Methodologies for Decision Making in Natural Resource Management

8

Use of Simulation Models for Ex-ante Evaluation

Ruben Darío Estrada
Oscar Chaparro
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CONDESAN COLCIENCIAS UNIVERSIDAD DE CALDAS

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
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1. Simulation 2. Exante Evaluation 3. Simulation Models 4. Linear Programming Models

The figure represents the set of tools for use in decision making in natural resource management. The tools represented by the green sections of the figure *(Participatory method for identifying and classifying local indicators of soil quality at the microwatershed level, Photo-topographical analysis (PTA) of land use trends in hillside areas*, and *Participatory mapping, analysis, and monitoring of natural resources in a microwatershed)* help identify, analyze, and prioritize biophysical components, such as natural resources at the farm, microwatershed, or sub-basin levels.

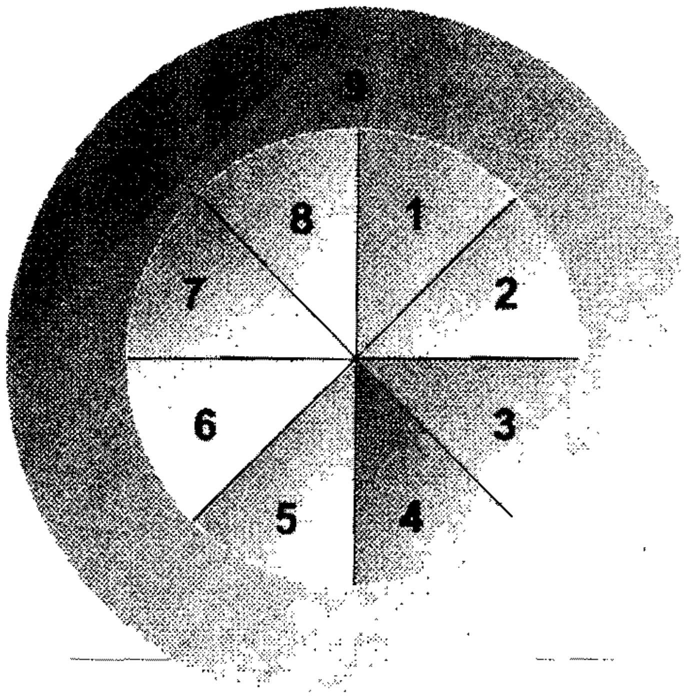
Those tools in blue (*Methodology for analyzing stakeholders involved in collective land management at the microwatershed level* and *Identifying levels of well-being to construct local, rural poverty profiles*) help identify relationships between the different users of natural resources. By identifying standards of living, the socio-economic components can be classified at the rural community, village, and regional levels.

The tool in yellow (*Atlas of Yorito and Sulaco, Department of Yoro, Honduras*) helps standardize integration, analysis, and presentation by mapping data generated by the tools in green and blue.

The tools in orange (*Identifying and assessing market opportunities for small rural producers* and *Use of simulation models for* ex ante *evaluation*) help facilitate the design of alternative scenarios to plan production at the farm and microwatershed levels.

Encompassing these eight decision-making tools, the purple tool (*Development of local organizational processes for collective management of natural resources*) helps (a) define the collective use of the other tools, and (b) disseminates results obtained through their application. This tool is useful for organizing communities in order to improve their decision-making in collective management of natural resources at the watershed level.

Methodological Tools for Making Decisions in Natural Resource Management



1. Participatory method for identifying and classifying local indicators of soil quality at the microwatershed level

2. Photo-topographical analysis (PTA) of land use trends in hillside areas

3. Participatory mapping, analysis, and monitoring of natural resources in a microwatershed

4. Methodology for analyzing the stakeholders involved in collective land management at the microwatershed level

5. Identifying levels of well-being to construct local profiles of rural poverty

6. Atlas of Yorito and Sulaco, Department of Yoro, Honduras

7. Identifying and assessing market opportunities for small rural producers

8. Use of simulation models for ex ante evaluation

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Introduction

Agricultural research and development face increasingly complex challenges, which demand new approaches from researchers and development agents in the analysis of a system's problems and potentials.

Today, there is a need to apply new strategies in the development of technologies in natural resource management, with which researchers and development agents can integrate different hierarchical levels, taking into account the total allocation of resources and the interaction of subsystems, especially crop productivity and soils.

In the formulation of methodologies to provide useful information for researchers and farmers about the trade-offs between sustainability and productivity at different levels of production, the use of models facilitates analysis in areas of interest in natural resource management. These areas include the development options of a watershed, the identification of the terms for trade-off between sustainability and fairness, and the exante quantification of technological alternatives.

The development and use of models has prompted research groups from CIAT, CONDENSAN and Latin American universities to resolve bottlenecks in decision-making for natural resource management. Experiences in different ecological basins in Colombia, Peru and Ecuador permit the documentation of this process and encourage the creation of training material to facilitate the use of simulation models in decision-making for natural resource management.

This guide proposes the use of simulation models as a methodological strategy that permits groups of researchers and development agents to explore different alternatives for the construction of more efficient production systems, from the biophysical, economic, social, and energy points of view.

The proposal is based on the construction and use of mathematical models that generate information to predict the benefits of technology. The models also permit analysis of the likelihood that this technology will fulfil the objectives of the project and contribute to the satisfaction of society's concerns about the rational use of natural resources, environmental protection, economic growth and competitiveness in a globalised economy.

The models presented permit the integration of different disciplines and systems. This allows the description and understanding of land use and its temporal and spatial dynamics, the analysis of spatial patterns in agricultural activities in the regional landscape and the sensitivity of land use to changes in the politics governing factors such as prices and growth.

The aim of the guide is to propose a working methodological strategy to the users which will permit decision-making in natural resource management in hillside regions through the construction and use of simulation models. We also hope to contribute to improving the analytical capacity of work groups by providing tools that allow for the integration of aspects such as productivity, fairness, sustainability and competitiveness in the short, medium and long terms.

This guide has four sections. In the first, we develop the conceptual foundation of simulation models and exante evaluation. In the second, we present existing simulation models for decision-making in the management of water, soil and plant resources in hillside areas. These models are EPIC, CROPWAT and LADERA. For each one, instructions are given for understanding and application. In section three, we propose procedures for users to build simulation models through linear programming. Finally, in section four, by way of example we present three cases of the application of simulation models in decision-making for natural resource management on hillsides.

The guide has been designed to be accessible to all groups of researchers and development agents who face problems related to sustainable management of natural resources in hillside zones in Latin America on a daily basis. It uses clear language and a didactic structure that goes from the simple and basic to the complex and general.

Users of the Guides

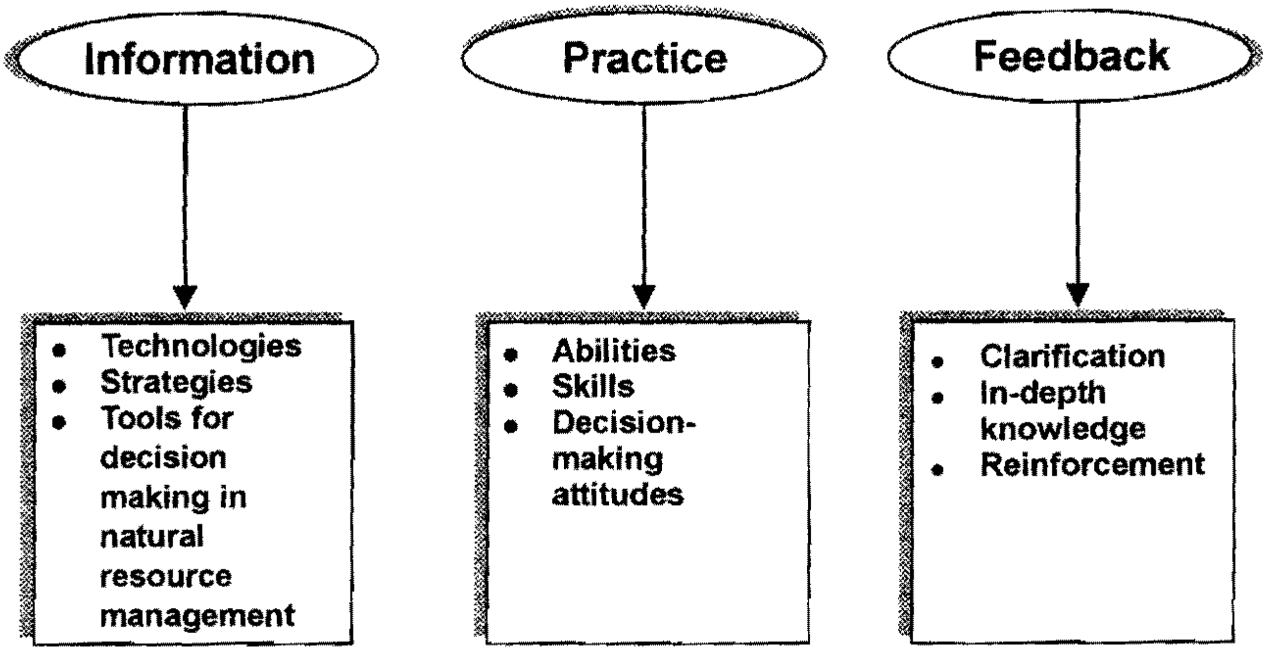
The series of nine Guides dealing with Methodological Instruments for Decision-Making in Natural Resource Management is directed to two types of specific users.

The first, made up of professionals and technicians that work for organisations and institutions in the private and public sectors, dedicated to research, development and training in renewable natural resource management. This type of user should take advantage of the guides to support planning, execution, follow up, and evaluation of their initiatives in those three areas of action. Moreover, we expect that this group, once trained in the use of the methodologies will exercise the role of multiplier for hundreds of professionals, technicians, volunteers, and producers in promoting, analysing and adapting these methodologies toward decision making in natural resource management at the local, regional and national levels.

The second group of users is made up of those who are ultimately the legitimate inheritors of the proposals for natural resource management, developed through research and presented in the guides: the inhabitants of the in tropical America. These persons, through training, consulting and support by a variety of non-governmental organisations and agencies of the State, will be able to make the methods and strategies presented herein their own, in order to actively participate in the management and conservation of natural resources.

These materials are especially dedicated to the teachers in the faculties and schools of agricultural and environmental sciences and natural resources. It is they who train the professionals and technicians, who will accompany the agricultural communities, in the immediate future, in the difficult task of maintaining or recuperating the natural resources placed in their custody for coming generations.

Learning Model



The series *Training Guides over Methodological Instruments for Decision-Making* follows an educational model based on learning by doing. This model proposes to the immediate users of these guidestrainers and multipliersa training process in which the input information, resulting from field research, serves as raw material for developing abilities, skills, and attitudes required by the ultimate users in making the proper decisions related to natural resource management.

The users of these guides will observe that the methodological components differ from other materials for the popularisation of technologies. Each one of the sections into which the guides are divided contains design elements that permit the trainer to exercise his job as a learning facilitator.

The Guides are oriented by a set of objectives that enable the teacher and participant to direct the learning process. This is accomplished through exercises from the field or other realistic scenes, in which the processes of analysis and decision making are practised, using walks, simulations, dramatisations, and applying different instruments for information collection and analysis.

Other components include the feedback sessions, in which the training participants, together with the trainers, have the opportunity to review the completed exercises and consider in more detail those aspects that should be reinforced. The feedback information constitutes the last portion of each session in the guide and is the preferred space for the trainer and the participants to accomplish conceptual and methodological synthesis of each aspect studied.

In summary, the model is made up of three elements: (1) the technical and strategic information, that is the product of research and constitutes the technological content necessary for making decisions; (2) the practicals, presented in the form of exercises in the training site and the field activities, directed toward the development of abilities, skills and attitudes for decision making; and (3) the feedback information that is a kind of formative evaluation to ensure that the participants master the underlying theoretical principles and their proper application.

The practicals are the central axis of the training and stimulate the reality lived by those who use the decision making instruments presented in each guide. Through the exercises the participants in the training experience the use of the instruments, the difficulties that arise from their application at the local level, and the advantages and opportunities represented by their introduction in the different decision making environments in the local or regional context of each country.

The exercises included in the guides were extracted from the local research experiences of the authors in small watersheds in Honduras, Nicaragua and Colombia. However, the trainers from other countries and regions will be able to extract excellent examples and cases from their own research projects to redesign the practicals and adapt them to the local context. Each trainer has in hand guides that are flexible instruments that can be adapted to the necessities of different audiences in different settings.

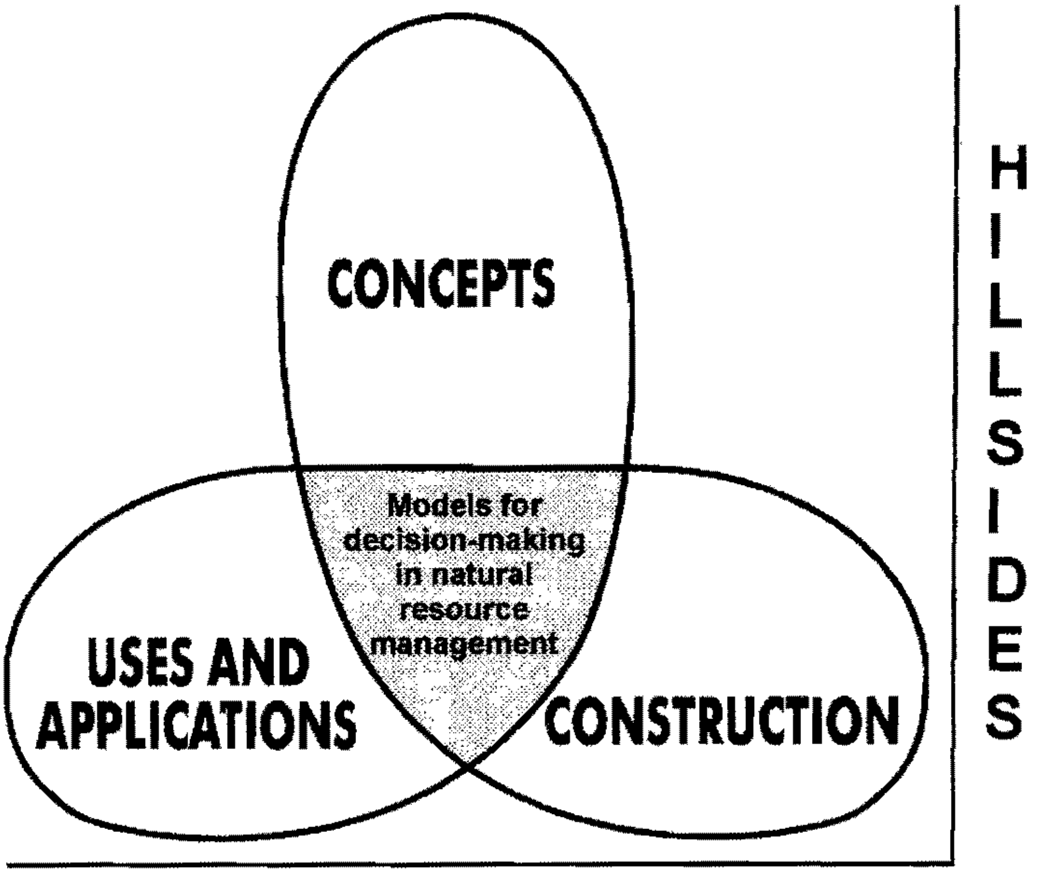
Uses and adaptations

It is important that the users of these guides (trainers, multipliers) understand the functional role offered by their didactic structure so that they use this for the benefit of the final users. They are the ones who are going to decide to introduce these instruments in the development process at the local level.

In order to achieve this, we emphasise the use of flow diagrams to help the trainers in the presentation of the different sections. We include: the orientation questions, which permit the establishment of a dialogue and promote the motivation of the audience before entering into theoretical detail; originals for transparencies that can be adapted for different necessities, introducing adjustments in their presentation; the appendices cited in the text will help study in depth those aspects briefly treated in each section; the recommended exercises and practicals, which as mentioned before, can be adapted or substituted by practicals about problems relevant to the local audience; the feedback sessions, in which it is also possible to include local, regional or national data to make them more relevant to solidifying the topics and didactic appendices (post-test, evaluation of the trainer, evaluation of the event, evaluation of the material, etc.) that help to complement the training activities.

Finally, we wish to leave a central idea regarding the training model that the guides follow: If practical exercises are the most important aspect in the learning process, the training should include enough time so that those who experience them have an opportunity to develop the abilities, skills and attitudes that reflect the training objectives. Only in this manner is it possible to expect the training to have the hoped-for impact on those who make decisions about natural resource management.

General Structure of the Guide



Explanation

Learning means incorporating new ways of relating to reality. This is done through two complementary processes: the assimilation of data regarding the reality of the subject, and the redefinition of the reality of the subject.

In this context the guide recognises the existence of the users' knowledge and experiences, and endeavours to generate spaces for the integration of existing concepts into new proposals in the use of simulation models for exante evaluation.

The guide is structured to provide opportunities for users to adopt the concepts and instruments in the construction and use of simulation models in responding to new challenges in decision-making in natural resource management in hillside zones.

The structure is based on the following elements: the concepts of modelling, use of models, their construction and applications, which are expressed through the fundamental questions: What is the conceptual basis for the use of models in exante evaluation? Which models exist and how can I use them to respond to my needs?

How are simulation models built? What applications have been made of simulation models for decision-making in natural resource management on hillsides? Each of these questions is analysed in a separate section.

The first question is considered in section one where a theoretical framework is proposed to respond to the following questions: What is a model? What are models used for? How are models classified? What are their advantages and limitations? What is ex-ante evaluation?

In section 2 the characteristics of three simulation models are presented. These have been successfully used in research and development projects in Latin America and in each one we propose to the user elements for understanding and use.

In section 3 we propose the application of linear programming for the construction of simulation models. Here we explain the steps for the user to build and use models using Excel electronic spreadsheets. These are used to respond to the needs of a production system in decision-making for natural resource management in hillside areas.

Section 4 presents three applications of simulation models in decision-making in ex-ante evaluation. In each one of the applications we emphasise the elaboration of the mental model, the collecting of information, the description of the model and sensitivity analysis.

The guide through its structure, provides the user with the opportunity to become involved in a continual process of innovation, invention, questioning, considering, discussing, planning, failing, succeeding, rethinking and imagining the knowledge presented in each of the examples and exercises proposed.

We hope that this collective exercise of knowledge building by researchers and development agents in the use of simulation models will be converted into concrete actions in the development of hillside zones in Latin America.

Self test

Instructions

Below the participants are asked to answer some questions. This is not a test, but rather an exercise to find out what perceptions and knowledge they have about the subjects presented in this guide.

Questions

1. What do you understand by a simulation model?

2. What do you consider to be the usefulness of models for decision-making in natural resource management?

3. What do you understand by ex-ante evaluation?

4. What simulation models are you familiar with, and what experiences have you had with their use?

5. What is the methodological procedure for the application of simulation models for decision-making in ex-ante evaluation?

Selftest Feedback

Instructions

Now the participant has examined his or her knowledge about the topics related to ex-ante simulations. Below the answers are compared with some suggestions made by the trainer.

Answers

For question 1

The simulation model is a representation of an object, concept or real system in such a way that, although different from the entity it represents, imitates its function and one or several of its attributes.

In the area of production systems, the term 'model' can be understood as an abstraction or simplified representation of the productive unit (organ, plant, animal, farm, small watershed, watershed, region).

In the ideal model the object or system is approximated as closely as possible. This implies that the model would slowly become useless, at least in the final stages, as the real system becomes accessible. However, it appears that this possibility is so remote that the disappearance of the model as a necessary mediator has yet to be considered.

For question 2

Simulation models can be used to explain and understand the system or to predict or duplicate the characteristic behaviour of a system. They have been used to simulate a component of the system, a farm as a whole, a watershed, or a region.

In the field of natural resource analysis, models are an important aid in that they allow the incorporation of the 'time' variable in the analysis, and they simulate decision-making in the production unit. This is done with regard to the target function, which is the desired situation for the producers or decision centre.

For question 3

Ex-ante evaluation is one of the components in the design of technological alternatives that looks for or anticipates the benefits of the technology. It also analyses the possibility of this technology fulfilling the project objectives and contributing to satisfying the challenges of sustainable, fair, and competitive management in hillside zones. In decision-making in research projects and rural development, the stage of designing technological alternatives is a basic component, in which the research team explores different proposals for more efficient production systems, from the biophysical, economic, social and energy points of view.

For question 4

A considerable number of models exist that simulate erosion as a function of soil characteristics and use, climatic and topographic conditions, and the cost and marketing structures. These models permit simulation of the soil loss and agricultural productivity, or the effects of implementing conservation practices to reduce erosion, runoff, and biological and economic productivity of the production systems. Among the best known models are: Epic (Environmental Policy Integrated Climate), Wepp (Wind Erosion Prediction System), Calsite (Calibrated Simulation of Transported Erosion), DSSAT (Decisions for agricultural system management), CROPWAT and LADERA.

For question 5

In general terms, the application of linear programming models implies a methodological procedure that includes the following stages:

1. Elaboration of a mental model. This constitutes a starting point that determines the usefulness of the mathematical model and that is specific to each particular case. The models are not universal; rather they are built in order to respond to concrete questions under specific conditions. The mental model keeps a relation to the kind of questions that the model should answer. The structure and function of the model are oriented precisely to respond to these questions.

2. Collecting information. The research team or development agents should decide about the availability of information to feed the model, in order to answer the different questions formulated by the mental model. There is a wide range of conditions in which the information may be totally available or absent in secondary sources. Those who build the model should evaluate the quality of the available information and the implications for collecting the missing information from primary sources.

3. Activities and constraints. Once the information has been collected, the constraints of the model and the alternative activities are defined.

4. Sensitivity analysis. One of the main strengths of linear programming models is their capacity to respond immediately to any change in parameters. Through changes in parameters of activities and constraints an untold number of potential scenarios can be considered. Many of these are impossible to carry out in practice because of high costs. These potential scenarios constitute the most important information that the models offer to the analysis.

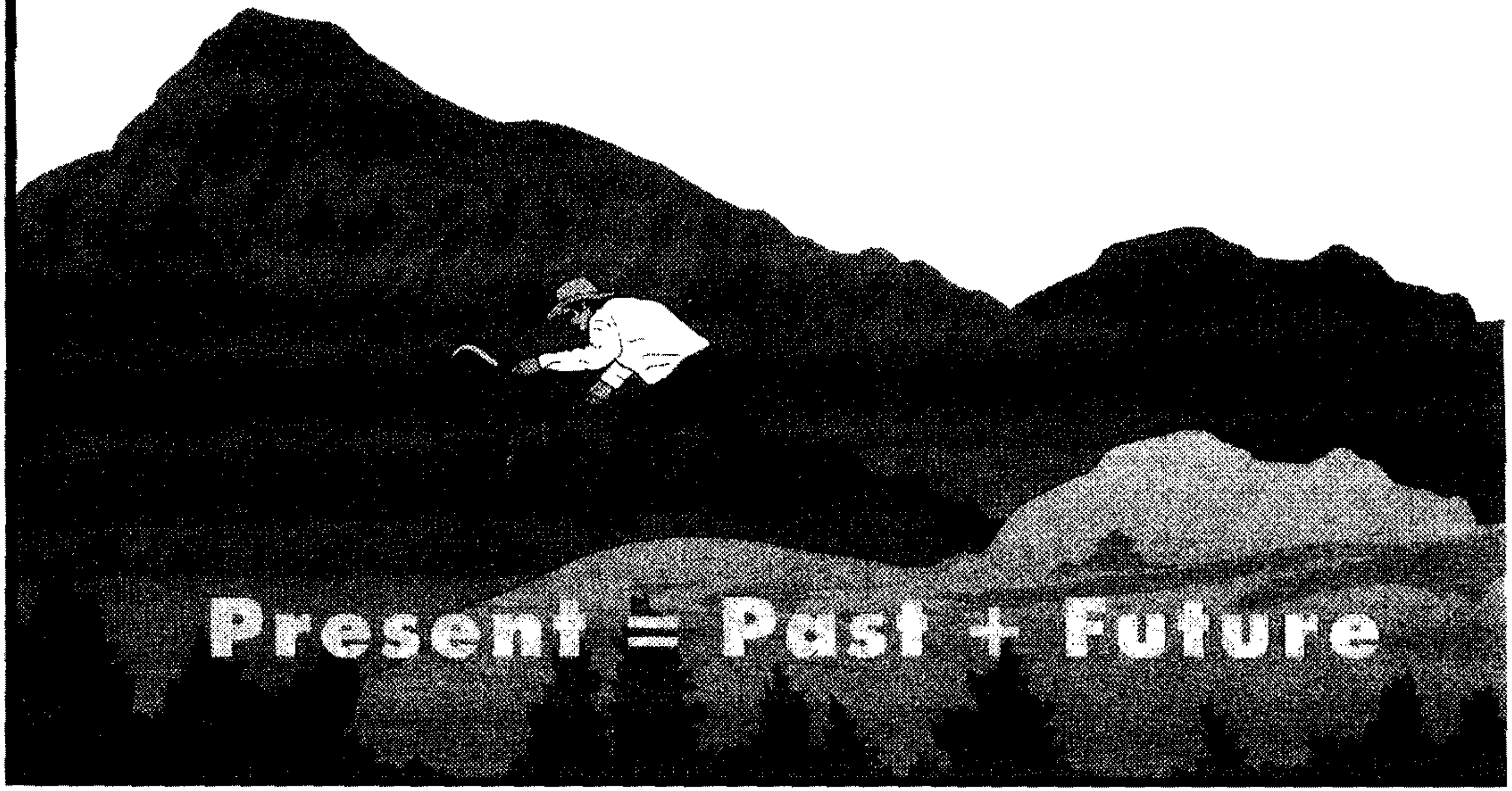
Objectives

After completing the guide the participants will be able to:

- ✓ Describe the concepts, uses and methodology for simulation through models.
- ✓ Describe the concepts, approaches and processes on which exante evaluation is based.
- ✓ Present a frame of reference for ex-ante evaluation of technologies in natural resource management. Case: Soil conservation.
- ✓ Present the possibilities and limitations of three models for natural resource management: EPIC, CROPWAT and LADERA.
- ✓ Present the structure and functions of the simulation models: EPIC, CROPWAT and LADERA.
- ✓ Acquire skill in the basic management of the simulation programs EPIC, CROPWAT and LADERA.
- ✓ Explain the main concepts and structure of simulation models based on linear programming.
- ✓ Build models using Excel spreadsheets.
- ✓ Be familiar with the applications of simulation models in decision-making in natural resource management in hillside zones.
- ✓ Describe the methodological steps for the application of simulation models in decision making in natural resource management.
- ✓ Identify the application of simulation models for analysing options for watershed development.
- ✓ Identify the application of simulation models in calculating the terms of trade-offs between political, sustainability, fairness and productivity criteria.
- ✓ Identify the application of simulation models in quantifying the trade-offs between fairness, productivity and sustainability in the design of technological alternatives.

Originals for Transparencies

The Use of Simulation Models for Ex-ante Evaluation



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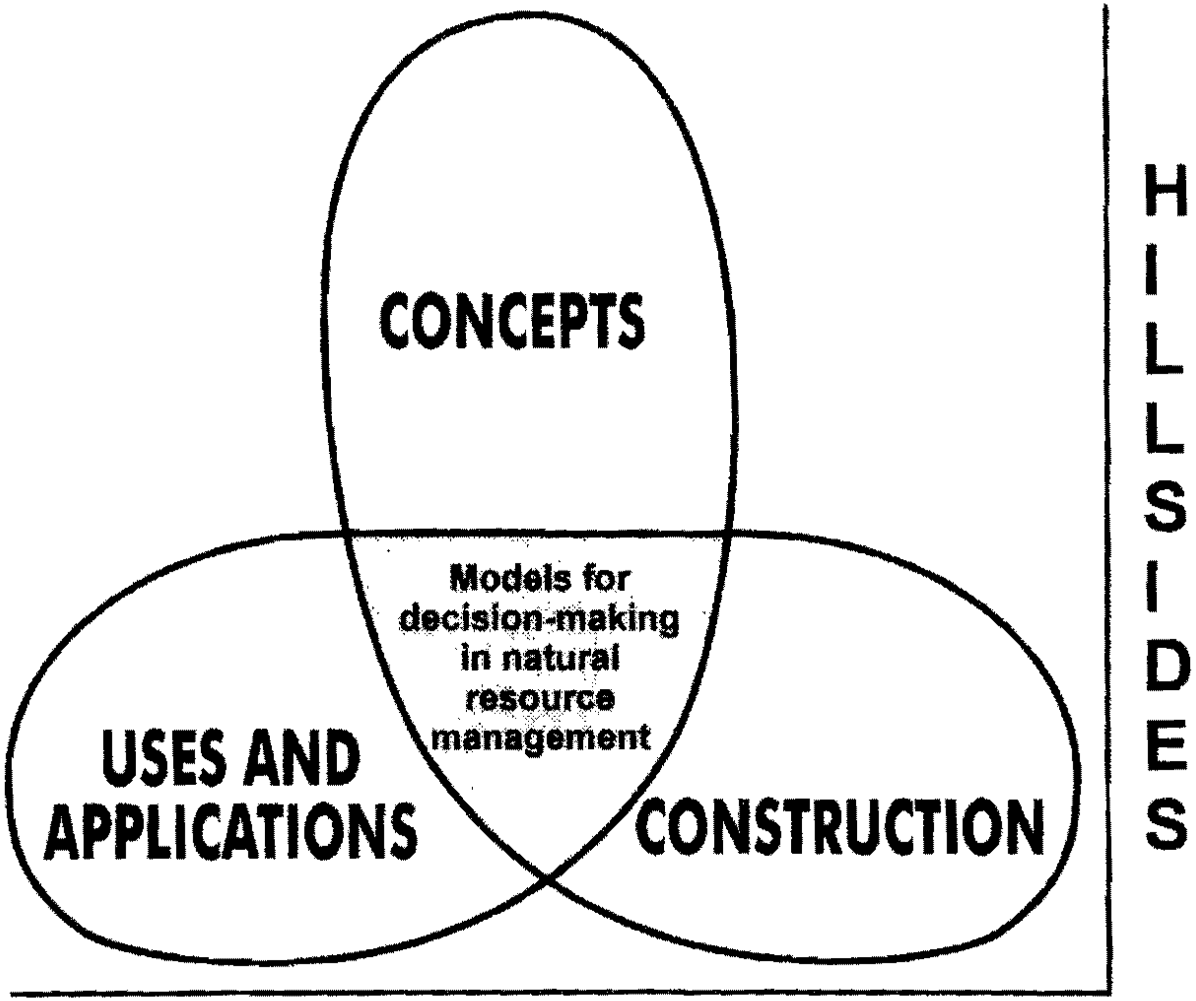


GENERAL OBJECTIVES

- ✓ Describe the concepts, approaches and processes on which ex-ante evaluation is based.

- ✓ Describe the concepts, uses and methodology of simulation using models.

- ✓ Present a frame of reference for ex-ante evaluation of technology in natural resources management.
  Case: Soil Conservation

- ✓ Present the limitations and possibilities of three simulation models for natural resource management: EPIC, CROPWAT and LADERA

- ✓ Present the structure and functions of the simulation models EPIC, CROPWAT and LADERA

GENERAL OBJECTIVES

- ✓ Acquire skill in the basic management of the simulation programmes EPIC, CROPWAT and LADERA
- ✓ Explain the main concepts and the structure of simulation models based on lineal programming
- ✓ Acquire skill in building models using Excel spreadsheets
- ✓ Be familiar with the applications of simulations models in decision-making for natural resource management in hillside zones
- ✓ Describe the methodological steps for the application of simulation models in decision-making for natural resource management

GENERAL OBJECTIVES

- ✓ Identify the application of simulation models for analysing options of watershed development
- ✓ Identify the application of simulation models in the calculation of the terms of trade-offs between political, sustainability, fairness and productivity criteria
- ✓ Identify tha application of simulation models in quantifying the trade-offs between fairness, productivity and sustainability in the design of technological alternatives

SELF TEST

1. What are the methodological phases for applying a simulation model in decision-making for natural resource management?

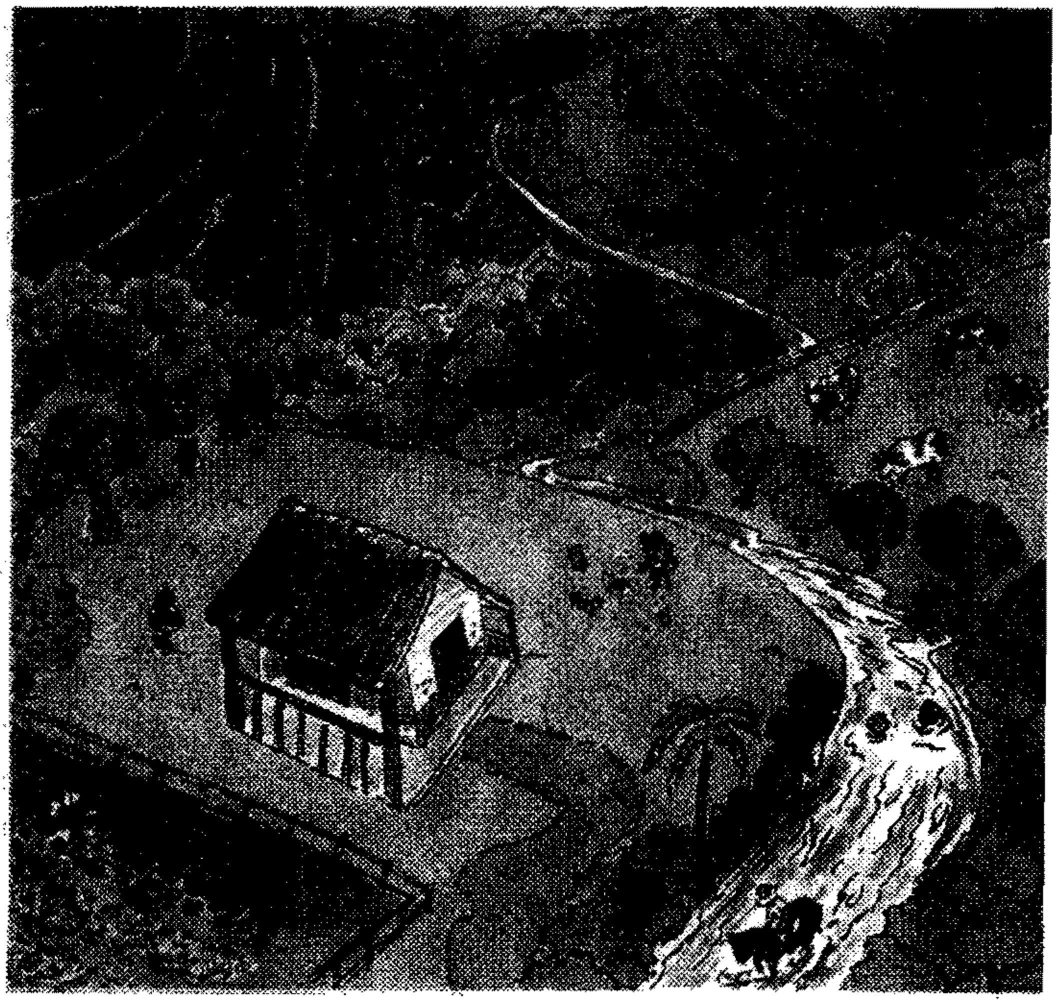
2. What are some relevant characteristics of simulation models used for analysing development options in a watershed?

3. What are the relevant characteristics in using simulation models for identifying the terms of trade-offs between sustainability, productivity and fairness criteria in a watershed?

4. What are the relevant characteristics in the use of simulation models for ex-ante quantification of trade-offs between fairness, productivity and sustainability in the design of technological alternatives?

Section 1

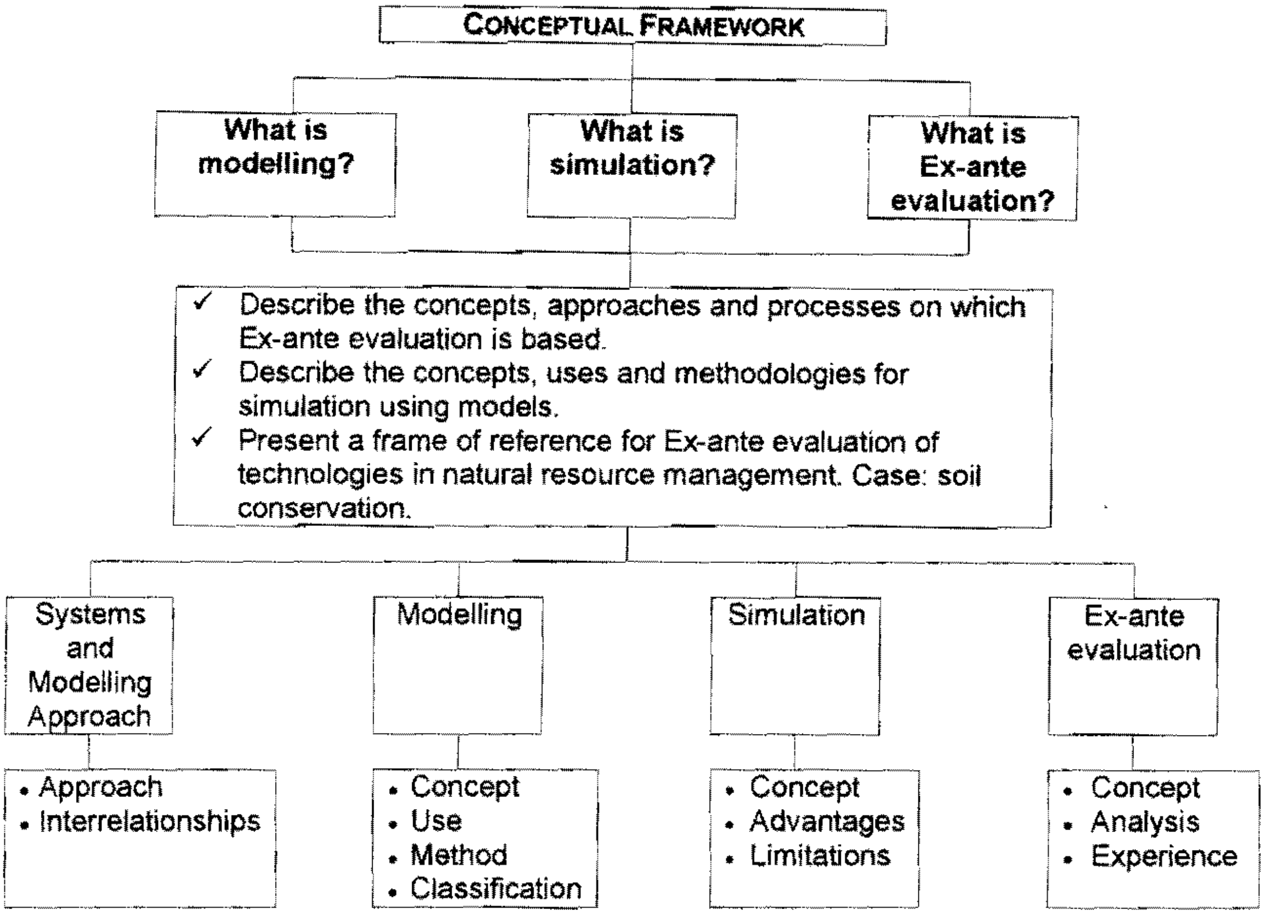
The Conceptual Framework for Ex-ante Evaluation



Section 1. The Conceptual Framework for Ex-ante Evaluation

Page

Structure of the Section



This section is made up of three components that together provide the necessary theoretical foundation for the use of simulation models in ex-ante evaluation.

The first component deals with the approach and methodology of production systems as a proposal for decision-making in natural resource management. The relationships between modelling, simulation, ex-ante evaluation and the systems approach are established.

The second component presents the theoretical framework in which the concepts of modelling and simulation are justified, developing elements such as: What are they? Why are they useful? How are they classified? How are they used? How are they made?

The third component deals with ex-ante evaluation, presenting its definition, its place in production systems methodology, and its context in natural resource management projects, using a case of soil conservation in hillside zones.

With the aim of generating opportunities for the participants to integrate their existing knowledge with new concepts, and build the necessary conceptual framework for incorporating simulation models in their every-day work, the section includes an exercise which invites them to formulate a series of questions relevant to their needs as researchers and development agents in their areas of work.

Objectives

At the end of the section the participants will be able to:

- ✓ Describe the concepts, approaches and processes on which ex-ante evaluation for natural resource management on hillsides is based.
- ✓ Describe the concepts, uses and methodology for carrying out a simulation through the use of models.
- ✓ Present a frame of reference for ex-ante evaluation of technologies in natural resource management. Case: soil conservation.

Orientation questions

1. How does modelling fit into the systems approach?
2. What is a simulation model?
3. How are simulation models built and used?
4. What is simulation and what are its advantages and limitations?
5. What is exante evaluation?
6. What aspects are involved in the process of ex-ante evaluation of technologies in Soil conservation?

1.1 Systems approach

What is the systems approach?

The systems approach came about as a consequence of current thinking that all objects and phenomena are part of larger components and that to understand them completely it is necessary to understand each of them and the interrelationships between the parts. Therefore, the 'whole' is not a simple sum of its separate parts. The 'whole' has come to be called a system and emphasis on its understanding has come to be called systems research. This current of thinking was translated, in operational terms, into a systems approach through which individual elements or parts can be integrated and the functioning of each within the system can be known. This approach seeks to evaluate the way the different parts fit together within the whole, how they interact and how the system behaves in relation to its environment and other systems in the same environment.

In order to achieve the sustainable use of resources, especially in hillside zones, it is essential to investigate the mechanisms that support sustainability or cause the deterioration of the systems, as well as the links between the systems at different hierarchical levels. This implies that an exclusively technological, discipline-oriented approach cannot be used. Thus it is necessary to use a systems approach which results from the application of the holistic paradigm. This allows description and understanding of land-use and its temporal and spatial dynamics, analysis of distributional patterns of agricultural activities in the landscape and the sensitivity of land use to changes in the policies for prices, development, etc.

The main characteristic of the systems approach is the recognition of interrelationships and of hierarchies. The systems hierarchies are defined as the structural relation in which each unit is composed of two or more subunits that, in turn, are similarly subdivided.

1.2 Systems hierarchies

Production systems are hierarchical systems with a wide range of categories that go from the level of the universe down to the level of farm, plant, animal, soil or cell. In order to study production systems, a minimum of three levels of analysis are required. These are: the priority level of the objective of the study, an upper level which provides the framework for the objective level, and a lower level that permits its description and understanding. For example, if in a project aimed at developing the sustainable use of soils, the objective level of analysis is the farm, it is necessary to characterise both the lower level (composed of soil, crops, animals and water) and the upper level (watershed, municipality and region).
The incorporation of hierarchical levels in the analysis is an essential condition for the development of an effective proposal. For example, the consideration of a higher level of a system may offer opportunities to substitute inputs, such as where fertility loss in a field can be improved by applying organic residues (that exist on the same farm) and that would normally be used for other purposes.

Additionally, a higher level in a system can offer opportunities for the substitution of activities. For example, the erosion associated with extensive crop production can become less of a problem if this is substituted by horticulture, a change made possible by building a road. At the highest level of a system, opportunities to achieve a balance between subsystems can be exploited. For example, investment in intensive agriculture in selected zones (with socially acceptable levels of pollution) can reduce the needs of the poor through the generation of employment and income, and generate a subsistence system in the hillside areas.

1.3 The Systems Approach and Simulation

The methodology for systems analysis is illustrated in Figure 1.1. If the approach is oriented toward modelling, these methodological steps can be expressed in the following way,

a. Identification of the system.
b. Elaboration of a conceptual or qualitative model.
c. Elaboration of a quantitative model.
d. Validation of the model.
e. Simulation for the selection of technology.
f. Modification and perfection of the model.
g. Validation of the technologies at the farm level.
h. Multiplication of the successful technologies.

The modelling phase begins in the elaboration of the conceptual model, which is a synthesis of the diagnostic stage. At this point the definition of the target function is essential in order to set the limits of the model (or system) and identify the inputs and outputs, as well as the constitutive elements and interactions.

Quantitative models are based on mathematical algorithms that are adjusted to the system being analysed and represent the relationships that exist between the components of the system.

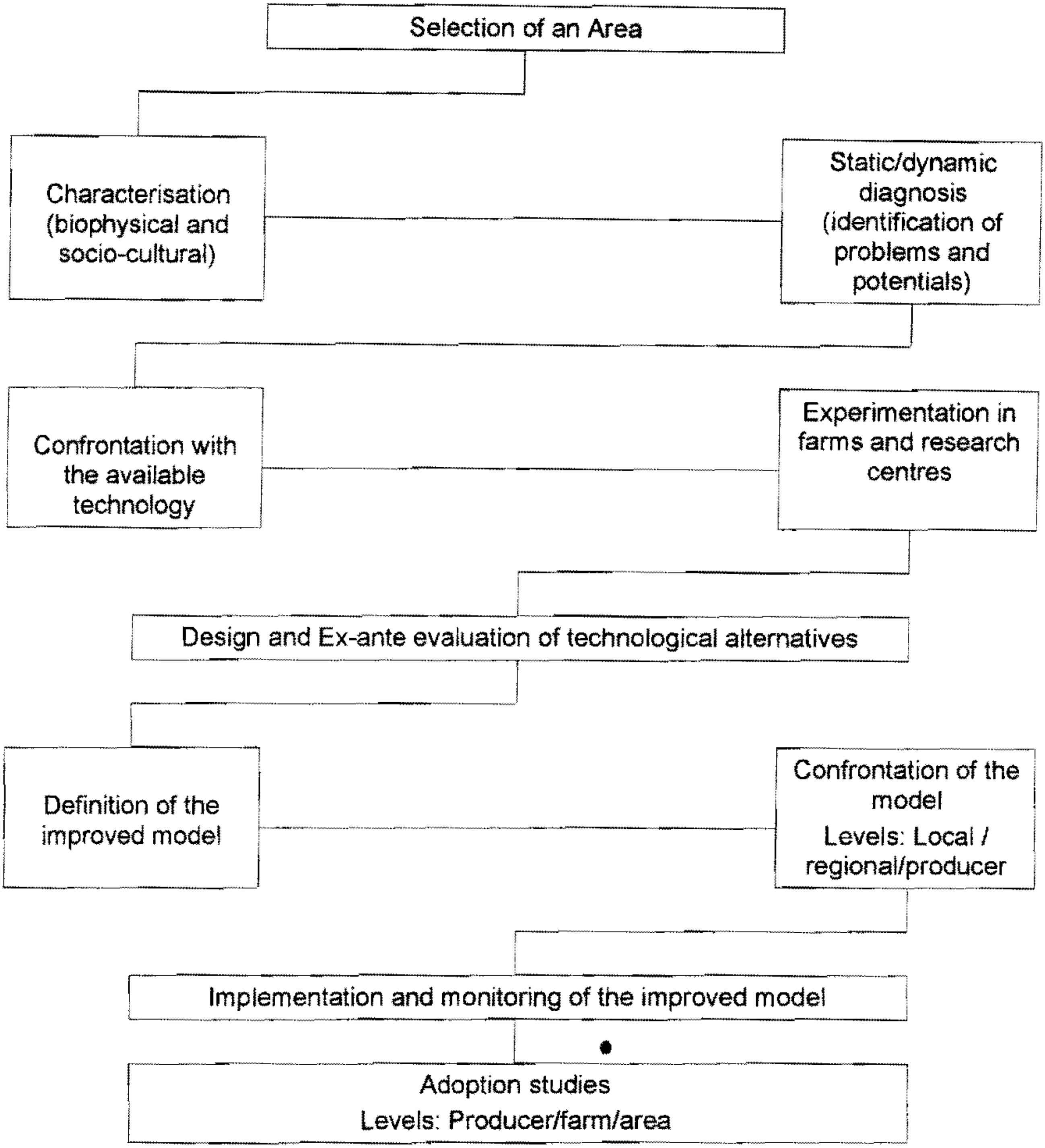


Figure 1.1 Methodological structure in production systems (adapted from Ruiz M. 1989)

Once the model has been structured a series of results are obtained that should be verified with information from the real world; this exercise is called validation. The validation process can take many forms. One is the verification of the performance of the separate components of the model and the hypothetical relationships with secondary information about the real system.

Another, more precise, verification is undertaken through an experiment in which the conditions of the model are given directly in the field in order to later compare the results and identify factors for correlation and adjustment.

Once the model has been verified, different scenarios are simulated in order to select and evaluate the impact of the technological proposal. This stage in the methodology of production systems research is called ex-ante evaluation, which is a process that explores different proposals for building more efficient production systems from the biological, social and energy viewpoints. The goal is to improve the production objective of the producer and the region.

1.4 What is a Model?

"No substantial part of the universe is simple enough that it may be understood and controlled without abstraction. Abstraction consists in replacing a part of the universe under consideration with a structurally similar but simpler model. Models are a central necessity of the scientific process" (Rosenblueth and Wiener, 1967). Reference to the works of Bunge (1983) such as 'The Concept of the Model', 'Models in Theoretical Sciences', 'Analogy, Simulation and Representation'; suffice to justify the need for scientists to work with models, theories and similar.

The model is a representation of an object, concept or real system in such a way that, while being distinct from the entity that is represents, it can imitate its functioning and one or more of its attributes (Aguilar and Caña, 1991)

In the production systems approach, the term model can be understood as an abstraction or simplified representation of the unit of analysis (organ, plant, animal, farm, small watershed, watershed or region).

Models should represent the principal activities and interrelationships of the system and should adapt themselves to various situations. They should also be general and accessible to researchers so that they can become valuable tools for interdisciplinary work groups.

The ideal model is as close as possible to the object or system being considered. This implies that the model will gradually become useless, at least in the later stages, as the system itself becomes accessible. However, this possibility is so remote that the disappearance of the model as a necessary intermediate step has yet to be proposed.

Models can help to explain and understand the system or to predict or duplicate the characteristic behaviour of a system. They have been used in this field of study to simulate many different components of the system, a farm as a whole, a watershed or region.

In the field of natural resource analysis, models make an important contribution by allowing the incorporation of the time variable into the analysis. They also permit the simulation of decision-making in the production unit, with relation to the target function, meaning the situation desired by the producers or decision centre.

When a researcher faces the problem of modelling a complex system, he or she has the possibility of combining different kinds of models, with different degrees of complexity and information demands. He or she can also use qualitative, quantitative, or predictive models, amongst others. In this manual we describe some of the models commonly used in research projects: EPIC (Environmental Policy Integrated Climate), CROPWAT, and LADERA.

1.5 Why are Models Useful?

Agricultural research and development face increasingly complex challenges that demand that the researcher and development agent approach the analysis of the problems and potentials of a system in new ways. In this context, models play a crucial role in the analysis of agricultural production systems. The value of the models depends on how they are applied to development and research processes, and ultimately on how they contribute to the solution of society's concerns about the rational use of natural resources, environmental protection, economic growth, and competitiveness in a global economy.

Below we present a summary of some of the most important advantages of the use of models in agricultural systems analysis (Estrada, 1995).

- They allow us to study the impact of changes in variables endogenous and exogenous to the system.
- They permit the study of interactions between activities that, given their complexity, would be difficult to isolate in reality.
- They facilitate understanding of the real world by permitting a detailed observation of the system through its components and interrelationships.
- They rank the elements of a system, permitting the prioritisation of the different components or interrelations with reference to an objective.
- They permit the evaluation of effects over time. This is of great importance in the study of natural resources, which by their nature demand a temporal analysis.
- They allow the simulation of situations that would demand high costs and a lot of time, such as soil loss, populational dynamics of insect plagues, genetic improvement of animals and sedimentation in rivers.
- They permit the prediction of the results of the implementation of new technological practices in the system, identifying potentials and problems that in the real world would mean failure in the experiment.
- They allow the identification of interchanges between the different hierarchical levels of a system, component, farm or region.
- They are an excellent way to facilitate interdisciplinary collaboration, which allows specialists a systemic view of reality, and forces researchers to consider all of the aspects of a system. This generates integral recommendations which are less biased toward the discipline-oriented knowledge of the specialists.

1.6 How are Models Made and Applied?

The essence of a model is related to the fact that it constitutes a system of known properties that are easily analysed. It is a system that describes the main traits which characterise another system of unknown properties. Below are some general theses that serve as a starting point in the conceptualisation and use of models:

- The world is made of objects that exist independently of the subject and interact with each other
- This collection of objects is constantly changing
- These objects are related to each other in the form of a system. This means that at least one relationship of equivalence and usually one hierarchical relationship can be established between them
- The set of living organisms requires a special interaction with the environment, and the use of that environment conditions the development and maintenance of the organisms.

According to Bergren (1982), the essential stages for the use of mathematical models are as follows:

- Analysis and formulation of the problem.
- Development of a mathematical model that represents the problem.
- Conception of a solution to the problem.
- Test of the model and the conceived solution
- Establishment of controls for the solution.
- Implementation of the solution.

According to León-Velarde and Quiroz (1995), in the modelling of a biological problem or phenomenon, the possibility of analysing the problem should be considered, the essential parts should be abstracted and the properties that characterise the system should be selected and modified. This is a cyclical process, undertaken until the results are satisfactory. The following aspects should be taken into account in the elaboration of models.

- Define the type of model to be constructed, according to its intended use. The model should represent the essential variables of the real system, that is, those that would cause significant repercussions in the system if changed. In the case of natural resources, the variables that make up the model should be relevant to the user. Soil loss, runoff, land use and soil retention capacity are usually variables of interest.

- For the elaboration of models, it is necessary to use information collected from the system under study, both by means of surveys and by research into its components. This information should be systematised in an easily accessible database of (electronic spreadsheet, file and text) to facilitate its use.

- The conception of the models should be simple and then complexity should be increased when they do not fulfil expectations. In this way, the time invested in developing complex models with little application can be reduced.

- Models should have a balance between generality, precision and realism. The closer to reality the model becomes, the more complex it becomes and precision and easiness of use are lost. If it is too precise, it loses generality.

1.7 How are Models Classified?

According to Shannon (1975), models can be classified by their structure:

Icons

These approximate a real system by representing the relevant properties of the system to scale in the model. E.g. maps, scale model, agricultural plots, physical model.

Analogue

These describe the use of a property to represent another in the real system. E.g. graphs in X and Y co-ordinates, artificial kidneys, etc.

Symbolic

Those in which the properties of the system are represented by numeric symbols. E.g. mathematical models.

According to Anderson (1981), models employed in the analysis of agricultural production systems can be classified according to elements of time and probability, which are:

Static Deterministic Models

These analyse a situation at a determined moment or period and presume an absolute certainty about the occurrence of the events, eliminating any random variation of the variables.

Dynamic Deterministic Models

Those in which the time variable is explicitly considered and the rest of the variables are given in a deterministic manner. In other words, they do not consider random factors.

Static Stochastic Models

These consider the probabilities within the selection process.

Dynamic Stochastic Models

These give the best representation of the productive processes in agricultural matters, given that they include the time variable and foresee the probabilistic risk factor resulting from natural factors.

According to Gutierrez-Alemann (1986), the modelling techniques most used in economic analysis of agricultural production systems are the following:

Whole Farm Budgets

These models have been used to measure the economic impact of a new technological alternative or a new management practice using economic returns as target function. This technique works best when considering changes within the particular farm, without changing the infrastructure. It requires knowledge of production levels and returns, and direct and indirect costs. One of its limitations is that it deals with prices as average values, without considering fluctuations during the study period.

Simplified Programming

This consists of an target function based on the economic returns and studies activities in terms of their monetary returns, subject to certain restrictions. It is useful for dealing with problems of limited resource distribution, and requires detailed, productive coefficients. Ghodake and Hardaker (1981) catalogue simplified programming as a more objective technique than that of total budgets and very close to lineal programming.

Lineal programming

This allows us to maximise or minimise the target function subject to technical restrictions imposed by the characteristics of the system. The target function and the constraints are presented in the form of lineal inequalities. This permits the incorporation of the fluctuation of prices, as well as the introduction of multiple values for the coefficients of the activities. It is limited to optimising only one target function, a situation that can be corrected through multicriterion programming. Lineal programming models have proved to be very useful tools for giving feedback on the processes of generation and transfer of technology.

Multicriterion programming

This is an extension of lineal programming applied to problems with more than one objective. Resources are allocated between different crops or possible productive alternatives under a particular production technique so as to optimise a set of objectives (maximise the gross margin, the economic risk, etc.), while respecting the constraints of the system (Maino et al., 1993).

Discrete stochastic programming

This kind of mathematical programming incorporates the risk factor under circumstances of uncertainty. The distribution of the input and output coefficients can be arranged in a discrete manner. Rae (1971) presents an example of the application of this technique in marketing fresh vegetables, for which the random effects of climate and market prices were included.

1.8 What is Simulation in Production Systems?

Simulation is the process of designing a model of a real system and carrying out experiments with it, in order to understand the system's behaviour or evaluate different strategies for its operation (Shannon, 1975).

Systems simulation is a numerical technique for foreseeing possible experimental results, using mathematical logic to describe the behaviour of production systems over time.

Simulation models are oriented towards the solution or study of a specific problem. There are two variations of this kind of model; one focuses on aspects of research and the other on productive, administrative or financial factors.

Simulation models constitute an experimental and applied methodology with which we seek to:

- Describe the behaviour of the systems.
- Construct hypotheses or theories that explain the observed behaviour.
- Use these theories to predict future behaviour; that is, the effect that will be produced through changes in the system or its method of operation.

1.8.1 Advantages and Limitations of Simulation Models

Advantages

- Models represent a relatively simple technique, with the possibility of manipulating biological and economic factors whose management presents difficulty in real life such as the modifications in production when surface area is increased.

- They allow us to order and visualise limited, existing knowledge. In this way it is possible to enter the context of the system under study.

- Models help us understand and explain the interrelationships between the elements of the system, and between these and the different hierarchical levels with which they interact.

- They permit ex-ante analysis of different aspects. This allows us to decide whether the problems to be solved involve components, interactions or factors that permit the proposal of alternative technologies for field validation.

- They help to prioritise lines of research aimed at solving a particular problem.

- They are dynamic with relation to time. Therefore, this element may be included in the model as a continuous or discrete variable. This allows the information from field research be used efficiently.

- They are useful for generating hypotheses about the functioning of biological systems and for selecting the most sensitive variables, that is, those that depend on research for a clear understanding and use in the development of technologies for farmers.

- They permit the evaluation of different scenarios in order to select those that represent better options for farmers.

- They allow for the valuation of the natural resources owned by farmers. This facilitates the establishment of the terms for a possible negotiation with environmental policy-makers or with those who benefit directly from conservation.

Limitations

- Models require that information is available and reliable.

- The development of a simulation model can be costly in terms of time and money, and requires trained staff

- The simulation can be imprecise and not measure the degree of imprecision. Therefore, the sensitivity analysis of a model should allow us to change the values of the parameters in order to partially overcome this difficulty.

- The results of modelling are normally numeric and provide only the information that the researcher selects. This can lead to the problem of attributing more value to the numbers than is justified.

- There has not been enough methodological development for including management variables with qualitative characteristics.

1.9 Ex-ante evaluation in the Design of Technological Alternatives

The stage for the design of technological alternatives is within the decision-making process in research and rural development projects. At this stage, the team of researchers explores different proposals for building more efficient production systems from the biophysical, economic, social and energy points of view.

Ex-ante evaluation is one component in the design of technological alternatives in which we seek to anticipate the benefits of new technology. We also analyse the possibility of this technology fulfilling the objectives of the project and contributing to satisfying the demands of sustainable, fair and competitive management of agriculture in hillside areas.

Due to the complexity of ex-ante analysis it is necessary to build models that facilitate the study of the system.

1.9.1 Analysis of Ex-Ante Evaluation in Research and Agricultural Development Projects

According to Estrada (1994), in ex-ante evaluation there are method, models and tools that are particularly suitable for economic analysis. Some of the characteristics identified in research and extension projects in agricultural systems are:

- There has been important progress in the use of quantitative tools such as simulation and multivariate analysis at the level of component and farm.
- There have been advances in the inclusion of the concept of biodiversity in system design.
- The producers are participating more and more in project design.
- The advances achieved are still limited; very few works consider hierarchical levels higher than the farm.
- The incorporation of risk in ex-ante analysis has advanced, however hesitantly, so as to be recognised as a fundamental factor in innovation.
- There is an imbalance between the productive and agricultural aspects and the socio-economic and environmental aspects.
- The existing models for predicting the dynamics of the degradation process are not being used in the design of projects.

Additionally, some recommendations are made, such as:

- Promote the creation of teams to adjust the present methodologies in order to analyse systems at different hierarchical levels.
- Incorporate complementary disciplines to undertake an adequate valuation of natural resources, thus allowing the better design of alternatives.

Some of the criteria for ex-ante evaluation proposed by Escobar (1993) are:

- The comparison between the expected and actual returns of the proposed technology, relative to the limiting factors
- Calculation of costs for the productive restructuring that is needed in the production system
- The agronomic and economic risks incurred by adopting other alternatives
- Possible effects of new or better production lines on marketing volumes

1.9.2 Application of Ex-ante Evaluation of Technologies: Soil Conservation in Small Producer Systems

In order to understand the process of ex-ante evaluation, we present the case of alternative technologies for soil conservation in small producer systems.

For this case, ex-ante evaluation is based on models of agricultural production systems such as EPIC (Environmental Policy Integrated Climate), WEPP (Wind Erosion Prediction System), and CALSITE (Calibrated Simulation of Transported Erosion), which simulate erosion as a function of soil characteristics, use, and climatic conditions. They also establish the relationship between soil loss and subsequent agricultural productivity. These models permit a simulation of the effect of implementing conservation practices on a reduction of erosion, and its impact on crop productivity.

By using the models in ex-ante evaluation, costs and benefits can be estimated by producers adopting this kind of practice. In the same way, the analyses can be made at higher hierarchical levels. For example, at the watershed level in order to incorporate the impacts of the eroded soil on its lower portions: sedimentation of the dams, the cost of treating drinking water, increase in the risk of floods, loss of production in fisheries and reduction in the availability of irrigation water.

Additionally, ex-ante evaluation can be used to analyse the rate of farmers' adoption of practices, considering that in most cases, this is voluntary. This prediction is fundamental for estimating the impacts and added benefits relevant to the watershed, especially if there are high fixed costs (research costs).

The products of an ex-ante evaluation in the area of soil conservation technologies are, among others, the following:

- A study of returns for the producer and, given this, his or her inclination to adopt the conservation practices.
- A valuation of the benefits for society as a whole over time.
- An assessment of the opportunities to transfer goods and services from society to the producers, in order to compensate the earnings lost by the producers through the adoption of practices desired by the society.
- A decision as to whether the implementation of conservation practices competes with other development alternatives, including non-agricultural ones.

Some limitations of ex-ante evaluation of soil conservation technologies are (Estrada and Seré 1995):

Biological Aspects
Frequently, models oversimplify biological complexity, especially regarding the various feedback mechanisms (Silsoe 1994). This aspect can be documented by analysing the models for the impact of erosion on productivity loss. In these much of the information is based on only one parcel and soil losses are calculated through an accumulation of annual losses caused by the continued use of a particular crop, generally the predominant one in the region (Estrada 1993). This way of calculating erosion can give significant restrictions in the yield, enough to increase the possibilities of justifying the use of conservation practices. However, the study of real systems shows that producers make adjustments to the production systems through changes in the crops and varieties, an aspect that greatly reduces the negative impact of erosion, at least in the short term. From this perspective soil loss is less and, therefore, the benefits of soil conservation are lower (Estrada 1993). The best alternative for reducing the limitation of the models is to incorporate these new variables into the existing programmes and carry out continual adjustments and validations of the results found through the modelling.

Relative Precision of the Analyses
This is a common limiting factor in diverse economic analyses. According to the disciplinary perception, the analysis develops certain aspects of the problem in great detail, while ignoring other aspects that may be more significant. The best alternative is to include different disciplines in the research team and to integrate different models that permit more realistic and better analyses for making political decisions.

Incorporation of External Effects
One common characteristic in many environmental problems is that there are effects that lie outside the sphere of the person intervening in the natural system. For example, someone who erodes a hillside to plant maize does not consider the impact of his action on those who live at lower elevations. Evaluating the external effects in the environment is an area of increasing importance in environmental economics (Wachter, 1992). Part of the difficulty is that analysis requires abundant information about consumer attitudes, information that generally does not exit or is not appropriate to the reality of developing countries.

Financial Analysis
In this aspect economists disagree about the focus of the analysis. For example, soil conservation practices are investments which are useful for several years and therefore the income flow should be discounted over time. The discrepancies centre on the discount rates to be applied and their conceptual justification. The opinion exists that environmental factors should not be discounted over time, because this causes a preference for the needs of the present generation over those of future generations. Therefore, many analysts propose using rates that will produce the levels necessary to justify adoption (Silsoe, 1994).

Predicting the Adoption Rate
Experience in development projects has shown that it is relatively easy to make recommendations but difficult to find someone to implement them. One reason for this situation is that projects do not dedicate sufficient time to analysing and classifying strategies for risk reduction, a key factor in deciding about adoption.

If the factors associated with adoption are not known, it is difficult to predict reliably the rate at which plots and producers will join the process. Thus, it is impossible to estimate the benefits generated by soil conservation projects during their useful life. At present prediction is based on information that, in addition to being empirical, is scarce. It is necessary to increase the projects that document the rates of adoption found in previous programmes and to analyse the causes of variation between them, with the aim of improving the levels of confidence in predictive models.

These considerations suggest that more synthetic proposals should be used in ex-ante evaluation, integrating producer participation as a tool for managing complexity. This does not mean that efforts to document and compare the magnitude of problems in the management of natural resource and their environmental services are not a valuable input for the decision-making process, which should be as complete and integrated as possible.

Exercise 1.1 Construction of the Concept: Use of Simulation Models for Ex-ante Evaluation in Natural Resource Management

Objective

✓ This exercise is designed so that the participant can apply the fundamental concepts of the use of simulation models for ex-ante evaluation. This is achieved by formulating questions that respond to their needs as researchers and development agents for ex-ante evaluation in natural resource management in hillside zones.

Trainer orientation

1. Organise work groups of four to six participants.

2. Give each group between 10 and 12 cards and the work sheet for the exercise.

3. Ask the participants to formulate at least six questions, related to ex-ante evaluation in natural resource management in hillside zones. Ask them to take into account the recommendations in the work sheet.

4. Ask them to organise the cards into groups that respond to a hierarchical classification of the system, farm, watershed, region and country.

5. In plenary session, "socialise" the information obtained with each group. For this, locate the cards in different places in the work area.

6. Analyse the various proposals, looking for differences and similarities as well as ways of classifying the questions. Keep in mind the hierarchy and complexity of the questions.

7. Study with the participants the feedback proposed for this exercise.

Necessary Resources

- Work sheet for each participant.
- Different colour cards large enough to write questions on. These can be 35 cm x 20 cm. (Minimum: 12 per workgroup).
- Adhesive tape.
- Flip chart and paper.
- Marker pens (at least two per group).

Suggested time: 60 minutes.

Exercise 1.1 Construction of the Concept: Use of Simulation Models for Ex-ante Evaluation in Natural Resource Management

Objective

✓ This exercise is designed so that the participants apply the fundamental concepts of using simulation models for ex-ante evaluation. This is achieved by formulating questions that respond to the actual needs that researchers and development agents have for ex-ante evaluation in natural resource management in hillside zones.

Participants' instructions

1. Form groups as indicated by the Trainer.

2. Based on the graph, put your workplace in context and discuss the relevant questions to be formulated in an ex-ante evaluation of natural resource management.

3. When formulating questions keep in mind the different hierarchical levels observed in the graph. These are, amongst others:

- Component: water, soil, plant, and environment.
- Farm: income, costs, distribution of activities and restrictions.
- Watershed: land use, crop specialisation, relation to natural resources, conservation of natural resources, and land use conflicts
- Regional: political decisions, product commercialisation, exchanges between different sectors in the region, and economic returns.

4. On the cards, write the questions that respond to the interests of your place of work for the different hierarchical levels.

5. Arrange the cards in groups that correspond to a hierarchical classification of system, farm, watershed, region, and country.

6. In plenary session, "socialise" the information obtained in each group. For this, place the cards in different places in the work area and select a person to present the group's work.

Exercise 1.1 Construction of the Concept: Use of Simulation Models for Ex-ante Evaluation in Natural Resource Management Feedback

The questions that can be made in ex-ante evaluation about natural resource management at different hierarchical levels are of the following kind:

Hierarchical Level	Question
Component or plot	• What structure should a crop have to reduce soil loss? • How much oxygen can be produced through a programme of reforestation with native species?
Producer or farm	• How can we obtain greater production at a lower unitary cost? • How much will the water on our farm increase if we restore the forest? • What would happen if the producers changed the land use of the farm from basic cereals to vegetables? • What would happen if the producers had access to credit?
Watershed	• How can we reorganise land use in a watershed in order to improve competitiveness and the conservation of natural resources? • How much sediment is produced on a hillside planted with maize and beans? • How much of the pollution of water sources in the watershed is due to the use of agricultural chemicals on the farms?
Region or country	• What political measures can be implemented to bring about changes in soil use? • What benefits do the producers of a region receive from their use of soil management and conservation practices? • How much does erosion cost a country?

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STRUCTURE OF THE SECTION

CONCEPTUAL FRAMEWORK

- **What is modelling?**
- **What is simulation?**
- **What is Ex-ante evaluation?**

✓ Describe the concepts, approaches and processes on which Ex-ante evaluation is based.
✓ Describe the concepts, uses and methodologies for simulation using models.
✓ Present a frame of reference for Ex-ante evaluation of technologies in natural resource management. Case: soil conservation.

- Systems and Modelling Approach
  - Approach
  - Interrelationships
- Modelling
  - Concept
  - Use
  - Method
  - Classification
- Simulation
  - Concept
  - Advantages
  - Limitations
- Ex-ante evaluation
  - Concept
  - Analysis
  - Experience

OBJECTIVES OF THE SECTION

- ✓ Describe the concepts, approaches and processes on which Ex-ante evaluation is based for natural resource management on hillsides
- ✓ Describe the concepts, usefulness and methodology for carrying out a simulation using models
- ✓ Present a frame of reference for Ex-ante evaluation of natural resource management technology
  Study case: Soil conservation

ORIENTATION QUESTIONS

1 How can modelling be integrated into a systems approach?

2 What is a model?

3 How is a model constructed and used?

4 What is simulation and what are its advantages and limitations?

5 What is ex-ante evaluation?

6 What aspects are involved in the ex-ante evaluation process of technologies for soil conservation?

MODEL

Representation of an object, concept or system in such a way that, although different from the entity it represents, it can imitate its functioning and/or one or more of its attributes

(Aguilar and Cañas, 1991)

Obective:

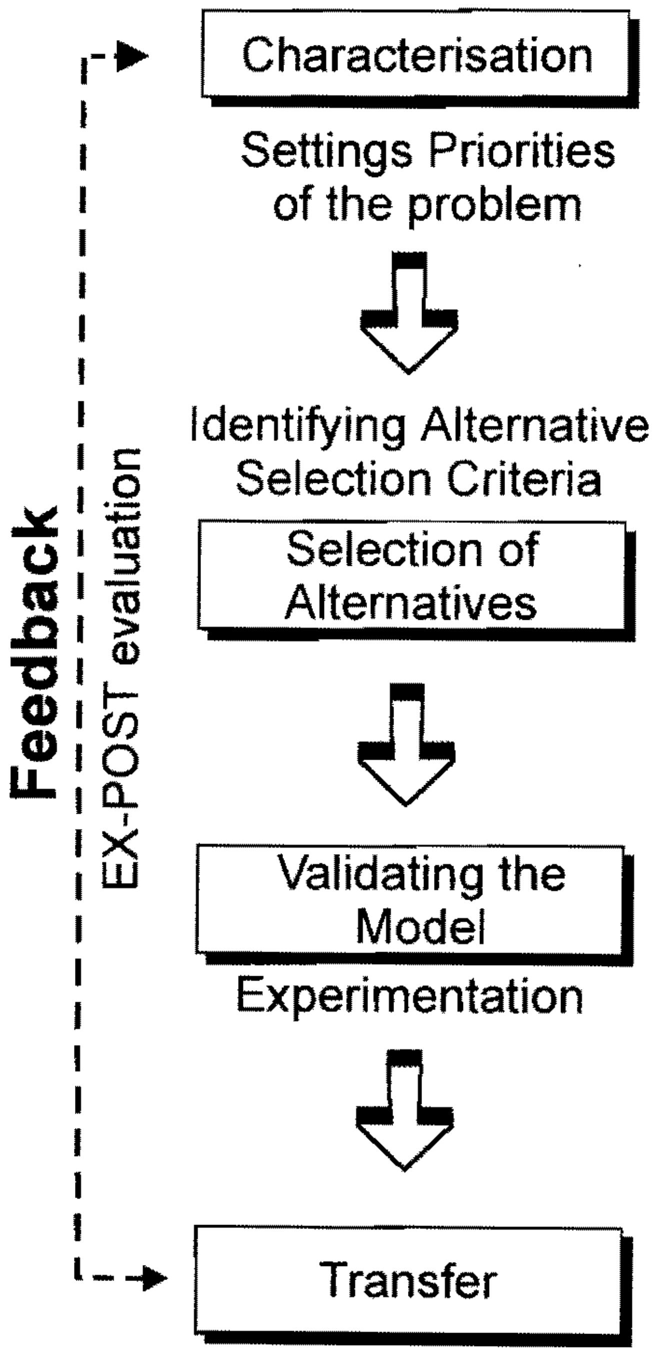
- ✓ Descriptive
- ✓ Prescriptive

TYPES OF MODELS

✓ **Icon**
✓ **Analogue**
✓ **Symbolic**

- Static or dynamic deterministic models
- Static or dynamic stochastic models
- Optimisation models

METHODOLOGICAL STAGES OF THE SYSTEMS ANALYSIS PROCESS



MODELLING

✓ Process through which a researcher designs and builds a model to represent real object or system

✓ Methodology that consists of making an abstraction of a real system in a model that reflects everything that is appropiate and pertinent

Should Allow

- Abstraction of the essential parts
- Selection of the characteristic properties
- Modification of the properties
- Analysis of a problem

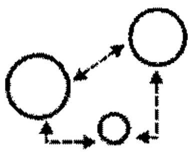
MODELS AND SYSTEMS ANALYSIS

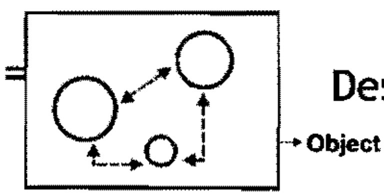
A model is the representation of an object or system in such a way that it permits doing experiments in order to understand the functioning or evaluate operational strategies of the system

(Aguilar, 1197)

Stages:

Analysis  Colection

System  Assembly

Function 

Design

SIMULATION MODELS

Representation of a "system" in such a way that, although different from the entity it represents, it can mimic its functions

√ Process of designing a model of a real system and conducting experiments with it to understand its behaviour or evaluate strategies for its operation

- Describe the behaviour of the system
- Construct hypotheses that explain its behaviour
- Use the hypotheses to predict future behaviour

OPTIMISATION MODEL

Is a simulation model, that by representing a system, mimics its functioning with the specific aim of optimising the function of the system (Y), which is influenced by several independent variables (Xi)

- Uses linear programming
- Permits the allocation of productive resources with the aim of maximising aernings or minimising costs

ADVANTAGES OF USING MODELS

- ✓ Describe and understand very complex systems
- ✓ Experiment with systems that do not exist
- ✓ Experiment with existing systems, without altering them
- ✓ Reduce institutional costs by improving the planning of activities
- ✓ Reduce the gap between research and innovation
- ✓ Meeting point for reductionists and holistics

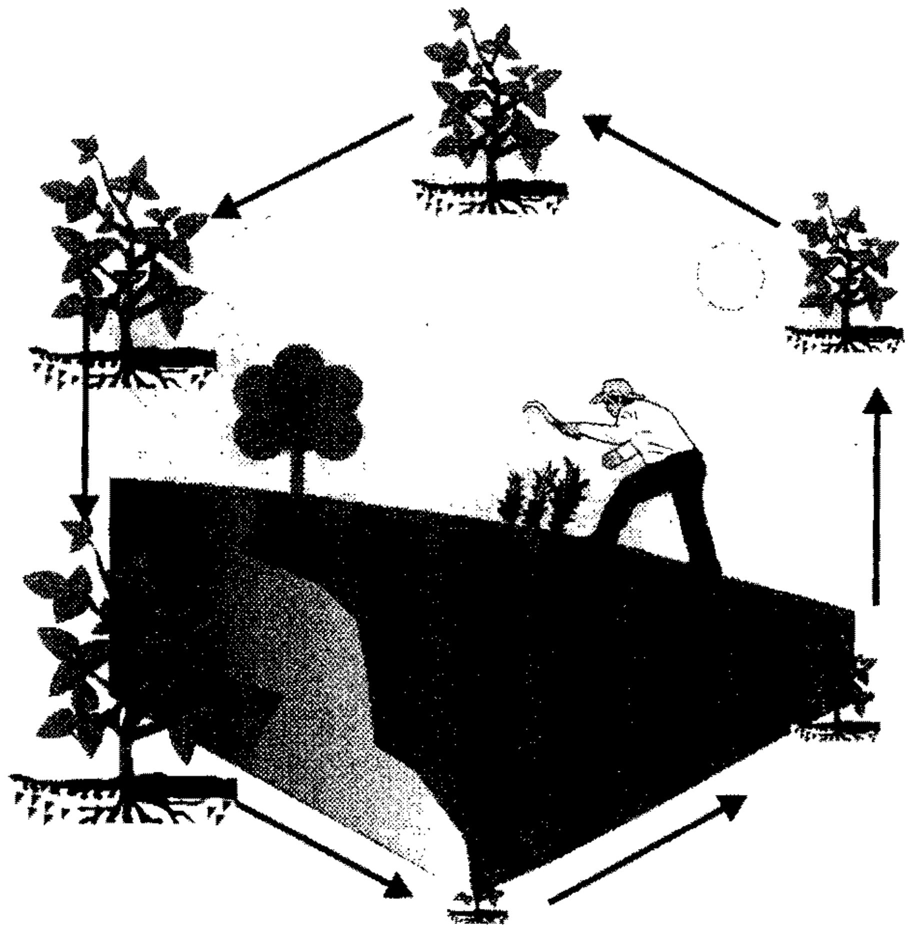
RESTRICTIONS OF MODEL USE

- Quantity and quallity of information
- Complexity
- User friendliness
- Equipment
- Costs of Software
- Discipline

Credibility Gap

Section 2

Models for Simulating Production Systems



Section 2. Models or Simulating Production Systems

Page

Structure of the Section

SIMULATION MODELS

What would happen?

How do we Simulate the Resources Soil – Plant – Costs?

- ✓ Present the limitations and possibilities of three simulation models: EPIC, CROPWAT and LADERA.
- ✓ Present the structures and functions of the simulation models: EPIC, CROPWAT and LADERA.
- ✓ Acquire skills in the basic management of the simulation programmes: EPIC, CROPWAT and LADERA.

- Model for simulating technology, resource: soil
- Model for simulating technology, resource: water
- Integrating model on hillsides

In this section, we present the characteristics of three simulation models developed by different institutions, especially Universities in the United States. These have been successfully used in research projects in several Latin American countries by CONDESAN (Consortium for the Sustainable Development of the Andes) and other institutions in Latin America, such as CORPOICA (Colombian Agricultural Research Corporation), INIAT (National Agricultural Research Institute, Peru), and CIAT (International Center for Tropical Agriculture)

The aim of the section is to illustrate the main characteristics of each programme in terms of their structure, use, advantages, limitations and applications. For each programme, we illustrate the logistics of its use, proposing a series of steps that will permit users to introduce, process and extract the information that is considered most relevant in each of the models.

To support the development of skills in the use of each programme, we give the corresponding references to the manuals for each and some references about the applications of the simulation models in different research projects.

Objectives

- ✓ Present the possibilities and limitations of the simulation models: EPIC, CROPWAT and LADERA.
- ✓ Present the structure and functions of the simulation models: EPIC, CROPWAT and LADERA.
- ✓ Acquire skills in the basic management of the simulation programmes: EPIC, CROPWAT and LADERA.

Orientation Questions

1. What is the application of simulation models in decision-making for natural resource management?
2. How are the simulation models EPIC, CROPWAT and LADERA structured?
3. What are the basic software commands for the simulation programmes EPIC, CROPWAT and LADERA and how are they used?

Introduction

Simulation programmes are practical instruments for helping researchers and development agents to make decisions in ex-ante evaluation.

The use of programmes provides technical elements for evaluating the potential of new technologies and setting development priorities. It also generates information for evaluating the impact of researchers' perceptions of technologies related to the recuperation and conservation of natural resources, especially water and soil. These are fundamental components in any production system, especially, in hillside zones. Additionally, the use of models contributes significantly to improving the analytical capacity of interdisciplinary research teams, because it facilitates the integration of aspects of productivity, fairness, sustainability, and competitiveness in a dynamic temporal dimension (short, medium and long-term).

2.1 Models for Simulating Soil Conservation Technologies

The lack of adoption of soil conservation practices by farmers in low-income countries has recently been identified as a high priority problem that should be solved in order to contain and control degradation. It is necessary therefore, to apply new strategies in the development of agrarian technologies. These strategies allow researchers to integrate different hierarchical levels, contemplate the total allocation of resources and the interactions between the subsystems, especially soil and productivity.

Many models exist that simulate erosion according to soil characteristics and use, climatic and topographic conditions, and cost and marketing structures. These models allow us to simulate loss of soil and agricultural productivity, as well as the effects of implementing conservation practices in terms of erosion, runoff and the biological and economic productivity of production systems.

Given the application that the EPIC model has had in several projects in Colombia, Ecuador and Peru, and the support provided by research teams at the Universities of Texas and Maryland in the United States, we present below the main characteristics of the model.

2.1.1 Environmental Policy Integrated Climate (EPIC)

EPIC is a simulation model developed by a research team at three institutions: the University of Texas, United States Agricultural Service (USDA) and the Natural Resource Conservation Service.

- **Objectives of EPIC**

EPIC is designed to:

- Simulate biophysical, environmental and economic processes of plant species.
- Simulate erosion processes and relate them to productivity within a temporal framework of 100 years.
- Apply to a wide range of soils, climates and crops.
- Simulate climate, hydrology, physical and chemical conditions of the soil, erosion, nutrient cycles, crop management practices, pesticide and nutrient transport in soil and water, and analysis of production costs.

- **Structure of EPIC**

The programme is structured into 10 components which carry out 40 mathematical functions on the basis of the interaction between 180 variables. The components are:

Climate

This integrates information related to daily precipitation, maximum and minimum temperatures, solar radiation, wind velocities, and relative humidity. These values are taken directly from a methodology database or from monthly averages. The programme can calculate the data by means of a climate generator based on a stochastic model.

Hydrology

This includes runoff, percolation, and underground currents. Four methods for calculating total evapotranspiration are offered, including that of PenmanMonteith.

Erosion

In this component, the model calculates the soil losses caused by wind and rain. Six models for erosion by water are offered: Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), Foster's Equation (AOF), Modified Equation for Small Watershed (MUSS), and two others that are modifications of the erodablity coefficient MUSLE (MUST and MUSI).

Soil Chemistry

This simulates the nitrogen and phosphorous cycles, and the movement and transformation of fertilisers, of mineral, animal and plant origin.

Pesticide Movement

This simulates the movement of pesticides in water and soil.

Soil Temperature

This simulates soil temperature as a response to climatic conditions, its humidity content and physical characteristics such as apparent density.

Cultivation Practices

This considers the effect of farm machinery and field operations on the soil and crop.

Crop Physiology

This component simulates the growth of a wide variety of crops, trees and some forage species used as animal pastures. The model permits changing the physiological indices of each species and introducing new species if necessary.

Soil and Crop Management

This component includes all field operations that are made in a crop, from preplanting to harvest, including irrigation, fertilisation and pest control.

Economic

This component calculates the cost structure of the crops analysed.

- **Applications of the model**

The programme has been used in different parts of the world for exante analysis in research projects. Reports exist for projects where more than 13,000 different combinations of crops, climates, conservation practices, and field operations have been analysed. At present, the Colombian Agricultural Research Corporation (CORPOICA) is carrying out a project on a national level to calculate how much money erosion is costing the country, using the EPIC model. Estrada (1998) documents the use of this model in two regions of Colombia. In Appendix 6.1, 50 references are included that document the application of EPIC in natural resource analysis.

- **Using the EPIC model**

The basic elements for managing EPIC respond to four commands that permit introducing data, presenting the data output, and modifying the programme coefficients for plant physiology and crop management practices (fertilisers, pesticides, and field operations). These commands are:

Input of data
EPIC has its own structure for inputting data, which should be carried out in the order requested by the database. To create and input data, enter the submenu for EPIC (C:\EPIC>) and write the three following words separated by a space: UTIL EPIC FILENAME. In other words, if you wish to create a file for the San Dionisio region, you can write: UTIL EPIC DIONISIO. This can be either in upper or lower case. Once the command is given, the programme will present a database structure in which a datum should be entered into each cell and confirmed with the ENTER key. Keep in mind that the first three lines of the database are for the introduction of information that refers to the model being built. This information is alphanumeric and is entered in sentence structure; its use in merely for reference, presenting the information in the model. Typing UTIL EPIC WS1, we have an example of the rotation of wheat, fallow, and cotton in the United States; if we type UTIL EPIC MIEL, we have an example from the mountains near Florencia in Colombia. Remember that with the F1 key, the programme will provide help for the input of each datum. To exit the file, type F3; if you wish to enter the same file again, just type UTIL EPIC again.

Data processing
For data processing, just enter the EPIC submenu (C:\EPIC>) and type EWQ FILENAME. The command is easy to remember since the three letters used are located in the upper left-hand corner of the keyboard. If you wish to process the data in the file Dionisio, type C:\EPIC>EWQ DIONISIO and the programme will process the data. It will internally organise the output in graph form or as an output file with the extension Out.

Presentation of output

The programme has the option of presenting the data as a text file or as graphs. For the former, just type LIST FILENAME with the extension OUT. For the case of San Dionisio, you would use C:\EPIC>LIST DIONISIO.OUT. Remember that you must add the extension OUT to the name of the file. Once you have given the command, the programme presents the user with a file with the characteristics of a text file, and with the output information. If you require graphic information, use the file for graphic control, with the command C:\EPIC>UTIL GRAF <ENTER>. This file allows you to select the number of graphs per screen. The maximum number is 8; the variable is called NGRAPH, and is located in the first row and first column. Starting in the second row of the file are the output variables of the programme, beginning with the maximum monthly temperature. In these rows it is possible to change the graph presentation values, introducing data with the following commands: YVAL (1) is the maximum value for an output variable. MARK (1) allows us to prioritise the presentation of the graphs on the screen. For this, assign the number 1 to the output variables from the programme you wish to appear first, the number 2 to the next, and so on up to 8, which is the maximum number of graphs accepted on the screen. ITYPE(1) permits four graphic forms: dots, continuous lines, discontinuous, etc. DESC(1), is the number with which EPIC orders and numbers the output variables. If you wish to print the graphs, just press the ALT key and P simultaneously, or when operating the programme with the EWQ command, type: C:\EPIC>EWQ FILENAMEg, that is, add a dash and the letter **g** at the prompt for processing data.

Modifying Programme Coefficients

For this EPIC offers the command UTIL, together with the name of the file you wish to modify. For example, to modify the physiological data of the crops, type C:\EPIC>UTIL CROP <ENTER>; to modify the tillage data, C:\EPIC>UTIL TILL <ENTER>; for fertilisers, C:\EPIC>UTIL FERT <ENTER>; and for pesticides, C:\EPIC>UTIL PEST <ENTER>.

2.1.2 Simulation in EPIC

The model can simulate each of the characteristics of its components daily. The functions are based on limiting factors, such as temperature, water, and air. The soil can be divided in up to 10 layers with different physical and chemical characteristics. The simulation offers 250 output variables in the various components presented above.

2.1.3 Installing EPIC

The version of EPIC[1] offered in this manual runs in the DOS environment. For installation, insert diskette No. 1 and type the word **install.** The programme will ask for diskette No. 2 and present the alternative of installing the climate databases found on diskette No. 3.

2.2 A Model for Simulating Technologies that Involve Water Resources

For modelling systems where water resources are of importance, such as irrigation systems, abundance calculations, and water balances, CROPWAT is recommended (Irrigation planning and management programme).

CROPTWAT is a programme for IBM or IBM compatible PCs with a minimum memory of 360 Kb and runs in DOS environment. It was developed in 1993 by Martin Smith of the United Nations Food and Agriculture Organisation (FAO), Promotion and Organisation of Water Resources Service.

2.2.1 Objective of CROPWAT

CROPWAT is designed to:

- Calculate evapotranspiration, sewage water necessities for the crops, and the irrigation requirements of a system
- Prepare alternatives for programming irrigation under different hypotheses
- Estimate crop production under different conditions of water availability.

2.2.2 Structure of CROPWAT

The programme is structured in three components:

Climate

The programme files and processes monthly climatic data for temperature, humidity, wind, radiation and evapotranspiration. The files generated in this component have the extension PEN or CLI.

Crop

The crop data information is processed in growth stages: the crop coefficients, root depth, exhaustion level, and production response factors. The extension for these files is CLI.

Field

Information is processed about the physical characteristics of the soil, as well as information about available moisture and field data such as planting date, crop water needs, etc. The extension of the files is CMP and the data can be created or modified through the CROPWAT programme.

[1] For more information about the programme, contact:
mitchell@brcsun0.tamu.edu
Phone: (817) 770-6514
Fax: (817) 770-6561
808 East Blackland Road, Tempe, TX 76502

2.2.3 Applications of the programme

The programme is based on the studies carried out by the FAO in several countries in Latin America, Africa and Asia. Between 1972 and 1990, irrigation and drainage information was collected for more than 37 crops, including trees, semi-annual and semipermanent crops. The programme is meant to serve as a practical instrument for calculating the water requirements of crops to aid professionals and technicians in the design and management of irrigation systems. It also allows us to make recommendations for improving irrigation practices under different conditions of water supply.

2.2.4 Using the CROPWAT model

The programme is easy to use due to its menu structure. The menus are automatically presented according to the calculation that is desired. The introduction of the climatic data is requested in order to present later calculations of water balances and irrigation schedule. The different menus offered by the programme are:

Main Menu
Presents six programme options that should be followed sequentially:

1. Calculation of Total Evapotranspiration [Eto Penman-Monteith]
2. Water requirements for the crops.
3. Irrigation schedule.
4. Water requirements of the irrigation system.
5. Printer control.
6. Directory selection.
7. CROPWAT output.

Total Evapotranspiration Calculation Menu
This menu permits the entry of climatic data for calculating evapotraspiration, using the PenmanMonteith method. The data required by the menu are:

1. Basic information from the meteorological station, country name, station name, elevation, longitude and latitude.

2. Monthly climatic data for temperature, relative humidity, solar radiation and wind velocity.

Crop Water Requirement Menu
This menu constitutes the central element of the CROPWAT programme and is divided in three different steps:

1. Input and processing of evaporation and precipitation data.
2. Input and processing of crop data and planting date.
3. Calculation of water requirements for the crops.

Irrigation Schedule Menu
This menu can be used once the water requirements of the crops have been calculated and permits:

1. Planning and developing the indicated irrigation programmes, adapted to the field operational conditions.
2. Evaluating the field irrigation schedules, in terms of the efficiency of water use and yields.
3. Simulating field irrigation schedules in conditions of water deficit, drought, and complementary irrigation.

CROPWAT data output menu

The programme presents the simulation results in three ways: by screen, to a printer or in a text file. To choose between these three options, select option **5** (Printer set-up) before running the programme from the main menu. This will guide the user in the decision concerning data output.

2.2.5 CROPWAT Simulation

The model allows us to establish the water requirements of the crops in the production system, as well as the relationship between water deficits and crop productivity. Outputs from the CROPWAT model for maize, bean and tomato crops under an irrigation system in Carchi (Ecuador), are shown in Appendix 6.2.

2.2.6 CROPWAT Installation[2]

The programme is on a 3.5-inch diskette with the programme files and a set of data files. To install, just insert the diskette in Drive A: and type the word **install**. The programme is installed automatically on the computer's hard drive. If you wish to work directly from the A drive, just type the word CROPWAT, which is the name of the programme's executable file.

[2] For more information, contact the Resources, Promotion and Water Ordering Sevices of the FAO, Valle delle Terme di Caracalla 00100 Rome, Italy.

2.3 An Integrating Model for Ex-ante Evaluation of Hillside Technologies

LADERA is a simulation model designed for the problems and challenges of hillside zones which are faced by the researcher and development agent. This has been done in the simplest manner, using basic information that exists in most watersheds or municipalities. The model runs in Lotus 123, a widely available spreadsheet. The processing speed depends on the equipment available and the version of Lotus used.

2.3.1 Objectives of the LADERA model

It is our hope that, through using the model, researchers and development agents working at the farm, watershed or regional level, will have access to technical elements that facilitate and orient decision-making in the following fields:

- Documenting in an ex-ante manner the impact of their own perceptions about resource conservation.

- Work in new areas of knowledge, generally long term, in which there is less experience. The documentation and systematic visualisation of the problem and the impact of alternative technologies, will permit a better understanding of the problem and thus the proposal of better solutions. This aspect is key to awakening the interest of politicians and decision-makers about the work being done.

- Contributing to identifying important parameters in the conservation of resources.

- Systematically documenting new technological parameters in a place or region to determine the economic and social feasibility of recommendations. These new parameters, in addition to contributing to knowledge, will solve site specific problems.

- Obtaining financial resources for the integrated development of the agricultural sector.

- Research and development projects must compete for resources at the regional and national level. A well-documented ex-ante analysis will give a proposal a comparative advantage.

- Improving analytical capacity.

- Analyses of the rational use of resources require the integration of the different aspects of productivity, fairness, sustainability and competitiveness over the short, medium and long term. For this, it is necessary to substantially improve the analytical capacity of the technicians at the field level and in the institutions that make the decisions and assign priorities.

2.3.2 Structure of the LADERA model

The main components of the model are based on the following aspects of the production system:

- Biophysical aspects of soil conservation on the farm. Functions include erosion and its relation to crop productivity. This is made up of the following elements:

- Soil loss

To simulate soil loss, Wischmeier and Smith's USLE equation (1978) is used.

P=RKLSMC

Where,

P = Soil loss (in metric tonnes/ha)
R = Erosive affects of rains (MJ.cm/ha per hr)
K = Erodability of the soil (t.hr/MJ. cm)
L = Length of the slope (m).
S = Slope (%)
M = Crop management
C = Conservation practices

The erodability of the soil is calculated by the formula

K=2.77*m^1.14*10^-6*(12-MO)+0.042(A-2)+0.032(D-3)

Where,

0M = Organic matter
M = Texture index
A = Type of aggregates
D = Permeability class

As can be observed in the preceding formulas, factors K and L are more stable through time under natural conditions. Therefore, the volume of annual erosion for a given soil depends on the total quantity of rain, its distribution throughout the year and the intensity of precipitation. The interaction of these factors is very important when the crop is in the preparatory phase or in the first stages of development during which the soil is without cover.

The model uses information on soil loss in one year expressed in metric tonnes (tm)/ha. Generally, this information comes from research done in the area. If this information is not available, other information from the region can be used, keeping in mind the previously mentioned variables.

In Appendix 6.3, several results are shown from different Latin American countries. This information could serve as a guide, keeping in mind the precipitation, slope and the crop.

- Interaction between accumulated erosion and crop yields.

This is the most difficult aspect due to the lack of adequate information. Generally, a linear relation does not exist between these two factors. It cannot be assumed that a 50% loss in soil will automatically cause a 50% reduction in yields and it is also not certain that a 1-cm loss of soil will affect all yields in the same degree. In this respect we have to consider two factors.

1. Soil loss and its effect on fertility levels, which depend on the existing nutrients in the different strata of the soil profile. The effect of 1 cm of soil loss can be very different, depending on the depth at which the profile is found.

2. The water retention capacity of the soil and its effect on agricultural productivity.

In addition to the effects on fertility, there is a change in the water retention capacity of the soil. This depends basically on the organic matter content and texture of the soil.

These factors not only affect yields, they also condition fertiliser use. On poor soils, farmers usually use organic matter as a water retention mechanism, more than to add nutrients to the soil.

Generally, this relation only can be obtained from a research project in experimental stations or in farms, but much evidence exists from the field level that farmers are capable of identifying and determining the most limiting factor.

- The impacts that the biophysical factors cause outside the farm.

In addition to the loss of crop yield, the eroded materials have an impact on other activities which are important at the regional level. Among the main impacts are:

1. Treatment of sediments in aqueducts and dams. We are increasingly aware of the damage caused by sediments in aqueducts and dams because they reduce the effective life of dams. Dams should be designed higher so that the accumulated sediments do not affect the operation of the turbines.

2. Soil nutrient loss. Eroded soils contain a series of nutrients that are lost. It can be argued that this loss influences yields and, thus, nutrient reduction is an important effect of soil erosion. For present day production systems, with low plant density and low yields, this may not have a great impact. However, much discussion has been generated on this subject, because this type of loss may be a major limitation in the modified systems of the future.

3. Retention of water in the soil. In regions generally have bimodal precipitation over a year. This means that it is relatively easy to use rivers and steams to provide water to the human population. However, the availability of water to rural aqueducts during critical periods is becoming more and more of a problem. This is closely related to the capacity of the soil to retain water, allowing that the final rains may be used during the dry season.

- Existing production systems.

A thorough knowledge of existing production systems in the region under study is the basis for the rational use of the model. It has been designed with sufficient flexibility to be used for the production systems typical of hillside zones in which there are intercropped and associated crops, rotation between clean crops and fallow fields, and where the adoption and impact processes are different for these two stages.

A good understanding of production systems is important for planning the analysis in the best manner possible based upon the interactions between the system and the use of natural resources, and for predicting the regional evolution in the adoption process. Emphasis should be given to the following points:

- The importance of fallow fields in production systems.

In general, users think about the management of soil erosion problems at the cultivation stage where production is obtained, and less importance is given to the fallow period. The gradual reduction of agriculturally apt areas means that fallow fields are playing a more important role, accelerating the recuperation process. Given the ratio between cultivated and non-cultivated areas, it may be of greater importance to increase the efficiency of fallow periods in order to accelerate fertility recuperation, control weeds, slow the erosion process during the cultivation stage and increase soil water retention and the direct production of forage crops and firewood.

- Adoption Levels over Time.

Knowledge of production systems will provide more information with which to determine adoption curves. Levels of income, the profitability of practices at the farm level and location in relation to roads, etc., will allow greater objectivity about the evolution of adoption and the maximum possible levels of adoption in a region or in a production system.

- How to extrapolate results from a farm to a region:

Number of units that are incorporated into a new process. The process of technological change is gradual and changes in magnitude over time. Studies show that a logistic function reproduces the process well. This process is characterised as being slow in its early stages, more dynamic while the benefits, behaviour and returns of the new technology are being understood, and then slowing down in the final stages until stabilising.

The annual displacement of the logistic curve is given by the expression:

Kt = A1+E^&+bt

Where,

Kt = The displacement of the curve in a given year
A = The asymptote of the logistic function or maximum adoption level
& and b = Parameters of the curve
t = Time

In technology transfer processes we try to modify the logistic adoption curve. It is possible to achieve an earlier beginning for the process, an increment in the number of farms adopting the technology each year, and an increase in the maximum level of adoption. Since measurement of the impact of a specific factor is desired, it is necessary to generate two logistic curves representing the evolution of the process when considering this factor.

In the model, four logistic curves are generated: two for the cultivation period and two for the fallow period. This occurs because we expect the adoption process to be different between the cultivation and the fallow stages and, additionally, because in each stage it is possible to stimulate the adoption process through transfer actions.

- Impact at the Regional Level

The impact at the regional level is determined by the increase in the number of units that are incorporated into the process each year, and by the progress that each unit achieves when the new technology is adopted. Therefore, in order to carry the results over to a unit area or to a region, the following steps are used:

1. The evolution of the process that will be obtained when the new technology is adopted is estimated for the unit area (farm or hectare).

   The progress of the process should be estimated for each of the variables (soil loss, crop productivity, water retention, etc.). Generally, processes related to soil conservation take several years; therefore, the horizon for analysis should be greater than 25 years.

2. The number of units adopting the new technology is determined for each year.
   The number of units adopting the technology is determined through the adoption curves. To do this, the **K** values are computed for a specific year and the previous one. The difference represents the number of units that entered the process during that year.

3. A matrix of regional evolution is determined. Based on the number of adopting units each year and the progress in each one, a matrix of regional evolution is generated. This matrix is needed because the intensity of the process through time is variable and depends on the number of years since the beginning. Although this makes the model more complex, it is necessary for simulating the processes of conservation of resources. For example, soil loss by erosion depends on the texture of the profile and usually there are several layers with different textures. Thus, the speed of the process is variable through time. If this matrix did not exist, it would be necessary to accept that in each year soil loss were equal and that the annual loss value of regional loss depended only on the number of units incorporated into the process.

- How to Incorporate Economic Efficiency Analyses

Economic efficiency analyses are divided into two groups.

a. Economic efficiency analyses to estimate the benefits of the technological change.

Prediction of the benefits for the biophysical matrix is based on the prices of raw material and products, during cultivation and fallow periods. The difference between the benefits generated for the two matrices (with and without stimulants) determines the benefit flow attributable to the technological change.

In order to make a valid comparison of cash flow, the value of each year is brought to the first year. This is done because the value of money is not the same through time, those activities realised earlier having more value for the same degree of benefit. To bring all cash flow to the beginning year the following formula is used.

$$C = C(t)/(1+R)^t$$

Where,

C = Capital in year 1
C(t) = Capital in year t
R = Interest rate

Bringing all the cash flow values to the same year is known as 'finding the actual value in each year.' The sum of these actual values is the real value of the activity.

The model calculates the cash flow for two options in the cultivation stage and two in the fallow period. These options correspond to the four adoption curves that the model considers in each execution. Comparing the actual value of cash flow between the two options for the cultivation stage the actual net value of this stage is obtained. The same occurs with the fallow period.

b. Economic efficiency analyses to estimate the benefits of the institutional investment in hillside initiatives.

The model is designed to obtain the benefits of the research or technology transfer initiatives realised by the institutions. To estimate the economic efficiency of any one of these initiatives, the percentage of the regional benefits resulting from the institution's action is determined and the institutional investment to realise the initiative is calculated. The cash flow (benefits - costs) that is obtained is the basis for finding the actual net value of the institutional investment.

2.3.3 Application of the Model

The model was developed by Rubén Darío Estrada, CIAT researcher. Its original access is free and it is a contribution of the 'ad hoc' consortium for hillsides, made up of CORPOICA, CIAT, and CIP, which works towards equitable development in the hillside zones of Colombia. The model has been applied in research projects in Peru and Ecuador.

2.3.4 Usefulness of the Model

The model is designed to evaluate the impact that a technology will have in a region, in both the cultivation and fallow stages. In this case the model would aid professionals who wish to incorporate economic aspects in the analyses of the rational use of resources. The model can be a useful tool for the following studies:

- Assigning research priorities in the country's watersheds

Most of the benefits from research in watersheds are closely related to the bringing together of the factors producing benefits (increase in productivity, control of losses from erosion, control of sediments in aqueducts and dams, among others) in the specific site. This model allows us to rapidly calculate in an ex-ante manner what the benefit will be from different kinds of research in different watersheds. This allows us to prioritise biological, economic and social benefits and thus make much more efficient use of resources at the country and regional levels.

- Carrying out an ex-ante analysis of the economic convenience of the technology transfer initiatives.

The economic benefits from research in hillsides are closely related to transfer and adoption processes. The model allows us to analyse how great the benefits will be with different adoption curves and thus the importance of the transfer initiatives in order to modify these curves.

- Determining the trade-offs between conservation and production initiatives.

It is extremely difficult to achieve increases in productivity and improve the conservation of natural resources in a given watershed at the same time. In general, the rational use of resources represents an equilibrium where productivity gains are considered on the one hand and losses in natural resources on the other hand. The model calculates these in their biological and economic aspects, which permits us to make a more reasonable decision about the uses of production systems.

- Determining the amount of subsidies and the trade-offs between urban and rural sectors for natural resource conservation initiatives.

Society is increasingly conscious that many of the processes for the conservation of natural resources should be subsidised for farmers, or at least that there should exist an exchange of resources between the consumers in the cities and the producers in the field. The model allows us to calculate the magnitude of these exchanges and determine the subsidies to make sure that these are lower than the total benefits generated by the different actions.

- Determining the Critical Route in Conservation Actions.

Each conservation action generates a different flow of benefits, depending on the watershed conditions. Through the model, different actions and adoption curves can be simulated, which allows for a positive flow over time, thereby making the process more viable. Through this mechanism, a critical route can be designed which permits a balance between actions and operational costs.

- Analysing the Impact of Land Use Policies

Through the model it is possible to calculate the benefits obtained through land use policies. For example, we can estimate the impact that would be seen from the mobilisation of inhabitants from hillside zones with poor soils to more level areas with deeper soils. Environmental impact, increase in productivity and in the producers and society's earnings can be calculated using the model.

2.3.5 Using the model

For ease of use, the LADERA model functions through menus and submenus. The programme may be executed from the hard disk or from a diskette. To work with the programme open Lotus 123 and call the file Laderas. Once loaded in Lotus, you may start the programme from the main menu typing [ALT] and [M] simultaneously (Figure 2.1).

The main menu is made up of 16 options. In the first position on the screen there are eight options including CONTINUE and QUIT. To summon the following eight options select the option CONTINUE.

1. Data entry: Main menu options

The main menu contains the following options.

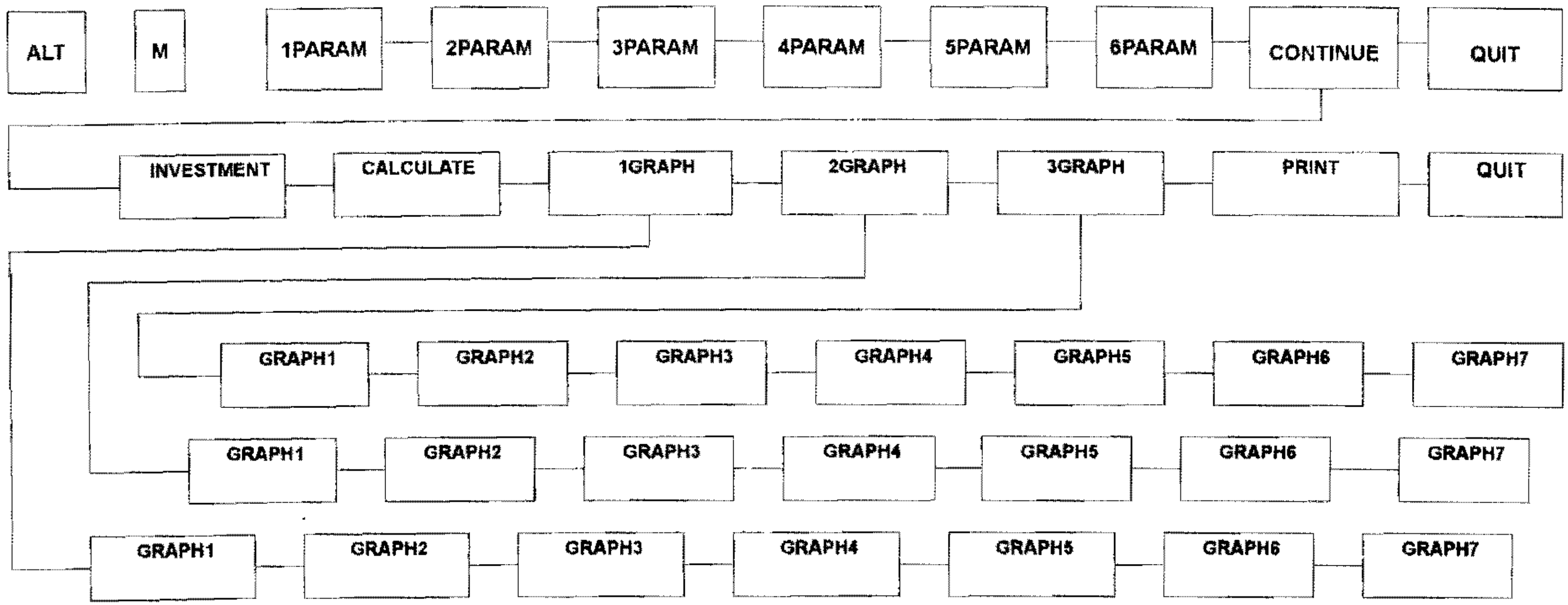
1PARAM

This option loads the parameters related to soil depth and the areas for the respective crops. When you click on 1param, the programme will ask for the following sequence of data:

a. Soil depth, in cm.
b. Total area in crops, in ha.
c. Name of the first crop.
d. Area of the first crop, in ha.
e. Name of the second crop.
f. Area of the second crop, in ha.
g. Name of the third crop.
h. Area of the third crop, in ha.
i. Unplanted area, in ha.

In order to simulate associated crops there are three crop alternatives. Therefore the total area in crops may be less than the sum of the areas of all the crops. When analysis is desired for only one crop, the values of **f** and **h** must be zero.

Figure 2.1Diagram of the LADERA model main menu. (Translated into English the original menu is in Spanish)



2PARAM

The 2param option loads the parameters related to the yields of different crops at the same time. Upon clicking on 2param, the programme asks for the following data in sequence:

a. Yield of the first crop, in metric tonnes (tm)/ha.
b. Yield of the second crop, in tm/ha.
c. Yield of the third crop, in tm/ha.
d. Forage production with native species on fallow fields, in tonnes/month per ha.
e. Forage production with introduced species on fallow fields, in tonnes/month per ha.
f. Additional production of firewood in crop areas, in tm/ha.
g. Additional production of firewood in fallow areas, in tm/ha.
h. Duration of the plot in crops, in years.
i. Duration of the plot without crops, in years.
j. Reduction of time for plots without cultivation, in years.
k. Reduction of risk in crop production, which can be achieved through a higher retention of humidity, generated by an accumulation of organic matter in the period in which the fallow pediod (dry matter), in %.
L. Conversion of forage into milk, in lt/kg of dry matter.

3PARAM

The 3param option loads the parameters related to soil loss into the programme. When you click on 3param, the programme will request the following data sequence:

a. Soil losses, without conservation practices, during the first 12 years of the crop, (tm/ha per year).
b. Soil losses, without conservation practices, during years 13 to 24 of the crop, (tm/ha per year).
c. Soil losses, without conservation practices, during years 25 to 35 of the crop, (tm/ha per year).
d. Soil losses, with conservation practices, during the first 12 years of the crop, (tm/ha per year).
e. Soil losses, with conservation practices, during years 13 to 24 of the crop, (tm/ha per year).
f. Soil losses, with conservation practices, during years 25 to 35 of the crop, (tm/ha per year).

A similar sequence is used for the soil losses with and without conservation practices during the periods with no cultivation.

4PARAM

The 4param option loads the parameters related to the loss of productivity in the different crops according to soil loss. When you click on 4param, the programme requests the following data sequence:

a. Loss of annual productivity of the first crop without conservation practices, during the first 12 years, in percentage.
b. Loss of annual productivity of the first crop without conservation practices, during the years 13 to 24, in percentage.
c. Loss of annual productivity of the first crop without conservation practices, during the years 25 to 36, in percentage.
d. Loss of annual productivity of the first crop with conservation practices, during the first 12 years, in percentage.
e. Loss of annual productivity of the first crop with conservation practices, during the years 13 to 24, in percentage.
f. Loss of annual productivity of the first crop with conservation practices, during the years 25 to 36, in percentage.

Similar sequences are used for the second and third crops, with and without conservation practices.

5PARAM

The 5param option loads into the programme the parameters related to the retention of water in the soil, the percentage of the aqueducts and dams affected by sedimentation, and the nutrients lost from the soil. When you click on 5param, the programme requests the following data:

a. Water retention in fallow fields during the first 12 years (m^3/ha per year).
b. Water retention in fallow fields during the years 13 to 24 (m^3/ha per year).
c. Water retention in fallow fields during the years 25 to 25 (m^3/ha per year).
d. Sediments that affect aqueducts during the first 12 years, (percentage).
e. Sediments that affect aqueducts during the years 13 to 24, (percentage).
f. Sediments that affect aqueducts during the years 25 to 35, (percentage).
g. Sediments that affect water in dams during the first 12 years, (percentage).
h. Sediments that affect water in dams during the years 13 to 24, (percentage).
i. Sediments that affect water in dams during the years 25 to 35, (percentage).
j. Nitrogen concentration in the type of soil lost in the first 12 years, in g/tm.
k. Nitrogen concentration in the type of soil lost in the years 13 to 24, in g/tm.
l. Nitrogen concentration in the type of soil lost in the years 25 to 35, in g/tm.

A similar sequence is used for the losses of phosphorous and potassium.

6PARAM

The 6param option loads the parameters related to the prices of inputs and products into the programme. When you type 6param the programme requests the sequence:

a. The price of the first crop, in US$/tonne.
b. The price of the second crop, in US$/tonne.
c. The price of the third crop, in US$/tonne.
d. The price of fresh milk, in US$/tonne
e. The price of nitrogen, in US$/tonne de N.
f. The price of phosphorous, in US$/tonne de P.
g. The price of potassium, in US$/ton de K.
h. The price of water, in US$/$m^3$.
i. The cost of sediment treatment in aqueducts, in US$/ton. of sediment.
j. The cost of sediment treatment in dams, in US$/ton. of sediment.
k. The price of firewood, in US$/ton.
l. The annual increase in the price of water, in percentage.
m. The annual increase in the price of firewood, in percentage.

CONTINUE

This option accesses the following options:

LOGISTIC

This option allows us to load the parameters for estimating the adoption of the new technology. The sequential order of the parameters for the adoption curve is the following:

a. Percentage of adoption in the initial period for the new technology used in the crops.
b. Time in which this percentage was achieved, in years.
c. Percentage of adoption in the final period for the traditional technology used in the crops.
d. Time in which this adoption percentage was achieved, in years.
e. Value of the asymptote of the K function (corresponds to the maximum value that R can achieve through the diffusion period). It is expressed as: 1 + maximum percentage achieved.

A similar sequence is followed for the adoption of the improved technology in fallow lands.

INVESTMENT

Using this option, investments or necessary costs for guaranteeing the continuation of the action that is being evaluated are entered into the model. The investment should be expressed in millions of dollars. Initially, the model requests the discount rate and the percentage of benefits that can be attributed to the institution. The model permits including the costs of investment for 20 periods, both for crops and for fallow lands. To end the cost flow in a given year, the number 999 is used.

CALCULATE

Once the different groups of parameters have been determined, we proceed to the calculation through the option **CALCULATE**. Initially, this option quantifies all of the biological and economic aspects for the period of cultivation, later for the fallow period, and finally analyses the economic efficiency of the investment in the hillside initiatives realised. The entire step is automatic and it is not possible to stop the process after each kind of calculation.

2.3.6. Simulation of the model

- The results of the model can be obtained on the screen or printed form. In the case under study the following options are presented:

- 1GRAPH. This is a set of six graphs related to soil loss, productivity per unit area and with the adoption processes.

- 2GRAPH. This is a set of seven graphs which show results after the adoption process in crops and fallow lands at the regional level.

- 3GRAPH. This is a set of seven graphs which show results at the regional level with respective economic calculations.

- Print. In the printed results the following information is achieved for characterising the respective 'run':

    1. Tables of basic information.
    2. Tables of biological results in crops
    3. Tables of economic results in crops
    4. Tables of biological results in fallow land
    5. Tables of economic results in fallow lands
    6. Printouts of the screen graphics.

- QUIT. There are two **QUIT** options. Each is in a group of eight options. With 'quit' located in the first group of options, the calculation section is terminated and with the second, the actions run in the second group are terminated.

Note:
In order to make changes after each 'run', the user should go to the group of parameters that he or she would like to modify. For all of the parameters, except those that refer to the research investment or transfer, the model assumes that the most recent information is the base for the next run.

Exercise 2.1 Use of the EPIC and CROPWAT Simulation Models

Objective

✓ This exercise is designed for participants to acquire skills in the use of basic commands for the EPIC and CROPWAT simulation models.

Trainer Orientation

1. Depending on the number of computers available and the number of participants, divide participants into groups with a minimum of two and a maximum of four people and put each group at a computer that has the EPIC and CROPWAT programmes installed.
2. Hand out the instructions defining the parameters of the simulation models.
3. Ask the participants to execute the programme and check the outputs.
4. Ask the group members to change the coefficients used in the model and to observe the variations in the solutions proposed by the model. The variations are suggested in the instruction sheet.
5. Ask each group to re-do one of the questions and solutions elaborated in Exercise 1. 1 using the models.
6. In plenary session, ask the groups to present the results obtained, as well as a summary of the difficulties found in the use of models.

Necessary resources

- Instruction sheet for each participant.
- Computers with the EPIC and CROPWAT programmes installed. The number will depend on the logistic capacity and the number of participants in the event. Try to obtain one computer for every two or three people. Insofar as Software is concerned, keep in mind that the guide includes two diskettes for the installation of EPIC and one diskette with CROPWAT. Also, one diskette is included with examples for both EPIC and for CROPWAT. In Section 3 the procedure for the installation of each programme is shown.
- 'Videobeam'
- Flipchart and paper
- Marker pens

Suggested time: 4 hours

Exercise 2.1 Use of the EPIC and CROPWAT Simulation Models

Objective

✓ This exercise is designed for participants to gain skills in the use of basic commands for the EPIC and CROPTWAT simulation models.

Instructions for the Participant

1. Form work groups, according to the instructions given by the trainer. Each group will have use of a computer with the EPIC and CROPWAT programmes installed.

2. The group will start work at the beginning with the EPIC programme. Use the file named LADERA as a guide for the application of basic commands. Based on the instructions presented in Section 2 Using the EPIC Model, execute the commands UTIL EPIC, LADERA, EWQ LADERA and LIST LADERA.OUT.

3. Change the slope parameters in values of 10%, 30%, 50%, 70%, and the conservation practices coefficient in values of 0.4, 0.6 and 0.9 and judge soil loss by water erosion in each of the scenarios generated by these changes.

4. Evaluate the dynamics of soil loss over time. To do this, change the time parameter for the simulation in the file LADERA for 1, 5, 10, 20, 50 and 100 years.

5. For the programme CROPWAT, based on the instructions in Section 2: Using the CROPWAT programme, work with the file LADERA and determine, for the conditions given, the water requirements for the cultivation of maize, which is planted on the 1st of March.

6. Reconsider the questions formulated in Exercise 1.1 and propose a series of steps where the EPIC and CROPWAT simulation programmes are used to answer the question selected.

7. The groups will present their results in plenary session, placing emphasis on the difficulties encountered in handling the models and on the steps proposed by each group to answer a question related to decision-making in the management of natural resources.

Time: 3 hours.

Exercise 2.1 Use of the EPIC and CROPWAT Simulation Models Feedback Information

Trainer Orientation

The basic commands for the execution of the EPIC programme are:

- For data input and/or modification enter the directory C:>\ EPIC>, type the command UTIL EPIC LADERA and press ENTER. Data corresponding to the example 'laderas' will appear on the screen. By using the arrows (cursor), you can move to the different cells of the database. Identify the cell corresponding to the duration of the simulation, which is located in the upper left hand portion of the file (Number of years of simulation), the slope variable (Slope steepness metres/metres), and the variable corresponding to the soil conservation practices coefficient (Erosion control practice). In each of these cells, the parameters can be changed as indicated in the instruction sheet. To do this, press ENTER, input the datum and move with the arrow. Once you have finished changing the data, press the key F3, in order to save the information and exit the database.

- To execute the programme, enter the EPIC directory and type EWQ, leave a space and the name of the file, which for this exercise is LADERA. Then press the ENTER key. The programme will execute the commands automatically and present the results on the screen in graph form.

- To read the results type the command LIST LADERA.OUT whilst in the EPIC directory. The programme will immediately output the information. You can move around within this file using the arrows or the keys PAGE UP or PAGE DOWN. Identify the variable USLE that gives information about the tonnes of soil lost through water erosion in one year.

The output of the CROPWAT model is shown below.

1. Results of the water balance in the cultivation of maize.

- Cultivation data used in the balance.

Growth stage	Begin	Devel.	Mean	Final	Total
Duration [days]	30	50	60	40	180
Cultural coefficient [Kc coef]	0.30	->	1.05	0.80	
Root depth [metres]	0.35	->	0.80	0.80	
Exhaustion level [frac]	0.70	->	0.70	0.70	
Answer in the yield coefficient Ky	0.40	1.50	0.50	0.20	1.25

- Evapotranspiration and water requirements of maize cultivation in the first semester

The resulting data are calculated for the conditions in a normal year.

Climate file: Ladera
Meteorological station: Ladera
Crop: Maize
Planting date: 1st March

Month	Dec.	Stage	Coef. (Kc)	ETc (mm/day)	ETc (mm/dec)	Pref (mm/dec)	NER (mm/day)	NER (mm/dec)
March	1	init	0.30	0.83	8.3	18.9	0.00	0.0
March	2	init	0.30	0.82	8.3	22.0	0.00	0.0
March	3	init	0.30	0.81	8.1	21.4	0.00	0.0
April	1	deve	0.38	1.01	10.1	20.8	0.00	0.0
April	2	deve	0.53	1.40	14.0	20.2	0.00	0.0
April	3	deve	0.68	1.80	18.0	20.1	0.00	0.0
May	1	deve	0.83	2.19	2.9	20.6	0.13	1.3
May	2	deve	0.97	2.59	25.9	20.9	0.51	5.1
May	3	mid	1.05	2.78	27.8	16.9	1.09	10.9
June	1	mid	1.05	2.77	27.7	12.9	1.48	14.8
June	2	mid	1.05	2.76	27.6	9.0	1.87	18.7
June	3	mid	1.05	2.88	28.8	7.4	2.14	21.4
July	1	mid	1.05	3.00	30.0	5.9	2.41	24.1
July	2	mid	1.05	3.12	31.2	4.3	2.69	26.9
July	3	late	1.02	3.07	30.7	4.5	2.62	26.2
August	1	late	0.96	2.92	29.2	4.6	2.46	24.6
August	2	late	0.89	2.77	27.7	4.8	2.29	29.9
August	3	late	0.83	2.55	25.5	6.0	1.95	19.5
Total					400.8	241.0		**216.5**

Etc = Evapotranspiration (for 1 day or for 10 days)
NER= Irrigation needs (for 1 day or for 10 days)
Dec = 10-day period
init = Initial stage of the crop
deve= Stage of crop development
mid = Middle cultivation stage
late = Final cultivation stage

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Originals for Transparencies

STRUCTURE OF THE SECTION

SIMULATION MODELS

What would happen?

How do we Simulate the Resources Soil – Plant – Costs?

- ✓ Present the limitations and possibilities of three simulation models: EPIC, CROPWAT and LADERA.
- ✓ Present the structures and functions of the simulation models: EPIC, CROPWAT and LADERA.
- ✓ Acquire skills in the basic management of the simulation programmes: EPIC, CROPWAT and LADERA.

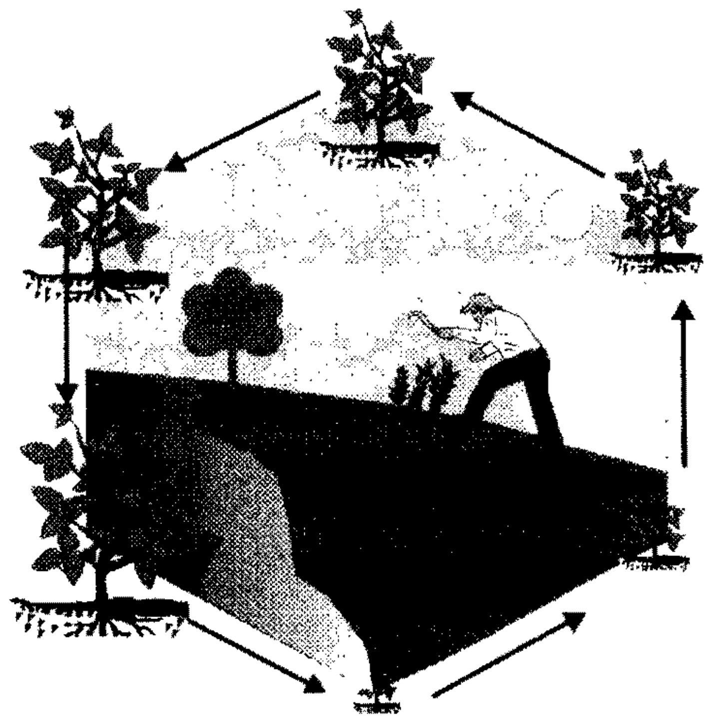
- Model for simulating technology, resource: soil
- Model for simulating technology, resource: water
- Integrating model on hillsides

OBJECTIVES OF THE SECTION

- ✓ Present the possibilities and limitations of the simulation models: EPIC, CROPWAT and LADERA.

- ✓ Present the structure and functions of the simulation models: EPIC, CROPWAT and LADERA.

- ✓ Acquire skills in the basic management of the simulation programmes: EPIC, CROPWAT and LADERA.



ORIENTING QUESTIONS

1 **What is the application of simulation models in decision-making for natural resource management?**

2 **How are the EPIC, CROPWAT an LADERA simulation models structured?**

3 **How are the basic commands used in the software of the simulation programmes EPIC, CROPWAT y LADERA?**

STRUCTURE SECTION 2 FOR THE MODELS EPIC, CROPWAT, LADERA

- ✓ Objective
- ✓ Application
- ✓ Structure
- ✓ Use
- ✓ Simulation
- ✓ Installation

EPIC
ENVIRONMENTAL POLICY INTEGRATED CLIMATE

- ✓ Simulates biophysical, environmental, and economic processes
- ✓ Simulates erosion processes (100 years)
- ✓ Applicable to a wide range of soils,climat and crops

CROPWAT

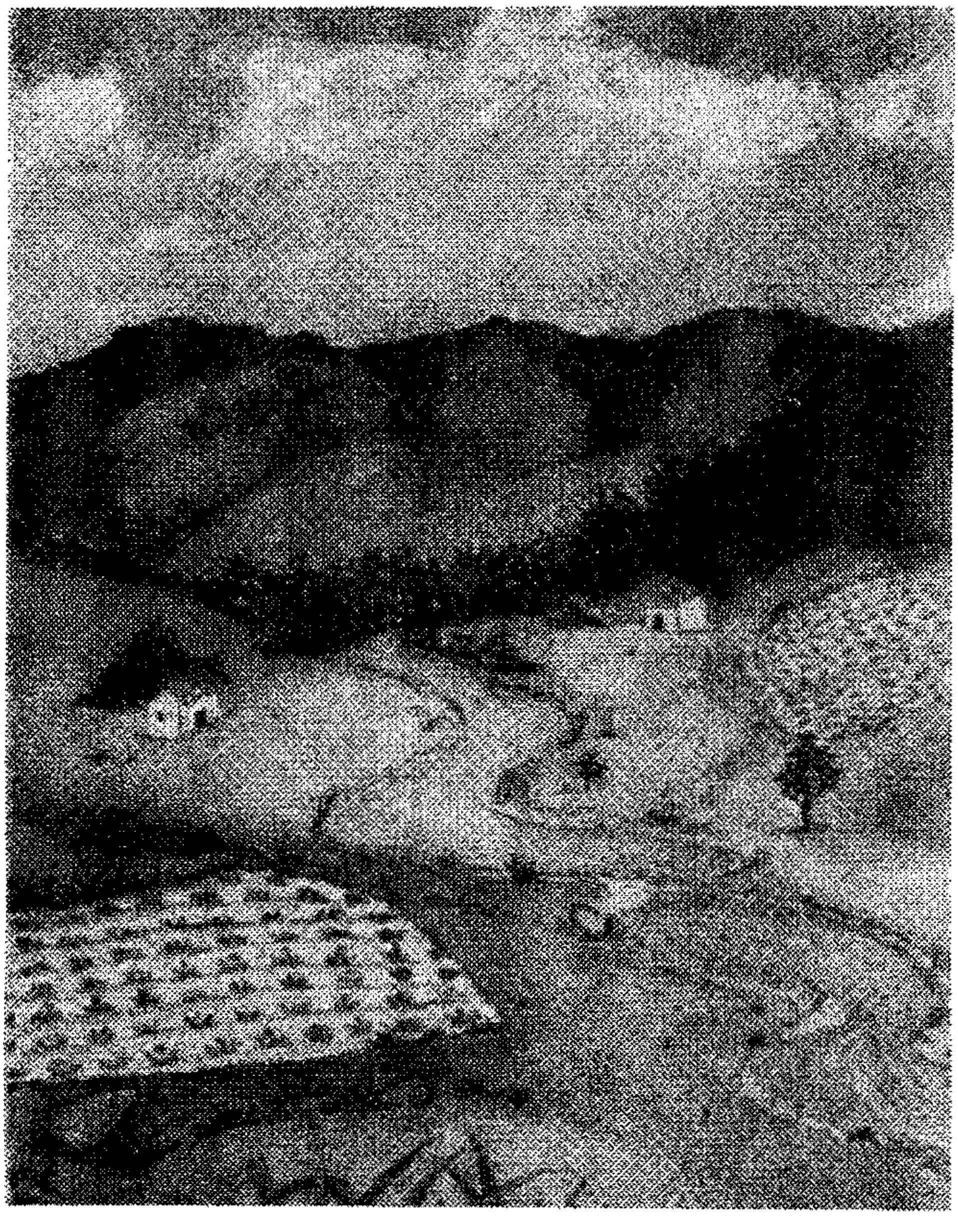
- ✓ Calculates evapotranspiration
- ✓ Calculates water requirements
- ✓ Estimates production under different conditions of water availability

LADERA

- ✓ Documents the impact on natural resource management
- ✓ Identifies parameters in soil construction
- ✓ Simulates adoption rates
- ✓ Simulates erosion

Section 3

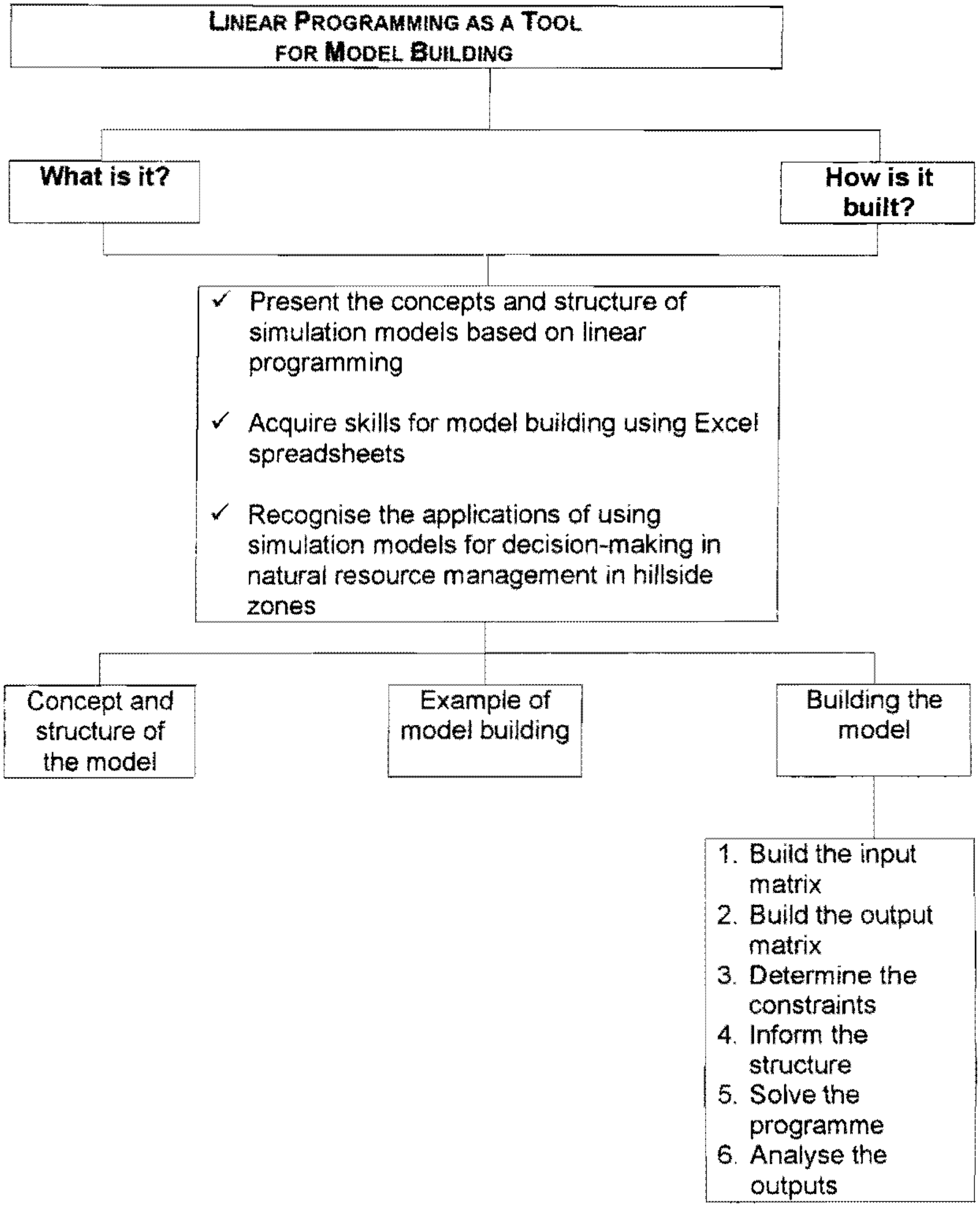
Linear Programming as a Tool for Model Building



Section 3. Linear Programming as a Tool for Model Building

Page

Structure of the Section



Section 3 responds to two questions related to model building for simulation using linear programming. These questions are: What is linear programming? How are linear programming models built?

This section first presents the concepts and constitutive elements of a model based on linear programming, emphasising the advantages and limitations of this type of model, as well as its field of application. To present the concept we develop an example concerning resource allocation on a farm with maize and bean crops.

The second component of the section deals with a methodological proposal for building models by means of linear programming. We propose the use of the Excel spreadsheet as a tool. The section shows the development of six steps; the first two are related to the construction of the data input and output matrices. The third step indicates the way the constraints of the model are determined. The fourth deals with the way that we inform the Excel programme about the structure of the model. The fifth step shows how the model is executed, and the last step shows how the model offers solutions to the user.

The third component offers the user a series of common cases in model building with linear programming, such as introducing into the model contracted workdays, buying workdays, the consideration of autoconsumption and the consideration of crops which last longer than six months.

Objectives

- ✓ Present the concepts and the structure of simulation models based on linear programming.
- ✓ Acquire the skills for model building using the Excel spreadsheet.
- ✓ Recognise the applications of simulation models for decision-making in the management of natural resources on hillsides.

Orientation Questions

1. What is linear programming?
2. What are the elements of a model?
3. How is a model built using linear programming?

Introduction

In this section we refer to the application of linear programming for Ex-ante evaluation. The aim is to permit researchers and development agents to make decisions based on the analysis, planning and development of a mathematical model based on a specific production system. The mathematical model to be developed through linear programming allows us to put forward problems concerning the allocation of limited resources within the system (land, labour, capital, natural resources) and find optimal solutions according to a proposed objective.

Linear programming, in the mathematical sense, studies the optimisation of a linear function subject to linear inequalities. This is the application of matrix algebra for the solution of equations using rules that ensure that the solution satisfies all of the constraints and thus permits the achievement of in terms of a proposed objective.

One of the basic principles of systems analysis consists in including the collaboration of people who are familiar with the system. This is especially useful when there is a need to make better use of the limited resources in a crop, farm, watershed or region.

According to Bergren (1992), the essential stages in the use of mathematical models for problem-solving are the following:

1. Analysis and formulation of the problem.
2. Development of a mathematical model that represents the problem.
3. Derivation of a solution to the problem.
4. Testing the model and the derived solution.
5. Establishment of controls for the solution.
6. Implementation of the solution.

3.1 Linear Programming

Linear programming was first developed and applied in 1947, when George B. Dantzing and Marshall Wood of the United States Air Force were in charge of researching the possibility of applying mathematical techniques to military programming and planning problems. A model was proposed that led to linear programming. The interrelationships between activities in an organisation are treated as a linear model and the optimisation programme was determined minimising an objective linear function.

There are many fields of application of linear programming in the agricultural sector. One of the typical applications is the allocation of limited resources, such as the land to be used, labour, irrigation, and working capital. These are allocated so that a particular component is optimised: production costs, labour utilised, production earnings or the returns from the natural resources used.

Additionally, the linear programming model permits the excecution of sensitivity analysis when there are a variety of different options, such as increases or decreases in the availability of the production factors involved, changes in the cost structure or a modification in the price of the products that affects the net earnings. The model also allows a comparison of activities with or without technological improvements, and the results indicate the kinds of changes that should occur in the structure of the production system if the alternative technology is incorporated.

3.2 Advantages and Limitations in the Use of Linear Programming Models

Advantages

- We can identify the technological development actions that have greater potential immediate impact and better cost-benefit relationships, in order to define priorities for research teams.

- We rapidly obtain an estimate of the results of the interaction between various factors. This would be impossible to execute experimentally, given the size of the factorial design required or the number of years necessary for its elaboration.

- Reduction in the costs of experimentation and in the time that the researchers must invest in field studies.

Limitations

- As in all simulation processes, the availability of reliable information is a primary requirement.

- Linear programming supposes linearity, that is, if we add 100 kg of nitrogenous fertiliser and we harvest 10 tonnes of green fodder, then with 300 kg we would harvest 30 tonnes. In reality this may result in overestimates given the law of decreasing returns.

- There has not been enough methodological development to include qualitative management variables.

3.3 Mathematical Model of Linear Programming

Linear programming is concerned with the study of optimisation maximisation or minimisation of a linear function with several variables, which is subject to a set of linear inequalities with several variables. The function that should be optimised we will call the **target function**, and the inequalities we will call **constraints** or **limitations**.

3.3.1 General structure of the model

- **Linear function**

The function F(x) in the variables x1,x2,x3,x4,x5,x6.....xn is linear because the exponent of the variables is equal to 1. This can be expressed as:

$$F(x) = a1x1 + a2x2 + a3x3 + a4x4 + \ldots\ldots\ldots anxn$$

The following expressions are linear:

$$c = 2X1 + 2X2 + X3 - 4X4$$
$$5X1 + 3X2 - 4X3 - 2X4 >= 80$$

For the analysis of the system **farm**, the function of the model can be gross earnings, cost structure, quantity of workdays, etc. By way of example, we express the function of gross earnings:

Gross margin = Gross earnings Variable costs

$$F(x) = 16.7^*(X1) + 314.5^*(X2) + 104.2^*(X3) + 67.25^*(X4) + 79.5^*(X5) - 0.8^*(X6) + 0.7^*(x7)$$

F(X) =Gross margin of the farm ($)
X1 = area planted in maize (ha)
X2 =area planted in coffee (/ha)
X3 = area planted in beans (/ha)
X4 = area planted in sugarcane (/ha)
X5 =area planted in cassava (/ha)
X6 = Number of contracted workdays (/ha)
X7 =Number of workdays that the producer sells outside of his farm (/ha)

The constants that accompany the variables ($116.7/ ha, $314.5 /ha, $104.2/ha...) are equal to the sale of the production of the crop in one hectare in one year less the costs of production of the crop in one hectare in one given year.

- **Activities**

These are structural variables of the model (X1, X2, X3,X4....Xn) and correspond to the different alternatives available in the model. For the model **farm**, these are the crops of the production system: maize, millet, tobacco, sorghum and pastures. These may be monocultures, associated cultures, intercalated crops or rotations of any vegetative period, being semi-annual, annual, or permanent. They may also include activities such as buying workdays, selling workdays, or in the animal husbandry field, number of animal units (cattle and/or poultry). The calculation can be made per bird or per cow or per number of cattle per hectare, etc. It is important to keep the same criterion for each activity when structuring the model in each of its constraints, that is, if working in production per hectare per year, all equations must be formulated in this manner.

- **Constraints**

These are the names of the different productive resources that the system has. They include the limiting resources imposed both by the biological and economic capacities of the system, and by the considerations of the producer or the regional politics. The constraints most used in building a mathematical model at the farm level are: capital available to the producer, family labour available in a given period, quantity of workdays bought, amount of available land, autoconsumption on the farm, the number of workdays that can be bought, maximum soil loss permitted in a crop of the farm, the quantity of irrigation water, the maximum animal carrying capacity per hectare, etc.

- **Feasible solution**

This is any set of positive values for the variables x1, x2, x3, x4,...xn ; that meet each and every one of the constraints of the mathematical linear programming model. Where it does not meet the condition of no-negativity or any of the constraints, it is defined as not feasible.

- **Optimal solution**

This is the set of values for the variables x1, x2, x3 ,x4...xn that satisfy the criterion of feasibility and optimise the target function of the mathematical linear programming model.

- **Limits to the activities**

These are the constraints on the values of the variables. They are normally located in the last row of the matrix in two cells, one with the word **MAX** where we put the maximum value that the variable can assume, that is the upper limit of an activity. The other cell is marked **MIN** and this is where we put the lower limit of the activity. This is often used in the case of autoconsumption, since in this way the model is forced to include a minimum value for this activity so that a certain part of the production is dedicated to autoconsumption.

3.4 Building the Model

The model is constructed as a double entry matrix where the productive activities of the system being analysed are crossed with the constraints to which it is submitted. To understand the structure of the model we present an example:

Let us consider a farm with the following characteristics: 10 hectares in surface area (suitable for planting maize and beans), 585 workdays /six month period as available labour and US$2000 /six-month period in capital. The requirements for planting 1 hectare of maize are 55 workdays and US$230 in capital, while for planting beans we require 124 workdays for each hectare and US$300. The net earnings per hectare of maize is US $85 and for beans US $176. According to the regional characteristics of the market, there exists a high risk of depressing the price of beans, if more than 4 hectares of these are planted.

3.4.1 Definition of the activities

For the present case: Maize (the area planted in hectares); Bean (the area planted in hectares).

3.4.2 Definition of the objective (function?)

This will be the net income that will be received in the farm for a harvest (per six-month period) and is defined as:

F(X) = 85*MAIZE + 176* BEANS MAX

We will search for the maximum income for the farm; for this reason the function is maximised.

3.4.3 Definition of the constraints

The model is submitted to four constraints

- **Land**

This first constraint is structured in the model though an inequality which states that the area planted in maize (**1*MAIZE**) added to the area planted in beans (**1*BEAN**) can be equal to 10 hectares at a maximum. It is important to note that the value of the constant the accompanies the variables is equal to 1, due to the fact that both crops have the same opportunity for occupying the farm in values that range from 0 to 10 hectares. The equation that represents this first constraint is:

LAND 1* MAIZE + 1* BEAN <= 10

- **Capital**

This constraint indicates to the model how much money is available to carry out the different activities of the system. In this case, the maximum amount of money available is US$2000. This amount can be divided for the MAIZE crop, for the BEAN crop, or for a combination of the two. The requirements of capital for each of the activities are US$230 per hectare of MAIZE and US$330 per hectare of BEAN. The equation that defines this constraint is constructed in the following manner:

CAPITAL230*MAIZE + 330* BEAN <= 2,000

Observe that the inequality is constructed as the sum of the capital requirements for the maize crop plus those for the bean crop. In this case the constants that accompany each of the variables are equal to the amount of money consumed in each activity (US$230/hectare for maize and US$300/ha for beans). The inequality used was less than or equal to (<=) this. This is because the available capital is US$2000 and, thus, what can be spent must be less than or, at a maximum, equal to the available quantity at the farm.

- **Labour**

In this constraint, limits are set for the use of available labour for carrying out the work on the crops. Its construction is similar to the capital constraint and is defined as the following inequality:

LABOUR 55*MAIZE + 124*BEAN <=585

Observe that the constant that accompanies the variables is equal to the requirements in workdays to obtain one hectare in each of the activities, 55 workdays/hectare in the case of maize and 124 workdays/hectare for beans. This quantity of workdays is equal to the sum of the workdays used in each of the production activities of the crops during the growing season (land preparation, planting, weeding, harvesting, etc.).

- **Bean constraint**

The problem sets forth that a maximum of four hectares may be planted in beans, given marketing situations. This inequality is structured in the following way:

CONST. BEAN 1*BEAN <=4

Observe that in this inequality the coefficient of the variable MAIZE is zero (0) and therefore, does not appear in the equation. The coefficient of the variable BEAN is 1 since it represents the fact that the area in beans may not be greater than 4 hectares. This variable may take any value between 0 and 4 hectares.

Finally, the matrix will be structured in the following form:

Activity / constraint	**Maize**	**Bean**	**Inequality**	**Available**
Target function	85	176		
Land	1	1	<=	10
Capital	230	330	<=	2.000
Labour	55	124	<=	585
Maximum	10	4		
Minimum	0	0		

Figure 3.1 graphically represents the different possibilities of production in the example presented. In the figure, the upper line signals the different possibilities for use of the land resource (10 ha) with two crops; that is, if 10 ha of maize is planted, it is not possible to plant beans.

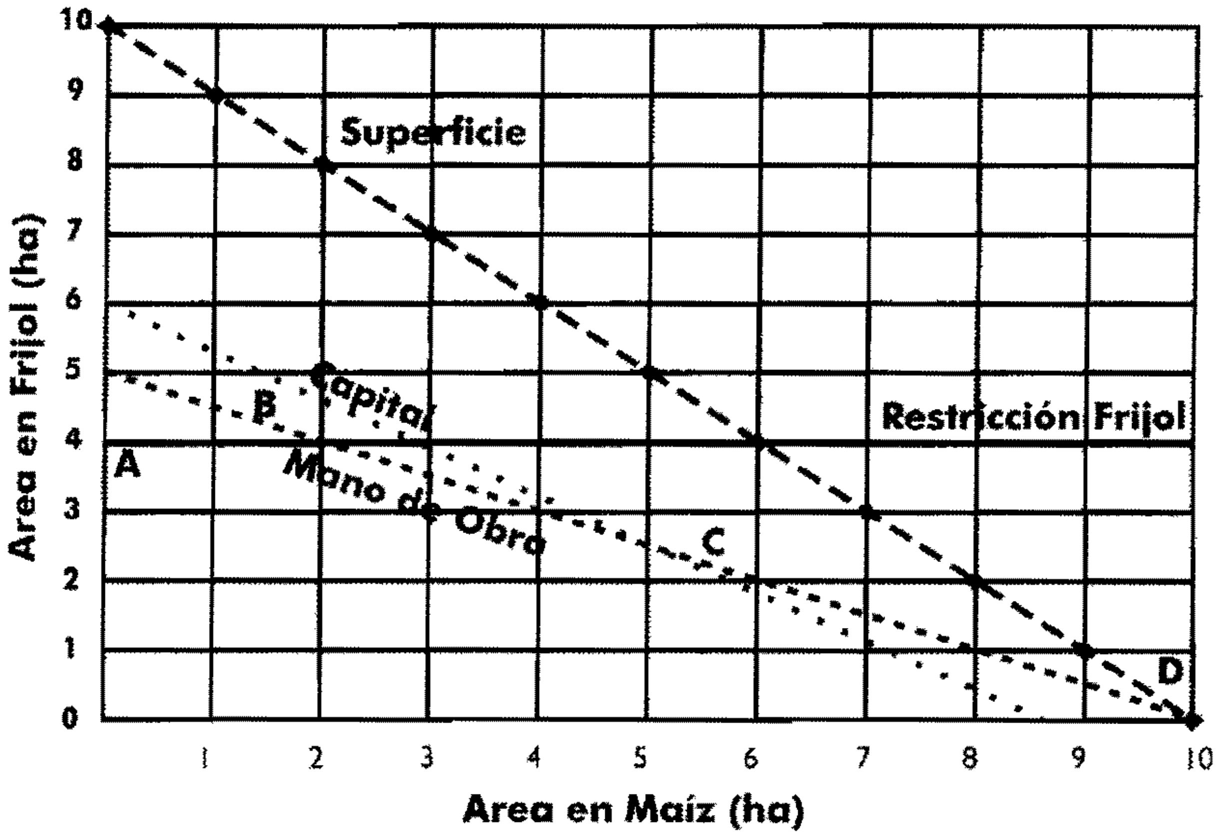


Figure 3.1 Representation of the Production Factors Obtained with the Use of Linear Programming.

The line for capital shows that with the money available a maximum of 6 ha of beans can be planted and a maximum of 8.7 ha of maize.

The extremes of the labour line indicate the number of hectares that can be planted in beans (4.7 ha) and in maize (10.6 ha), given the available workdays. Along this line the way in which the labour may be divided is presented, for managing different areas of land with the two crops.

The bean constraint line shows that this crop should be planted to 4 ha at a maximum.

Only within the shaded area (below the line ABCD) can a feasible solution be found in the sense that this will not be constrained by any of the factors considered. Along the line AB the dominant factor is the bean constraint, while along the line BC it is labour, and along the line CD, capital. The optimal point to achieve the highest net income is found along the line ABCD. This is detected by calculating the income at each point and selecting the highest value, which for the example is point C where 5.2 ha of maize and 2.4 ha of beans are planted.

3.5 Use of an Electronic Spreadsheet for Building a Linear Programming Model

The electronic spreadsheet Excel has, as do also Lotus and Qpro, an automatic macro called **Solver** that permits the mathematical solution of linear programming models. To use this it is necessary to undertake the following steps:

3.5.1 Building the Matrix

All of these programming packages ask for information in matrix form where we put the constraints, activities and the target function. The matrix is built in such a way that the columns represent the activities of the system with the characteristic, and in the last one the available values for the constraints (land, capital, labour, etc.) is found. In the rows we describe the constraint equations in addition to the equation for the target function. This distribution of information is similar in all packages and spreadsheets.

With the aim of unifying the software, we suggest that for this document the electronic spreadsheets such as Lotus, Qpro, or Excel are used. In Table 3.1 we show an example of building a model for linear programming.

Table 3.1 Example of building a model for linear programming.

	A	B	C	D	E	F
1						
2		Activities				
3	Constraints	Maize	Bean s	Inequalitie s	Available	
4	Target function	85	176			
5	Land	1	1	≤=	10	
6	Capital	230	330	≤=	2000	
7	Labour	55	124	≤=	585	
8						
9	Maximum	10	4			
10	Minimum	0	0			
11						
12	Quantity					
13						

In this matrix the activities are crossed with each of the constraints. In the target function it is important to observe the consistency of the units, since for each activity all values are given on the basis of 1 hectare ($/hectare, workdays/hectare) and that there is consistency within each of the constraints: (Land in hectares, Capital in US$, Labour in workdays, Earnings in US$).

The first column gives the indications that identify each of the constraints. In the following columns, we find the coefficients of the variables for each of the constraints. In the penultimate column, we find the values of the inequalities (that may be <, >, <=, >=) and in the last column the available values are presented for each of the resources of the system.

The first row of the matrix (row 4 of the electronic spreadsheet) has the equation of the target function in such a way that values are assigned for each of the proposed activities.

The second row of the matrix (row 5 in the spreadsheet) contains the land constraints with coefficients of one (1) for both beans and maize, the inequality of <=, and the available value which for this resource of 10 hectares.

The third row of the matrix (row 6 of the spreadsheet) has the coefficients of the capital constraint, the inequality, and the value for the available capital on the farm. The remaining constraints of the model are similarly identified.

Once the constraints have all been included, we proceed to create the row for quantities, writing the word in the first column (of row 12 in the spreadsheet) and leaving the corresponding cells in this row free of any values at this moment (Table 3.1).

The **quantity** row is used by the model for assigning the values that result from the calculations made by the programme. The values of the variables that meet with the constraints of the model and allow optimising the target function are placed in this row.

At the end of the matrix, we write the lower (minimum, row 10) and the upper (maximum, row 9) of each of the variables. In this case, the upper limit for maize is 10 hectares and for beans it is 4 hectares, given its marketing constraint. The lower limit of both of these activities is zero (0) given that there is no constraint that obliges the activity to have a minimum value.

3.5.2 Building the output matrix

Once the matrix for the initial information has been made, it is necessary to repeat it in the lower portion of the spreadsheet. To do this we write once again in the first column of the row for TARGET FUNCTION (cell A15 in the spreadsheet) LAND (cell A16 in the spreadsheet), CAPITAL (cell A17 of the spreadsheet), and LABOUR (cell A18 of the spreadsheet). The values in the cells B15 to C18 are the products of multiplying the initial matrix by the QUANTITY row; the formulae are shown in Table 3.2.

Table 3.2Data output matrix.

A	B	C
Target function	+B4 * B$12	+C5 * C$12
Land	+B5 * B$12	+C6 * C$12
Capital	+B6 * B$12	+C7 * C$12
Labour	+B7 * B$12	+C8 * C$12

To write the formulae, the simplest procedure is to write the first formula in the cell B15 (+B4 * B$12) and then to copy this in the other cells corresponding to all of the constraints.

3.5.3 Determining the Equations for the Constraints

After having repeated the working matrix, the sums of each of the rows corresponding to the target function and all of the constraints are made. To do this we use the function **sum** of the electronic spreadsheet in the TOTALS column from B15 to C15. The respective equations are shown in Table 3.3.

Table 3.3 Equations used for determining the constraints of the model.

	A	B	C	D	E	F
15	Target function	+B4 * B$12	+C4 * C$12			=SUM(B15:C15)
16	Land	+B5 * B$12	+C5 * C$12		10	=SUM(B16:C16)
17	Capital	+B6 * B$12	+C6 * C$12		2000	=SUM(B17:C17)
18	Labour	+B7 * B$12	+C7 * C$12		585	=SUM(B18:C18)

In addition, the available values are copied in the column E of the electronic spreadsheet with the coefficient '10' for the land constraint in the cell E16, 2000 for the capital constraint in the cell E17, and 585 for the labour constraint in the cell E18.

At this point, the electronic spreadsheet shown in Table 3.4. has been constructed

3.6 Informing the Programme about the Structure of the Model

Once the matrix has been structured, it is necessary to give indications to the programme about the ranges possible for each of the equations. For this, we activate the tools menu and make use of the SOLVER command. This command is an automatic macro. If the computer does not facilitate this command, we activate the automatic macros in the **Solver** command. If it does not appear, it will be necessary to load this into the programme.

Once the solver command has been activated, the menu shown in figure 3.2 will appear on the screen.

Table 3.4Structure of the linear programming model.

	A	B	C	D	E	F	G
1							
2							
3	Constraints	Maize	Beans	Inequality	Availability	Totals	
4	Target function	85	176				
5	Land	1	1	≤ =	10		
6	Capital	230	330	≤ =	2000		
7	Labour	55	124	≤ =	585		
8							
9	Maximum	10	4				
10	Minimum	0	0				
11							
12	Quantity						
13							
14							
15	Target function	+ B4 x B$ 12	+ C4 X C$12		= SUM (B15:C15)		
16	Land	+ B5 x B$ 12	+ C5 X C$12	10	= SUM (B16:C16)		
17	Capital	+ B6 x B$ 12	+ C6 X C$12	2000	= SUM (B17:C17)		
18	Labour	+ B7 x B$ 12	+ C7 X C$12	585	= SUM (B18:C18)		
19							
20							

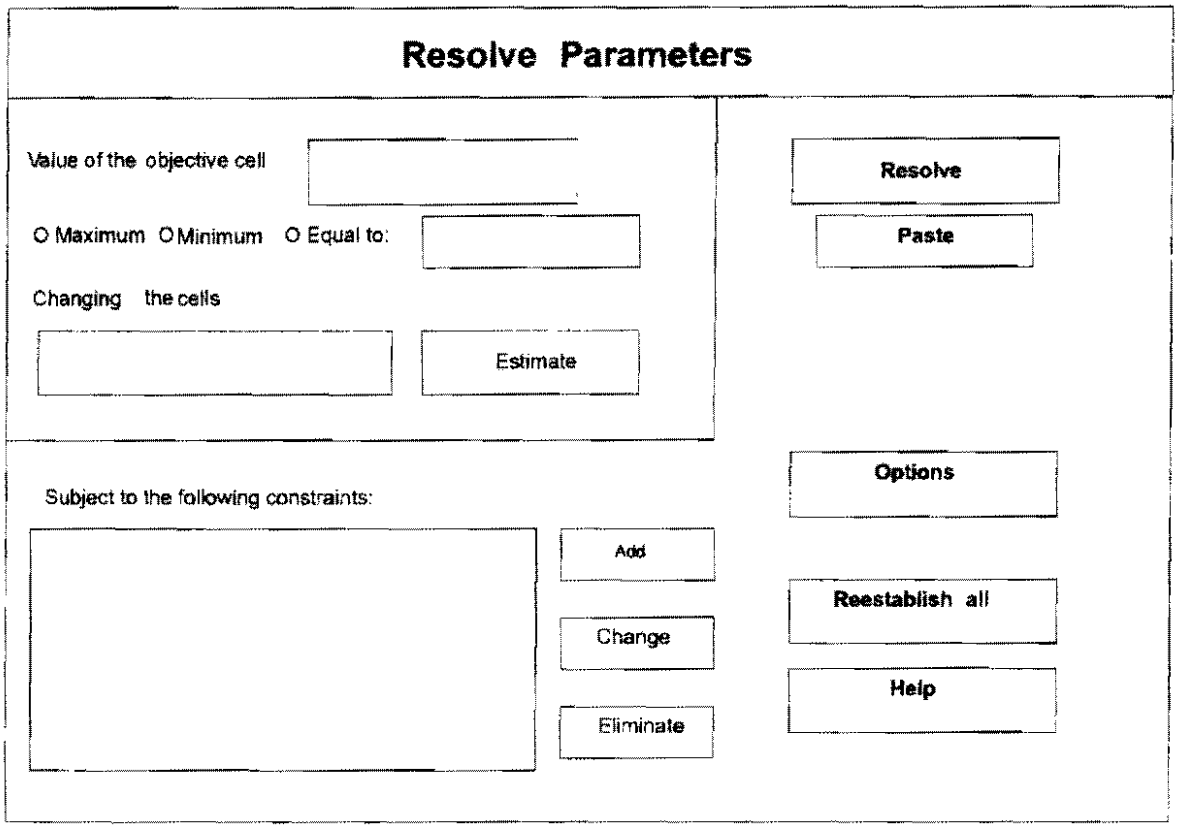


Figure 3.2 Solver Parameters

The requested information is:

Objective Cell
In this box, write the cell which contains the formula for totalling the contribution of each of the activities to the target function. This cell is determined in the previous step 3 (Table 3.4) and is cell F15 (=SUM(B15:C15)).

Value of the objective cell
The programme presents three options: Maximise, Minimise, or Equal to the target function. In the example we are developing, maximise is selected, using the mouse.

Changing the cells
In this box we indicate the row in which the quantities for each of the activities were created. On giving the formula it is necessary to anchor the cells using the symbol $, in order to facilitate changes in the structure of the model. This allows the programme to always recognise these cells as those for quantity; in the present example, we would type $B12: $C$12

Constraints
All the constraints by which the model is limited are included in this box. The menu presents three options for this to be done; Add, change, eliminate. With the mouse select the desired option, for example Add. On doing so the computer will present on the screen, the menu illustrated in Figure 3.2. The cell titled Cell Reference, located at the left of the menu, is for writing the result of the sum of the contribution of each of the activities for each constraint. For example, in the case of the constraint LAND, the value to be written in the cell is the one we calculated in the preceding step, that is the **cell F16 (see Table 3.4).** In the centre of the screen, you must select the inequality for the constraint, which may be <, >, <=, >=, =. The value to be entered in the right side of the menu, in the box labelled Constraint is the value found in the column E of the spreadsheet and for the case of the constraint LAND is the cell E16 (Table 3.2). The constraints for CAPITAL and LABOUR are entered in the same manner.

Constraints on maximum and minimum values
In order to inform the model about the maximum and minimum values of the variables the following equations are used: For the Maximum values:
`$B$12:$C$12<= $B$9:$C$9` and for the Minimum values `$B$12:$C$12>= $B$10:$C$10`

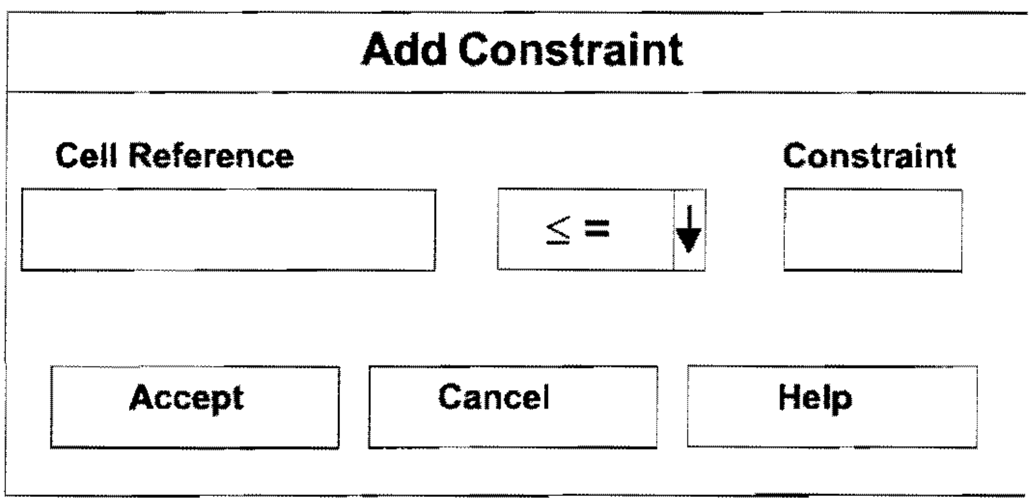


Figure 3.2Menu for adding constraints.

3.6.1 Resolving the model

Once the matrix has been built and the parameters demanded by SOLVER have been established, we proceed to the solution for the problem. For this we activate the command SOLVER located in the upper right portion of the SOLVER parameter menu.

The computer realises the mathematical calculations appropriate to linear programming and offers a menu as illustrated in Figure 3.3.

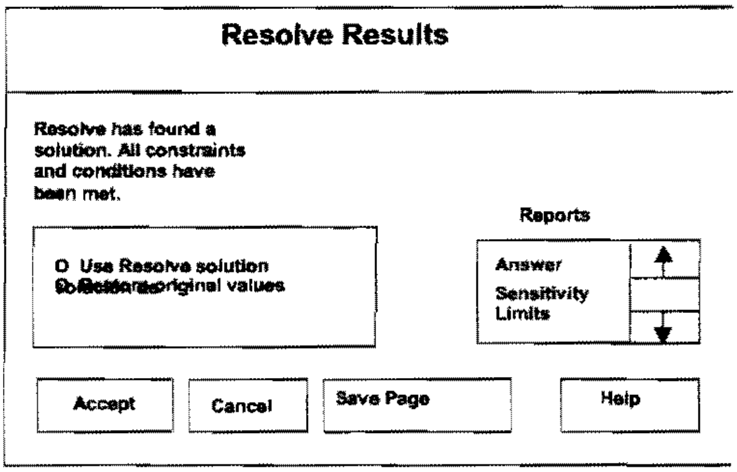


Figure 3.3 Output menu for results of Solver.

This menu offers the user three ways for outputting the solution of the model; answers, sensitivity and limits. In each of these options, the Excel programme transforms them into electronic spreadsheets as can be observed in Tables 3.5 and 3.6.

The programme calculates the values of each of the activities that fulfils the constraints and permits the maximisation of the target function. In this case, the area values are 5.3 hectares for MAIZE and 2.37 for BEAN for a total of 7,67 hectares. This value is inferior to 10 hectares, which indicates that the land resource is not limiting for the system given that 10 hectares is available and only 7.67 are to be used. Insofar as capital is concerned, the maize crop uses US$1218.76 and the bean crop uses 871.24 for a total of US$2,000, which indicates that the solution utilises all of the available capital. For labour, a similar situation occurs as in capital because the solution requires all of the available workdays in order to carry out the proposed activities.

The total of the target function is US$867.07, which is the MAXIMUM earnings that can be obtained with the proposed constraints.

3.7Sensitivity Analysis

Once the optimal solution has been found, it is important to analyse the production system in terms of the use of resources and technological changes in multiple situations. This is achieved through a sensitivity analysis. This analysis consists of evaluating change in the solution to the problem as a result of changes in some of the problem parameters. The sensitivity analyses that can be carried out are related to the change in the quantity of capital available, in the prices of the products and, thus in the value of the production, in the quantity of workdays available, in the constraints of autoconsumption and effects in the system due to the introduction of an alternative technology.

3.8 Examples of Model Building at the Farm Level

3.8.1 Model Where the Autoconsumption of a Product is Included

In order to represent the constraint of autoconsumption in the model, it is necessary to calculate the area (in hectares) that must be planted in the crop to guarantee the quantity consumed by the family in the time period corresponding to the analysis of the model (six months, one year, etc.). The calculation of the area is done through the average crop yield and the quantity of the product consumed:

Area (ha) = Total product consumed (kg)/ Crop yield (kg/ha)

The area value is placed in the row of the matrix that corresponds to the lower limit (usually in the lower part of the matrix) and in the column corresponding to the activity of the crop. For example, if the quantity of maize consumed during one year by the family is 500 kg and the maize yield is 1500 kg/ha, the area in autoconsumption is 0.3 ha. This value is placed in the lower limit below the maize activity.

3.8.2 Model with limited workdays

It may be necessary to limit the number of workdays that can be contracted on the farm, due to the scarce demand for work in the region where the farm is located. For this we place the maximum value for workdays in the row of the matrix that corresponds to the upper limit and beneath the column of contracted workdays. For example, if the region where the farm is located the maximum number of workdays to be contracted is 500 in one year, this value is located in the row of the upper limits (maximum), below the column of contracted workdays. In the same manner, the model can be limited in the quantity of workdays the producer can sell outside of the farm. The value will depend on the supply of work in the region that permits the producer to work outside the farm.

Table 3.5Answer report 1.

Microsoft Excel 5.0 Answer report
Spread sheet: [PRUEPL.XLS]MODELO
Report created: 12/10/94 23:48

Objective cell (max)

Cell	Name	Original value	Final value
$F$4	Target function totals	553.5	867.073833

Cell	Name	Original value	Final value
b12	Quantity maize	0.3	5.298939248
c12	Quantity bean	3	2.367405979

Cell	Name	Cell value	Formula	State	Divergence
F%	<= TOTALS	7.666345226	$F$5<=$E$5	Optional	3.333654774
$F$6	<= TOTALS	2000	$F$6<=$E$6	Obligatory	0
$F$7	<= TOTALS	585	$F$7<=$E$7	Obligatory	0
$B$12	Quantity maize	5.298939248	$B$12<=$B$9	Optional	4.701060752
$V$12	Quantity bean	2.367405979	$C$12<=$C$9	Optional	1.635594021
$B$12	Quantity maize	5.298939248	$B$12<=$B$10	Optional	5.298939248
$C$12	Quantity bean	2.367405979	$C$12<=$C$10	Optional	2.367405979

Table 3.6Sensitivity Report 1.

Microsoft Excel 5.0 Sensitivity report
Spreadsheet: [PRUEPL.XLS]MODELO
Report created: 12/10/94 23:48

Cell	Name	Final reduced value	Objective cost	Coefficient	Permitted increase	Permitted reduction
$B$12	Maize	5.298939248	0	85	37.66666667	6.935483873
$C$12	Bean	2.367405979	0	176	15.63636364	54.04347826

Cell	Name	Final price value	Shadow Price	Permitted constraint	Permitted increase	Reduction
$F$5	<= Totals	7.666345226	0	10	1E+30	2.333654773
$F$6	<= Totals	2000	0.082931533	2000	350.7246377	307.8181818
$F$7	<= Totals	585	1.198649952	585	73.60869565	106.7391304

Limits Report 1
Microsoft Excel 5.0 Limits report
Spreadsheet: [PRUEPL.XLS]MODELO
Report created: 12/10/94 23:48

Cell	Cell objective name	Value
$F$4	Target function totals	867.0732883

Cell	Changing cells names	Value
$B$12	Maize	5.298939248
$C$12	Bean	2.367405979

Lower limit	Objective result	Upper limit	Objective result
0	416.6634523	5.298939248	867.0732883
0	450.409836	2.367405979	867.0732883

3.8.3 Model where workdays are contracted or sold

If in the production system that is being structured there is a contracting of, and/or sale of workdays it is necessary to represent this reality as an activity of the model. The way to do this is to create the following activities:

- Sale of workdays (Sale WD)
- Buying of workdays (Con WD)
- Transference of workdays (family) Tranf1
- Transference of workdays (contracted) Tranf2

In the same way, the following activities should be created:

- Total workdays (Total Labour).
- Family labour (Fam Labour).
- Contracted labour (Cont Labour)

The structuring of the model is:

	Sale WD	Con WD	Tranf1	Tranf2		available
Land	0	0	0	0		
Family labour	1		1		<=	550
Contracted labour		-1		1	<=	0
Total labour	1	-1	-1	-1	<=	0
Target function	4000	-4500				
Maximum	300	500				
Minimum						

The restriction of the family labour indicates to the model that for each workday that is sold US$4 should be applied to the target function, but should be subtracted from the total labour, since this workday that is sold cannot be used in any activity on the farm. This is achieved through the variable Tranf1, which discounts the labour in the restriction of the total labour (-1).

The restriction of contracted labour discounts the value of US$4.50 from the target function for each workday that is contracted. But each workday that is contracted is also added to the total labour.

In the lower portion of the matrix, we find the upper and lower limits for the activities. For the case being analysed, it is supposed that the maximum quantity of workdays to be sold is 300 and the maximum quantity to be contracted is 500 workdays.

3.8.4 Annual model with semi-annual crops

When it is desired to build a model where the period of analysis is one year and there are semi-annual crops we recommend dividing each of the constraints into six-month periods. Thus the constraints could be:

Constraint	Bean 1	Bean 2	Maize 1	Tomato 2	Cassava	Pastures		Hectares
Land 1	1		1		1	1	≤	8.5
Land 2		1		1	1	1	≤	8.5

3.8.5 Annual Model with Permanent Crops

In order to analyse different temporal situations with permanent crops such as fruit trees, we must give information to the model about the different stages of cultivation in a year. The concept to be applied is similar to that of the present value used in financial analyses. Three activities should be created for each crop:

- **Planting (first year)**

This is an activity that has a coefficient of 1 in the land constraint (for both the first and second six-month periods). In "workdays" and "capital" put in the necessary values for the first year of cultivation. The target function will be negative given that in the first year there will be no harvest which means there are no earnings, only costs.

- **Establishment**

This is an activity that permits quantifying the work done on the crop during its establishment. It should have a value of 1 in land and the values for capital and labour are the same as those used during one year of establishment. The target function will also be negative since it contemplates only costs and zero production.

- **Harvest**

In this activity the costs in capital and labour are quantified for the year during which the crop is in production. This activity will supply to the target function a value corresponding to the sales less the harvesting costs.

To represent this reality in the mathematical model, the model is asked to consider, for each hectare that is harvested, the planting and establishment activities. For this, it is necessary to create two constraints:

a. *Planting constraint*: an equality must be formulated which forces the model to include the cost of planting, distributed throughout the production period as a percentage of one year of costs. To do this, the fraction corresponding to planting is calculated in the production period. For example, if the crop has a duration of 10 years in production as in the case of citrus crops, the fraction to be included in the equation is equal to one year, which is the period of planting divided in 10 years (1/10). This value is used in the equation with the value of -0.1 in the constraint under the harvest of citrus crops and the coefficient of 1 under the activity of citrus planting.

b. *Establishment constraint*: This is calculated in the same manner as the planting constraint, but the coefficient is: establishment time / production time. For the case of citrus crops, we have 4 years of establishment / 10 years of production (4/10). This value is located under the citrus harvest with a value of -0.4 and the under establishment activity with a value of 1 in an equality to zero.

The structure of the model is:

	Harvest	**Planting**	**Establishment**		**Available**
Land	1	1	1	<=	10
Plant. Constr.	-0.1	1		<=	0
Estab. Constr.	-0.4		1	<=	0
Objective funct.	260.300	-175.500	-153.200		

The preceding examples are just a few of the possible alternatives in the formulation of constraints.

Exercise 3.1 Building an Optimisation Model for Ex-ante Evaluation of Alternative Technologies

Objective

This exercise is designed so that the participants acquire skills in using the Excel electronic spreadsheet to build a linear programming model.

Trainer Orientation

1. Depending on the number of computers available and the number of participants, divide them into groups of two to four people and locate each group at a computer with the Excel programme.

2. Hand out the worksheet that defines the parameters of the model that they are to build.

3. Ask the participants to build the information entry matrix based on the recommendations in Section 3, number 3.5.

4. Ask the group members to modify the coefficients used in the constraints of the model and then to observe the variations between the solutions presented by the model.

5. According to the time available for the exercise, propose that the participants incorporate more constraints. For this, we suggest that you use the information presented in Section 3, number 3.8.

6. The groups should share their results. For this, if a videobeam is available, allow two or three groups to present their results. If this equipment is not available, the groups should swap members to share the results. Make sure that each group selects a spokesperson to explain to the new partners the model that has been built, the constraints proposed and the solutions obtained.

Necessary resources

- Worksheet for each participant.

- Computers with the Excel programme installed. The number will depend on the number of participants in the event and the logistics of the site. Make sure there is a computer for every two or three people. For the software, any version of Excel will work, as long as the macro SOLVER is activated in the Tools menu. Remember that SOLVER is an automatic macro and may not always be activated.
- In Section 3, we explain the procedure for loading this macro where it is not available.
- Videobeam
- Flipchart and paper
- Marker pens

Suggested time: 90 minutes for the matrix construction exercise. The time may extend to up to three hours if all of the constraints proposed in Section 3 are attempted.

Exercise 3.1 Building an Optimisation Model for Ex-ante Evaluation of Alternative Technologies

Instructions for Participants

1. Form groups as indicated by the trainer.

2. Using the worksheets as a basis, elaborate a simulation model by means of the linear programming technique. For this follow the steps proposed for building a linear programming model explained in Section 3, number 3.5

3. Evaluate the solutions suggested by SOLVER for the model, for each of the scenarios given by the constraints proposed in the worksheet.

4. Make a list of the operational difficulties encountered in the construction of this model.

5. Share your model, results, and the difficulties encountered, according to the trainer's instructions.

Total time: Basic exercise 1 hour, and plenary 30 minutes.

Exercise 3.1 Building an Optimisation Model for Ex-ante Evaluation of Alternative Technologies Procedure

1. For the elaboration of the linear programming model, we propose taking the data from the example developed in Section 3. The basic information used in the example is as follows.

Let us consider a group of farms that share the following characteristics: area of 10 hectares (appropriate for planting maize and beans). 585 workdays/six-month period as available labour, and a capital of US$2,000/six-month period. The requirements for planting maize are 55 workdays and US$230 of capital per hectare, and for beans 124 workdays and US$330 per hectare. The net earnings per hectare of maize (Target function) are US$85 and US$176 for beans. According to the regional marketing characteristics, there is an elevated risk of depressing the price of beans if these farms plant more than 4 hectares in this crop.

2. Once the model has been built and solved using the Excel electronic spreadsheet, it is suggested that the structure of the model be modified and/or extended in the following scenarios:

2.1. The possibility exists of obtaining credit that would double the capital from US$2,000 to US$4,000/six-month period. Make the necessary modifications in the model and solve it. In the same manner, do a sensitivity analysis with several capital values that the group may consider pertinent.

2.2 Through the introduction of an alternative technology in maize, the target function can be increased by 30% (the target function would be a value of US$110.50/six-month period), costs reduced by US$30 and labour to 40 workdays. Make the necessary modifications in the model and evaluate the impact of the proposal of improved maize in regard to the three changes proposed in the system. In the same manner, the group may propose changes in the system with alternatives for improved bean cultivation. Suggestion: create an activity called **Improved Maize**.

2.3 The erosion caused by planting maize is 20 tonnes per hectare of soil per six-month period and the loss of soil in bean cultivation is 10 tonnes/six-month period. If we want the total losses in soil to be less than 80 tonnes/six-month period, how should the planting of the farm be organised?

2.4 The farms can contract or sell workdays; the price for selling each workday is US$2 and the price for buying is US$2.50. Based on this information, elaborate the labour constraint and solve the model. Identify and apply other values for buying and selling workdays. Do a sensitivity analysis in this regard.

2.5 The precipitation in the area where these farms are located and the water requirements for the crops are presented in Tables 1 and 2. Using this information, elaborate constraints for the available water in each of the months and solve the model.

Table 1. Precipitation and water requirement data per hectare for cultivating maize during the first six months of the year.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July
Precipitation (mm of water)	65	129	200	245	300	268	200
Requirements (mm of water)	0	24.6	42.1	75.6	84.1	91.9	82.4

Table 2. Precipitation and water requirement data per hectare for cultivating beans during the first six months of the year.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July
Precipitation (mm of water)	65	129	200	245	300	268	200
Requirements (mm of water)	0	0	28	70.6	83.6	68.1	0

Exercise 3.1 Building an Optimisation Model for Ex-ante Evaluation of Alternative Technologies

Feedback

Number 1

Activities					Totals
Constraints	Maize	Bean	Inequality	Available	
Target function	85	176		10	
Land	1	1	<=	2000	
Capital	230	330	<=	585	
Labour	55	124	<=		
Maximum	10	4			
Minimum		0			
Quantity	5.29893925	2.36740598			7.66634523
					Totals
Target function	450.409836	416.663452			867.073288
Land	5.29893925	2.36740598			7.66634523
Capital	1218.75603	781.243873			2000
Labour	291.441659	293.558341			585

Number 2 Evaluation of improved technology in maize

2.1 Analysis of sensitivity to capital

Activity	US$1000	US$2000	US$3000	US$4000
Maize (ha)	0	5.298	9.492	9.492
Bean (ha)	3.03	2.367	0.5072	0.5073
Unused (ha)	6.97	2.335	0.0008	0.0007

2.1 Sensitivity to maize technologies

To be able to introduce the improved technology in the model, create a new activity that represents the changes of the alternative technology.

The model for the alternative that increases yield in 30% is formed in the following way:

Activities						Totals
Constraints	**Maize**	**Improved maize**	**Bean**	**Inequality**	**Available**	
Target function	85	110.5	176		10	
Land	1	1	1	<=	2000	
Capital	230	230	330	<=	585	
Labour	55	55	124	<=		
Maximum	10	10	4			
Minimum						
Quantity	0	5.29893925	2.36740598			7.66634523
						Totals
Target function	0	585.532787	416.663454			1002.19624
Land	0	585.532787	2.36740598			7.66634523
Capital	0	5.29893925		781.243973		2000
Labour	0	291.441659		293.558341		585

Outputs from the model for the different sensitivities are:

Sensitivity	Maize (ha)	Improved maize (ha)	Beans (ha)	Net earnings (US$)
Production increase of 30%	0	5.2989	2.3674	1002.2
Cost reduction of US$30	0	8.2631	1.052	887.63
Reduction of workdays to 40	0	3.5869	3.5607	931.56

Structure of the model incorporating the constraint for buying and selling workdays (WD) is:

Constraints	Maize	Bean	WD sold	WD bought	Tranf1	Tranf2	Inequal.	Available	Total
Target function	85	176	2	-2.5					
Land	1	1					<=	10	
Capital	230	330					<=	2000	
Family labour			1		1		<=	585	
Contracted labour				-1	1		=	0	
Total labour	55	124	1	-1	-1	-1	<=	0	
Maximum	10	4	100	300					
Minimum		0							
Quantity	8.48	0.1495	100	0	0	0			8.63
									Total
Target function	721	26.307	200	0	0	0			947
Land	8.48	0.1495	0	0	0	0		10	8.63
Capital	1951	49.325	0	0	0	0		2000	2000
Family labour	0	0	100	0	0	0		585	585
Contracted labour	0	0	0	0	0	0		0	0
Total labour	466	18.534	100	0	0	0		585	585
Total labour	0	0	0	0	0	0		585	0

2.1 Incorporating erosion

The erosion constraint leads to a recommendation to increase in the planting of beans.

Activities					Totals
Constraints	**Maize**	**Bean**	**Inequality**	**Available**	
Target function	85	176		10	
Land	1	1	<=	2000	
Capital	230	330	<=	585	
Labour	55	124	<=		
Erosion	20	10	<=	80	
Maximum	10	4			
Minimum					
Quantity	2.11	3.7824			5.891
					Totals
Target function	179	665.7			844.9
Land	2.11	3.7824		10	5.891
Capital	485	1248.2		2000	2000
Labour	116	469.02		585	585
Erosion	42.2	37.824		80	80

2.1 Workday constraints

Structure of the model incorporating the constraint for buying and selling workdays (WD).

Constraints	Maize	Bean	WD sold	WD bought	Tranf1	Tranf2	Inequal.	Available	Total
Target function	85	176	2	-2.5					
Land	1	1					<=	10	
Capital	230	330					<=	2000	
Family labour			1		1		<=	585	
Contracted labour				-1	1		=	0	
Total labour	55	124	1	-1	-1	-1	<=	0	
Maximum	10	4	100	300					
Minimum		0							
Quantity	8.48	0.1495	100	0	0	0			8.63
									Total
Target function	721	26.307	200	0	0	0			947
Land	8.48	0.1495	0	0	0	0		10	8.63
Capital	1951	49.325	0	0	0	0		2000	2000
Family labour	0	0	100	0	0	0		585	585
Contracted labour	0	0	0	0	0	0		0	0
Total labour	466	18.534	100	0	0	0		585	585
Total labour	0	0	0	0	0	0		585	0

2.1 Water balances

Structure of the model for analysing the water balances that guarantee the greatest productivity as follows:

	Activities					Totals
Constraints	**Maize**	**Bean**	**Rain**	**Inequality**	**Available**	
Target function	85	176			10	
Land	1	1		<=	2000	
Capital	230	330		<=	585	
Labour	55	124		<=	0	
Water January	0	0	-65	<=	0	
Water February	24.6	0	-129	<=	0	
Water March	42.1	28	-200	<=	0	
Water April	75.6	70.6	-245	<=	0	
Water May	84.1	83.6	-300	<=	0	
Water June	91.9	68.1	-266	<=	0	
Water July	82.4	0	-200	<=	0	
Useful rainwater	-1	-1	1	<=	0	
Maximum	10	4	1			
Minimum						
Quantity	0	3.4703	1			3.470255
						Totals
Target function	0	610.76	0	<=	10	610.7649
Land	0	3.4703	0	<=	2000	3.470255
Capital	0	1145.2	0	<=	585	1145.184
Labour	0	430.31	0	<=	0	430.3116
Water January	0	0	-65	<=	0	-65
Water February	0	0	-129	<=	0	-129
Water March	0	97.167	-200	<=	0	-102.8329
Water April	0	245	-245	<=	0	3.29E-11
Water May	0	290.11	-300	<=	0	-9.886686
Water June	0	236.32	-268	<=	0	-31.67564
Water July	0	0	-200	<=	0	-200
Useful rainwater	0	-3.4703	1	<=	0	-2.470255

LINGO

This section explains how to model with LINGO (a programme developed by LINDO Systems INC) instead of MS EXCEL. LINGO is easier to use than EXCEL and permits developing more complicated models. The following example of modelling is made with LINGO version 5 that runs in the Windows environment. A limited version of LINGO 5 can be downloaded free from the Internet site www.lindo.com or can be ordered from Systems INC, 1415 North Dayton Street, Chicago, IL 60622 USA. The limited version has a licence that lasts for six weeks. The book explaining the programme can be ordered from the same Internet site.

Using LINGO

Installation of the LINGO programme is done automatically by running the LINGO5.exe programme. After installing this file, the programme is run from the start menu of Windows. A page will open for Lingo.

The models are not written in a spreadsheet as in Excel. They are written in algebraic form. We use the same data as in the exercise with Excel: The model of a small farm is written as follows:

```
Max = 85 * Maize +  176 * Bean;
!land limitation;
Maize + bean <= 10;
!labour limitation;
55 * Maize + 124 * bean <= 400;
!capital limitation;
230 * Maize + 330 * bean <= 2000;
!market limitation;
bean <= 4;
```

First, we write the target function and later, the limitations of the production factors (land, labour, capital) and the market limitation. The comment lines begin with an exclamation mark "!".

When the equations of the model are ready, execute *solver*. A compiler checks the validity of the model. If there is an error, the programme will indicate in which line and space of the line the error is located. The user should return to the editor in order to make the changes until the model is correct.

Results

The first lines of the results give the model statistics. This statistical information is of little interest when the model is small. In order to select a more interesting page it is better to select the command SOLU. The following lines will appear:

VARIABLE	VALUE	REDUCED COST
MAIZE	7.27	0.00
BEAN	0.00	15.63636

ROW	SLACK OR SURPLUS	DUAL PRICE
1	618.1818	1.00
2	2.727273	0.00
3	0.00	1.545455
4	327.2727	0.00
5	4	0.00

"VARIABLE " Gives the list of model variables
"VALUE" Gives the optimal value for each variable.
"REDUCED COST": Gives the reduced cost of a variable; there are two explanations for this:

First, the reduced cost of a variable is the value of the lost earnings if the farmer desires to use a hectare in a production that is not profitable.

Second, the reduced cost can be interpreted as the necessary increase in the net earnings per hectare of a variable so that is profitable (and appears in the optimal solution). This increase can be obtained through a reduced cost, a better price, or better productivity.

In the example of the model it is estimated that the farm should produce 7.27 hectares of maize and no beans to maximise that earnings under the given limitations. If the farmer wishes to produce one hectare of beans, he will lose Lps (Honduran Lempiras) 15.63 in total earnings. Or if the net earnings of one hectare of beans can be increased more than Lps. 15.63, then the beans will be profitable (and appear in the solution).

In the box of the rows ("ROW"):
"SLACK OR SURPLUS" of the first line shows the value of the net earnings for the whole farm. In the example the net earnings are Lps. 618.18.

"DUAL PRICE" on line 1 is not of any interest in this exercise. The following lines (2 to 4) show the "SLACK" or "SURPLUS" of the 4 limitations. In these cases, this shows if the available quantities had been completely used or not.

In the example, there are:

A SURPLUS of 2.72 hectares of land (line 2)
No SURPLUS labour (line 3)
A SURPLUS of Lps.237.27 of capital (line 4)
A SURPLUS in the market limitation (line 5).

"DUAL PRICE" of a limitation is the shadow price of a limitation and has two explanations:

1. It is the increase in total earnings that will result from the addition of a production unit or factor.

2. It also is the real price of a rare factor. If the farmer rents one unit of the limiting factor at a higher price than the "DUAL PRICE", he will lose money. If the rent for this unit is set at a price lower than the "REDUCED COST", the farmer will earn money.

In the example there is only one shadow price of Lps.1.54 for labour. If the personnel of the farm can work one day more the earnings will increase in Lps.1.54. It is also the real price of one day of labour. Only if the farmer obtains a workday at less than Lps.1.54 will he spend more money.

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Originals for Transparencies

STRUCTURE OF THE SECTION

LINEAR PROGRAMMING AS A TOOL FOR MODEL BUILDING

What is it?

How is it built?

- ✓ Present the concepts and structure of simulation models based on linear programming
- ✓ Acquire skills for model building using Excel spreadsheets
- ✓ Recognise the applications of using simulation models for decision-making in natural resource management in hillside zones

Concept and structure of the model

Example of model building

Building the model

1. Build the input matrix
2. Build the output matrix
3. Determine the constraints
4. Inform the structure
5. Solve the programme
6. Analyse the outputs

OBJECTIVES OF THE SECTION

- ✓ Present the concepts and the structure of simulation models based on linear programming.
- ✓ Acquire the skills for model building using the Excel spreadsheet.
- ✓ Recognise the applications of simulation models for decision-making in the management of natural resources on hillsides.

ORIENTING QUESTIONS

1 What is lineal programming?

2 What are the elements of a model?

3 How is a model built using lineal programming?

STAGES FOR USING MODELS

- √ Analysis and formulation of the problem
- √ Structuring the Mathematical Model
- √ Resolving the Model (solution)
- √ Validation of the Model and the solution
- √ Implementation of teh solution

Consider a Group of Farms that share the Following Characteristics

Available

10 ha of surface area appropriate for maize and beans
Available labour: 585 WD/6-months
Capital: US$ 2000/6-months

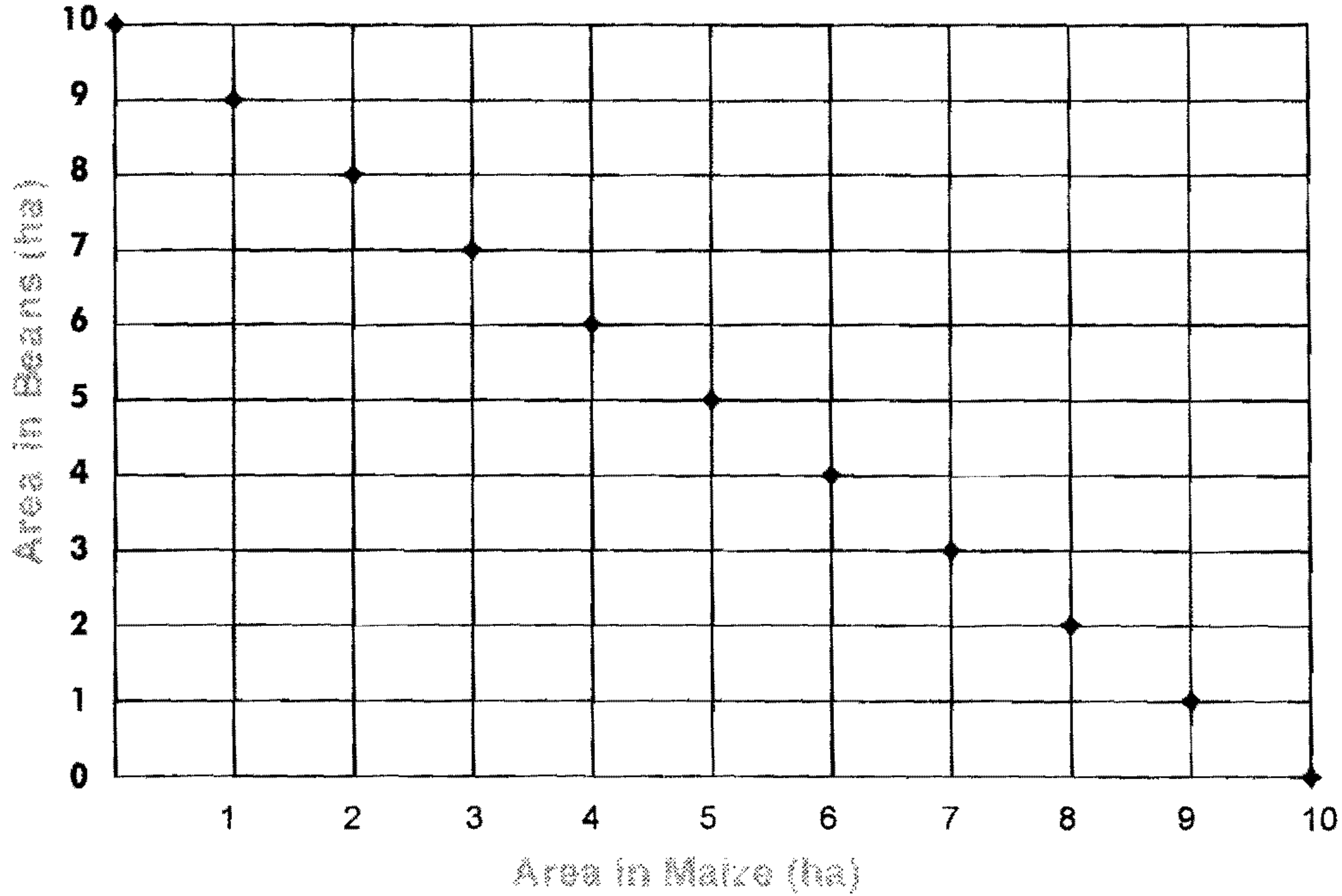
Requirements

Planting one hectare of maize	Planting one hectare of beans
Workdays = 55	Workdays = 124
Capital = US$ 230	Capital = US$ 330

Net income is:

US$ 85 per ha of maize and US$ 176 for beans
Marketing constraint of 4 ha maximum in beans

LINEAL PROGRAMMING MATRIX



STRUCTURE OF THE MODEL

Objective Function
Activities
Constraints

Objective Function

$F(x) = 116.7 * X1 + 314.5 * X2 + 104.2 * X3$
$F(x)$ = Gross margin of the farm US$
$X1$ = Area planted in maize (hectares)
$X2$ = Area planted in coffee (hectares)
$X3$ = Area planted in beans (hectares)

Constants are per hectare earnings for each crop US$/ha

SET OF FEASIBLE OPTIONS

Plan	Maize (ha)	Beans (ha)	Net earnings
A	0	4	US$ 704
B	1.6	4	US$ 840
C	5.2	2.4	US$ 864.4
D	8.7	0	US$ 739.5

CONTRAINTS:
IMPOSED LIMITATIONS

Land	X1 + X2 +X3 <=10ha
Autoconsumption	X1 > = 1 ha
Labour	mX1 +iX2 + oX3.. <=400 WD
Erosion	aX1 + bX2 +cX3 +.. <=60 ton/ha
Water Requirement	aX1 + bX2 = 0
Capital	aX1 + bX2 +cX3 +... <=200 US$ha
Market	aX1 + .. <=5 ha

SENSITIVITY ANALYSIS

- Prices
- Land
- Management Practices
- Technological Alternatives
- Climatic Factors
- Capital
- Market

STRUCTURE OF THE LINEAL PROGRAMMING MODEL

	A	B	C	D	E	F
1	A	B	C	D	E	F
2						
3	Constraints	Maize	Beans	Inequality	Available	Totals
4	Object. Function	85	176			
5	Land	1	1	< =	10	
6	Capital	230	330	< =	2000	
7	Labour	55	124	< =	585	
8						
9	Maximum	10	4			
10	Minimum	0	0			
11						
12	Quantity					
13						
14						
15	Object. Function	+ B4xB$ 12	+ C4xC$ 12			SUM= + (b15:C15)
16	Land	+ B5xB$ 12	+ C5xC$ 12		10	SUM= + (B16:C16)
17	Capital	+ B6xB$ 12	+ C6xC$ 12		2000	SUM= + (B17:C17)
18	Labour	+ B7xB$ 12	+ C7xC$ 12		585	SUM= + (B18:C18)
19						
20						

Constraints

Objective Function:
Maximise net income

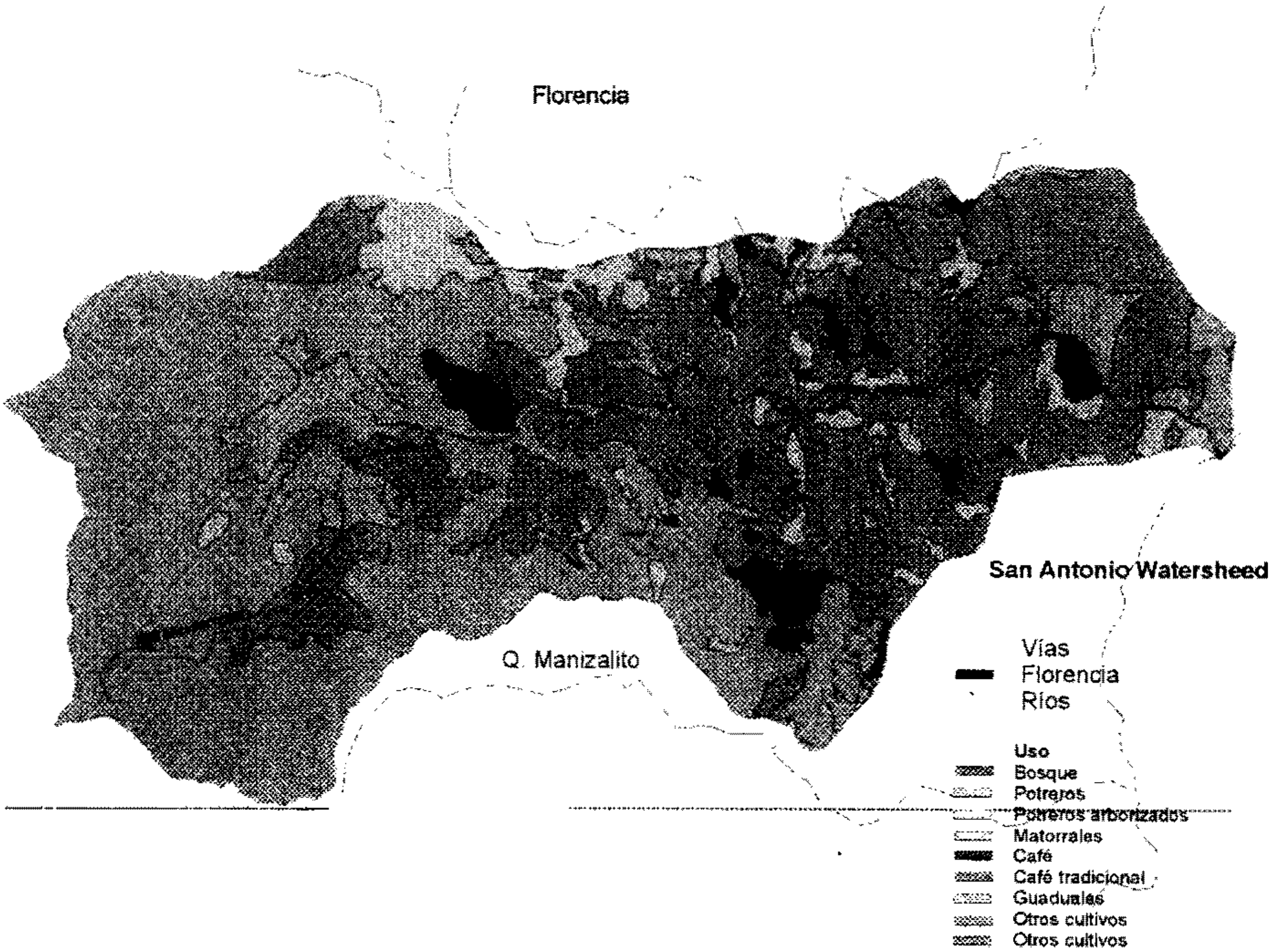
Activities

Lineal Programming Model

Constraint	Activity		Inequality	Available
	Maize	Beans		
Objective Function	85	176	<=	
Land	1	1	<=	10
Labour	55	124	<=	2000
Capital	230	330	<=	585

Section 4

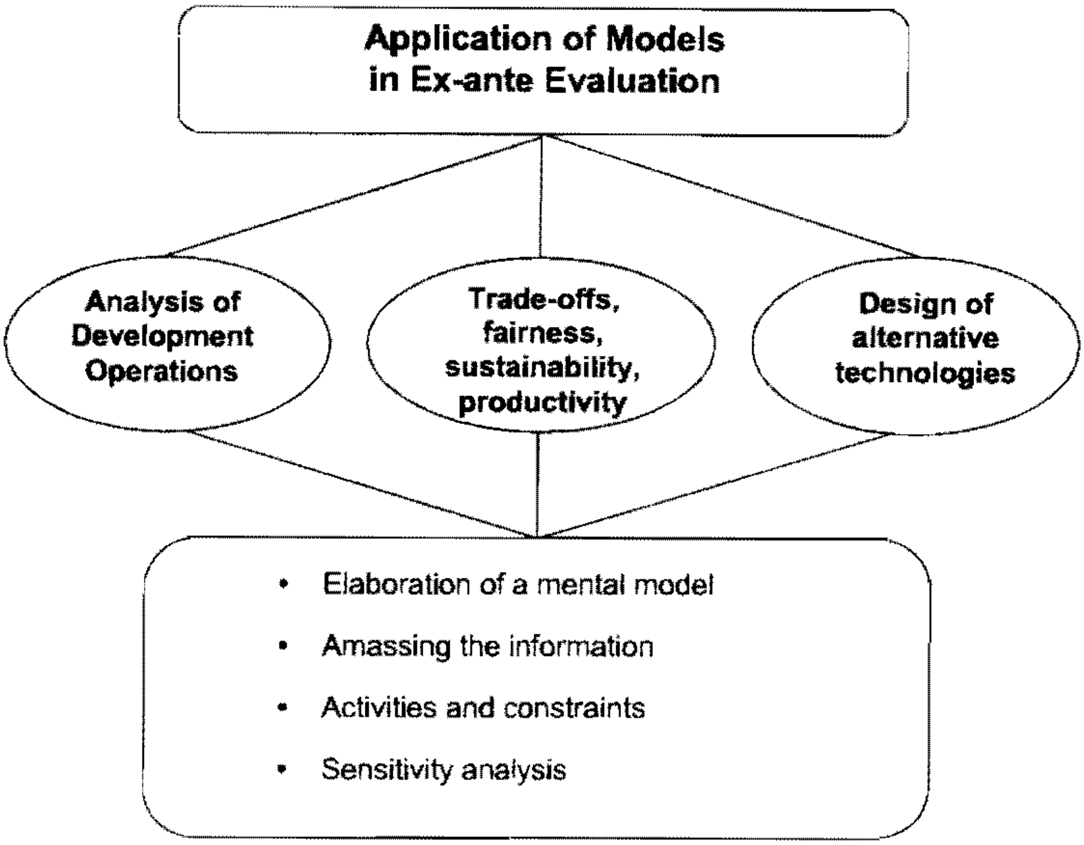
Applications of Linear Programming Models in Ex-Ante Evaluation



Section 4. Applications of Linear Programming Models in Ex-ante Evaluation

Page

Structure of the Section



In this section, we present three applications of simulation models for ex-ante evaluation, in three areas of interest for natural resource management (NRM):

- The identification of the trade-offs between political criteria in the San Antonio River watershed
- The ex-ante quantification of the trade-offs between fairness, sustainability and
- Productivity for the design of technological alternatives in the cultivation of arracacha.

For each of these applications, we used a methodology incorporating the following phases: elaboration of a mental model, collecting the information, definition of activities and constraints, and sensitivity analysis.

The structure of the section is based on the documentation of each of the methodological phases carried out in the three Colombian watersheds by teams of researchers from different institutions. For this reason, we set out the cases in detailed form, beginning with the conceptualisation and extending to the ex-ante analysis, going through the steps of building three different models that facilitate decision-making for natural resource management in hillside zones. Finally, we propose an exercise in which participants carry out an analysis of the information resulting from linear programming models in production systems typical of hillside zones.

Objectives

After completing this portion of the training, the participants will be able to:

- ✓ Describe the methodological steps in the application of simulation models in decision-making for the management of natural resources.
- ✓ Explain how simulation models are used for the analysis of development options in a watershed.
- ✓ Explain how simulation models are used to calculate the trade-offs between political criteria: sustainability, fairness and productivity.
- ✓ Clarify how to apply models for the quantification of trade-offs between fairness, productivity and sustainability in designing alternative technologies.

Orientation Questions

1. What are the methodological phases for applying a simulation model in decision-making for natural resource management?

2. What are some relevant characteristics in the use of simulation models for the analysis of development options in a watershed?

3. What are the relevant characteristics in the use of simulation models for identifying the trade-offs between the criteria of sustainability, productivity and fairness in a watershed?

4. What are the relevant characteristics in the use of simulation models for ex-ante quantification of the trade-offs between fairness, productivity and sustainability in designing alternative technologies?

Introduction

Decision-making about priorities in land use at the level of the parcel, watershed, microregion, region or country is a complicated process. This is due to the conflicts between the criteria of competitiveness of the agricultural activity, the sustainability of agroecosystems and the distribution of the benefits of agricultural development. Using linear programming models to understand the trade-offs between these criteria can help researchers and development agents to make decisions about assigning priorities. The model defines the target function favoured by the system being analysed and optimises it according to several constraints. These include resource availability, economic, environmental or social objectives that the model hopes to reach or that the political framework demands.

In general terms, the application of linear programming models implies a methodological procedure that includes the following phases:

a. Elaboration of a mental model. This constitutes the starting point that determines the usefulness of the mathematical model and is specific for each particular case. These models are built in order to respond to concrete questions under specific conditions. The mental model maintains a relationship to the kind of questions the operator is trying to answer. The structure and function of the model are oriented precisely to respond to such questions.

b. Collecting the information. The team of researchers or development agents should make a decision about the availability of information for feeding the model so that it can respond to the questions presented by the mental model. There is a wide range of specific conditions in which information from secondary sources may be available or lacking. Those who build the model should evaluate the quality of information available and the need to obtain the missing information from primary sources.

c. Activities and constraints. With the collected information we define the constraints that the system is faced with and the alternative activities that can be developed.

d. Sensitivity analysis. One of the main strengths of linear programming models is their capacity to respond in an immediate manner to any changes in parameters. Through these changes in activities and/or constraints, an unlimited number of potential scenarios can be considered, many of which would be impossible to carry out in practice or whose high cost could not be met. The scenario is not necessarily a prediction of what will happen, it merely permits a better understanding of what might happen if certain conditions are met. These potential scenarios constitute the most important information that models provide in decision-making.

In this section three case studies are documented in which an ex-ante analysis was carried out using linear programming models that respond to different questions presented by researchers and development agents.

- Analysis of development options in the Doña Juan River watershed (Ríos et al., 1998).
- Trade-offs between political criteria in the San Antonio River watershed (Rivera & Estrada, 1998).
- Ex-ante quantification of the trade-offs between fairness, productivity and sustainability for designing alternative technologies in the cultivation of arracacha (Rivera & Estrada, 1995)

4.1 Analysis of Development Options in the Doña Juana River Watershed

4.1.1 Elaborating a mental model

The upper zone of the Doña Juana River watershed has 4,050 ha and a population of 878 people. There are 169 parcels of land, located between 1250 and 1750 m, dedicated to dual-purpose cattle raising, coffee, cocoa and garden crops. The watershed exhibits the problems involving natural resources: water, soil, and biodiversity that have been experienced in extensive regions of Colombia since the 1950's, where cattle ranching has been continuously extended. This process includes deforestation and establishment of pastureland by the colonists, their displacement by the landowners to the upper portions of the watershed, where the water is produced and regulated. This process is exacerbated by the combination of low prices for products such as coffee and cocoa, the increasing costs of transportation due to the lack of roads, and the presence of plant sanitary problems, especially in coffee and cocoa.

Water has several basic functions for agricultural production, but also influences the processes of formation and erosion of soils. At the same time, the availability of this resource in the lower portions of the watershed for use in aqueducts or irrigation projects depends not only on climatic conditions (precipitation and humidity) but also on consumption by the vegetation and the retention capacity of the soil. The mental model indicates that potential competition exists for water between the different agricultural production activities in the watershed, the needs of the aqueduct in the village of La Victoria and possibly the needs of the aqueduct in La Dorada. Additionally, the mental model sets forth the existence of competition between the present land use practices (with their erosive processes) and the costs of sediment removal that affect the aqueducts involved.

The linear programming model was constructed by maximising the net earnings of the producers located in the watershed, based on the different production scenarios and the conservation of natural resources, in order to anwser the following questions:

- What is the impact of maintaining the present production systems?
- What improvement is feasible in the soil use, by placing value on the water and sediments in the watershed?
- What are the technological changes possible in the production systems?

4.1.2 Amassing the information

The information about the size of the parcels, the area under cultivation, the use of labour, use of raw materials, productivity, and production techniques was obtained from secondary sources. A principal source was the social and economic characterisation of production systems carried out by CRECED - CORPOICA in the Middle Magdalena (Department of Caldas; Abad, 1996; Loaiza, 1996; Muñoz & Ibarra, 1997). The information about agricultural production costs was provided by the Municipal Unit of Technical Agricultural Assistance (UMATA) of the municipality of Victoria, Caldas. The information about cover and present use of land came from Quiroga (1994) and the environmental and hydrological studies of the watershed from Giraldo et al. (1993) and Guzmán (1993).

With the information on soil and climate, soil losses were determined for the different crops in the watershed, using one of the subroutines of the EPIC model (Wischmeier & Smith, 1978).

Water consumption in the different crops present in the watershed was calculated using the CROPWAT model, prepared by the FAO (Smith, 1993) based on information on precipitation, temperature, relative humidity, wind velocity and radiation, taken from the Santa Helena station (Cenicafé, 1996) close to the study zone.

4.1.3 Activities and constraints

The information generated was integrated into a linear programming model that optimises the net earnings as the target function sales less variable cash costs of the products of the watershed. In addition to the net earnings (criterion of competitiveness), we also incorporated a sustainability criterion into model. For this we used the scenario under which substantial changes occur in the present use of the soil in order to occasion a smaller loss and to provide more flow to the watercourse. We also analysed the implications of changes in soil use on employment generation as a criterion of fairness.

Information about size of the area, use of labour and available capital determined in the characterisation was used as constraints in the model (Table 4.1). The labour constraint was determined by the current availability, but the model has the option of using or selling the workdays of the family. The capital constraint was determined by the present use, but the model allow us to include decisions about farmers' investments, with which the target function is affected in a negative manner by the cost of capital (10% interest in real rates). The maximum area utilised is 4,050 ha, the annual availability of family workdays is 150,127 and the capital is $84,322,000 (Colombian pesos). The maximum number of workdays it is possible to contract is 30,000.

An additional restriction used was the availability of water. Based on total precipitation (4,235 mm/year) and its distribution throughout the year, it was determined that the availability in the watershed for each of the three-month periods was 14,090, 12,830, 5,770 and 8,660 m^3/ha, respectively.

Table 4.1 Use of soil, labour and capital costs (not including investment) in the upper zone of the Doña Juana River watershed.

Crop	Land (ha)	Labour (workdays)	Capital ($ x 1000)
Coffee	117	13.742	19.820
Grasses	2762	33.145	11.048
Cattle *		10.248	24.602
Cocoa	167	15.017	0
Annual crops	166	15.609	3.321
Pastures	838	8.803	0
TOTAL	**4050**	**96.600**	**58.791**

* Equivalent to 2017 cows, with a animal capacity of 0.7 head/ha

Table 4.2 presents the information used to characterise each of the activities that were offered to the model, in terms of requirements (capital, workdays and water), sediment generation and production.

Table 4.2 Information about Requirements and Production in Different Activities of Land use in the Upper Zone of the Doña Juana River Watershed.

	Units	Coffee	Grass	*Cattle	Cocoa	Annual	Pastures
Raw material + Depreciation	$1000/ha	225.9	10.0	16.2	50.0	20.0	0.0
Cash costs	$1000/ha	168.8	5.0	12.2	0.0	20.0	0.0
Capital	$1000/ha	200.0	30.0	360.0	250.0	0.0	0.0
Workdays	No./ha	117	12	5	90	94	10
Water consumption	m^3/ha	1.008	1.008		756	760	1.008
Sediments	T/ha	8.8	2.2	0.8	5.9	10.0	1.2
Production	kg/ha	800		*109	400	4120	*3
Value	**$/kg**	**1587**		**1250**	**412**	**1800**	***27000**

* The information for cattle is not given per ha, rather per head.
In addition to meat production, the cows produce 313 l of milk per head with a value of $400/l (Colombian pesos)
Pasture production is expressed in m^3

In the sensitivity analysis of the model, several scenarios were explored by assigning value to the water for use in aqueducts and the sediments produced. New alternative technologies were evaluated based on production systems not found in the watershed such as maize cultivation in alleys of leguminous trees and rubber cultivation. There is a general consensus among researchers and extension personnel in the region about the potential of these technologies. The information used for the feasibility analysis for planting maize in alleys was generated by Sánchez (1998) with data from experiments and test plots installed by different entities that work in the development of agricultural technology of the watershed and other localities with similar agroecological and socio-economic characteristics. For the case of rubber cultivation, information generated by the Caldas Agroindustrial Committee (1997) was used. Also, a sensitivity analysis of the model was carried out on an increase in the productivity of cocoa in the watershed.

4.1.4 The Impact of Maintaining the Present Production Systems

Even if the production levels can be considered low according to the standards from other agricultural zones, owing to topographic restrictions, climate and infrastructure, the returns for agricultural activities is sufficiently attractive due to the reduced use of external raw materials. Without considering the value of investments in land, infrastructure and cattle, the net earnings of a farm on an annual basis is $5.779.200 (Colombian pesos), which is 2.8 times the minimum wage. This means that the farm constitutes a strategy for family employment that affords sufficient income for the maintenance of the family, even generating some excess for stock capitalisation. However, the present production systems do not resolve the phenomenon of unemployment and are fragile when faced with an eventual increment in productivity that might result in the reduction of the prices of products.

The results of the linear programming model indicate that land use is adjusted to the socio-economic and agroecological conditions of the region. The possible increase in the target function between the real situation and the optimal is only 5% (Table 4.3). The optimal model increases the areas in grasses and cassava to a greater proportion than the present situation. However, the present tendency is in fact reflected in the optimal model in the sense that large areas in coffee, cocoa and plantain are being converted to pastures. It can be argued that the model is confirming the economic rationality of the peasant by proposing as the principal change the substitution of grassland for coffee, cocoa and plantain in order to optimise the present use.

The present land use utilises only 59% of the labour available in the watershed. The optimal model reduces the use of labour to 60.489 workdays, which signifies that there are few options for land use with high productivity (Table 4.3). Cocoa, an activity that generates the highest use of workdays for unit area, has been going through a period of low prices for several years, added to a reduced production caused, in part, by phytosanitary problems.

Coffee, a crop that also makes extensive use of labour, has agroclimatic restrictions given the location between 750 and 1250 m, which makes this crop marginal because of the high levels of the coffee bean borer. The problem of unemployment in the watershed constitutes one of the principal socio-economic restrictions faced by the region as it is a medium for generating problems of violence and peasant migration toward the areas producing illegal crops.

The production of water remains practically constant between the present situation and optimal solution from the model analysis. In the same manner, the production of sediments has an insignificant increment from 3.2 to 3.4 Tm/ha per year).

In the watershed, the low productivity of the labour can be identified as the most worrying element for the development of sustainable systems. All of the probable scenarios with the present use of land point more toward situations of unemployment and poverty than toward conflicts over the deterioration of natural resources. The estimated losses of soil reach an average of 3.2 Tm/ha per year, a level considered medium and not as high as expected. This is because most of the cultivation systems do not require disturbing the soil, the areas cleared and cut for planting maize are small, indices of cover for the most important crops are high, and rains are adequately distributed throughout the year. The most attractive option economically and environmentally would appear to be an increase in cattle ranching in the watershed. However, the capacity for generating employment through this activity is too low to be considered a development strategy, in that it contributes to an increase in poverty, unemployment and violence.

Table 4.3 Comparison of present land use in the watershed and that predicted by the optimal model.

Activity	Present use	Optimal model
Coffee (ha)	117	0
Grass (ha)	2.762	3.728
Cocoa (ha)	167	0
Cassava (ha)	49	120
Plantain (ha)	97	0
Maize (ha)	16	0
Maize in alleys (ha)	0	0
Rubber (ha)	0	0
Fallow (ha)	838	202
Target function ($x1000 x farm)	5.864	6.172
Use of labour (No. workdays)	80.195	60.489
Water (million m^3)	153,7	153,5
Sediments (Tm/year)	13.233	14.057

4.1.5 Feasible improvement in the use of soil through appreciating the value of water and of sediments

The sensitivity of the model to assigning values between $5 and $40/m³ (Colombian pesos) to water that is produced in a marginal manner and assigning values up to $39,000/Tm for not sedimenting did not show any change in the present land use. The model only suggests a reduction in the area in grasses and its substitution by fallow as an optimal solution, when it is possible to pay $40.000 for every Tm of sediment that is not produced. However, this is too high a cost for the final consumer to pay as a retribution to the process of cleaning the water. This solution would generate even greater conflicts, given the social dimension of the production system, because of the negative impact it has on the generation of employment (Figure 4.1). In summary, the model does not identify any potential scenarios for adding value to the water resources or for assigning incentives for the reduction of sedimentation on the part of the consumers, for them to provide changes in the present use of soils. Thus, the internalisation of external considerations is not necessarily reflected in the design of more efficient systems from the point of view of agroecology.

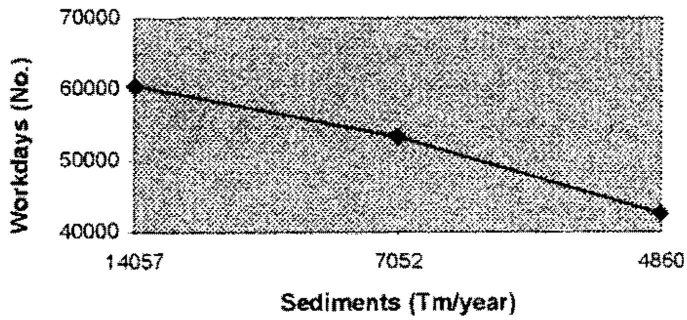


Figure 4.1 **Trade-offs between the reduction in sedimentation levels in the watershed and the reduction in the number of workdays per year.**

4.1.6 Feasible changes in the production systems

The simulation exercise for introducing maize cultivation in alleys of leguminous trees, indicates that, with the returns obtained in an experimental manner (1.400 kg/ha), it is not feasible to generate changes in the production systems of the watershed (Table 4.5). The model is only sensitive to increments in productivity superior to 114%, that is 3,000 kg/ha of maize, a goal that is practically utopian for the research programmes in the region, owing to the agroclimatic and socio-economic characteristics found there.

The simulation exercise incorporating the cultivation of rubber indicates that it is a competitive option as it increases the target function by 56% when all the labour and capital resources are dedicated to it. However, as a crop that generated 0.21 permanent jobs per ha/year (Comité Agroindustrial de Caldas, 1997) the optimal situation from the economic standpoint would have serious social restrictions given that only 46.159 workdays (31% of those available in the watershed) would be used. There would be an excess of 103.967 workdays, which would cause an aggravation of the unemployment problem.

From the acroecological point of view, cocoa cultivation has better development options than coffee although both utilise labour in an intensive manner. Cocoa appears to have a greater potential contribution to fairness, in terms of the generation of employment options in the watershed. With an increase of 30% in productivity (from 400 kg/ha per year to 520 kg/ha per year) there would be a notable effect on the land use and, more importantly, on employment generation. In this case, the model reduces the area in grasses, eliminates the area in cassava and dedicates 1.158 ha to cocoa cultivation, which provides permanent employment to all of the available labour in the watershed. This option does not have any significant effects on water production and has only minimal effects on the production of sediments, which goes from 3.2 to 4 Tm/ha (Table 4.5).

Due to its contribution to employment generation in the watershed, and for permitting higher net earnings for the producers, the best technological option for the present production systems appears to the rubber and cocoa crops, ensuring a higher productivity for the latter (at least 520 kg/ha per year). The target function is maximised at $10,490,000 (Colombian pesos), five times the minimum wage, which is an indicator of competitiveness. This provides a better consumptive use of the water and a relatively low contribution of sediments to the riverbed, indicators of agroecological sustainability.

Table 4.5 Simulation exercises for models introducing new technological options for production systems in the watershed.

Activity	Maize in alleys (1400 kg/ha)	Maize in alleys (3000 kg/ha)	Rubber	Cocoa (520 kg/ha)	Cocoa (520 kg/ha) and rubber
Coffee (ha)	0	0	0	0	0
Grass (ha)	3.728	2.738	0	2.468	0
Cocoa (ha)	0	0	0	1.158	1.308
Cassava (ha)	120	0	0	222	0
Plantain (ha)	0	0	0	0	0
Maize (ha)	0	0	0	0	0
Maize in alleys (ha)	0	1.110	0	0	0
Rubber (ha)	0	0	1.038	0	1.038
Uncultivated (ha)	202	202	3.012	202	1.704
Target function ($x1000 x farm)	6.172	6.647	9.173	9.061	10.490
Labour (no. of workdays)	60.489	66.244	46.159	150.127	150.127
Water contribution (Million m^3)	153,5	153,8	154,3	153,8	154,3
Sediments (Tm/year)	14.057	14.154	9.325	16.670	14.948

The sensitivity analysis of the model, used as a tool for ex-ante evaluation, makes the processes of research and technology transfer more efficient. The option of cultivating maize in alleys of leguminous trees, in whose development two years of research were invested, has little viability because it requires a productivity increase that is difficult to realise. The alternative of rubber presently promoted as the panacea for the watershed could worsen the unemployment situation. On the other hand, cocoa cultivation which has received little attention from institutions, appears to be a competitive, fair and sustainable option, if a 30% increase in production is obtained. The analysis indicates the viability of the model for simulating scenarios that would not be feasible to carry out in practice, and to understand the trade-offs between the criteria for conservation, employment generation and the productivity of the workers in the field.

4.2 Trade offs between Political Criteria in the San Antonio River Watershed

4.2.1 Elaborating a mental model

La Selva, in Florencia (Caldas), which lies between 1700 and 2100 m, is a zone which is especially rich in diversity of fauna and flora, and is fundamental in the regulation of water flow due to high levels of precipitation there (over 6,500 mm per year). However, an accelerated process of deforestation is placing the survival of this ecosystem in serious danger. From an original area of 11,400 ha of forest in 1963, now only 6,600 ha remain. The San Antonio River begins in this zone and is an important tributary of the La Miel River, where at present the hydroelectric complex Miel I is being built.

A total of 253 families reside in the San Antonio River watershed, holding 3,972 ha between them. According to the social, environmental and land use characteristics, four types of farms have been identified: upper, upper middle, lower middle and lower. Owing to factors adverse to production such as low luminosity, the lack of improved varieties adapted to local conditions and inefficiency in fertiliser use caused by the high precipitation levels, the producers have few opportunities for increasing their income through agricultural productivity. Additionally, owing to the high precipitation levels and the steep slopes found there, the area is considered as high risk for soil degradation. The farmers priorities for land use are determined by the need for improving returns under the prevailing restrictions, but enter into conflict with the interests of the hydroelectric facility for having abundant and clear water that improves the returns on the investment.

The mental model for the construction of the mathematical model is related to the competition for water between the agricultural productive activities and the needs of the dam. It also deals with the competition between the present land use and its impact on sediment production, and the aim of achieving a long useful life for the dam. The starting points for determining the 'shadow' prices were the agricultural productivity parameters in each zone and the value of the products in the market. It is assumed that the construction of one of the most efficient dams in the world should generate a high opportunity cost for water availability and for the reduction of sediments. The objective of the optimisation exercise was to find the point at which, through appreciating the value of water production (in two distinct periods) and of sediments, it is feasible to achieve a substantial change in the present land use.

4.2.2 Amassing the information

Information was taken from secondary sources about the villages, climate, topography, hydrology and land use. A survey was made of 25% of the farmers in the watershed and a typification exercise was carried out by means of multivariate and principal component analysis, using the correlation matrix. Water use and conservation status at the water supply points was evaluated with a survey of 70% of the resident families. Table 4.6 presents the use of resources and the total earnings for each of the four zones in the San Antonio River watershed.

The upper zone is located in La Selva and its bordering area, at an average of 1,352 m, and has the larger parcels (42 ha) and a higher proportion of forest and fallow. The most important crop for income generation is coffee, followed by forest products (charcoal, firewood and lumber). Within the context of the watershed, farms produce the highest net earnings (2.7 times the minimum wage). The upper middle portion is found at an average of 1,172 m and has farms with steeper slope (205%). The farms have 11.1 and 4.4 hectares and grow coffee from which they exclusively derive their cash earnings. The lower middle zone has the highest density of families (102) and is located at 1,047 m. Here the farms are the smallest of the whole watershed (5.7 ha) and make the most intensive use of labour (71 workdays/ha). In this zone, 55% of the farmland is dedicated to coffee and this crop provides the highest productivity. These are the farms with the lowest capital investment, the lowest income (1.6 times the minimum wage), and the greatest number of workdays sold outside of the farm. The lower zone, located at an average of 857 m, is distinguished from the rest of the watershed, principally for its dedication to cattle ranching (21.2 animal units per parcel), the higher investment that this activity demands and the diversification of earnings through the cultivation of sugar cane and the production of brown sugar loaves.

Table 4.6Resource use and earnings in four zones of the San Antonio River watershed.

	Upper	Upper middle	Lower middle	Lower
Land				
Area (ha)	1.754	967	582	669
Coffee (ha)	182	381	320	37
Grasses (ha)	191	135	53	397
Sugar cane (ha)	5	44	60	42
Garden crops (ha)	46	71	40	17
Forest/uncultivated fields (ha)	1.330	337	109	175
Labour				
Available workdays	12.904	20.385	29.100	7.453
Coffee (workdays)	10.945	22.860	31.050	3.827
Grasses (workdays)	2.977	2.112	1.158	8.262
Sugar cane (workdays)	132	2.176	5.215	3.456
Garden crops (workdays)	2.143	3.318	1.968	852
Forest/uncultivated fields (workdays)	5.318	1.346	435	701
Total (workdays)	21.517	31.812	39.826	17.098
Capital costs				
Coffee ($x1000)	17.311	35.814	31.626	3.437
Grasses ($x1000)	2.332	2.319	0	7.972
Sugar cane ($x1000)	0	0	270	0
Garden crops ($x1000)	365	0	0	0
Forest/uncultivated fields ($x1000)	0	0	0	0
Total ($x1000)	20.008	38.132	31.896	11.409
Investment capital				
Coffee ($x1000)	36.483	85.725	80.025	8.279
Grasses ($x1000)	66.520	47.359	19.713	183.257
Sugar cane ($x1000)	658	4.352	5.995	4.215
Total ($x1000)	103.661	137.435	105.732	195.751
Earnings				
Coffee ($x1000)	182.730	415.439	389.109	37.884
Milk and meat ($x1000)	31.396	22.363	12.530	109.141
Brown sugar loaves ($x1000)	1.034	11.575	41.513	28.660
Forest/uncultivated fields ($x1000)	107.692	24.229	8.163	12.094
Total ($x1000)	322.852	473.606	451.315	187.779

1 US$ = $1000 Colombian pesos

It was hoped that there would be a very intense land use in the region as a consequence of the size of the families and the limited alternatives for work outside of the agricultural area. However, 49% of the farm area was found to be forest and uncultivated pastures, reaching 76% in the largest farms located in the upper portion. The slope on the farms is very steep and under traditional quality parameters these lands would not be considered appropriate for use in agricultural production. The minimum slope seen is individual lots was 75%, reaching values over 300% on occasions. The average slope of the coffee plantations was 164% and 158% in the family garden plots. Labour use is relatively intense: a total of 110,249 workdays, that is, 28 workdays/ha or 436 workdays/farm. In addition to utilising totally the family labour resource, 218 workdays/farm are bought on average. The contracting of workdays is concentrated in the periods of harvest in general and in the trimming period for coffee.

In addition to the information about land use characteristics, water consumption was estimated for each of the crops in each of the different zones of the watershed, using the CROPWAT model of the FAO (Smith, 1993). To verify the contribution that the small watershed of the San Antonio River makes to the La Miel watershed, the rates of flow were estimated during one year at the point where the tributary flows into the larger river. These evaluations were made twice a month, measuring the velocity of the river (by using a float), and daily the surface area of water (from the elevation level).

Soil losses were estimated by using the EPIC model (Environmental Policy Integrated Climate) (Wischmeier, W.H. and Smith, D.D. 1978). In addition, five runoff parcels of 12 x 2 m were installed in maize, cassava and bean crops, and in fallow for testing the results of the EPIC model (Arroyave et al., 1998). In order to verify the total contribution of sediments during one year, daily turbidity measurements were taken from the flow at the capture point on the San Antonio River. From this turbidity, the total quantity solids in the water was estimated.

The model 'Represas', developed by CIAT-CONDESAN (Estrada, R. 1998, Com. Pers.), was used for simulating the opportunity of the sediments, expressed as present net value per tonne of sediments. This calculation was made based on the benefits that are generated for the hydroelectric project and uses the technical parameters that the construction company for the project has published (HIDROMIEL, 1997).

4.2.3 Activities and constrictions

The information was integrated into a linear programming model that optimises the net earnings (sales less variable cash costs) of the farmers in the watershed as its target function, using the most representative values for crops at harvest, although these values are generally lowest. In addition to this criterion of competitiveness, a criterion of sustainability was incorporated into the model. This was the scenario under which substantial changes occur in present land use to bring about a reduction in soil loss and a higher contribution of water to the reservoir in two different periods (maximum and minimum precipitation). The implications of changes in land use on the generation of employment were also analysed as a criterion of fairness.

The model used the constraints on area, use of labour and capital, as determined in the characterisation (Table 4.7). Owing to the fact that the garden crops are for personal consumption in the farms and, as a consequence, do not contribute to the target function, it was necessary to incorporate into the model the present areas, as a minimum. The constraints on labour were determined by the current availability, but the model had the option of using family workdays in the farm's activities or selling them for activities outside of the farm. The availability of workdays for selling was estimated at 41.274. In the same manner, the capital constraints were determined for the present use, but the model allowed for the farmer to make decisions about investment, in which case the target function was affected negatively by the cost of this capital (10% in real terms).

Table 4.7 Constraints used for the linear programming model.

Zone	Capital	Area	Labour
Upper	20.008	1.754	12.904
Upper middle	38.133	967	20.385
Lower middle	31.896	582	29.100
Lower	11.409	669	7.453
TOTAL	**101.446**	**3.972**	**69.842**

Table 4.8 presents the information used to characterise each of the activities that were offered to the model, in terms of requirements (capital, workdays, and water), production, and generation of sediments.

Table 4.8 Information about requirements and production in the different land use activities in the upper portion of the San Antonio River watershed. (monetary values in Colombian pesos)

	Unit	Zone	Coffee	Grasses	*Cattle	S. cane	Garden	Uncultivated
Raw materials + depreciation	$1000/ha	U	152	6	17	0	8	0
		UM	158	10	14	20	0	0
		LM	161	6	6	24	0	0
		L	158	10	16	20	0	0
Cash expenses	$1000/ha	U	95	0	11	0	8	0
		UM	94	4	8	0	0	0
		LM	99	0	0	4	0	0
		L	93	4	12	0	0	0
Capital	$1000/ha	U	200	30	355	0	0	0
		UM	225	30	355	100	0	0
		LM	250	30	355	100	0	0
		L	225	30	360	100	0	0
Workdays	No./ha	U	60	12	4	0	47	4
		UM	60	12	4	50	47	4
		LM	97	18	4	87	49	4
		L	104	16	4	82	49	4
Water consumption water in rainy season	m^3/ha		7.260	7.000		7.500	7.500	3.000
Water consumption in dry season	m^3/ha		2.740	3.000		2.800	2.800	1.000
Sediments	T/ha	U	34	3			108	8
		UM	47	4		27	79	5
		LM	15	2		10	49	1
		L	17	2		11	51	2
Production	kg/ha	U	632		96			3
		UM	691		96	1.000		3
		LM	765		104	2.500		3
		L	650		126	2.500		3
Value	$/kg		1.600		1.100	· 273		27.000

Zones: U= upper, UM = upper middle, LM = lower middle, L = lower

* The information about cattle is not presented per ha, but rather per head.

In addition to meat production, the cows produce 259, 259, 437 y 302 l of milk/cow, in zones U, UM, LM and L respectively, with a value of $300/lt.

The production for uncultivated land is expressed in m3.

The precipitation was 7,539, 7, 573 mm/year in the upper and upper middle zones, and 6,918 mm/year in the lower middle and lower zones, constraining the use of the model, in accordance with its distribution (Table 4.9)

Table 4.9 Constraints due to water availability (m^3/ha) in 4 zones of the San Antonio River watershed.

Precipitation period	Upper	Upper middle	Lower middle	Lower
Maximum (rainy season)	55.690	56.790	53.000	53.000
Minimum (dry season)	19.700	18.930	16.180	16.180

Different scenarios were explored in the sensitivity analysis of the model. This was done by assigning values to the water generated in a marginal way in periods of maximum and minimum precipitation, as well as to the sediments that were not produced. According to the results of the model **'Represas',** the savings achieved by the society of consumers by the reduction of the sedimentation levels begin to take on importance 83 years after the construction of the dam. These benefits when translated to net present value (NPV) represent $2,560/T of sediments, considering a sedimentation rate of 40T/ha with increments of 10T/ha at years 10 and 20.

4.2.4 Analysis of trade offs between political criteria

On average, the farms of the watershed generate 2.04 times the minimum wage ($172,000 Colombian pesos/month). In general terms, a positive correlation is observed between the size of the farm and earnings. However, in the lower zone, which is marginal for coffee production, in spite of a larger relative area, the cattle owners must distribute the benefits from meat production in such a way that the net earnings are relatively low. The results of linear programming indicate that land use appears to be closely adjusted to the conditions of the region, if it is considered that the increment in the target function, after the optimisation exercise, was only 8% (Table 4.10). The main changes in land use proposed by the optimisation model refer to the reduction of the areas planted in grasses in the upper, upper middle and lower middle zones, and to an increase in the areas in grasses in the lower zone (reducing the portion in forest and fallow. In the upper middle and lower middle zones, the area dedicated to coffee is increased. The rational logic of the peasants is not incorporated into the model and generally explains these differences. They are based on the need to make grasses available for pasturing animals, aimed primarily at capitalisation, risk reduction, and for personal consumption, independent of the economic criteria. The production of water increases slightly to 264.8 m^3, but the sediments also increase to 63,950 metric tonnes.

Table 4.10 Comparison between the present land use (in ha) in the different zones of the watershed and that proposed by the optimisation model.

Activity	Zone	Present use	Optimal model
Coffee (ha)	Upper	182	182
	Upper middle	381	465
	Lower middle	320	395
	Lower	37	37
Grasses (ha)	Upper	191	0
	Upper middle	135	0
	Lower middle	53	0
	Lower	397	605
Sugar cane (ha)	Upper	0	0
	Upper middle	44	0
	Lower middle	60	0
	Lower	42	10
Uncultivated fields (ha)	Upper	1.330	1.526
	Upper middle	337	431
	Lower middle	109	146
	Lower	175	0
	Target function ($x1000 x farm)	3.653	3.992
	Labour (No. workdays)	111.051	111.118
	Water contribution (million m^3)	263.9	264.8
	Sediments (Tm)	60.121	63.950

The sensitivity of the model to the assignation of value to the water that is produced marginally, between $5 and $40/m³, was minimal. The values for water consumption estimated by the CROPWAT model were very similar between the distinct types of land use. Assigning a value to the increase in the volume of water in the watershed does not promote changes in the soil use nor does it have an impact on the production of water or sediments.

The sensitivity of the model to proposing changes in land use by assigning a value to the reduction in the production of sediments turned out to be higher than that in the valuing of the water. In Table 4.11, it is observed that when a value is given for the no-sedimentation, the levels are reduced. However, an important impact on the contribution of water to the dam is not obtained. The point at which this response begins to be seen is at about $11,000/Tm of sediments that are reduced, too high a value for a dam in the construction phase. As a consequence, it should not be expected that by assigning a value of $2,560/Tm to the sediments not to be produced, which the hydroelectric facility should be inclined to pay due to the benefits received, that important changes will be achieved in the soil use of the watershed.

Table 4.11 Sensitivity analysis of the linear programming model to changes in the price of sediments on the total production of sediments (in Tm) and the contribution of water to the dam (million m^3).

Value of the sediments not produced ($/Tm)	Sediment contribution (Tm)	Water contribution (million m3)
0	63.950	264.8
4.000	63.866	264.8
8.000	63.322	264.8
12.000	42.458	266.0
16.000	33.463	261.8
20.000	33.463	261.8
24.000	27.929	264.2

In Figure 4.2 show how valuing the sediments that are not produced generates conflict with the social dimension of the system of the watershed, in that it has a negative impact on the generation of employment. Not only is contracted labour outside of the farm reduced, but also it would tend to affect also the possibilities of present employment of family labour.

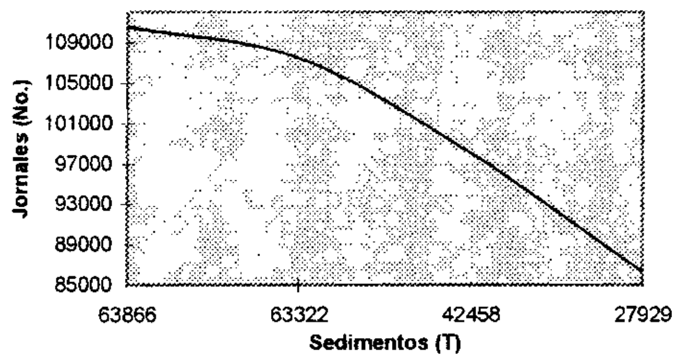


Figure 4.2 Trade-offs between reducing sedimentation levels in the watershed and reducing the number of workdays per year.

One way of reducing the quantity of sediments produced is through the development of cultivation practices in the garden crops and coffee activities, that have a potential for reducing soil loss and, at the same time, increasing the productivity of the crop. Assuming investments of $60,000/ha (Colombian pesos) per year for conservation practices in 751 ha of the watershed and stimulating the producers with $6,000/Tm of sediments that are not produced, it would be possible to maintain the earnings of the producers and, at the same time, reduce the sedimentation level without affecting the generation of employment.

There are a few possibilities for capturing external resources with the argument of generating changes in the use of soils that might favour a higher return and a longer useful life of the hydroelectric project. Valuing the water at reasonable levels for the consumers would not permit increasing the contributions to the watershed, either in periods of maximum nor periods of minimum precipitation. The changes in the cultivation practices suggest such a slight impact on the production of available water that no attractive scenario for the dam results. Ultimately, this does not constitute an important negotiation point for the producers, especially if we keep in mind that they cannot control their contribution to the dam. On the other hand, the levels of soil loss are relatively low and to obtain substantial changes in the watershed would require greater investments than the hydroelectric facility would be willing to finance, through the internalisation of the external factors for sediment reduction ($2.560/Tm). Valuing the sediments that are not produced would have a convenient intervention time of 83 years after the construction of the dam. The Law number 99 of 1993 (Law of the Environment) states the obligation of the company that administers the project to transfer 6% of the resources from the mass sale of energy for conservation and social development processes. It seems logical that in this situation the community have, on the one hand, more interest in negotiating educational support as a strategy for development and on the other hand in maintaining the participation in the management of the reserve that the State has acquired in La Selva in Florencia.

The information generated by the models made an ideal starting point for valuing the resources held by the producers and the personal commitment to those values. It also provided a basis for proposing the terms for an eventual negotiation with those who design environmental policy and those who directly benefit from the conservation process. Among those who benefit we include the consumers of the energy and the company that administers the hydroelectric project.

4.3 Ex-ante Quantification of the Trade-offs between Fairness, Productivity and Sustainability for the Design of Alternative Technologies in Arracacha Cultivation

4.3.1 Elaborating a Mental Model

The location of Cajamarca (Tolima) in relation to markets, elevation, precipitation, organic matter in the soil, and the lack of frost, make this region suitable for the production of arracacha in Colombia. Erosive processes, owing to the extreme slopes and to the use of insecticides to control **the "chiza" plague,** are the environmental costs that worry those responsible for designing new technological options for improving this productive system. Despite the great inefficiencies that have been identified in the system such as a soil loss of 20 t/ha, the fact that 50% of the production cannot be commercialised due to attacks by the "**chiza**" and the contamination of the water by agrochemicals, no important efforts have been made to modify the productive system.

The arracacha production process involves three participants with very different interests, who must be considered when designing a solution. Firstly, the owner of the land whose objective is to renew his pastures for milk cows of which he or she will receive 50% of the production. Secondly, the middleman who supplies seeds, fertilisers and insecticides and receives 25% of the production. And finally the peasant who supplies the labour and receives the other 25%.

As a consequence, the main questions that we would hope to resolve with the model are the following:

- What is the effect of crop rotation on arracacha and milk productions, under different levels of soil loss?
- What is the effect of the soil conservation practices on the production of arracacha?
- What is the effect of erosion control on labour use?
- How are the benefits distributed between the different participants?

4.3.2 Collecting the Information

Information was amassed from secondary sources about the following aspects of arracacha cultivation: growth and development of the plant, agronomic management during cultivation, management of insect plagues and epidemiology of the "chiza", and production and marketing costs for the product (CORPOICA, 1994 y 1995). Also from secondary sources, parameters were generated with relation to soil losses (Gamboa y Palomino. 1993) and the effects of control practices on erosion, production of grasses and animals.

4.3.3 Activities and constraints

The maximum dry weight of the tuberous root is obtained at 330 days, with a production of 1,000 g per plant. The effect of biological control can be considered insignificant against the pressure of the insect pest. For this reason the farmers continue to apply 50 cm^3 of a mixture containing 1% **Furadane** per plant. The planting distance does not affect production, but does affect the commercial volume. The production costs per hectare for sharecroppers are $675.000 and for medium-sized producers $280.000.

The relation between slope of the land, distance between rows, area occupied by conservation efforts and erosion are presented in Table 4.11. There is a direct relation between slope and the area needed in order that conservation efforts have a 70% efficiency. This area is discounted from the planted area, having a direct incidence in the per hectare production. It also affects the use of workdays for conservation.

Table 4.11 Conservation practices, occupied area and soil losses.

Slope (%)	Distance between rows (m)	Area occupied in conservation (m^2/ha)	Erosion (Tm/ha per year)
9	22.9	436	0.8
27	7.7	1.295	2.3
47	4.7	2.114	4.1
70	3.5	2.869	6.0
100	2.8	3.537	8.6

The production of grass dry weight (kikuyo variety) is 20 t/ha per year, distributed proportionally with the precipitation in two dry and two wet periods. Losses caused by animal trampling was estimated at about 30%. Fertilisation options for the grasses other than the residual effect of the crop rotations were not considered.

Milk production was characterised by the use of double purpose Norman animals. Males were sold after weaning. The average production is 1,350 l/milking period, birth rate is 60% and mortality is 2% in young and 3% is adults. The weight at weaning is 140 kg, at 8 months of age.

4.3.4 Analysis of the Effect of Rotation on the Production of Arracacha and Milk, at Different Levels of Soil Loss

The main objective of the landowner is the production of milk with a potential of producing between 2,500 and 4,300 l/ha per year. The production of arracacha is favoured by the number of times that cultivation is realised during the rotation. However, milk production shows an inverse relation; the more rotations, less production. The landowner will maintain his/her economic interest, even with three cultivations of arracacha per rotation, paying no attention to the soil loss, at least to a level of 9 Tm/ha.

4.3.5 Effect of Conservation Practices on the Production of Arracacha

Carrying out control practices in order to reduce erosion forces the producer to plant less arracacha, have more area in conservation and maintain less pasture. As a consequence, when the constraint of soil loss increases, the production volume decreases.

4.3.6 Relationship between Erosion Control and Labour Use

Under the scenario where society restricts the possible levels of erosion, the landowner decides to increase cattle ranching, with lower use of labour, and reduces the planting of arracacha, which uses a greater number of workdays. The consequence is a substantial reduction in 76 workdays/ha when the erosion level is 9 Tm/ha and in 35 workdays when erosion is 5 Tm/ha.

4.3.7 Distribution of the Benefits Among the Different Participants

When the price of arracacha is favourable (US$ 0.90/kg), all of those involved receive benefits, independent of the constraints on the level of the erosion or the number of crops per rotation. When the system is converted into a good deal for everyone, there is motivation in favour of conservation.

If the price of arracacha is reduced to US$ 0.09/kg, the person who most benefits is the landowner, even more when 1, 2, or 3 crops are realised per rotation. The peasant who supplies the labour and realises the conservation practices not only receives less income from the system but earns less as the number of cultivations of arracacha increases per rotation.

In all of the scenarios, the landowner is the one who receives greater benefits from the productivity of the system. However, when society imposes constraints for erosion control and the strategy is to reduce the number of cultivations per rotation cycle, his earnings are reduced from US$1,200 to **US$50/Tm (???)** per year, a cost too low for him to be willing to consider under current circumstances.

Independent of the prices of arracacha, the greatest benefits are obtained by the landowner through the recuperation of grasses. Since the owner dominates the system, the soil loss by erosion is lower in that there will not be several arracacha crops on the same lot.

When the demand for reducing erosion is low, the changes occur by carrying out conservation practices in arracacha, paid for by the income of the peasants who supply the labour. But if the level of these demands increases, the landowner is forced to contribute to conservation by leaving more area fallow, reducing the area cultivated in arracacha, and reducing employment.

Exercise 4.1 Ex-ante Analysis and Evaluation in Natural Resource Management - Applications

Objective

This exercise is designed so that the participants can analyse and evaluate the application of simulation models in ex-ante evaluation in decision-making in natural resource management, by searching for answers to questions about the viability of proposals and analysing different scenarios.

Trainer orientation

- Organise the participants in groups of from 4 to 6.

- Hand out the work sheets to each group, explaining the contents.

- Orient the work groups toward solving the questions presented in the work sheet. To do this, invite the participants to identify indicators related to the use of the resources such as efficiency, profitability, costs, and workday value, so that they may compare the different solutions proposed by the model and draw their own conclusions from them.

- Carry out a plenary session where each group responds to each of the proposed question. Compare the insights and encourage analysis of the application of the models to the reality of the places where the participants work.

- Share the feedback information with the participants.

Necessary resources

- Worksheet for each of the participants.
- Flipchart and paper.
- Marker pens (at least two per group).
- Calculators, at least one per group.
- *Suggested time: 90 minutes.*

Exercise 4.1 Ex-ante Analysis and Evaluation in Natural Resource Management - Applications

Objective

This exercise is designed so that the participants can analyse and evaluate the application of simulation models in ex-ante evaluation in decision-making in natural resource management, by searching for answers to questions about the viability of the proposals and analysing different scenarios.

Instructions for the Participants

1. Form workgroups as indicated by the trainer

2. Select a spokesperson

3. Using the worksheets as a basis, carry out an ex-ante evaluation of the system. Some of the questions might be:

- Is it worth the effort for the producer to put the resources at his disposal to a better use?
- What happens if the producers had access to credit?
- What would happen if the price of maize were reduced?

4. After completing this analysis, the group should propose at least two questions that a researcher may want to solve through the use of linear programming.

5. In plenary session, each group will present its conclusions.

Exercise 4.1 Ex-ante Analysis and Evaluation in Natural Resource Management - Applications - Worksheet

Distribution of resources in the production system

Average area of the farms	: 8.3 ha
Available capital first six months	: US$270
Available capital second six months	: US$190
Family labour first six months	: 350 workdays
Family labour second six months	: 323 workdays

Traditional model available to the producer

Activity	Land		Capital		Labour		Net income	
	1st 6-m	2nd 6-m	1st 6-m	2nd 6-m	1st 6-m	2nd 6-m	1st 6-m	2nd 6-m
	ha	ha	(US$/ha)	(US$/ha)	(WD/ha)	(WD/ha)	(US$/ha)	(US$/ha)
Maize/sorghum	0.92	0	30.2	0	80	0	120	0
Sorghum 1 6m.	0.47	0	9.5	0	24	0	37.3	0
Maize 2 6m	0	0.47	0	17.5	0	52	0	83.2
Sorghum 2 6m.	0	0.5	0	13.5	0	22	0	67.2
Tobacco	0.92	0	157.2	0	174	0	759	0
Tomatoes		0.22	0	157.2	0	384	0	34
Beans	1	0	37.5	0	80	0	192	0
Cassava	0.15	0.15	29.3	37.5	60	58	40	40
Citrus	0.5	0.5	35	29.3	17	17	60	60
Pastures	4.34	4.34	3.7	35	105	105	30	30
Birds (per head)	0	0	1	3.7	0.35		2.17	2
Fallow	0	2.12	0	1	0	0.3	0	0
Workdays contracted	100	232		0		0		

Cost of the workday US$2.
Total net income of the farm per year: US$740

Results of linear programming

The solution proposed by the mathematical model using the resources at the disposal of the producer is the following:

	First six months	**Second 6m**
	ha	ha
Maize/sorghum	0.51	0
Sorghum 1 6m	0.4	0
Maize 2 6m	0	0.08
Sorghum 2 6m	0	0.74
Tobacco	0.82	0
Tomatoes	0	0
Beans	1.39	0
Cassava	0.15	0.15
Citrus	0	0
Pastures	2	2
Birds (per bird)	57	57
Fallow	3.03	5.33
Workdays contracted	60	65

Area used first six months: 5.27 ha
Area used second six months: 2.97 ha

Capital used:

First six months: US$270
Second six months: US$190

Target function: US$1200

Sensitivity of the Model to Changes in Capital

The results of the model exploring the possibility that the producer has more capital for investing in the activities of the farms are as follows:

Capital US$460

Activity	1 6m (ha)	2 6m (ha)
Maize/sorghum	0.51	0
Sorghum 1 6m	0.4	0
Maize 2 6m	0	0.08
Sorghum 2 6m	0	0.74
Tobacco	0.82	0
Tomatoes	0	0
Beans	1.39	0
Cassava	0.15	0.15
Citrus	0	0
Pastures	2	2
Birds (per bird)	57	57
Fallow	3.03	5.33
Workdays contracted	60	65

Area used first six months: 5.27 ha
Area used first six months 2.97 ha

Capital used:
First six months: US$270
Second six months: US$190

Target function:
US$1200

Capital US$860

Activity	1 6m (ha)	2 6m (ha)
Maize/sorghum	0.51	0
Sorghum 1 6m	0.4	0
Maize 2 6m	0	1.74
Sorghum 2 6m	0	0.74
Tobacco	2.57	0
Tomatoes	0	0
Beans	2.86	0
Cassava	0.15	0.15
Citrus	0	0
Pastures	2	2
Birds (per bird)	57	57
Uncultivated fields	0	3.7
Workdays contracted	420	114

Area used first six months 5.27 ha
Area used first six months 2.97 ha

Capital used:
First six months: US$270
Second six months: US$190

Target function: US$1200

Capital US$1410

Activity	1 6m (ha)	2 6m (ha)
Maize/sorghum	0.51	0
Sorghum 1 6m	0.4	0
Maize 2 6m	0	4.63
Sorghum 2 6m	0	0.74
Tobacco	5.37	0
Tomatoes	0	0
Beans	0.06	0
Cassava	0.15	0.15
Citrus	0	0
Pastures	2	2
Birds (per bird)	57	57
Uncultivated fields	0	0.8
Workdays contracted	895	96

Area used first six months 5.27 ha
Area used first six months 2.97 ha

Capital used:
First six months: US$270
Second six months: US$190

Target function:
US$1200

Exercise 4.1 Ex-ante Analysis and Evaluation in Natural Resource Management - Applications Feedback

Based on the study of the information resulting from the activities, constraints and target function of the model, in addition to the solutions proposed in the optimal model, the following analysis can be made.

Comparison between the traditional system vs. the optimal model using resources held by the producer.

- **Land resource.** The model proposes leaving a greater quantity of land fallow during the first six-month period, by reducing the area dedicated to maize/sorghum by 50% and a reduction of pastures by 2.43 hectares (55%). The area in tobacco is kept about the same and an increase of approximately 40% in beans is proposed. In the same manner, the model proposes not planting tomatoes, maize or citrus trees. Regarding poultry, the optimal solution proposes 57 birds instead of the 34 in the traditional model.
- **Labour resource.** The model proposes contracting fewer workdays (125) than the 332 used in the traditional model.
- **Capital resource.** The model uses a total of US$460, a capital investment equal to that of the traditional model.
- **Target function.** The net family income with the improved model is US$1200, higher than the US$740 of the traditional model.

Conclusions:

The model proposes distributing the activities is such a way so as to use fewer contracted workdays, making the family workday more profitable, passing from US$1.10 to US$1.70 per day. This is achieved by an increase of nearly 50% both in beans planted and in the number of poultry.

In the same way, we can conclude that the administration and decision-making about natural resources exercised by the producers under the traditional model are similar to those proposed by the optimal model, with the exception of tomato and maize activities in the second six month period. Therefore, it is worthwhile considering this difference in detail and asking ourselves: why does this happen?

The answer to this question is found in the sensitivity to capital. The model demonstrates how the optimal solutions respond positively to the capital investment used in the tobacco activity, which gives a return of US$4.36/workday, this being the highest value achieved by the activities developed under the traditional model. With an increase in capital investment of US$400, earnings of US$1200 can be obtained, a value three times higher than the investment made.

In conclusion, the model responds in a sensitive way to changes in capital, which is invested in the tobacco activity, requiring a greater contracting of workdays. This situation should be analysed in the context of the region where the model was developed, given that no constraints on contracting workdays have been estimated which is a situation that could occur under the scenario where more hectares of tobacco are planted.

From the analysis of the solutions presented by the model we can also conclude that the model is highly sensitive to the use of labour. This sensitivity should be kept in mind by the research group or development agents in proposing alternative technologies that optimise the use of this resource. It is in this manner that proposals for natural resource management will face limitations in their adoption, owing to the demands made on a factor that is limiting for the system.

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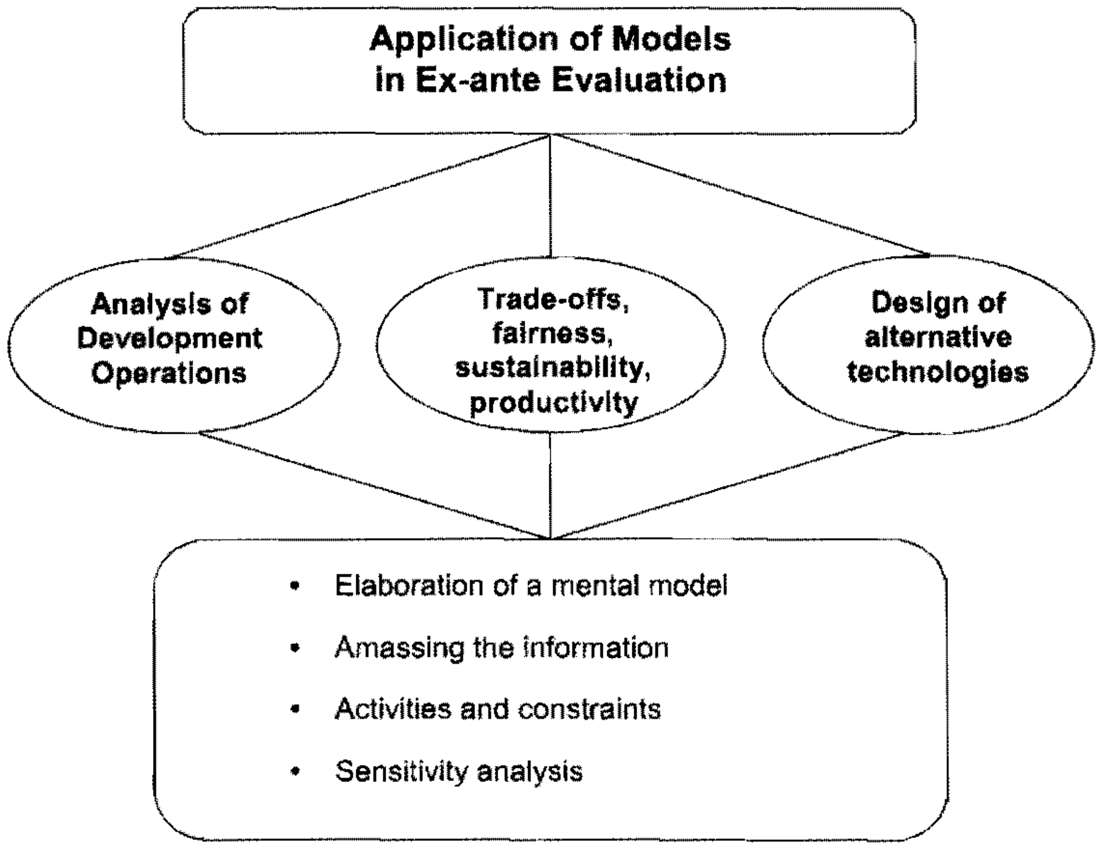
SECTION STRUCTURE



SECTION OBJECTIVES

- ✓ Describe the methodological steps in the application of simulation models in decision-making for the management of natural resources.
- ✓ Explain how simulation models are used for the analysis of development options in a watershed.
- ✓ Explain how simulation models are used to calculate the trade-offs between political criteria: sustainability, fairness and productivity.
- ✓ Clarify how to apply models for the quantification of trade-offs between fairness, productivity and sustainability in designing alternative technologies.

Information for the Doña Juana River watershed

Activity	Unit	Coffee	Grass	Cattle	Cocoa	Annuals	Oldfields
Inputs + Depreciation	$ 1000/ha	225.9	10.0	16.2	50.0	20.0	0.0
Cash costs	$ 1000/ha	168.8	5.0	12.2	0.0	20.0	0.0
Capital	$ 1000/ha	200.0	30.0	360.0	250.0	0.0	0.0
Workdays	No./ha	117.0	12.0	5.0	90.0	94.0	10.0
Water consumption	m3/ha	1,008.0	1,008.0		756.0	760.0	1,008.0
Sediments	T/ha	8.8	2.2	0.8	5.9	10.0	1.2
Production	kg/ha	800.0		*109	400.0	4,120.0	*3
Value	$/kg	1,587.0		1,250.0	412.0	1,800.0	*27000

* Information for cattle is not for hecatares, but per head
In addition to meat production, the cows produce 313 lt of milk/cow with a value of $400/lt

Production of fallow is expressed in m3

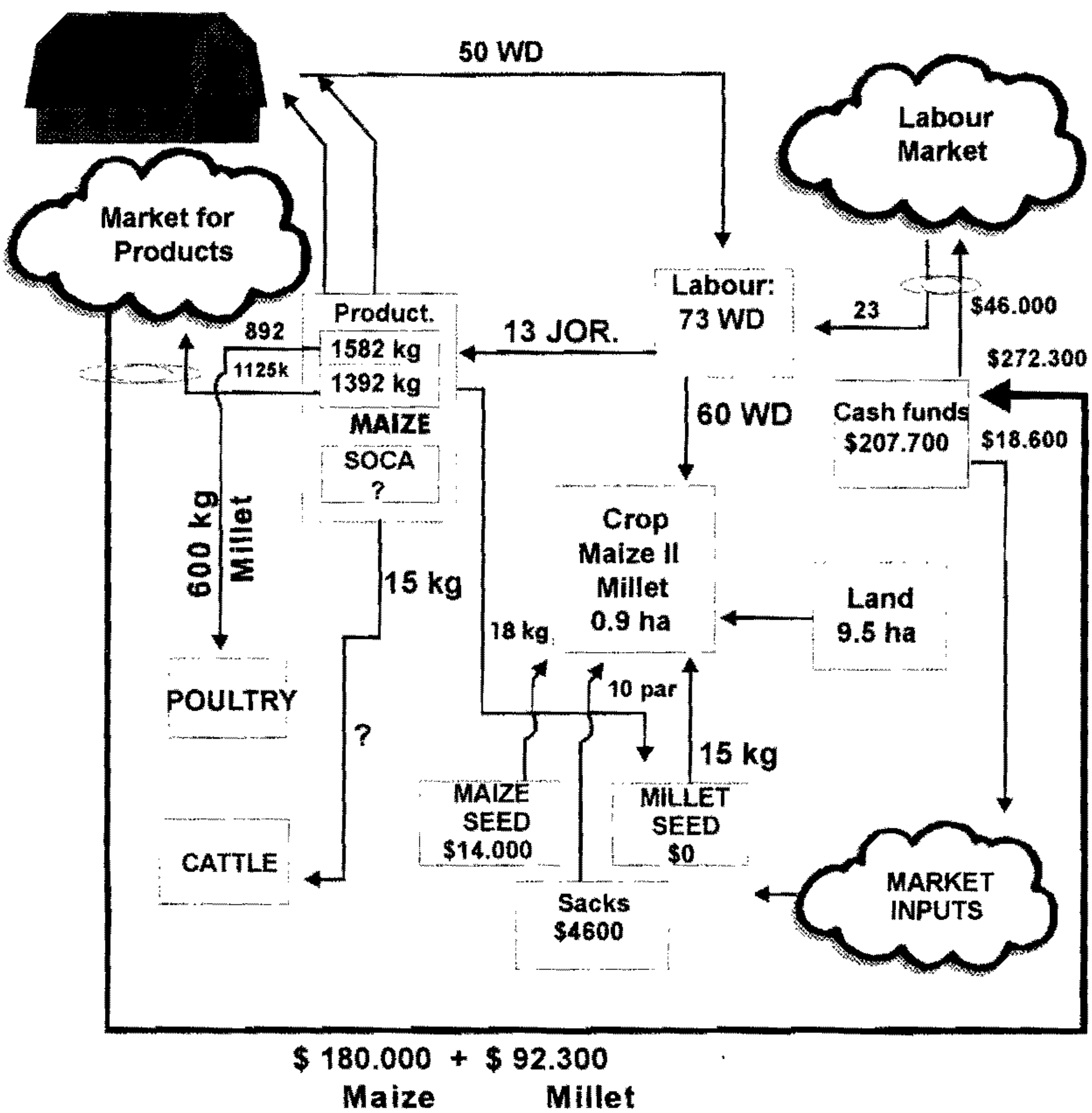
Information for the San Antonio River Watershed

Activity	Upper	Upper Middle	Lower Middle	Lower
Land				
Area (ha)	1,745.0	967.0	582.0	669.0
Coffee (ha)	182.0	381.0	320.0	37.0
Grasses (ha)	191.0	135.0	53.0	397.0
Sugar cane (ha)	5.0	44.0	60.0	42.0
Garden crops (ha)	46.0	71.0	40.0	17.0
Scrub and fallow (ha)	1,330.0	337.0	109.0	175.0
Labour				
Available workdays	12,904.0	20,385.0	29,100.0	7,453.0
Coffee (ha)	10,945.0	22,860.0	31,050.0	3,827.0
Grasses (ha)	2,977.0	2,112.0	1,158.0	8,262.0
Sugar cane (ha)	132.0	2,176.0	5,215.0	3,456.0
Garden crops (ha)	2,143.0	3,318.0	1,968.0	852.0
Scrub and fallow (ha)	5,318.0	1,346.0	435.0	701.0
Total (workdays)	21,517.0	31,812.0	39,826.0	17,098.0
Capital Costs				
Coffee ($x1000)	17,311.0	35,814.0	31,626.0	3,437.0
Grasses ($x1000)	2,332.0	2,319.0	0.0	7,972.0
Sugar cane ($x1000)	0.0	0.0	270.0	0.0
Garden crops ($x1000)	365.0	0.0	0.0	0.0
Scrub and fallow ($x1000)	0.0	0.0	0.0	0.0
Total ($x1000)	20,008.0	38,132.0	31,896.0	11,409.0
Investment Capital				
Coffee ($x1000)	36,483.0	85,725.0	80,025.0	8,279.0
Grasses ($x1000)	66,520.0	47,359.0	19,713.0	183,257.0
Sugar cane ($x1000)	658.0	4,352.0	5,995.0	4,215.0

Sensitivity Analysis of the Quantification of Trade-offs

Slope (%)	Distance between rows (m)	Area dedicated to conservation (m2/ha)	Erosion (TM/ha/year)
9.0	22.9	436.0	0.8
27.0	7.7	1,295.0	2.3
47.0	4.7	2,114.0	4.1
70.0	3.5	2,869.0	6.0
100.0	2.8	3,537.0	8.6

Cocoa (ha)	167.0	0.0
Cassava (ha)	49.0	120.0
Plantain (ha)	97.0	0.0
Maize (ha)	16.0	0.0
Maize in alleys (ha)	0.0	0.0
Rubber (ha)	0.0	0.0
Fallow (ha)	838.0	202.0
Target function ($x1000xfarm)	5,864.0	6,172.0
Labouruse (No. workdays)	80,195.0	60,489.0
Water contribution (million m3)	153.7	153.5
Sediments (Tm/year)	13,233.0	14,057.0


50 WD
Labour
Market
Market for
Products
Labour:
73 WD
23
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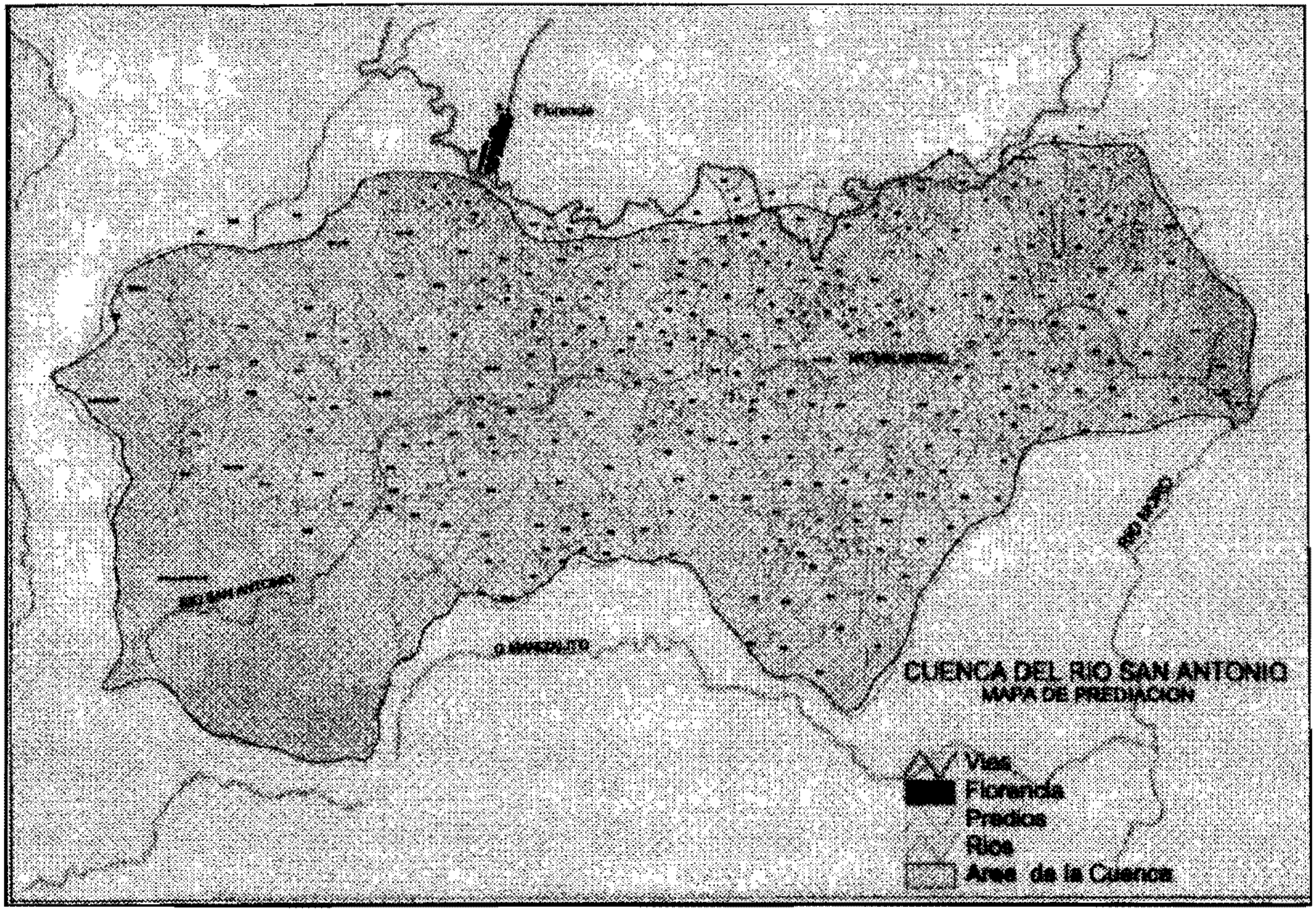
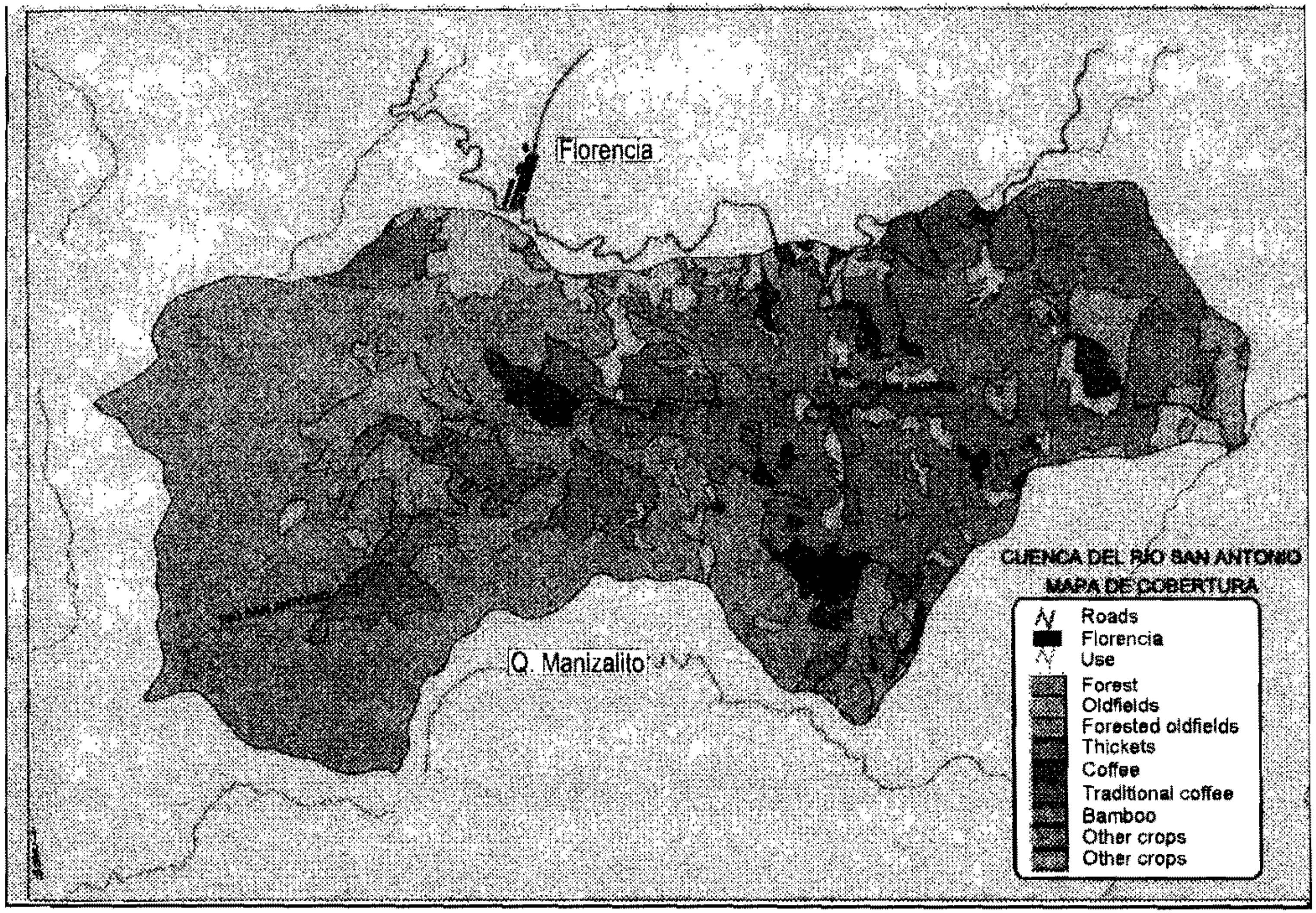
892
Product.
1582 kg
1125k
1392 kg
13 JOR.
$272.300
60 WD
Cash funds
$207.700
$18.600
MAIZE
SOCA
?
600 kg
Millet
15 kg
Crop
Maize II
Millet
0.9 ha
Land
9.5 ha
18 kg
10 par
POULTRY
?
15 kg
MAIZE
SEED
$14.000
MILLET
SEED
$0
CATTLE
MARKET
INPUTS
Sacks
$4600
$ 180.000 + $ 92.300
Maize Millet

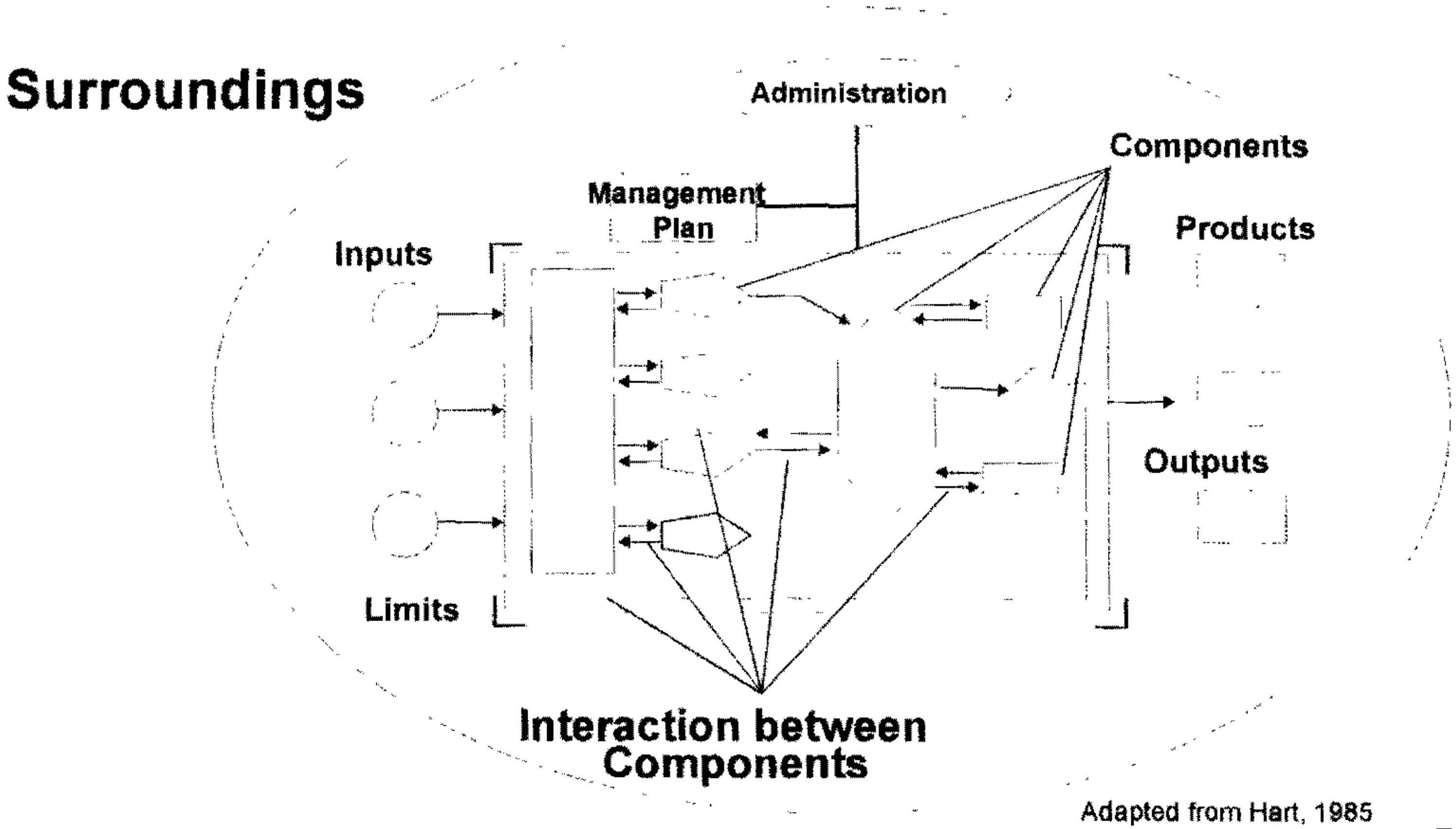
San Antonio River Watershed



SAN ANTONIO RIVER WATERSHED



Elements of an Agricultural Production System: The Farm as Example



Adapted from Hart, 1985