90-100% of farm fuel needs.

4.3 Rice Yield

Figures 16-19 show model-simulated results for rice yield for the 4 scenarios mentioned. Referring to the Appendix Figure A.15 will help in understanding the dynamics of the next four plots. Variability in rice yield comes from six sources: the technologically potential rice yield, water availability, draft power availability, fertilizer use, farmer knowledge, and inherent soil fertility (not shown on flow diagram). The potential yield is a theoretic standard that equals 4.3 tonnes/ha in 1970 and increases 2.5% per year thereafter.

The potential can be achieved if all other input factors contributing to rice yield are supplied in their requisite amounts. A shortfall in any of the inputs -- water, fertilizer, draft power, knowledge, or soil fertility -- translates into lower yields according to a crop response curve drawn for each input factor.

The rice yield formulation is particularly interesting because it acts as a hub or locus that brings together several disparate parts of the system. Farm family economics influence the ability of farmers to purchase and apply fertilizer; the integrity of the irrigation works and the variability in rainfall affect water availability; draft livestock availability and health affect paddy preparation; the existence of an agricultural extension program influences farmer knowledge; and, the use of agro-fuels for cooking, rather than for soil building, affects soil fertility over time.

4.3.1 Rice Yield with No Project

Figure 16 provides the rationale for initiating the project. High rainfall variability causes immense variability in rice yields. This, in turn,

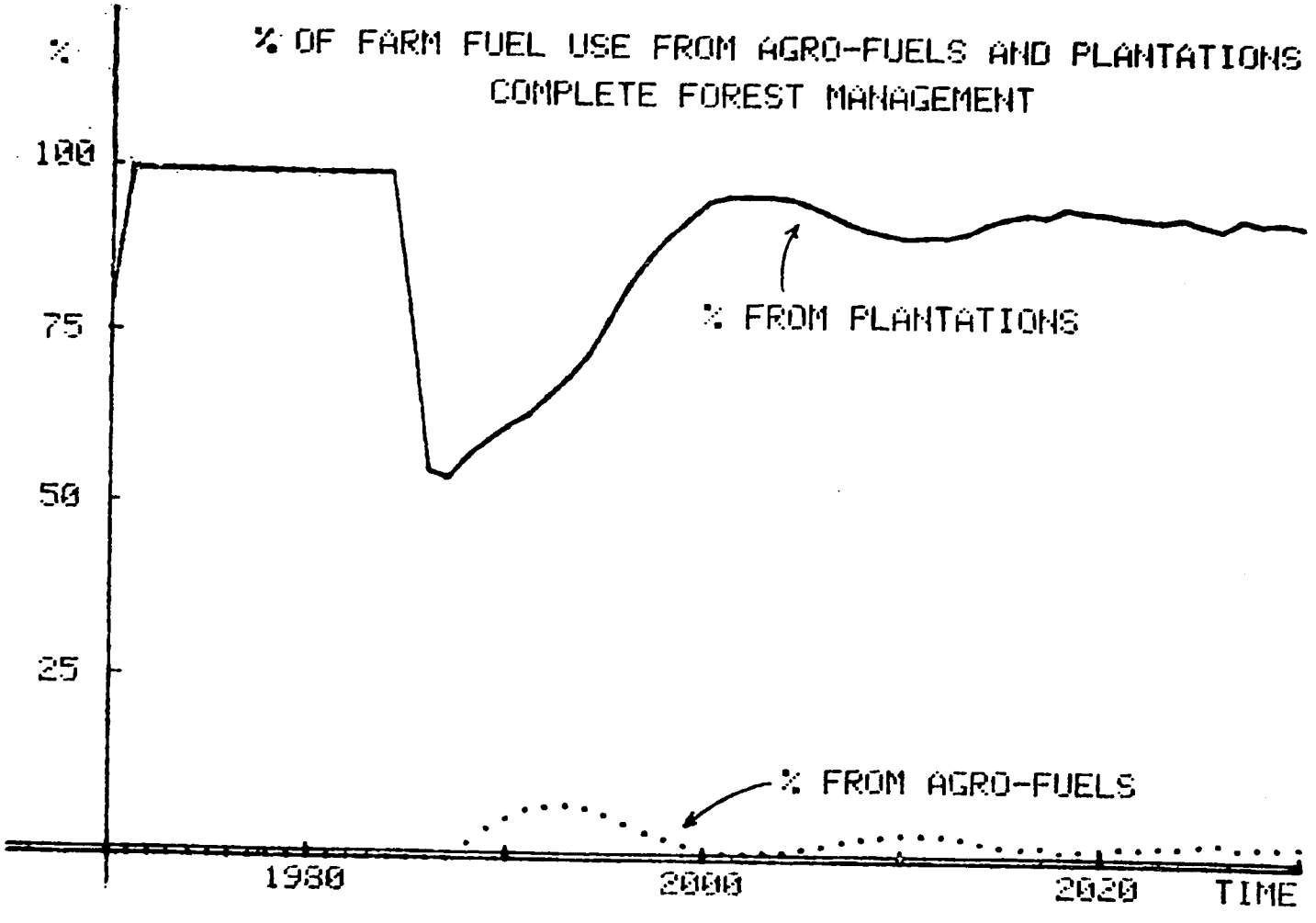

% OF FARM FUEL USE FROM AGRO-FUELS AND PLANTATIONS
COMPLETE FOREST MANAGEMENT
%
100
75
50
25
% FROM PLANTATIONS
% FROM AGRO-FUELS
1980
2000
2020
TIME

Figure 15.

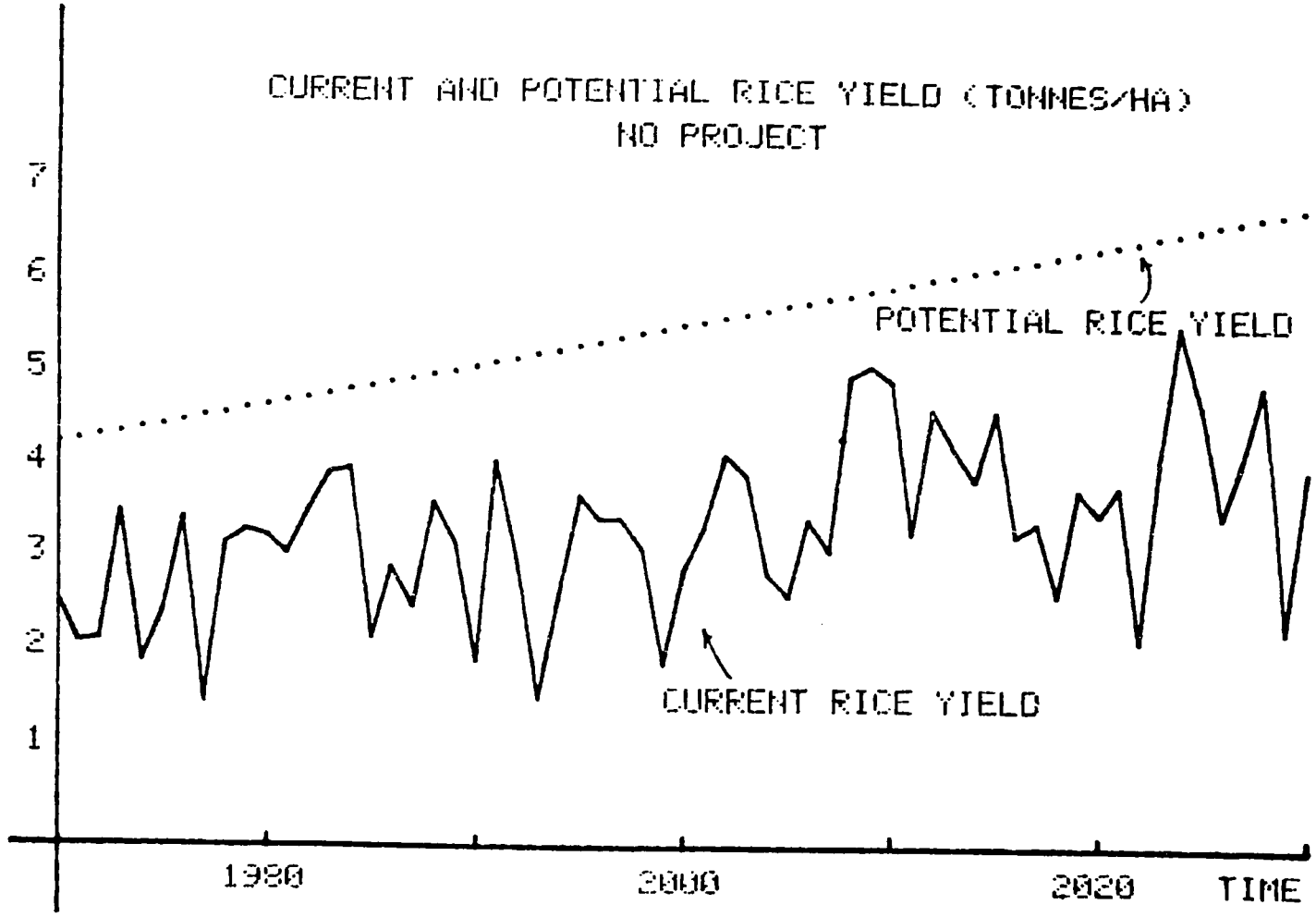

CURRENT AND POTENTIAL RICE YIELD (TONNES/HA)
NO PROJECT
7
6
5
4
3
2
1
POTENTIAL RICE YIELD
CURRENT RICE YIELD
1980
2000
2020
TIME

Figure 16.

creates a highly risky farm economic environment. Farmers are at the whim of a rainfall pattern that can vary as much as 600 mm/ha from one year to the next. Some trend increase in yields is detectable. This is due to the steady increase in the base potential yield. Although other factors do contribute to the deviation of current from potential yields, they are small in comparison to the water effects.

4.3.2 Rice Yield in Project Scenario "A"

Figure 17 shows the behavior of rice yield under the Project Scenario "A". With project start-up there is a noticeable smoothing out of the yield fluctuations. The irrigation works have come on line and provided a perennial water source for paddy farmers. Rice yields continue to fall below potential, however. each input factor --fertilizer, draft power, knowledge, and soil fertility -- contributes to the shortfall. Fertilizer application is inadequate during the middle years of the simulation, 1990-1998, due to a temporary depression in the farm economy. The main contributor to yield shortfalls is declining soil fertility. This commences shortly following the diversion of agro-fuels from the field to the stove. The steadily increasing gap between current and potential rice yields is due to the increasing usage of agro-fuels for cooking. Hence, a shortage of fuelwood has created a shortfall in potential rice production of about 30% of potential at the end of the run.

The two spikes in rice yield that occur after 2020 are due to irrigation works siltation. Deforestation of upland areas has accelerated the siltation process. The model assumes a useful irrigation works lifetime of 65 years. Siltation, then, is an inevitability. When its magnitude is great enough, water availability becomes dependent on rainfall. As shown above, rainfall in this area is not dependable.

4.3.3 Rice Yield with No Forest Management

Figure 18 shows the trend in rice yields under the No Forest Management case. The steep increase in agro-fuel consumption that occurs around 1992 causes the precipitous, long-term decline in rice yields. The widespread diversion of organic matter has mined the soil of the project area. Although the abruptness of the decline is perhaps suspect, the point is clear: neglecting forestry in a project of this scope has far-reaching systemic implications.

4.3.4 Rice Yield with Complete Forest Management

Figure 19 shows rice yield under a comprehensive forest management regimen. In this case, the project area paddy soil retains its fertility. Abundant plantation fuelwood has precluded the consumption of crop stubble and dung for fuel. Soil fertility is not compromised and, hence, does not limit rice production. The main limit on yields in this scenario is knowledge. In the absence of a widespread agricultural extension program, farmers are unable to keep pace with all the new techniques and information pertinent to the cultivation of the newer, higher-yielding varieties. Although this constraint is active in all the earlier cases, it is under these conditions that a knowledge "shortfall" provides the most potent check on rice yields.

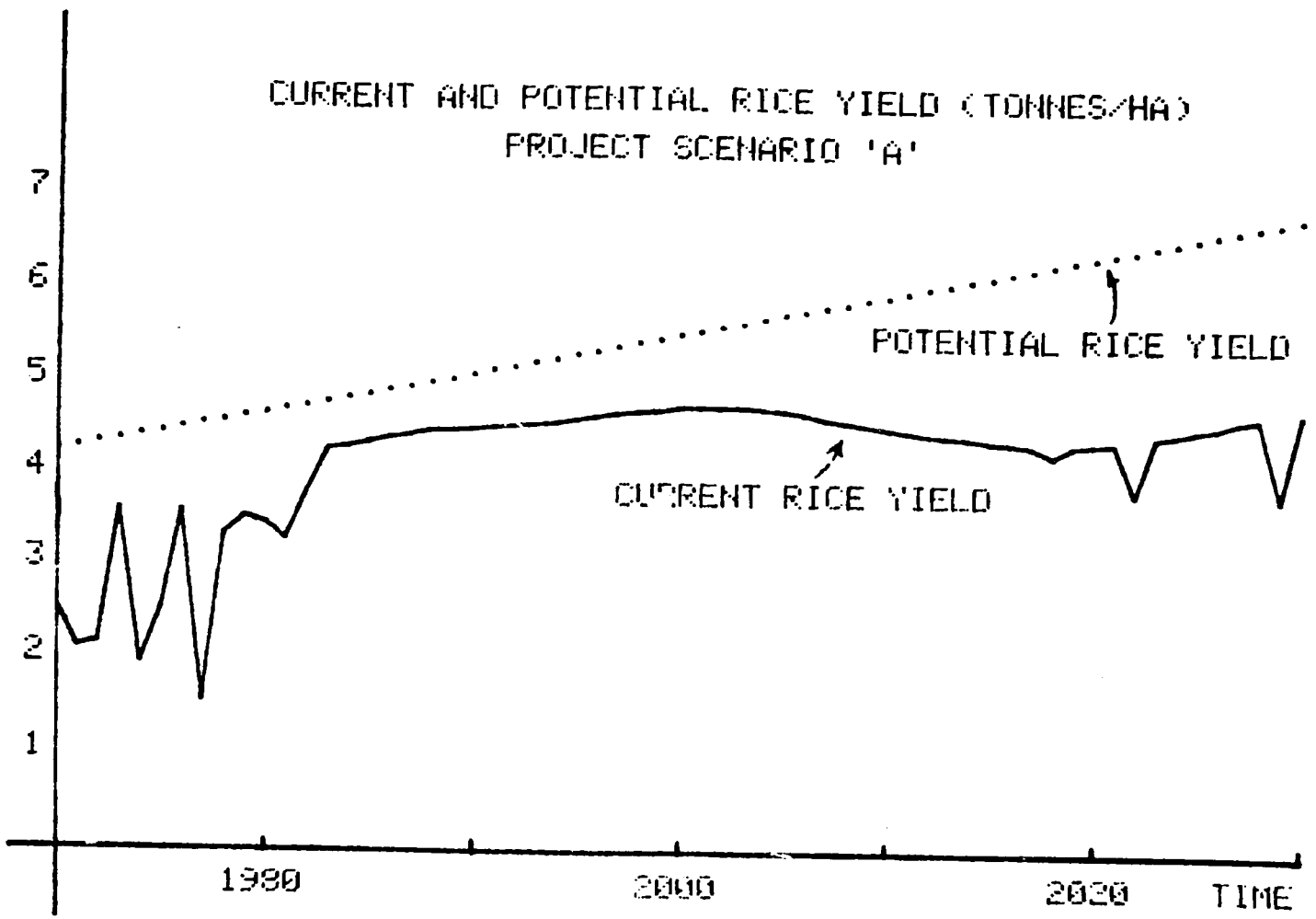

CURRENT AND POTENTIAL RICE YIELD (TONNES/HA)
PROJECT SCENARIO 'A'
POTENTIAL RICE YIELD
CURRENT RICE YIELD
7
6
5
4
3
2
1
1980
2000
2020
TIME

Figure 17.

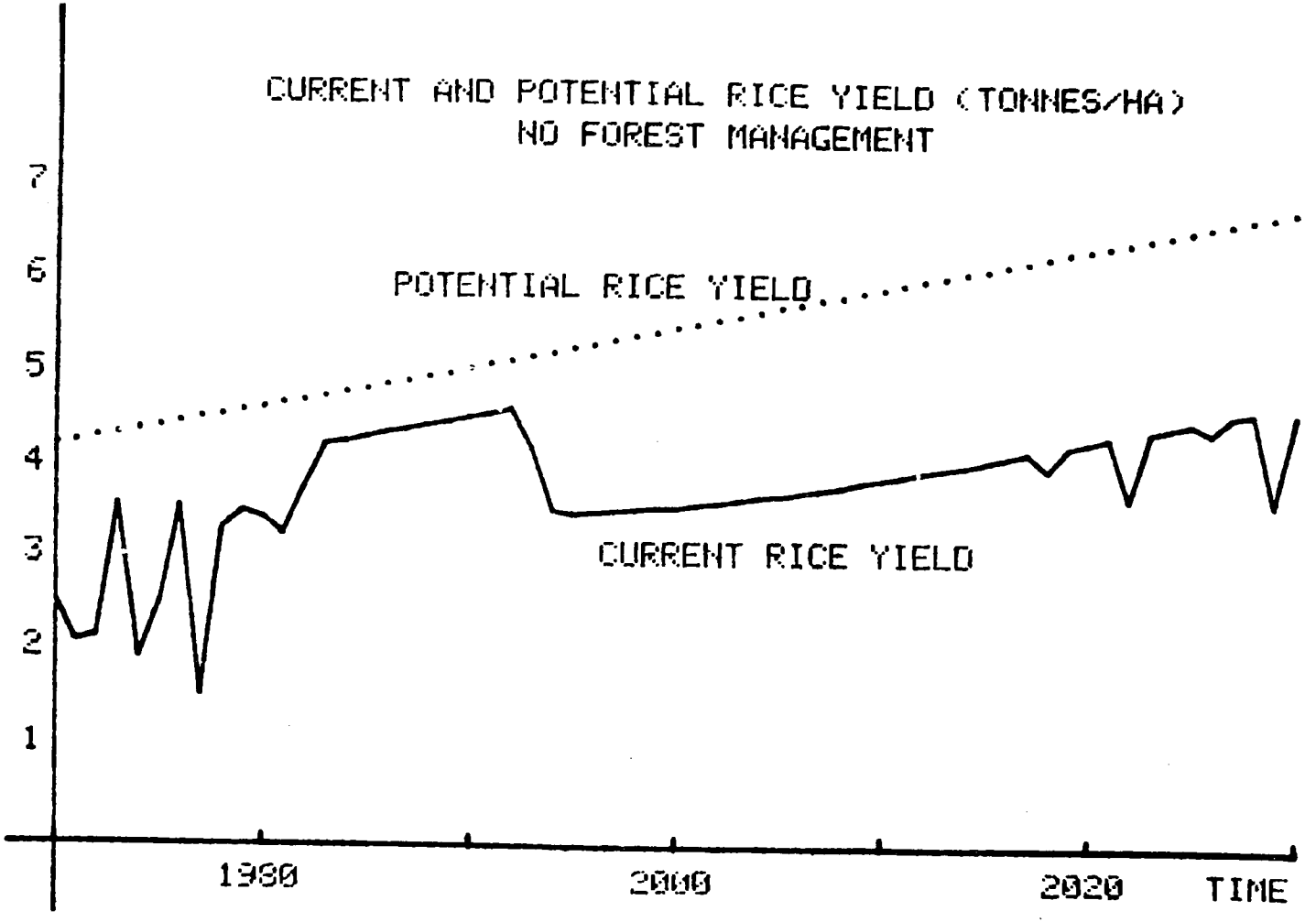

CURRENT AND POTENTIAL RICE YIELD (TONNES/HA)
NO FOREST MANAGEMENT
POTENTIAL RICE YIELD
CURRENT RICE YIELD
7
6
5
4
3
2
1
1980
2000
2020
TIME

Figure 18.

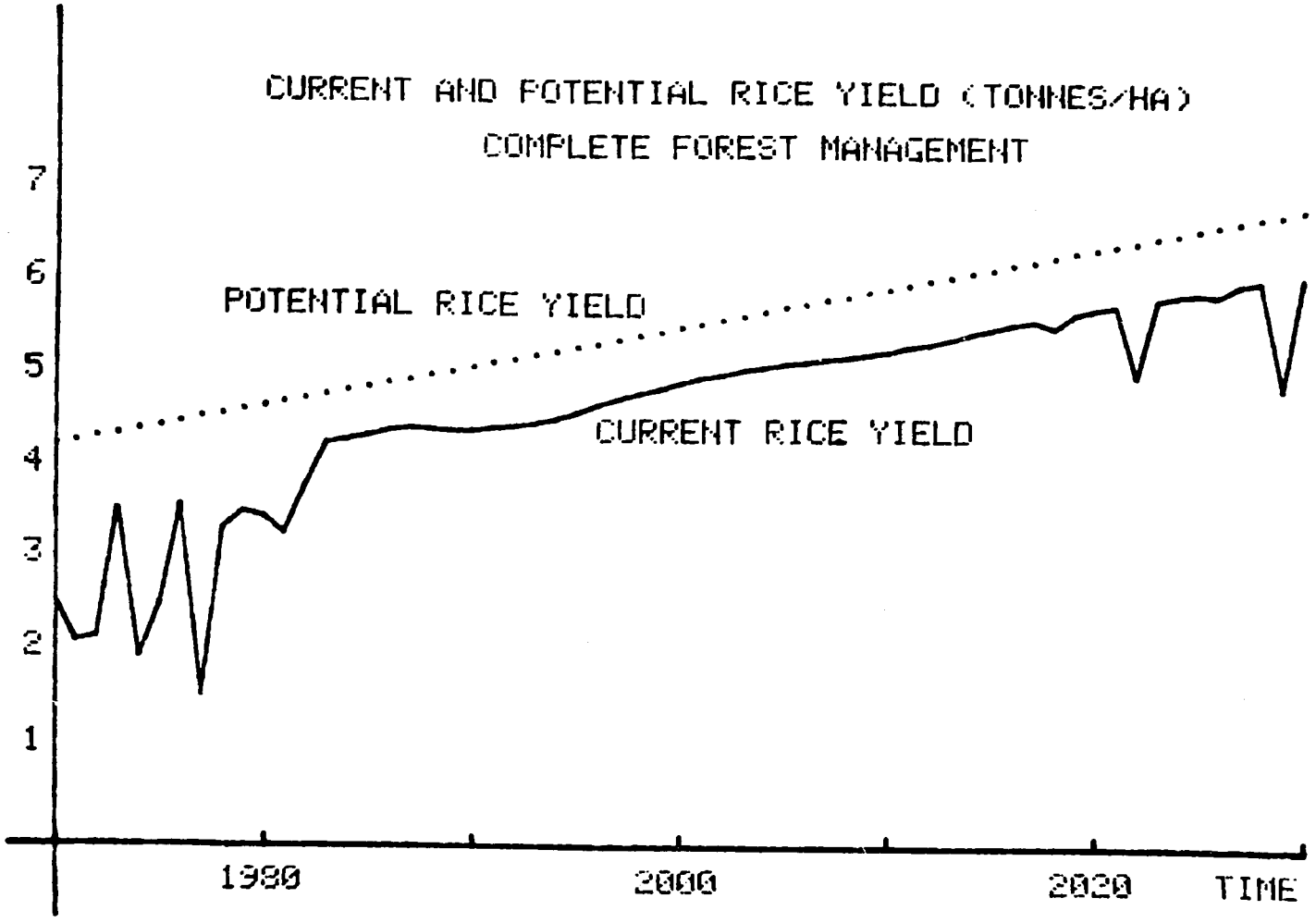

CURRENT AND POTENTIAL RICE YIELD (TONNES/HA)
COMPLETE FOREST MANAGEMENT
POTENTIAL RICE YIELD
CURRENT RICE YIELD
7
6
5
4
3
2
1
1980
2000
2020
TIME

Figure 19.

In comparing agricultural performance as measured by rice yields across the four scenarios, an integration of the yields over the 35 years from 1995 to 2030 shows the total loss of rice per hectare to be roughly 20 tonnes with complete forest management, 50 tonnes with the current project (Scenario "A") and 70 tonnes without the project or with a project omitting the forestry sector. As current value for rice of about Rs. 4500 (which varies from a government support price of 2200 to a market price of 6500) or $280, this translates to a cummulative loss to the farm of nearly $20,000 per Ha. with no project or single sector (e.g. agriculture) management. With the current project, about $14,000 less than potential sales are realized and with complete forest management, about $5,500.

4.4 The Relative Prosperity of the Farm and Non-Farm Populations

Figures 20-24 illustrate a central revelation of the systems model: the project is relatively well-planned for the farm population; non-farmers fare much more poorly.

Figure 20 shows the model-generated farm and non-farm populations. The farm population suddenly increases six-fold with the inmigration of 34,560 families. The farm population overshoots its long-term equilibrium slightly due to the high birth rates that occur during the initial years of the project. Higher births mean more families and, hence, "crowding" in the rural areas. This leads to a wave of rural-to-urban migrations. The relatively steep increase in the non-farm population from 1985-1990 is due to this migration. Non-farmers also migrate into the project area due to their perception that they will receive some land for farming (a disappointed expectation) or that they will find a job (more likely than getting land but still unlikely).

The factors influencing farm birth rates, infant mortaility rates, outmigration rates, and mortality rates also influence these rates for the non-farm population. Nutrition, fuel adequacy, economic outlook, housing and health infrastructure access -- all of these influence each population's dynamics in accordance with that population's ability to obtain these factors.

Figure 21 compares the life expectancies of farmers with non-farmers (all the following plots simulate Project Scenario "A" which is essentially current planning). Average farm life expectancy declines somewhat sharply at the project outset. This is due to general public infrastructure inadequacies that emerge with the fast growing population, e.g. it takes longer to get to a hospital. The effects on non-farm life expectancy are more varied and severe. Nutritional and fuel inadequacies, in addition to infrastructure shortfalls, combine to make living harder for non-farmers. Although both life expectancies erode gradually during the simulation, the gap between them stays steady at around 8 years.

Figure 22 shows the other end of the lifetime spectrum, comparing farm and non-farm birth rates (expressed in births per thousand). High infant mortality rates and declining per capita income in the initial years of the project contribute to the escalating birth rates of both populations. Again, for non-farmers, the conditions giving rise to higher birth rates are more pronounced.

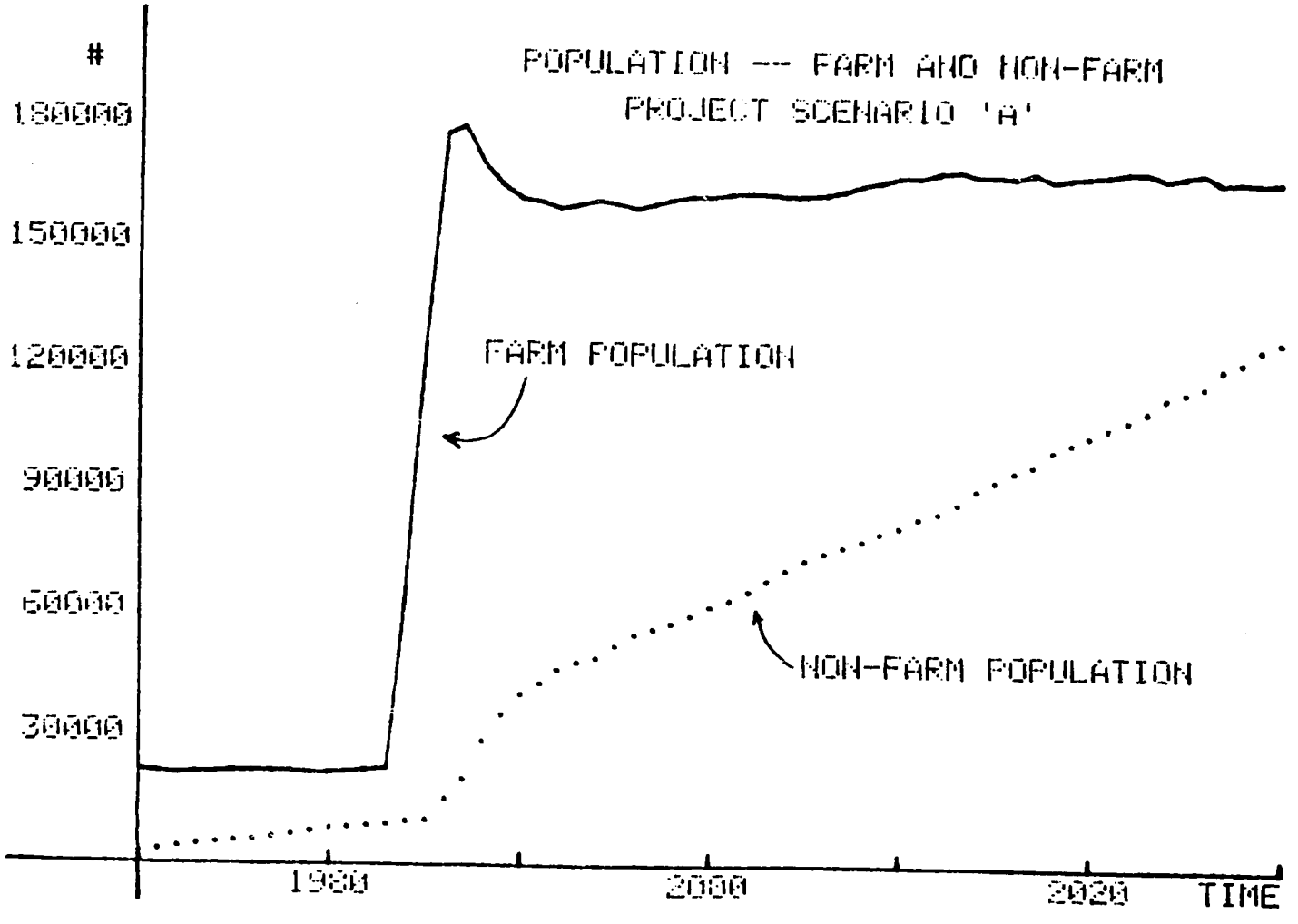

POPULATION -- FARM AND NON-FARM
PROJECT SCENARIO 'A'
#
180000
150000
120000
90000
60000
30000
FARM POPULATION
NON-FARM POPULATION
1980
2000
2020
TIME

Figure 20.

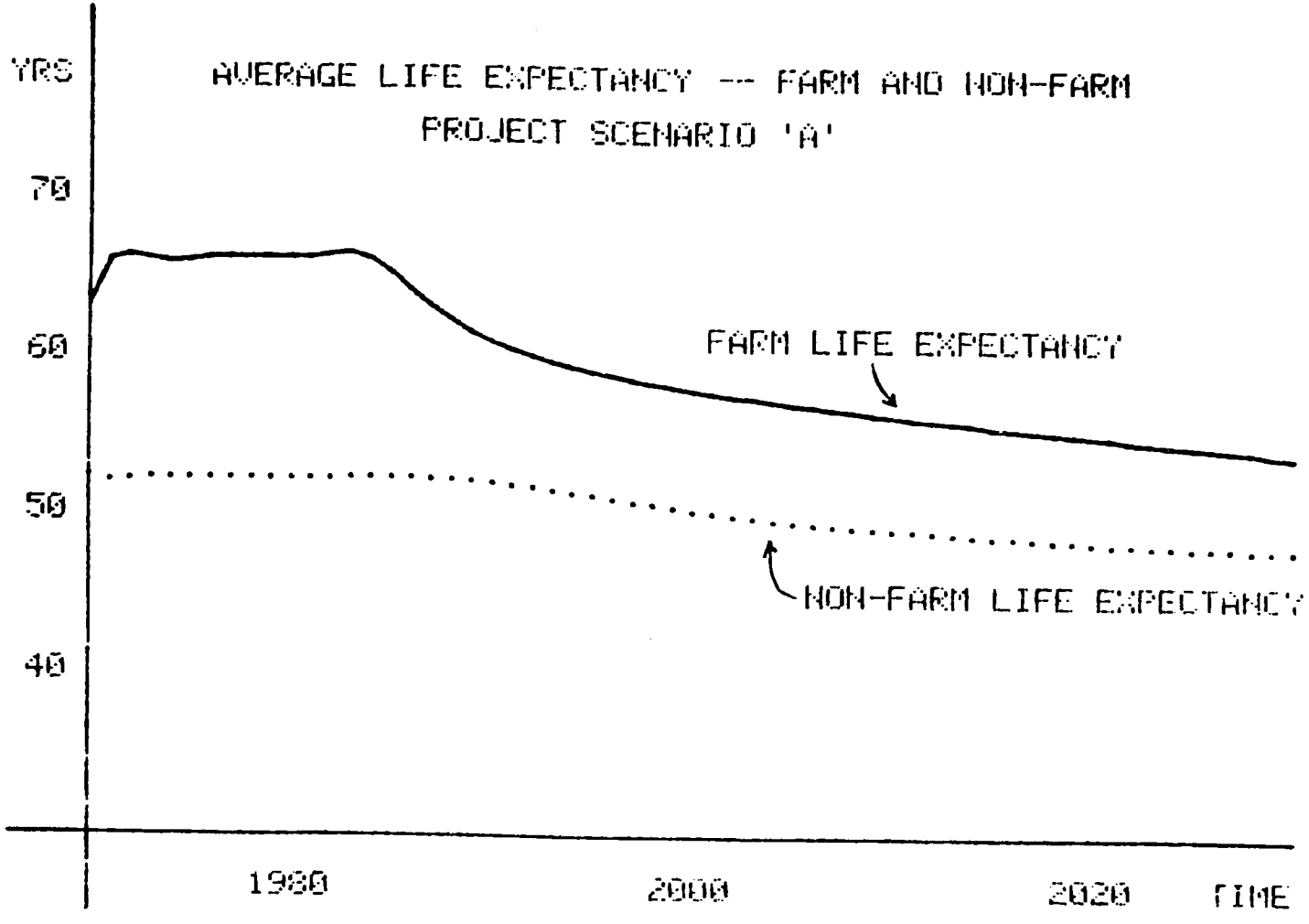

YRS
AVERAGE LIFE EXPECTANCY -- FARM AND NON-FARM
PROJECT SCENARIO 'A'
70
60
50
40
FARM LIFE EXPECTANCY
NON-FARM LIFE EXPECTANCY
1980
2000
2020
TIME

Figure 21.

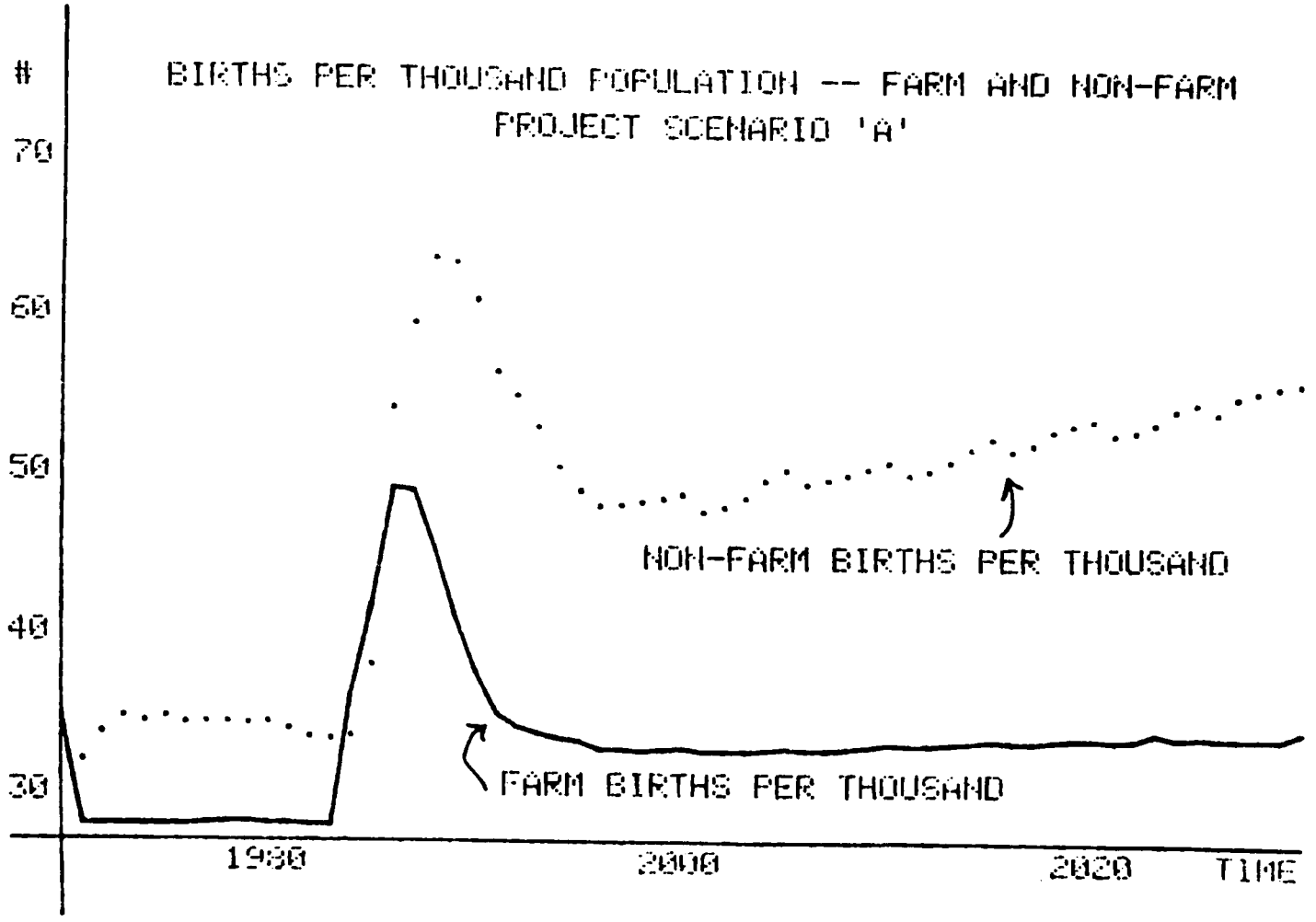

BIRTHS PER THOUSAND POPULATION -- FARM AND NON-FARM
PROJECT SCENARIO 'A'
#
70
60
50
40
30
NON-FARM BIRTHS PER THOUSAND
FARM BIRTHS PER THOUSAND
1980
2000
2020
TIME

Figure 22.

Figure 23 shows the logical extension of higher birth rates: greater average family sizes for non-farm than for farm families. This, of course, is significant as it presents a larger economic burden in terms of nutritional and fuel requirements per family. Farm family sizes tend to stabilize at around 4.5, the Sri Lankan average. Non-farm families show a steady increase from 5 to 6 members per family, with no signs of stabilizing.

Finally, Figure 24 compares the percent of fuel needs unsatisfied for the farm and non-farm populations. Again, non-farm people have it much tougher than farmers. Although perhaps exaggerated by the model, non-farmers experience heavy fuel shortages. Toward the end of the simulation, farm families begin to experience problems in meeting their fuel needs. Their shortages are not severe when compared to the non-farm population, however.

Taken as a whole, these plots relate a story of relative prosperity. This condition is unusual in developing countries. It is important to point out that the model is richer in detail for the farm sector than for the non-farm sector. This was not a conscious decision, but, rather, an artifact of the best available information contained in research studies of the area and presented by workshop participants. In short, much more is understood about the world the farmer will live in than is understood about the world the non-farmer will experience.

A MENU OF PERFORMANCE INDICATORS FOR 5 MODEL SCENARIOS

SCENARIO	POPULATION		BIRTH FRACTION		LIFE EXPECTANCY (Years)		AVERAGE RICE YIELD (Tons/H)	TOTAL HA OF NATIVE FOREST DEGRADED FOR FUELWOOD
	FARM	NON-FARM	FARM	NON-FARM	FARM	NON-FARM		
1/ No Project	20,945	88,321	.030	.053	62.9	52.4	3.47	10,574
2/ Population Scenario "A"	153,590	111,430	.032	.056	60.5	50.7	4.05	15,688
3/ Scenario "A" with no Forest Management	153,340	109,430	.032	.056	58.9	50.6	3.93	24,834
4/ Scenario "A" with Complete Forest Management	153,950	121,090	.031	.056	60.7	50.6	4.23	7,659
5/ Scenario "A" with Complete Forest Management, Family Planning Program, and Agricultural Extension	145,070	115,640	.026	.048	64.7	51.4	4.52	7,733

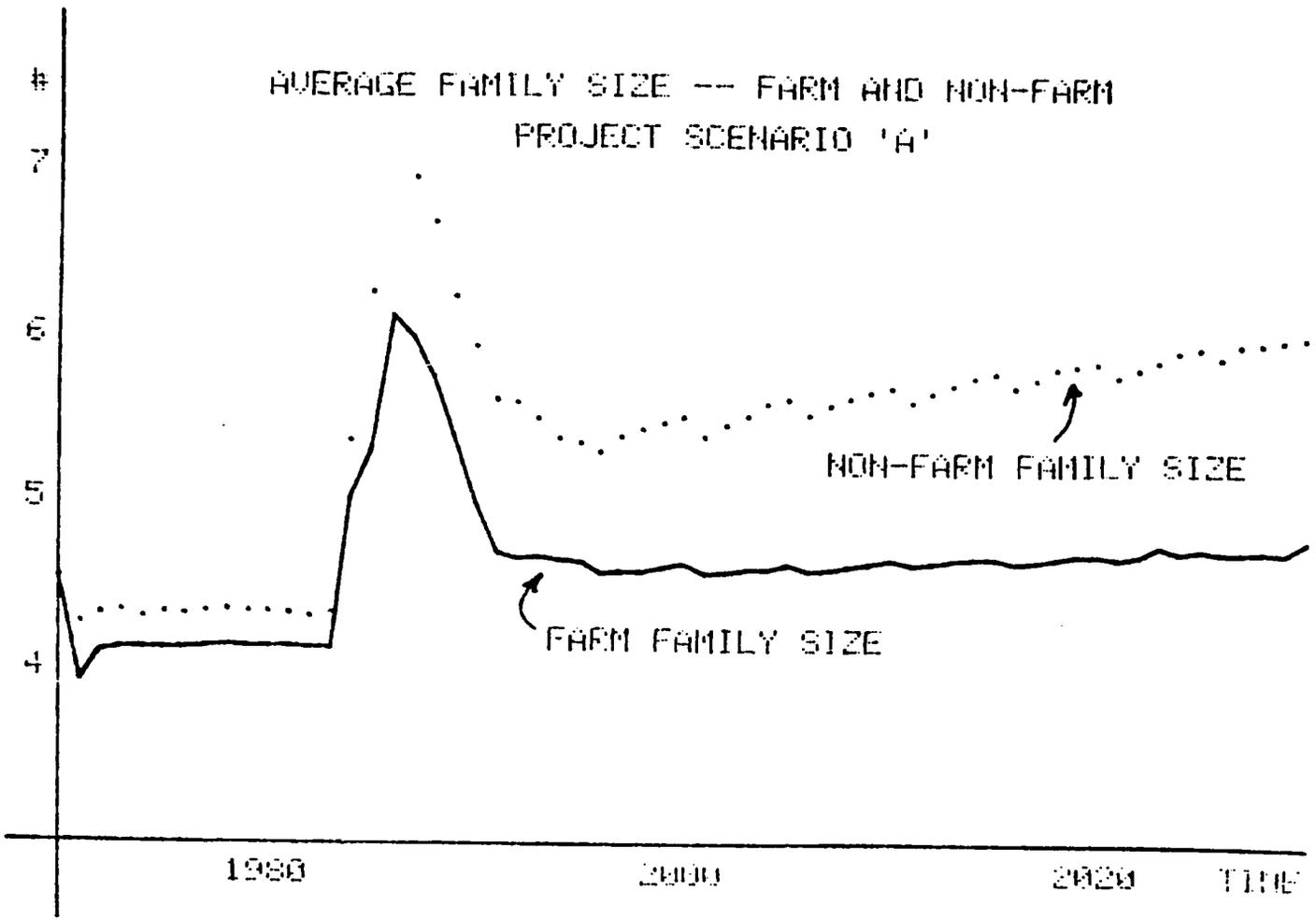

AVERAGE FAMILY SIZE -- FARM AND NON-FARM
PROJECT SCENARIO 'A'
#
7
6
5
4
NON-FARM FAMILY SIZE
FARM FAMILY SIZE
1980
2000
2020
TIME

Figure 23.

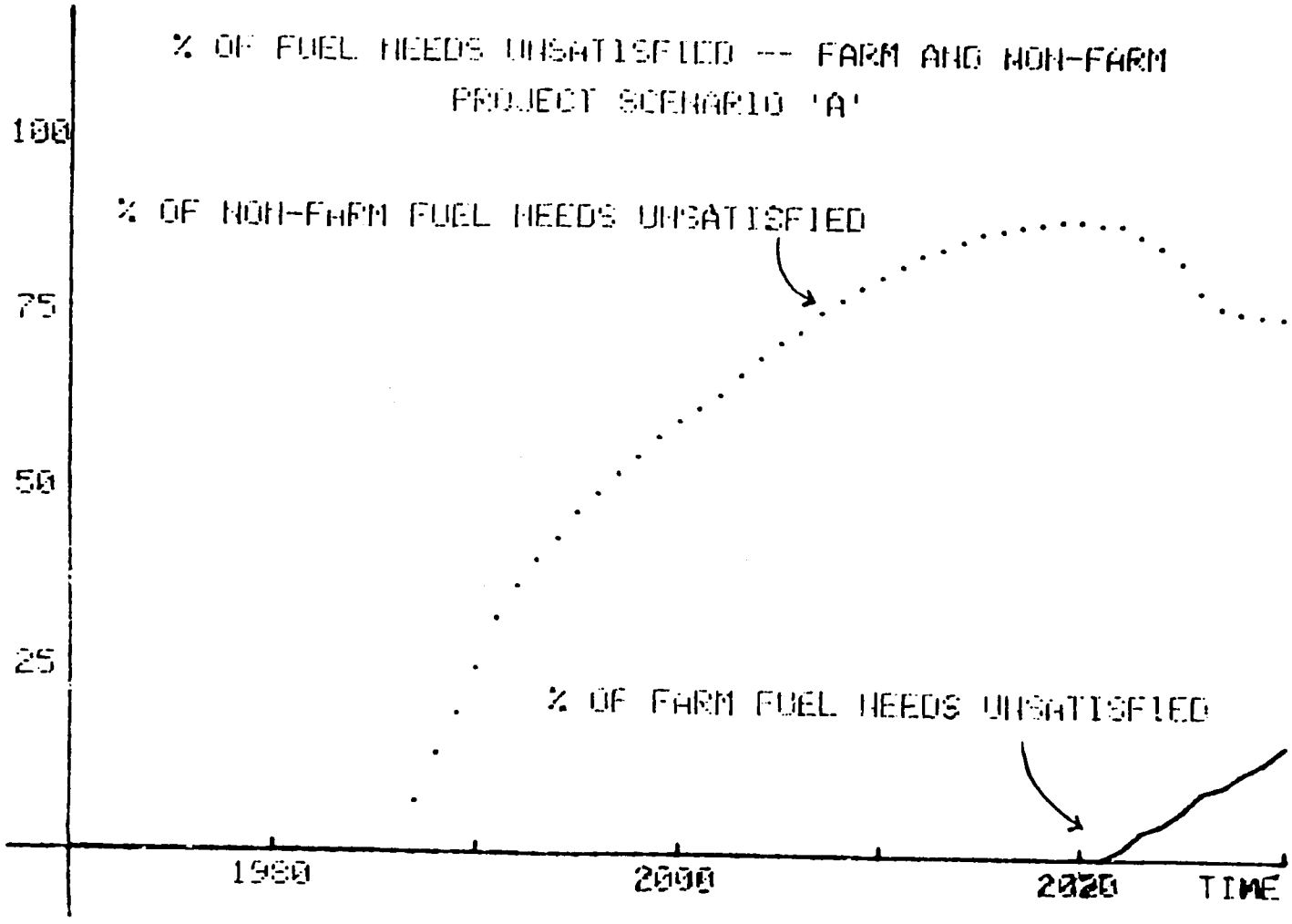

% OF FUEL NEEDS UNSATISFIED -- FARM AND NON-FARM
PROJECT SCENARIO 'A'
100
75
50
25
% OF NON-FARM FUEL NEEDS UNSATISFIED
% OF FARM FUEL NEEDS UNSATISFIED
1980
2000
2020
TIME

Figure 24.

MAJOR DATA SOURCES

ACRES, 1979. Maduru Oya Project. Feasibility Report, Annexes A-N. Acres International
Limited. Niagara Falls, Canada.

TAMS, 1981. Environmental Plan of Action. Accelerated Mahaweli Development Programme. Tippets-Abbett-McCarthy-Stratton. New York.

US/AID. 1982. Mahaweli Environmental Project. AID Project Number 383-0075.

APPENDIX A
MODEL DOCUMENTATION

A.1 INTRODUCTION

This paper provides a description of 8 sectors of the systems model constructed during the April 9-13 Bioresources Systems Modeling Workshop. Caveats and introductory concepts are presented in this introduction.

The model contains the information and knowledge of workshop participants. Rather than being the product of one or two modelers working in isolation, it reflects the collective consensus of the disciplinary experts and AID personnel who attended the workshop. A great deal was learned by each participant about the effects of their sector of interest on other sectors. This is a principal advantage of the workshop modeling format.

Any systems model is, by necessity, an abstraction of the real system. In order to avoid "modeling the system" and constructing a model that was as complex as the real system and, consequently, as difficult to understand, we exercised discretion in choosing the system factors to include in the model. We did not determine the relative importance of system variables arbitrarily, however. Instead, we began the modeling effort by posing several key questions to guide the selection of system factors. If we considered a factor critical in providing insight to the key question, we included that factor.

For example, one key question of the socio-economic sector was: Does sufficient infrastructure currently exist for the first group of migrants? In discussing the factors that would help us answer this question, we determined that we should include an out-migration variable that was caused by the dissatisfaction emerging from insufficient infrastructure. We could then accumulate the number of dissatisfied out-migrant over the duration of the project to obtain an idea of the relative sufficiency of infrastructure. Conversely, at first, we did not think it critical to disaggregate infrastructure into the various types: transportation, market, health, etc.

Our concept was that a shortfall in any of these infrastructure types would generate problems within the project area that would, in turn, cause out-migration. Thus, we decided that breaking infrastructure out into the various types would not necessarily yield any more benefit in terms of answering our key question. This is not to say, however, that disaggregating infrastructure is not an important step to take in seeking to answer other key questions. In fact, after running the model subsequently, we found that such disaggregation into three types of infrastructure was useful.

Finally, we chose to model the Maduru Oya System B project because it has been intensively studied. It is a data-rich region. Thus we have, where possible, initiated levels and constants with numbers available from the various project studies (most predominantly TAMS and ACRES reports). Factors such as the initial population of the project area, birth and infant mortality fractions, average lifetimes of people, cost data for various farm production inputs, farm product prices, farm debt ceilings, fuel requirements, livestock

numbers, livestock carrying capacities, and the hectarages of the different land classifications are documented specifically for the project area. Other data needs such as nutritional requirements of people, crop fertilizer and water requirements, and habitat-specific densities of wildlife species were derived from general sources.

Also, there are factors for which no numerical data are available or for which there exists, as yet, no convenient metrics (e.g. farmer knowledge). While we acknowledge the difficulty in measuring the multitude of factors that determine farmer expertise, we also recognize that the sum total of a farmer's experience and learning critically influences the productivity of that farmer's cropland. We also know that farmer knowledge is affected by certain policy initiatives available to project managers, such as an agricultural extension program. The upshot is that quantities deemed important to the model are used, directly if possible. If not, then factors that can be measured are used as referents or indexes to the behavior of interest are modeled and used. For example, the number of agricultural extension agents per farmer can be used as an index to farmer knowledge.

The sectors in the socio-economic portion of the model are described below.

A.2 SOCIO-ECONOMIC SECTOR

A.2.1 Population

As pointed out by one of the workshop participants, the implicit goal of any development project is to upgrade the quality of life for the people of the impacted area. The perception of whether or not people are better off is formulated to a large extent, through observing how many people remain in the area. Thus, the numbers of people, and the forces that determine in-migration and out-migration, family sizes, infant mortality, and the average lifespan of people, are clearly important in evaluating project performance.

People are central to many of the key questions posed by each sector. The agriculture sector asks: Will total agricultural production achieve both nutritional and economic self-sufficiency for the farmer family? The natural resources sector asks: Is there sufficient energy for the population over time? From the socio-economic sector: Will population growth exceed carrying capacity with respect to infrastructure and natural resources? And, how will the new population be assimulated/accommodated with regard to land tenure and industry?

Because of the central importance of population to the rest of the model, the population sector is relatively rich in dynamics. This systems model is, in a sense, a human population model. Much of the model depends on the human population or is devoted to estimating that population.

The units of population are persons. At the beginning of each run, the total population is set to 25,700. The number of families is determined by dividing the total population by average family size. Average family size is initialized at the Sri Lankan average, but is dynamic in the model. Further, the population is divided into two groups, farm and non-farm population.

A.2.1.1 Farm Population (FPOP) Figure A.1

The number of people residing on farms and living a primarily agrarian existence is considered to be the farm population (FPOP). This population is initialized at 23,000, 90% of the total population. The farm population is a level affected by seven rates (people per year): (1) population transfer due to project startup; (2) birth rate; (3) infant mortality rate; (4) out-migration rate; (5) rate of out-migrant return; (6) the rate of rural-to-urban migration within the project; and (7) mortality rate.

Population transfer (PT) is the rate at which families are brought in to settle the project area. This is the PLANNED in-migration rate, and does not include in-migrants who are attracted by their perception of available land or job opportunities (inflow into the non-farm population). Sri Lanka is characterized by relatively high literacy. Since this project is newsworthy, the word gets out, stimulating "spontaneous" in-migration. The population transfer rate is exogenously determined. That is, it is an adjustable parameter that can be changed to simulate different rates of transfer.

Population level and birthrate interacts in a positive feedback loop relationship (Figure A.2). The birth rate (BR) is obtained by multiplying the population by the population birth fraction. The population birth fraction is determined by three factors. The normal birth fraction is a constant set to 0.035, the normal Sri Lankan birth rate. The normal birth fraction can be modulated upward or downward by three variable effects: (1) perceived child survivability on the birth fraction (EPCSBF); (2) the perceived economic value of children (EPEVC); and, 3) the effect of family planning on the birth fraction (EFPBP). EPCSBF is determined by the infant mortality rate, increasing as the infant mortality rate increases. This simulates the concept that parents will compensate for infant mortality by having more children. The economic value of children depends on the perceived requirements for labor. Poor farmers place a higher value on the labor provided by their children, responding by having more children. More prosperous farmers can hire labor, therefore they tend to have fewer children.

EFPBF is determined by the existence and success of a family planning program (SFPP). The success of the program, in turn, depends on the extent to which project area residents participate in the program and on the sufficiency of the public infrastructure necessary to administer the program.

Infant mortality rate (IMR) is the number of children dying per year. This rate is composed of a normal infant mortality fraction (NIMF) modulated by nutritional and health services availability effects. The nutritional effect (ENIF) is a synergistic combination of protein and caloric requirements. A shortfall in protein and/or calories will increase ENIF. IMR is also affected by health infrastructure, declining as health infrastructure increases.

The out-migration rate (OMR) is a key matric for assessing the success of the project. OMR is caused by (1) people leaving the area if they are dissatisfied (OMPD). In the real world, dissatisfaction results from unfullfilled expectations. This is approximated in the model by relating OMPD to infra-

structure. A shortfall in infrastructure implies squalid conditions (poor housing, transport, education, political institutions, markets, etc.). OMPD will increase if infrastructure does not keep up with population. A second source of out-migration comes from surplus farm family members. These typically migrate out to seek foreign employment. In the model, this term is OMLE (out-migration due to labor export).

Labor export to, say, Saudi Arabia, is motivated by the desire to send back foreign cash to the family. Thus if the farm liquidity is low, a greater number of people will travel abroad to find work. Out-migration is a limiting, regulatory feedback to the population level, a negative feedback loop (Figure A.3).

Accompanying this outflow rate is a return rate, the return of out-migrated laborers (ROML). A certain percentage of out-migrated laborers return to their farm families each year (currently assumed to be 50%).

The phenomenon of migration from rural areas to large villages and urban areas must be included in the model. If the migration rate into villages and cities exceeds the demand for their labor, high unemployment, with its attendant squalor and social unrest, may result. This is modeled as FNFM, farm to non-farm migration.

FNFM was modeled, after lengthly discussions in the workshop, based on the concept that each farm can support only a certain number of people at any one time: the farm "carrying capacity." Exceeding this "carrying capacity" will result in migration from farm to urban areas. Two decision rules are implemented in the model: (1) a theoretic maximum that the combined hectarage of paddy and homestead (1.4 ha) could support; and (2) the maximum number of nuclear families supportable per homestead (MFPH). Both of these maxima can be adjusted to reflect changes in productivity and extended family sizes. The former controller is a physical limitation, the second is a socially determined value, reflecting various norms concerning family size and structure.

The last rate affecting farm population is the mortality rate (MR). This is calculated by dividing the population by the average lifetime per person. The average Sri Lankan lifespan is 60 years (TAMS). This lifespan is modulated by (1) nutrition; and (2) energy consumption. The effect of energy availability on lifespan is related to an assumed nutritional loss due to lack of fuel for cooking and other food-preparation tasks. Mortality rate tends to limit population, hence the negative feedback loop in Figure A.4.

Under the conditions of extreme infrastructure shortfall and poor food and fuel availability, these negative feedback loops will dominate population system behavior. Dominance by the negative feedback loops implies a slowing of population growth, or in extreme cases, a population decline. This trend is offset by the birth and in-migration rates. It is likely that the positive feedback forces outweigh the negative since it is the poorest countries with the fastest population growth.

A.2.1.2 Non-Farm Population (NFPOP); Figure A.5

Non-farm population is defined as that group of people who dwell in project area towns and cities. They provide a majority of the labor pool required for industrial and commercial development. They are landless. NFPOP is initialized at 2500, 10% of the total population.

There are six rates that affect the level of non-farm population. (1) birth rate (NFBR); (2) infant mortality rate (NFIMR); (3) out-migration rate (NFOMR); and (4) mortality rate (NFMR). These rates are analogous to the corresponding farm population rates. At this point, data do not support differences in these rates between urban and rural populations.

The fifth rate affecting non-farm population is the Increase in Non-Farm population from Rural to Urban Migration rate (INFRUM). This rate is negligible in the beginning years of the simulation, but begins to generate large migrations as the paddy and settlement lands approach their carrying capacities. It is assumed that 75% of migrating farm families stay in the project area.

There is no planned in-migration into the non-farm sector. Project planners anticipate a natural in-migration of approximately 11,000 families (50,000 people). It is unclear how this figure was determined by the planners. Apparently there is an empirically derived "optimum" ratio of farm to non-farm population (4:1 for predominantly agrarian societies). The estimate of 11,000 conforms to this ratio.

This natural in-migration rate is modeled using certain assumptions. In-migration occurs because people outside the project perceive the region to be an attractive place to live. We have modeled attractiveness as arising from two sources: (1) perceived land availability; and (2) perceived economic opportunity. These perceptions may lag behind the actual conditions. For example, off-site people may be under the impression that land is available long after all good land has been claimed. Likewise, people from cities with high unemployment will willingly gamble on supposed opportunities in the project area.

These mechanisms must be modeled with some degree of realism in order for the dynamics of in-migration to be simulated. One way for the perceptions described above to be distributed is by word of mouth. Out-migrants would provide a source of information about the attractiveness of the project; however, as we have seen, out-migrants are dissatisfied. Therefore, we anticipate that the rate of in-migration will decrease, with a delay, as rate of out-migration increases.

This constraint on in-migration is modeled as a function of internal model behavior and acts as a negative feedback on project area population. The alternative to this approach would have been to attempt to model conditions in neighboring cities, which would have required costly extension of the system boundaries. While this model certainly cannot give a complete picture of the sociology of migration, the approach is reasonable and may well provide a good prediction of the relative rates of in-migration to out-migration.

A.2.2 Land Use; Figure A.6

The land use sector accounts for the land transfers that occur, over the duration of the project, between seven land categories: (1) rice paddy; (2) settlements; (3) native forest; (4) plantation forest; (5) chena; (6) parkland; and (7) degraded land. Land use transfers can be planned, as with the transfer of native forest to paddy at project start-up; or they can be unplanned, as with the degradation of native forest due to excessive fuelwood poaching.

The land use transformations that occur at project startup are large. The Maduru Oya engineering works, the land clearing, the settlement preparation will dramatically alter the face of the land. These changes will create a new set of ecosystems in the area which will have ripple effects on the system: changes in wildlife habitat, soil fertility and integrity, settlement and homestead population density, and so on.

Each land category is initialized at its 1978 value, the transfers are those planned for and reported in the ACRES Maduru Oya Main Report (1979). Some of these land categories were mapped and loaded into a computer spatial modeling program called MAP (Map Analysis Package), which was used to generate the maps in the main body of the report.

A.2.2.1 Paddy (P)

Paddy land starts as a pre-project level of about 14,000 ha. By the year 2000, approximately 31,000 additional hectares (one for each in-migrating family) will have been transferred to paddy areas accessible to the water provided by the irrigation structures. These additional hectares come from three land use types: (1) chena; (2) native forest, and (3) parkland. Every family receives one hectare of paddy which cannot be subdivided or sold. Paddy immediately adjacent to villages can be degraded.

A.2.2.2 Settlements (S)

Land allocated to settlements are initialized at approximately 5000 hectares. By the year 2000, an additional 19,000 hectares will be transformed to settlement areas. These transfers come primarily from land that is currently in chena or native forest.

A.2.2.3 Native Forest (NF)

Native Forest is a combination of the medium and dense (jungle) forest as defined in TAMS studies. The stock of native forest was about 51,000 hectares, over half of which (27,000 hectares) will be cleared for paddy, irrigated upland, and settlements. Native forest can also be converted into chena for subsistence agriculture or degraded from excessive fuelwood harvesting. This is a dynamic linkage with the socio-economic sector.

A.2.2.4 Plantation Forest (PF)

Plantation forest is initialized at 4500 ha, about half of which are transferred to settlements and paddy. Plantation forests grow the fuel of choice for farm families. Plantation hectares can be augmented through a policy to reforest degraded land.

A.2.2.5 Chena (C)

Chena is the successional scrubland that results from slash and burn agriculture and shifting cultivation on forested lands. Chena is initialized as approximately 33,000 ha. Transfers to paddy and settlements bring chena land to around 14,000 by the year 2000.

A.2.2.6 Parkland (PL)

Parkland is light forest. When parkland is adjacent to a river or standing water, it can provide grazing land and wildlife habitat. Parkland decreases from 14,000 ha to about 6,000 ha with project startup.

A.2.2.7 Degraded Land (DL)

Degraded lands come from chena under compressed rotation times (less than 10 years) or extended cultivation time (over 3 years). It also arises from overgrazing adjacent to villages and on parkland. In addition, native forest degrades over time from excess fuelwood harvesting. Degraded land is the target of the reforestation efforts.

A.2.3 Infrastructure (I); Figures A.7-A.9

The infrastructure emerged as a pivotal sector in the model. Because the primary beneficiaries of the project are the in-migrants and their progeny, their well-being will be strongly influenced by the infrastructure established at the outset and developed throughout the project.

One of the workshop participants commented that the central concerns of the AID mission in Sri Lanka had shifted in focus from physical engineering to social engineering. This view was reinforced throughout the workshop. Infrastructure is intimately tied with several factors influencing population, agricultural productivity, and capital service sector dynamics.

Infrastructure, for all its importance, is difficult to quantify. Infrastructure includes such physical structures as roads, buildings, irrigation works, power stations, marketplaces, schools, and hospitals. In addition, social infrastructure includes health, education, and political organizations. As a first pass, we dimensioned infrastructure in terms of "units". To be consistent within the model, we arbitrarily decided that 1 unit of infrastructure could serve 10 people. A shortfall or surplus catalyzes many system-wide responses, several of which are detailed in the population sector description.

The infrastructure sector consists of 2 levels: (1) Infrastructure (I) that is in use; and (2) Infrastructure On Order (IOO) that is under construction or formulation. Infrastructure can be ordered by three entities: (1) government; (2) farm families; or (3) capital services. After infrastructure is ordered a time lag is required to simulate the delay in design, construction, or other implementation of the desired edifice or service. This time lag is the Infrastructure Construction Time (ICT). ICT is affected by the amount of Capital Services (CS) in the area. The notion here is that local sources of supplies, skills, and labor will shorten the time that it takes to complete infrastructure. Given service resources (CS), we assumed the normal value of ICT to be 2 years. This parameter is adjustable, but not dynamically controlled at this time.

Infrastructure depreciation is scheduled over a 25 year period, set by a parameter called Infrastructure Depreciation Rate (IDR). This simulates general wear and tear on physical infrastructure. Again, this parameter is adjustable.

The notion of one generic infrastructure variable became more tenuous as the model grew in complexity. Therefore, some disaggregation was necessary. We decided to keep track of the cumulative investments in infrastructure from the government, farm families, and capital services. Public Investments in Infrastructure (PII) provide transportation infrastructure, health, political, and educational infrastructure. Farm Family Investments In Infrastructure (FFII) provide the wherewithal for farm transport networks, warehouse storage capacity, and marketing capabilities (both local and export). Capital Services Investments in Infrastructure (CSII) provide buildings, marketplaces, and machinery.

A.2.4 Capital Services (CS)

Capital Services (CS) are the commercial organizations of the project area. They provide jobs and market products demanded by individuals and organizations within the area. As with the Infrastructure sector, Capital Services are measured in "units."

This sector is an indicator of the forces encouraging or discouraging industrial growth in the area. In this model, (CS) is conceived as the driver for job opportunities for non-farm residents.

Structurally, the capital services sector resembles the infrastructure sector. A Capital Services On Order (CSOO) level provides a delay between the order and completion of capital services. The construction time (CSCT) is dependent on the availability of both infrastructure and capital services. A normal construction time of 2 years is assumed. This time will be decreased by a surplus in capital services, and increased in the case of capital services shortages. A Capital Services Depreciation Rate (CSDR) of 20 years is assumed.

To capture some of the dynamics of industrial growth in the model, we included a self-investment "bootstrapping" loop. Under favorable business conditions (e.g. growth in farm economy), internal investments in capital

services create orders for more capital services. Investments can also be allocated to infrastructure if a lack of commercial infrastructure is, in some way, hampering sales.

A.2.5 Employment Opportunities (EO)

If the project area is to prosper in the long term, some industrial and commercial activity is necessary. This implies employment opportunities for area residents. Project per capita income goals require that the non-farm residents have employment opportunities open to them.

Jobs are provided from two sources: (1) infrastructure and (2) capital services. Any structures under construction also provide employment. The number of jobs provided per infrastructure and capital service unit is an adjustable parameter in the model. This parameter can be used to simulate a capital intensive industrial base or a labor intensive industrial base. This parameter is useful for testing the effect of these assumptions on overall system dynamics.

Other parameters are the fraction of non-farm and farm family members available for the labor pool (40% for non-farm families and 10% for farm families). These are of course, adjustable parameters.

Any excess non-farm labor creates the unemployed landless population (ULP). It is this group that will resort to shifting cultivation, converting native forest to chena and degraded lands. They will also place pressures on native forest because of excessive fuelwood collection.

The wages generated through employment are assumed to be approximately 7,500 Rupees per year per worker. This is another adjustable parameter.

A.2.6 Money Balanc FMB, NFMB)

The savings and ..h on hand of farm and non-farm families are critical variables in determining project performance. Two key questions directly involve the cash balances of project families: (1) Will total crop production achieve economic self-sufficiency for the farmer family?; and (2) will the project deliver on income-per-capita goals? These questions point to the importance of the annual income and expenses of the average farm and non-farm family.

The units of the farm and non-farm money balances are in Rupees per family. Again, these values represent the average family.

A.2.6.1 Farm Money Balance (FMB); Figure A.10

Farm Money Balance (FMB) is a level with 2 inflows and 3 outflows. Farm Income (FI) and Farm Short Term Debt Assumption (FSTDA) augment the farm family money balance. Farm maintenance expenses (FME), farm debt payments (FDP), and farm cash allocations to investments (FCAI) diminish the money balance.

Farm Income has four components: (1) Farm Income from Rice Sales (FIRS) is obtained by multiplying the amount of rice sold by the market price of rice; (2) Farm Income from Cash Crop Sales (FICCS) is obtained by multiplying the amount of cash crops sold by the market price of cash crops; (3) Farm Income from Off-Farm Employment (FIOFE) is obtained by multiplying the average number of off-farm workers per farm family by the average annual salary for off-farm employment (10% of farm family members are assumed to be a part of the general labor pool); and (4) Farm Income from Foreign Remittances (FIFR) tracks the amount of cash sent back to the farm family from family members working abroad.

Farmers place Short Term Debt (FSTDA) when their liquidity is low and they must purchase fertilizer, feed, and other necessities. FSTDA is necessary to cover the gap between purchase of necessities and the sale of crops.

Farm money balance is diminished through Farm Maintenance Expenses (FME) and Farm Debt Payments (FDP). Farm maintenance expenses come from five sources: (1) Farm Production Input Expenses (FPIE) are the cash outlays for fertilizer, pesticides, etc.; (2) Farm Livestock Maintenance Expenses (FLSME) are the annual cash outlays for feed, veterinary and structural expenses involved in maintaining a healthy herd; (3) Farm Food Expenses (FFE) are the cash outlays for any rice the farm family repurchases from government inventories (made only when family rice store dip below a desired inventory of rice); (4) Farm Family Support Expenses (FFSE) are the cash outlays for the miscellaneous items (clothing, television sets, etc.); (5) Farm Cash Allocation to Investment (FCAI) are outlays for capital and infrastructure investment.

Farm Liquidity (FL) (Figure A.11) is the major indicator of economic health in the farm family. Liquidity is an index derived by dividing the current money balance by a "desired" money balance. "Desired" in this case, is a long-term average of the total annual farm cash outlays. Desired expenditures include debt repayments. A liquidity greater than unity indicates a healthy, economically viable farm operation. In this case, the farmer can afford extra investments in machinery or structures on the farm or elsewhere. A liquidity of less than one indicates that the farm is barely breaking even or taking a loss. Under this condition, farm families shift toward the production of subsistence crops and thus consume most of the food they grow. This, of course, impacts their cash balances (Figure 6).

A.2.6.2 Farm Debt (FSTD); Figure A.12

As mentioned, farm income comes in fits and starts with the periodic biannual harvests. To smooth out the fluctuations in their money balances, farmers take on short-term debt. The Short Term Debt Assumption (FSTDA) has a term of 6 months (TAMS). The amount that farmers repay (FSTDR) of their outstanding debt depends on their liquidity (FL): high liquidity -- full repayment; low liquidity -- partial repayment. If liquidity sinks too low, a percentage of outstanding debts default (FSTDD). This particular feedback from liquidity to default on debt is not yet linked up with any population migration dynamics. Conceivably, farmers that default on debt may have to sell

their land and move to cities. Consequently, a land concentration process in the farm sector and overcrowding in the urban areas may ensue.

Farm Debt Payments (FDP) include both Farm Dept Payment on Principal (FDPP) and Farm Debt Interest Payments (FDIP). The term of debt is assumed to be six months; the interest rate is assumed to be 10%. The debt ceiling is assumed to be 1620 Rupees per year (TAMS). As with all policy variables, these are adjustable parameters that can be changed from run to run.

A.2.6.3 Non-Farm Money Balances (NFMB); Figure A.13

Non-Farm Money Balances are the savings and cash on hand of non-farm families. They receive income from employment (NFIE). As mentioned, 40% of all non-farm family members are in the labor pool. Those who are employed earn the average annual wage of Rs 20,000.

Non-farm expenses (NFE) are cash outlays for food, fuel, and family support.

A.3 AGRICULTURAL SECTOR

A.3.1 Farmer Knowledge; Figure A.14

The skill and experience of the farmer strongly influence the rice and cash crop yields of that farmer. A farmer's agricultural knowledge increases naturally through experience. Having a desired number of agricultural extension agents in the area (DAEA) acts to augment the normal learning rate. Learning accelerates if the farmer is enthusiastic about farming and feels a sense of ownership and participation (PART) in the project area (Effect of Participation on Knowledge Accumulation Time, EPKAT). The goal or ideal ratio is assumed to be 1 extension agent to 2000 farmers.

A.3.2 Current Rice Yield; Figure A.15

The current rice yield is defined as the production of rice on a one-hectare plot, grown by the average farm family. The unit of measure for the current rice yield is tonnes per hectare per season. At each harvest time (the model assumes two seasons per year) the current rice yield is used, along with the amount of land for rice cultivation, to calculate the amount of rice that will be put into the family rice stores.

The current rice yield is determined by the potential rice yield and the fraction of the potential rice yield realized. The potential rice yield is an exogenous input reflecting the seed technology or variety. An initial potential or maximum attainable yield is chosen and grows over time (the "ramp function" in Dynamo does this) at the growth rate specified. This growth rate in potential rice yield embodies an assumption about future changes in seed technology.

Affecting the technological potential rice yield is the inherent soil ferility of the paddys. Thus, the fraction of technical potential yield (FTPYR) is based on amount of organic matter (crop stubble and dung) a farmer returns to the soil. Organic matter has another use: fuel for cooking. A shortage of fuel wood would cause farmers to burn agro-fuels, thus robbing soils of organic matter. Potential yields fall as a result.

The farmer's ability to realize the potential rice yield is also a function of input use and management. Three inputs are important in determining yields, and the fractions of the potential yield realized from the use of each of these inputs is calculated. The three inputs are draft power, fertilizers and water. For each of these inputs the desired or suggested amount is com- pared with the actual level of input use. Table functions (crop response curves) determine the fraction of the potential yield realized based upon the comparisons for each of the inputs. For draft power and fertilizer use the actual amount used depends on the desired input level and the farmer's ability to pay (liquidity). The desired level for fertilizer depends on farmer know- ledge and a recommended level of use for the crop type.

Water inputs are calculated in a different way. The desired level of water application is a function of the crop type, the amount of land under production, and the number of seasons per year. The water desired per hectare is a constant for rice production. The amount of water actually applied is determined by the effective rainfall (randomly generated: mean = 900 mm/y, STD = 300 mm/y), the amount of water available from the reservoir, and the water needed for other uses.

A.3.3 Draft Livestock; Figure A.16

Draft livestock are important to the agriculture and the forests of the project area. Not only do draft livestock provide draft power (not explicitly modeled), and nutrition, but they can provide a serious degrading influence on the forest from grazing.

Draft livestock are modeled as a level. The level represents the total number of draft livestock in the project area. Four rates are associated with this level: births, mortality, sales, and slaughter of draft livestock. The birth rate is a function of a normal birth rate, the desired number of draft livestock per family and the actual draft livestock per family. The notion here is that the farm family will try to maintain some desired number of draft livestock for its use. If this desired level is not achieved, the birth fraction increases; if the actual number of draft livestock is approaching the desired, then the birth rate slows.

Draft livestock mortality is a function of the livestock carrying capacity of the project area measured in animals per hectare, and the actual number of draft livestock per hectare. As long as the livestock carrying capacity exceeds the draft livestock density, the mortality rate is maintained at a normal fraction; but if the livestock density exceeds the carrying capacity, the mortality rate increases.

The sale of draft livestock is simply a function of the numbers of draft livestock and the draft livestock sale time. This sale time is really the useful life of the draft livestock, so if the sale time is 9 years, then 1-ninth of the draft livestock are sold each year.

Finally, the slaughter rate is determined by the protein consumption per person. If the protein consumption is maintained above the minimum protein requirement, then a normal slaughter fraction is also maintained. However, if the protein consumption falls below the minimum requirement, the draft livestock slaughter rate increases.

A.3.4 Livestock Carrying Capacity; Figure A.17

The livestock carrying capacity is the measure of the project area's ability to provide forage. This carrying capacity is measured as animal unit years per hectare of forage land.

The livestock carrying capacity can adjust itself over time. This adjustment occurs when the indicated livestock carrying capacity is different from the actual carrying capacity. The actual carrying capacity adjusts to the indicated carrying capacity over a 2-year period. The indicated carrying capacity is implied by the current livestock density. If stocking is higher than the normal carrying capacity, then the indicated carrying capacity decreases. If stocking is less than the carrying capacity, the indicated carrying capacity is equal to the carrying capacity. The density is determined by the total numbers of draft livestock by the product of the forage area and the associated per hectare carrying capacities of each type of forage area. The forage area consists of land in paddy, parkland, and villu. The livestock carrying capacity is a weighted average of the normal carrying capacity for paddy, parkland, and villu. The capacity of the project area to support draft livestock changes as the area of these categories change (Figure A.18).

A.3.5 Protein and Calorie Consumption; Figure A.19

Protein and calorie consumption in the project area are important measures of health and well-being. As such, these two indicators are determinants of human population mortality. Also, protein consumption is a factor in determining the slaughter rate of draft livestock. The structure of the protein and calorie consumption models are identical, as both protein and calories are derived from all food sources, so only the protein model will be described here.

Protein is derived from both animal and vegetable sources. Vegetable protein comes from the consumption of rice, and a pulse crop which is grown on the family's garden plot. The protein per person from rice consumption is the rice consumed per family, divided by the average family size, multiplied by a conversion factor to get from tonnes rice to kilograms protein. The protein per person from the consumption of the pulse crop is calculated in a similar fashion. Rice consumption is a function of the family grain stores and a

desired consumption level for rice, while pulse consumption is determined by the pulse yield and the amount of land in the garden plot (subsistence agriculture — also a constant). A most important deteriminant of protein consumption per person thus becomes the average family size. As family size goes up, the protein per person will tend to decline.

Protein from animal sources comes from the consumption of meat and milk. Meat sources include fish and poultry consumption (both constants) and draft livestock consumption. This is determined by the slaughter rate and the average family size. For each of these meat sources, an appropriate conversion factor is used to determine the protein consumed per person per year from the meat consumption per person per year. Finally, protein is derived from milk consumption. Protein per person from milk is a function of the number of draft livestock per family, the milk production per head, the average family size, and a conversion factor.

A.3.6 Rice Inventories; Figure A.20

Farm family rice stores serve as the family's buffer for their primary food. Additionally, modeling the family rice stores allows the model to duplicate inter-annual fluctuations in liquidity, an important determinant for short-term debt assumption. Without this structure, short-term debt would appear unimportant, as its sole purpose is to smooth out or dampen the fluctuation in money balance. The government inventory serves to collect surplus production from the project area and export it, or resell it locally as necessary. The government and family stores are also important in determining the local market price of rice.

Twice a year, the rice is harvested and is placed in the family rice stores. The amount of rice put into the store is a function of the current rice yield and the amount of tillable land allocated to paddy cultivation. The harvest pulse allows the rice to flow into the stores only as many times as there are seasons per year. The family tries to maintain some desired amount of rice in its stores. This is determined by the average family size, the desired amount of rice per person per year, and the length of time for which the family is trying to cover its consumption. If the amount of rice in the farm family store exceeds the desired level of rice in the store, the family sells the excess to the government. If on the other hand, the family rice stores fall below a minimum level, the family will purchase rice back from the government, depending on how much money the family has and how much rice the government has to sell. Rice consumption is based on family size, the desired rate of rice consumption per person per year, and the amount of rice in the family store.

The government inventory of rice is increased by total farm sales -- the sales per family multiplied by the number of families. The government will purchase all rice that the family desires to sell. The government can sell back locally if the demand is present, and can also export rice out of the project area. The amount of exports depend on the size of government inventory and the time it takes to export the rice. This export time is determined by the amount of agricultural infrastructure in the project area. The greater

the agricultural infrastructure, the shorter the time required to export. A fast export time keeps the government inventories down, and tends to boost prices.

A.3.7 Market Price of Rice; Figure A.21

Prices provide incentives and signals to farmers, telling them what to produce. In this model, farmers grow three crops: rice, a subsistence crop, and a cash crop. We have modelled the prices of rice and the cash crop explicitly to allow for changes in farm production trends over time. The price models then, are linked to the tillable land allocation model and the farm money balance.

The market price of rice is the maximum of the free market price of rice and government support price. Thus, the support price, a policy variable, acts as a floor below which the market price of rice cannot fall. The free market price of rice is modelled as a level which adjusts with a constant adjustment time to the indicated free market price of rice. This structure adds stability to the model. The indicated free market price may change quite rapidly over the year, but the free market price will change much more slowly.

The indicated free market price is calculated from a base which is the world market price of rice. The world market price of rice is exogenous, with a given starting value and a given growth rate for the price of rice. This world market price is multiplied by a constant effect of quality to determine the indicated Sri Lankan price of rice. The assumption embodied here is that the Sri Lankan rice quality is not up to world standard. This indicated Sri Lankan price of rice is then modulated by the effect of local supply on the free market price of rice. If the total local supply of rice is less than the total desired local supply of rice, the price of rice will be greater than if equilibrium conditions existed. Similarly, if there existed a surplus of rice locally, the price would be less than the indicated Sri Lankan price. The total local supply of rice is simply the government inventory of rice plus the farm family rice stores times the number of farm families. The total desired local supply of rice is the desired government inventory, a constant, and the desired farm family stores times the number of farm families.

The market price for the cash crop is much simpler, being a function of the world market price for the crop (a constant) and an effect of agricultural infrastructure on the price. If there is enough agricultural infrastructure to market the total crop, the cash crop price is maintained. However, if the agricultural infrastructure is not adequate, the price falls.

A.3.8 Tillable Land Allocation; Figure A.22

Each farm family in the project area is given a certain amount of land to till. This must be split between three crops: rice, a subsistence crop, and a cash crop. These allocations link to the farm money balance model, as the allocation for each crop determines the level of expenses and income for each crop. The structure for this decision module is shown in flow chart number 10.

Each family is given a constant amount of paddy land and homestead land to cultivate. This land cannot in any way be increased or decreased by the farm family. A certain amount of this total tillable land is set aside for subsistence agriculture, based on family needs, a function of family size. Also, each farm family sets aside a minimum amount of paddy land to meet its food needs. This is a function of the average rice yield and the desired family rice stores; the amount of land set aside being equal to the desired family rice stores divided by the average rice yield. The remaining or residual tillable land can be allocated by the farm family as it sees fit, to rice production or cash crop production.

The family will try to allocate the residual land in a way that produces the greatest economic benefit. The family estimates the perceived benefits from both paddy and cash crop farming and allocates land to each use according to the contribution to the total perceived benefits. Thus, if both cash crop and paddy farming are expected to return the same benefit per cultivated hectare, an equal amount of land will be allocated to each activity. The perceived benefits to each type of cultivation is the difference between the expected income and the expected cost. The expected income per hectare is based on average yields, prices, and price variability; the expected cost is based on the level and price of production inputs required.

A.4 NATIVE FOREST -- CHENA SECTOR; Figures A.23 - A.26

The transfer of Native Forest (NF) to Chena (C) is a main indicator of physical deterioration arising from social problems. According to our model, native forest is encroached upon for two reasons: (1) subsistence farming by unemployed, landless families and (2) their requirements for fuelwood.

When these families encroach upon native forest, land is transferred from the Native Forest (NF) level to the Native Forest Chena (NFC) level (termed "jungle chena" by TAMS). If the encroachment is temporary (as when, for example, the unemployed landless find employment in towns), native forest will regenerate naturally after a 3-year delay (ADNFC, Average Duration of Native Forest Chena). If the encroachment is long-term, the land will ultimately become less productive, deteriorating to degraded land. The time constant for this long-term degradation is assumed to be 10 years (NFCDT, Native Forest Chena Degradation Time).

A.4.1 Native Forest Volume (VNF)

The volume of native forest is expressed in cubic meters of standing wood biomass. This volume sector tracks the flow of wood to and from native forest hectares. There are eight rates that affect the volume of native forest, two inflows and six outflows.

Native forest volume is augmented through an average annual net growth (NGNF) and through successional regeneration from jungle chena (VRJC).

Native forest volume is lost at project startup due to land transfers to the paddy and settlement (VTNFP, VTNFS). Volume is harvested through two rates: (1) subsistence agriculture and illegal fuelwood collecting, and (2) fuelwood harvesting for market and farm families.

Finally, native forest volume is lost due to lopping for livestock fodder (VNFLL). This rate becomes active when the collective livestock carrying capacities of parkland, paddy, and villus are exceeded and herders must seek other forage for their animals.

A.4.2 Fuelwood Plantations (FP); Figure A.27

Fuelwood plantations are the result of policies to convert degraded lands to plantations. This policy variable, RDL (Regeneration of Degraded Lands) is an adjustable parameter which can be set at any time during the simulation.

Fuelwood plantations are divided into 2 age classes: (1) Young Forest Plantations (YFP) that have a rotation time of 3.5 years; and (2) Mature Forest Plantations (MFP) with a 4-year rotation. Area additions to young forest plantations come from reforestation of degraded land (RDL); also, mature areas that have been harvested will, given proper management, be replanted as YFP. When the expertise required to manage plantation land is low, plantation land will degrade over time.

A.4.3 Fuelwood Plantation Volume (VFP); Figure A.28

The standing woody volume (cubic meters) in forest plantations is augmented by two rates and diminished by two others. Volume growth is augmented by Net Growth in Fuelwood Plantations (NGYFP and NGMFP) which accounts for the average annual productivity of the plantation. Young forest plantations grow at 4 cubic meters per year, mature forest plantations at 8.

Volume is reduced by the Volume Harvested from Fuelwood Plantations (VHFP) which depends on the volume in fuelwood plantations and the rotation time. Rotation times are shortened if there is perception of farm fuel shortages.

A.5 FUELWOOD SECTOR

The fuelwood sector consists of three explicit subsectors: (1) farm fuelwood use, (2) non-farm fuelwood use; and (3) fuelwood price. The current model version does not have a variable price formulation; this is a priority in further model development.

Fuelwood is the energy source of choice in the project. If fuelwood is scarce or too expensive, kerosene is used as a substitute by non-farm families. Although the farm families are assumed to have ready access to fuelwood, a fuelwood market exists for both farm and non-farm families.

A.5.1 Non-Farm Fuel Purchases; Figures A.29, A.30

To determine the amount of fuelwood purchased by non-farm families (NFF), the first step is to calculate the aggregate amount of fuelwood this subpopulation would consume were that amount both affordable and available. Thus the Non-Farm Purchased Fuel Requirements (NFPFR) is the product of non-farm families and Fuel Requirements Per Family (FRPF). This is equal to 3.6 cubic meters (124 cubic feet) (TAMS). The purchased fuel requirements are then divided into either fuelwood or kerosene purchases according to (1) the relative cost per meal (FWPPM, KPPM) of using either fuel; and (2) the ability of the non-farm family to afford the fuel. This last factor is determined by non-farm liquidity (NFL).

A.5.2 Farm Fuel Use; Figures A.31, A.32

Farm families use either fuelwood or agro-fuels as their primary energy sources. We assume that the people prefer fuelwood. Total Fuel Demand from Farm Families (TFDFF) is calculated based on the product of farm families (FF) and fuel requirements per family (FRPF). Given this amount, farm families collect what they can from fuelwood plantations. If there is still a shortfall after plantation harvests, farm families then may obtain permits to collect fuelwood in the most accessible native forest areas. The fuel of third choice for farm families comes from the fuelwood market. The fourth fuel of preference is obtained through illegal poachings from native forest areas. Finally, if a shortfall exists after all fuelwood sources have been used, farmers will use agro-fuels, i.e. crop residues and dung, for their fuel needs.

Accessibility of the native forest is based on three factors: (1) the area in native forest; (2) the volume of forest on that land; and, (3) the density of the population relative to the native forest areas. As mentioned above, this accessibility index (NFAI) affects the amount of fuelwood harvested by farm families from native forests. The notion here is that, as accessibility decreases and farm family members must spend a greater portion of their time collecting wood, the alternative fuel sources become more attractive.

A.5.3 Management Expertise; Figures A.33, A.34

Management expertise (ME) is the capability of project area natural resource managers to manage the forest plantations, wildlife, and national parks of the project area. This is expressed as a ratio of the expertise on hand relative to that needed for full, competent management of the natural resources of concern.

Expertise on hand is expressed as the product of the number of project area resource managers (PANRM) and the expertise per manager (EPANRM). PANRM is a level increased by recruitment (RPANRM). RPANRM is a policy variable that can be adjusted by the user. The number of managers declines naturally due to expected turnover (TPANRM). The average term of residence is assumed to be 18 years.

Expertise is also a level ranging from 0 to 1 (total incompetance to absolute mastery). Expertise increases with recruitment (each recruit brings an average expertise of 0.2). Expertise increases by .035 per manager per year. This expertise is lost as managers depart.

The required management expertise (that needed to manage the project natural areas) is expressed as a product of the desired number of managers (DPANRM) and the maximum management expertise per manager (MMEPM = 1.0). Desired number of managers is the sum of the optimal number of resource managers for each of the three resource areas (forest plantations, wildlife, and national parklands). The requirements are assumed to be 1 manager per 200 Ha of forest plantations, 1 per 200 Ha of national parkland, and 50 for wildlife management (increasing when wildlife populations become low to account for increased need to protect against poaching, etc.).

A.6 WILDLIFE SECTOR

One of the most deleterious impacts of the project will be on habitat of indigenous wildlife species. In a very real sense, wildlife are the victims of the project. While the activities within the project area severely influence the wildlife, wildlife in turn have minimal impact within the project area (ignoring potential income from tourists to view animals). To a large extent, we can infer the integrity of wildlife habitats from the changes in land use that occur during the project. The richest wildlife habitats are found in the transition areas between adjacent ecosystem types as well as within the native forest. Thus, as these land categories change, so does the wildlife population and speciation.

The current model version explicitly models four wildlife species: elephants, leopards, axis deer, and langur monkeys. These species are used as indicators to the general wildlife habitat quality in the project area.

A.6.1 Elephant Sector (EP); Figure A.35

The Asiatic elephant is a rare and important resident of the project area. The number of elephants (E) in the project area is a level that is changed by three rates: elephant birth rate, poaching rate of elephants, and the elephant mortality rate.

The elephant birth rate (EBR) is the product of the number of elephants by the elephant birth fraction (%/yr). The birth fraction is assumed to be 0.08 or 8 elephants born per 100 live elephants per year.

The poaching rate of elephants is a more complex formulation that is calculated by multiplying the elephant population by the fraction of elephants poached each year (FEP). The fraction of elephants poached is the product of 3 factors: a normal fraction (NFEP = 0.05), an effect from per capita income, and an effect of managerial expertise. As the per capita incomes of both the farm and non-farm populations decline, pressures to poach elephants rise. This pressure can be stemmed if the requisite amount of managerial expertise

is operative within the project area. An insufficient amount of management expertise indicates that poaching is easier than normal. Hence, in this case, poaching actually increases. With high per capita incomes and high management expertise, however, poaching pressures are defused and can be erased entirely under fortuitous circumstances.

The elephant mortality rate (EMR) is calculated by dividing the number of elephants by the average elephant lifetime (AEL). The average elephant lifetime is composed of a normal (NAEL = 65) multiplied by an effect of elephant habitat on the normal lifetime. If elephants exceed the elephant carrying capacity (ECC), the average elephant lifetime diminishes. On the other hand, elephants may live long if their numbers are well within their carrying capacity.

Elephant Carrying Capacity (ECC) is composed of six habitat varieties and their corresponding carrying capacities: 1 elephant for every 10,000 Ha of native forest; 3 elephants for every 1,000 Ha of parkland; 3 elephants per 1,000 Ha of chena; 8 elephants for every 10,000 Ha of forest plantation; 1 elephant for every 1,000 Ha of cropland edge; and, 3 elephants for every 1,000 Ha of villu.

A.6.2 Leopards; Figure A.36

Leopards are also a rare and valuable wildlife indicator species of the project area. As with the elephants, leopards are affected by three rates: leopard birth rate (LBR), leopard poaching rate (LPR), and leopard mortality rate (LMR).

Leopard birth rate is the product of the number of leopards (L) by the leopard birth fraction (LBF). The leopard birth fraction is assumed to be 0.175 (17 per 100 leopards per year).

The leopard poaching rate is analogous to the elephant poaching rate. It is derived by multiplying the level of leopards by the fraction of leopards poached (FLP). The fraction of leopards poached is composed of a normal fraction (NFLP = 0.05) multiplied by effects from poaching and management expertise.

The leopard mortality rate is calculated by dividing the number of leopards by the average leopard lifetime (ALL). The average leopard lifetime is composed of three factors: the normal average leopard lifetime (NALL = 10), the effect of leopard habitat on leopard lifetime, and the effect of leopard predation success on leopard lifetime.

The effect of leopard habitat on leopard lifetime is calculated by taking the ratio of the number of leopards to the leopard carrying capacity (CCL). If there are more leopards that can be supported, average lifetime decreases. Alternatively, if there are fewer leopards than their habitat can support, the average lifetime increases. Leopard carrying capacity is composed of five habitat types and their corresponding carrying capacities: 1/1,000 Ha of native forest; 1/1,000 Ha of parkland; 1/100 Ha of chena; 1/10,000 Ha of cropland edge; and 2/1,000 Ha of villu.

The effect of leopard predation success on leopard lifetime (ELPSL) is a synergistic combination of the effects from axis deer predation success (EDPSLL) and from langur monkey predation success (EMPSLL). These are predator-prey systems that regulate the populations of the three wildlife types. The leopard -- deer predator-prey system is based on an assumed equilibrium population of 20:1. That is, all else being equal, twenty deer for every leopard will create an equilibrium for each population. More deer relative to leopards will increase leopard predation success, and so on. The langur monkey loop works the same way.

A.6.3 Langur Monkeys; Figure A.37

The population model for Langurs is essentially the same as for elephants and leopards (LM = Langur Monkey Population, LMBR = birth rate, LMMR = mortality rate). The langur birth fraction (LMBF = 0.275 or 27/100 per year).

Mortality (LMMR) is given by dividing LM by the average lifetime (ALMLT). ALMLT is the product of three factors: the normal monkey lifetime (NALMLT = 4), the effects of habitat and leopard predation.

As with the other species, the effect of habitat (ELMHAL) is the ratio of langurs to the carrying capacity (LMCC). LMCC is composed of seven habitat types and their corresponding carrying capacities. 15/100 Ha of native forest; 7/100 Ha of parkland; 8/100 Ha of chena; 2/100 Ha of forest plantation; 8/100 Ha of cropland edge; 2/10 Ha of villu; and 6/100 Ha of settlements. Population depends on habitat and leopard predation success as discussed above.

A.6.4 Axis Deer; Figure A.38

Axis deer (AD) are the final indicator wildlife species. The population model is similar to elephant and leopard with three rates affecting the level of deer (ADBR = birth rate, ADPR = poaching rate, ADMR = mortality rate). ADBR = 0.25 (25 per 100). Poaching rate is analogous to elephant and leopard rates, which is the product of AD and FADP (fraction of axis deer poached). FADP is the normal poaching fraction (NFADP = 0.1) multiplied by effects from per capita income and management expertise.

Mortality rate is AD divided by average deer lifetime (ADLT). ADLT is the product of normal lifetime (NADLT = 8), the habitat effect, and the leopard predation effect.

As with langur, the predation effect (ELPADL) assumes an equilibrium of 20:1. The habitat effect (EADHAL) is the ratio of AD to carrying capacity (ADCC). ADCC is composed of seven habitats as above: 5/10,000 Ha of native forst; 1/100 Ha of forest edge; 5/100 Ha of parkland; 4/100 Ha of chena; 5/100 Ha of forest plantation; 1/100 Ha of cropland edge, and 4/100 Ha of villu.

Cropland edge is the product of total cropland (TCL) by the assumed fraction of edge (FECL = 0.05). Total cropland is the sum of paddy (P) and homestead land (HL) which is assumed to be 80% of the total settlement area.

Similarly, forest edge is the product of native forest area (NF) by an assumed edge ratio (FNFNFE) which is the product of a normal fraction (NFENF = 0.025) and the effect of diminished native forest (EDNFAE). This factor accounts for pockets of open area created by transfer of native forest to other sectors.

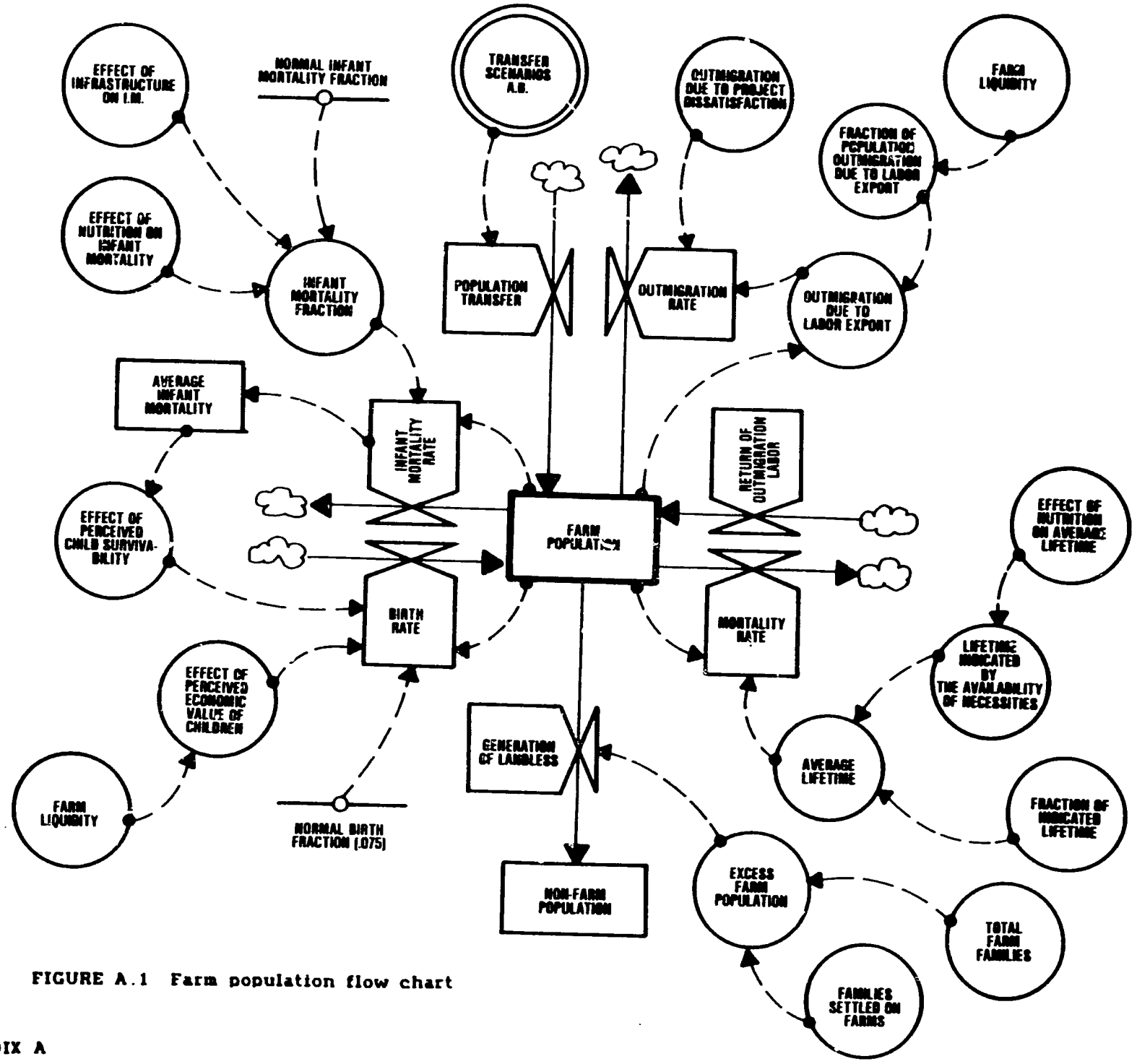


FIGURE A.1 Farm population flow chart

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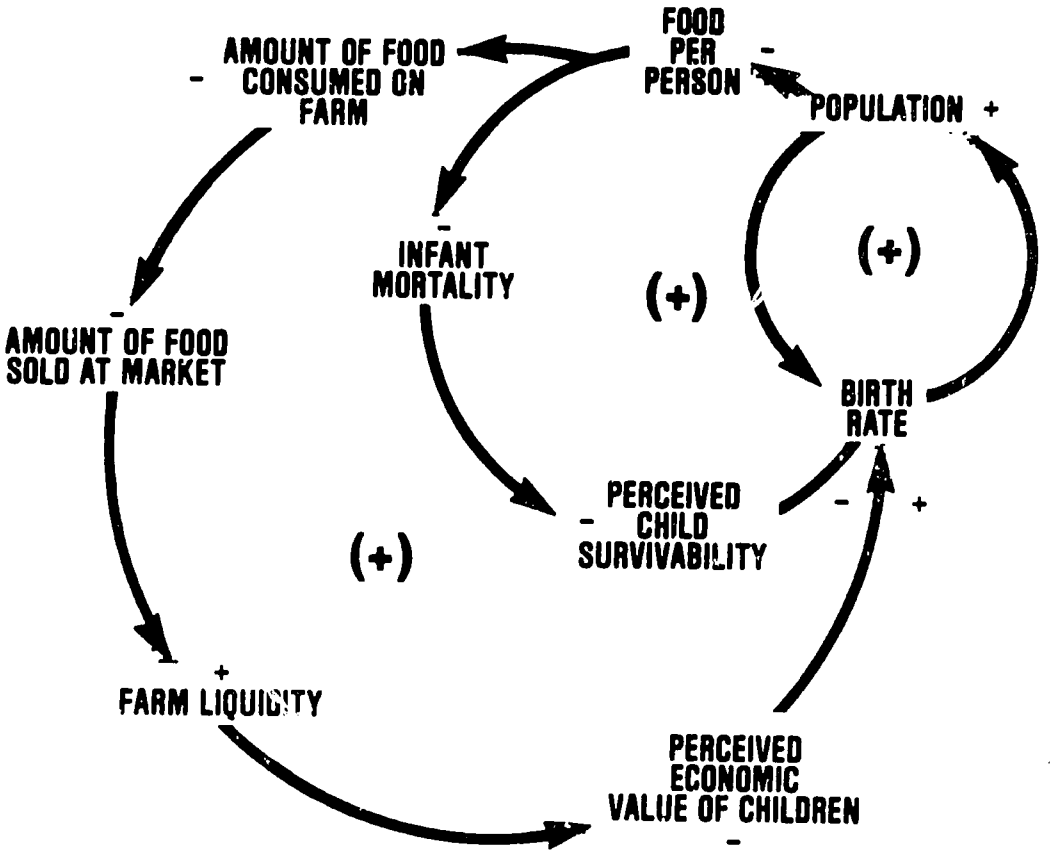

FIGURE A.2

THREE REINFORCING POSITIVE FEEDBACK LOOPS THAT CAN GENERATE POPULATION GROWTH.

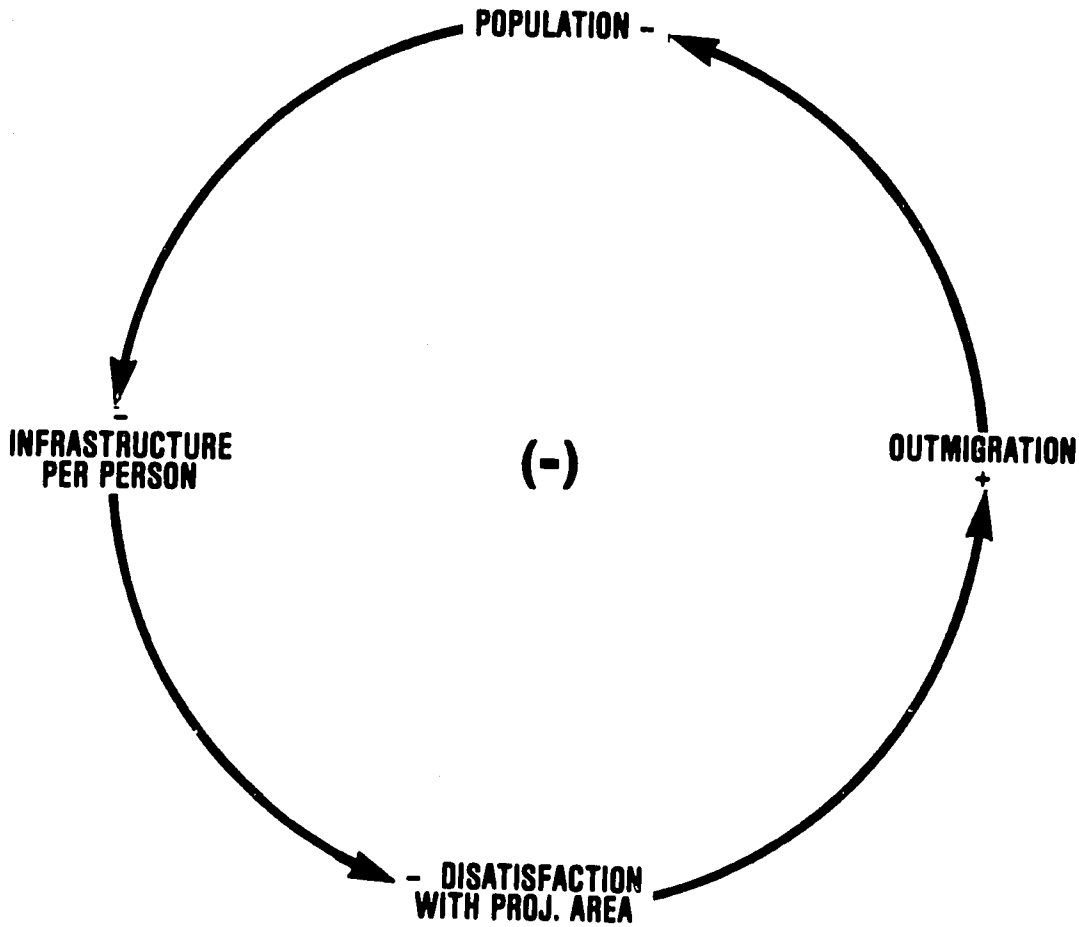

FIGURE A.3

INSUFFICIENT INFRASTRUCTURE TO MEET THE NEEDS OF THE POPULATION CAN CREATE DISSATISFACTION WITH THE PROJECT. THIS LEADS TO INCREASED OUTMIGRATION:
A NEGATIVE FEEDBACK LOOP THAT SEEKS TO CONSTRAIN POPULATION TO WITHIN THE "CARRYING CAPACITY" OF INFRASTRUCTURE.

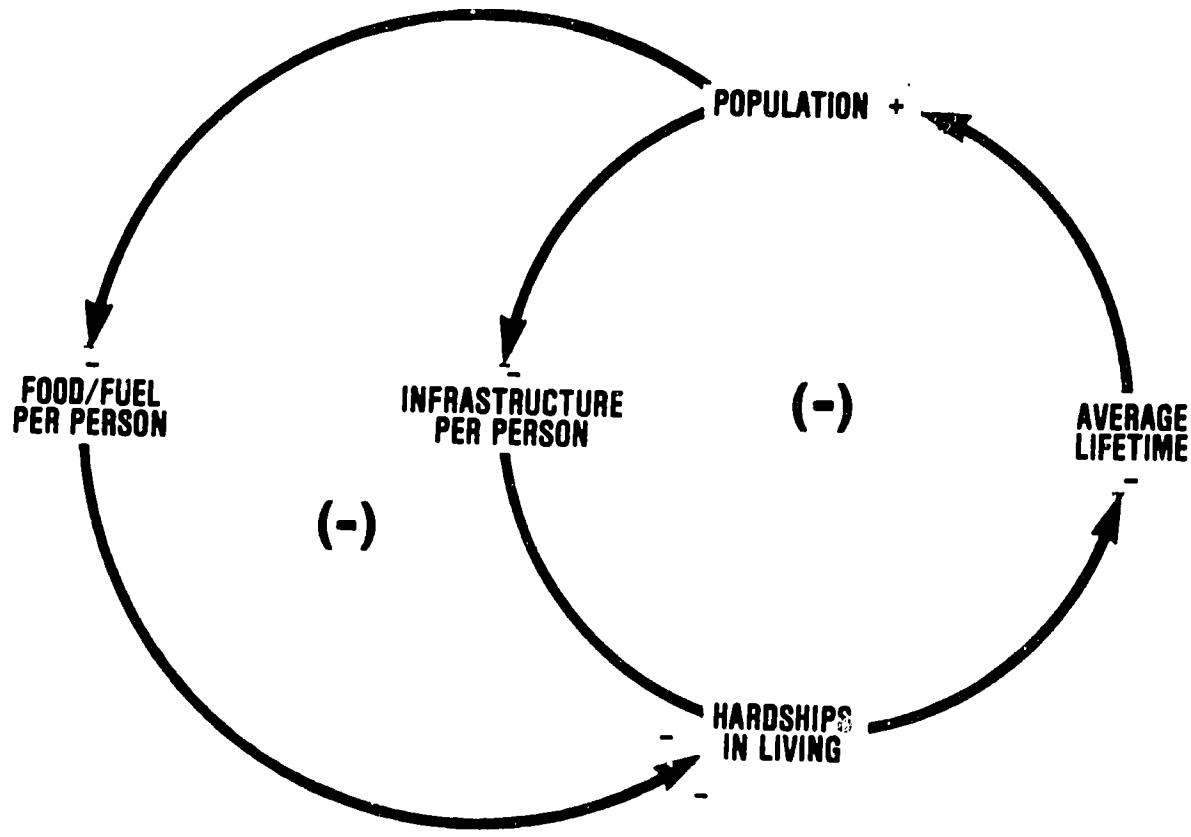

FIGURE A.4

TWO CONSTRAINTS ON POPULATION GROWTH:
1) LOWER INFRASTRUCTURE PER PERSON.
2) LESS FOOD AND FUEL PER PERSON.
BOTH CREATE HARDSHIPS IN LIVING THAT ACT TO DECREASE THE LIFE EXPECTANCY OF PEOPLE.

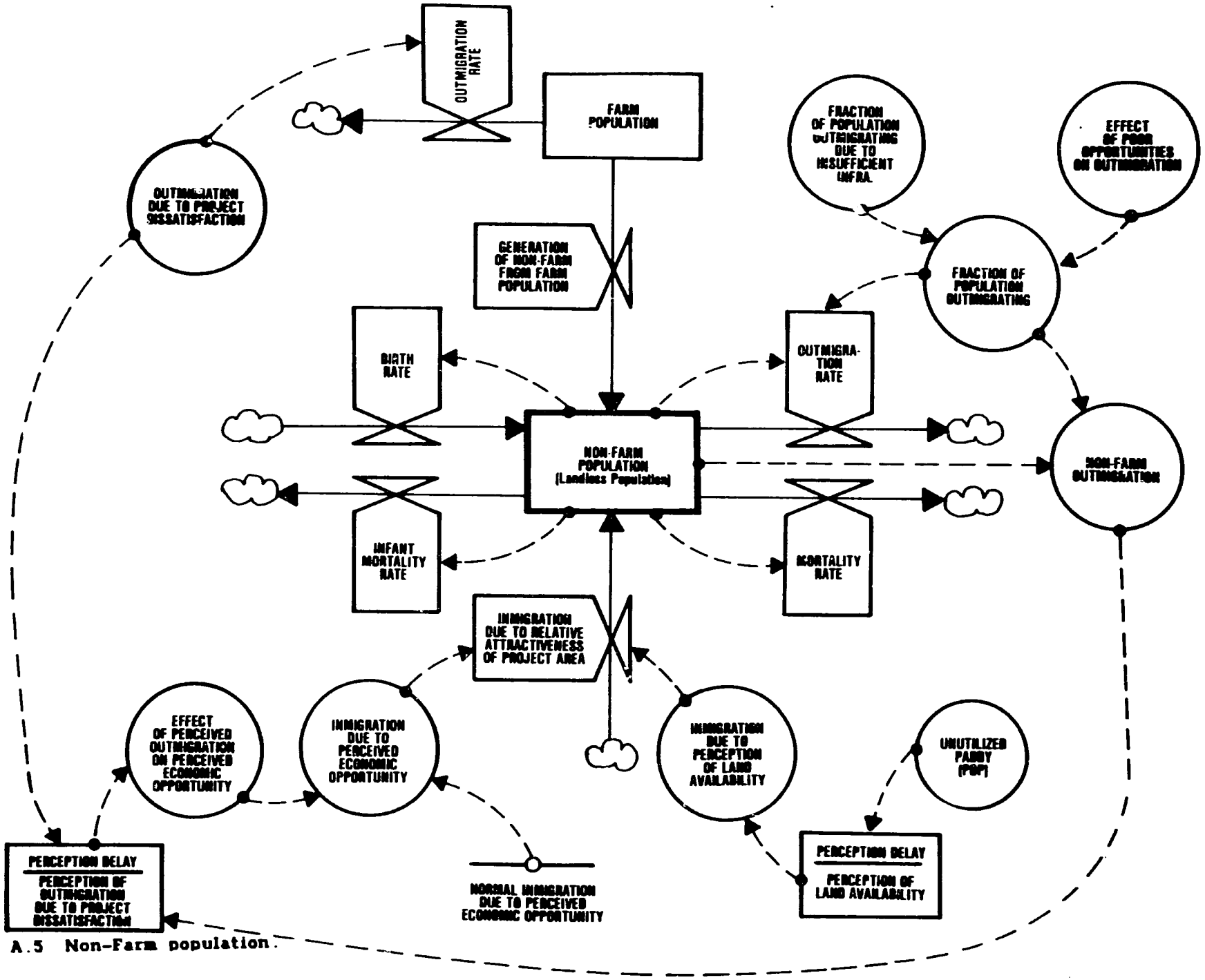

FIGURE A.5 Non-Farm population.

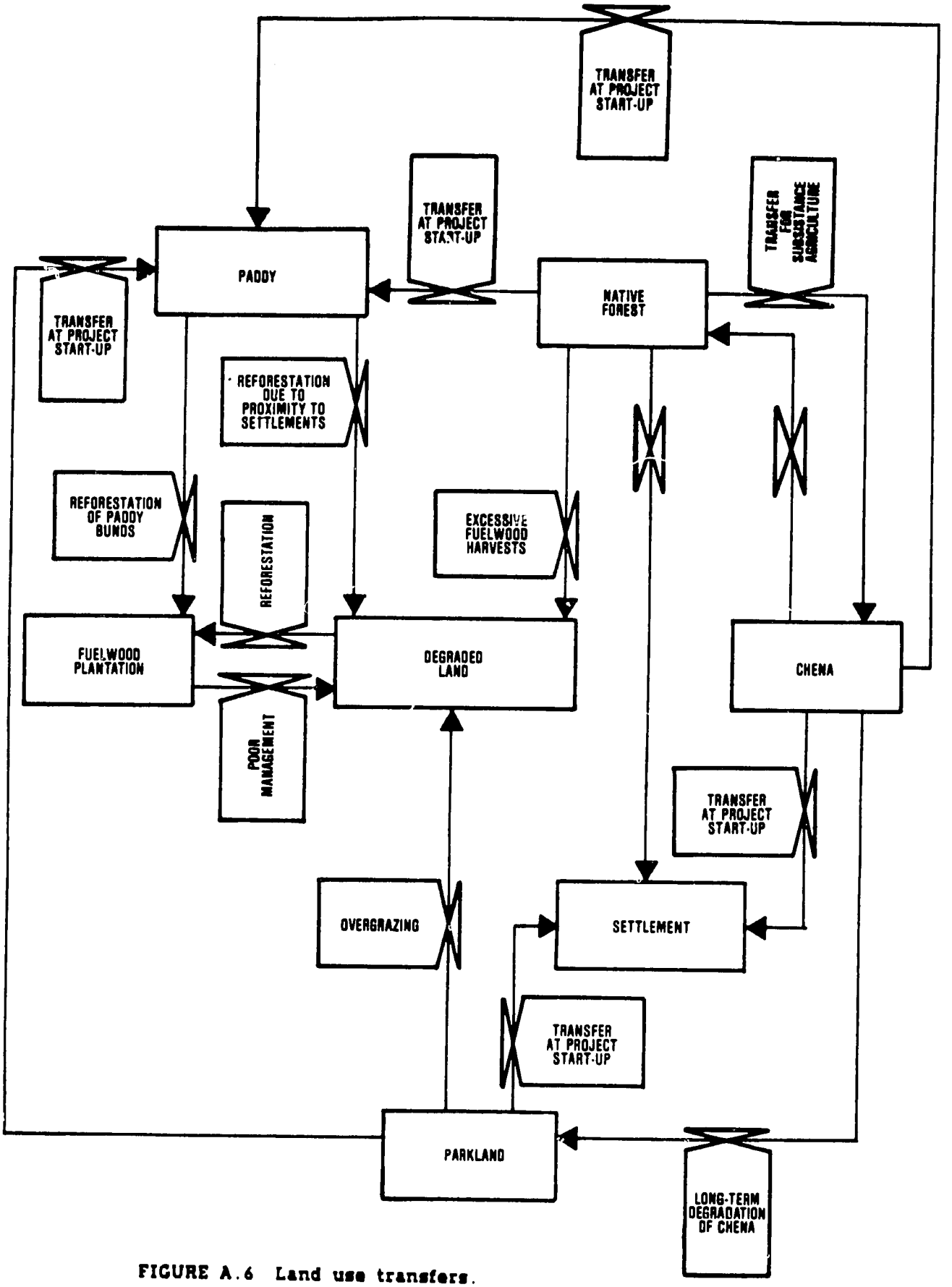

FIGURE A.6 Land use transfers.

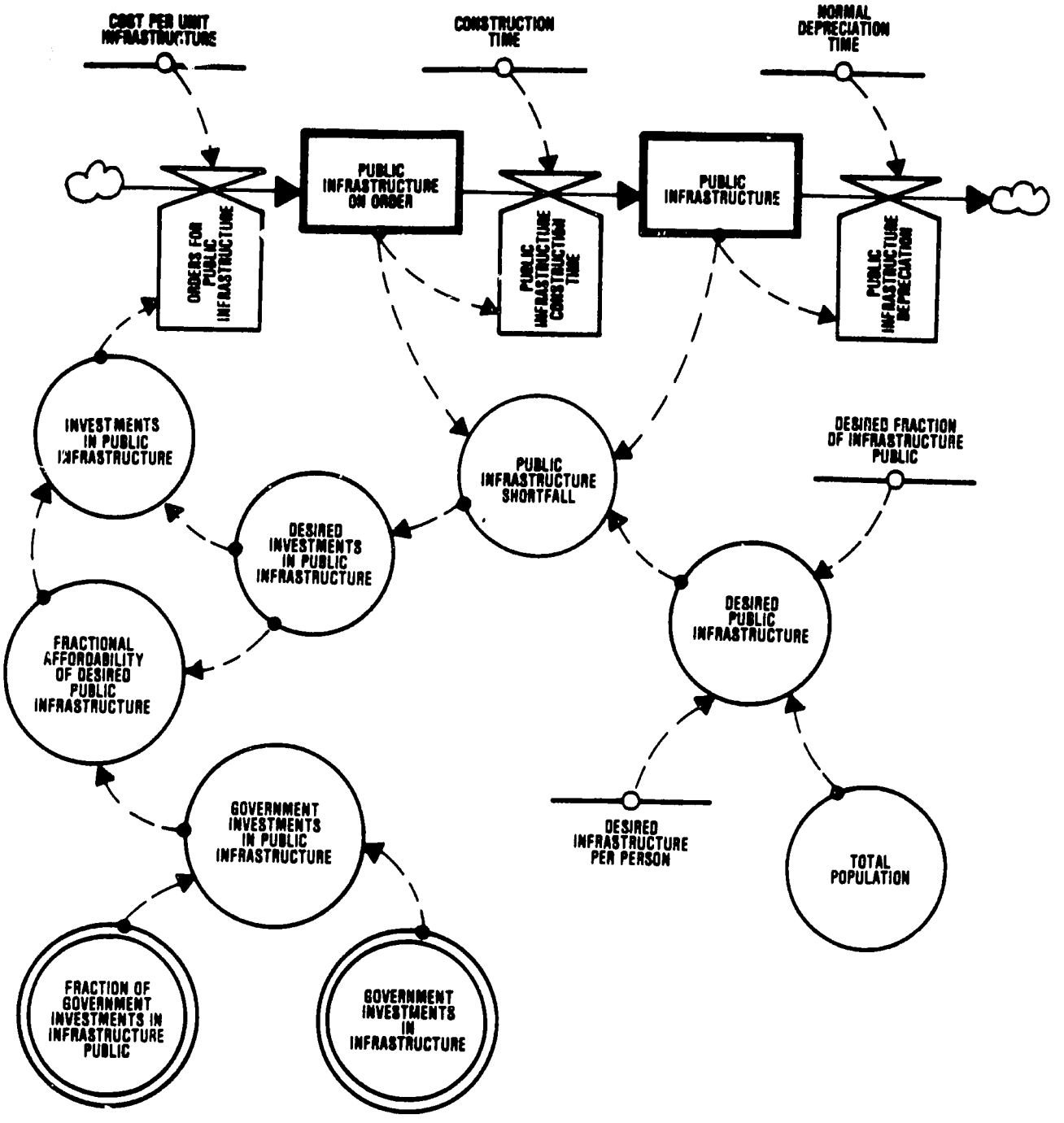

FIGURE A.7 Public infrastructure (schools, housing, Hospitals, Political Institutions, etc.)

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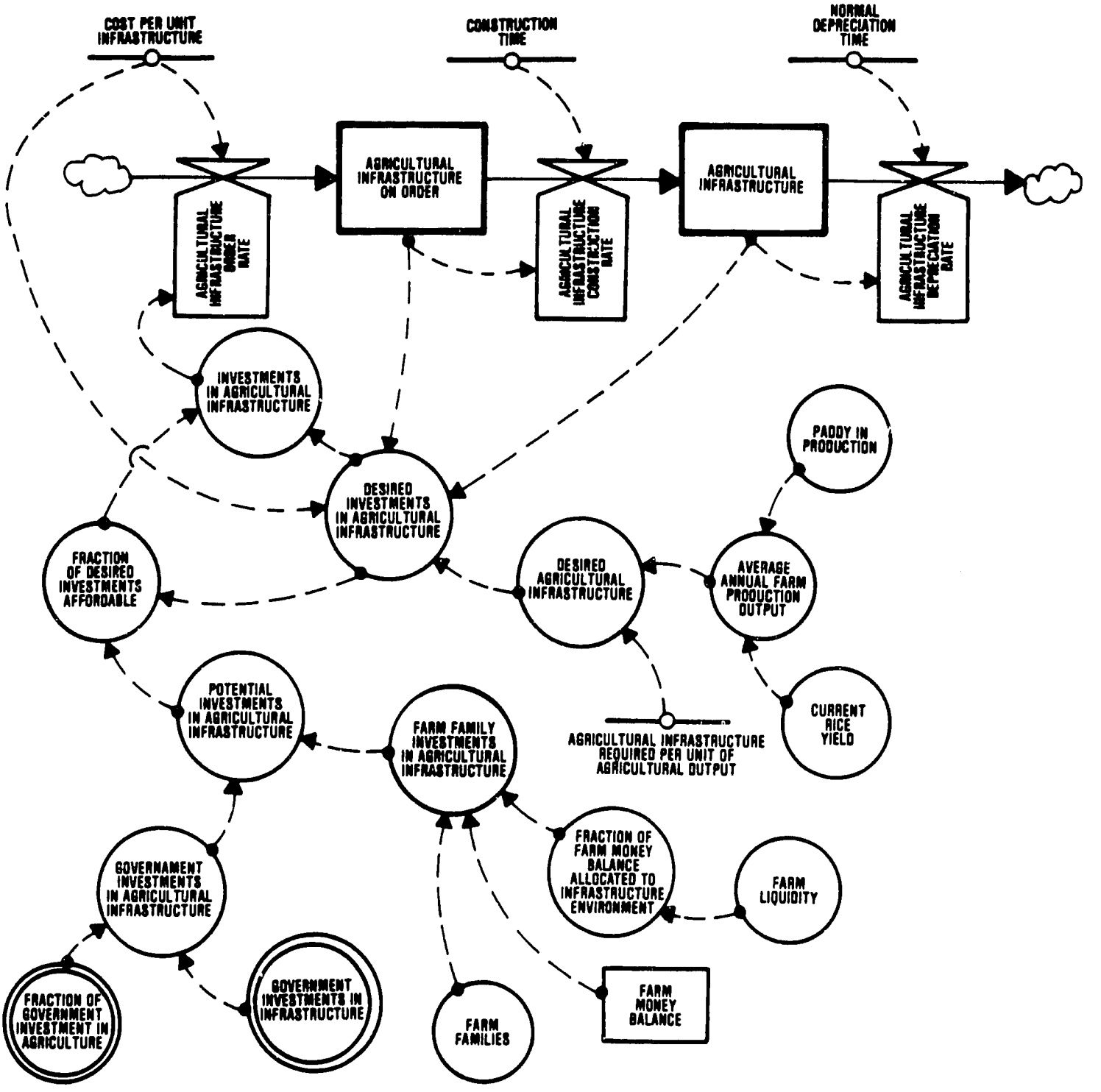

FIGURE A.8 Agricultural infrastructure.

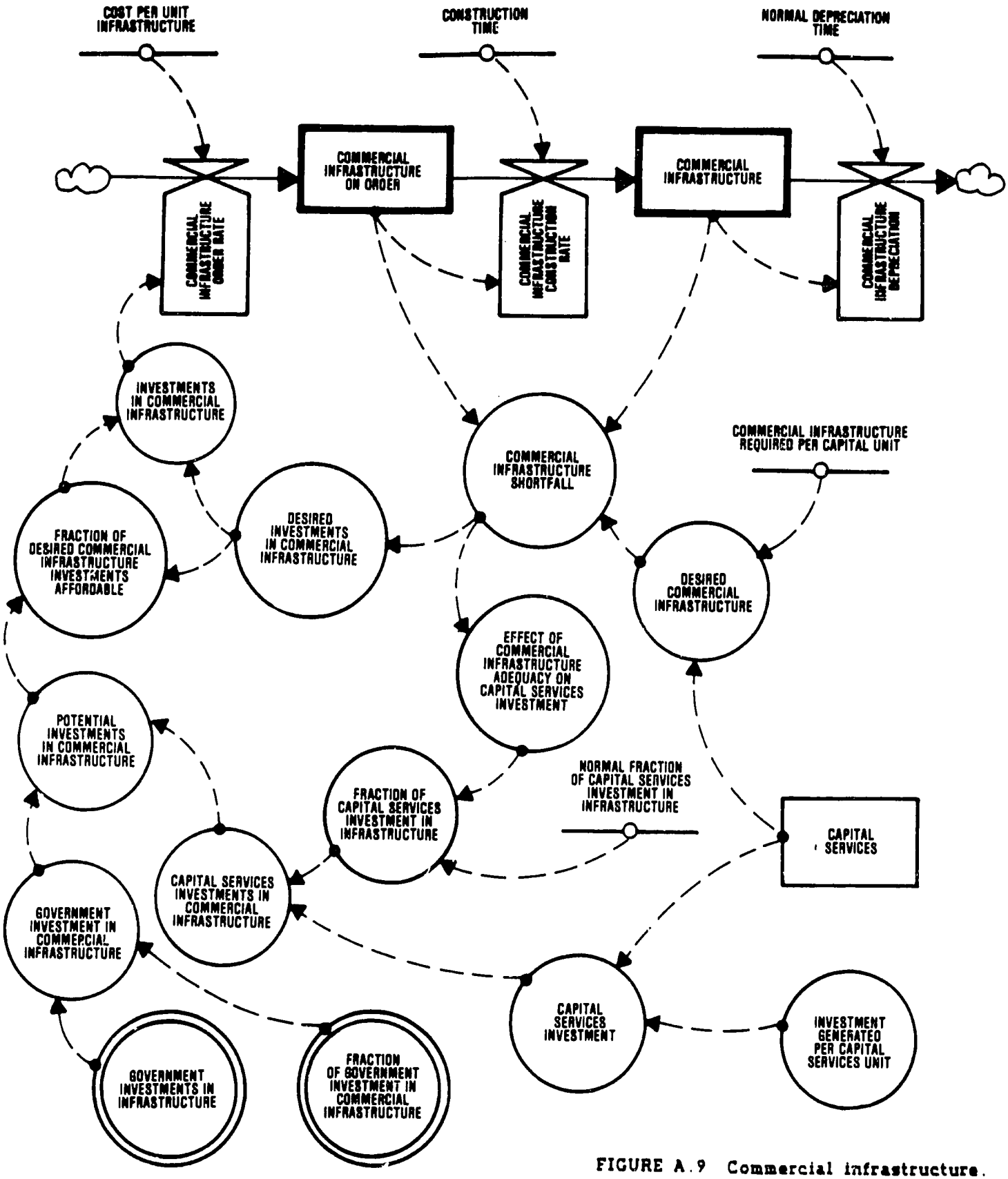

FIGURE A.9 Commercial infrastructure.

FIGURE A.10 Farm money balance.

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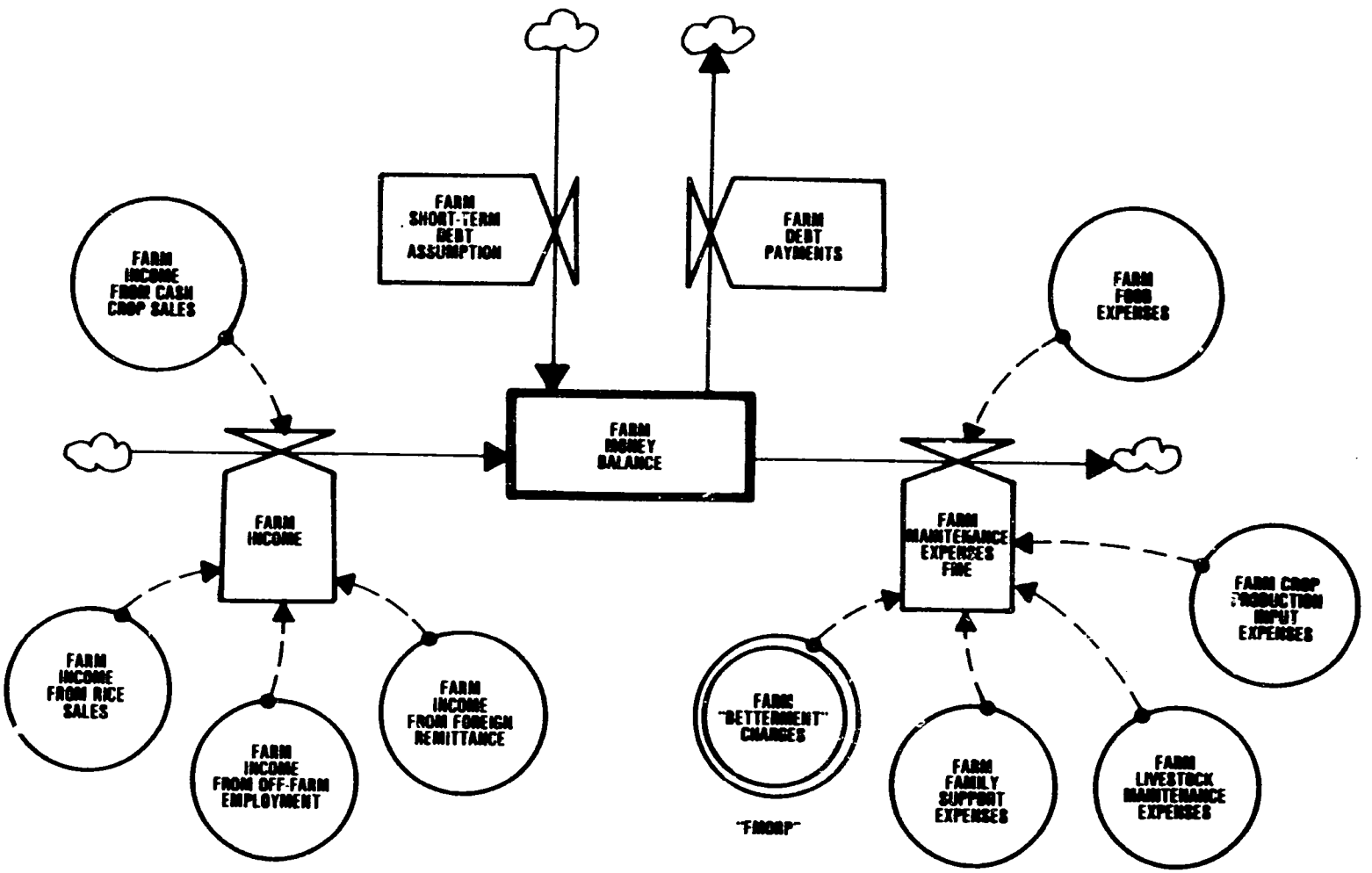

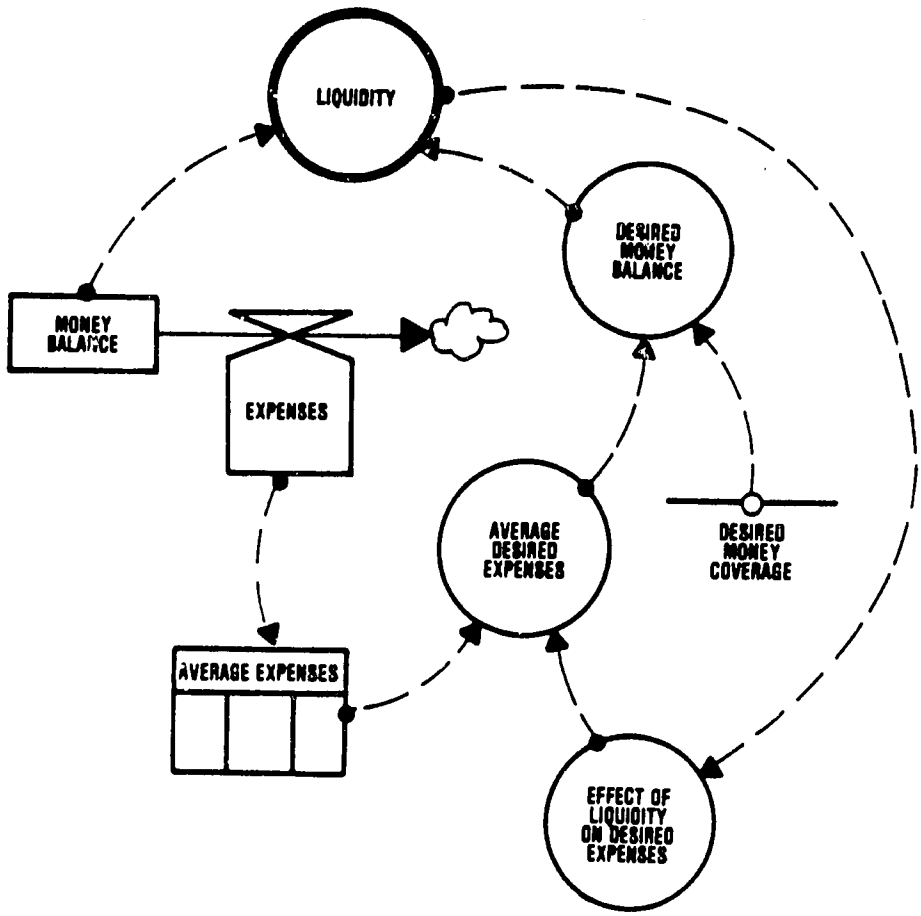

FIGURE A.11 Generalized liquidity formulation.

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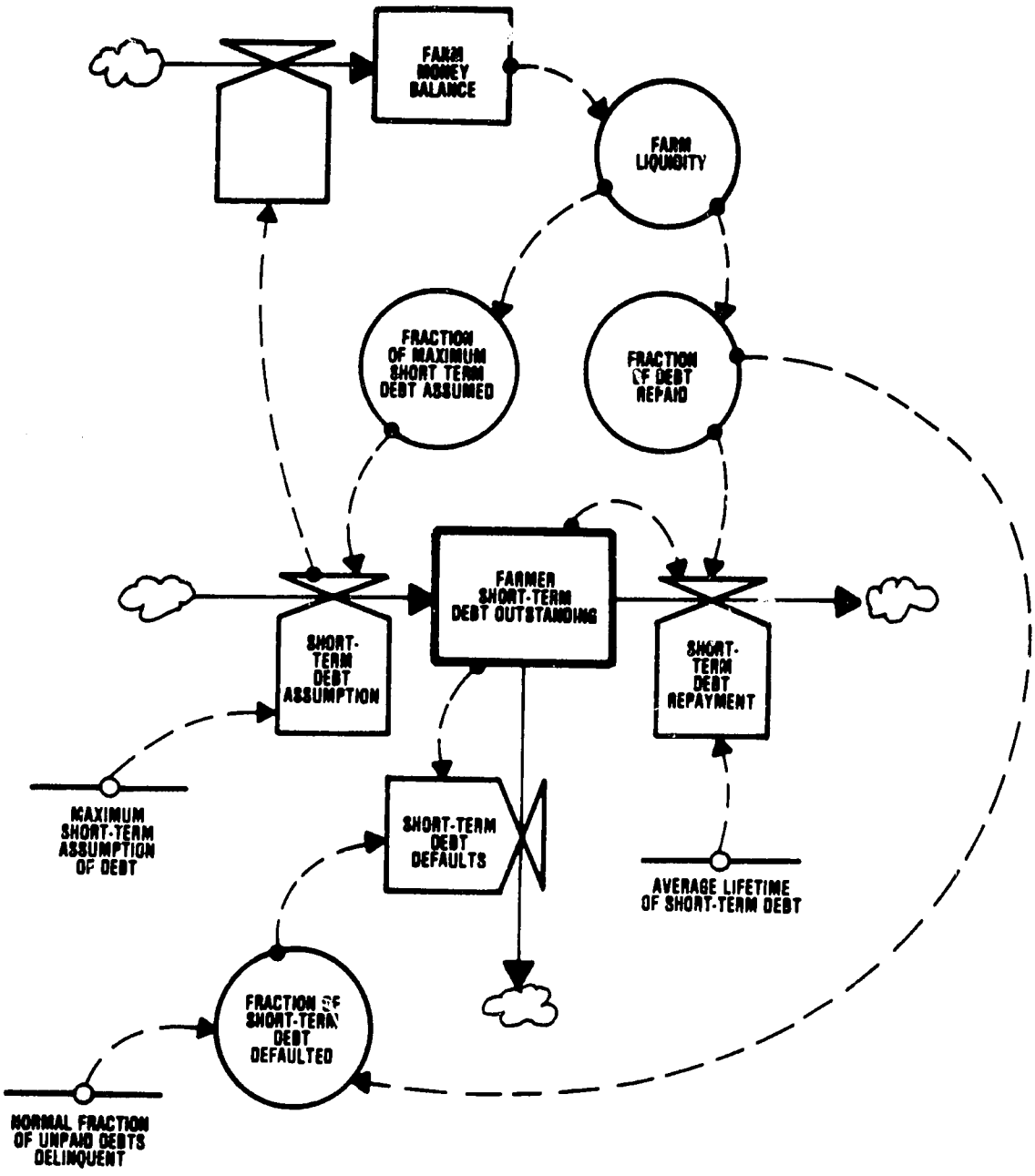

FIGURE A.12 Farmer Debt.

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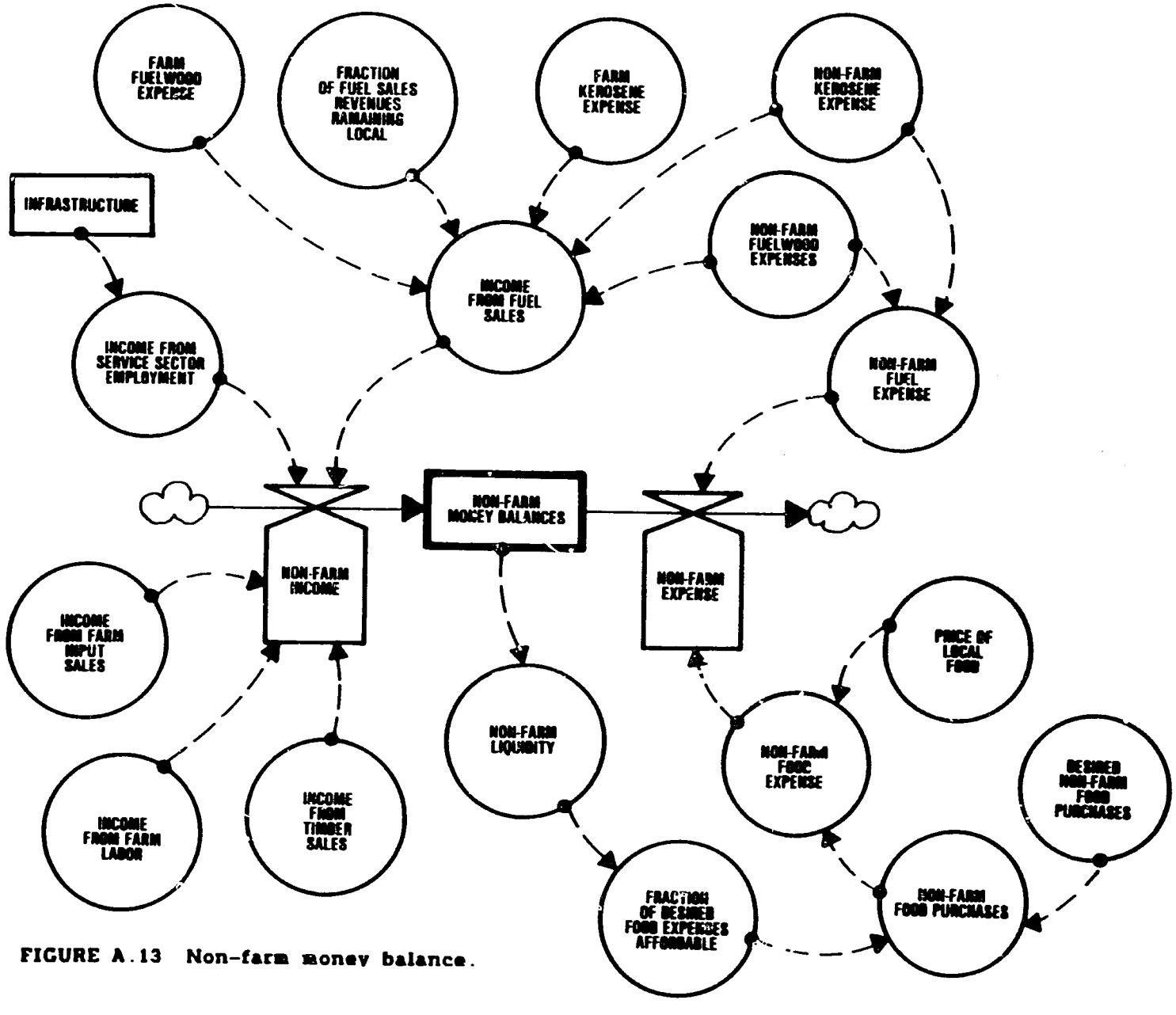

FIGURE A.13 Non-farm money balance.

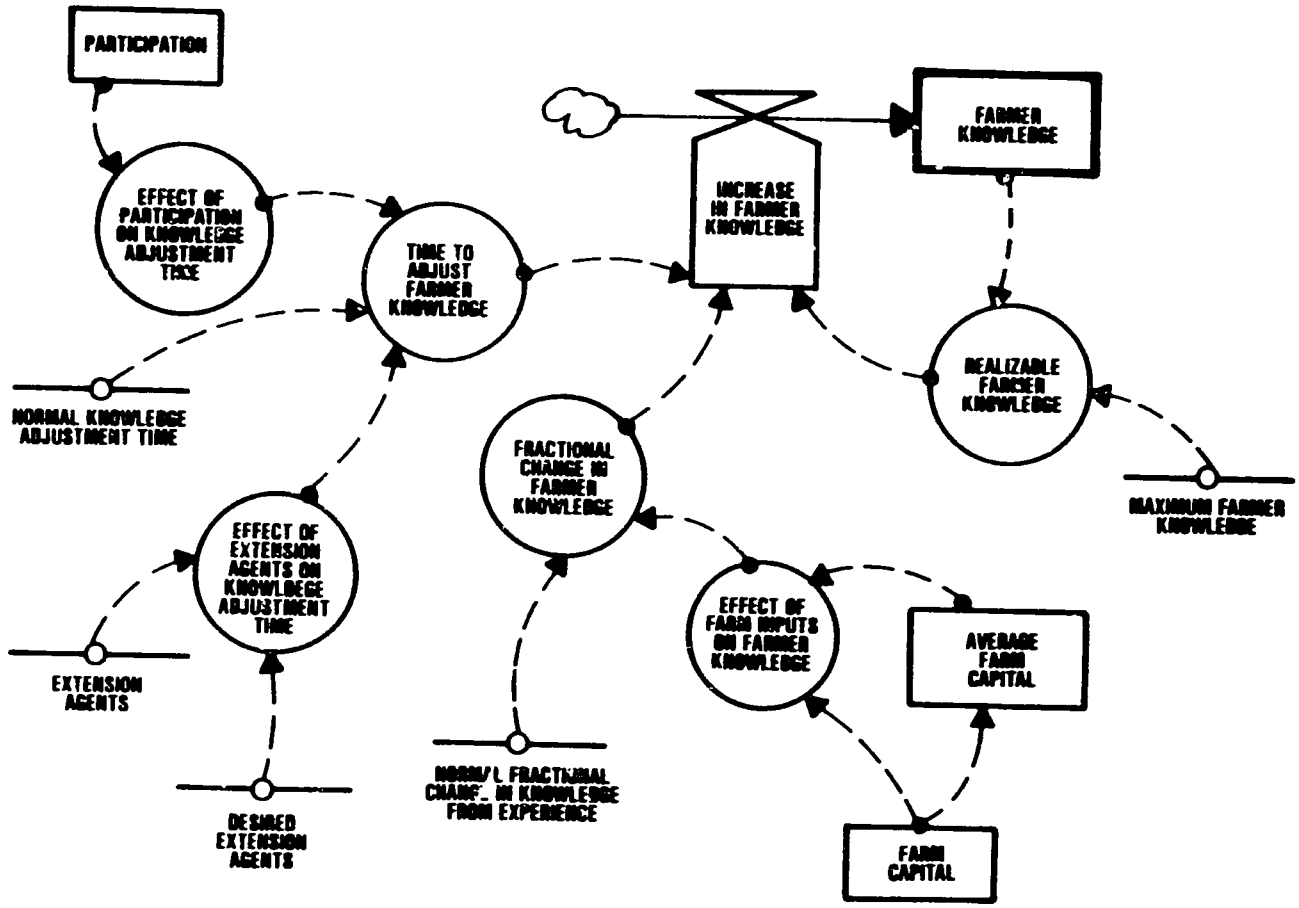

FIGURE A.14 Farmer knowledge.

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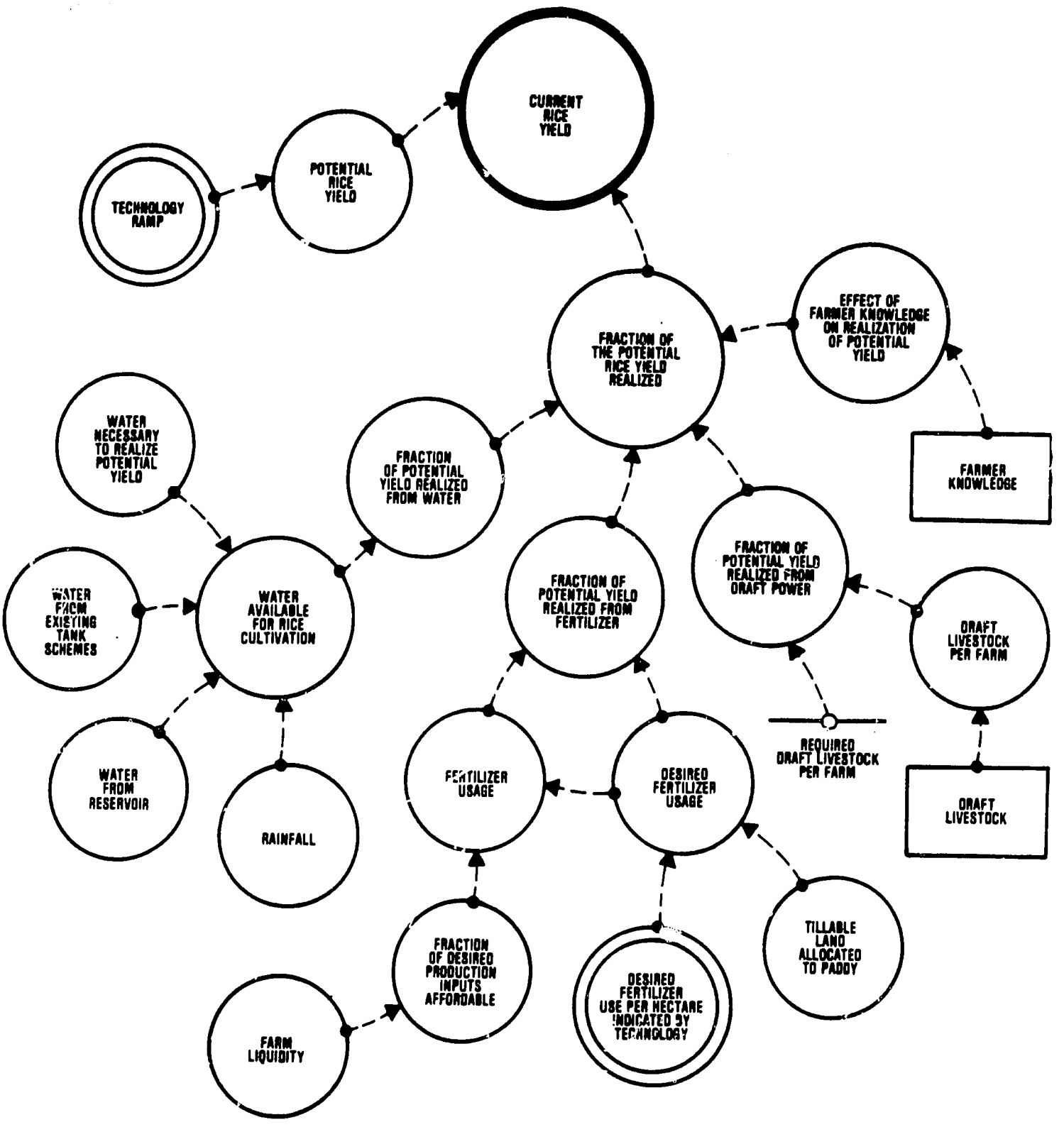


FIGURE A.15 The components of current rice yield.

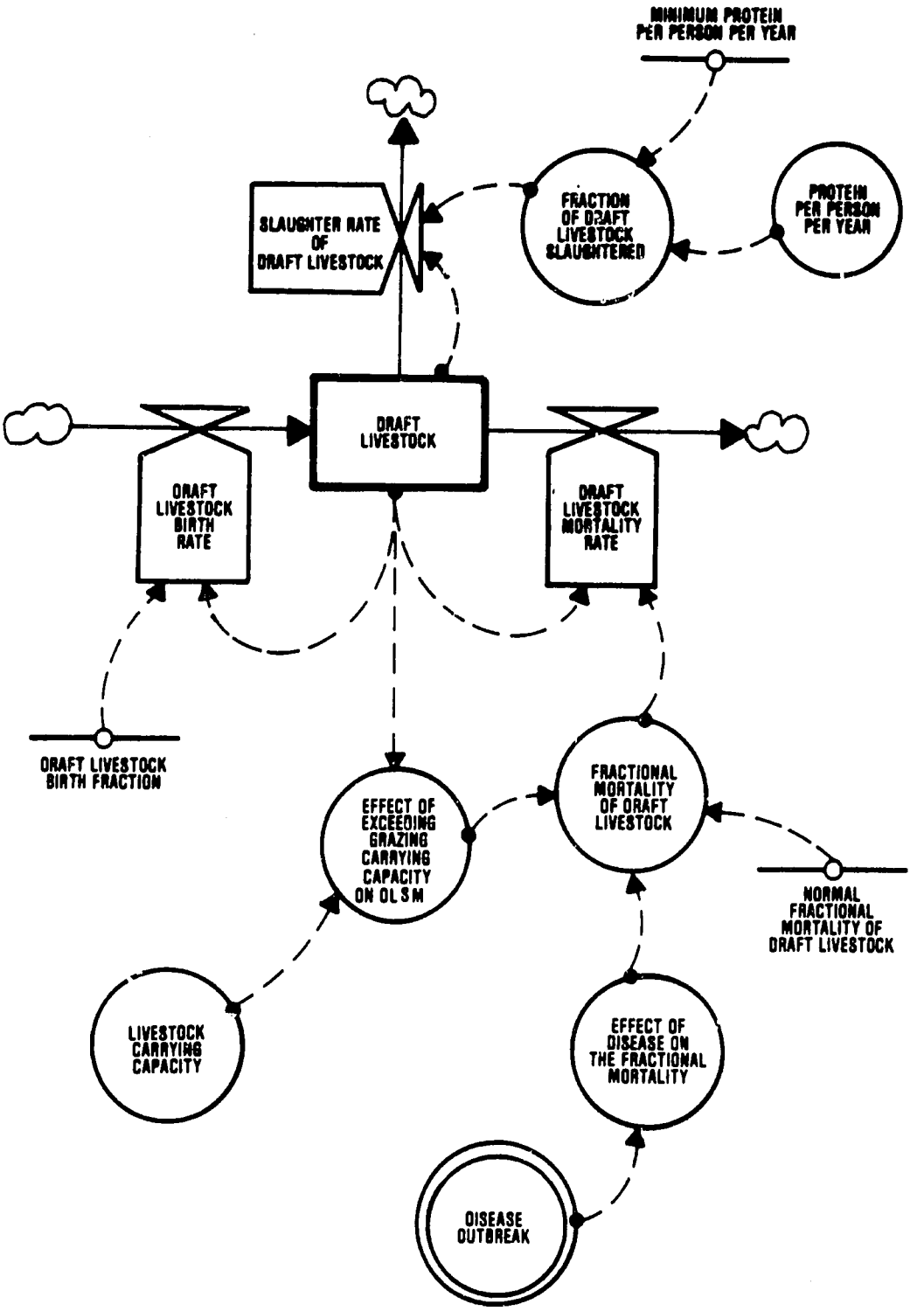


FIGURE A.16 Draft livestock.

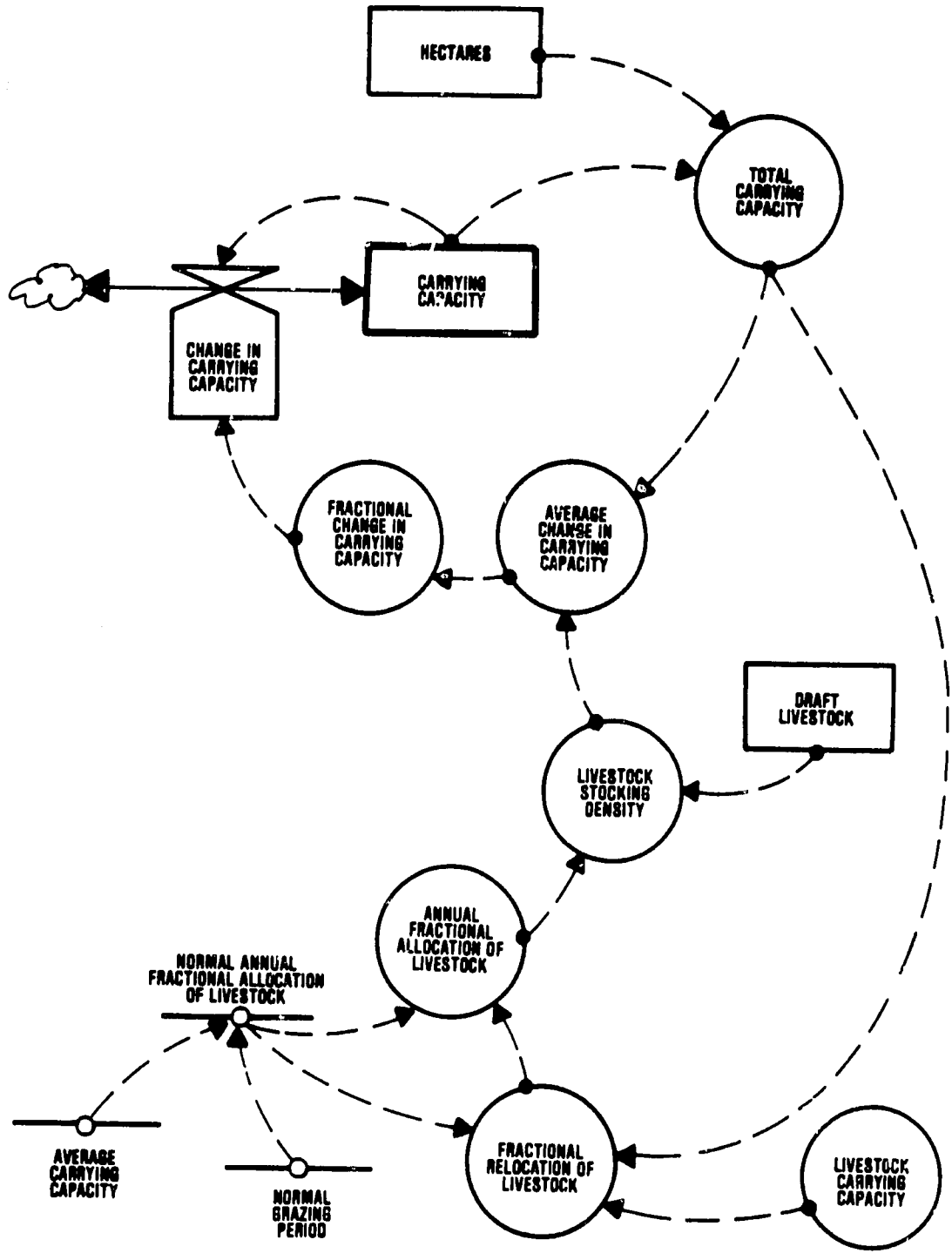


FIGURE A.17 Generic form of the carrying capacity formulation.

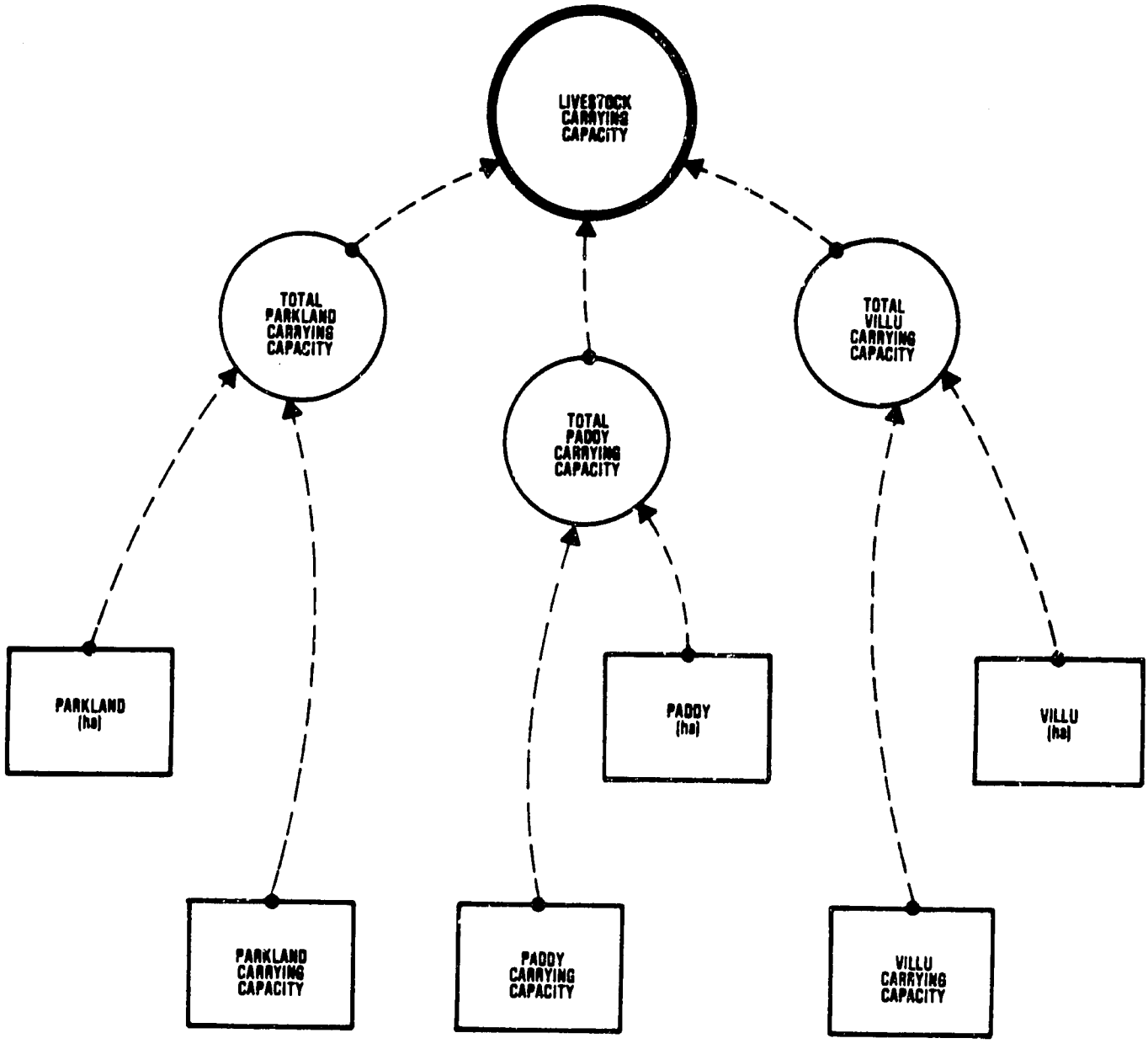


FIGURE A.18 Determinants of livestock carrying capacity.

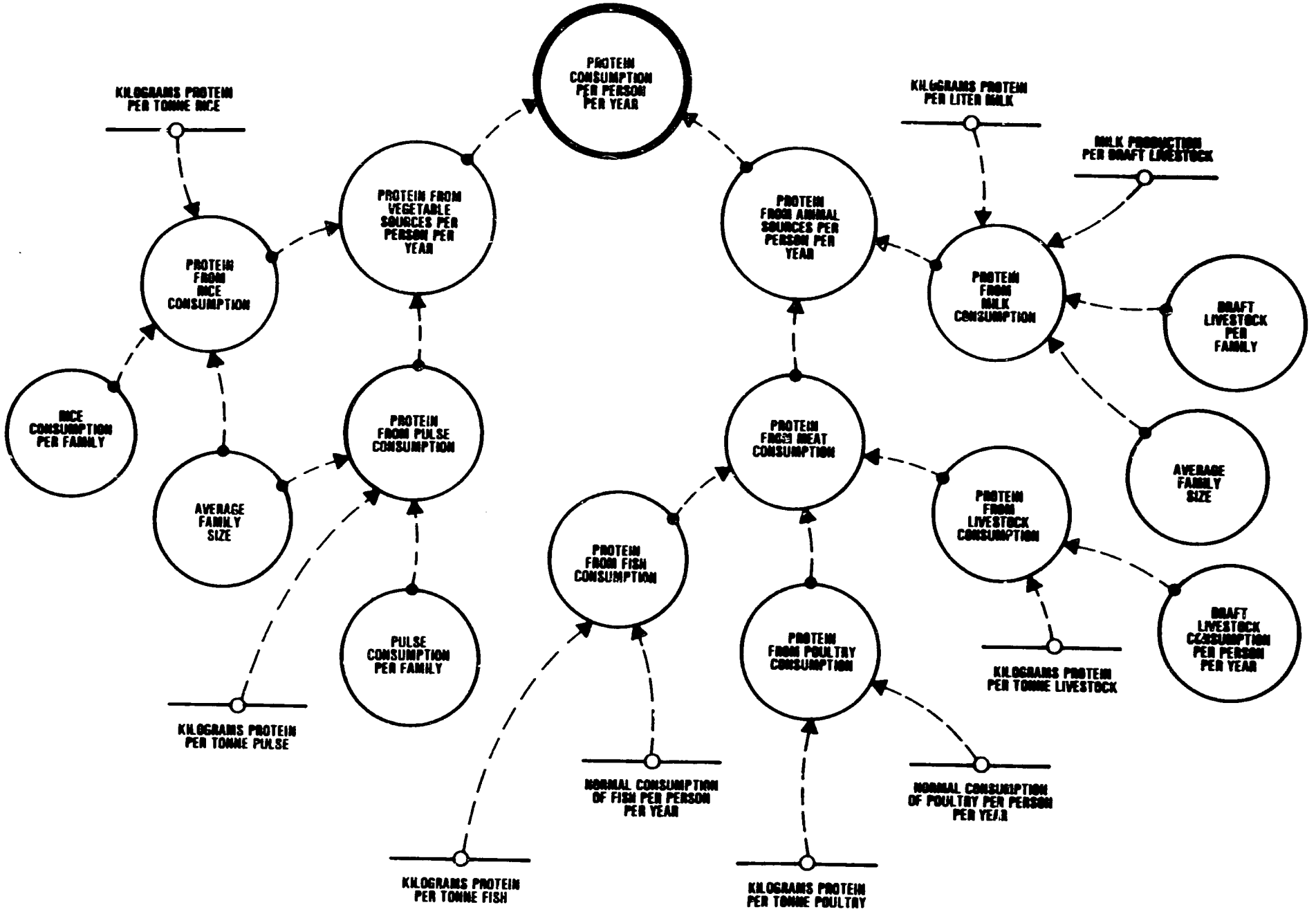


FIGURE A.19 Protein consumption per person (same as calorie consumption).

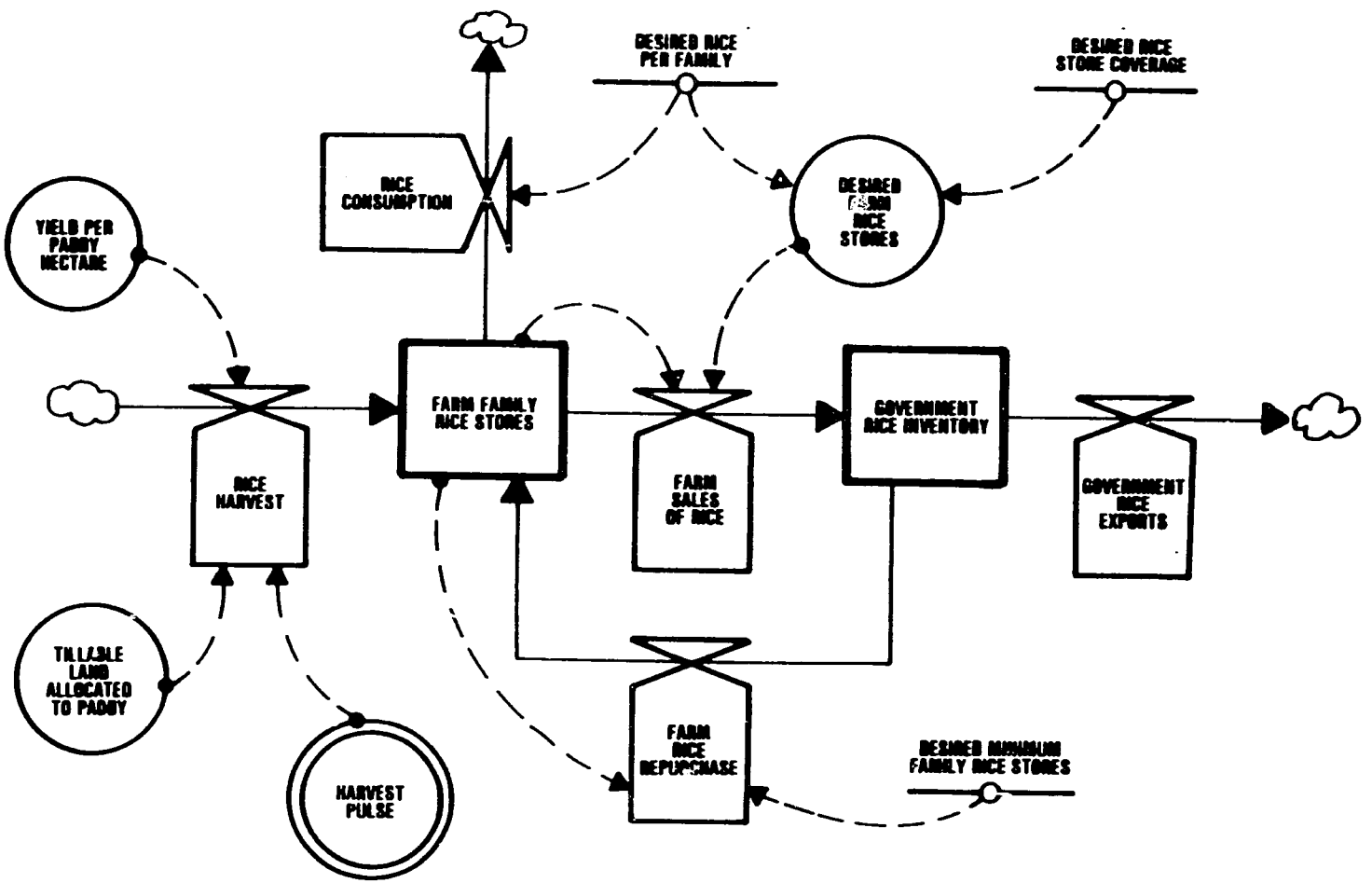
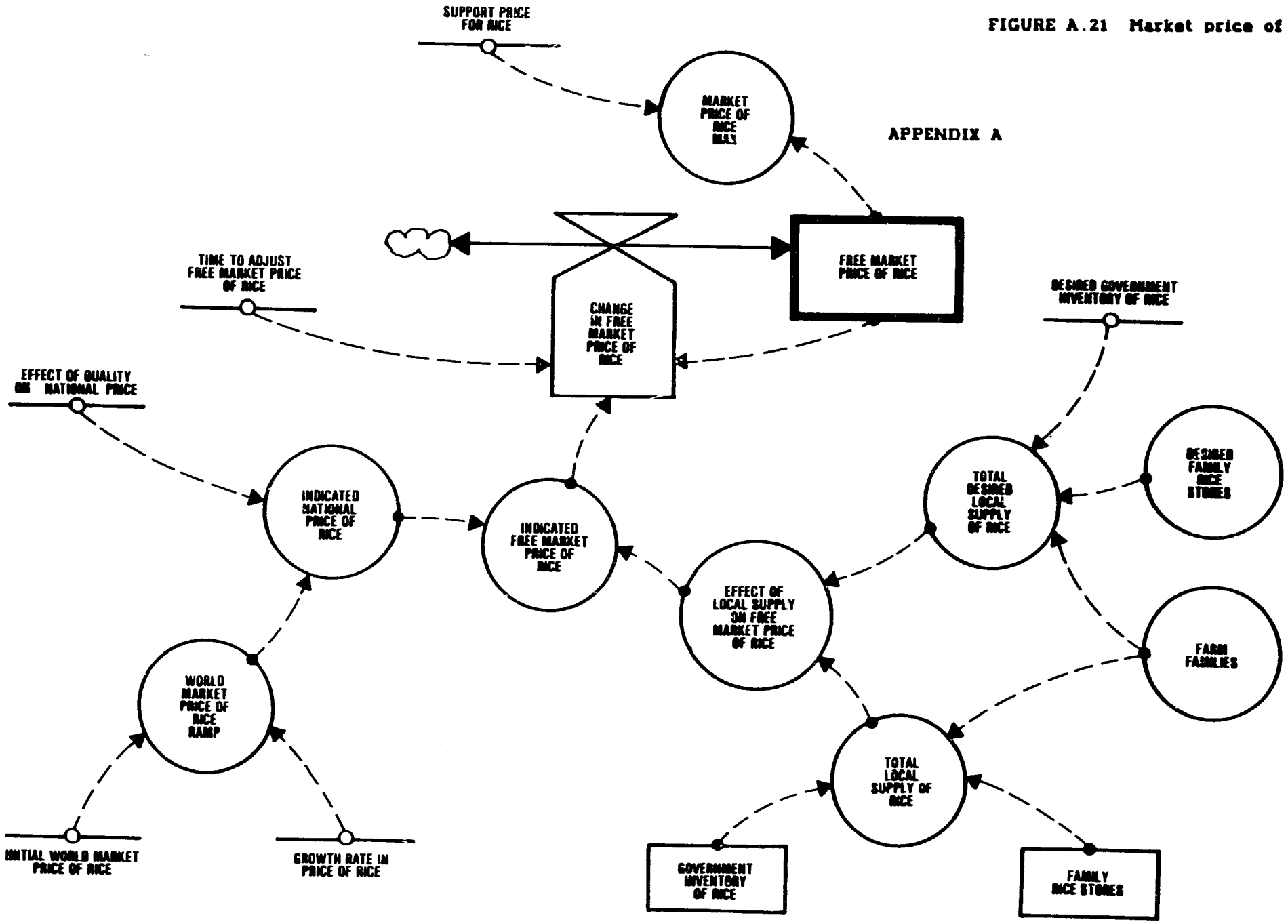


FIGURE A.20 Rice and grain inventory.

FIGURE A.21 Market price of rice.



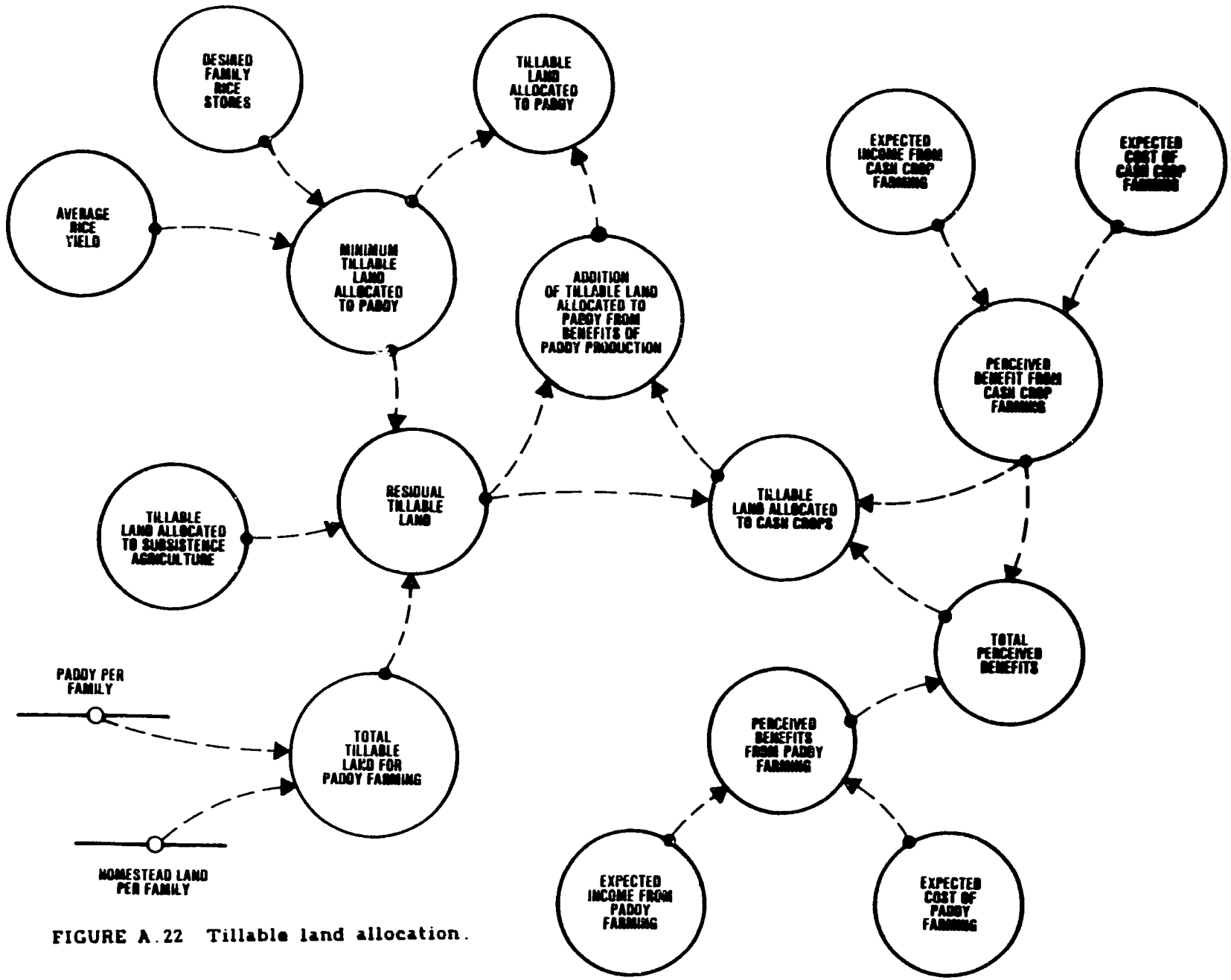


FIGURE A.22 Tillable land allocation.

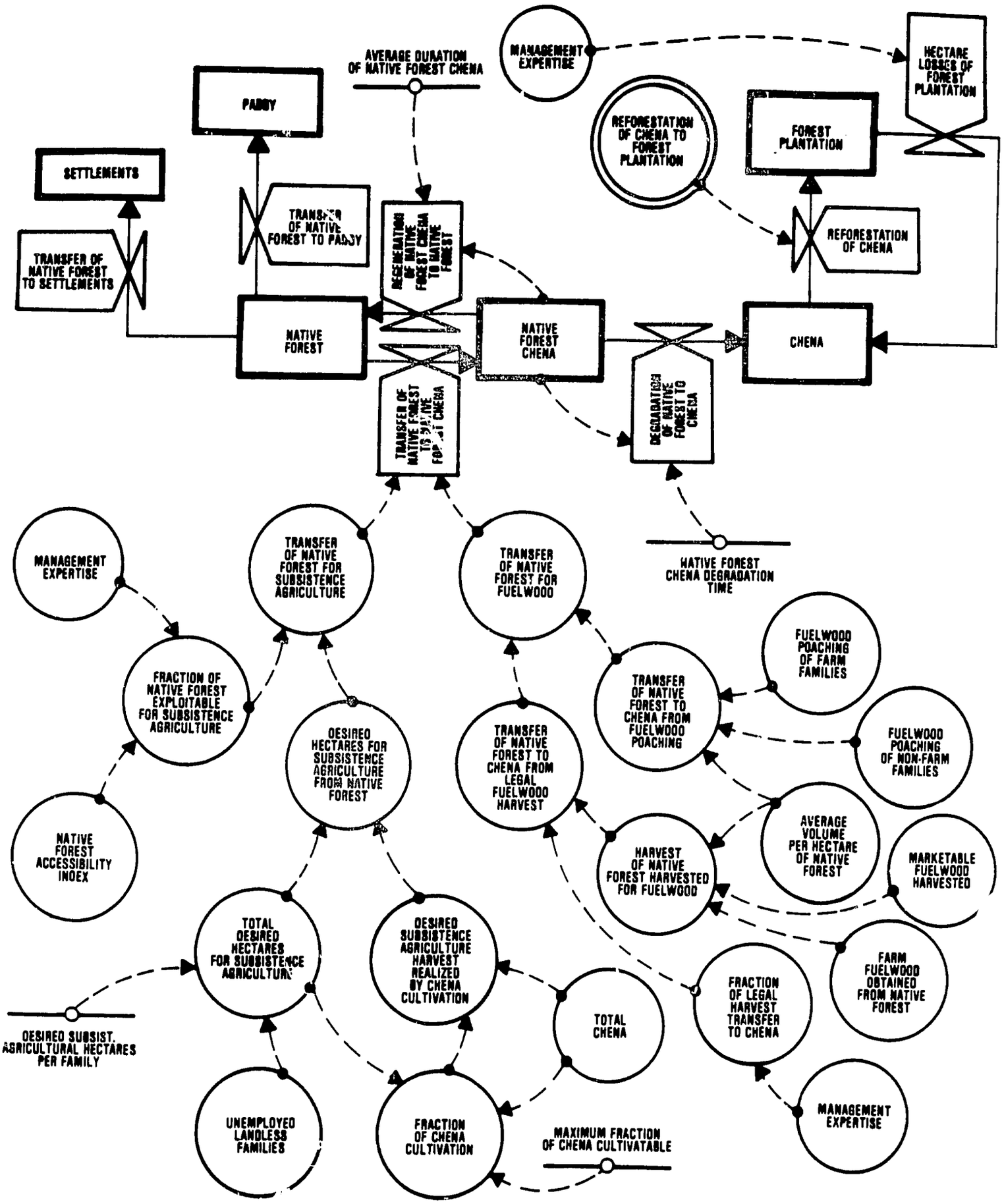


FIGURE A.23 The forces of deforestation and reforestation.

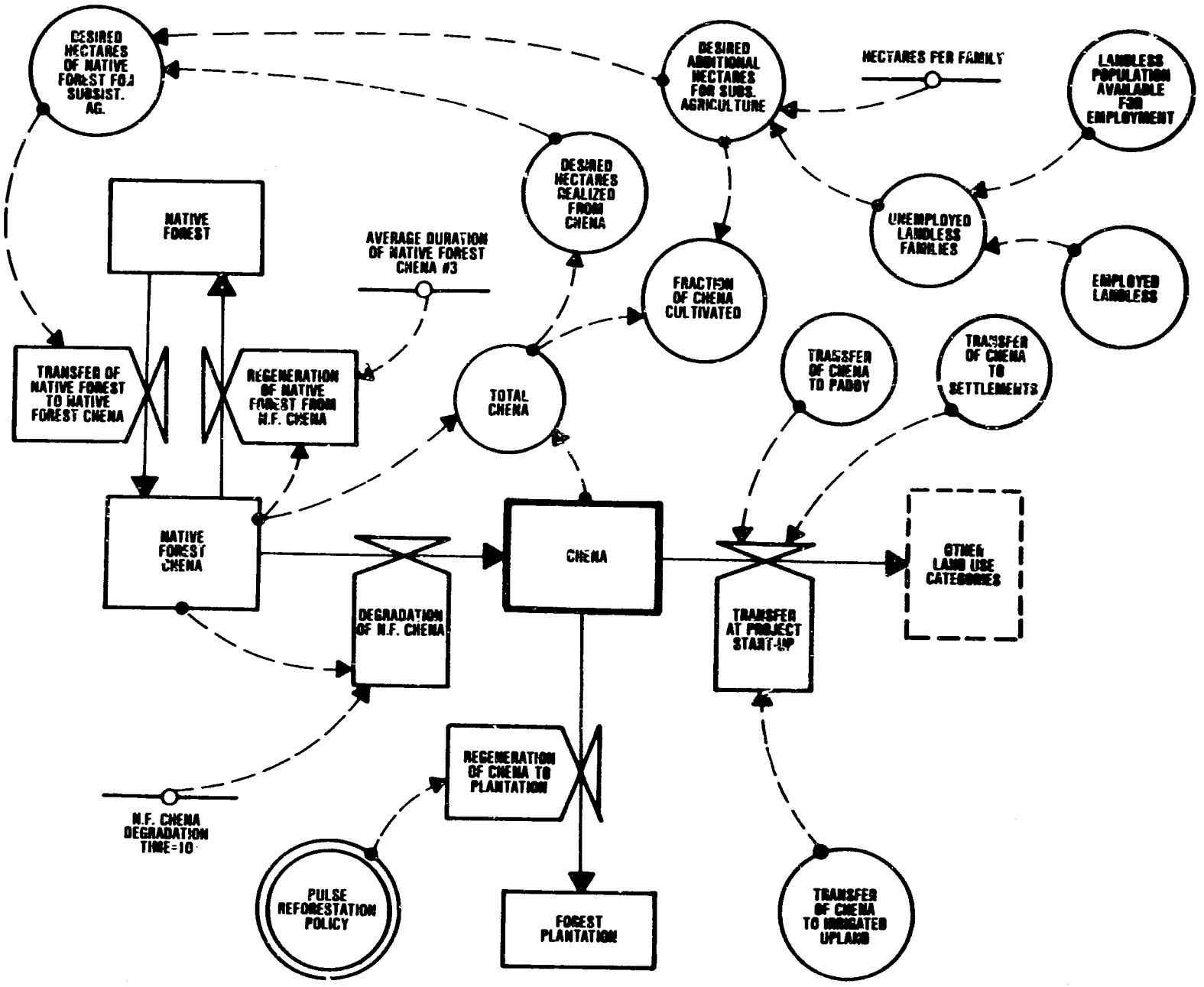


FIGURE A.24 Conversion of native forest to chena.

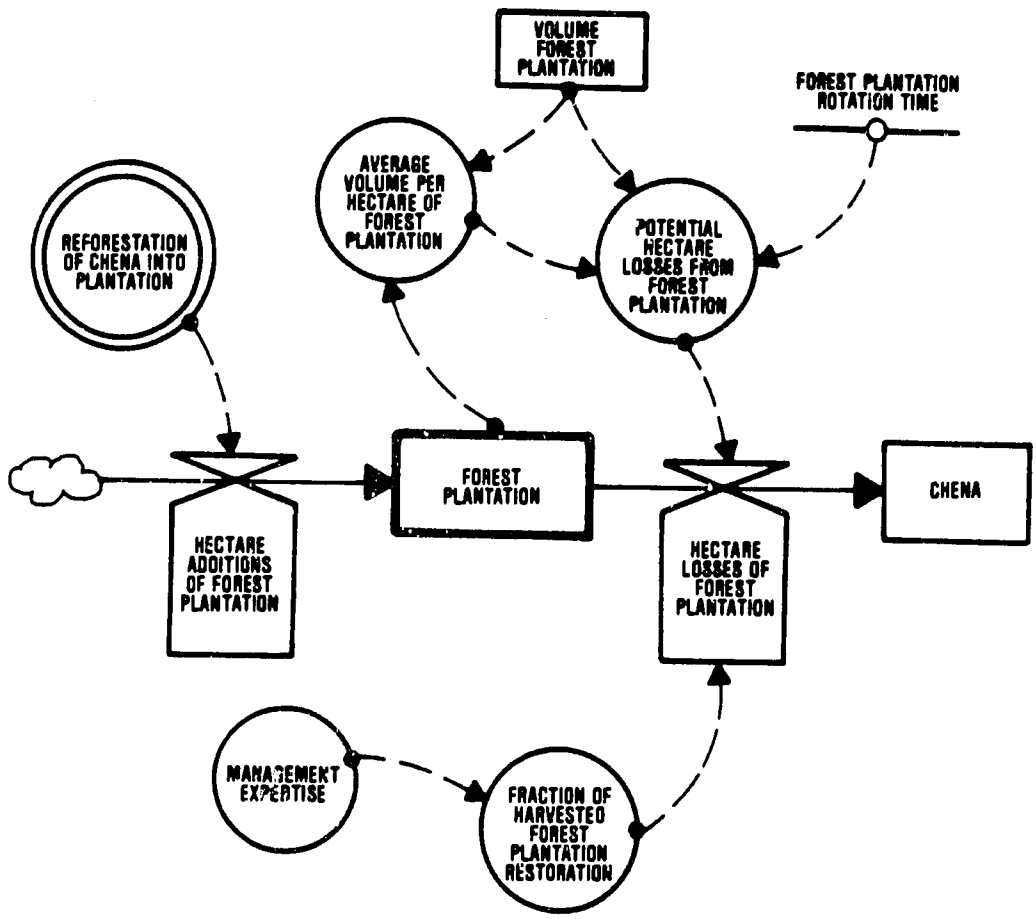


FIGURE A.25 Conversion of forest plantation to chena.

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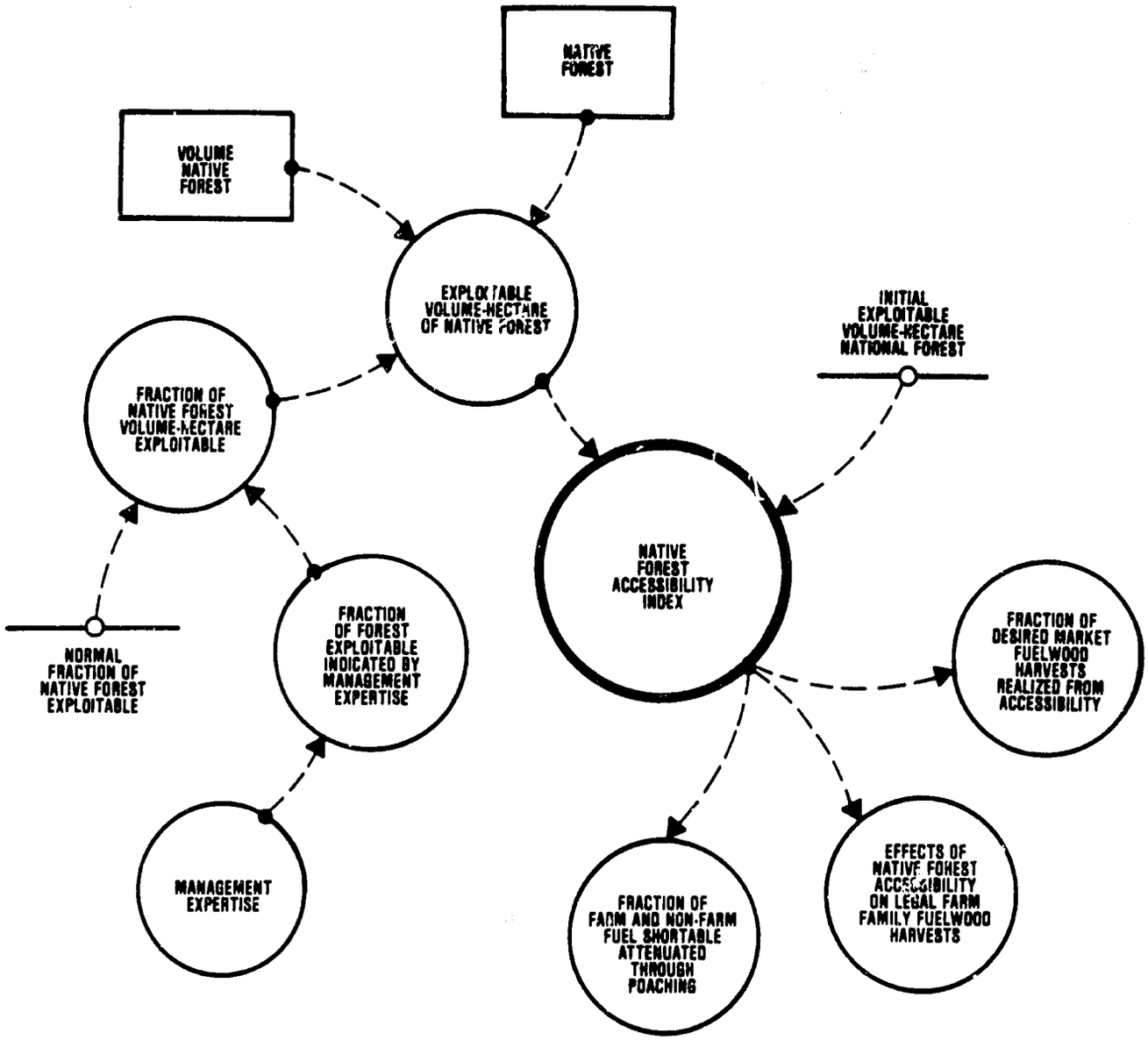


FIGURE A.26 Native forest accessibility and its effects.

APPENDIX A

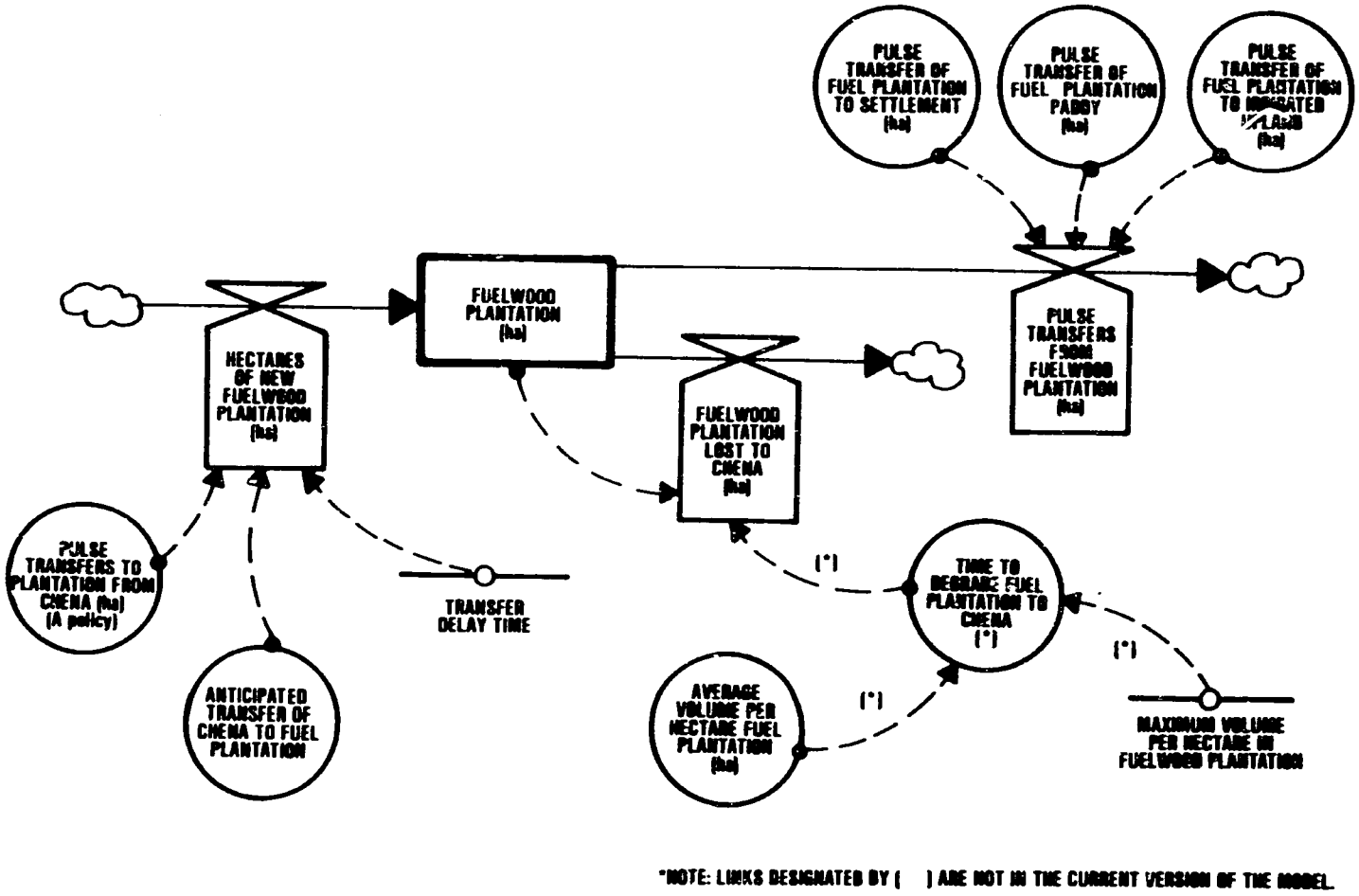


FIGURE A.27 Fuelwood plantation.

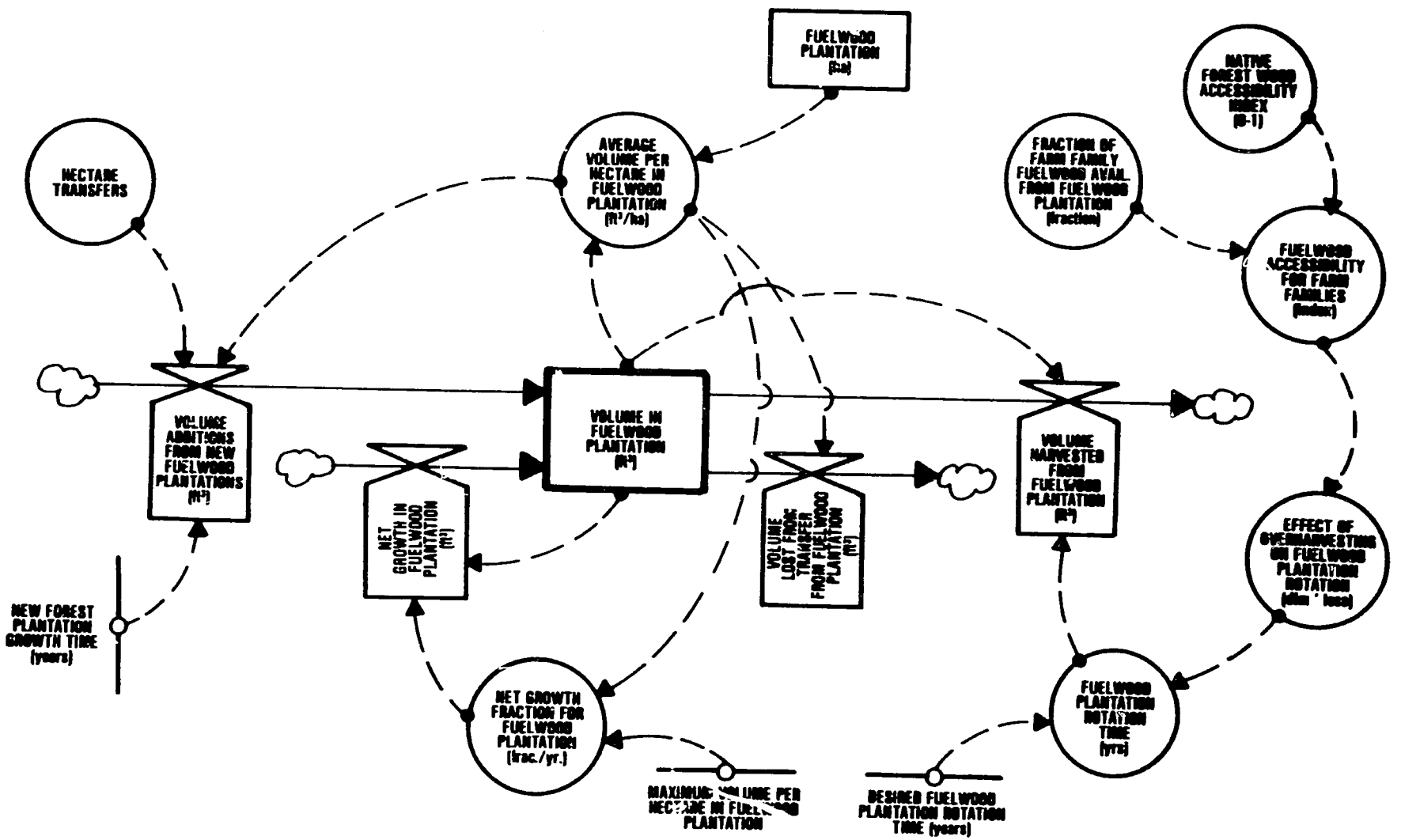


FIGURE A.28 Volume in fuelwood plantations.

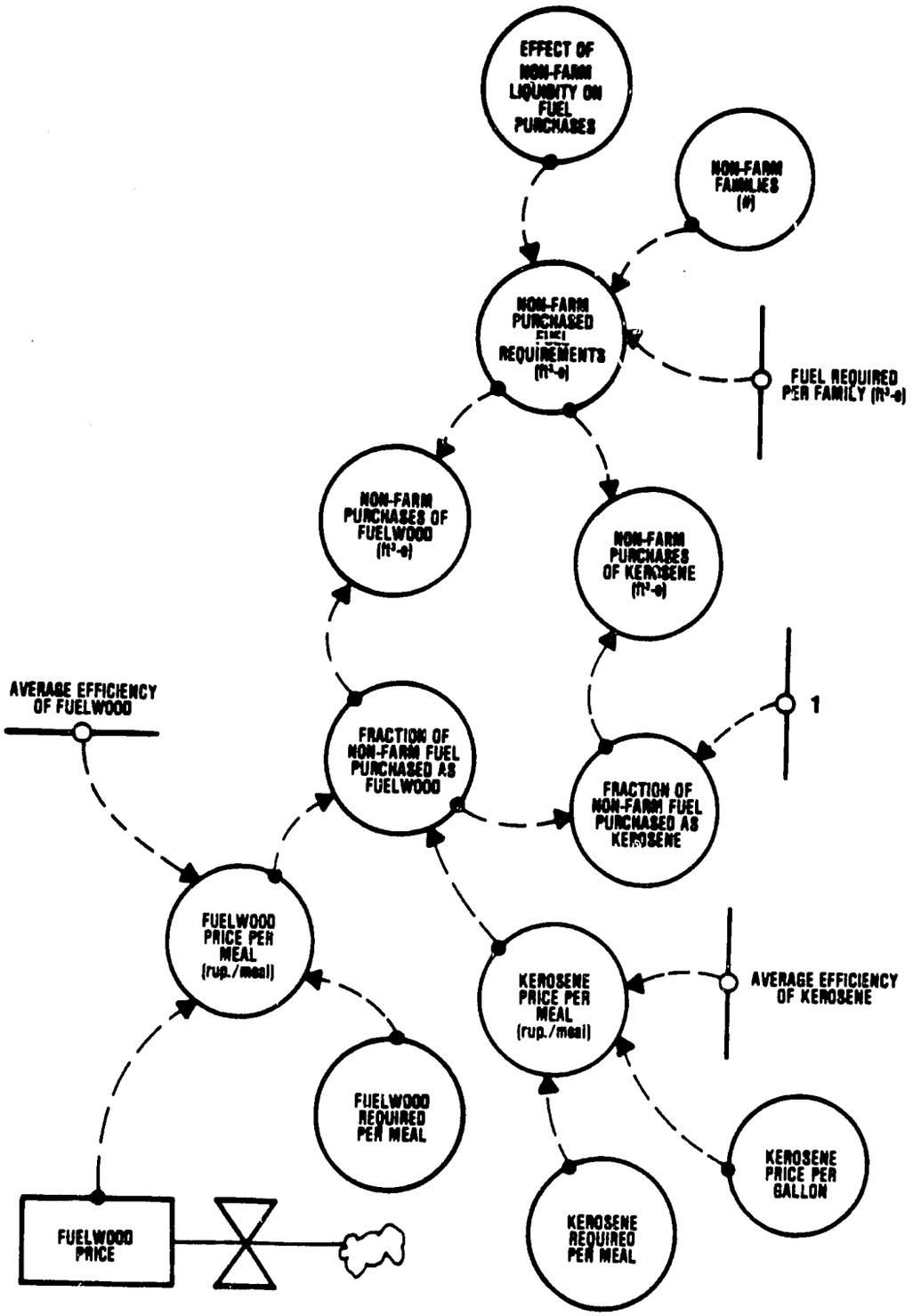


FIGURE A.29 Non-Farm fuel purchase.

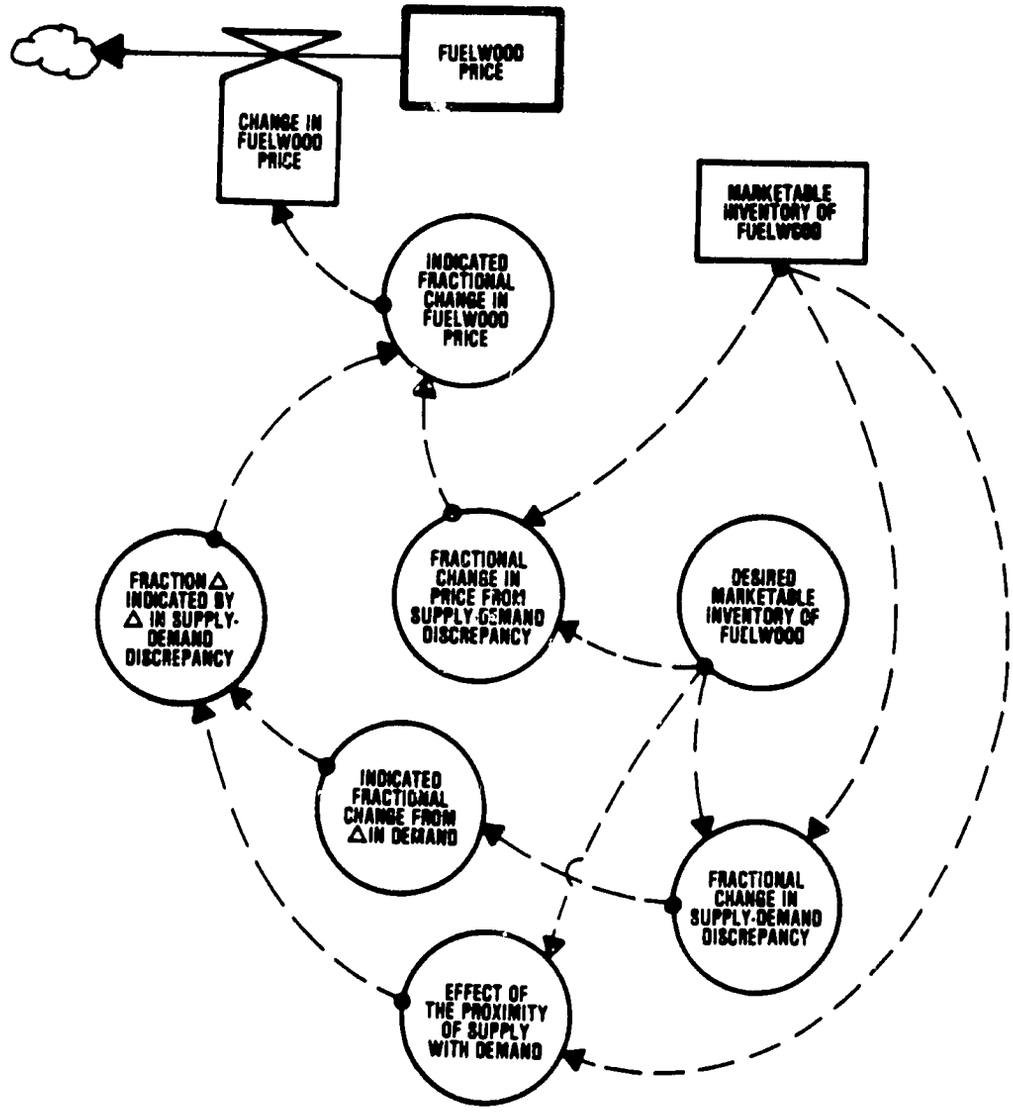
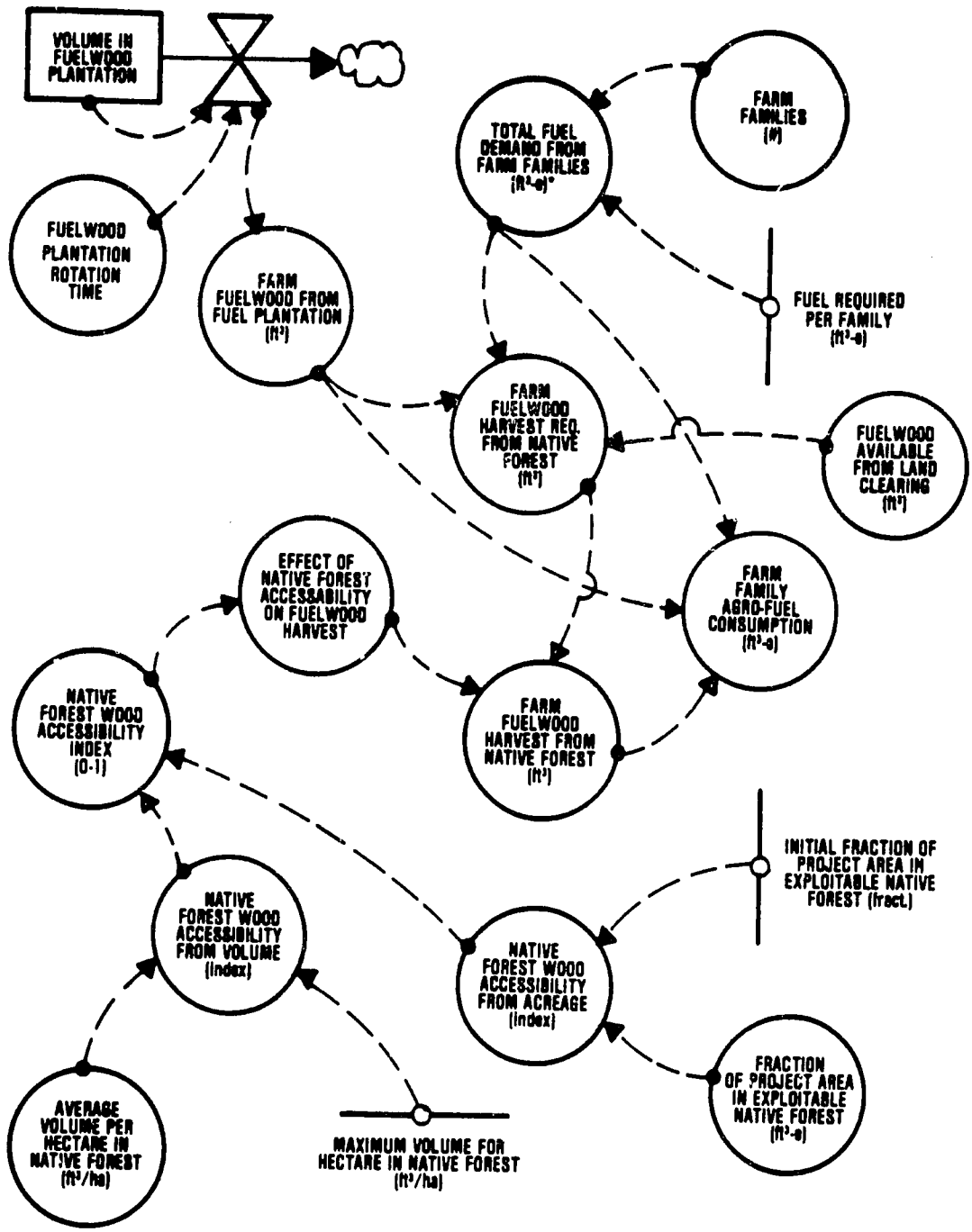


FIGURE A.30 Fuelwood price formulation.



*ft³-e=All fuel demand is in cubic feet fuelwood-equivalents.

FIGURE A.31 Farm fuelwood use.

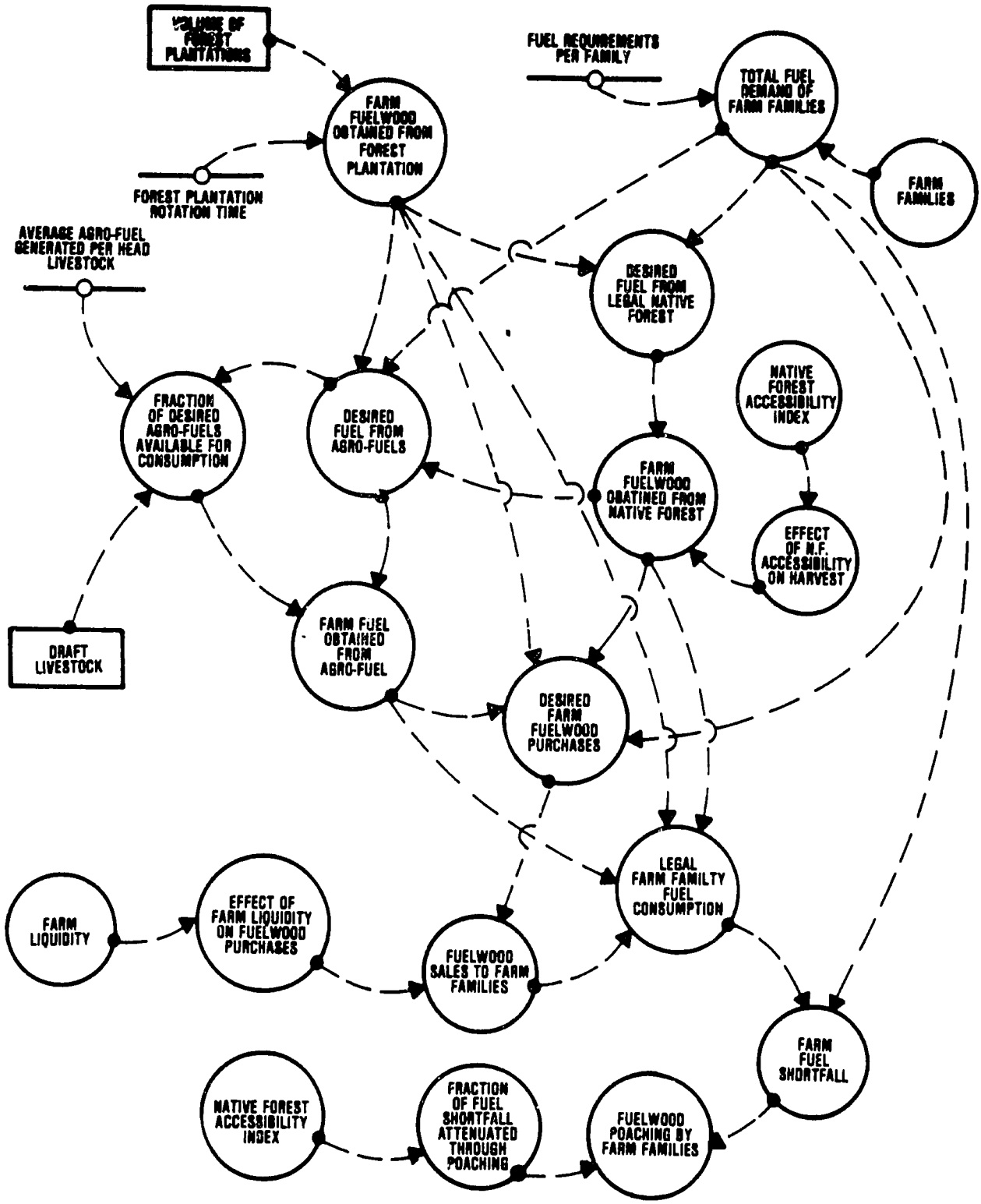


FIGURE A.32 Fuel allocations.

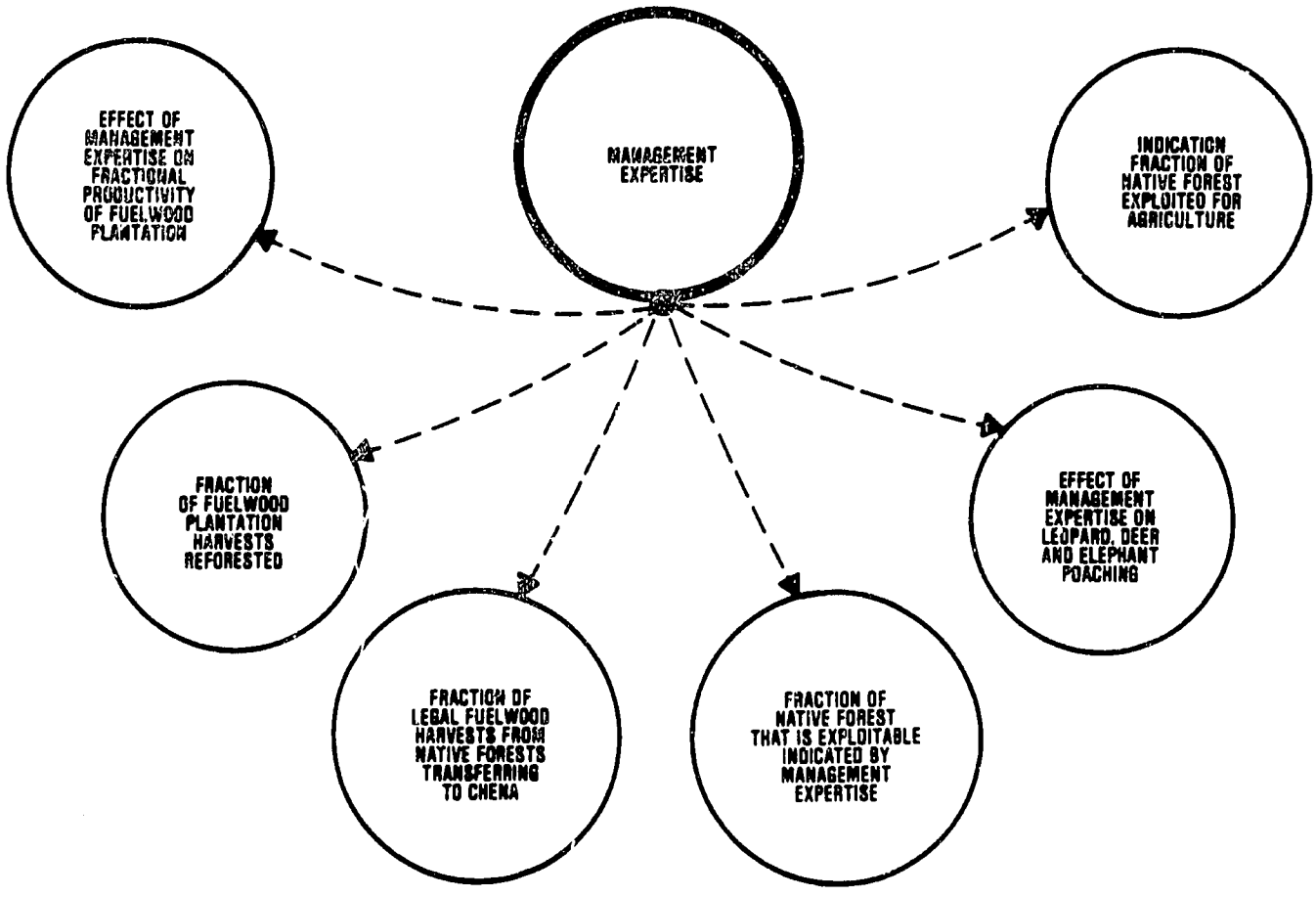


FIGURE A.33 Six effects of management expertise.

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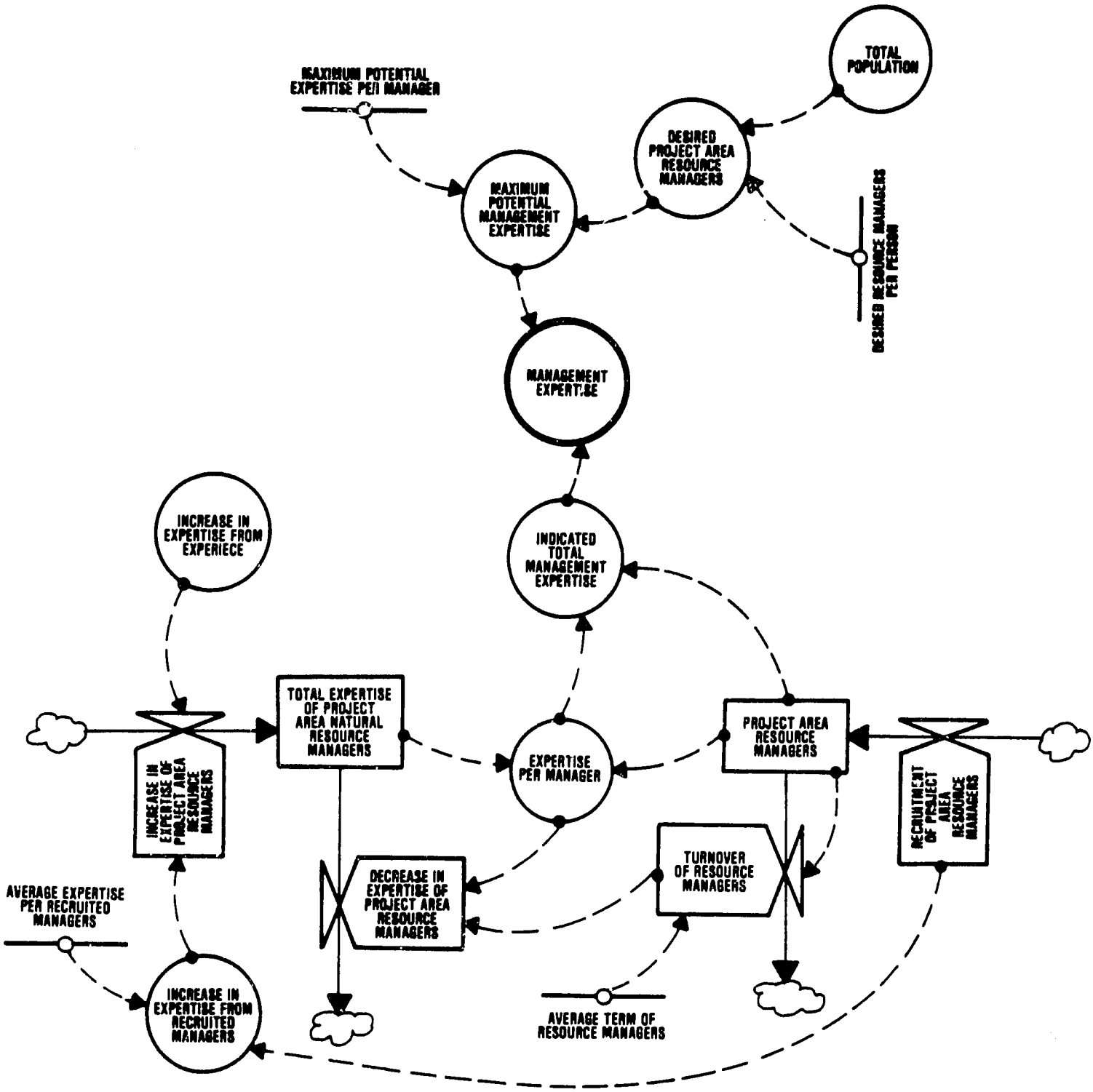

FIGURE A.34 Natural resource management expertise.

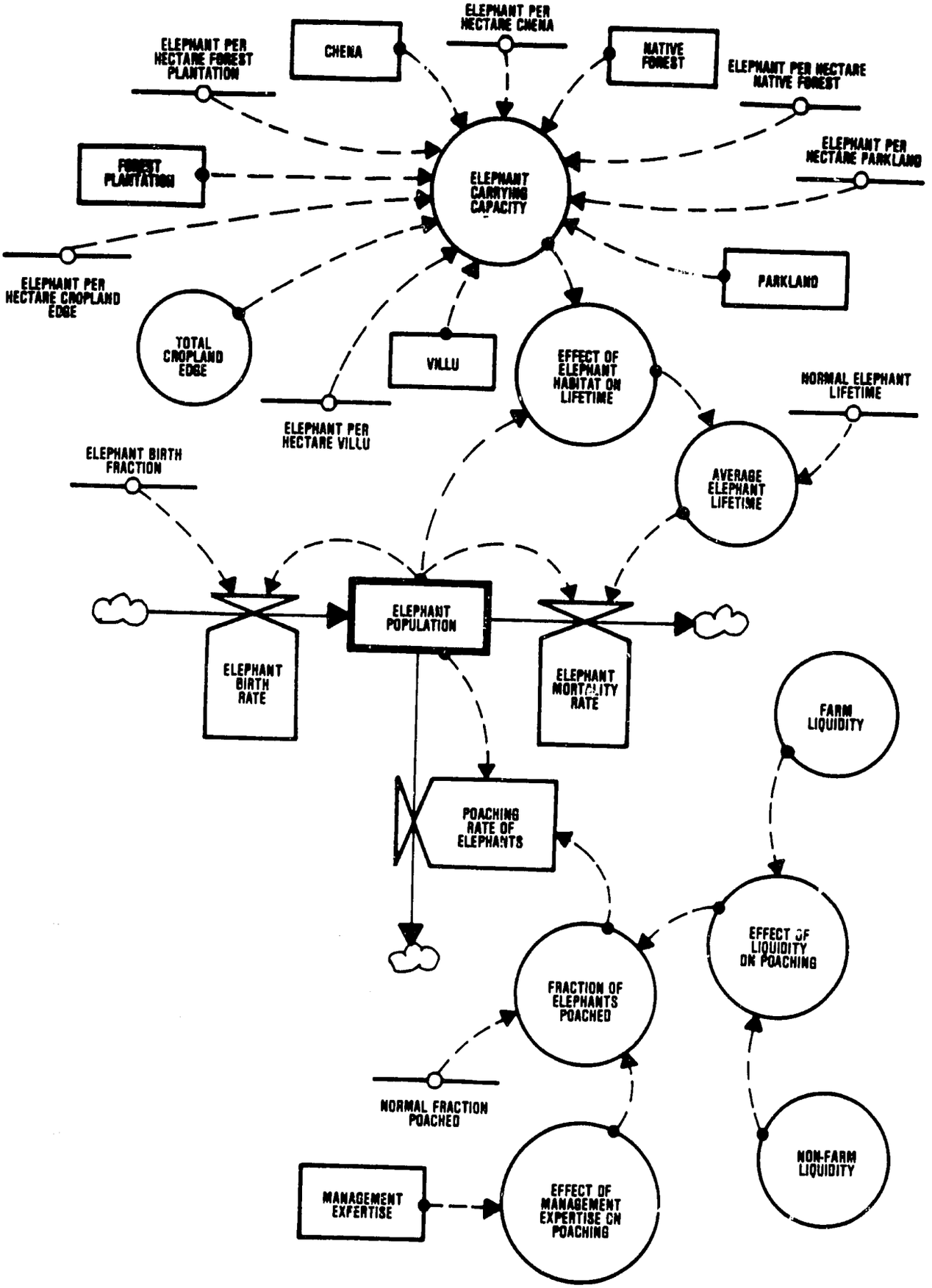

FIGURE A.35 Elephant population.

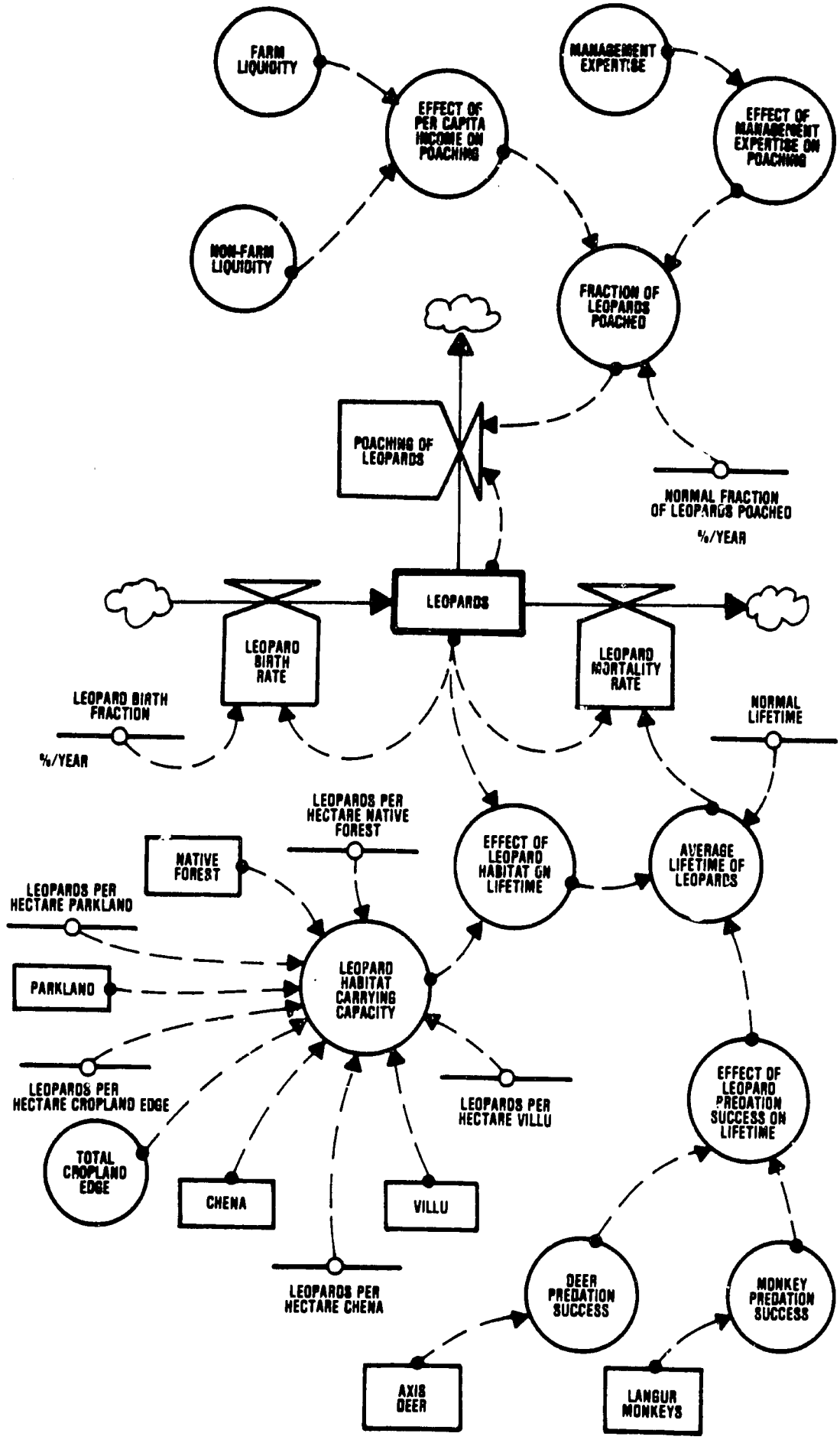

FIGURE A.36 Leopard population.

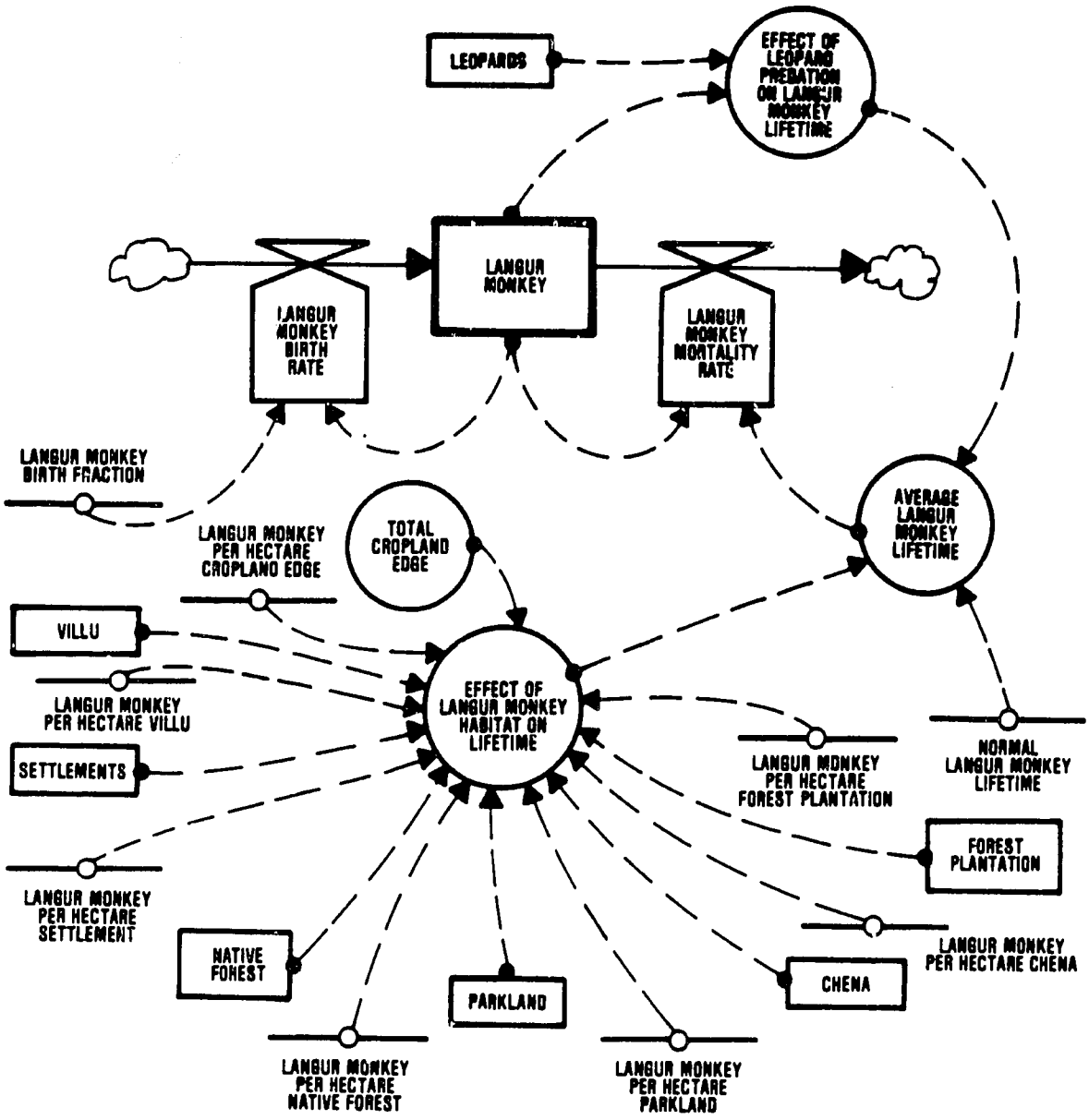

FIGURE A.37 Langur monkey population.

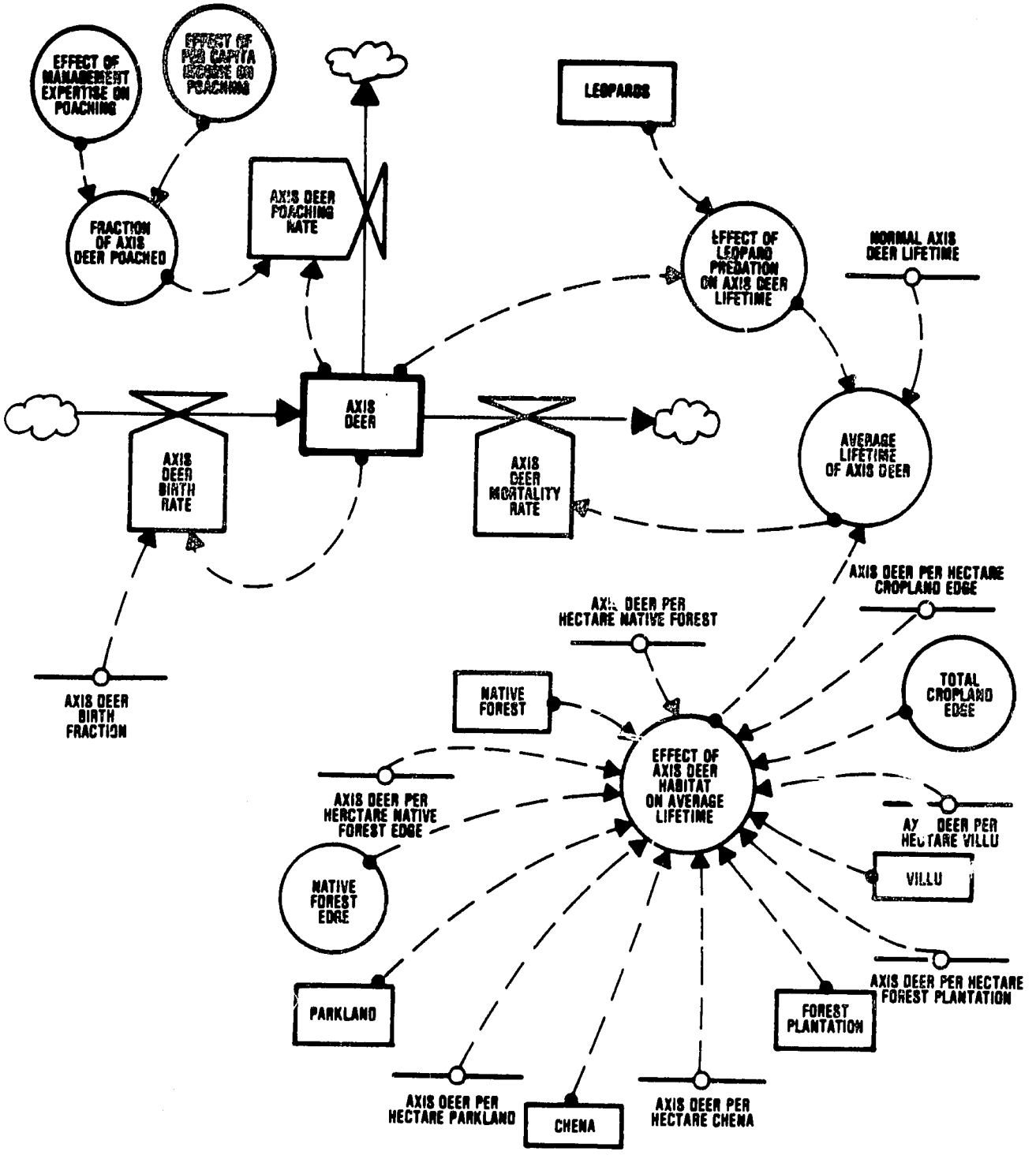

FIGURE A.38 Axis deer population.

APPENDIX B
BIORESOURCE SYSTEMS DEVELOPMENT WORKSHOPS

B.1 SUMMARY

In an effort to be more effective in realizing the goals of development projects, planners have searched for and used a variety of planning methods and techniques. Still however, the potential effectiveness of most projects is not achieved, and planners are eager to try new methods if they offer some promise of greater success.

The reference group (workshop) method of system dynamics computer modelling offers a new opportunity for development planners to increase the effectiveness of their efforts. Specifically, the reference group workshops offer:

- a relatively inexpensive method for developing a tool to analyze different plans or alternatives for a specific project;
- a forum in which development planners and scientists with varying backgrounds and responsibilities can share their concerns and problems on a given project in a structured environment;
- a means by which development planners and scientists can work toward a concensus on a plan for development of a particular area or project;
- a way of sensitizing planners and scientists to the interrelated nature of seemingly unrelated aspects of a development project;
- a means of discovering subtle or unexpected elements, behaviors or problems of a project and its environment.

Products of the workshops include:

- a library of system dynamics models of particular projects with relevant data;
- development and analysis of plans and their optimization for particular projects;
- a report that documents the process, product, data and assumptions;
- the possibility of achieving a concensus on a development plan;
- a heightened awareness of the complicated feedback and linkages involved in development projects.

B.2 BIORESOURCE SYSTEMS DEVELOPMENT PROJECT: ONE DAY WORKSHOP

The heart and soul of the Bioresource Systems Development Project is the workshop. It is in the workshop where the reference group method of systems modeling can achieve its potential efficiency and power in improving the planning and implementation of effective development strategies in developing countries.

Two workshop formats are being developed for the project. There will be a 3-4 day workshop to produce or refine a model of a development scheme, and a one-day workshop with the primary purpose of fostering an appreciation of the applicability, process, and products of an integrated systems approach and a simulation model for development planning. It should also generate interest in the longer workshop. The shorter workshop is primarily educational in nature rather than a means to develop a specific product as the 3-4 day workshop does.

B.2.1 Format

The term "one day workshop" is something of a misnomer as used here. The one day workshop will require one working day of the participants time, but over two days. The workshop has been broken up into four discrete two-hour sessions and spread out so that workshop team facilitator/modelers can gain the greatest familiarity and credibility with the participants in a short span of time. Additionally, the two day format provides time for the necessary analytical work between sessions three and four.

The plan for the one day workshop is to hold three two-hour sessions on the first day and one two-hour session on the second day. The two-day schedule would be as follows:

Day One

8:00 - 10:00 am	Facilitator/modelers meet individually with as many group participants as possible to introduce themselves, determine available skills and resources and discuss workshop.
10:00 - 12:00	Workshop session #1
1:00 - 3:00 pm	Workshop session #2
3:00 - 5:00	Workshop session #3
Evening	Model development and testing by facilitator/modeling team.

Day Two

8:00 - 12:00 am	Model development and testing, cont.
1:00 - 3:00 pm	Workshop session #4
3:00 - 5:00	Extra time to work with interested participants

The format has been set up with a generous amount of slack time to allow for unforeseen problems, and also to provide for extra workshop time with participants if they so desire. This informal time should encourage the interest of the group participants, and will allow the facilitators to take advantage of the enthusiasm that was generated to continue discussions with participants on topics of their choice.

Agenda

Session #1: The principal objective of the first session is to introduce the reference group to a method of systems modeling. The purpose of the method must be clearly articulated, as well as the purpose of both the one and three day workshops. The goals of the first session should be: 1) to establish the credibility of the group facilitators, 2) to establish the need for the method, and 3) to establish a rapport between group facilitators and participants. Session #1 would be outlined as follows:

Session #1

0:00 - 0:15	Introduction of workshop and facilitators by some responsible adherent within the participant group or mission.
0:15 - 0:30	Need, purpose, and objectives of workshop.
0:30 - 1:00	Explanation of how methodology has been used in the past. AID workshops, DEC, theses and in actual planning.
1:00 - 1:10	Discussion of workshop agenda.
1:10 - 1:40	Show videotape from first workshop.
1:40 - 1:50	Discuss videotape. Explain how video is similar to or different from current workshop.
1:50 - 2:00	Slack time. Discuss group concerns, questions, issues brought. Make note of unresolved issues to discuss at appropriate times.

If the first session is successful it will have laid down a foundation of enthusiasm among the group members which the team can build upon in later sessions.

Session #2. In Session #2 the substance of the reference group method of modelling is outlined for the group participants. An example is provided which shows the type and quality of results which can be produced by the method.

Session #2

0:00 - 0:45	"Introduction to System Thinking". Explanation of major concepts of system dynamics with group discussion.
0:45 - 1:30	"Seven steps of reference group model building". Use Mahaweli model as example to clarify and intrigue.
1:30 - 1:50	Overview of Mahaweli model. Presentations of sector diagrams and broad results.
1:50 - 2:00	Wrap up, discussion, what's next

This second session of the workshop will be more like a lecture seminar than the other sessions. This session can be very interesting though, and it is necessary in order to impart a thorough and consistent understanding to the group. In the presentation of the model, the group will begin to get a flavor of the complexity and power of the method.

Session #3. The third session attempts to provide the group with a sense of what is involved in the three day seminar and the reference group modelling method. The group will model a small part of the system of interest and in so doing will hopefully come to appreciate the potential of the method. Further, the group will likely gain some sense of "ownership" in the model, which will encourage their interest and enthusiasm.

Session #3

0:00 - 0:10	Review of previous sessions. Outline of future events.
0:10 - 1:00	Selection of sector(s) to model by group. Detailed explanation of flow diagrams that show current structure of sector of interest.
1:00 - 1:55	Revision or creation of sector(s) by group.
1:55 - 2:00	Recap.

Between the third and fourth session there will have to be a long adjournment. The analysts will need to take the structure which the group created and integrate it into the existing model developed beforehand and brought to the workshop with a portable computer. This will require equation writing, programming, testing, and revision. This work will have

to be done overnight and during the next day. The analysts may have to confer with individual group members to clarify concepts or theories, and to obtain data.

Session #4. The last session of the workshop will be spent completing the demonstration of the reference group method of modeling, discussing the method and its results, and resolving any outstanding issues raised earlier by the group.

Session #4

0:00 - 0:30	Presentation of pre-selected model runs comparing the old model with the version done by the group.
0:30 - 1:00	Model runs as suggested by the group. Interpretation and critique.
1:00 - 1:15	Group discussion of methodology, its usefulness to development planners and its applicability to development problems.
1:15 - 1:30	Recap of workshop. What was learned? What was demonstrated? Conclusions.
1:30 - 1:45	Resolution of outstanding issues by group leaders. Reach closure.
1:45 - 2:00	Solicitation of written comments on workshop, format, methodology, etc.

B.3 BIORESOURCE SYSTEMS DEVELOPMENT PROJECT: THREE DAY WORKSHOP

The three day workshop planned for the Bioresource Systems Development Project is much more than simply an expanded version of the one day workshop. The products of the three day workshop are much more tangible and a great deal more support work is required.

In addition to senstizing development planners to the nature of linkage, feedback, cause, effect and intervention in development projects, the three day workshops will:

- Provide a forum for development planners with different backgrounds and responsibilities to share their concerns and problems on a given project in a structured environment.
- Provide a means for development planners to work toward a concensus concerning a plan of development for a particular project.
- Provide a tool with which to analyze different development plans for a given project with written documentation.

B.3.1 Format

The three day workshop has been partitioned into six four-hour sessions. These six sessions would be grouped into two "sub-workshops", due to the nature of the analysis and model development.

A model will be developed for each three day workshop so a substantial amount of preworkshop preparation will have to be done. A working model of the development project of interest will have to be completed before the workshop starts so that the most effective use of the participants time can be made. Attempts will be made to secure a corpus of imporant background literature such as environmental assessments, feasibility studies, project papers and germane research. The assumption here, and throughout the workshop planning, has been that the scarcest commodity will be the time of the Mission personnel. If a working version of the simulation model is available, the group participants will not have to wait for the facilitators to code and debug a complete model from scratch. Additionally, if the working version is reasonable, preliminary testing and policy analysis can be done. Given models currently on hand and depending upon the number of existing models and their affinity to the system and project under consideration, about two man-months will be required to complete a preliminary working version (with documentation and sources) of the model.

The first two days of the workshop will be used to introduce the reference group method of modelling, critique and revise the working version's structure and to test the model and interpret the results. The working version of the model will only serve here as a springboard for the group. The group will add to and subtract from the model, shaping it to reflect their own understanding and knowledge of the environment and project. The participants serve as the reference group, providing the expertise upon which the conceptual and theoretical formulation of the model is based.

After two days with the group, the facilitators will leave for approximately one month in order to rework the model to the specifications of the group. The structure of the model will have to be changed, the model will have to be reprogrammed, tested and debugged. In addition, the facilitators will do a full set of policy tests as requested by the group and write up a report on the model and the results of the policy analysis.

When the model rework is completed and the results written up, one of the facilitator/modelers will return and present the results to the group. This presentation will make up the third day of the workshop. The participants will have another opportunity to interact with the model using different scenarios and interventions. Using these runs, a report will be finalized and submitted. A menu-driven version of the model will be left with a users guide for the participants' use.

B.3.2 Alternate Formats

Other schedules for the three day workshop are possible. If the third day of the workshop cannot be scheduled after the model has been revised, a break

of about 2 weeks could be arranged between the second and third days of the workshop. The disadvantage here however, is that the facilitators will have less time to revise the working version of the model. Similar runs and interaction will occur as with the first format.

An additional format is possible which uses aspects of the reference group method to clarify a particularly difficult problem without actually using a computer. In this format little pre-workshop preparation or post-workshop analysis is called for. The method is used to structure a problem that a mission is having. In this format the problem statement, key questions, reference modes, dynamic hypothesis are developed as in the regular workshop. Additionally, the structural specification is done, completing a graphical representation of the structure of the problem. However, the process stops there. By going through the exercise of model building, without actually writing equations or coding a model, clarity can arise out of confusion, just as structure arises out of a variety of descriptions and mental models. This technique has been employed successfully at the Digital Equipment Company.

Session #1 (Day 1)

0:00 - 0:15	Introduction of the facilitators by a responsible person within the participant group.
0:15 - 0:30	Need, purpose, and objectives of workshop.
0:30 - 1:00	Explanation of how method has been used previously. AID workshops, DEC, theses, and in actual planning.
1:00 - 1:10	Outline of workshop agenda.
1:10 - 1:40	Show videotape from first workshop.
1:40 - 1:50	Discuss videotape. Explain how video is similar to or different from current workshop.
1:50 - 2:00	Break.
2:00 - 2:30	Discussion of the group's expectations. What is possible and what is not. Issues and concerns brought by the participants. Previous experiences with modelling. Inventory of resources available, e.g. supporting literature, data, etc.
2:30 - 4:00	Hand simulation game. The group simulates a simple resource system by hand. Each group member "becomes" a rate or a level and the group plays out a policy test. This exercise helps the group to understand the feedback nature of systems, counterintuitive behavior, and the use of modelling; and also helps to break the ice. Discussion follows.

Session #2 (Day 1)

0:00 - 0:45	"Introduction to Systems Thinking". Explanation of major concepts of system dynamics with group discussion of video, hand simulation game and personal experiences.
0:45 - 1:30	"Seven steps of reference group model building." Explanation of reference group method.
1:30 - 2:00	Discussion of project to be modelled. Description of activities, purposes, goals, concerns, weak spots, problems, etc.
2:00 - 2:15	Break
2:15 - 3:00	Discussion of project, cont.
3:00 - 4:00	Formalization of discussion of project. Problem statement and key questions.

Session #3 (Day 2)

0:00 - 1:00	Formalization of discussion of project, cont. Dynamic hypothesis and reference modes.
1:00 - 2:00	Mapping of model boundary. Decide on necessary elements to produce model behavior and replicate reference modes. Compare this with model boundary done for working version of the model.
2:00 - 2:15	Break
2:15 - 3:45	Small group session #1. Presentation of working versions structure (flow diagrams) to small groups by facilitators. Critique and reformulation.
3:45 - 4:00	Brief presentation by each group on changes made.

Session #4 (Day 2)

0:00 - 2:00	Small group Session #2. Continued development on working version of the model. Critique and reformulation.
2:00 - 2:15	Break.
2:15 - 3:00	Small group Session #2, cont.

3:00 - 4:00	Use of microcomputer for sample analysis using working version of the model. Group discussion of results and specification of policy tests to be performed with revised version.
4:00 - 4:30	Wrap up. Preliminary conclusions. What will be done on return.

Session #5 (Day 3, One Month Later)

0:00 - 1:00	Review of first 2 days. Purpose and goals of project. Review of expectations. Review of problem statement, key questions, reference modes, and dynamic hypothesis.
1:00 - 2:00	Presentation of revised model's structure. Sector boundary diagram and flow diagrams.
2:00 - 2:15	Break
2:15 - 4:00	Detailed presentation of model results. Results of policy tests selected by group. Interpretation, discussion, and critique.

Session #6 (Day 3, one month later)

0:00 - 2:00	Hands on microcomputer analysis. Further testing and analysis of model by group with interpretation, discussion and critique of each test.
2:00 - 2:15	Break.
2:15 - 3:15	Conclusions from model development and testing. Critique of current development plans. Reflection on earlier statements of problems, concerns, weak spots, etc. General discussion.
3:15 - 4:00	Review of key questions and reference modes. Were these questions answered? Were reference modes replicated? General comments and conclusions.
4:00 - 4:30	Wrap up. Comments and critique of method. How to improve its usefulness?

B.4 PERSONNEL

If enough resources are available three persons should comprise the facilitator/modeler team. The team leader should be a person with broad

experience in the field of development and resource science. The most important characteristic of the team leader is credibility in the eyes of the participants—e.g. someone with field experience who works for the agency, etc. The person should have an advanced degree in a substantive area of sectoral interest such as forestry, ecology, agriculture, economics or sociology.

The two other team members should be persons who have the analytical and programming skills which will be required by the modelling exercises. These analysts should be skilled in the use of system dynamics and should be familiar with the use of the reference group modelling method. The analysts should have some substantive background in such areas as are listed above. In addition, all team members must have strong speaking and writing skills, be able to interact well with people and be able to accept criticism, in fact solicit it, without taking umbrage.

B.5 EQUIPMENT NEEDS

Because of the nature of the workshops, some sophisticated equipment will be required. Much of the equipment will likely be provided by the host Missions, but some will have to be brought in with the team. The equipment list is as follows:

- Portable microcomputer. IBM compatible; 512K internal memory; hard disk drive; adaptable for 200V.
- Printer. Preferably with some graphics capability.
- Videotape player.
- Overhead and/or slide projector.
- Color television or color monitor.
- Chalkboard.

B.6 BUDGET ESTIMATES

One Day Workshop. Two budgets are presented here -- for a one workshop trip, and for a five workshop (of one day) trip. Economies of scale are evident. Each budget assumes two facilitators make up the team and 1 1/2 days are required for international travel to and from the mission.

One Trip Workshop

10 person-days @ $200/day	$2,000
Indirect costs (software, communications, report preparation, computer time)	1,000
Travel (2 persons)	6,000
Per Diem (10 days @ $75/day)	750
Total	$9,750

Five Trip Workshop Assumes 10 days of workshops and 7 days of travel per person.

34 man-days @ $200/day	$6,800
Indirect costs (as above)	4,000
Travel (2 persons)	11,000
Per Diem (34 days @ $75/day)	2,550
Total	$24,350
$24,350/5 workshops	$4,870 per workshop

Three Day Workshop. This budget assumes one month for workshop preparation, 5 days for the workshop and one month for revision and a return trip for one facilitator.

85 person-days @ $200/day	$17,000
Indirect costs (as above)	4,000
Travel (2 persons/round trip, 1 person additional round trip)	9,000
Per diem (15 days @ $75/day)	1,125
Total	$31,125

APPENDIX C

BIORESOURCE SYSTEMS MODEL DATA SOURCE LIST

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Initial Paddy (IP)	13,700 Ha	Acres, Annex A, Table A-3.1, Pg. 21	
Total Project Area (TPA)	1,300 Km^2	Acres, Annex A, Pg. 1	
Development Transfer Time (VDTT)	5 years	TAMS, Environmental Assessment, Pg. 3	
Transfer of Native Forest to Paddy	14,400 Ha	Acres, Annex J, Table J-4.1, Pg. 45.	This is the planned transfer of hectares
Transfer of Chena to Paddy (TCP)	13,140 Ha	Acres, Annex J, Table J-4.1, Pg. 45	
Transfer of Parkland to Paddy (TPLP)	4,530 Ha	Acres, Annex J, Table J-4.1, Pg. 45	
Fraction of Paddy Areas in Bunds (FPB)	5%	Assumed by the modeler	The percent of total paddy area in bunds is important since these bunds, or dikes, are being targeted to supply a part of farm family fuel needs.
Initial Parkland (IP)	11,200 Ha	Acres, Annex A, Table A-3.1, Pg. 21	
Normal Long-term Chena Degradation Time (NLTCDT)	30 years	Based on Acres, Annex A, Pgs. 30, 31	This is the time it takes for intensively cultivated chena to degrade permanently into man-made parkland.
Initial Settlements (IS)	2,900 Ha	Acres, Annex A, Table A-3.1, Pg. 21	
Transfer of Native Forest to Settlements (TNFS)	10,900 Ha	Acres, Annex J, Table J-4.1 Pg. 45	
Transfer of Chena to Settlements (TCS)	6,900 Ha	Acres, Annex J, Table J-4.1, Pg. 45	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Transfer of Parkland to Settlements (TPLS)	1,000 Ha	Acres, Annex J, Table J-4.1, Pg. 45	
Initial Fraction of Forest Plantation Young (IFFPY)	75%	Based on footnote to Table A-2.2, pg. 11 Acres	Acres reports that approx. 4,500 Ha were in forest plantation prior to development start-up. They also report that plantations are, on average, under 15 yrs. old, Hence, the bias toward young forest plantations.
Young Forest Plantation Maturation Time (YFPMT)	3.5 years	Based on TAMS Environmental Assessment, Vol. I, Pg. 47, Vol IV, Pg. M-17	This is the time it takes for a hectare of young plantation to mature into mature plantation. That hectare has another 5 yrs. in mature plantation before it is desirable for harvest.
Initial Volume Per Ha of Young Forest Plantation (IVPHYP)	1,000 ft^3/Ha	From: TAMS, Environmental Assessment, Vol. I, Pg. 47	
Normal Volume Growth Per Ha. Per Year of Young Forest Plantations (NVGPHY)	400 ft^3/Ha/yr	From: TAMS, Environmental Assessment, Vol. I Pg. 47, & Vol. IV, Pg. M-17.	
Initial Forest Plantation (IFP)	4,500 Ha	Acres, Annex A, Table A-3.1, Pg. 21	
Mature Forest Plantation Rotation Time (MFPRT)	4 years	Based on TAMS, Environmental Assessment, Vol. I, Pg. 47, Vol. IV, Pg. M-17	Total fuelwood plantation rotation time in 7.5 years. TAMS reports ipi-ipi rotations of 5 yrs (TAMS, Environmental Assessment, Main Report, Oct. 1980, Page 47).
Initial Volume Per Ha. Mature Forest Plantation (IVPHMP)	2,000 ft^3/Ha	Acres, Annex H, Table H-8.1, pg. 44	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Normal Volume Growth of Mature Forest Plantations (NVGMFP)	600 ft^3/Ha/Yr	Based on TAMS, Environmental Assessment, Vol. I Pg. 47; Vol. IV, Pg. M-12.	
Initial Native Forest (INF)	51,100 Ha	Acres Annex A, Table A-3.1, Pg. 21.	
Average Duration of Native Forest Chena (ADNFC)	3 years	Acres, Annex A, Page 30.	This is the maximum cropping period for chena cultivation (slash and burn) that is cut from native forest jungle.
Selective Fuelwood Harvesting Bias (SFWHB)	5 (dimensionless)	Assumed by the modeler	This multiplier proxies the effects of selective fuelwood harvesting by those either poaching or legally gathering wood from native forest. In effect, this multiplier causes gatherers to walk further into the jungle to get wood rather than to progressively clear cut the outer perimeter of the forest.
Initial Volume Per Hectare of Native Forest (IVPHNF)	918 ft^3/Ha	TAMS, Environmental Assessment, Vol. II Table D-1, Pg. D-6.	
Volume Growth Per Ha. Per Year of Native Forest (VGPHNF)	20 ft^3/Ha/yr.	Assumed by the modeller	
Average Volume Per Ha. of Regenerated Chena (AVPHRC)	250 ft^3/Ha	Assumed by the modeller	This is the average amount of forest biomass per hectare of chena land that, due to absence of cultivation, is reverting back to native forest.
Normal Fraction of Native Forest Lost to Lopping (NFNFLL)	.25% (.0025)	Assumed by the modeller	This is the percent of the native forest volume that is lopped off to help feed livestock.
Initial Chena (IC)	32,800 Ha	Acres, Annex A, Table A-3.1, Pg. 21	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Maximum Fraction of Chena Under Cultivation (MFCC)	40%/yr	Based on Acres, Annex A, Pg. 30	According to Acres, the normal fraction (%) of chena under cultivation is 20%. The fig. 40% effectively puts a cap on the amount of chena that can be cultivated in any one yr. Reaching this ceiling implies that any additional subsistence farming must be cut out of the native forest.
Fraction of Paddy Immediately Proximate to Settlements (FPPS)	50%	From Dr. Stephen H. Berwick, IIED	This figure allows the model to consider the spatial configuration of paddy to setlement. Any paddy immediatly proximate to settled areas has the potential for long-term degradation. This is due to the increased traffic and population pressures on those areas bordering settlements. (based on Von Thuren's theory of concentric activity)
Fuelwood Harvest Time (FWHT)	.25 years	Assumed by the modeller	This is a delay between the harvesting and actual marketing of fuelwood.
Fuelwood Decay Time (FWDT)	2 years	Acres, Annex H, Pg. 37	This is the time it takes for fuelwood to rot if it is allowed to sit in "inventory". The purpose of including this decay time is to deal realistically with the massive amount of fuelwood that is cut at project start-up. Some of this decays.
Desired Fuelwood Inventory Coverage (DFWIC)	.1 years		This is the amount of fuelwood equal to 1/4 yrs supply that the fuelwood market desires to have in inventory.
Fuel Requirements Per Family (PRPF)	125 ft^3/yr	Acres, Annex H, Pg. 11	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Normal Fuel Generated Per Head Livestock (NFGPHL)	25 ft^3/head/yr. (In cubic ft equivalents)	Assumed by the modeller	This is the fule value of the dung generated by one livestock per year.
Fraction of Rice Yield Burnable as Stubble (FRYBS)	50%	Assumed by the modeller	This is the percent of each ton of rice produced that is potentially available for burning as fuel.
Fuel Value of Rice Stubble (FVRS)	10 ft^3 equivalent per ton of stubble	Assumed by the modeller	
Fuelwood Consumed Per Family Per Meal (FWCFPM)	1 ft^3	David Van Wie, Maine Audubon Society	
Average Energy Efficiency of Fuelwood (AEFW)	25%	David Van Wie, Maine Audubon Society	
Average Efficiency of Kerosene (AEK)	35%	David Van Wie, Maine Audubon Society	
Initial Fuelwood Price (FWP)	1.5 Rupees/ft^3	Acres, Annex H, Pg. 33	
Initial Total Population (TPOP)	25,757	Acres, Annex A, A-4.2, Pg. 43	
Initial Fraction of the Population Rural-Farm (IFPF)	90%	Assumed by the modeller	
Normal Birth Fraction (NCBF)	.0356	Acres, Annex A, Table A-4.6, pg. 51	This is the percent, per 1,000 of the population, that are born each year of the average. (35.6 per year)
Tables of Population Inmigration (TFRSA, TFRSB)	34,560 families over 3.5 yrs for Scenario A 34,560 families over 7.5 yrs for Scenario B	From Acres: Main Report, Table 5-2.	
Normal Maximum Families Per Ha of Homestead (NMFPH)	3 families	Carol Bradford-Ward A.I.D.	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Normal Infant Mortality Fraction (NIMF)	.005	Carol Bradford-Ward, A.I.D.	This is the percent of the population that normally dies before the age of 5.
Normal Average Lifetime (NAL)	68 years	TAMS Environmental Assessment, Vol. II	
Desired Fuel Per Family Member Per Year (DFPFM)	20.12	TAMS, Environmental Assessment, Vol II Pg. D-25	
Fraction of Initial Population who are Related to Project Area Residents and who are Temporarily Out-migrated (FPOMLR)	.001/yr	Dr. Donald Hertzmark Asian Institute of Technology, Bangkok	
Fraction of Out-migrated Laborers Intending to Return to Project Area (FOLRAR)	.5/yr	Dr. Donald Hertzmark, Asian Institute of Technology, Bangkok	
Fraction of Out-migrated Laborers Returning to Project Area (FOMLRA)	.1/yr	Dr. Donald Hertzmark, A.I.T., Bangkok	
Fraction of Out-migrated Laborers Permanently Leaving the Project Area (FOMLD)	.1/yr	Dr. Donald Hertzmark, A.I.T., Bangkok	
Normal Average Family Size (NAFS)	4.6 people/ family	Acres, Annex A, Table A-4.5, Pg. 50	
Desired Subsistence Agriculture Hectares per Encroaching Family (DSAHPF)	1 Ha	Assumed by the modeler	This is the number of hectares an unemployed, landless family will claim for chena.

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Land Availability Perception Delay Time (LAPDT)	1.5 years	Assumed by the modeler	This is the time it takes for the perception of land availability within the project area, as perceived from without, to be in line with the actual condition of land availability.
Normal Inmigration of Non-Farm People Due to Perceived Economic Opportunities (NINFPO)	50 people/yr	Dr. D. Hertzmark A.I.T., Bangkok	This is the normal amount of people who will inmigrate to the project area each year when outmigration from the area is relatively low (2,500/yr)
Dissatisfied Outmigrant Perception Delay Time	1.5 yrs	Dr. D. Hertzmark A.I.T., Bangkok	
Fraction Rural-to-Urban Migrating Farm Families Remaining in the Project Area (FMFFRP)	50%	Assumed by the modeler	
Normal Average Salary Per Off-Farm Laborer (NASPOL)	7,500 rupees/yr	Assumed by the modeler	
Average Annual Earnings Per Out-Migrated Laborer (AAEPOL)	30,000 rupees/yr	Dr. Hertzmark	
Average Production Input Cost Per Cash Crop Ha (ACPCCH)	3,500 rupees/Ha	Acres, Annex L, Table L-4.6, pg. 41	
Average Cost Per Subsistence Agriculture Hectare (ACPSAH)	1,000 rupees/Ha	Assumed by the modeler	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Average Support Expense Per Person (ASEPP)	500 rupees/ person/yr	Assumed by the modeler	
Normal Annual Operating Cost Per Head Livestock (NAOCPH)	600 rupees	Acres, Annex G, Table G-4.3, pg. 41	
Short-term Interest Rates (STIR)	.1 (10%)	Assumed by the modeler	
Desired Money Coverage (DMC)	.25 years	Assumed by the modeler	This is the time, over which expenses are averaged, to determine the desired amount of savings or cash on hand each family considers as adequate.
Average Term of Short-term Debt (ALSTD)	.5 years	Acres, Annex G, Appendix G II-3	
Average Rice Yield Per Chena Hectare (ARYPCH)	2 tons	Assumed by the modeler	
Government Support Price for Rice (GSPR)	2,000 R/ton	Paul Faeth, Economic Research Service, USDA	
Average Fertilizer Cost (AFC)	364 Rupees/Ha	Acres, Annex G, Table G-3.1, pg. 32	
Kerosene Price Per Gallon	35.62 R/gal.	TAMS, Environmental Assessment, Vol IV. Pg. M-9.	
Initial Free Market Price of Rice (IFMPRG)	5,434 R/ton	TAMS, Environmental Assessment, Vol. IV. Table M-3, Pg. M-10.	
Homestead Land Per Family (HLPF)	.4 Ha	Acres, Annex G, Pg. 49	
Average Yield Per Cash Crop Ha (AYPCCH)	1.5 tons/Ha	Acres, Annex, G, Table G-3, Pg. 32	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
World Market Price for Cash Crops (WMPCC)	7,500 Ru/ton	Acres, Annex G, Table G-3.1, Pg. 32	
Initial Potential Rice Yield (IPRY)	4.3 tons/Ha	Based on Acres, Annex L, Table L-4.6, Pg. 41	
Standing Water (SW)	3,200 Ha	Acres, Annex A, Table A-3.1, Pg. 21	This is the amount of water held in irrigation tanks prior to the project.
Hectares Irrigated Per Ha of Standing Water (HIPHSW)	4 Ha	Acres, Annex A, Pg. 20	
Cubic Meters Per Millimeter-Ha (CMMMHA)	10	Paul Faeth, ERS	
Desired Rice Consumption Per Person (DRCPP)	.11 tons/yr	Acres, Annex G, Pg. 51	
Million Calories Per Ton of Rice (MCPTR)	1.631	Larin Robison, Brigham Young Univ.	
Million Calories Per Liter Milk (MCPLM)	.000703	Dr. Larin Robison, BYU	
Million Calories Per Ton Pulse (MCPTPLS)	1.587	Dr. Larin Robison, BYU	
Million Calories Per Tonne Livestock Meat (MCPTLM)	1.975	Larin Robison	
Minimum Calories Per Person Per Year (MCPPPY)	.584 (million cals.)	From: McGraw-Hill Encyclopedia of Food, Nutrition, and Agriculture, 1977.	
Kilograms Protein Per Ton Rice (KGPPTR)	35.2	From: Food Values, Bowes and Church, 1970	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Kilograms Protein Per Ton of Pulse (KGPPLS)	105.6	From: World Protein Resources Allen Jones, 1974	
Normal Milk Production Per Head Livestock (NMPHLS)	183 liters/yr	Dr. Larin Robison, BYU	
Kilograms Protein Per Liter Milk	.027	From: McGraw-Hill Encyclopedia of Food, Nutrition, and Agriculture, 1977	
Minimum Protein Per Person Per Year (MPPPPY)	32.85 Kg	From: World Protein Resources, Allen Jones, 1974	This is based on a minimum of 90g protein consumed per person daily.
Normal Kg Protein Per Ton Livestock Meat (NKGPTL)	168 Kg	From: World Protein Resources, Allen Jones, 1974	
Initial Draft Livestock (IDLS)	45,000	Acres, Annex F, Table F-2.1, Pg. 6	This is the number of livestock in private herds.
Draft Livestock Birth Fraction (DLSBF)	.08/year	Assumed by the modeler	
Normal Fractional Mortality of Draft Livestock (NFMDLS)	.05/yr	Acres, Annex F, Appendix Table 1, Pg. 79	
Initial Farmer Knowledge (FK)	.25 units out of a possible 1.	Assumed by the modeler	Farmer knowledge is an index variable that ranges from 0-1, 1 being the highest amount of knowledge a farmer can possess.
Normal Increase in Farmer Knowledge (NIFK)	.04 units	Assumed by the modeler	This is the normal increment of knowledge per year due to learning and experience.
Desired Agriculture Extension Agent: Farm Family Ratio (DEAFR)	1:2,000	TAMS, Environmental Assessment, Vol. 1, pg. 81	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Initial Participation (PART)	.9	Assumed by the modeler	This is also an index variable with a high range of 1.
Construction Time (CT)	1.25 years	Assumed by the modeler	This is the time required to construct infrastructure and capital services.
Normal Depreciation Time (NDT)	30 years	Assumed by the modeler	This is the normal lifetime (useful) of infrastructure and capital services.
Cost Per Unit Infrastructure (CPUI)	16,000 rupees	Assumed by the modeler	
Desired Infrastructure per Person	.1 unit	Assumed by the modeler	
Desired Fraction of Infrastructure	.6	Assumed by the modeler	
Forecast Horizon (FH	5 years	Assumed by the modeler	This is the time period over which government analysts forecast population.
Long-term Farm Production Averaging Time	6.5 years	Assumed by the modeler	This is the time over which commercial service analysts forecast long-term growth in the farm economy.
Initial Employment Generated Per Capital Service Unit	.5 jobs	Dr. Donald Hertzmark, A.I.T.	
Average Employment Generated Per Unit Infrastructure (AEGPUI)	.5 jobs	Dr. Donald Hertzmark	
Average Employment Generated Per Unit Under Construction (AEGPCP)	1 job	Dr. Donald Hertzmark	
Fraction of Farm Family Members Available for Employment (FFAOFE)	.1 (10%)	Dr. Bert Levison, (A.I.D.)	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Fraction of Non-Farm Population Available for Employment (FNFPAE)	.4 (40%)	Dr. Bert Levison, A.I.D.	
Average Villu Carrying Capacity (AVCC)	1 head livestock per Ha/yr.	Acres, Annex F, Pg. 2	
Normal Villu Grazing Period (NVGP)	.75 years	Acres, Annex F, Pg. 2	
Time to Change Carrying Capacity (TCCC)	2 years	Assumed by the modeler	
Villu (V)	10,000 Ha	Acres, Annex F, pg. 2	
Change in Villu (PHCV)	5,000 Ha	Acres, Annex F, Pg. 2	
Average Parkland Carrying Capacity (APLCC)	.33 livestock per ha/yr	Acres, Annex F, Pg. 3	
Normal Parkland Grazing Period (NPLGP)	.25 years	Acres, Annex F, Pg. 3	
Average Paddy Carrying Capacity (APCC)	2 livestock per ha/yr	Acres, Annex F, Pg. 4	
Normal Paddy Grazing Period (NPGP)	.75 yrs	Acres, Annex F, Pg. 4	
Maximum Management Expertise Per Manager (MMEPM)		Assumed by the modeler	This is an index variable with a high range of 1.
Resource Managers Required Per Ha. Forest Plantation (RMRPHP)	.0057	Based on recommendations in TAMS, Environmental Assessment, Vol. 1, Pg. 49	This is based on a ratio of 200 forest rangers & guards for 35,000 ha of forest plantation.
Normal Required Wildlife Managers (NRWM)	100	Based on recommendations in TAMS, Environmental Assessment, Vol. 1, pg. 49	This is an initial value of 100 forest rangers for the entire wildlife population of the project area.

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Natural Resource Managers Required to Manage National Forests per Ha (NRMRMF)	.0175	Based on TAMS, Environmental Assessment, Vol. I, pg. 49	This is based on 100 forest rangers and 150 forest guards for 20,000 ha of national parkland.
Average Duration (term) of Project Area Natural Resource Managers (ADPARM)	18 years	Assumed by the modeler	
Average Initial Expertise Per Resource Manager (AEPRM)	.5 units	Assumed	Expertise is an index variable with a range of 0-1, with 1 at the high end.
Average Expertise Per Incoming Resource Manager (AEPIRM)	.2 units	Assumed	
Normal Annual Increase in Expertise from Experience (NAIE)	.035 units	Assumed	
Normal Elephant Birth Fraction	.08/yr (8%)	Dr. Stephen Berwick, IIED	
Normal Fraction of Elephants Poached (NFEP)	.05/yr (5%)	Dr. Stephen Berwick, IIED	
Normal Average Elephant Lifetime (NAEL)	65 years	Dr. Berwick, IIED	
Elephants per Ha Native Forest (EPHNF)	.0001	Dr. Berwick, IIED	This is a carrying capacity concept.
Elephants Per Ha Parkland (EPHPL)	.003	Dr. Berwick, IIED	
Elephants Per Ha Chena (EPHC)	.003	Dr. Berwick, IIED	
Elephants Per Ha Forest Plantation (EPHFP)	.0008	Dr. Berwick, IIED	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Elephants Per Ha Cropland Edge (EPHCL)	.001	Dr. Berwick, IIED	
Elephants Per Ha Villu (EPHV)	.003	Dr. Berwick, IIED	
Normal Leopard Birth Fraction (NLBF)	.175/yr (17.5%)	Dr. Berwick, IIED	
Normal Fraction of Leopards Poached (NFLP)	.05/yr (5%)	Dr. Berwick, IIED	
Normal Average Leopard Lifetime (NALL)	10 years	Dr. Berwick, IIED	
Leopards Per Ha Native Forest (NPHNF)	.001	Dr. Berwick, IIED	
Lepards Per Ha Parkland (LPHPL)	.001	Dr. Berwick, IIED	
Leopards Per Ha Chena (LPHC)	.001	Dr. Berwick, IIED	
Leopards Per Ha Cropland Edge (LPHCL)	.0001	Dr. Berwick, IIED	
Leopards Per Ha Villu (LPHV)	.002	Dr. Berwick, IIED	
Normal Langur Monkey Birth Fraction (NLMBF)	.275/yr (27.5%)	Dr. Berwick, IIED	
Normal Average Langur Monkey Lifetime (NALMLT)	4 years	Dr. Berwick, IIED	
Langur Monkeys Per Ha Native Forest (LMPHNF)	.15	Dr. Berwick, IIED	
Langur Monkeys Per Ha Parkland (LMPHPL)	.07	Dr. Berwick, IIED	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Langur Monkeys Per Ha Chena (LMPHC)	.08	Dr. Berwick, IIED	
Langur Monkeys Per Ha Forest Plantation (LMPHFP)	.02	Dr. Berwick, IIED	
Langur Monkeys Per Ha Cropland Edge	.08	Dr. Berwick, IIED	
Langur Monkeys Per Ha Villu (LMPHV)	.2	Dr. Berwick, IIED	
Langur Monkeys Per Ha Settlements (LMPHS)	.06	Dr. Berwick, IIED	
Normal Axis Deer Birth Fraction (NADBF)	.25/yr (25%)	Dr. Berwick, IIED	
Normal Fraction of Axis Deer Poached (NFADP)	.1/yr (10%)	Dr. Berwick, IIED	
Normal Axis Deer Lifetime (NADLT)	8 yrs	Dr. Berwick, IIED	
Deer Per Ha Native Forest (DPHNF)	.0005	Dr. Berwick, IIED	
Deer Per Ha Native Forest Edge (DPHNFE)	.01	Dr. Berwick, IIED	
Deer Per Ha Parkland (DPHPL)	.05	Dr. Berwick, IIED	
Deer Per Ha Chena (DPHC)	.04	Dr. Berwick, IIED	
Deer Per Ha Forest Plantation (DPHFP)	.005	Dr. Berwick, IIED	
Deer Per Ha Cropland Edge (DPHCLE)	.01	Dr. Berwick, IIED	
Deer Per Ha Villu (DPHV)	.04	Dr. Berwick, IIED	

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
Fractional Edge of Cropland (FECL)	.05 (5%)	Assumed	
Fraction of Settlements Homestead Land (FSHL)	.8 (80%)	Dr. Michael Sobcyak, TAMS	
Average Evapotranspiration Losses Per Season (AETLPS)	700 mm-ha/ha	Paul Faeth, Economic Research Service, USDA (ERS)	
Average Deep Percolation Losses Per Season (ADPLPS)	400 mm-ha/ha	Paul Faeth, ERS	
Water Necessary for Land Preparation (WNFLP)	180 mm-ha/ha	Paul Faeth, ERS	
Mean Effective Rainfall (MERFL)	900 mm	Paul Faeth, ERS	
Standard Deviation of Effective Rainfall (SDERFL)	300 mm	Paul Faeth, ERS	
Desired Water Volume for Other Uses (DWVOU)	$1 * 10^7$ m^3/yr	Paul Faeth, ERS	
Time to Fill Reservoir with Silt	70 years	Assumed by the modelers	
Average Volume Per Ha of Fuelwood from Native Forest Cleared at Project Startup (AVCNFW)	500 ft^3/ha	Acres, Annex H, Pg. 30	
Sri Lankan Rice Quality Bias (SLRQB)	.8 (80%)	Paul Faeth, ERS	Sri Lankan rice is generally considered of inferior quality to the Thai standard. This bias helps adjust the market price of rice (MPR) to account for this.

Variable (Model Acronym)	Numeric Value	Source of the Data	Comments
World Free Market Price of Rice (WFMPR)	5,434 Rupees/ton	TAMS, Environmental Assessment, Vol. IV, Table M-3.	
Initial Capital Cost of Reforestation per Ha (ICCRPH)	1,375 Rupees/Ha	Acres, Annex H, Table H-8.1, Pg. 44.	
Annual Wage Per Agricultural Laborer (AWPAL)	5,475 Rupees/yr	TAMS, Environmental Assessment, Vol. IV Pg. L-18	Based on daily wage of 15 Rupees
Fertilizer Use Indicated by Seed Technology (FUIST)	340 Kg/Ha/yr	Acres, Annex E, Table E-6.1, Pg. 112	
Average Fertilizer Cost (AFC)	36.4 Rupees/Kg	Acres, Annex G, Table G-31.	
Desired Minimum Rice Stores Per Person (DMRSPP)	.05 tons/person/yr	Paul Faeth, ERS	
Million Calories Per Ton Draft Livstock Meat (MCPTLM)	1.975 million calories	Larin Robison	
Normal Consumption of Fish Per Year (NCFPY)	.02 tonnes/ person/yr	Larin Robison	
Million Calories Per Tonne of Fish (MCPTF)	1.528	Larin Robison	
Normal Consumption of Poultry Per Person Per Year (NCPPY)	.02 tonnes/ person/yr	Larin Robison	
Kilogramsof Protein Per Tonne of Fish (KGPPTF)	259 Kg	Larin Robison	