DEVELOPMENT OF
A COMPUTERIZED AID TO INTEGRATED LAND USE PLANNING
(CAILUP)
AT REGIONAL LEVEL IN IRRIGATED AREAS

A case study
for the Quan Lo Phung Hiep region
in the Mekong Delta, Vietnam

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PROPOSITIONS

1. For proper land use planning, operational integration of bio-physical and socio-economic factors is a pre-requisite. *[This thesis]*

2. The bio-physical and socio-economic realms can be compared with the 'body' and the 'mind' of a person, i.e. they require different methods for survey, study and management, but functionally they are always integrated. *[This thesis]*

3. 'Biodiversity' leads to a large number of land use types with various production techniques, while 'sociodiversity' results in a variety of socio-economic objectives and preferences. *[This thesis]*

4. A qualitative approach may seem appropriate for a complex issue like land use planning, but it causes confusion to the planner, because of the subjectivities in interpretation of results and the difficulties in comparative analysis of land use scenarios. A quantitative approach, based on mathematical modelling, avoids this confusion, but requires appropriate system approaches. *[This thesis]*

5. Attempts have been made to convert qualitative data into quantitative data for mathematical modelling, by applying conventions for classification at international, national or local levels. Conversion of qualitative data into quantitative data, however, remains a major challenge in modelling. *[This thesis]*

6. Integration not only implies addition or multiplication to combine parts or plans from different sectors, but includes deletion of detail through 'a fine filter' to allow incorporation of the various parts in the framework of a common plan. *[This thesis]*

7. The problem of integration in some countries has been noticed by the Vietnamese: work done by one person there may be equivalent to that by three persons in other countries, but that done by ten persons is only equivalent to that by one person in those other countries.

8. As both planning and plan implementation are carried out by "people", both the planning method and the output should be acceptable to the people having to implement the plan. *[This thesis]*

Propositions

9. Land use decisions are continuously being made; they cannot be postponed because of lack of knowledge, data, maps, manpower, funds, etc. Hence, irrespective of quality, plans have to be formulated, and subsequently information and knowledge gaps must be identified and gradually filled through monitoring and research. *[This thesis]*

10. The ultimate objective of land use planning is not to provide values for production or land use maps, but to assess positive and negative impacts of alternative actions to exploit land resources, on production, socio-economic conditions and environment. *[This thesis]*

11. If two models can be applied to provide the same output, a practical user, such as a manager, will prefer the simpler one, but others, such as many research scientists, may prefer the complexer one because they think: (i) that complex models are more appropriate representations of the real world; (ii) that complex models offer a wider scope for analysis; (iii) there is a preference for complexity in model structure similar to the 'love of long words and complex structures' in using language. *[This thesis]*

12. What we know of bio-physical interactions and socio-economic behaviour is much less than what we do not know. *[This thesis]*

13. It has taken thousands of years to reach the current conditions in land use in a region. The same time could be required for a study to develop a model closely representing this reality.

14. Planners can prepare a land use plan that is regarded as "sustainable" for a region. However, most of them would have difficulty in answering the question: "Can you prepare a sustainable plan for your life?"

15. For a student from a developing country, studying in a developed country, writing a thesis is hard work, requiring great effort, similar to preparing Vietnamese food. However, reading the thesis, which may be compared to eating the food, is even much more difficult. *[This thesis]*

Propositions by Chu Thai Hoanh for "Development of a Computerized Aid to Integrated Land Use Planning (CAILUP) at regional level in irrigated areas: A case study for the Quan Lo Phung Hiep region in the Mekong Delta, Vietnam" - Ph.D. thesis, Wageningen Agricultural University. 4 June, 1996.

PREFACE

Diversity in land use, including 'biodiversity' and 'sociodiversity', is the greatest challenge in land use planning. The more diverse the land use pattern, the more important integration in planning and management. Therefore, this thesis, the result of research at the International Institute for Aerospace Survey and Earth Sciences (ITC), includes the integration of expertise from many people.

Where the contributions of the Vietnamese to the study are concerned, I first of all want to thank the farmers, leaders and people in the Quan Lo Phung Hiep region, and in the Mekong Delta in general, from whom I have learned about sustainable land use for subsistence and development, as testified by their presence there. However, in the traditional way of the Mekong Delta, I gratefully refer to them by their order in the family, as Mr. Two, Ms. Three, Mr. Four, Mr. Five, Ms. Six, Mr. Seven, Mr. Eight, Ms. Nine and Mr. Ten.

Where the Vietnamese Government institutions are concerned, I hereby express my sincere appreciation to Mr. N.C. Dinh, Minister of Water Resources, Mr. P.S. Ky and Mr. N. Gioi, Vice-Ministers, Mr. V.V. Vinh, Director of the Sub-Institute for Water Resources Planning and Management (SIWRPM) and Mr. H.T. Quang, Director of the Department of International Cooperation, who strongly supported my study.

My study received contributions from a number of planners and engineers from sectoral institutions to all of whom I wish to express my appreciation. A few of them I would like to mention hereby, i.e. Dr. H.T. Dien, Mr. N.D. Thue, Mr. N.T. Vinh, Mr. T.Q. Tang, Mr. D.T. M. Tam, Mr. L.Q. Xo, Mr. P.X. Phuong, Ms. N.T. Quy and Mr. T.D. Dong from SIWRPM; Mr. N.X. Thi, Mr. C. Khoan, Mr. N.D. Luyen, Mr. T.N. Linh, Mr. D.V. Nam and Ms. T.T. Hoa from the Institute of Hydraulic Survey and Design in the South; Mr. T.A. Phong, Mr. L.V. Tac, Mr. N.A. Tiem, Mr. T.Q. Tuan, Mr. N.B. Hoai, Mr. C.D. Phat, Mr. T.Q. Khanh and Mr. P.V. Tru from the Institute of Agricultural Planning and Projection; Mr. P.L. Tam, Mr. T.T. Xuan, Mr. N.T. Tung. Mr. N.D. Hung, Mr. D.V. Tien and Mr. T.C. Khanh from the Institute of Aquaculture Research II; Mr. T.T. Long and Mr. N. An from the Sub-Institute of Forest Inventory and Planning; Mr. L.T. Thu from the Institute of Hygiene and Public Health; Mr. L. Qua from the Center for Scientific and Economic Transportation in the South; Prof. P.T. Ngan and Mr. T.T. Dung from the Faculty of the Environment, Ho Chi Minh City University, Mr. D.H. Trung from the Water Resources Department of Can Tho province; Mr. L.H. De from the Water Resources Department of Soc Trang province; Mr. T.Q. Thanh, Mr. L.P. Que and Mr. N.V. Buong from Water Resources Department of Minh Hai province; Mr. T.C. Thien from the Agro-Forestry University of Ho Chi Minh City.

My special thanks go to the core modelling and planning group whose contributions can be found throughout this thesis. The group comprises Prof. N.N. Khue, Mr. N.X. Hien, Mr. N.V. Ngoc, Ms. T.P. Dung, Mr. L.K. Chien, Mr. P. Thai, Ms. T.T.T. Huong (water resources modelling and planning), Mr. T.K. Thanh and Mr. T.T. Dung (economic analysis), Mr. H. Dung and Mr. N.V. Duyet (forestry modelling and planning), Mr. N.M. Hung (agricultural modelling and planning), Mr. T.D.P. Anh (transportation planning), Ms. N.T. Mai (demography, public health and social impacts), Mr. T.D. Can (fisheries modelling and planning), Ms. N.T. Loan and Mr. T. Triet (environmental impacts).

Where the international scientific institutions are concerned, I wish to thank ITC as a whole and the DISH Organization which generously provided my fellowship. In my study I received valuable assistance from many people at ITC: Prof. K.J. Beek, Rector and also a member of the Reading Committee of my thesis; Prof. A.M.J. Meijerink from Department III, Earth Resources Surveys; Prof. W. v. Wijngaarden, Prof. H.A. Luning, Dr. M.A. Sharifi, Ir. M.C. Bronsveld, Dr. J. de Leeuw, Ir. C.A.J.M. de Bie, Dr. D.v.d. Zee, Drs. E.J.M. Dopheide, Drs. J.C. de Meijere, Mr. B. Krause from Department II, Land Resource and Urban Sciences; with all of whom I had many stimulating discussions during my study. I also appreciate the contacts and discussions with my colleagues at ITC, especially Mr. C. Amuyunzu, my roommate, Mr. T. Cecarelli, Dr. J.O. Kufoniyi and Mr. H.V. Phuc.

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I am particularly grateful to Prof. H. van Keulen of Wageningen Agricultural University, promotor, and Dr. H. Huizing at ITC, co-promotor. The only way to appreciate their support to my study is by considering their scientific contributions, the stimulating discussions on the conceptual aspects and critical reviews of the thesis as one third of the study.

The second third has been gradually acquired during the past 40 years of my life, especially during my participation in Mekong projects. In this respect I wish to acknowledge Mr. B. van der Boon, the first Dutch expert from the Netherlands Delta Development Team, with whom I worked in my first study after graduation from university. Further, Dr. L.H. Ti and Mr. T.V. Truong at the Mekong Secretariat, Dr. T.P. Tuong at IRRI, and the Canadian team, in particular Dr. P. McNamee, Mr. N. Soontag and Mr. G. Sutherland, with whom I started modelling for integrated planning for the Quan Lo Phung Hiep region. And also the NEDECO team headed by Dr. W.H. van den Toorn and Mr. G. Sluimer, from whom I received a great amount of information, data and thematic studies. My study during three and half years at ITC in the Netherlands and at SIWRPM in Vietnam can be considered as the final third.

Finally, I want to express my profound gratitude to my wife, N. Kim Chi, and my son, C.G. Thuy for their support to my study. I must emphasize that without the encouragement and assistance from my wife and my son, I would not have been able to complete this study.

To the readers of this thesis, I want to convey that writing a thesis is hard work, requiring great efforts, similar to preparing Vietnamese food. However, reading a thesis, compared to eating, is much more difficult. Therefore, I thank you all for such hard work.

March 1996 Chu Thai Hoanh

SUMMARY

The problem - Objectives of the study

Land use planning is an essential activity in any country, because the demands for different land uses usually exceed the available resources. Land use planning implies weighting of trade-offs among conflicting goals, as different interests exist in society. Demands for water often also exceed the available resources.

The objectives of this study are to develop and implement a method and corresponding software system for integrated land use planning at regional level in irrigated areas, and to test the method and the system in the Quan Lo Phung Hiep region in the Mekong Delta, Vietnam. The System Development Methodology (SDM) comprising seven specific phases was applied in the study. A Computerized Aid to Integrated Land Use Planning, "CAILUP", was formulated.

The research concept

The greatest challenge in land use planning is how to incorporate the diversity in land use, comprising land users, goals, management and technologies, into the planning process. The CAILUP approach takes into account the diversity in land use by integrating promising land uses for agriculture, fisheries and forestry with land uses for other purposes.

Integration is a major issue in land use planning. CAILUP focuses on integration of land use selections at different hierarchical levels, of bio-physical and socio-economic factors, of local expertise and global (international) expertise, and computer technology and land use planning.

CAILUP takes into account integration among hierarchical levels by combining top-down and bottom-up approaches. Interventions are based on the goals of regional development in the context of the whole country. The feasibility of these interventions is judged by taking into account the preferences and priorities of the local land users, and subsequently all achievements and impacts from these interventions are evaluated. Decisions on land use can be considered as 'public decisions' with contributions from scientists, planners, decision-makers, sectoral agencies and land users. Integration in 'public decision' is carried out by simulating the decision process.

An IBS (Integrated Bio-physical and Socio-economic) approach is proposed to assess the effects of water management. Integration requires the equal resolution (in space and time) of data on both bio-physical and socio-economic factors. Land units are delineated by administrative boundaries and limits of key physical interventions.

Land use planning can also be considered as a process of multi-sectoral integration. A key intervention is determined, i.e. construction of a water management system for an irrigated region. Other interventions are supplementary interventions to improve water management efficiency. A land use planning team needs to comprise a wide range of expertise. CAILUP comprises a knowledge base that integrates expert knowledge from both local (regional and national) and global expertise.

Simulation modelling is a promising technique in land use planning to achieve integration. The strategy in modelling of CAILUP is to integrate simple sub-models of all relevant components, rather than only to include a few complex sub-models developed for single disciplinary research. CAILUP provides functions to analyse the impact of different hypotheses or scenarios formulated by planners. A scenario comprises a set of actions and effects in which goals are achieved to a certain degree. The impact of water management on the physical conditions is first evaluated. The new physical conditions lead to new bio-physical production levels that are used to determine an integrated feasibility for each land use type by comparison with socio-economic criteria at farm level. This feasibility is used, in combination with Government policy objectives, to formulate a land use plan. Finally, achievements based on this plan and its impacts on bio-physical and socio-economic conditions are examined.

Integration of computer technology and land use planning will be achieved by developing a system consisting of quantitative models, databases and GIS based on the concepts of decision support systems and expert systems.

A Computerized Aid to Integrated Land Use Planning

CAILUP consists of four units: a core expert unit, a database unit, a GIS unit and a model unit. The model unit, a major component to realize the system function, comprises a mathematical model developed on the basis of a conceptual model.

The conceptual model is developed in a sequence of identifying issues, goals and indicators, relevant land use types, relevant components, factors, spatial extent and spatial resolution, time horizon and time steps, and "without" and "with" intervention cases.

The mathematical model comprises 14 sub-models:

[1] *Intervention Generating Sub-model* to generate a data set for the "without" or "with" intervention cases.

[2] *Physical Impact Sub-model* to generate a data set of modified physical conditions.

[3] *Bio-physical Sub-model (Agriculture, Fisheries, Forestry)* to estimate yields and the selected crop calendars under modified physical conditions.

[4] *Economic Sub-model at Farm Level* to generate the combined bio-physical/economic feasibility based on financial criteria defined at farm level.

[5] *Social Sub-model at Farm Level* to integrate social preferences with bio-physical/economic feasibility to generate integrated feasibility.
[6] *Demography Sub-model* to generate data on population and labour force.
[7] *Land Use Weighting Sub-model* to determine weighting factors based on the integrated feasibility and Government policy.
[8] *Land Use Allocation Sub-model* to generate land resource use on the basis of the weighting factor and rules in land use conversion.
[9] *Production Sub-model* to generate total production by multiplying area with yield.
[10] *Supplementary Intervention Sub-model* to generate supplementary interventions required to support the land use scenario.
[11] *Economic Sub-model at Regional Level* to calculate the economic returns at land unit and regional levels.
[12] *Social Sub-model at Regional Level* to calculate the socio-economic indicators at land unit and regional levels.
[13] *Environmental Impact Sub-model* to calculate indicators expressing environmental impacts.
[14] *Goal and Impact Analysis Sub-model* to generate a ranking value for the selected scenario.

An example in the real world

The Quan Lo Phung Hiep region, with a total area of approximately 450,000 hectares and located in the Mekong Delta, Vietnam, was selected for the case study. Agricultural production in this region is constrained by adverse soil and water conditions. Low rainfall during the dry season prevents agricultural production without irrigation. However, salt water intrusion from the sea makes water quality in most parts of the region unsuitable for irrigation. In the early part of the rainy season, leachates from the acid sulphate soil area contaminate surface water and reduce its pH to values below 4, which is detrimental to agricultural and aquacultural production.

In the region, 85% of the population is engaged in agricultural, fisheries and forestry activities. The relevant land use types are single crops (rice, sugarcane, etc.) or a combination of various crops/activities (double rice, rice+beans, rice+shrimp, etc.) under different management techniques. Rice is the most important crop. Living standards are reportedly lower in areas of salt and brackish water than in areas of fresh water.

Water management to prevent salt water intrusion and to increase the supply of fresh water from the Mekong river is considered a key intervention for development of the region. Main objectives of water management are to increase total food production and income and to improve living conditions. A medium scale protection option, i.e. protection and irrigation of the central part by 11 medium-size sluices, was selected. Seven schedules of water management construction were formulated, depending on the availability of funds and the strategy in minimizing the acid water effects.

Four land use strategies were formulated: Maximize rice production, Maximize income from rice production, Crop diversification and Minimize effects of acid water.

CAILUP for the Quan Lo Phung Hiep region has been developed and used in analysing the effects of different construction schedules and land use strategies.

Data used for calibration are data on water conditions in 1989-1990, data on yields from 1986 to 1990, data on population and land use areas in 1985 and 1990, and data on production from 1985 to 1990. Calibration of single sub-models was followed by calibration of series of sub-models. The model then was validated with inventory data from 1991 to 1994.

Twenty eight development scenarios, combining 7 construction schedules of the water management system with 4 land use strategies, were compared with a "without case" in which the new water management system was assumed absent. Single goal scores and total score were used as main outputs for evaluation of development scenarios. Sensitivity analysis has been carried out to provide a measure of the sensitivity of the outputs to either parameters, functions or sub-models, and to analyse the impact of changes in values of inputs on scenario scores.

A construction schedule was selected on the basis of development objectives and possible impacts reflected by scenario scores, taking into account the institutional situation in the region. Selection of a land use strategy is more difficult because each land use strategy has the highest score for at least one of the goals in the situations considered. A rice-oriented strategy has been selected, with more crop diversification outside of the protected area.

Conclusions and recommendations

The objectives of the study have been attained. Taking into account major issues in land use planning methodology, CAILUP was developed to facilitate integration in land use planning. A corresponding software system was developed and tested successfully for the Quan Lo Phung Hiep region. To be developed and applied successfully, CAILUP requires suitable conditions in terms of human resources, data and information, and hardware and software packages.

Although the above conditions have been adopted, development and applications of CAILUP are still confronted with many challenges, each deriving from the existence of two alternatives (see Chapter V: Section 2). A cycle exists in which one challenge becomes dominant and is the main subject of many studies during a number of years, and there is also a cyclic behaviour of the two alternatives of each challenge. The attempt in further studies is to develop and apply the CAILUP system adapted to these cycles.

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CHAPTER I INTRODUCTION

1.1 THE PROBLEM

1.1 Land use planning is an essential activity in any country, because the demands for different land uses usually exceed the available resources. Land use planning implies weighing of trade-offs among conflicting goals [FAO, 1993], as different interests exist in society. Land use planning aims at making the best use of land in view of vested objectives with respect to the use of limited resources to satisfy increasing demand, of which food supply is usually the main concern.

1.2 Demands for water often also exceed the available resources. Water differs from land in that it is not spatially fixed and can be shared in a region among different resource users. For an agricultural region as the Mekong Delta in Vietnam, water management has proven a key intervention to increase food production and income from land use. Since water is a medium for transporting substances, water management may also have significant effects on the environment.

1.3 FAO guidelines propose ten steps in land use planning, in which a major activity is the selection of land use alternatives based on land evaluation (LE), which combines bio-physical and socio-economic factors [FAO, 1993]. From the 1970's onwards, new methodologies such as farming system analysis (FSA) have been developed and widely applied to take into account the preferences and priorities of local land users in a bottom-up approach [FAO, 1990]. The LEFSA sequence was suggested to combine farming system analysis with land evaluation [Fresco et al., 1992].

1.4 However, any procedure such as LEFSA (as well as LE and FSA) essentially contains a number of qualitative steps in assessing the future of limited resources while operationalization of sustainability requires quantification of causal relationships among system components and implies understanding of ecological and socio-economic interactions in land use to assess the changes in land use systems [Fresco et al., 1992]. Moreover, a recent FAO draft report contains the following complaint: "... very little progress has been made in developing a relationship between government policy and land use decision making..." [FAO, 1994, cited in Luning, 1995].

1.5 A qualitative approach (conventional land evaluation) seems to be suitable for a complex problem like land use planning, but in fact it causes confusion [van Diepen, 1982; Fox, 1986; van Diepen et al., 1991] to the planner because of flexibility in application and difficulty in comparison of evaluation results. A quantitative approach, based on mathematical modelling, may help to avoid this confusion, but requires appropriate system approaches.

1.2 OBJECTIVES OF THE STUDY

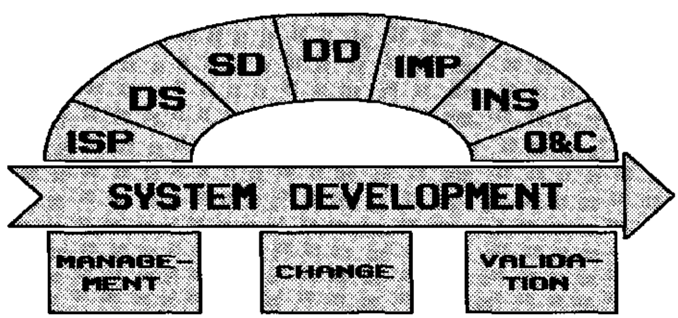
1.6 *The objectives of this study are*:

- *To develop and implement a method and corresponding software system for integrated land use planning at regional level in irrigated areas, taking into account interactions among bio-physical and socio-economic factors, as well as effects of government interventions on land use.*
- *To test the method and the system in the Quan Lo Phung Hiep region in the Mekong Delta, Vietnam.*

1.3 RESEARCH METHOD

1.7 The System Development Methodology (SDM) [Cap Gemini Publishing, 1991, Paresi, 1991a, 1991b, 1991c, 1991d] was applied in the study. As illustrated in Fig. 1, SDM comprises seven specific phases in developing a system (phase names are adopted from SDM):

Figure 1: Life cycle of a system [adopted from Cap Gemini Publishing, 1991].



1/ *Information system planning (ISP)*: Problems and current situations in land use planning, research objectives and initial concepts of the approach are identified in this phase. A research plan for three and a half years was developed.

2/ *Definition of study (DS)*: In this phase, problems in land use planning and research concepts were identified. The general structure of the computer system, i.e. "CAILUP", a Computerized Aid to Integrated Land Use Planning, was formulated.

3/ *System design (SD)*: The structure of CAILUP was refined so that modules, their functions and their interactions were determined. Structures of modules were also outlined in this phase.

4/ *Detailed system design (DD)*: Modules of CAILUP were identified in detail, based on information and data collected during fieldwork. Each sub-program corresponds to a specific component in the calculation procedure. Suitable hardware and programming language for CAILUP were selected in this phase.

5/ *Implementation (IMP)*: The computer program was implemented and tested. First, the general structure of CAILUP was created as a framework for the system. Then, modules were gradually developed and linked to the frame.

6/ *Installation (INS)*: CAILUP was applied in a case study in the Mekong Delta. Additional data were collected during further fieldwork. The CAILUP model was calibrated on the basis of land use data for the period 1985-1990, subsequently validated on the basis of data for 1993-1994 and applied for analyzing effects of development scenarios.

7/ *Operation and control (O&C)*: This last phase in the SDM process will be carried out following the current study period. The research approach and CAILUP are proposed for application in other areas under similar conditions.

1.8 Because of the importance of documentation in SDM, after the completion of one or more phases, a report was prepared [Hoanh, 1993a, 1993b, 1994]. These reports were used as basic documents to build up expertise, and eventually served as building blocks for the thesis.

I.4 LIMITATION OF THE RESEARCH

1.9 As reflected in the thesis title, this study is limited to integrated land use planning in areas where irrigation is the key intervention. Integrated land use planning deals with multi-disciplinary, multi-sectoral and multi-level issues and has to take into account a large number of bio-physical and socio-economic factors. However, knowledge about interactions among these factors and the capacity of the human brain in handling and analyzing data, are limited. Therefore, CAILUP focuses mainly on integration and only deals with major problems and relevant factors.

1.10 The CAILUP approach may have to be generalized or adapted for application in regions with conditions similar to those of the pilot area, but equations and the corresponding computer programs should be modified to take into account the specific characteristics of each region.

1.11 Another limitation of the research is update of data and information in the case study area for modelling. In a developing region such as the Mekong Delta in Vietnam, factors affecting land use are changing very fast. Data update and model refinement, therefore, are always required to adapt to the requirements for planning for dynamic processes such as land use.

I.5 ORGANIZATION OF THE THESIS

1.12 In Chapter I (this Chapter), an introduction is given to the problem, objectives, the method and limitation of the research.

Chapter II, resulting from phases 1 and 2 in the SDM process, presents problems and current situations in land use planning, and CAILUP concepts.

Chapter III, an output from phase 3, introduces the general structure of CAILUP and each of its units. Interactions among units as well as among sub-models of the CAILUP model are discussed in this chapter.

Results from phases 4, 5 and 6, dealing with the detailed system design and implementation of CAILUP, and testing it for the Quan Lo Phung Hiep region, are presented in Chapter IV.

The thesis ends with conclusions and some recommendations in Chapter V.

CHAPTER II THE RESEARCH CONCEPT

II.1 MAJOR ISSUES IN LAND USE PLANNING METHODOLOGY DETERMINING THE CONCEPT OF CAILUP

2.1 Planning has been defined in a variety of ways [Roberts, 1978], for example:

(i) a means of making decisions concerning future actions;
(ii) an effort that places a high value on rationality and the utilization of knowledge;
(iii) a means of achieving the "social good" or realizing the "public interest";
(iv) a means of creating blueprints for the future;
(v) a synonym for management.

A comprehensive definition has been suggested by Conyers and Hills [1984]: "a continuous process which involves decisions, or choices, about alternative ways of using available resources, with the aim of achieving particular goals at some time in the future".

FAO [1993] defines land use planning as "the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options".

From these definitions, the requirements for CAILUP can be identified as follows:

(i) aiming at particular goals;
(ii) simulating a continuous process lasting into the future;
(iii) aiming at explicit bio-physical and socio-economic effects of interventions;
(iv) including decisions or choices;
(v) including formulation and evaluation of land use alternatives or scenarios.

2.2 Problems in land use planning have been indicated by Fresco [1994a]: "Today's paradox is that, notwithstanding the great technological advances and our increased knowledge of the natural resource base, land use planning has not become easier and the challenges are perhaps greater than ever." The greatest challenge is the diversity in land use, including land users, goals, management and technologies. From day to day, this diversity increases with the improvement in transport, trade and communication facilities, and it becomes so great that FAO [1993] has noted: "land cannot be graded from 'best' or 'worst' irrespective of the kind of use and management practise because each kind of use has special requirements." It implies that presently, in evaluating land, the 'use' of land has become more important than the land itself with its natural resources. Hence, land use planning does not focus on the resource potential, but on the 'use' potential. Land (resource) management has been converted to land use management.

The CAILUP approach takes into account the diversity in land use. By integrating promising land uses for agriculture, fisheries and forestry with land uses for other purposes such as settlement, infrastructure for public works, transport and irrigation, etc. CAILUP helps in identification of the potentials of land resources and of the conflicts in land use management for different objectives.

2.3 Land use planning is an essential activity in any country. Land use planning aims at making the 'best' use of limited resources to achieve an explicit set of objectives by [FAO, 1993]:

i) assessing present and future needs and systematically evaluating the land's ability to satisfy them;
ii) identifying and resolving conflicts between competing uses, between the needs of individuals and those of the community, and between the needs of the present generation and those of future generations;
iii) seeking sustainable use options and selecting those that best meet identified needs;
iv) planning to bring about desired changes;
v) learning from experience.

To attain these aims, CAILUP comprises the following capabilities:

(i) starting from current conditions;
(ii) estimating and testing desired changes in the future;
(iii) gaming with different scenarios.

2.4 Three major issues addressed in land use planning are [FAO, 1993]:

i) conflicts over land use as demands exceed the land resources available;
ii) inadequate access to land or benefits from its use for many people when land is still abundant;
iii) degradation of land resources.

CAILUP provides functions for:

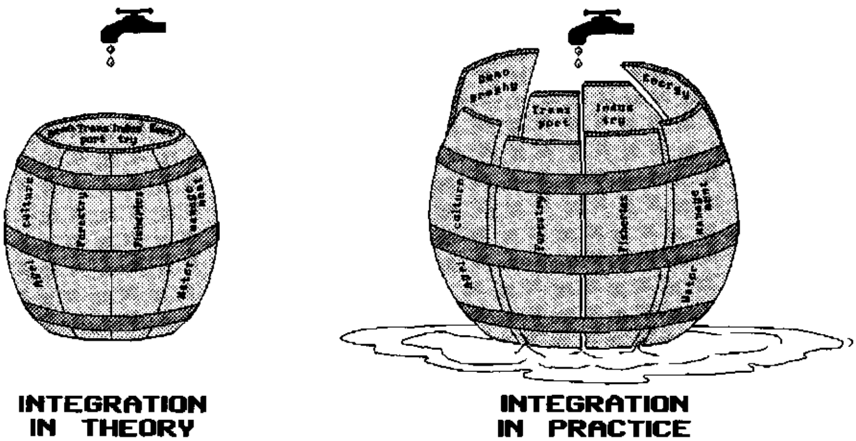
(i) balancing between demand and supply of land resources;
(ii) calculating benefits for land users;
(iii) analyzing long-term impacts.

2.5 Although it is non-sectoral by definition, the land use plan has to be implemented by sectoral agencies [FAO, 1993]. Land use planning can be considered as a process of multi-sectoral integration to improve the consistency of supporting actions from various agencies relating to land use, but not to replace sectoral planning. Integration of disciplines and sectors, therefore, is a major issue in land use planning. This integration is necessary to [Luning, 1986]:

(i) aid communication and cooperation;
(ii) link natural resource studies to the social and economic development process;
(iii) improve resource use efficiency;
(iv) help ensure that all parties in the development process are aiming at the same goals.

Even if in many cases, land use planning can be considered a form of (regional) agricultural planning, it is an intermediate level planning of sectors and regions within the national economy, therefore it should not be too much isolated from other sectors and regions of a country [Fresco et al. 1992]. FAO guidelines emphasize: "Planning has to integrate information... Therefore, land use planning is not sectoral... An integrated approach has to be carried down the line from strategic planning at the national level to the details of individual projects and programmes at district and local levels." [FAO, 1993]. "Land use planners and managers are now faced with having to evaluate a wide range of considerations from physical to economic and social. The need for integrated land evaluation will thus become more pressing." [Davidson, 1992]. The normal situation in integrating different sectors into a common plan is illustrated in Figure 2.

Figure 2: Integration in theory and in practice. [Idea from Tran et al., 1987]



In CAILUP, integration is not only addition or multiplication to combine different parts or plans from different sectors, but it includes deletion of detail through 'a fine filter' to allow incorporation of the various parts in the framework of a common plan. With respect to the functions of each sector in the development process, the institutional structure is taken into account in formulating components in CAILUP.

2.6 There are several reasons why a permanent <u>institution</u> that is responsible for land use planning does not exist in many countries:

i) There is no clear boundary between land use planning and other aspects of rural development. Land use planning is non-sectoral, but a land use plan has to be implemented by sectoral agencies [FAO, 1993]. Land use planning involves integration of various established disciplines (engineering, agricultural and social sciences) [FAO, 1993];

ii) An special institution for such planning would have to cover too wide a range of subjects, and thus become unwieldy, while many of its activities would overlap with those of sectoral agencies. Therefore, very often a multi-disciplinary team is set up during a project in which land use planning is considered, and when the project is finalized, the sectoral agencies will continue by incorporating the land use plan in their sectoral plans, with a weaker coordination;

iii) Depending on the development plan, different phases of development require different sectoral agencies taking the lead in land use planning. Such allocation of responsibilities is always needed to help the Government accomplish basic infrastructures under limited financial resources.

In most countries, there is an agency in charge of 'land management', which considers land as a piece of the earth's surface, but does not focus on its qualities for different uses. Inventories by such an agency can be used as basic information on land resources to allocate land to land use types.

In CAILUP, a key intervention is determined, e.g. construction of a water management system for an irrigated region. Other bio-physical and socio-economic interventions such as application of fertilizer, improvement of transportation, a birth control programme, low interest credit, etc., are supplementary interventions to improve water management efficiency. When the water management construction is realized, a new planning phase with other key intervention(s) will be started.

2.7 Land use planning has to be carried out at many levels, from national to district (or regional) and village level, and needs a wide range of special expertise [FAO, 1993]. This requirement, again, indicates that coordination is an important aspect in land use planning. Without effective coordination, many agencies at different levels or in different sectors each may produce their own land use plans with different objectives.

FAO guidelines propose 10 steps in land use planning [FAO, 1993]:

Step 1: Establish goals and terms of reference.
Step 2: Organize the work.
Step 3: Analyze the problems.
Step 4: Identify opportunities for change.
Step 5: Evaluate land suitability
Step 6: Appraise the alternatives: environmental, economic and social analysis.
Step 7: Choose the best options.
Step 8: Prepare the land use plan.
Step 9: Implement the land use plan.
Step 10: Monitor and revise the plan.

In this procedure, a major activity is the selection of land use alternatives based on land evaluation (LE) carried out in steps 5 to 7 [FAO, 1993]. Land evaluation methods have been proposed by FAO since 1976 [FAO, 1976] and at present cover various land use types [FAO, 1983; 1984; 1985; 1991a]. The key activity in the FAO method can be summarized as a process of matching land requirements and land qualities to assess land use suitability. Two-stage or parallel approaches can be applied, depending on how bio-physical evaluation and socio-economic analysis are combined.

Some authors consider the FAO land evaluation methodology basically as a top-down approach and have noted that it often failed during recent years [Fox, 1986; van Diepen et al., 1991; Huizing, 1991]. From the 1970's onwards, new methodologies such as farming system analysis (FSA) have been developed and widely applied to take into account the preferences and priorities of the local land users in a bottom-up approach [FAO, 1990; Huizing, 1991; Hengsdijk & Kruseman, 1993] on the basis of diagnostic procedures. FAO also pays attention to the bottom-up planning with its advantages and disadvantages [FAO, 1993] and has proposed a two-way procedure linking planning at different administrative levels [FAO, 1993; 1995]. Land use planning at regional (sub-national) level comes to grips with the diversity of the land and its suitability to meet particular goals. At this level, conflicts between national and local interests will have to be resolved [FAO, 1993].

It is realized that land evaluation (LE) and farming system analysis (FSA) are complementary and need to be integrated. The LEFSA (LE+FSA) sequence was suggested in guidelines prepared by ITC (International Institute for Aerospace Survey and Earth Sciences, The Netherlands) and Wageningen University (The Netherlands) at the request of FAO [Fresco et al., 1992]. However, as indicated by the authors of LEFSA, LE and FSA stem from very diverse backgrounds and incorporation of LEFSA into existing land use planning and technology development procedures will be a lengthy and difficult process. The authors of LEFSA also noted that in some cases it may be useful to select appropriate elements rather than the entire sequence, and recommended that an application programme be formulated to further elaborate and test it [Fresco et al, 1992]. Remaining questions are: 'Can their integration fill the gaps in each approach?' and 'How to integrate them in practice?'.

CAILUP takes into account the integration among hierarchical levels by combining top-down and bottom-up approaches to help planners in answering questions from decision-makers. Simulation of the decision-making process is an appropriate method. In the first step, decision-makers are assumed to apply a top-down approach in selecting interventions based on the goals of regional development in the context of the whole country. In the second step, decision-makers have to verify the feasibility of these interventions by following a bottom-up approach taking into account the preferences and priorities of the local land users. In the final step, all achievements and impacts from these interventions are evaluated by comparison with socio-economic and environmental goals.

2.8 Planning is for people [FAO, 1993]. However, in the FAO method, it was recommended that "People are considered to the extent that they participate in land use, and then not as actors but as management skill or labour" [van Diepen et al., 1991]. As both planning and plan implementation are carried out by people, the planning method should be acceptable to the people having to implement it, as should be the output (the land use plan).

Three categories of people are involved in land use planning, i.e. land users, decision-makers and the planning team [FAO, 1993].

i) Land users, defined more broadly than only farmers living in the planning area and/or using it, but also the people who depend on their products and are affected by their use of the land. By this definition, 'land users' may include traders and consumers [Hengsdijk & Kruseman, 1993] who influence indirectly, but not less importantly, land use decisions.

ii) Decision-makers, who bear overall responsibility for planning and for plan-implementation. The land use plan is implemented by sectoral agencies through their sectoral plans under the supervision of decision-makers.

iii) The planning team has to formulate and analyse the land use scenario. This team has to comprise a wide range of special expertise. Contributions of research scientists to regional development are more effective if they are incorporated in the plan prepared by the planning team.

Recently, FAO has identified: "land users and other stakeholders, or interested parties, are individuals, communities or governments that have a traditional, current or future right to co-decide on the use of the land." [FAO, 1995].

Within the current socio-economic conditions in both national and international contexts, decisions on land use are not only made by decision-makers or farmers, but they can be considered as 'public decisions' with contributions from scientists, planners, decision-makers, sectoral agencies and land users. However, within these groups, different opinions may exist, for example, "a major constraint in land use planning highlights the differential time horizon between decision-makers and planners or scientists" [Fresco, 1994b]. Depending on local bio-physical and socio-economic conditions, in a certain period, each group may play a major role in the decision. In these groups, planners are considered the most knowledgeable in integrating knowledge and objectives from the others.

Therefore CAILUP is designed to help planners in land use planning to answer questions from decision-makers. These questions are mainly related to impacts on bio-physical and socio-economic aspects of land use and may also be based on reactions from land users to interventions carried out by sectoral agencies.

2.9 Every year, or every season, or every month, land use decisions are being made; they cannot be delayed because of lack of knowledge, data, maps, manpower, funds, etc. Even if the quality of the plan is low due to the shortage of basic data, a plan should be formulated, then the knowledge and information gaps are identified and gradually filled through monitoring and research. Therefore, land use planning is considered an applied science, and may present a conflict between "the desire for deeper scientific understanding and the need for the design of rapidly applicable methodology and corresponding tools" [Fresco, 1994b].

CAILUP combines both objectives of an applied science: a tool for rapid application and a tool for scientific research. The first version is developed for the need of application, then gradually refined to become a tool to improve the knowledge about the interactions among factors.

2.10 Land use planning implies weighting of trade-offs among conflicting goals [FAO, 1993], as diverse interests exist in society. The two major themes are land as a resource and land as part of the environment, and the latter is increasingly emphasized today [Vlasin & Bronstein, 1978]. Land use planning does not aim at providing values of future production or land use maps, but at assessing positive and negative impacts on production, socio-economic conditions and environment of alternative series of actions to exploit land resources. The 'best' alternative in land use is always dependent on the objectives to be pursued [Fresco et al., 1992]. Land use planning should result in the identification of projects and/or programmes, and it is important in land use planning to suggest changes in policies that do affect the use of land [Fresco et al, 1992]. Various decision-making techniques have been applied for the selection of land use types [Cohon, 1978; Romero & Rehman, 1989; Sharifi, 1992a], but due to the lack of a universally applicable method for public decision-making problems [Cohon, 1978], different rankings for land use alternatives may result. Even an individual has multiple objectives, therefore, optimization requires methods that assign weights and priorities to the different objectives [Brinkman, 1994]. Two approaches have been applied to identify the best alternative in planning:

i) on the basis of all possible alternatives by applying mathematical utilities as optimization techniques;

ii) on the basis of a limited set of alternatives, according to 'good enough' or 'satisfactory' alternative [Turban, 1993].

CAILUP provides functions for establishing priorities by simple multicriteria methods [Nijkamp et al., 1990]. *In view of the diversity and increasing numbers of factors and goals in integrated land use planning, and the 'bounded rationality' of human capacity* [Turban, 1993] *the second method in finding the best alternative is applied in CAILUP.*

2.11 Integration of bio-physical and socio-economic factors is necessary in land use planning, which is still a problem, due to differences in accuracy in estimation of intervention impacts with higher accuracy levels in the bio-physical realm. Moreover, differences in spatial and temporal resolution are also an important issue in such integration. The spatial and temporal resolution of bio-physical factors, such as soil types, climate, water conditions, etc. is usually higher than that of socio-economic factors, such as market prices, availability of capital, etc. Integration becomes extremely complicated when many technical, socio-economic and environmental criteria have to be considered. FAO [1993] proposed that after the physical evaluation in Step 5, the analysis of environmental, economic and social impacts is carried out in Step 6 (see 2.7).

In CAILUP, integration requires the same resolution (in space and time) of data on both bio-physical and socio-economic factors. Land units that are homogenous with respect to the relevant characteristics, have similar problems and opportunities and will respond in similar ways to management [FAO, 1993] *are identified in CAILUP. A problem is that the relevant socio-economic factors are very dynamic and are generally not reported in the same spatial and temporal format as are bio-physical factors, but per administrative unit, for example, in the population census.*

As indicated in the FAO guidelines, planners have to work with land units and decision-making (administrative) units simultaneously [FAO, 1993], *hence, land units delineated by administrative boundaries and limits of key physical interventions are appropriate in integrated planning. Special techniques such as grouping of farm systems* [Hazell & Norton, 1986; Schipper, 1991] *and land use classification* [Mucher, 1992; Mucher et al., 1992] *can be applied for each land unit.*

2.12 There are various definitions and classifications related to the goals in planning. For example, three levels of goals: goals, objectives and targets were identified by Hall [1975: in Roberts, 1978] or objectives, principles and standards, etc. Romero and Rehman [1989] defined a criterion comprising attribute, objective, goal or target. Decision-makers have to trade-off among decision-making criteria [Romero & Rehman, 1989]. Goals in land use planning (= the 'best' use of the land) can be grouped under the headings of efficiency, equity and acceptability, and sustainability [FAO, 1993]. Efficiency is achieved by matching different land uses with the areas that will yield the greatest benefits at the least cost. Equity refers to the reduction of inequality or, alternatively, to attack absolute poverty [FAO, 1993]. Sustainability may be defined as meeting the needs of the present without compromising the ability of future generations to meet their needs [WCED, 1987], or in other words, to maintain productivity when subject to stress or perturbation [Conway, 1985]. FAO has indicated: "An integrated approach to planning the use and management of land resources ... requires the identification and establishment of a use or non-use of each land unit that is technically appropriate, economically viable, socially acceptable and environmentally non-degrading" [FAO, 1995].

Assessment of the impacts of a land use plan requires a technique for estimating the effects of bio-physical and socio-economic conditions during a long period over a large spatial extent, when the land use plan is implemented. For such a complex problem, a qualitative approach (conventional land evaluation) seems to be suitable, but in fact it causes confusions [van Diepen, 1982; Fox, 1986; van Diepen et al., 1991] to the planner because of its flexibility and difficulty in comparison of achievements from different land use types. With the support of a computer, a quantitative approach may help the planner to avoid these confusions.

In CAILUP, goals are explicitly expressed in quantitative values. However, decision-makers or farmers do not always clearly define indicators representing their goals, and usually express development goals in qualitative form. In this case, planners have to help them in the selection of indicators, and in the conversion of qualitative terms to quantitative values. It should be noted that distinguishing between 'qualitative' and 'quantitative' is relative and depending on the objectives of expression. For example, production can be expressed in tonnes by an exporter, but also in number of oxcar loads by farmers; or 'the time to go hungry again', a measure for rice quality under a subsistence economy is being replaced by US$/tonne under a market economy.

2.13 However, due to lack of knowledge [Fresco et al. 1992], "what we know of social, economic, and environmental behaviour is much less than what we do not know" [Holling, 1978], and the uncertain future [Holling, 1978; Gittinger, 1982; Fresco et al., 1992; Fresco, 1994a], an analysis of risk and uncertainty has always to be involved in planning. In this situation, gaming [Hazell & Norton, 1986; van Schaik, 1988; Romero and Rehman, 1989; Hengsdijk & Kruseman, 1993] is a useful method.

In CAILUP, evaluation of land use scenarios comprises both, effects of land resource exploitation (production, economic benefits, etc.) and impacts on the environment. CAILUP provides functions for ranking the land use alternatives and can be used as a gaming tool to analyze the impact of different hypotheses or scenarios formulated by planners.

2.14 Water management is considered a key intervention in integrated land and water resources development for an irrigated area. Different viewpoints on water management exist:

- For an agronomist, it is a key intervention to increase agricultural production;
- For an environmentalist, it is an action with both positive and negative environmental impacts, and therefore, a technique for environmental management;
- For an economist, it is an investment for improving production and water user's income;
- For a sociologist, it is a tool for reducing differences in income;
- For a decision-maker, it is a tool for influencing long-term development of the region.

Land use (or land and water resources planning), therefore, has to consider both individual projects with specific objectives and general policies [FAO, 1993], i.e. it requires projects to improve natural resource management and appropriate policies acting as driving force to achieve project objectives. However, a recent FAO draft report contains the following complaint: "... very little progress has been made in developing a relationship between Government policy and land use decision making..." [FAO, 1994, cited in Luning, 1995].

CAILUP is designed as a tool for both purposes, i.e. appraisal of a water management project and analysis of the effects of Government policy on land use.

2.15 Currently, the economic view of development is not only limited to the growth of GNP (Gross National Product) or GNP per capita, but extends to the redistribution of growth [Todaro, 1992; Hengsdijk & Kruseman, 1993]. In agricultural development, a major issue is the transition from subsistence to diversified and specialized production for the market [Todaro, 1992]. Therefore, the goals in land use planning should not be limited to high production or income, but extend to socio-economic and environmental objectives.

A land use plan is considered a large and long-term project which has to be evaluated. The concept of 'without' and 'with' cases in project appraisal [Gittinger, 1982] *is applied in CAILUP. The output is a comparison between 'without' and 'with' interventions to help decision-makers make a selection. Various scenarios of 'with' interventions may be developed, but only one 'without' case is formulated on the basis of current conditions and used as 'base scenario'. All 'with' cases are compared to this base scenario for evaluation.*

II.2 INTEGRATION OF EXPERTISE IN LAND USE PLANNING

2.16 A land use planning team needs to comprise a wide range of expertise [FAO, 1993], because land use is a multi-disciplinary and multi-sectoral activity. Expertise for land use planning is available from two sources, i.e. local (regional and national) and global (international). Local expertise includes knowledge of all groups with a stake in land use, as discussed under 2.8, and is concentrated in a planner group. In recent years, local expertise has improved in many developing countries and should be considered as a major human resource in planning. For bio-physical factors, global expertise on advanced technology may be adapted to local conditions, while for socio-economic factors, local expertise is essential for each region (sub-national level).

For both short-term and long-term, the methodology and technique applied in land use planning should be applicable to local conditions. FAO also noted that its guidelines should always be adapted to the local situation [FAO, 1993]. External assistance (for instance, from an international organization) for land use planning at a certain point in time will not be effective if the local population cannot follow up the planning process, in particular in view of the present rapid changes in socio-economic conditions.

CAILUP consists of a knowledge base that integrates expert knowledge from both local (regional and national) and global expertise.

2.17 Planning is a learning process and can best be learned by doing [FAO, 1992]. Knowledge on interactions among components in land use can be derived from literature and/or experiments. However, with increasing diversity in land use, knowledge on interactions among factors is not always available from literature or could be extracted from experiments, therefore, expert knowledge is acceptable to establish the rule base for planning. 'Expert' knowledge has been, more and more, applied in land use planning. For example, Bouma et al. [1991] have distinguished five levels for the soils input into systems approaches for agricultural development, i.e.

Level 1 Farmer's knowledge;
Level 2 Expert knowledge and associated data needs;
Level 3 Simple capacity models and associated data needs;
Level 4 Complex mechanistic models and associated data needs;
Level 5 Very complex models for subprocesses and associated data needs,

or "Existing (expert) knowledge and local knowledge specific for a study area on relations between land, land management and crop yields is used to assess proportional yields for land qualities." [Huizing et al., 1994].

CAILUP is formulated in a flexible way to include expert knowledge with qualitative judgement rather than precise mathematical calculations.

II.3 COMPUTER TECHNOLOGY APPLICATIONS IN LAND USE PLANNING

2.18 During recent years, computer science has made a significant progress, especially the availability and quality of hardware and software packages has increased. Currently, microcomputers are a familiar tool in many developing countries. In addition to a large calculation capacity for modelling and efficient data handling through database management systems, microcomputers have become a tool for spatial and temporal analyses, and for communication with many graphic software packages. Therefore, the most promising tools for land use planning are: database management systems, geographic information systems (GIS) and modelling [Fresco et al., 1992].

Land use planning is a complicated process that is impossible to standardize. Therefore customers of any specific planning software package are so limited that they do not represent a lucrative market to attract investment by the computer industry. Most models or software packages listed in 2.20 below have been developed for scientific research rather than for commercial purposes. To some extent, this phenomenon limits the application of advanced computer technology in these models and software packages as well as their distribution to a wider group of users.

With the advance of computer technology, many new concepts and techniques have been or can be applied in land use planning, such as decision support systems and expert systems [Fresco et al., 1992; Sharifi, 1992a]. The basic idea underlying an 'expert system' is simple. Expertise is transferred in a structured fashion from the human brain to the computer so that the computer can generate specific advice, and explain, if necessary, the logic behind the advice [Turban, 1993].

An expert system will never replace 'a human expert', but can do more than a human expert [Naylor, 1987]. FAO [1993] also indicated that "the procedure is the same whether a computer is used or not, but the computer package enables the decision-maker to take account of much more information and to learn from predicted consequences of alternative decisions". However, in investigating the effectiveness of decision support systems, van Schaik [1988] concluded that the quality of decision-making is hardly influenced by the availability of a decision support system, while it is significantly improved when decision-makers understand the sequence of steps to be taken in the decision-making process. This conclusion points to the requirement for a decision support system with explicit description of the processes in the system in a lucid way for the users.

CAILUP includes all advantages of computer applications in the planning process. The greatest advantage in computer applications compared with conventional methods is the large calculation capacity, that allows planners gaming with a large number of land use scenarios.

2.19 Main components of an integrated land evaluation system are [van Diepen et al., 1991]:

(i) a geographic information system (GIS) with bio-physical and socio-economic information;
(ii) a database management system;
(iii) analytical tools (models) to assess physical land use performance and formulation of land use scenarios;
(iv) analytical tools for evaluating land use scenarios.

CAILUP focuses on the two last components, but comprises all above components in a structure suitable for the functioning of the system as a whole.

2.20 Many techniques and models related to land use planning have been developed as summarized by van Diepen et al. [1991], Davidson [1992], and Chidley et al. [1993]. Models can be classified in different types, depending on the criteria used such as research and management models, deterministic and stochastic models, reductionistic and holistic models, static and dynamic models, linear models and nonlinear models, causal and black box models. Or they can, depending on the subject, be described such as biodemographic, bioenergetic or biogeochemical types in ecological models [Jorgensen, 1994]. Or, depending on the modelling techniques, as iconic (physical models), analog (analogous but not physical, including conceptual models) and symbolic (mathematical models) [Dykstra, 1982].

On the basis of their functions in integrated land use planning, models can be classified in the following types:

i) Models describing interactions among physical factors: climate, soil, water such as HEC-1 [U.S. Army Corps of Engineers, 1987: in Chow et al., 1988], SSARR [U.S. Army Corps of Engineers, 1987], VRSAP [Khue, 1991a, 1991b; NEDECO, 1992a], SAL [NEDECO, 1992b], DUFLOW [Spaans et al., 1992], TRISULA [Delft Hydraulics, 1988], SAFLOW [Delft Hydraulics, 1989], etc. These models are used to estimate physical conditions in natural situations or under human activities.

ii) Models describing interactions among physical (climate, soil, water) and biological factors (crops) such as LECS [Wood & Dent, 1983: in Fresco et al., 1992], RICEMOD [McMennamy & O'Toole, 1983], IBSNAT [Uehara, G. & G.Y. Tsuji, 1991], QUEFTS [Janssen et al., 1989: in van Diepen et al., 1991], WOFOST [van Diepen et al., 1988], CERES [Godwin et al., 1990: in Bachelet & Gay, 1991], ALES [Rossiter & van Wambeke, 1993], SWACROP [Wesseling et al., 1989], MACROS [Penning de Vries et al., 1989], RICESYS [Graf et al., 1991: in Bachelet & Gay, 1991], PLANTGRO [Hackett et al., 1991], CROPWAT [Smith, 1992], ORYZA1 [Kropff et al., 1994], etc. These models are used to estimate crop yield or crop suitability under natural conditions or under various management regimes. Bio-physical factors are the focus in these models while socio-economic factors are excluded or only used as boundary conditions.

iii) Models describing interactions among socio-economic factors such as population, income, net present value, internal rate of return, etc. Contrary to type ii), in these models bio-physical factors are used as boundary conditions. Several software packages for linear programming such as MPSX [IBM, in: Hazell & Norton, 1986], PC-PROG [Kalvelagen, 1988], MicroLP [Scicon Ltd., 1989], XPRESS-MP [Dash Associates, 1991], GAMS [Brooke et al., 1988: in NEDECO, 1993b], etc., can be used for this type of models. Some other models have been applied to questions of policy [Hazell & Norton, 1986].

iv) Models developed for the formulation and evaluation of land use plans, or in land use management such as LESA [Wright, 1983: in van Diepen et al., 1991], LEM2 [Smit et al., 1984: in van Diepen et al., 1991], LUPLAN [Cocks et al., 1983, 1986], CRIES [Schultink, 1987], LUPIS [Ive et al., 1988], MULBUD [Etherington & Matthews, 1985: in van Diepen et al., 1991], CAPPA [Verceuil, 1990; Maetz, 1991; FAO, 1991b], ARIS [Sharifi, 1992b], etc. These models can be considered decision support systems or expert systems focusing on integration of bio-physical and socio-economic factors.

Another approach to computer applications in land use planning is to provide a database with some functions for combining different models for land use planning [FAO, 1995], such as SOTER [Engelen & Wen, 1995], STIPA, CLICOM, APT, CYPPAC, AEZ-CCS, PERFECT, CIMIS [in Chidley et al. 1993], ECOCROP [FAO, 1994], CYSLAMB [in: Brinkman, 1994], Land Use Database [de Bie et al., 1996].

In integrated land use planning, management models are needed, but many of the existing models, in particular type ii), are research models [Versteeg & van Keulen, 1986] and spatial aspects are often neglected [van Wijingaarden, 1991]. Taking into account the problem of data quality [van Keulen, 1990] and their level of detail, these models would be rather used to provide a knowledge base (such as effects of physical interventions, interactions among physical factors and biological indicators) to integrated land use planning rather than be included in model structure.

It should be emphasized that the argument 'a more complex model should be able to account more accurately for the complexity of the real system' is not true because the increasing number of parameters will lead to an increase in uncertainty [Jorgensen, 1994]. Versteeg and van Keulen [1986] have remarked: "... some simple calculation methods produce predictions of production potentials of irrigated crops in different environments similar to those obtained from computer simulation models." Therefore, the International Workshop on Quantified Land Evaluation Procedures, Washington, D.C. 1986, recommended further research on "Simple models that are less demanding of data and computing facilities while still giving useful predictions." [Beek et al., 1986].

Modelling is a promising technique within CAILUP, but for integrated land use planning, the strategy in modelling of CAILUP is to integrate simple sub-models of all sectors rather than only to include a few complex sub-models developed for single disciplinary research.

2.21 Local conditions are a main problem in the application of models, as expressed by van Diepen et al. [1991]: "deterministic models usually need calibration or 'fine tuning' when applied to new situations in spite of their promise of universal applicability." or "there are questions of scale, validation of models developed in other environments, appropriate systems and hardware, the values of expert systems to assist extension staff". [Beek et al., 1986]. Therefore, a region-specific structure is required, and depending on local problems, the above models may be applied.

CAILUP is developed on the basis of local problem-identification and adapted on the basis of local knowledge in computer applications as well as available facilities.

2.22 In addition to the complexity and diversity of the real world which affect model validation, the availability of reliable input data is also a major issue. Validation of a model is so difficult, or quite often impossible [Fresco, 1994a]. Holling [1978] has remarked: "Note that no model - mental or mathematical - is 'true'. Because degrees of credibility and usefulness can be defined, not, as is often done, by attempting to tune parameters to fit a given set of historical data; rather, the effort should be directed to invalidate, and not to validate the model."

In the bio-physical realm, models can be calibrated and validated on the basis of experimental data, therefore modelling in this realm has been successfully developed. On the other hand, in the socio-economic realm, experiments to generate data for validation are difficult to be implemented, and 'history never repeats', thus the validation of models is more limited. However, Jørgensen [1994] has indicated that if validation cannot be obtained as expected, the model can always be used as a management tool to present all the open questions to decision-makers.

Validation of a system for integrated planning as CAILUP is based on both experimental data and 'expert' judgement.

2.23 Integrated land use planning always deals with various goals. Multiple goal analysis techniques, mostly based on linear programming, are proposed to optimize (maximize or minimize) a number of development goals [Ayyad & van Keulen, 1987; de Wit et al., 1988; Shakya et al., 1989; van Diepen et al. 1991; van Keulen, 1991; Huizing, 1992; Erenstein & Schipper, 1992]. These techniques have been applied in explorative studies aiming at exploring possibilities and potentials for a particular farm or region in the long run [Rabbinge & Ittersum, 1994], and can be much better incorporated in policy formulation [Davidson, 1992].

Multicriteria evaluation is applied in CAILUP to assess policy implications. Optimization through linear programming can be applied under appropriate conditions.

II.4 AN APPROPRIATE METHOD FOR INTEGRATED LAND USE PLANNING

2.24 Integration is a major issue in land use planning. CAILUP focuses on four types of integration:

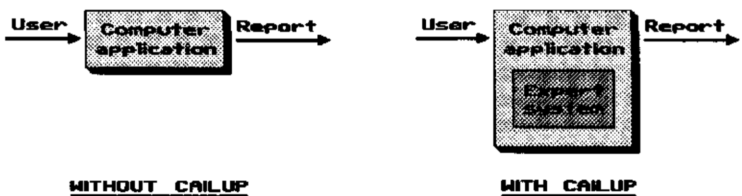
i) between land use selections at different hierarchical levels;
ii) between bio-physical and socio-economic factors;
iii) between local expertise and global (international) expertise;
iv) between computer technology and land use planning.

2.25 An IBS (Integrated Bio-physical and Socio-economic) approach is proposed to assess the effects of water management based on the following concepts:

- Sustainable development should not only consider bio-physical but also socio-economic aspects;
- Multisectoral integration at different hierarchical levels is required to guarantee harmony between projects and policy;
- Water is considered a major environmental factor, a basic requirement for human life and an economic good for production.

2.26 CAILUP represents the concept of an <u>expert system</u> embedded within a computer application [Harmon & Sawyer, 1990] (Fig. 3).

Figure 3: With and without CAILUP [adapted from Harmon & Sawyer, 1990].



The computer application illustrated in Figure 3 comprises database management, modelling and GIS. The expert system, broadly defined, is a knowledge base interacting with the model unit in CAILUP and consists of a set of rules that are executed when triggered by appropriate conditions [Naylor, 1987]. With the knowledge base representing the expertise, a non-expert can achieve performance comparable to that of an expert in that particular problem domain [Davis & Olson, 1985].

2.27 CAILUP is only a <u>computerized aid</u>, therefore:

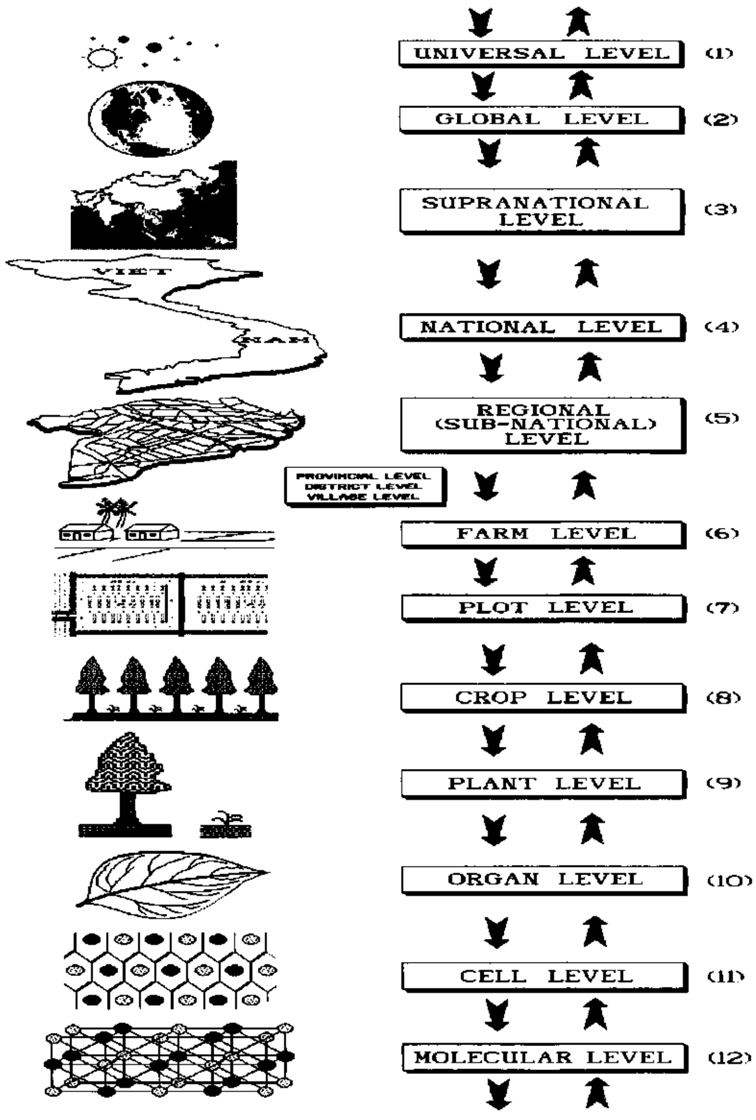
- CAILUP does neither replace planners in land use planning, nor does it contain everything required in land use planning such as data, maps, tables, graphs;
- CAILUP aids planners in steps in which computerization is helpful, i.e. activities from steps 3 through 8 in the 10 steps of land use planning proposed by FAO [1993] mentioned in 2.7. However, data processing should precede these steps before using CAILUP, in particular to provide a knowledge base used in models. Identifying the limitations of CAILUP is one important issue to be considered by the user.

2.28 Depending on the objectives of analysis, different <u>spatial levels</u> may be selected for modelling. For example, in models of pedogenesis, eleven different levels of hierarchy can be distinguished, i.e. [Hoosbeek and Bryant, 1992: in Bouma & Beek, 1994]

(i-4)	molecular	(i)	pedon	(i+4)	region
(i-3)	basic structure	(i+1)	field	(i+5)	continental
(i-2)	secondary structure	(i+2)	catena/watershed	(i+6)	world level
(i-1)	soil horizon	(i+3)	county		

Similar spatial levels can be applied to analyze the effects of policy in land use, depending on the type of interventions, as shown in Fig. 4.

Figure 4: Spatial levels in modelling.

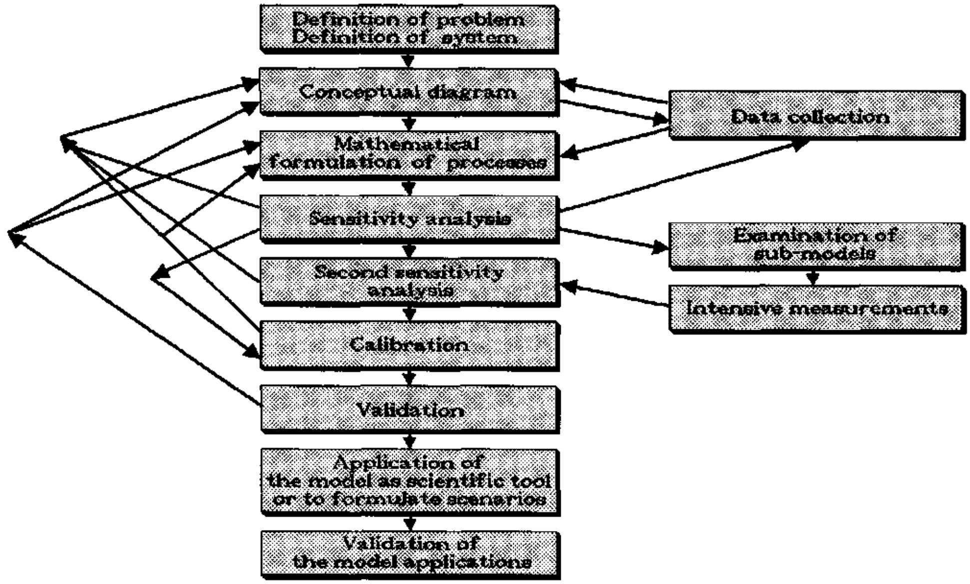


Each level is affected by and also influences higher and lower levels. Because an irrigation system usually covers areas exceeding a farm or village, and expertise and data at regional level are available for use of a computer aided system, CAILUP is developed for the regional level.

2.29 Simulation modelling is a promising technique in land use planning to achieve the integration [van Diepen et al., 1991; van Keulen, 1991; Fresco et al., 1992, FAO, 1993]. A model is a simplified representation of a system, defined as "a limited part of reality with related elements" [van Keulen, 1990], or "a representation or abstraction of an actual object or situation" [Dykstra, 1982]. It can be used as a management tool, as well as a scientific tool in survey of complex systems, in revealing system properties, the gaps in our knowledge and in tests of scientific hypotheses [Jorgensen, 1994]. Models are used in 'conditional predictions' to answer the question 'what if' [Vercueil, 1990; Bouma and Beek, 1994]. In CAILUP, the model is a major component to realize the system function, not to predict what will happens in the future, but to identify possibilities if interventions are implemented in the region.

For system analysis and simulation in agro-ecology, Rabbinge and de Wit [1989] introduced ten steps in model building to formulate a conceptual model, a comprehensive model and consequently a summary model. The modelling procedure proposed by Jørgensen [1994] is applied in CAILUP, as shown in Figure 5.

Figure 5: Modelling procedure [Jørgensen, 1994].



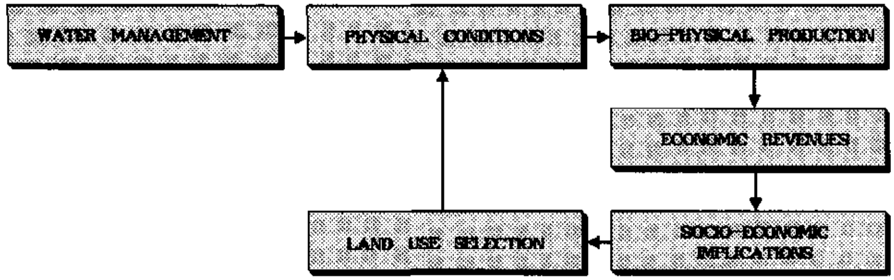
Models include interactions among components with a common hierarchical structure expressing causal relations in the form of equations, graphs or tables based on knowledge of sectoral experts. Hypotheses or assumptions are used to take into account uncertainty, and information gaps are identified. In this way, bio-physical and socio-economic factors can be integrated as they are in the real world. Simulation of the planning process guarantees that the decision quality is at least equal to (or better than) that achieved without the help of CAILUP.

2.30 Land use scenarios are evaluated through integrating the effects of bio-physical and socio-economic factors. Fresco [1994a] has remarked "Scenarios are not to be confused with forecasts: they do not predict, but allow us to explore technical options based on explicit assumptions given a set of goals."

In CAILUP, a scenario comprises a set of actions and effects in which goals are achieved to a certain degree (possibly not completely, and taking into account side effects). A scenario is usually identified by a specific name, e.g. maximize rice production, maximize income, that expresses the strategy to achieve goals while focusing on one specific goal.

The simulation sequence in CAILUP is shown in Figure 6.

Figure 6: Simulation sequence in CAILUP.



Starting from the current conditions, the impact of physical interventions (water management) on the physical conditions is first evaluated. These new physical conditions lead to new bio-physical production levels from different land use types*. These new production levels are used to determine an integrated feasibility for each land use type by comparison with socio-economic criteria at farm level. This feasibility is used, by combining with Government policy objectives, to formulate a land use plan at regional level. Achievements from this plan and its impacts on bio-physical and socio-economic conditions have to be examined to modify the plan or to take them into account in subsequent years.

2.31 The knowledge base in CAILUP is formulated on the basis of an expert system. First, simple interactions among factors are established on the basis of expertise from planners. Then, the rules of interactions are revised by comparison with knowledge of scientists, from literature, and from the local population. To incorporate expertise into CAILUP, the AEAM (Adaptive Environmental Assessment and Management [Holling, 1978; Mekong Secretariat, 1982; ESSA, 1982; Walters, 1986]) procedure with several workshops is a promising technique.

* Yet there is no satisfactory and commonly accepted method of defining and classifying land use globally [van de Putte, 1989; Turner II et al., 1995], although attempts have been made to develop such a method [Stomph et al., 1994]. Hence in CAILUP, local definitions are considered most appropriate.

Integration of local expertise and international expertise is proposed to be carried out gradually in two steps. In the first step, on the basis of local expertise, models are developed and land use scenarios are formulated. This step may result in a simple system with a high capability of communication. In the second step, international expertise, expressed in more accurate process descriptions or more advanced models, gradually improves or replaces local models, if necessary and suitable. Subsequently, CAILUP is refined and improved on the basis of both local and global expertise during the ongoing planning process.

The system developed in such a way is appropriate to local conditions, and also helps to judge the applicability of global models. Transfer of technology is realized through the gradual improvement of the system on the basis of global expertise. The system should have a flexible structure consisting of individual modules that can be linked to/replaced by alternative modules, and should be as independent as possible of hardware, software and lifeware (user) requirements.

2.32 Integration in 'public decision' is carried out by simulating the decision process. Human behaviour is probably impossible to predict. However, in most cases, decisions on land use are based on logical reasoning, thus the techniques of decision support systems can be applied. By gaming with models, different alternatives can be tested and conflicts among groups can be identified. Conflicts cannot be solved by CAILUP, but it may help to explicitize the trade-offs in 'public decision'.

2.33 Integration of computer technology and land use planning will be achieved by developing a system consisting of quantitative models, databases and GIS based on the concepts of decision support systems and expert systems. The capability of computer technology to provide diagrams, spread sheets and graphic views will be very helpful for analysis and communication.

Many software packages for database management, worksheet calculation, GIS, etc. have been developed and are rapidly improving. The user is advised to use existing software packages rather than to develop his own program with similar functions. Therefore, CAILUP will consist of individual modules using as much as possible available software packages.

2.34 The major objective of CAILUP is integration rather than improvement of individual components, such as crop-yield models with higher accuracy or better economic calculations, although options for improvements may be identified, recommended and implemented during integration of the various components.

Planning includes monitoring and evaluating the results to revise the plan [Roberts, 1978; van den Hoek, 1992; FAO, 1993]. CAILUP is used to simulate a dynamic process, i.e. input and output data may vary with respect to space and time. CAILUP itself is also dynamic, i.e. all units may be modified and improved as improved knowledge or computer facilities become available.

CAILUP is not an automated tool. One objective of CAILUP is to integrate expertise from different sources. An automated tool is useful in saving labour and time, but not effective in achieving expertise mobilization. Therefore, in the system, automation is only applied in steps involving purely physical transfer that does not require any expertise, such as arithmetic, data conversion, graphic display, etc. Moreover, the system is designed as transparent as possible, for example, not only the final results are generated, but also intermediate data, to allow the user to follow the calculation procedure.

2.35 Taking too much time and manpower is one point of criticism that may be counteracted by using planning methods appropriate for the purpose of planning in each specific situation and by being very target-oriented and selective in defining the required information and the methods of obtaining the data [Fresco et al., 1992].

Due to problems in coordination, a tendency of sectoral agencies is usually to collect as many data as possible. However, essential information may be lacking, and very often, data collection for an enormous database, rather than data use, becomes an objective of sectoral activities. In integrated land use planning, the concept of 'data collection' has to be replaced by 'selective data collection'. The same collection tendency is apparent in using scientific tools or applying advanced techniques: sometimes, the selected tool or technique becomes an objective in itself (e.g. the purchase of new computers and advanced software packages), its application is not given due attention. The same holds for intermediate products of land use planning. For example, yield prediction may be the ultimate goal of crop growth modelling, however, in land use planning, it should be rather an assessment of the possibilities of different crops [van Keulen, 1990].

To answer the question "Why are agricultural sector models not widely used?", Vercueil [1990] indicated three factors: skills, maintenance and communication, and concluded that sophisticated modelling efforts are jeopardized by a devastating marriage of bureaucratic stubbornness and academic lack of practical sense.

From a practical viewpoint, CAILUP is developed on the basis of a problem-oriented concept. All components as well as the required data have been selected to realize specific functions of the whole system. Some routines or subsets of parameters are included in more detail than others and influence model results disproportionally [Fresco, 1994b]. Critical questions to be always asked when a component or process is considered to be included in the system are "Is it really essential to the system and the problem? Why? How?" [Jorgensen, 1994].

2.36 However, the lack of specification of the local conditions is a main problem in the application of models. For different regions with specific problems, the structure of CAILUP may have to be modified. First, a simple structure based on available local expertise and data is developed. Then, improvements will be carried out by comparison to other systems and models developed by international experts or through learning during the continuous planning process.

CHAPTER III A COMPUTERIZED AID TO INTEGRATED LAND USE PLANNING (CAILUP)

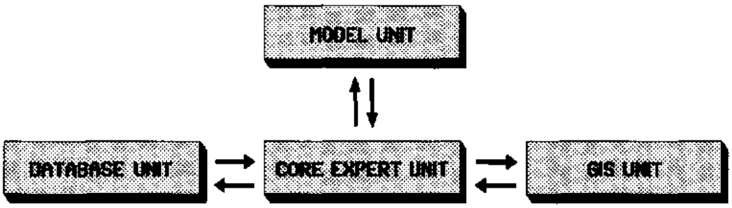
Chapter III

III.1 INTRODUCTION TO CAILUP

3.1 As discussed in Chapter II, the main function of CAILUP is to support planners in integrated land use planning at the regional level to assess the impacts of different land use scenarios with water management as the key intervention. This chapter describes the structure of CAILUP as resulting from phase 3 'System Design' in the SDM process. The objectives of this phase are to refine the requirements and to design the system so that subsystems and functions within subsystems can be defined [Cap Gemini Publishing BV, 1991].

3.2 CAILUP consists of four units as described in Fig. 7.

Figure 7: Structure of CAILUP.



A core expert unit:	functions as a 'central processing unit' to manage the system and control the analysis process;
A database unit:	handles all input/output data to/from other units;
A GIS unit:	displays and analyzing spatial data;
A model unit:	calculates model outputs from input data by applying rules of interaction among components.

3.3 To illustrate the functions of each unit, CAILUP may be compared to a research institute comprising four main units with a common objective: evaluating land use scenarios:

- The Core Expert Unit is the Directorate of the Institute;
- The Database Unit is the Data Management Department;
- The GIS Unit is the Mapping Departement
- The Model Unit is the Research Department;

3.4 As mentioned in 2.17, analytical tools in the Model Unit are the focus of CAILUP and functions of other units are mainly to support the modelling process.

3.5 Reviewing and checking are considered important issues in CAILUP (two steps forward, one step back [FAO, 1992]). After the use of any function or model, a review by means of tables, graphs or maps is always required. Hence, calculation sequences should be easily managed to review input and output data in each step and to identify any error propagation in the model. A readable format, i.e. ASCII format, could be applied to all input/output data. However, such a format requires excessive storage capacity, therefore, for large data sets, the binary format is used for data exchange among sub-units, and the ASCII format is provided as an option for displaying selected data to the user.

3.6 In the whole system, common principles are applied. Specific principles are applied in individual units. Common principles applying to all units are:

1/ To provide flexible operation, external interactions with the system are performed in two ways:

a/ either through the Core Expert Unit, then, depending on the required function, the Core Expert Unit will call the relevant unit, or

b/ by direct access to the corresponding unit for certain functions.

2/ To guarantee consistency in CAILUP, each function is assigned to a single unit, i.e. two units cannot perform the same function *(e.g. calculations are only carried out by the Model Unit and not by any other unit, even if they could be done in the Database Unit or the GIS Unit).*

3.7 The following design aspects have to be taken into account for each unit:

1/ Functions assigned to each unit are derived from the common objectives of the system;

2/ Structures of each unit:

- logical (or conceptual) structure: completely based on functions of each specific unit and expressed by a sequence of calculations;
- operational structure: translated from the logical structure to provide easy operation for the user;
- physical structure: translated from the operational structure to match with software and hardware conditions.

3.8 Only functions and logical structures can be applied to different regions with different problems. Operational structures and physical structures have to be designed for each specific region.

In the phase 'System Design' introduced in this Chapter, functions and logical structures are emphasized, and operational structures are only outlined. Details of operational and physical structures will be presented in the next Chapter, dealing with the 'Detailed System Design' phase for a pilot study.

3.9 The structure of a system is more difficult to explain theoretically than to apply. Therefore, in System Design, many examples are given to illustrate the system. These examples are taken from problems in specific regions, and may not be applicable for other areas.

III.2 DESCRIPTION OF UNITS

III.2.1 Core Expert Unit

3.10 Function: comparable to that of the Directorate of an institute, the Core Expert Unit has to manage the entire system. Its structure and functions are simple, but important for the operation of CAILUP.

3.11 Logical structure of the Core Expert Unit:

1/ a management component to provide information on the structure of the system and each of its units.

2/ a control component to control the calculation and analysis sequence. This component can transfer the user's action to the corresponding units.

3.12 Operational structure of the Core Expert Unit comprises a hierarchy of a main menu and sub-menus with which the user can interact. Both components are combined in the hierarchical menu system.

III.2.2 Database Unit

3.13 Function: handle all input/output data to/from other units. Development of a database management system is a secondary objective of CAILUP because the database is only a tool to support the Model Unit.

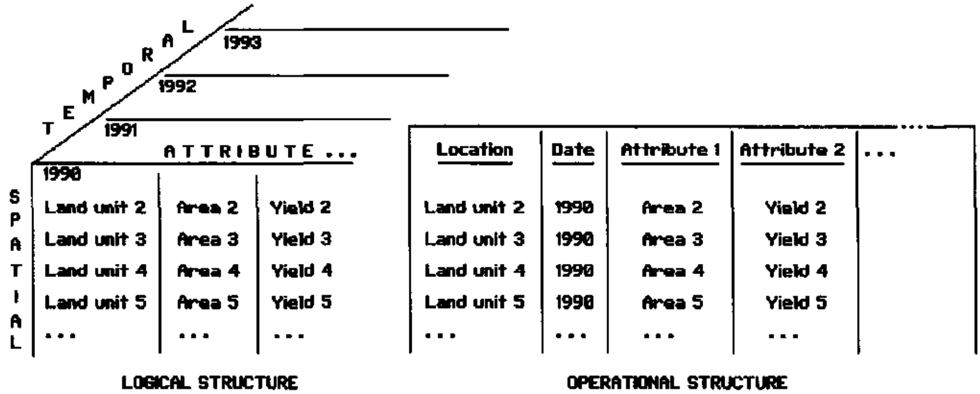
3.14 From this function, the following features are derived:

1/ All input/output data are handled by the Database Unit. Data in CAILUP are only used for evaluation of land use scenarios, therefore, they only comprise data from sectoral agencies and local authorities. Processing of raw or primary data is not an activity included in CAILUP.

2/ The Database Unit only handles data required by other units, i.e. those used for calculation and analysis by the system. Qualitative or descriptive data, used for reporting only, are not included in the system.

3/ A relational database structure is used in CAILUP, because it is simple and widely used in many database and worksheet software packages. A common format is applied for all data sets containing the same type of information. For example, the logical structure of spatial and temporal data sets is fixed and translated to an operational structure as presented in Fig. 8.

Figure 8: Logical and operational structure of spatial and temporal data sets.



3.15 The Database Unit comprises three sub-units:

1/ a sub-unit for scenario definition, that handles data on scenarios such as lists of input and output data files, sub-model operations, etc.
2/ a sub-unit for input data, that handles input data for the CAILUP model.
3/ a sub-unit for output data, that handles all output data from each sub-model. These data can be used as input data in the subsequent sub-models and the GIS Unit.

3.16 Data should be accompanied by comments as presented in Sub-Chapter IV.3 Development of CAILUP for the Quan Lo Phung Hiep region. CAILUP has a function similar to that in programming languages, to accommodate these comments in input data files ("C" in FORTRAN, "REM" and "'" in BASIC or "&" in DBase).

III.2.3 GIS Unit

3.17 Function: display spatial data in map format for analysis. Although many GIS software packages have been developed and are being improved to include more functions such as database management, modelling, etc., their current capacities are still too limited to play a core role in a complex process as integrated land use planning. It is more efficient to run the model outside the GIS and to display the model results in the GIS [Heuvelink, 1993]. Therefore, similarly to the Database Unit, the GIS Unit is also a tool to support to the Model Unit.

3.18 Logical structure of the GIS Unit:
1/ a base map of the region,
2/ a set of thematic input maps, and
3/ a set of output maps.

3.19 The operational structure of the GIS Unit depends on the software package.

III.2.4 Model Unit

3.20 Function: generate quantitative outputs from input data and rules of interaction among factors. The calculations illustrated in this Chapter are only based on general rules identified in the system design phase. Specific equations applied for the pilot region are presented in Chapter IV, dealing with detailed system design and implementation.

3.21 From a practical viewpoint, CAILUP has been developed for planning purposes rather than for research purposes, hence, the relations are more descriptive than explanatory. The validity of a model is primarily determined by its purposes [van Keulen, 1976]. Most models are 'grey', as they contain some causalities but also incorporate empirical expressions to account for some of the processes [Jørgensen, 1994], therefore the boundary between descriptive and explanatory levels is relative. Moreover, as in any modelling exercise, simplification should be accepted in CAILUP. On the basis of more information from monitoring or increased knowledge from research, the model will better represent the real world. The user can apply CAILUP as a gaming tool or a tool for sensitivity and risk analysis by modifying the hypotheses for simplification applied in the model *(e.g. increasing the price of a certain commodity or input; changing preferences of farmers; expanding the construction period).*

3.22 Logical structure of the Model Unit:

The Model Unit comprises a mathematical model that combines several sub-models, each corresponding to an analytical step. As present knowledge and available data may be inadequate for quantitative description of many interactions in the real world, the conceptual model is required for identifying the issues which can be included in the mathematical model and those that require further improvement of knowledge and data collection. The conceptual model is also used to qualitatively assess the development scenarios. The mathematical model is developed on the basis of a conceptual model.

III.2.4.A Conceptual model for integrated land use planning

3.23 The conceptual model is developed in the following sequence:

1/ Identifying issues to be included: goals and constraints of development *(e.g. increased food production, lack of fresh water)* and indicators to evaluate goal achievements from land use scenarios *(e.g. total food production, total income from land use, economic revenues from water management interventions).*

2/ Identifying relevant land use types related to these indicators. Because the plan will be implemented by the local population, local definitions are used to define land use types. Several ways of definition may be applied by the local population, for example:

- product *(e.g. rice)*
- specific product *(e.g. high yielding rice)*
- product with crop calendar *(e.g. Summer-Autumn rice, double rice in rainy season, Spring-Summer beans between two rice crops)*
- combination of two products *(e.g. shrimp-rice)*
- product and cultivation technique *(e.g. intensive prawn rearing)*
- non-productive use *(e.g. settlements, fallow area).*

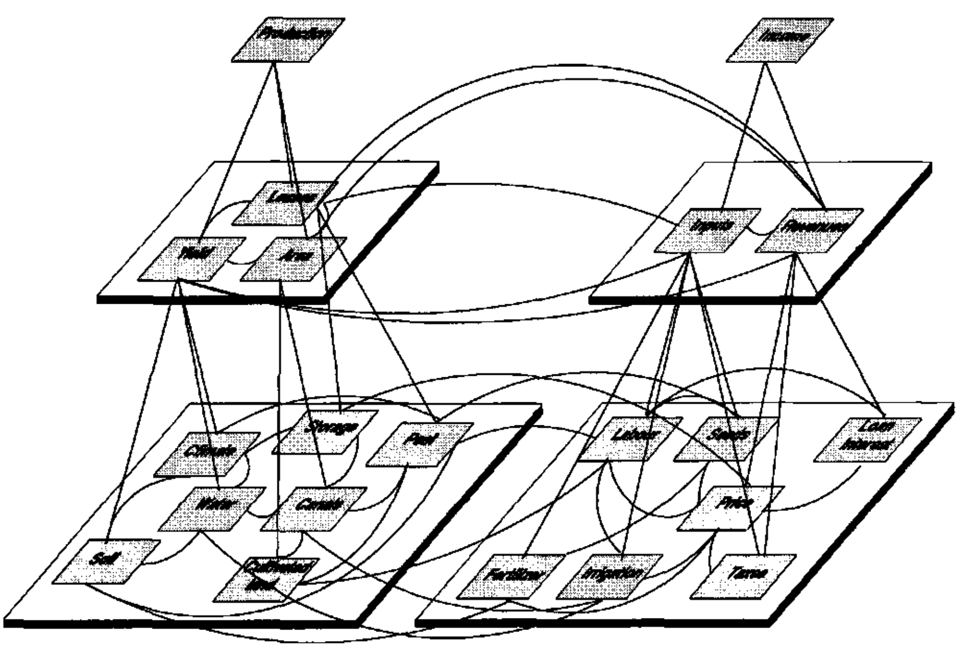
Only land use types directly affecting the specific indicators are analyzed in detail. Other land use types are only assigned part of the total land area *(e.g. when dealing with increasing food production, the area needed for settlements is calculated, but interventions for settlement improvement are not considered).*

3/ Assigning indicators and land use types to relevant <u>components</u>. As interventions will be carried out by sectoral agencies, these components are based on present institutional structures *(e.g. irrigation, agriculture, forestry, transportation).* Sub-models of the mathematical model are based on these components. However, as the model represents an integrated system, some sub-models are related to many components *(e.g. Land Use Allocation Sub-model, Production Sub-model).*

4/ Identifying the bio-physical and socio-economic <u>factors</u> affecting the production from these land use types. The following steps are proposed:

a) Start from each indicator as the top of a hierarchical structure (Fig. 9).

Figure 9: An example of a hierarchical structure (for rice production).



b) Identify factors directly affecting the indicator. It should be emphasized that only the direct effect is taken into account in this step, to avoid confusion of a complex interaction scheme with many indirect effects *(e.g. for rice production, soil properties, water conditions and fertilizer input are taken into account. Interactions between water and soil are not considered in this step)*;

c) Define the relationship between each factor and the indicator. If the relationship can be quantitatively expressed or estimated, it may be included in the mathematical model *(e.g. effect of water conditions on rice yield)*. Alternatively, only a qualitative analysis can be performed, or in several cases, an "unknown" relationship is noted [ESSA, 1992b]. Selection among these levels of analysis (quantitative, qualitative or unknown) is based on present knowledge and information. At the same time, gaps in knowledge and information are identified;

d) At lower levels in the hierarchical structure, each factor is considered an indicator and the procedure starts from step a). Because an attempt to develop a completely explanatory structure may lead to a very complex system (Fig. 9), the practical limit for planning purposes is always kept in mind during these steps. On the basis of expert knowledge, the hierarchical structure can be significantly simplified to match the capability of existing computers [Harmon & Sawyer, 1990] and the 'bounded rationality' of human capacity [Turban, 1993];

e) When hierarchical structures have been formulated for all indicators, integration is performed by the interactions among components in the system. For integration of a complex system comprising many components, the interactions may be simply presented in a matrix of data exchange as illustrated in Table 1 in 3.30.

f) Review the levels of analysis (quantitative, qualitative or unknown) of interactions among factors to keep consistency of accuracy in the whole system *(e.g. temperature variation in the region may cause a variation of 0.5% in crop yield, but that is negligible in comparison to a 20% variation as result of differences in water conditions)*. Planners should carefully select the quantitative interactions to be considered in the mathematical model, in particular interactions that are not amenable to interventions *(e.g. the effect of variations in temperature due to change of global climate, on sugarcane production)*.

For a combination of factors, "if-then" statements are used to formulate the logical structure.

E.g.: if rainfall is low (less than 200 mm in June) then:
if irrigation water is abundant (≥ 2 l/s available for each hectare), then rice yield reduction is not significant (less than 3%)), or
if irrigation water is limited (< 0.5 l/s available for each hectare) then rice yield reduction is significant (up to 30%),
but if rainfall is sufficient, rice yield reduction is not significant.

g) Identifying interventions may be carried out by reviewing all factors and interactions. Key and supplementary interventions should be distinguished *(e.g. a key intervention is the improvement of the irrigation system, and supplementary interventions are the supply of more fertilizer or improvement of transport or processing facilities).*

h) Conceptually evaluate the impacts of interventions by using simple rating levels, *(e.g. significant/insignificant positive, significant/insignificant negative, none or unknown).* This evaluation provides guidelines for verification of the mathematical model.

5/ Identifying the <u>spatial extent</u> of the planning area: for irrigated areas, boundaries are usually determined by the extent of the irrigation system. However, the planning area may also be defined by the Government as a regional (sub-national) development unit or may include surrounding areas where effects of the key intervention are significant.

6/ Determining the <u>spatial resolution</u>: the planning area is divided into water management units, defined as areas which are relatively homogenous with respect to the modifications in water conditions. Two nested levels of spatial resolution are represented in the model:

i) At the first level, the water management unit is delineated by the major canals (primary irrigation system); in total there are some tens thereof in the planning area;

ii) Each water management unit is divided into a number of smaller water management sub-units, with a total of several hundreds. Since secondary and tertiary irrigation systems are the responsibility of the village authorities, each sub-unit is defined by the intersection of the village boundaries and the water management unit boundaries. All irrigation system in one sub-unit are assumed to be accomplished in the same year. All bio-physical and socio-economic characteristics *(e.g. climate, soil, elevation, farmer group, investment capacity)* are assumed to be homogenous in each sub-unit and defined by the dominant type *(e.g. dominant soil type, dominant farmer group)* or by a weighted average value as illustrated in 3.29. This more detailed spatial resolution is necessary to more accurately characterize and describe the effects of interventions on the production of important products.

7/ Identifying the <u>time horizon</u>: CAILUP must simulate a period over which benefits as a result of investments in interventions can properly accrue. The time horizon (or in other words, length of the planning period) should thus be beyond:

- the year wherein the irrigation system reaches its full effect *(e.g. year 10 from the starting year)*;
- the year when the crop with the longest growth cycle is harvested *(e.g. if a perennial crop (pineapple) is irrigated from year 5 onwards and has a cycle of 3 years, year 8 is the time limit)*;
- the year when significant positive or negative effects are predicted *(e.g. the year in which the soil becomes unsuitable for crop production due to the lowering of the groundwater table)*;

- the last year required for economic analysis, in which investments in key interventions in land use are considered a project investment *(e.g. 20 to 30 years).*

A far away time horizon is required for economic analysis, hence a long-term land use plan is formulated, but it should be regularly updated.

8/ Determining the time step in each sub-model: the time step is a time interval [de Wit & van Keulen, 1972] selected in accordance with the requirement for calculations in each sub-model *(e.g. 1 hour in the tidal hydraulic sub-model, half a month in the annual crop growth sub-model, 1 year in the forestry sub-model, 1 year in the economic or demography sub-model).* If data are exchanged among sub-models with different time steps, it is assumed that they are equally distributed or summed during the time step, i.e. an average value is used *(e.g. average water level during a half month time step is calculated from hourly water level data and transferred from the water sub-model to the rice yield sub-model).*

9/ Determining the "without" and "with" intervention cases to be analyzed. The number of "with" cases corresponding to different land use scenarios may be large. The "without" case may be a continuing trend of current development, and it does not mean that present land use patterns are maintained during the planning period *(e.g. the settlement area may be expanded under the influence of population growth at the expense of the cultivated area).*

3.24 The operational structure of the conceptual model can be in the form of word models, picture models, box models, input/output model, matrix model, computer flow charts, signed diagraph models [Jørgensen, 1994] formulated by the user. The conceptual model should be reviewed and modified in a simple way. For integration purposes, the appropriate format is a matrix of data exchanged among sub-models (Table 1 in 3.30).

III.2.4.B Mathematical model for integrated land use planning

3.25 The function of the mathematical model is to generate quantitative information of different land use scenarios on positive and negative impacts on production, socio-economic and environmental aspects. A land use scenario should be selected on the basis of the key intervention and the strategy to achieve goals (see 2.30) before running the model.

3.26 The strategy for developing the mathematical model is to include only those indicators and factors necessary for the evaluation of the development scenarios. However, all the issues treated in the conceptual model are always to be referred to, in analysing the mathematical outputs.

3.27 General characteristics of the mathematical model:

1/ A model comprising 14 sub-models is described through a sequence of calculations in 3.30. A detailed description of sub-models is presented in 3.32.

2/ These sub-models are connected in a calculation sequence, but the user can stop the calculations at any step to review or modify input data, then continue the sequence with new data or return to the preceding step.

3/ If a sub-model is too detailed and requires a long time for calculation, compared with other sub-models *(e.g. tidal hydraulic and salinity model with time steps of 1 hour and a network of 500 canal nodes)*, or has been developed with different data format and user interface that is impossible to be linked to CAILUP *(e.g. existing crop yield models with specific input data structure)*, it is used independently as a tool to support the knowledge base before using CAILUP *(e.g. two levels of water extraction for cultivation, i.e. 125 m^3/s and 175 m^3/s, are applied in a tidal hydraulic and salinity model. These outputs are used in CAILUP for the extraction cases of 125±25 m^3/s* and 175±25 *m^3/s*, respectively).

3.28 First, the mathematical model is used to evaluate the "without" intervention case to generate the base scenario. Subsequently, various "with" intervention cases (by implementing different options of key intervention) are evaluated.

3.29 Problems of data aggregation are treated in the mathematical model as follows:

1/ For aggregation of spatial data of a factor, a weighted average value (similar to areal average applied in hydrology [Chow et al., 1988]) or the value of dominant type of that factor *(e.g. dominent soil type, common elevation)* are used:

$$\text{AggVal}(s) = \sum_{t=1}^{N} \left[\text{Val}(s,t) * \frac{\text{Area}(s,t)}{\text{TotArea}(s)} \right]$$

or:

$$\text{AggVal}(s) = \text{Val}(s,td)$$

where:
AggVal(s) = aggregated value of sub-unit (s);
Val(s,t) = value of type (t);
N = number of types in sub-unit (s);
Area(s,t) = area of type (t);
TotArea(s) = total area of sub-unit (s);
Val(s,td) = value of dominant type td covering largest area (highest Area(s,t)).

E.g.: In a sub-unit (s) with a total area TotArea(s) = 100 ha and 3 levels of elevation Ele:

1: Area(s,1) = 70 ha, Ele(s,1) = 0.8 m
2: Area(s,2) = 20 ha, Ele(s,2) = 0.6 m
3: Area(s,3) = 10 ha, Ele(s,3) = 0.4 m

If the weighted average elevation is used, elevation AggEle(s) of the sub-unit will be:

$$AggEle(s) = \sum_{l=1}^{3}\left[Ele(s,l) * \frac{Area(s,l)}{TotArea(s)}\right] = 0.80 * \frac{70}{100} + 0.60 * \frac{20}{100} + 0.40 * \frac{10}{100}$$

$$= 0.72\ m$$

If the value of the dominant elevation is used, elevation AggEle(s) of the sub-unit will be:

$$AggEle(s) = Ele(s,3) \quad \text{(covering largest area } Area(s,3) = 70\ ha)$$

$$= 0.80\ m$$

2/ For aggregation of temporal data over a particular period *(e.g. growing period)*, an average value is used:

$$AveVal(s,p) = [\sum_{t=1}^{N} Val(s,t)] / N$$

where: AveVal(s,p) = average value for period (p);
N = number of time steps in period (p);
Val(s,t) = value in time step (t).

This method may cause error when the aggregated value is used in further calculations. For example, if the pH of water is instantaneously below 4, all fish may die, and yield would be 0 even if average pH over the whole period is high. Such phenomena can be included in sub-models for crops highly sensitive to environmental conditions as in aquaculture by using a 'dead control' value:

$$DCVal(s) = Min\ [\ Val(s,1), Val(s,2), ..., Val(s,N)\ ]$$

where: DCVal(s) = dead control value;
Val(s,t) = value in time step (t);
N = number of time steps taken into account.

If the 'dead control' value is below a threshold value, *(e.g. below 4 for the water pH)*, the final yield is 0, even if the average for the whole period is high. However, taking into account the capability of re-introduction of fish after the critical time step, i.e. water pH below 4, the average pH is still used to calculate the fraction of maximum yield. Some planners also argue that during the period of low-pH water, farmers usually find some measures to protect their fish *(e.g. preventing the intrusion of low-pH water, by a small ditch)*, therefore using an average value is appropriate.

3/ For aggregation of the effects of soil, water, climate, etc. on crops, parametric methods [Huizing, 1991; Driessen & Konijn, 1992; Davidson, 1992] are applied. The effects of single factors are first assessed individually. The effect of each factor on yield is represented by the proportion of maximum observed yield after reduction by that factor. Then, these effects on yield are arithmetically combined. Depending on the specific crop, averages, addition, multiplication, exponent or minimum value functions can be applied.

E.g.:

$$Yield(s,lut) = MaxY(lut) * YSoil(s,lut) * YClim(s,lut) * Min\,[\, YpH(s,lut)\, ,\, YSal(s,lut)\,]$$

where: *Yield(s,lut)* = *resulting yield from land use type (lut) in sub-unit (s);*
MaxY(lut) = *maximum observed yield;*
YSoil(s,lut) = *effect of soil type on yield;*
YClim(s,lut) = *effect of climate on yield;*
YpH(s,lut) = *effect of water pH on yield;*
YSal(s,lut) = *effect of water salinity on yield.*

Any aggregation will cause loss of accuracy, but cannot be avoided in regional planning, although it may cause differences between observed data and model outputs. If the land is heterogenous, even if very high spatial resolution is applied to generate a large number of sub-units or pixels, in many sub-units or pixels, small parts that are still different, will remain.

Some guidelines such as "It is impossible to consider simultaneously (for example in one model) more than three aggregation levels" or "First compute/calculate and then average", have been proposed, to prevent aggregation tensions and conflicts between aggregation levels and disciplines [Rabbinge & van Ittersum, 1994].

For regional planning, point data need to be aggregated to generate area data. Hence, coefficients for spatial and temporal adjustment are required to reflect the spatial and temporal variations of influencing factors. They can be used to correct for aggregation errors during model calibration *(e.g. monthly average rainfall data at some stations are applied for the whole region causing error in estimation of rainfall in individual water management units; or, only large canals are included in the model, but small creeks may cause differences in soil moisture from place to place. Hence, spatial-temporal adjustment coefficients for local climate or water availability in local canal networks are needed for model calibration).*

3.30 The structure of the mathematical model is shown in Fig. 10. Interactions among sub-models are described in a matrix presenting the exchange of data among sub-models (Table 1). To describe the data structure, parentheses have been used. For example, (s,y,lut) implies: per water management unit or sub-unit, per year and per land use type.

Figure 10: CAILUP model structure.

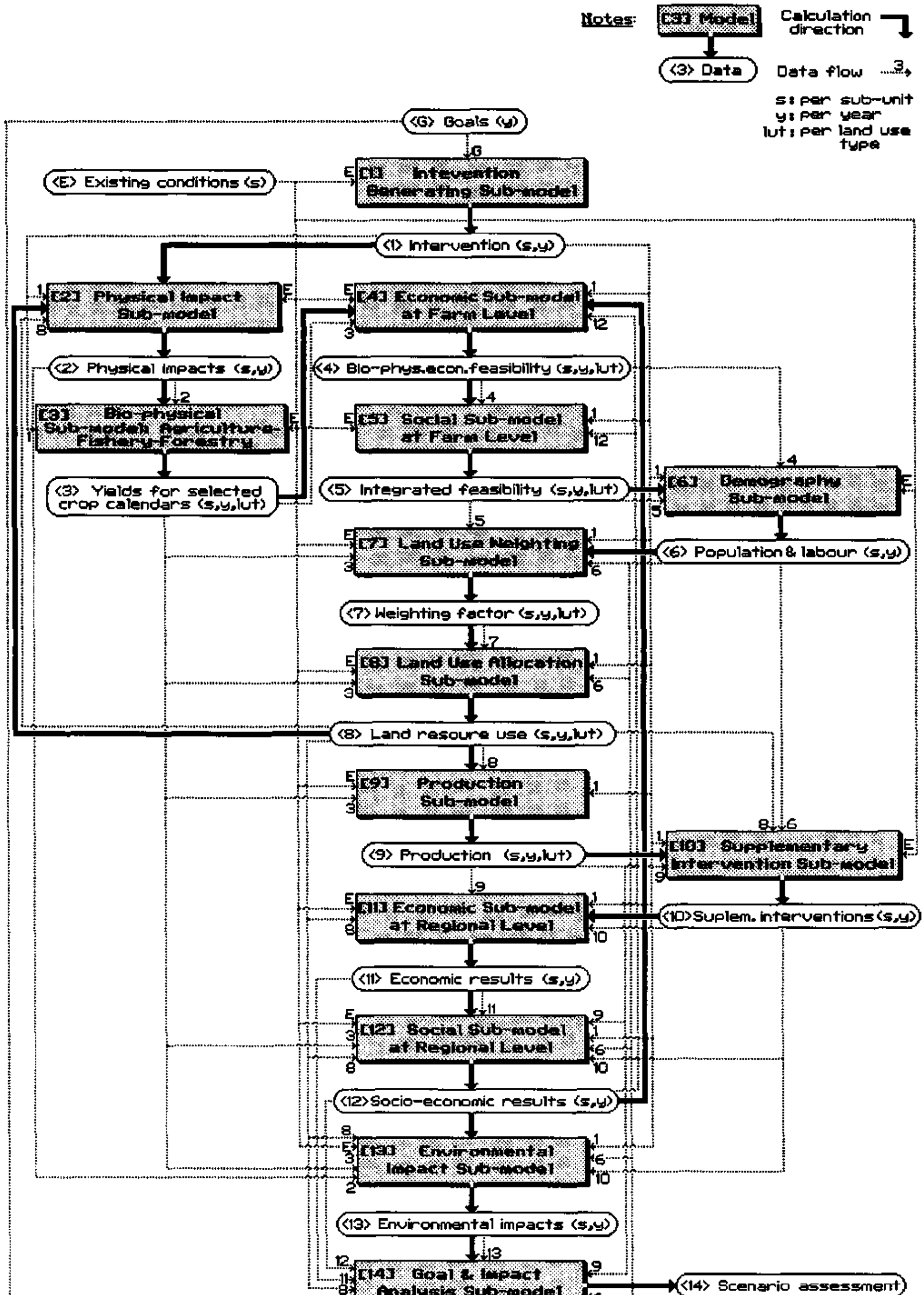


Table 1: A matrix of data flows indicating interactions among sub-models. Note: (s,y,lut) = per sub-unit, per year, per land use type

Sub-model receiving data ---> / Data set or sub-model generating data (v)	[1] Intervention Generating Sub-model	[2] Physical Impact Sub-model	[3] Bio-physical Sub-model	[4] Economic Sub-model at Farm Level	[5] Social Sub-model at Farm Level	[6] Demography Sub-model	[7] Land Use Weighting Sub-model	[8] Land Use Allocation Sub-model	[9] Production Sub-model	[10] Supplementary Intervention Sub-model	[11] Economic Sub-model at Regional Level	[12] Social Sub-model at Regional Level	[13] Environmental Impact Sub-model	[14] Goal&Impact Analysis Sub-model
<E> Existing conditions	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	<E> Existing conditions (s)	
<G> Goals of development	<G> Goals(y)													<G> Goals(y)
[1] Intervention Generating Sub-model		<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Interventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	<1> Inter-ventions (s,y)	
[2] Physical Impact Sub-model			<2> Physical impacts (s,y)										<2> Physical impacts (s,y)	
[3] Bio-Physical Sub-model (Agriculture, Fishery & Forestry)				<3> Yields (s,y,lut)			<3> Yields (s,y,lut)	<3> Selected crop calendars (s,y,lut)	<3> Yields (s,y,lut)			<3> Selected crop calendars (s,y,lut)	<3> Selected crop calendars (s,y,lut)	
[4] Economic Sub-model at Farm Level					<4> Bio-physical economic feasibility (s,y,lut)	<4> Net income (s,y,lut)								
[5] Social Sub-model at Farm Level						<5> Integrated feasibility (s,y,lut)	<5> Integrated feasibility (s,y,lut)							
[6] Demography Sub-model							<6> Population (s,y)	<6> Population & labour force (s,y)		<6> Population & labour force (s,y)		<6> Population & labour force (s,y)	<6> Population (s,y)	<6> Population & labour force (s,y)
[7] Land Use Weighting Sub-model								<7> Weighting factor (s,y,lut)						
[8] Land Use Allocation Sub-model		<8> Land resource use (s,y,lut)							<8> Land resource use (s,y,lut)	<8> Land resource use (s,y,lut)	<8> Land resource use (s,y,lut)	<8> Land resource use (s,y,lut)	<8> Land resource use (s,y,lut)	<8> Land resource use(s,y,lut)
[9] Production Sub-model										<9> Production (s,y,lut)	<9> Production (s,y,lut)	<9> Production (s,y,lut)		<9> Produc-tion (s,y,lut)
[10] Supplementary Intervention Sub-model											<10> Supplem. intervention (s,y)	<10> Supplementary intervention (s,y)	<10> Supplem. intervention (s,y)	
[11] Economic Sub-model at Regional Level												<11> Economic results (s,y)		<11> Economic results (s,y)
[12] Social Sub-model at Regional Level				<12> Socio-economic results (s,y)	<12> Socio-economic results (s,y)									<12> Socio-economic results (s,y)
[13] Environmental Impact Sub-model														<13> Envir. impacts (s,y)
[14] Goal and Impact Analysis Sub-model														<14> Scenario assessment

Each sub-model corresponds to one analytical step. The sequence of model operation consists of 14 steps characterized by the calculation direction and the data flow in Fig. 10 and can be presented as follows:

1) Run the Intervention Generating Sub-model [1] to generate a data set for the "without" or "with" intervention (s,y) case in both the bio-physical and socio-economic terms, throughout the planning period *(e.g. build a new irrigation system; improve shrimp processing facilities).*

2) Run the Physical Impact Sub-model [2] to generate a data set of physical conditions (s,y) both "without" and "with" physical interventions *(e.g. water conditions without and with irrigation system).* In this step, a change in land use is temporarily assumed not to affect the physical conditions *(e.g. existing water conditions are not affected when the area of rice is increased).* This issue will be reconsidered in step 8.

3) Run the Bio-physical Sub-model [3] (Agriculture, Fishery, Forestry) to estimate yields (s,y,lut) and the selected crop calendars (s,y,lut) under modified physical conditions *(e.g. rice yield from Summer-Autumn and Winter-Spring crops with irrigation; shrimp yield from intensive shrimp production).*

4) Run the Economic Sub-model at Farm Level [4] to generate the combined bio-physical/economic feasibility (s,y,lut) based on financial criteria defined at farm level *(e.g. based on net income, the bio-physical/economic feasibility of Winter-Spring rice is higher than that of eucalyptus forest).*

5) Run the Social Sub-model at Farm Level [5] to integrate social preferences with bio-physical/economic feasibility (s,y,lut) *(e.g. integrated feasibility of Winter-Spring rice is low because this crop would have to be harvested during the New Year holidays).*

6) Run the Demography Sub-model [6] to generate data on population and labour force (s,y) *(e.g. 1,000 people, including 450 labourers in year 5 in sub-unit 14).*

7) Run the Land Use Weighting Sub-model [7] to determine a weighting factor (s,y,lut) based on the integrated feasibility from the Social Sub-model at Farm Level [5] and the Government policy *(e.g. weighting factors of 80 and 20 for Summer-Autumn and Winter-Spring rice, respectively).*

8) Run the Land Use Allocation Sub-model [8] to generate land resource use (s,y,lut) on the basis of the weighting factor (s,y,lut) and rules in land use conversion *(e.g. 2,000 ha and 50 ha for Summer-Autumn rice and intensive shrimp production, respectively).* Land resource use is expressed as the area (s,y,lut) and the water volume (s,y,lut) allocated to each land use type.

A return to the Physical Impact Sub-model [2] is needed subsequently to analyze the effect of the generated land use scenario on physical conditions. Two situations are possible:

a. If the new physical conditions are significantly different from those at step 2 then repeat steps 3 to 7. The new weighting factors generated in step 7 may be different from the old ones in the following:

   i) from year 1, i.e. the land use plan has to be modified from the beginning *(e.g. rice can only be cultivated during 3 years after burning peat, because thereafter nutrient availability becomes too low, and therefore, this land use type cannot be applied)*;

   ii) only from the year with a significantly different impact. Thus the land use plan is updated from that year *(e.g. after 3 years of pineapple on acid sulphate soils, a rice crop may be possible)*;

   If the land use scenario leads to a severe negative physical impact *(e.g. serious salt water intrusion at downstream sites due to the diversion of fresh water)*, then step 1 may have to be repeated to generate another set of interventions *(e.g. damming the downstream site)*;

b. If the new physical conditions are similar to those at step 2 *(e.g. only slight differences in salinity at downstream sites)*, then a return to sub-model [2] is not needed and the calculation sequence is continued at step 9. Water demand, under those conditions, is satisfied by water supply and represents water resource use in the land use scenario.

   The number of iterations may be very large because changes in physical conditions require changes in land use, and differences in land use lead to different physical conditions. Therefore, after every run, outputs have to be analysed, and a limit is selected to identify whether a return to sub-model [2] is continued or not *(e.g. if differences in salinity between two runs are less than 0.1 g/l, the calculation sequence is continued with step 9)*.

9) Run the Production Sub-model [9] to generate total production (s,y,lut) by multiplying area (s,y,lut) with yield (s,y,lut). Effects such as disasters or improper input supply can be included in this Sub-model *(e.g. pest in an unfavourable year may cause 20% reduction in total production of the Summer-Autumn rice crop in the whole region)*.

10) Run the Supplementary Intervention Sub-model [10] to generate supplementary interventions (s,y) required to support the land use scenario *(e.g. a new canal system requires 10 bridges with a total cost of 500,000 US$; 400 m^3 of fuelwood will be needed when melaleuca forest has been converted to pineapple fields)*.

11) Run the Economic Sub-model at Regional Level [11] to calculate the economic returns at sub-units (s,y) and regional level *(e.g. input and income from different land use types, net present value, internal rate of return, etc.).*

12) Run the Social Sub-model at Regional Level [12] to calculate the socio-economic indicators at sub-unit (s,y) and regional level *(e.g. total food production and its distribution in the region; employment in each sub-unit and the region; etc.).*

    If the socio-economic conditions at regional level in a certain year cause significant changes in socio-economic factors at farm level, these changes are included in the new input data set before returning to step 4, the Economic Sub-model at Farm Level, to affect the calculations for the following year *(e.g. high production in the whole region in year 10 may cause lower farm gate prices, lower income for the farmer, and consequently, less capital availability in year 11).*

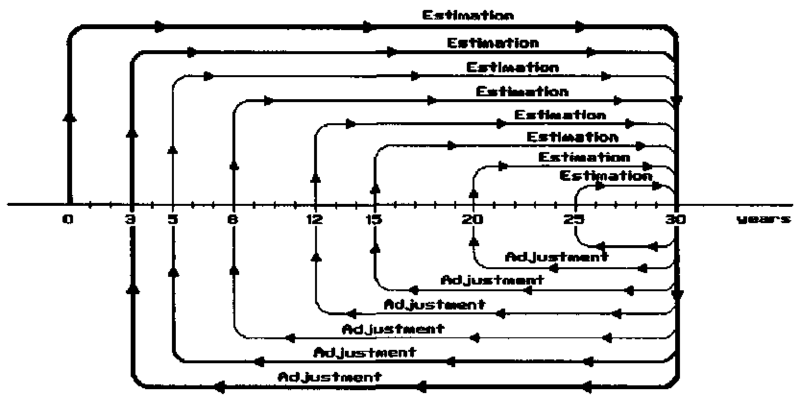
13) Run the Environmental Impact Sub-model [13] to calculate indicators expressing the environmental impacts (s,y,lut) caused by the key intervention and the selected land use scenario *(e.g. the total number of people newly supplied with fresh water; total pesticide requirement; total land cover in the dry season).*

14) Run the Goal and Impact Analysis Sub-model [14] to generate a ranking value for the selected land use scenario *(e.g. ranking value based on net present value, internal rate of return and/or total production).*

3.31 During calculation and analysis at each step, the results may require modifications to the interventions. A return to the Intervention Generating Sub-model [1] is then necessary to modify the scenario or to generate another scenario *(e.g. accelerate the construction schedule of the irrigation system; larger proportion of shrimp processing before export).* Depending on the conditions affected by the modifications, only the relevant steps have to be repeated.

The model can be applied interactively with two alternate steps of estimation and adjustment as shown in Fig. 11. The number of iterations depends on the time horizon and the variation in the relevant factors, *(e.g. new input data are applied for years that major components of the irrigation system are completed, or years that the supply of food exceeds demand which may cause a reduction in price).* However, as analysis of long-term impacts is always required in designing the interventions and the policy in land use, any model run should cover the whole planning period.

Figure 11: Interactive operation of the model.



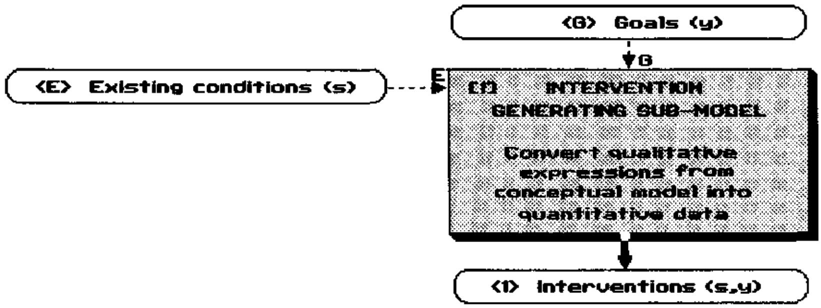
III.2.4.C Description of sub-models

3.32 The model structure as well as codes for each sub-model (e.g. [1], [2] for sub-models 1, 2) and for each data set (e.g. <G> for goals, <E> for existing conditions, <1> for output data from sub-model [1]) are given in 3.30 (Fig. 10).

3.33 Intervention Generating Sub-model [1]

The structure of sub-model [1] is shown in Fig. 12.

Figure 12: Structure of sub-model [1].



<u>Function</u>: Generate an intervention data set (s,y) as input for the other sub-models. This sub-model is an interface between the conceptual model and the mathematical model to convert qualitative expressions selected in the conceptual model into quantitative values.

Input data:

<G> Qualitative data from the conceptual model on the goals and constraints of development *(e.g. increase in food production; increase in supply of fresh water for domestic use)*;

<E> Existing conditions (s) in the region *(e.g. current rice production; existing water quality)*.

Calculations:

Qualitative information from the conceptual model is translated into quantitative data *(e.g. from the goal of rapid increase in food production in the conceptual model, construction of an irrigation system in a short period, or fertilizer application to the rice crop is derived; based on this, a construction schedule or the fertilizer supply should be determined)*.

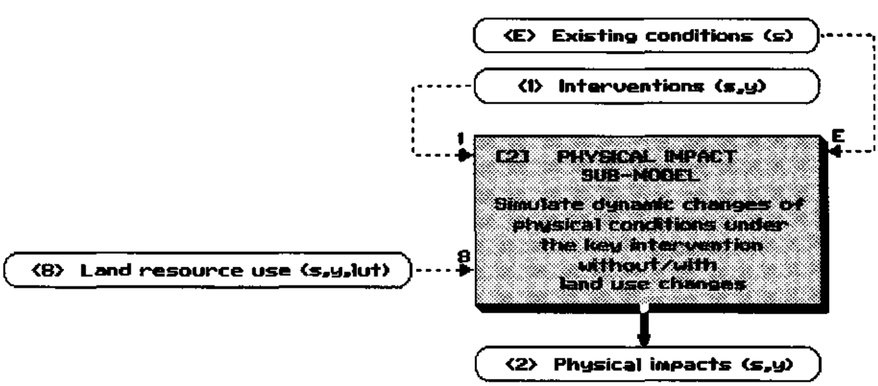
Output data:

<1> Interventions (s,y) as input data for other sub-models *(e.g. construction schedule into the Physical Impact Sub-Model* [2]*; amount of fertilizer into the Bio-physical Sub-Model* [3]*)*.

3.34 Physical Impact Sub-model [2]

The structure of sub-model [2] is shown in Fig. 13.

Figure 13: Structure of sub-model [2].



Function: Simulate the dynamic changes in physical conditions under the key intervention without and with land use changes.

Input data:

<E> Existing conditions (s) of soils, water, climate, infrastructures *(e.g. hydrological and climate data, existing canal network and structures for the water model)*;

<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. new structures including location, size, construction schedule)*;

<8> Land resource use (s,y,lut) in terms of area (s,y,lut) and water volume (s,y,lut). Present land resource use (s,0,lut) is applied for initial conditions in year 0. Land resource use (s,y,lut) in the future is generated by the Land Use Allocation Sub-model [8].

Calculations:

- Depending on the key intervention, the Physical Impact Sub-model [1] may comprise different components *(e.g. water quantity and water quality components to estimate water conditions under the new irrigation system; soil-water interaction components to estimate effects of land reclamation on water quality).*
- This sub-model has to be run several times as discussed in 3.30 8/:
  - In the first run, physical conditions (s,y) are assumed to depend only on the key physical intervention (s,y) *(e.g. expansion of the canal system, building of a dam)* and present land use (s,0,lut);
  - When a return from the Land Use Allocation Sub-model [8] is carried out, the new plan of land resource use (s,y,lut) is used to generate the physical conditions (s,y) 'with land use changes'.

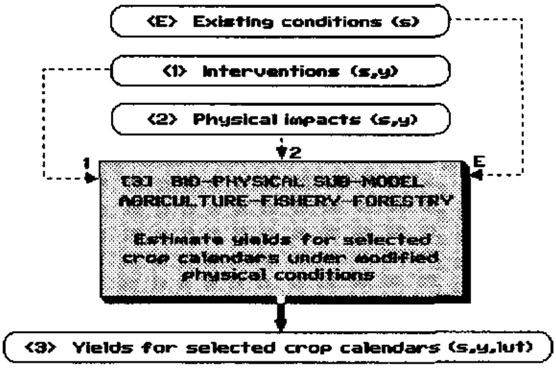
Output data:

<2> Physical conditions (s,y) under the selected intervention and land use scenario *(e.g. water level and salinity level when the irrigation system has been improved).*

3.35 Bio-physical Sub-model [3] for Agriculture, Fishery and Forestry

The structure of sub-model [3] is shown in Fig. 14.

Figure 14: Structure of sub-model [3].



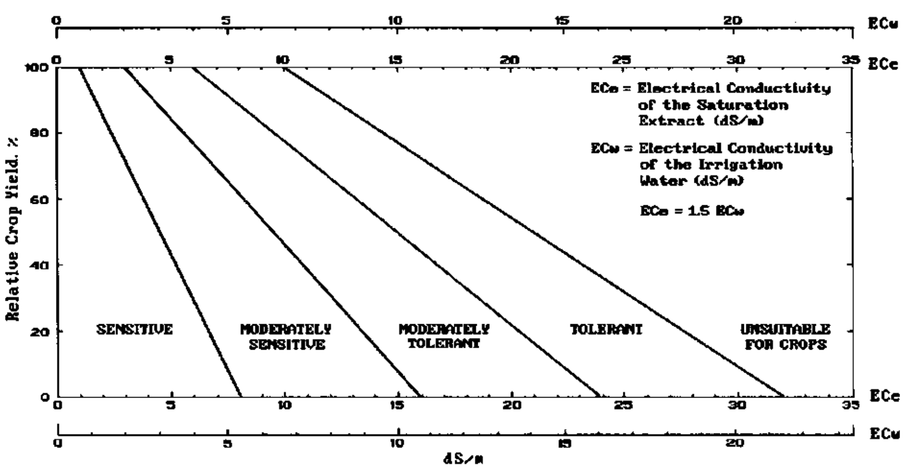
Function: Estimate yield for selected crop calendars under modified physical conditions.

Input data:

<E> Existing physical conditions (s), *(e.g. soil, climate, water conditions)*, land use factors (s) *(e.g. possible maximum yield; variety; cropping system; cultivation techniques; spatial-temporal adjustment coefficients)* and effects of physical factors (s,y) on yield (s,y,lut), based on present knowledge and expressed in one of the following forms:

- x-y coordinates of a linear graph *(e.g. a graph showing the relation between electrical conductivity of irrigation water and relative crop yield in Fig. 15).*

Figure 15: Classification for relative salt tolerance ratings of agricultural crops [source: Mass, 1984: in Ayers & Westcot, 1985].



If the graph is not linear, it is divided into small linear parts.

- a rating table. *E.g. a rating table (Table 2) showing the effect of tidal fluctuations on mangrove performance* [ESSA et al., 1992b]:

Table 2: A rating table showing the effect of tidal fluctuations on mangrove performance.

Site class	*Tidal fluctuations*
Poor	*< 0.5 m or > 2.5 m*
Medium	*0.5 to 1.0 m and 2.0 to 2.5 m*
Rich	*1.0 to 2.0 m*

The yield of mangrove can be determined by site class and age (see 4.62).

<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. amount of additional fertilizer; irrigation capacity)*;

<2> Physical impacts (s,y) from the Physical Impact Sub-model [2].

<u>Calculations</u>:

- Yield (s,y,lut) is estimated on the basis of interactions between physical factors and yield. Simple parametric methods as discussed in 3.29 are applied. No model can take into account all influencing factors, only factors that may be changed by interventions are considered in detail, while effects of other factors are integrated in the value of maximum possible yield and the spatial-temporal adjustment coefficients.
- A crop calendar is normally selected on the basis of the highest yield that can be attained with the same inputs. Alternately, all promising crop calendars are selected in this sub-model *(e.g. all crop calendars with yield > 0.4 times maximum yield)* and one of them will be selected in the Economic Sub-model at Farm Level [4] on the basis of income.

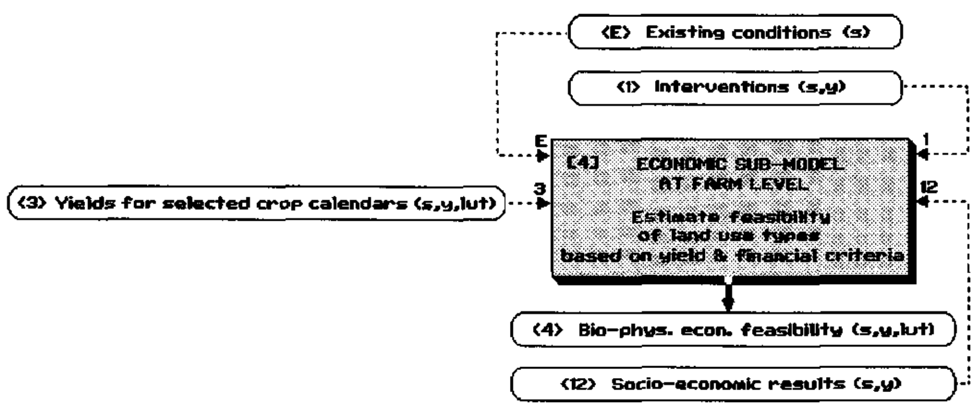
<u>Output data</u>:

<3> Yields (s,y,lut) for selected crop calendars (s,y,lut) *(e.g. yield of Winter-Spring rice from November to February; intensive shrimp rearing from June to December; mangrove forest all year-round).*

3.36 Economic Sub-model [4] at Farm Level

The structure of sub-model [4] is shown in Fig. 16.

Figure 16: Structure of sub-model [4].



<u>Function</u>: Predict which land use types will be selected by farmers based on yields generated in the Bio-physical Sub-model [3] and economic/financial criteria at farm level.

<u>Input data</u>:

<E> Existing economic/financial conditions (s,lut) *(e.g. farm-gate prices of inputs and outputs; capital availability; financial criteria used by farmers to select land use types)*;

<1> Economic/financial interventions (s,y,lut) from the Intervention Generating Sub-model [1] *(e.g. low interest credit; special price for gasoline for farmers)*;

<3> Yields (s,y,lut) and crop calendars (s,y,lut) from the Bio-physical Sub-model [3];
<12> New financial data (s,y,lut) from the Social Sub-model at Regional Level [12], if available (see 3.30 12/) *(e.g. new farm-gate prices under surplus production in the entire region).*

Calculations:

- Based on predicted yields (s,y,lut), input and output farm-gate prices and availability of capital, a financial balance is calculated for each land use type in each year. Then, depending on the financial criteria, the bio-physical/economic feasibility (s,y,lut) is generated:

  BEF(s,y,lutm) = 1 if NetInc(s,y,lutm) is highest

where: BEF(s,y,lutm) = bio-physical/economic feasibility;
lutm = land use type with the highest net income;
NetInc(s,y,lutm) = net income (US$, Dutch Guilder or VN Dong);

  and, for other land use types:

  BEF(s,y,lut) = NetInc(s,y,lut) / NetInc(s,y,lutm)

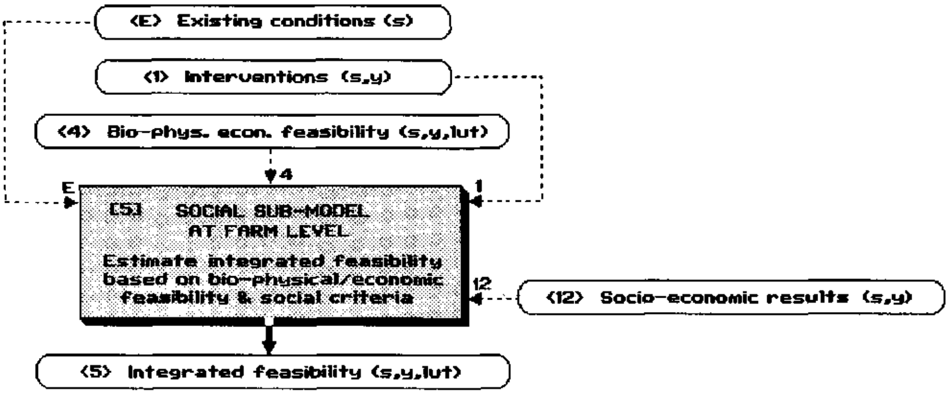
- When a return from the Social Sub-model at Regional Level [12] occurs in year y, a new balance is established for that year, and will affect the outcome in the subsequent year y+1 *(e.g. lower prices of sugarcane in year 5 due to surplus production, and consequently, less capital input for farmers in year 6).*

Output data:
<4> Bio-physical/economic feasibility (s,y,lut) and net income (s,y,lut) at farm level.

3.37 Social Sub-model [5] at Farm Level

The structure of sub-model [5] is shown in Fig. 17.

Figure 17: Structure of sub-model [5].



Function: Predict which land use types will be selected by farmers, based on the bio-physical/ economic feasibility generated in the Economic Sub-model at Farm Level [4] and social criteria at farm level.

Input data:

<E> Existing social conditions (s,lut) in terms of preferences of the farmer or the local population *(e.g. not eating a specific product; preferring traditional varieties for local consumption; having long New Year holidays)*;

<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. convince the local population to change their traditional preferences to high yielding varieties or to shorten New Year holidays)*;

<4> Bio-physical/economic feasibility (s,y,lut) from the Economic Sub-model at Farm Level [4] *(e.g. bio-physical/economic feasibility = 100 and 70 for Winter-Spring rice and sugarcane, respectively)*;

<12> New socio-economic data (s,y,lut) from the Socio-economic Sub-model at Regional Level [12], if available (see 3.30 12/) *(e.g. higher average income in the entire region causes changes in preference towards high quality products).*

Calculations:

- This sub-model takes into account the fact that farmers do not always select the land use type with the highest economic returns. Based on social criteria, a social feasibility (s,y,lut) is determined and combined with the bio-physical/economic feasibility (s,y,lut) to generate an integrated feasibility (s,y,lut):

  InFe (s,y,lut) = BEF (s,y,lut) * SoFe (s,y,lut)

  where: InFe(s,y,lut) = integrated feasibility;
  BEF(s,y,lut) = bio-physical/economic feasibility;
  SoFe(s,y,lut) = social feasibility.

  (e.g. bio-physical/economic feasibility of Winter-Spring rice is higher than that of Summer-Autumn rice, but its integrated feasibility may be lower due to its low social feasibility, because this crop should be harvested during the New Year holidays; a cash crop such as vegetables has a high bio-physical/economic feasibility, but high risks in marketing cause a low integrated feasibility).

  The social feasibility (s,y,lut) is determined by a ranking method [Nijkamp et al., 1990]. Land use types are ranked in order of preference with regard to a condition. If the condition is satisfied, a social feasibility (s,lut) different from 1 is assigned *(e.g. if the difference in net income between pineapple and rice is lower than a predetermined ratio, the rice crop is preferred due to storage flexibility and food self-sufficiency considerations).*

- When a return from the Social Sub-model at Regional Level [12] occurs in year y, the social feasibility in year y+1 may change *(e.g. lower prices for sugarcane in year 5 due to surplus production cause high risks to farmers and consequently, lower social feasibility of this crop in year 6).*

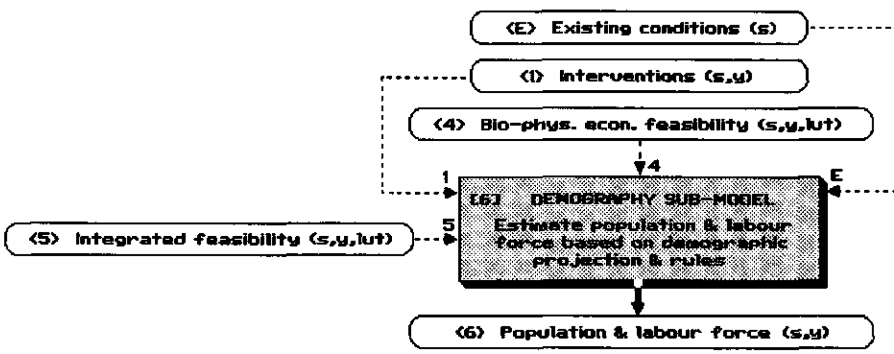
Output data:

<5> Integrated feasibility (s,y,lut) *(e.g. integrated feasibility = 50 and 70 for Winter-Spring rice and sugarcane, respectively).*

3.38 Demography Sub-model [6]

The structure of sub-model [6] is shown in Fig. 18.

Figure 18: Structure of sub-model [6].



Function: Estimate population and available labour force taking into account the effects of population growth, immigration, and population redistribution in the region due to changes in income and living conditions, created by the interventions.

Input data:

<E> Existing demographic conditions (s) *(e.g. population in each sub-unit, of which 45% is involved in agriculture in rural sub-units)*;

<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. birth control programme to reduce population growth rate from 2.5 to 2.0% in year 10)*;

<4> Net income (s,y,lut) from the Economic Sub-model at Farm Level [4];

<5> Integrated feasibility (s,y,lut) from the Social Sub-model at Farm Level [5].

Calculations:

- From the current population (s), the population (s,y) during the planning period is calculated on the basis of projected natural population growth rate (y):

$$Popu(s,y) = Popu(s,y-1) * (1 + NGRate(y))$$

where: Popu(s,y) = population (persons);
NGRate(y) = population growth rate.

Other complex estimation techniques applying different rules may be applied if data are available *(e.g. the current average of 6 children per woman will be reduced to 4 and 2 in year 10 and 20, respectively, and 60% of the children are female).*

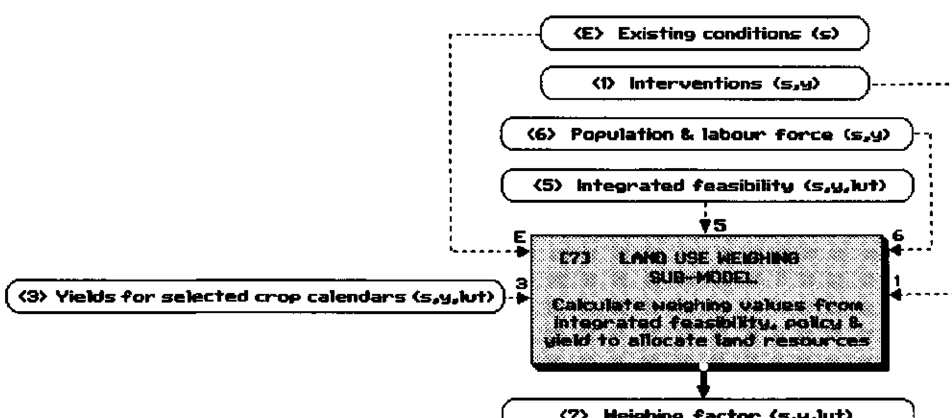
- Migration (s,y) to/from a sub-unit is estimated on the basis of a projected migration policy and added to/subtracted from population (s,y) *(e.g. 2% of the population migrates to big cities outside the region in year 5).*
- Changes in physical conditions, and associated changes in land use may cause migration within the region. Migration (s,s,y) among sub-units is estimated on the basis of differences in net income from land use and population density and in accordance with migration regulations applied in the region *(e.g. migration only possible within a district, from high population density villages to those with low population density if income in the destination is attractive).* Then, migration (s,s,y) is included in the population (s,y).
- The labour force (s,y) is calculated as a proportion of the population (s,y).

Output data:
<6> Population (s,y) and labour force (s,y) *(e.g. 1,000 people and 450 person-years labour in sub-unit 5 in year 10).*

3.39 Land Use Weighting Sub-model [7]

The structure of sub-model [7] is shown in Fig. 19.

Figure 19: Structure of sub-model [7].



Function: Generate weighting factors to allocate land resources to each land use type. The use of weighting factors is illustrated in the Land Use Allocation Sub-model [8].

Input data:
<E> Existing land resource use (s,0,lut) *(e.g. 50 ha for Winter-Spring rice)*;
<1> Interventions (s,y) reflecting the policy of the Government *(e.g. the national land use plan stipulates that food production should be concentrated in the eastern water management units of a region, hence higher policy factors are assigned to food crops for these units (see Calculations))*;

<3> Yields and crop calendars (s,y,lut) from the Bio-physical Sub-model [3];
<5> Integrated feasibility (s,y,lut) from the Social Sub-model at Farm Level [5];
<6> Population (s,y) from the Demography Sub-model [6].

Existing conditions <E>, interventions <1> and population <6> are used as references for the selection of policy (s,y,lut).

Calculations:

- For allocation of land resources, land use types can be classified in two categories:

i) Non-productive land use types *(e.g. settlements, roads, parks)*, controlled by demographic rules *(e.g. settlements and public constructions are expanded in proportion to the population increase)* and only indirectly affected by the key intervention *(e.g. more land for settlements is required in areas with increasing productivity due to migration).* Weighting factors for these land use types are determined by the projected developments *(e.g. no expansion of area for settlements is allowed from the year 2000).*

ii) Productive land use types *(e.g. agriculture, fishery, forestry)*, directly controlled by land use changes *(e.g. expansion of crops with high yield or high income).* Two expressions can be applied to calculate weighting factors (s,y,lut) of these land use types:

1/ Weig (s,y,lut) = InFe (s,y,lut) * PoFa (s,y,lut)

where:
- Weig(s,y,lut) = weighting factor;
- InFe(s,y,lut) = integrated feasibility generated from the sub-model [5], representing the integrated result from a set of four sub-models [2], [3], [4] and [5];
- PoFa(s,y,lut) = policy factor selected by the planner, reflecting the policy of the Government with respect to the area of each land use type compared to that of other land use types.

Notes on this equation:

a. The feasibility and policy factors applied to land use types could range from 0 to 1 or 0 to 100, but this would be immaterial because they are applied to all land use types in a relative sense.

b. In formulating a land use scenario, the first factor, integrated feasibility (s,y,lut), is an objective factor, while the second, policy (s,y,lut), is a subjective factor to the planner. The former reflects the priority of farmers, while the latter expresses the objectives of decision-makers with respect to the development of the region in relation to the environment and the national development plan. Incorporation of the policy in the land use selection is necessary, because farmers are often more concerned with their immediate income than with overall environmental or economic impact.

c. The policy is implemented via Governmental instruments such as administrative regulations, extension programmes, consumption supports, subsidies, etc. If policy enforcement by the Government is not strong, policy factors (s,y,lut) for all land use types are equal *(e.g. all PoFa(s,y,lut) = 1)*, and the integrated feasibility (s,y,lut) is the only factor in land allocation.

d. In the opposite case (strong Government policy enforcement), policy factor (s,y,lut) may be very different for two land use types with the same integrated feasibility (s,y,lut) *(e.g. PoFa(s,y,lut1) = 100 for rice and PoFa(s,y,lut2) = 1 for pineapple, both having an integrated feasibility of 80).*

e. However, policy (s,y,lut) may not be able to support a land use type with very low feasibility (s,y,lut) *(e.g. if the integrated feasibility = 0, no land resource will be allocated to this land use type, even if the maximum policy factor of 100 has been assigned).*

f. To reduce the number of values to be selected by the planner *(e.g. 200 sub-units x 30 years x 20 luts = 120,000 values)*, policy factor (s,y,lut) can be selected on the basis of water management units (wmu) in the years when policy changes start *(e.g. 20 wmu x 6 five-year periods x 20 luts = 2,400 values)*, which may be followed by fine-tuning for each specific sub-unit if variation is too large.

2/ In addition to the two above factors (feasibility and policy factor), the second expression also takes into account the bio-physical yield, because the integrated feasibility (s,y,lut) may be limited by socio-economic factors *(e.g. markets; local tradition as holidays)*, while a high yield can be achieved:

$$\mathrm{Weig}(s,y,lut) = \mathrm{InFe}(s,y,lut) * \mathrm{PoFa}(s,y,lut) * \mathrm{Yield}(s,y,lut) * \frac{\sum_{i=1}^{NP}[\mathrm{InFe}(s,y,i) * \mathrm{PoFa}(s,y,i)]}{\sum_{i=1}^{NP}[\mathrm{InFe}(s,y,i) * \mathrm{PoFa}(s,y,i) * \mathrm{Yield}(s,y,i)]}$$

where:

Weig(s,y,lut)	=	weighting factor;
InFe(s,y,lut)	=	integrated feasibility as defined in 1/;
PoFa(s,y,lut)	=	policy factor as defined in 1/;
Yield(s,y,lut)	=	yield (s,y,lut) from sub-model [3];
NP	=	number of land use types producing the same product;
i	=	land use type.

<u>Notes on this equation</u>:

a. This expression is appropriate when the opportunities to remove socio-economic constraints exist *(e.g. high possibility of convincing farmers to reduce their New Year holidays)*, and the demand for a certain product is high *(e.g. production of food crops under self-sufficiency condition)*;

b. If policy enforcement by the Government is very strong, *(e.g. full subsidy to a land use type to maintain a protected species)*, the integrated feasibility (s,y,lut) may be removed from this expression so that only the yield ratio (s,y,lut) and policy factor (s,y,lut) are used.

- Since irrigation is the key intervention to be considered, productive land use types are the major concern in CAILUP. However, as a consequence of population growth and economic development, non-productive land use types will be significantly expanded into areas of high productivity. Hence, these land use types have to be taken into account to balance the demand for land with the available land resources in each successive year during the planning period.

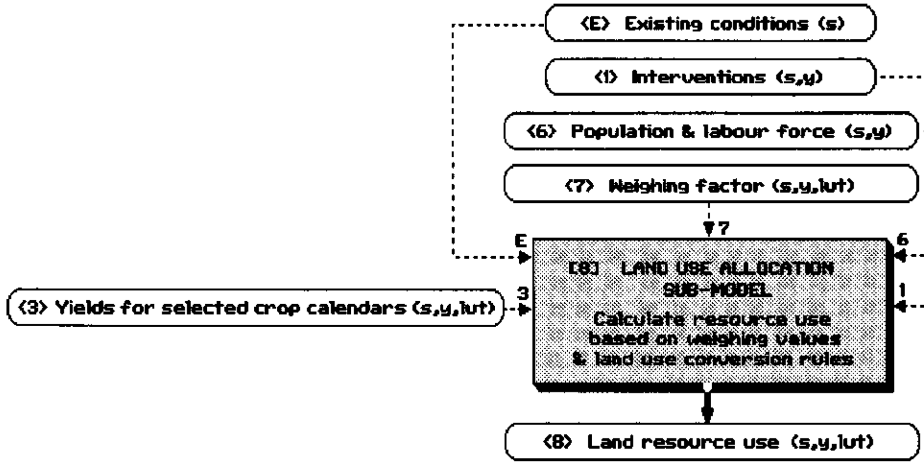
- This sub-model can be used as a gaming tool by modifying the policy factor (s,y,lut), in particular, to analyze extreme cases: 'without' intervention and 'with' strong interventions.

Output data:
<7> Weighting factors (s,y,lut) *(e.g. 30 and 50 for Winter-Spring and Summer-Autumn rice, respectively).*

3.40 Land Use Allocation Sub-model [8]

The structure of sub-model [8] is shown in Fig. 20.

Figure 20: Structure of sub-model [8].



Function: Generate land use allocation to each land use type from the total area per sub-unit.

Input data:

<E> Current total area (s) and rules of land use conversion (lut,lut) *(e.g. the area for double rice cropping can only originate from the area for single rice or upland crops, and not from other land use types; each year, a farmer can convert 1 hectare from fallow to Eucalyptus forest or 0.5 ha from rice field to fish pond)*;

<1> Interventions (s,y) from the Intervention Generating Sub-model [1] related to land use conversion *(e.g. machinery support to reclamation in fallow area leads to reduction of labour requirements)*;

<3> Yields (s,y,lut) and crop calendars (s,y,lut) from the Bio-physical Sub-model [3];

<6> Population (s,y) from the Demography Sub-model [6];

<7> Weighting factors (s,y,lut) from the Land Use Weighting Sub-model [7].

Calculations:

- Calculate the area (s,y,lut) of non-productive land use types on the basis of weighting factors:

$$\text{Area}(s,y,\text{sett}) = \text{Area}(s,y-1,\text{sett}) + \text{AAS} * \text{Weig}(s,y,\text{sett}) * \text{Max}[(\text{Popu}(s,y) - \text{Popu}(s,y-1)), 0]$$

where:
- sett = the code of land use type for settlements;
- Area(s,y,sett) = area for settlements in year y (ha);
- Area(s,y-1,sett) = area for settlements in year y-1 (ha);
- AAS = average area per capita for settlements in the region (ha/person);
- Weig(s,y,sett) = weighting factor for settlements expressing policy on expansion of settlement area:
  - . Weig(s,y,sett) = 0, i.e. expansion is not allowed;
  - . Weig(s,y,sett) > 0, i.e. expansion is possible;
- Popu(s,y) = population in year y (number of persons);
- Popu(s,y-1) = population in year y-1 (number of persons);

Note: 'Max [(Popu(s,y)-Popu(s,y-1)), 0]' means that the value is equal to 0 if Popu(s,y)-Popu(s,y-1) is negative, and equal to Popu(s,y)-Popu(s,y-1) if it is positive'. This term indicates that the assumption 'no change in area of settlements in case of population decrease' is applied.

- Calculate remaining area for productive land use types:

$$\text{RemArea}(s,y) = \text{TotArea}(s) - \sum_{lut=1}^{NN} \text{Area}(s,y,lut)$$

where:
- RemArea(s,y) = remaining area for productive land use types (ha);
- TotArea(s) = total area of sub-unit (ha);
- NN = number of non-productive land use types.

- Allocate the remaining area (s,y) to each of the productive land use types based on weighting factors (s,y,lut):

$$Area(s,y,lut) = RemArea(s,y) * Weig(s,y,lut) / [\sum_{i=1}^{NP} Weig(s,y,i)]$$

where: Area(s,y,lut) = area of productive land use type (ha);
Weig(s,y,lut) = weighting factor;
i = productive land use type;
NP = number of productive land use types.

- In the allocation procedure, conditions for land use conversion are always met to check whether the areas calculated in the above equations are possible. If not, the maximum possible area is assigned *(e.g. from the calculation using the weighting factor, 200 ha of double rice is required in year 5, but only 150 ha is available from the area of single rice and upland crops in year 4. Hence, in year 5, only 150 ha of double rice is allocated; or availability of labour is only sufficient for 100 ha of eucalyptus forest although 120 ha is estimated from its weighting factor. Hence, in year 5, only 100 ha is allocated to Eucalyptus forest).* In other words, land use conversion may limit allocation to certain land use types even if the integrated feasibility and policy factor (combined in the weighting factor) is higher, i.e. weighting factors are adjusted in this sub-model according to these conditions.

- Water use is set equal to calculated water demand for critical time steps in the year *(e.g. dry season)* on the basis of the area (s,y,lut) and crop calendar (s,y,lut), or population (s,y). Different equations are applied for different water use categories.

E.g.: For irrigation of sugarcane, water use would be:

$$WAU(s,t,y,sugarcane) = Area(s,y,sugarcane) * [(Kc(t) * ETo(t)) + Perc - (P(t) * Pe) + Sat(t,lut)] / IRRe$$

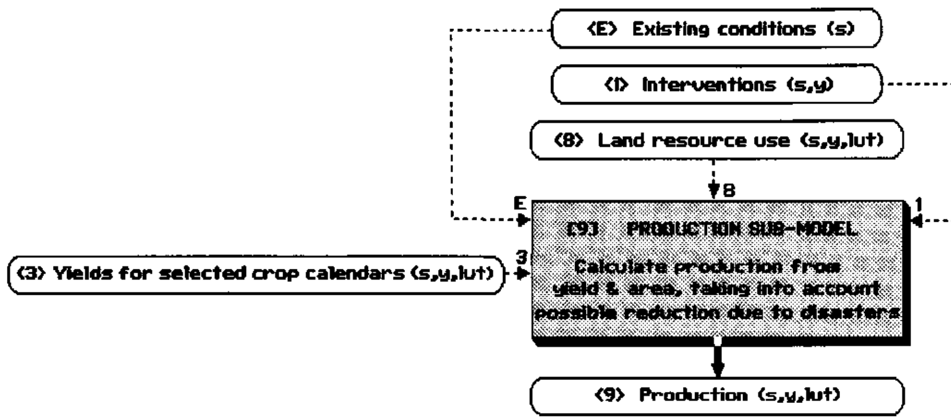
where: *t* = *time step;*
WAU(s,t,y,sugarcane) = *water use for sugarcane* (m^3);
Area(s,y,sugarcane) = *area of sugarcane* (m^2);
Kc(t) = *crop factor for sugarcane;*
ETo(t) = *reference crop evapotranspiration (m);*
Perc = *percolation (m);*
P(t) = *rainfall (m);*
Pe = *effective rainfall coefficient;*
Sat(t,lut) = *amount of water (m) needed to saturate the soil for land preparation in the initial time step. For other time steps, Sat(t,lut)=0;*
IRRe = *irrigation efficiency.*

Output data:
<8> A land resource use plan comprising the area (s,y,lut) and water use (s,t,y,lut) *(e.g. 5 ha of settlements, 10 ha of homestead gardens and 100 ha of Winter-Spring rice in year 10)*

3.41 Production Sub-model [9]

The structure of sub-model [9] is shown in Fig. 21.

Figure 21: Structure of sub-model [9].



Function: Calculate the production of each product from yield and area, taking into account possible reduction due to causes such as disasters or improper input supply.

Input data:

<E> Current land use area (s);
<1> Interventions (s,y) from the Intervention Generating Sub-model [1] in terms of disaster prevention;
<3> Yields (s,y,lut) from the Bio-physical Sub-model [3];
<8> Area (s,y,lut) from the Land Use Allocation Sub-model [8].

Calculations:

- Total production per product is simply calculated by multiplying area and yield:

$$Prod(s,y,lut) = Yield(s,y,lut) * Area(s,y,lut)$$

where: Prod(s,y,lut) = production (tonnes for agricultural products or m^3 for wood);
Area(s,y,lut) = area (ha);
Yield(s,y,lut) = yield (tonnes/ha or m^3/ha).

- Effects of 'disasters' *(e.g. pest and diseases)* on production in certain years are unpredictable. Therefore, an average yield is selected and applied for the complete planning period. This implies that in the long-term, these effects are assumed to be smoothed, therefore the variation in production is not yet included in the Bio-physical Sub-model [3]. However, depending on when these phenomena occur, outputs from economic analysis may be different because of depreciation *(e.g. if a severe pest outbreak causes a substantial yield reduction in year 1, it will more significantly affect the net present value than a similar one in year 30).*

Land use scenario is formulated on the basis of average yields from sub-model [3], then a run for 'risk analysis' can be carried out to analyse the economic returns:

a. A reduction in total production in the entire region by disaster may be assumed *(e.g. 0% in a favourable year, 20% in a medium year (average value used in the yield model) and 40% in an unfavourable year).*

b. Random values for the three levels (corresponding to favourable, medium and unfavourable years) is used to reflect disaster incidence. Over the complete planning period (30 years), the number of occurrences of each level should be equal (10 years each). To compare different scenarios, the same series of random values should be applied in all scenarios, including 'without' and 'with' cases.

c. A 'worst case' scenario with a sequence of 10 unfavourable years at the beginning, 10 medium years and 10 favourable years can be applied to produce extremely unfavourable outputs, and vice versa.

d. Effects of interventions (s,y) can be included by assuming a lower reduction in total production *(e.g. introduction of a pest control system may limit the yield reduction in unfavourable years to 20%).*

- Another effect on production may be the delay in application of inputs such as fuel, fertilizer, pesticide due to insufficient supply or capital availability to farmers *(e.g. delay in supply of fertilizer and pesticide usually occurs in remote sub-units).* Hence, yield estimated on the basis of physical conditions and normal cultivation techniques in the Bio-physical Sub-model [3] may be reduced *(e.g. reduction of 10% in yield due to effects of limited input availability).* Like in the case of disasters, this effect is identified after the land use selection has been made, therefore it is only taken into account from this sub-model onwards in the sequence of calculation.

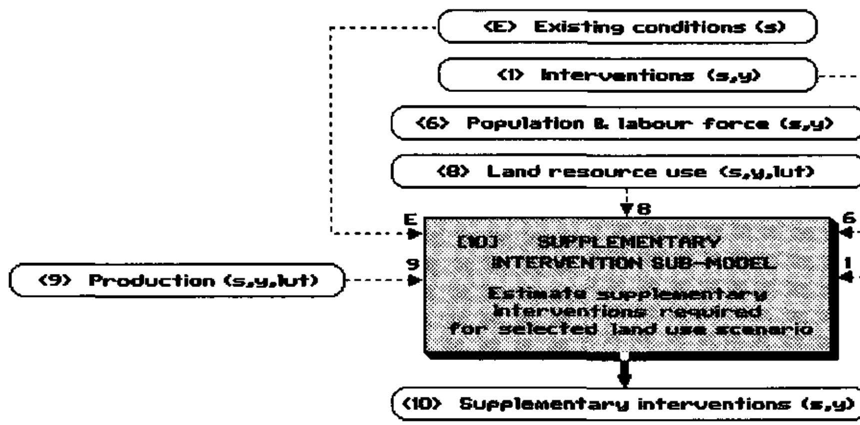
<u>Output data</u>:

<9> Production (s,y, lut) of each product *(e.g. 200 tons of high yielding rice from the Winter-Spring crop; 10 tons of fish from natural catch).*

3.42 Supplementary Intervention Sub-model [10]

The structure of sub-model [10] is shown in Fig. 22.

Figure 22: Structure of sub-model [10].



Function: Identify supplementary interventions required to support the selected land use scenario. These interventions refer to two issues:
(i) using effectively the production from the region;
(ii) supplying adequate input materials for production.

Input data:

- <E> Existing conditions of product use (s) *(e.g. average consumption of each product per capita, capacity of shrimp processing factories, total storage facilities)* and supply *(e.g. total capacity of fertilizer factories)*;
- <1> Interventions (s,y) from the Intervention Generating Sub-model [1] on projected local consumption, reduction of post-harvest losses, improvement of infrastructures and supply of materials for production *(e.g. plan to upgrade existing rural roads in year 5, increase in pesticide supply)*;
- <6> Population (s,y) and labour force (s,y) from the Demography Sub-model [6];
- <8> Land resource use (s,y,lut) from the Land Use Allocation Sub-model [8];
- <9> Production of each product (s,y,lut) from the Production Sub-model [9].

Calculations:

- Production of each product (corrected for post-harvested losses) is compared to the demand of the local population to identify the surpluses to be marketed outside the region or the shortages to be compensated *(e.g. 2,000 tonnes of shrimps to be processed and exported from year 5; or 10,000 tonnes/year of fuel to be supplied to replace fuelwood, when the forest has been converted to rice fields)*.

- Additional activities to increase income from crop products *(e.g. pig or duck raising on rice bran)* are considered in this sub-model. Each activity requires a specific calculation, as presented in Chapter IV.

- Demand for major production inputs which, when in short supply, may cause significant reductions in yield *(e.g. fertilizer, pesticide, fuel)*, is estimated.

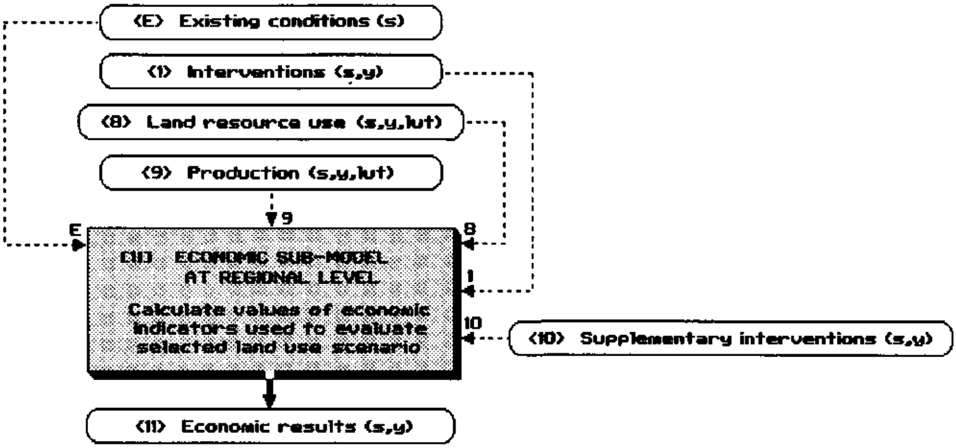
  This sub-model generates data on volumes of products and materials, and the associated costs to evaluate the selected land use scenario, hence only issues directly related to the selected land use scenario are examined and the calculations are not as detailed as those made by sectoral agencies.

Output data:
<10> Supplementary interventions (s,y) *(e.g. supply 2,000 tonnes of fertilizer from year 5 onwards; transport 500,000 tonnes of rice from year 10 onwards; produce 1,000 tons of pork from rice bran).*

3.43 Economic Sub-model [11] at Regional Level

The structure of sub-model [11] is shown in Fig. 23.

Figure 23: Structure of sub-model [11].



Function: Estimating the economic outputs of the selected land use scenario. As discussed in 2.6, a land use plan is considered to be a large and long-term project. Therefore at this level, economic analysis for the entire region is carried out. Financial analysis for the entire region can also be carried out by this sub-model.

Input data:
<E> Existing economic conditions (s) *(e.g. prices)* and interactions between regional level and farm level *(e.g. if there is surplus production, farm-gate prices are lower)*;
<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. subsidies, taxes, total costs of the irrigation systems)*;
<8> Land resource use (s,y,lut) from the Land Use Allocation Sub-model [8];

<9> Production (s,y,lut) from the Production Sub-model [9];
<10> Supplementary interventions (s,y) from the Supplementary Intervention Sub-model [10].

<u>Calculations</u>:

Values of economic indicators are calculated by applying project economic analysis *(e.g. net present value, internal rate of return, benefit-cost ratio, payback period, production costs and benefits in each sub-unit).*

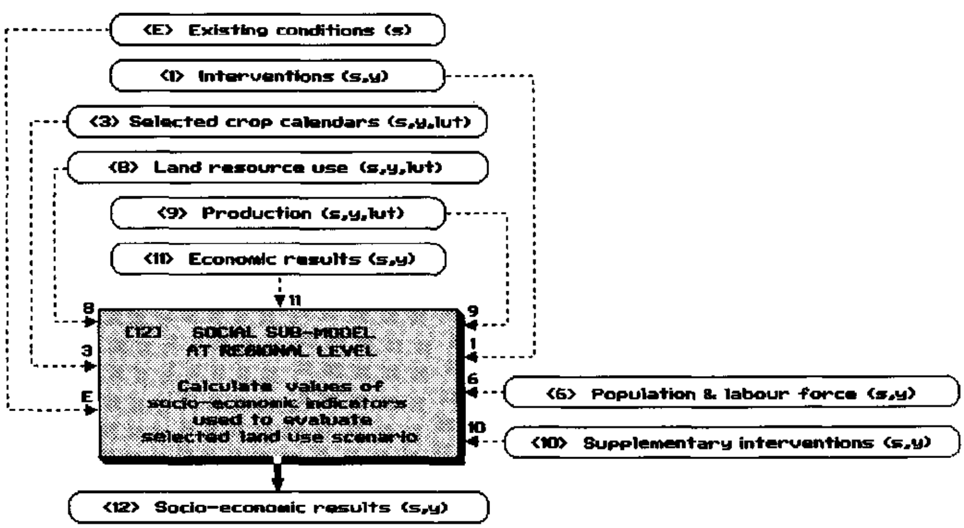
<u>Output data</u>:

<11> Values of economic indicators (s,y) for each sub-unit and the region as a whole required for evaluation of the selected land use scenario.

3.44 Social Sub-model [12] at Regional Level

The structure of sub-model [12] is shown in Fig. 24.

Figure 24: Structure of sub-model [12].



<u>Function</u>: Estimate the socio-economic outputs of the selected land use scenario in each sub-unit and their distribution in the region.

<u>Input data</u>:

<E> Existing socio-economic conditions (s) *(e.g. production per capita, average consumption of each product per capita)*;
<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. number of working days per labourer; skilled and unskilled labour requirements for land use conversion or cultivation)*;

<3> Selected crop calendars (s,y,lut) from the Bio-physical Sub-model [3];
<6> Population (s,y) and labour force (s,y) from the Demography Sub-model [6];
<8> Land resource use (s,y,lut) from the Land Use Allocation Sub-model [8];
<9> Production (s,y,lut) from the Production Sub-model [9];
<10> Supplementary interventions (s,y) from the Supplementary Intervention Sub-model [10];
<11> Economic results (s,y) from the Economic Sub-model at Regional Level [11].

Calculations:

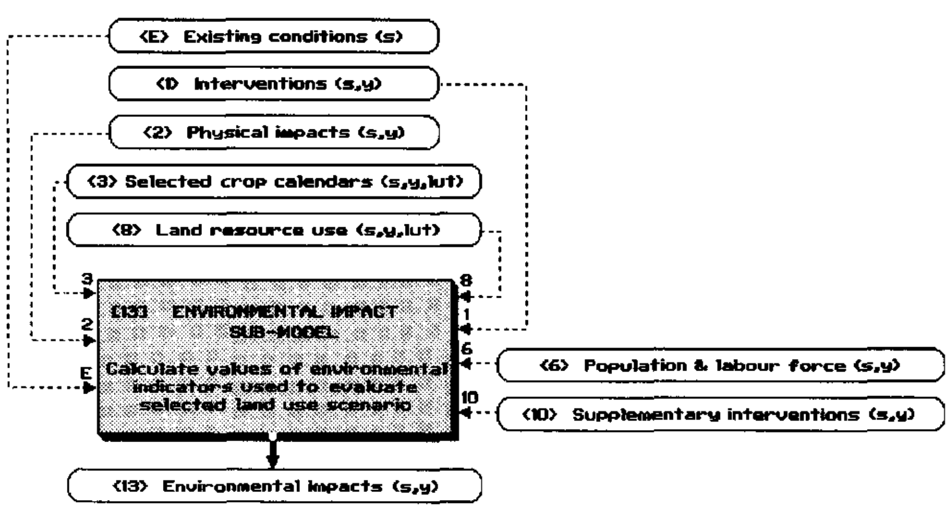
- Values of socio-economic indicators for each sub-unit and the region as a whole are calculated from production, income, population and labour force, generated from the preceding sub-models *(e.g. production and income from land use, skilled and unskilled labour requirements, supply and demand of labour).*
- As discussed in sub-model [4], economic and socio-economic outputs from sub-models [11] and [12] are analysed to identify the interactions between regional level and farm level and to examine whether a return to sub-model [4] is needed.

Output data:
<12> Values of socio-economic indicators (s,y) required for evaluation of the selected land use scenario.

3.45 Environmental Impact Sub-model [13]

The structure of sub-model [13] is shown in Fig. 25.

Figure 25: Structure of sub-model [13].



Function: Estimate environmental impacts (s,y) of the selected land use scenario.

<u>Input data</u>:

<E> Existing environmental conditions (s) *(e.g. water quality)*;
<1> Interventions (s,y) from the Intervention Generating Sub-model [1] *(e.g. applying high water quality standards, water-borne disease control program)*;
<2> Physical impacts (s,y) from the Physical Impact Sub-model [2];
<3> Selected crop calendars from the Bio-physical Sub-model [3];
<6> Population (s,y) from the Demography Sub-model [6];
<8> Land resource use (s,y,lut) from the Land Use Allocation Sub-model [8];
<10> Supplementary interventions (s,y) from the Supplementary Intervention Sub-model [10].

<u>Calculation</u>:

Values of environmental indicators (s,y) for each sub-unit and the region as a whole are calculated. Depending on specific problems in the region, these indicators may be different *(e.g. total population newly supplied with fresh water for domestic use in areas intruded by salt water; incidence of new diseases due to modified physical conditions; total pesticide use in the region).*

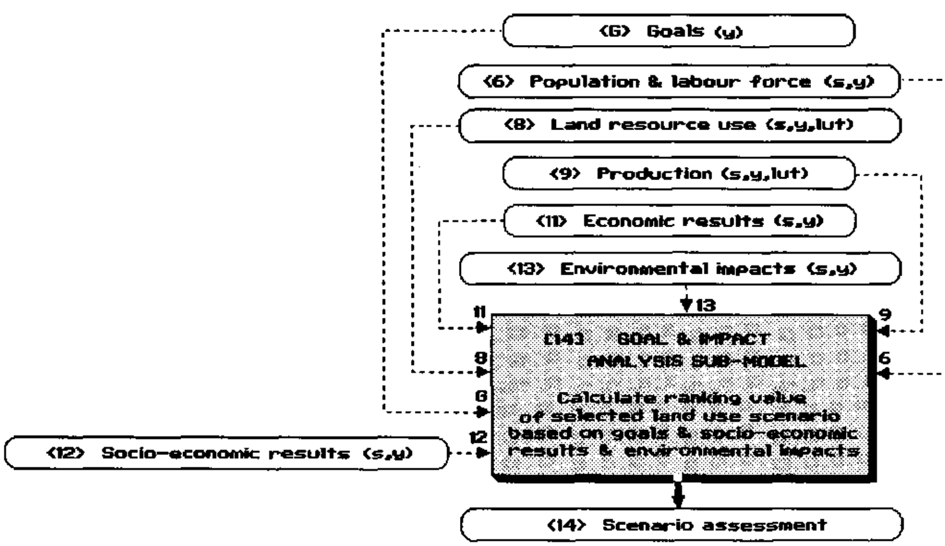
<u>Output data</u>:

<13> Environmental indicators (s,y) required for evaluation of the selected land use scenario.

3.46 Goal and Impact Analysis Sub-model [14]

The structure of sub-model [14] is shown in Fig. 26.

Figure 26: Structure of sub-model [14].



<u>Function</u>: Integrating all socio-economic results and environmental impacts from the selected land use scenario with the goals for scoring and ranking of selected land use scenario.

<u>Input data</u>:

<G> Targets of development goals *(e.g. annual income of 200 US$/capita from year 10; annual rice production 1,000 kg/capita from year 5; difference between highest and lowest incomes less than 50%, in the region from year 7; fresh water supplied to 1,000,000 people from year 15)*;

<6> Population (s,y) from the Demography Sub-model [6];

<8> Land resource use (s,y,lut) from the Land Use Allocation Sub-model [8];

<9> Production (s,y,lut) from the Production Sub-model [9];

<11> Economic results (s,y) from the Economic Sub-model at Regional Level [11];

<12> Socio-economic results (s,y) from the Social Sub-model at Regional Level [12];

<13> Environmental impacts (s,y) from the Environmental Impact Sub-model [13].

<u>Calculations</u>:

- A ranking value for the selected land use scenario is calculated. Various multicriteria methods [Nijkamp et al., 1990] can be applied. Depending on the criteria selected by the planner, different ranking values may result *(e.g. high priority may be given to the food production objective, hence a scenario with a large rice area will get a high ranking).* For integrated land use planning, a method understandable to local decision-makers is preferred.

- For comparison of goals expressed in different units, such as tons of rice, US$ per capita, etc., standardization is applied by using a relative deviation of realized value from target, defined as the ratio of (realized value - target)/target. To evaluate the future impact of realized values of indicators such as rice production, economic returns, etc. in the course of the planning period, depreciation is applied:

$$PVI(g) = \sum_{y=1}^{NY} [RDev(g,y) / (1 + DRate(g,y))^y]$$

or

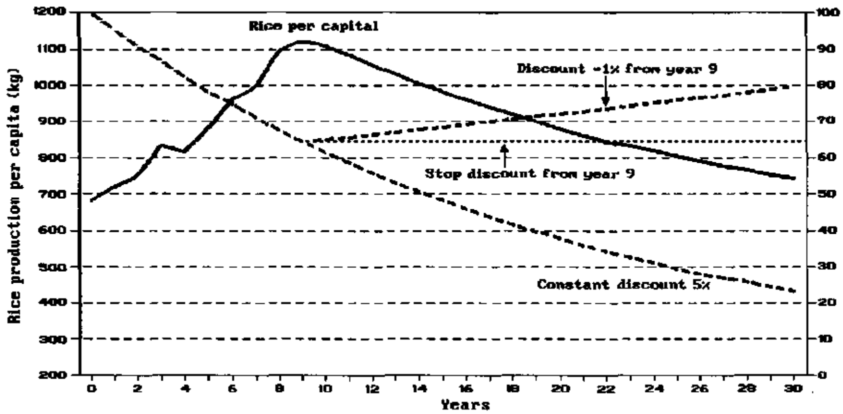
$$PVI(g) = \sum_{y=1}^{NY} [RDev(g,y) * DFact(g,y)]$$

where:

g	=	code of a single goal;
PVI(g)	=	present value of relative deviation of realized value from target;
NY	=	number of years in the planning period;
y	=	year number;
RDev(g,y)	=	relative deviation of realized value from target;
DRate(g,y)	=	discount rate;
DFact(g,y)	=	discount factor.

However, depreciation with a constant discount rate during the complete planning period may lead to insignificant values for impacts in the distant future. Therefore, a variable discount rate is applied to allow flexible assessment. An example of depreciation with a variable discount rate is given in Fig. 27.

Figure 27: Example of application of a variable discount rate.



As a result of the improvement of the water management system, rice production per capita gradually increases during the first eight years and a discount rate of 5% is applied during that period. From year 9 onwards, the annual increment in production is lower than the population growth rate, thus rice production per capita will decrease, i.e. food demand will become important from that year onwards. Then, no further discount is applied and the discount factor is kept constant during the remaining period, or, if food demand is a high priority for the region, a negative discount rate may be applied.

Depreciation with a variable discount rate can also be used for environmental impact assessment such as 'total pesticide use', that may cause significant environmental damage above a certain threshold level as estimated by the environmentalist.

- A simple rating method [Nijkamp et al., 1990] is applied to calculate a final score for ranking of scenarios. Scores are calculated for single goal values, based on priority setting and relative deviation of realized value from target, and added to arrive at the total score:

$$\text{GScore}(g) = \text{Prior}(g) * \sum_{y=1}^{NY} (\text{RDev}(g,y) * \text{DFact}(g,y))$$

$$\text{MGScore} = \sum_{g=1}^{NG} \text{GScore}(g)$$

where:
g = code of a single goal;
GScore(g) = score of single goal;
y = year number;
Prior(g) = priority value of single goal, determined by decision-makers;
RDev(g,y) = relative deviation of realized value from target;
DFact(g,y) = discount factor;
MGScore = multiple-goal score of scenario.
NG = number of goals taken into account;

Output data:

<14> Scores of single goals and total score of the selected land use scenario.

CHAPTER IV AN EXAMPLE IN THE REAL WORLD

IV.1 THE QUAN LO PHUNG HIEP REGION AND ITS ISSUES

IV.2 CONCEPTUAL MODEL FOR THE QUAN LO PHUNG HIEP REGION

IV.3 DEVELOPMENT OF CAILUP FOR THE QUAN LO PHUNG HIEP REGION

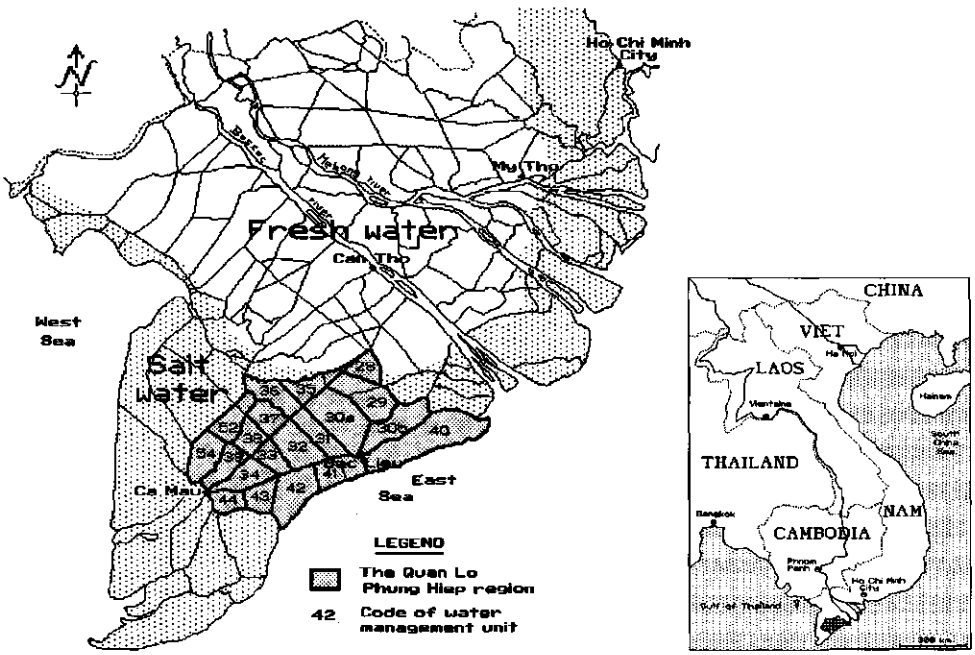
IV.4 APPLICATIONS OF CAILUP FOR THE QUAN LO PHUNG HIEP REGION

IV.1 THE QUAN LO PHUNG HIEP REGION AND ITS ISSUES

IV.1.1 The Quan Lo Phung Hiep region in the country

4.1 The Quan Lo Phung Hiep region (hereafter called the Region), with a total area of approximately 450,000 hectares, is located in the Ca Mau Peninsula, Mekong Delta, Vietnam (Fig. 28) and includes major portions of Soc Trang and Minh Hai provinces.

Figure 28: Location of the Quan Lo Phung Hiep region.

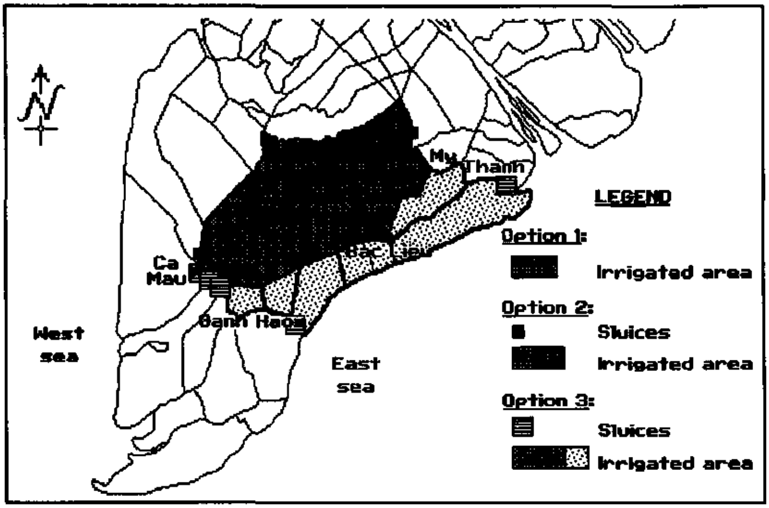


The Vietnamese Mekong Delta is the main "rice bowl" of Vietnam. In the foreseeable future, land use in the Mekong Delta will continue to be agriculture-oriented, or more precisely, rice-oriented. However, diversification is also required to increase farmers' income. Since natural and socio-economic conditions in the fresh water area in the Mekong Delta are more suitable for agricultural diversification, rice production will be expanded to the salt water area where the Region is located (Fig. 28).

IV.1.2 Studies on water management in the Quan Lo Phung Hiep region

4.2 Water management to prevent salt water intrusion through two large rivers, the My Thanh and the Ganh Hao, and to increase the supply of fresh water from the Mekong river, is considered a key intervention for the development of the Region. In 1989, three water management options were studied (Fig. 29) [Sonntag & McNamee, 1989]:

Figure 29: Three water management options.



(1) protection against salt water intrusion for each small unit bordered by lateral canals; irrigation of some units near the main streams;

(2) protection against salt water intrusion and irrigation of the central part;

(3) protection and irrigation of the whole Region by construction of a large dike and sluices system along the seashore.

Based on the AEAM (Adaptive Environmental Assessment and Management) methodology [Holling, 1978; ESSA, 1982; Mekong Secretariat, 1982; Walters, 1986], an integrated planning model was developed to analyze the effects of each of these three water management options. The intermediate scale option (2) was selected on the basis of costs, compatibility with the existing management capabilities and capacities of institutions, and environmental impact, particularly on the mangrove forests which line the coastal areas of the Region.

The follow-up study was a Pre-Feasibility Study for a Water Control Project, financially supported by the Government of Vietnam and CIDA, Canada, and was accomplished in 1992 [ESSA et al. 1992a, 1992b, 1992c]. The integrated planning model developed in the preceding study was improved during the follow-up study. At the same time, a study on the Mekong Delta Master Plan supported by UNDP was carried out by NEDECO from 1991 to 1993 [NEDECO, 1993a].

CAILUP for the Quan Lo Phung Hiep region has been developed on the basis of knowledge on modelling, and information and data acquired in these studies [Sonntag & McNamee, 1989; Duyet, 1991; Khoan, 1991; Thu, 1991; Can, 1992; ESSA Ltd. et al., 1992a, 1992b, 1992c; Qua, 1992; Sub-NIAPP, 1992; NEDECO, 1993a, 1993b, 1993d, 1993e]. Reports prepared in these studies are also the main references in the following introduction to the Region and its issues.

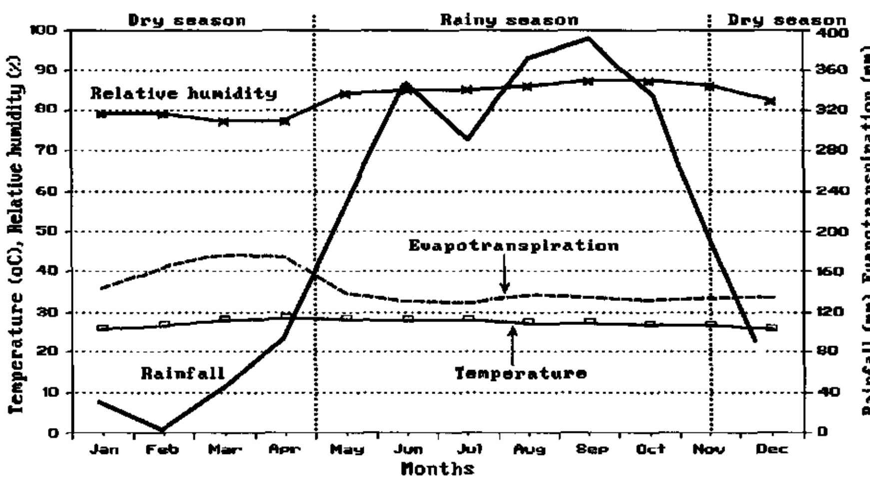
IV.1.3 Current conditions in the Quan Lo Phung Hiep region

IV.1.3.A Physical environment

4.3 Rainfall: two seasons are distinguished in the Quan Lo Phung Hiep:
1/ the rainy (or wet) season from May to November;
2/ the dry season from mid-November to April.

Roughly 90% of the annual rainfall (2400 mm at Ca Mau station) is concentrated in the rainy season and provides a mean monthly rainfall of over 200 mm (Fig. 30). However, dry spells, up to 30 days in unfavourable years, may occur from May to July.

Figure 30: Average climatic conditions at Ca Mau station.



Temperature and radiation conditions in the Region are excellent for producing tropical food crops. The mean monthly temperature fluctuates less than 3 degrees (25.4 - 28.2 °C), and relative humidity usually exceeds 80%. Potential evapotranspiration is about 140 mm per month, and only slightly higher in the hot dry season (February to April).

During the dry season when rainfall is nearly absent, fresh water availability for irrigation is a major constraint. However, as solar energy for photosynthesis in the dry season is more abundant than in the rainy season, rice crops in the dry season usually yield more.

4.4 A number of different geomorphological units can be distinguished in the Region: flood plains, inland swamps, inter-ridge depressions, and levees of alluvial soils along the canals. Essentially, the Region is a low-lying, flat delta with little variation in elevation. Nearly all of the Region lies less than 1.5 m above the mean sea level. The central depression with an elevation of less than 0.3 m above mean sea level is usually inundated to more than 0.5 m for three to four months.

4.5 The fourteen <u>soil types</u> in the Region (Table 3) can be grouped into four main groups. The two most important groups are the acid sulphate soils (52% of the total area, including salino-acid), and the saline soils (47%). Sandy and peaty soils only cover about 1% of the total area.

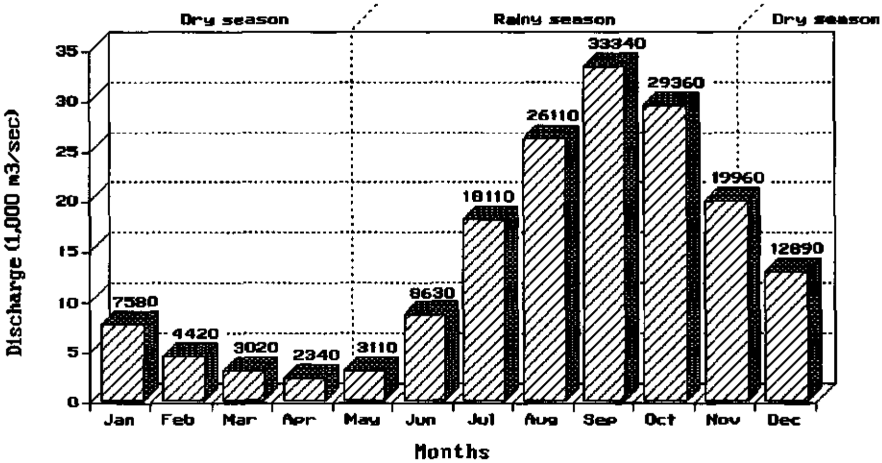
The acid sulphate soils, the main problem soils in the Region, comprise strongly acid sulphate soils (20%), and moderately and slightly acid sulphate soils (32%). Digging canals and placing the soil spoils on the banks is perhaps the main cause of the wide spread occurence of acid water. Using salt water for reclamation is a method to improve the quality of acid sulphate soils.

Table 3: Area of the various soil types in the Quan Lo Phung Hiep region.

Vietnamese classification		Area (ha)	FAO classification	USDA classification
Code	Soil types			
Cz	Sandy ridge soils	4,385	Haplic Arenosols	Fluentic Tropo-psamments
Sj1	Strongly active acid sulphate soils (sulphuric horizon 0-50 cm)	1,378	Orthi-Thionic Fluvisols	Sulfaquepts
Sj2	Moderately and slightly active acid sulphate soils (sulphuric horizon > 50 cm)	7,019	Orthi-Thionic Fluvisols	Pale Sulfic Tropaquepts
Sj1M	Strongly active salino-acid sulphate soils (sulphuric horizon 0-50 cm)	62,546	Sali-Orthi-Thionic Fluvisols	Sulfaquepts, Salic
Sj2M	Moderately and slightly active salino-acid sulphate soils (sulphuric horizon > 50 cm)	103,328	Sali-Orthi-Thionic Fluvisols	Sulfic Tropaquepts, Salic
Sp1Mm	Strongly potential salino-acid sulphate soils under mangrove (sulphuric horizon 0-50 cm)	1,018	Sali-Sulfi-Thionic Solonchaks	Sulfaquents, Salic
Sp1M	Strongly potential salino-acid sulphate soils (sulphuric horizon 0-50 cm)	24,123	Sali-Sulfi Thionic Fluvisols	Sulfaquents, Salic
Sp2Mm	Moderately and slightly potential salino-acid sulphate soils under mangrove (sulphuric horizon > 50 cm)	427	Sali-Sulfi Thionic Solonchaks	Sali-Sulfic Hydraquents
Sp2M	Moderately and slightly potential salino-acid sulphate soils (sulphuric horizon > 50 cm)	37,296	Sali-Sulfi Thionic Fluvisols	Sulfic Tropaquents, Salic
TS	Peaty acid sulphate soils	119	Thionic Histosols	Sulfihemist Sulfohemist
Mi	Slightly saline soils	157,255	Stagni-Salic Fluvisols	Tropaquepts, Salic Ustropepts, Salic
M	Moderately saline soils	24,556	Stagni-Salic Fluvisols	Tropaquepts, Salic
Mn	Strongly saline soils	30,021	Gleyic Solonchaks	Fluvaquents, Salic
Mm	Saline soils under mangrove forest	5,115	Gleyic Solonchaks	Hydraquents, Salic

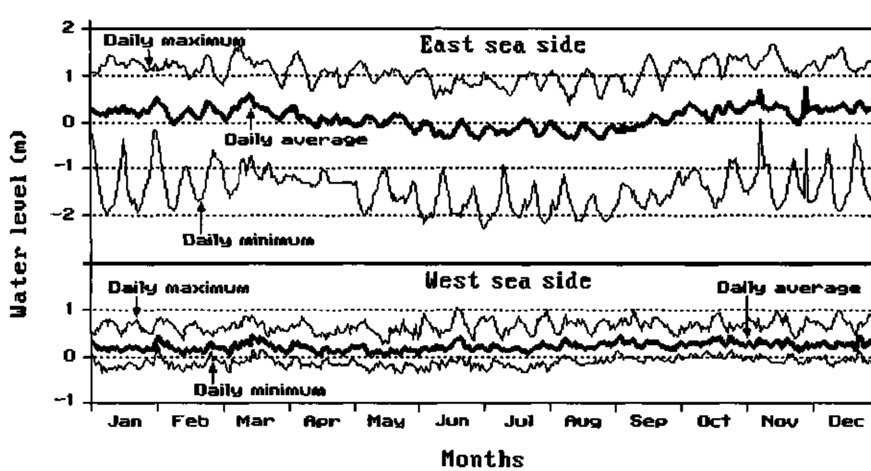
4.6 The <u>hydrological regime</u> in the Region is governed by the flow of the Mekong river and the tide from the sea. The Mekong river flow, with an average of approximately 14,000 m^3/s, is run-off from the monsoon rainfall over a large catchment area (approximately 795,000 km^2) with a seasonal distribution pattern (Fig. 31).

Figure 31: Average discharge of the Mekong river into the Delta.



The East and West seas (the South China Sea and the Gulf of Thailand) are hydrologically different in terms of tidal amplitude and daily water levels (Fig. 32). During the dry season, the difference in <u>tidal regimes</u> drives flows from the East sea to the West sea across the Region. Hence, protection against salt water flowing from the East sea through the My Thanh and Ganh Hao rivers is of major concern in water management.

Figure 32: Water levels at East sea and West sea sides.



During the past century, canals have been constructed to provide transport routes. These canals intersect and connect with the natural rivers, thus providing multiple routes for both fresh water supply and drainage, and salt water intrusion into the entire Region. From January to June, water in most canals is too saline for irrigation. Water extraction for irrigation upstream may aggravate the salinity conditions.

Special attention is given to the problem of acid water in the Region. At its eastern side, water quality in the rivers and canals appears relatively favourable in terms of acidity, the pH varies from about 6.5 to over 8, but is normally around 7-7.5. In contrast, at its western side, distinct seasonal influences acidity occur. During the early part of the rainy season, the pH drops from normal values (6-7) to below 4, under the influence of acid water flushed from the strongly acid sulphate soils.

Confined aquifers with good quality groundwater supplies exist in the Region. However, groundwater is only used for domestic consumption and small industries, because of its limited discharge.

IV.1.3.B Biological environment

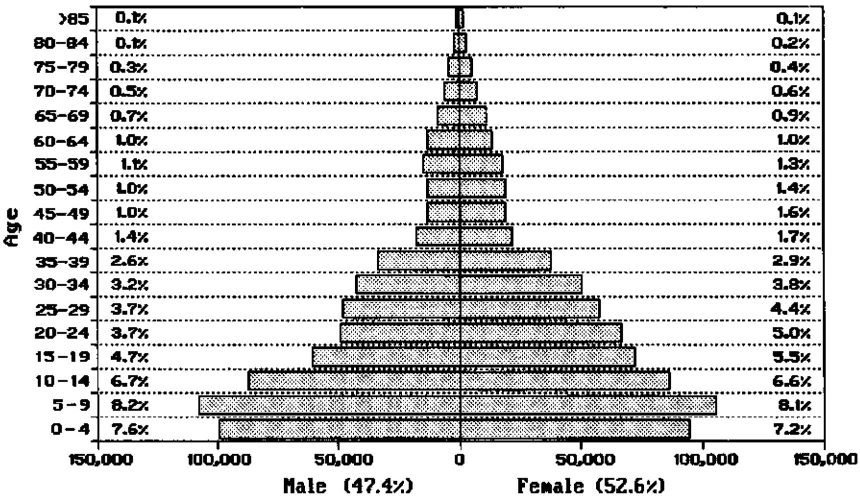
4.7 Most of the terrestrial ecosystem in the Region has come under human influence of some sort, particularly for the production of agricultural, fisheries, and forestry products, as well as for human settlement. Pockets of more or less natural ecosystems still exist, including forests of mangrove, nipa palm, melaleuca and 'grassland' (mainly reeds and sedges (*Eleocharis spp.*) growing on acid sulphate soils). Wildlife and ecosystem sanctuaries are maintained in some small areas in the Region.

4.8 In general, natural conditions in the Region create a complex aquatic environment for phytoplankton, aquatic plants and both brackish and fresh water animals. The Region has a relatively large area of permanent surface water bodies (7.8% of the total area), excluding the area of aquacultural ponds (5.6% of the total area) and also not including the area used for combined aquaculture/rice cropping (2.9% of the total area). The rivers and canals support some 191 species of fish and 34 species of shrimps and prawns, many of which are economically important.

IV.1.3.C Social environment

4.9 The total population in the Region was about 1.3 million persons in 1990, corresponding to a density of 280 persons/km^2, lower than the average for the Mekong Delta, of 376 persons/km^2. The percentage of the population below 15 years of age is 44% (Fig. 33). The rural population is about 85% of the total. The average size of a rural household is 5.6 persons, comprising 2.5 labourers, cultivating an average of 1 hectare of land.

Figure 33: Age distribution in the Quan Lo Phung Hiep region based on the population census of 1989.



The natural growth rate in the Region is 2.3% annually, compared to 2.0% for the Mekong Delta as a whole. The actual rate of population increase (including immigration) depends on the economic conditions. In the past, people migrated to the large cities outside the Region, but from 1990, many people have immigrated to the newly reclaimed areas in the Region, thus the actual rate of increase has been approximately 4% per year. Vietnam has set a national target of natural population growth of 1.7% annually, by the year 2000. However, for the two provinces of the Region, the target is set at 2.1%.

4.10 The general nutritional level in the Region is rather low, both in terms of total caloric intake and protein consumption. In 1990, over 30% of the total population consumed less than 6300 kJ (1500 kCal) per day while the minimum daily caloric consumption for a mature healthy individual is considered to be 8400 kJ (2000 kCal). Hence, raising food production has a high priority in the development plan.

In 1990, 75% of the population in the Region used surface water, 13 to 15% municipal tap water and 10 to 12% groundwater, for domestic use. Salinity levels in the canals and shallow wells lead people to buy expensive water from the deep wells. Hence, they are expecting fresh water supply from the Mekong river. Using canal water also causes a high incidence of water-borne diseases.

Malaria is common throughout the Region, especially in the transition zone from fresh water to salt water.

Most farm families live in small settlements situated at the intersections or along the banks of the canals and rivers. Over 70% of the houses in the Region consists of thatch huts constructed from nipa palm. The remaining 30% have tile roofs and some houses have wooden or cement walls.

4.11 People in the Region identify themselves with a village. A village in Vietnam is an administrative unit comprising several hamlets that are considered social units. A village population comprises 1,500 to 15,000 people, with an average of 7,000.

Women in the Region appear to be generally independent and mobile, and perceive themselves as full partners on the farm. They tend to be the business heads of the family and responsible for finances. Petty trade, including marketing is almost exclusively run by women.

4.12 The current labour force in the Region comprises 44 to 51% of the total population. The majority (85%) is engaged in agricultural, fisheries and forestry activities, as compared to 5% in industry and a similar proportion in trade and transportation. People prefer a rural above an urban life. A survey in 1990 showed that 86% of the land owners, 97% of the tenants, 100% of the owner/tenants and 87% of the farm workers preferred owning land above a city job.

4.13 As land is the major source of income in most villages, socio-economic status is largely determined by the size of the landholding. Average annual income per capita from cultivation in 1990 was approximately 35 US$, but varied from 25 for extremely poor farm households to 100 for better-off farm households. More than half of the income is spent on food. Limited availability of long-term credit remains a major constraint to agricultural development. Living standards are reportedly lower in areas of salt and brackish water than in areas of fresh water.

4.14 Currently, high levels of underemployment prevail in the Region. For rice farming, farmers work only 100 days a year, on average. A survey in 1990 indicated that over 64% of the workers participated less than 220 working days per annum in agricultural activities and off-farm employment in cottage industries and handicraft. About 37% of the children aged 5 to 14 years and 80% of the persons aged over 60 are engaged permanently or part-time in agricultural activities or handicrafts. The highest demand for labour is at the beginning and the end of the rainy season (during planting and harvesting of the rainfed rice crop).

IV.1.3.D Economic environment

4.15 Production of rice, upland crops and livestock is the largest sector of the economy in the Region, with rice as the single most important crop. Rice production in the Region totalled over 800,000 tonnes in 1990 with an annual increment of about 4-7% since 1980. Approximately 50 to 60% of the rice produced in the Region goes to local consumption by people, livestock and post-harvest losses. The remainder is marketed outside the Region.

"Perennial" (also called "industrial") upland crops (pineapple and sugarcane), and annual cash crops (mainly beans) are almost entirely exported from the Region. Total production of these upland crops is approximately 100,000 tons, mainly sugarcane (50%) and pineapple (30%).

Livestock production in the Region, concentrating on pigs and poultry, is always integrated with arable crop systems (principally rice). Pigs are the most widespread domestic animals in the Region, numbering over 227,000 in 1990. Ducks (over 1.4 million) and chickens (over 370,000) are kept in the Region for meat, eggs and duck feathers. Duck raising generally coincides with the rice fallow season, when the ducks are released into the paddy fields at about 30 days of age to consume crop remains and aquatic organisms in the ditches and ponds. Water buffalo and cattle are mainly used as draught animals.

The first stage in processing rice consists in threshing and drying the crop in preparation for storage or milling. Rice is mainly dried in yards around farm buildings, but if access is possible, asphalt or other roads are also used for drying. A large proportion of the rice, particularly that harvested during the rainy season, is stored with a too high moisture content. Post-harvest losses, therefore, are still high (15%). Rice mills for export-quality rice, with a total capacity of 350,000 t/y in 1990, are available in large cities. Many small rice mills (up to a thousand), with a capacity of 3 to 5 t/d, are operated for local consumption. Processing facilities for other crops (sugarcane and pineapple) or animal products (pork and poultry) are not only limited in capacity but also in processing quality.

Provincial warehouses, with a capacity of some ten thousand tonnes, are only available at ports and transportation centres. Therefore, farmers store their rice in open bins at their houses. In addition to the market and transport problem, the limited storage facilities are a reason why grain crops such as rice and beans are selected, although cash crops such as fruits and vegetables may give higher benefits.

Constraints on agricultural production can be summarized as follows:

- poor quality of soils and water, in particular water salinity and acidity;
- poor quality and low availability of major crop inputs such as fertilizer and pesticides;
- inadequate supplies of equipment and lack of spare parts;
- relatively weak processing infrastructure for crop and animal products;
- inadequate funds for breeding and propagation of new crop plant varieties;
- relatively weak extension services;
- lack of access to affordable agricultural credit;
- limitation of marketing, storage and tranport facilities.

4.16 Aquaculture and fisheries constitute another major category of economic activity in the Region. In 1990, aquaculture and fisheries production was estimated at approximately 6,000 tonnes of brackish and salt water shrimps, 3,000 tonnes of fish and 200 tonnes of fresh water prawns.

Aquatic products are an important component of the Vietnamese diet, accounting for 8% of the daily protein intake. In the Mekong Delta as a whole, 21 kg/capita of fish are consumed annually compared with the national average of 12 kg. Export earnings from aquatic products from the Mekong Delta amounted to 94 million US$ in 1990, representing 45% of the total national export value for aquatic products. Most of the export sales comprise frozen shrimps, prawns and fish.

Constraints on aquaculture and fisheries production are:

- poor water quality at critical stages of the year;
- reduced natural sources of shrimps and fish through habitat loss and over-exploitation;
- lack of facilities for providing artificial seed sources and feeds for aquaculture;
- lack of facilities for transporting aquaculture and fisheries products from rearing and catching locations to processing points and/or transportation hubs;
- limited institutional support such as research, extension services and credit facilities.

4.17 Forests and trees in the Region are used for various purposes, including fuelwood, construction, furniture, food, and environmental protection. As local wood demands are approximately 400,000 m^3/y (assuming 0.3 m^3/person-year), and exploitation of scattered trees covers approximately 10% of the demand, heavy exploitation of Melaleuca and mangrove forests for domestic use has taken place. A reforestation program involving Melaleuca, Eucalyptus and mangrove has been set up at provincial level. Nipa palm, a tree used for housing construction, only grows or is planted in a brackish water environment.

4.18 Industry in the Region is underdeveloped, and generally limited to agro-industry. About 70% of the industrial output comes from small, cottage-type industries such as milling and local sugar production.

Transportation in the Region is largely by water through the well-developed canal system that can be used by small rowing boats as well as motorized barges up to 250 tonnes. The road system comprises the more than 100 km of National Highway No. 1 and over 400 km of provincial roads which latter are mainly suited for 4-wheel drive vehicles and motorcycles, some of them only in the dry season.

Electrical power is supplied by a 60 kV transmission line from the national grid to towns, villages and institutional buildings in the Region. The capacity is limited, hence fuels such as gasoline and diesel are used for water pumps and other agricultural machinery. Firewood is the main material used for cooking in both rural and urban areas.

IV.1.3.E Institutional environment

4.19 In general, all sectors in Vietnam are organized in a three-tier hierarchy, i.e. the national, regional and local (province, district, village) levels.

At the central government level, the Council of Ministers is the main decision-making body and the State Planning Committee is responsible for macro planning in the whole country. Within each Ministry, a national sectoral planning institute operates, and sub-institutes responsible for regional planning have been established. At local level, People's Committees play a role similar to that of the Council of Ministers. Within People's Committee at provincial and district levels, departments exist for sectoral activities, including planning, design and implementation. These local departments belong to both vertical and horizontal structures: they are technically connected to the corresponding Ministries, but are administratively and financially responsible to the local People's Committee. A district is considered as an independent economic unit.

4.20 Three forms of land use organization can be distinguished:

1/ *Statefarms*: these manage the newly reclaimed areas, covering only a few percent of the Region. These areas are characterized by unfavourable soil and water conditions, hence production is low. The main products are industrial crops such as pineapple and forest. A new policy that allocates these areas to farm households seems successful in increasing production and income.

2/ *Cooperatives*: these constituted the dominant farm organization throughout Vietnam before 1990. Cooperatives still control about 75% of the total cultivated area and produce about 50% of the total agricultural production. A typical cooperative comprises about 350 families.

3/ *Private farms*: before 1990, a relatively small proportion of the total number of families cultivated land outside the cooperative or statefarm framework. This land included areas too sparsely populated to merit collective organization and the 5-6% of the area of family land used as homestead gardens which provide the nutritional supplements to foodgrains.

After 1990, the distinction between cooperative and private economy has been blurred by the return to family farming under the freemarket system. The production targets of agricultural cooperatives have been abolished, permitting free choice among production activities, and marketing freedom for all products and inputs, except land. The role of the cooperatives is confined to input supply, services, tax collection, representation of the interests of members, and social functions. Farmers may sign a contract on crop protection with the Agricultural Services, or buy fertilizers, pesticides, etc. in the free market. Moreover, recently the Agricultural Development Bank has opened offices in each district to provide opportunities for farmers to obtain credit for production.

IV.1.4 Integrated land use planning in the Quan Lo Phung Hiep region

IV.1.4.A Land use inventory and land use types

4.21 An agency responsible for land use planning *persé* does not exist. The General Department for Land Management, an agency directly reporting to the Council of Ministers, mainly concentrates on administrative management of the land.

The inventory of main land use categories at village level, provided by this Department every five years, is used as official database in land use planning. An example of such an inventory is summarized in Table 4.

Table 4: Land use inventory in 1990 for the Quan Lo Phung Hiep region

Items	Area (ha)	%
Total area	458,586	100.0
A. Arable farming	320,881	70.0
A.1 Annual crops	244,381	53.3
A.1.1 Rice crops	235,408	51.3
A.1.1.1 Single rice cropping	216,686	47.2
A.1.1.2 Double rice cropping	18,722	4.1
A.1.2 Upland crops	8,973	2.0
A.2 Homestead gardens	38,470	8.4
A.3 Newly reclaimed land for agriculture	12,563	2.7
A.4 Open water for agriculture (including aquaculture)	25,467	5.6
F. Forestry	15,457	3.4
F.1 Forests	12,287	2.7
F.2 Fallow land reserved for forests	3,170	0.7
S. Specific use (settlements, roads, salt fields, etc.)	40,705	8.8
U. Uncultivated area	81,543	17.8
U.1 Fallow area	45,812	10.0
U.2 Open water	35,731	7.8

Source: General Department of Land Management.

Many Ministries such as those of Agriculture and Food Industry, Fisheries, Forestry, Water Resources, Construction, Transport-Communication and Post, etc., deal with specific aspects of land use planning. Since agriculture is the most important sector in the country, a land use plan is usually prepared by agricultural planning institutes at different levels, from central to regional and local. However, that land use plan is formulated without much attention to the coordination between different sectors.

4.22 The current pattern of land use in the Region is characterized by:

- the small proportion of the land devoted to upland crops (1% of the total area, as compared to 53% for rice) due to the inundated conditions;
- the small area of double rice (4% of the total area) compared to that of single rice, reflecting the lack of fresh water for irrigation in the dry season;
- a relatively large area of shrimp rearing (6% of the total area), reflecting the salt water intrusion;
- a relatively large area in fallow (13% of the total area) due to poor soil and water conditions;
- a large area of 'non-productive' land use (23% of the total area) due to a large rural population (1.1 million persons).

4.23 Many different productive land use types are present in the Region. These land use types comprise single crops (rice, sugarcane, etc.) or combinations of several crops (rice+bean, rice+shrimp, etc.) produced with different management techniques. They are grouped in different production systems distinguished by planning agencies, based on the main product, such as rice, products from upland crops, from aquaculture and forestry.

IV.1.4.B Agricultural land use

4.24 Five main types of rice production are distinguished by the local population and considered in the agricultural development plan (see Table 5 in 4.32). While soil type is a main factor in selecting the production system, water conditions (water availability represented by water level in the canals, water salinity and pH) are a major factor in selecting cropping calendars. For example, due to different water conditions, thirteen different cropping calendars for a specific high yielding rice variety can be distinguished in the Region (see Sub-model [3] in 4.62). Construction of the first 3 sluices was started in 1992 and completed in 1993. The effects of these sluices on water conditions and subsequently on land use, have been observed since 1994, showing an increase of 15,000 ha in double rice cropping in the area protected from salt water [Statistical Department of Minh Hai Province, 1994; Statistical Department of Soc Trang Province, 1994]. At the same time, under the "reform" policy, rice production has shifted from a subsistence economy to a market economy, and farmers' income from rice cultivation to farmers has gradually increased.

Pest and disease influences on rice production fluctuate from year to year; in light pest years (when no control would result in ≤20% yield losses), 1.7 kg/ha of liquid pesticides seems sufficient to control pests, while in 'bad' years (risk of up to 100% losses), 5 kg/ha are required. However, without the advice of Agricultural Services, farmers usually apply the maximum dosis (5 kg/ha) whenever pests and diseases are detected.

4.25 A wide variety of annual upland crops such as bean crops (soybean, mungbean and other pulses), root and tuber crops (sweet potatoes, cassava), corn, vegetables (onions, garlic, chilies, lettuce, etc.), are grown on raised beds in the Region. These crops only occupy small scattered fields or part of the homestead gardens, since then are only grown to meet local consumption. Due to the limitation of marketing and storage facilities, the emphasis in future annual upland crop-rice rotations will likely be on bean (pulse) crops.

4.26 Both main "perennial" upland crops, i.e. sugarcane and pineapple, are more suitable to acid sulphate soils than annual upland crops, and are also planted on raised beds. Generally, one crop of sugarcane or pineapple yields three harvests in three years.

IV.1.4.C Aquaculture and fishery production

4.27 Three main types, i.e. shrimps, prawns and fish are reared in the Region, with different cultivation techniques and input levels.

Shrimp species commonly cultivated are *Penaeus merguiensis* (White shrimp), *Penaeus indicus* (Indian white shrimp), *Penaeus semisulcatus* (Green tiger shrimp), *Penaeus monodon* (Giant tiger shrimp), *Metapenaeus ensis* (Greasyback shrimp), *Metapenaeus lysianassa* (Yellow-white shrimp). A typical production system is the rice-shrimp combination in which farmers dig ditches around the rice field and strengthen the field bunds following the rice harvest for rearing shrimps. In 1993, diseases and inadequate water quality control caused substantial losses in shrimp cultivation. It has made farmers more cautious in investing in this type of aquaculture.

In a small part of the Region, currently not affected by salt-water intrusion, fresh water prawn aquaculture is practised, using the fresh water giant prawn *Macrobrachium rosenbergii*. Rice-prawn systems are practised much in the same way as rice-shrimp systems, except that prawns and rice are usually produced concurrently (i.e., the prawns are grown in the ditches surrounding the rice fields). The main limitation of this system is that pesticides cannot be used in the rice crop.

Specific practices with respect to the source of shrimp and prawn seeds have been noticed. Adult shrimps mainly live in the sea water environment, off-shore or along the coast, but breeding occurs at inland brackish water locations. Adult prawns, however, live in fresh water environments at upstream sites, whereas breeding takes place at the river mouths where water is brackish.

Fish culture can operate year-round. The dominant fish culture technique in the Region is rearing fresh water fish in small ponds (100-200 m^2) and ditches. This fish is mainly raised on manure (cattle, pig, chicken) and agricultural offal (rice-bran, oil-cake, vegetable and slaughter house waste), as well as on human sewage where ponds are associated with homes.

Three levels of inputs are distinguished in aquaculture:

1/ *Extensive*: shrimps or prawns are grown in large farms (7 ha on average, subdivided into 1-3 ha ponds). Farmers depend completely on natural seed and natural food, transported into the pond by the tide.

2/ *Semi-intensive*: ponds are generally smaller than in the extensive systems (1-2 ha in size, totalling on average 6.5 ha per farm) to facilitate management in terms of feeding, water control, etc. A higher stocking density is maintained generally by supplementing natural seed with some hatchery production. In addition to natural food, farm-made mixed feed and pelleted feed are used.

3/ *Intensive*: pond size is similar to that in the semi-intensive systems, but the investments in construction, inputs and operation are much higher. These systems are currently not operational in the Region.

Catching natural shrimps, prawns and fish is also an activity providing additional income to the local population. Many residents along the canals operate bamboo weir traps for shrimps or prawns, or fixed fishing net sites, and more temporary sites where several dozen cut stems are placed in the water to attract fish during some months before the catch.

IV.1.4.D Forest production

4.28 In the past, mangrove forests covered a large part of the brackish and saline water area, but most forests have recently been cut down to provide firewood and to convert the land for other land use types such as rice or shrimp cultivation, in particular in the period 1985-1990 when shrimps became a valuable product for export. Local authorities have now recognized the importance of mangrove forests in maintaining marine habitats, hence protection of the remaining mangrove forests and reforestation have been included in their development plans.

Melaleuca is the most suitable species for the acid sulphate soil area and is tolerant to fresh or brackish water inundation during some months. Most natural Melaleuca forests in the Region have been cut down for firewood or construction material and the land has been converted to agricultural land. Areas of remaining Melaleuca forest are mainly owned by statefarms, but small parcels are managed by individual farmers.

Eucalyptus is a promising species in the Region, because of its high production potential and its tolerance to acidity from acid sulphate soils. High investments are required for the construction of raised beds in the inundated area, and the impact of Eucalyptus production on the surrounding habitat is still in question. Nevertheless, some millions of scattered Eucalyptus trees have been introduced, scattered along roads and canal banks.

Nipa palm, a species planted or naturally grown along brackish water canals, is used as construction material for housing, and to protect rice fields along the coast against the wind with saline moisture from the sea. Since nipa palm is inundated during the flood tide, the area of nipa palm is included in the area of surface water.

IV.2 CONCEPTUAL MODEL FOR THE QUAN LO PHUNG HIEP REGION

IV.2.1 Development goals and indicators

4.29 Taking into account the situation in the Region, five main development objectives have been identified in the studies on water management:

1/ increase total food production and improve its distribution;
2/ increase total income and improve its distribution;
3/ increase foreign currency earnings;
4/ improve living conditions;
5/ sustain the economic development rate.

4.30 Goals and indicators have been selected on the basis of the present conditions and the expected impacts of the new water management system in the Region against the background of the general situation of the country. Goals and indicators have been grouped in four categories:

1/ Food production at regional level: total food production, average food availability per capita and food distribution. Many statistical indicators such as mean, standard deviation, skewness, etc. can be used to characterize food distribution, but a simple indicator used by decision makers in the Region is the proportion of the population with a food availability below a pre-defined fraction, e.g. 0.6, of the average amount of food available per capita in the region. Rice, the main staple in the Region, is used as indicator;

2/ Economic indicators at regional level: net present value (NPV), benefit-cost ratio (B/C), benefit-investment ratio (N/K), internal rate of return (IRR) and payback period;

3/ Socio-economic indicators at regional level: income per capita, income distribution (expressed in a similar way as food distribution), employment generation;

4/ Environmental impact indicators at regional level: proportion of the population supplied with fresh water for domestic use, minimum land cover in the dry season (important in the Region to restrict oxidation in acid sulphate soils), total pesticide use (influencing fauna habitat, in particular natural sources of shrimps, prawns and fish).

Some goals can be expressed by different indicators; for example, generated employment and reduction in unemployment. Only one indicator will be used in the current analysis, although decision makers may require values for both. Other goals such as total food production and food distribution, and income and income distribution are interrelated but refer to different issues, and all are used in the analysis.

4.31 Increasing production and processing for export are major activities to improve foreign currency earnings. Therefore, economic and socio-economic indicators are calculated for two cases: 'without' and 'with processing' of major exported products.

IV.2.2 Land use types in integrated land use planning

4.32 Relevant land use types have been identified by sectoral planning agencies and can be grouped in five categories as given in Table 5.

Included in the fourth category (land for other uses) are settlements, roads and other infrastructures, salt fields, canals, rivers, etc. The area for some specific production purposes, e.g. salt fields, is almost fixed, because such land use requires specific conditions, but the area of other land use types such as settlements, roads, etc., may change in the course of development of the Region.

IV.2.3 Model components

4.33 The model structure presented in Chapter III (III.2.4 Model Unit) is applied to the Region. Components of each sub-model are identified on the basis of goals, bio-physical and socio-economic conditions, key interventions, institutional structures, current knowledge and data required for other sub-models. The hierarchical model structure for the Region is shown in Fig. 34.

Some effects are only dealt with qualitatively such as change in water pH, change in soil productivity, effects of regional socio-economic conditions on those at the farm level. Many other effects are assessed as 'unknown', such as:

- long-term effects of rice cultivation on soil production capacity;
- effects of changing water conditions on natural fisheries;
- effects of pesticide use on aquatic habitats;
- effects of water management on groundwater quantity/quality;
- effects of new demands of the country on the Region;
- effects of policy changes and institutional modifications on water management;
- effects of variations in world market prices of major products produced in the Region.

Hence, these effects have not been included in the model structure. Assumptions can be made in the mathematical model in incorporating qualitative analyses and in identifying the effects of uncertainties on the final ranking of a selected scenario.

Figure 34: Model components for the Quan Lo Phung Hiep region.

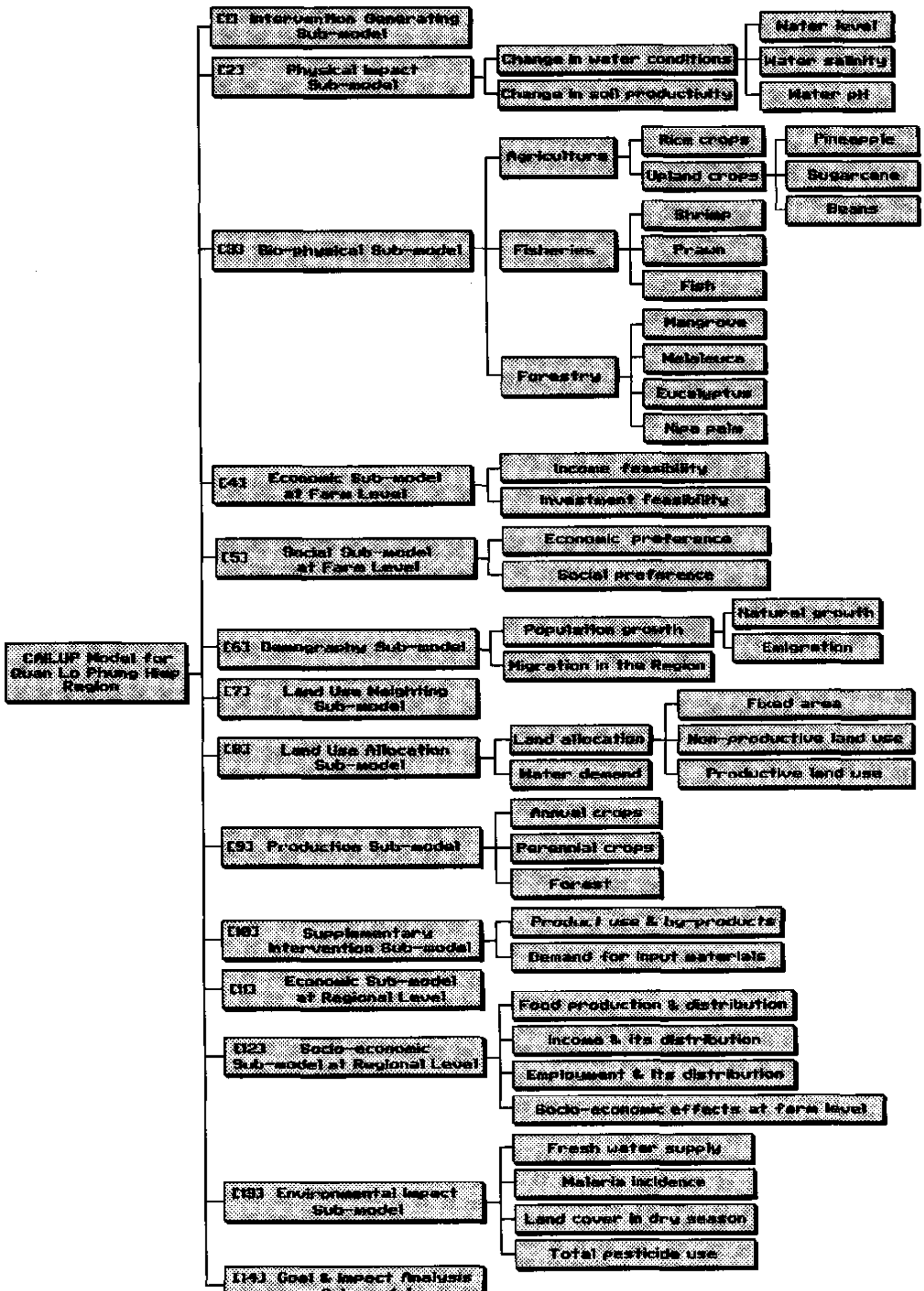


Table 5: Land use types distinguished in the Quan Lo Phung Hiep region in 1990 (Compiled by sectoral planning institutes)

Description	Area (ha)	%
Total area	458,586	100.0
A. Agriculture (arable farming)	247,819	54.1
A.1 Annual crops	243,157	53.0
A.1.1 Rice crops	243,157	53.0
1. Single rice cropping, traditional variety	109,673	23.9
2. Single rice cropping, high yielding variety	114,762	25.1
3. Double rice cropping	18,722	4.0
a. Summer-Autumn and 2nd rainfed crop, traditional variety	18,657	4.0
b. Summer-Autumn and 2nd rainfed crop, high yielding variety	0	0.0
c. Summer-Autumn and Winter-Spring	65	0.0
A.1.2 Annual upland crops	0.0	0.0
1. Summer-Autumn beans in rotation with rice	0	0.0
2. Winter-Spring beans in rotation with rice	0	0.0
3. Spring-Summer beans in rotation with rice	0	0.0
A.2 "Perennial" upland crops	4,662	1.0
1 Sugarcane	1,224	0.3
2 Pineapple	3,438	0.7
B. Aquaculture	29,109	6.3
B.1 Shrimps	25,288	5.5
1. Shrimps in ponds	21,646	4.7
2. Shrimps in rotation with salt fields	3,642	0.8
3. Shrimps in rotation with rice (included in area for rice crops)	12,990	2.8
B.2 Prawns	29	0.0
1. Prawns in ponds, one crop per year	29	0.0
2. Prawns in ponds, two crops per year	0	0.0
3. Prawns in rice fields, one crop per year	80	0.0
4. Prawns in rice fields, two crops per year	0	0.0
B.3 Fish ponds	3,792	0.8
C. Forestry	12,287	2.7
C.1 Eucalyptus forests	0	0.0
C.2 Mangrove forests	8,083	1.7
C.3 Melaleuca forests	4,204	0.9
C.4 Nipa palm (included in area for canals and rivers)	2,130	0.1
D. Other uses	107,826	23.5
D.1 Specific uses (Settlements, roads, etc.)	37,063	8.0
D.2 Homestead gardens	35,032	7.7
D.3 Canals and Rivers	35,731	7.8
E. Uncultivated area	61,545	13.4

IV.2.4 Factors and interactions among components

4.34 Each component of the model requires specific calculations dealing with specific factors as presented in IV.3 (Development of CAILUP for the Quan Lo Phung Hiep region). Interactions among sub-models and relations among factors are presented in a matrix of data exchange (Table 6, pages 94-95).

IV.2.5 Spatial extent

4.35 In the preceding studies on water management in the Region, several discussions have taken place to identify the boundaries of the Region in relation to the Ca Mau Peninsula, and the Mekong Delta as a whole. Finally, taking into account the key intervention, i.e. 'construction of the new water management system', and its impact on fisheries production, the boundaries of the region have been defined as shown in Fig. 28.

The water management system, designed for protection against salt water intrusion, and irrigation of the central part of the Region (hereafter called the Inside, see 4.2) with fresh water, will affect water conditions and land use in the area downstream. To assess these off-site effects, the economic analysis and the goal and impact analysis are carried out for two situations: i) the Region as a whole and ii) the Inside, as a water management project.

IV.2.6 Spatial resolution

4.36 Two levels of spatial resolution have been distinguished:

1/ The first level is defined by the main (primary) canals that divide the region into 20 water management units (Fig. 28);

2/ The second level comprises 181 sub-units in the Region, delineated by the combination of the village boundaries and the water management unit boundaries. Average elevation, soil type, population type (rural or urban), dominant farmer group, etc. were identified for each sub-unit on the basis of available information from maps (elevation map, soil map), inventories (population census) and expert knowledge (dominant farmer group based on knowledge of local planners).

IV.2.7 Time horizon

4.37 For the Quan Lo Phung Hiep region, the time horizon should exceed:

- the year when the water management system exerts its full effect (depending on construction schedule, possibly up to 17 years);
- the year when the longest growing crop is harvested (12 years for mangrove forest);
- the final year of economic analysis of the investment in the water management system (30 years).

Consequently, a time horizon of 30 years has been applied.

IV.2.8 Time steps

4.38 Based on current knowledge and available data on interactions among indicators and factors, four time steps have been selected:

- one hour: applied in the tidal hydraulic and salinity calculations;
- half a month: applied in the crop growth calculations;
- one year: applied in the socio-economic calculations, and intermediate goal and impact assessments;
- whole planning period (30 years): applied in the final goal and impact assessment.

IV.2.9 Water management and land use scenarios

4.39 Seven schedules of water management construction have been formulated based on the availability of funds and the strategy in minimizing the acid water effects:

A: main sluices construction sequentially from east to west over a period of 7 years;

B: main sluices initiation at the same time in both the Soc Trang and the Minh Hai province and realized within 5 years;

C: as B, but the construction period is 7 years in the case of lack of investment funds;

D: as A for main sluices, but in addition, secondary canals are constructed early in the areas with active acid sulphate soils, to allow for sufficient leaching of acid by salt water, prior to the initiation of the introduction of irrigation;

E: as B for main sluices, and as D for secondary canals.

F: the area protected from salt water is divided into 2 parts on the basis of river networks conveying saline water (the My Thanh and Ganh Hao rivers, Fig. 29), and protection is separated by five years to allow monitoring of the environmental, social and economic impacts.

G: as F, but the area protected from salt water is divided into 3 parts on the basis of soil types.

Table 6: A matrix of data flows expressing interactions among sub-models (for the Quan Lo Phung Hiep region).

Sub-model receiving data ------> / Data set or sub-model generating data (v)	[1] Intervention Generating Sub-model	[2] Physical Impact Sub-model	[3] Bio-physical Sub-model	[4] Economic Sub-model at Farm Level	[5] Social Sub-model at Farm Level	[6] Demography Sub-model	[7] Land Use Weighting Sub-model
<E> Existing conditions	<E> Existing socio-economic conditions (s)	<E> Current hydraulic scheme Current water level, salinity and pH (s)	<E> Existing physical conditions (s) Maximum observed yield (lut) Crop calendar (lut)	<E> Household type (s)	<E> Relative preference (lut)	<E> Current population (s) Population type (s)	<E> Current land use (s,lut)
<G> Goals of development	<G> Goals and indicators (y)						
[1] Intervention Generating Sub-model		<1> Modified hydraulic scheme Construction schedule (s,y)	<1> Construction schedule (s,y) Cultivation technique (s,y) Rules for crop yield in relation to physical conditions (lut)	<1> Construction schedule (s,y) Cultivation costs (lut,y) Product prices (p,y) Credit support (s,y)	<1> Construction schedule (s,y) Family labour demand (lut)	<1> Projected growth rate (s,y) Immigration rule (s,y) Working days per labourer (s,y)	<1> Government policy (s,y)
[2] Physical Impact Sub-model			<2> Modified water level, salinity and pH (s,y)				
[3] Bio-Physical Sub-model: Agriculture, Fishery & Forestry				<3> Yield (s,y,lut)			<3> Yield (s,y,lut)
[4] Economic Sub-model at Farm Level					<4> Bio-physical economic feasibility (s,y,lut) Financial income (s,y,lut)	<4> Financial income (s,y,lut)	
[5] Social Sub-model at Farm Level						<5> Integrated feasibility (s,y,lut)	<5> Integrated feasibility (s,y,lut)
[6] Demography Sub-model							<6> Population (s,y)
[7] Land Use Weighting Sub-model							
[8] Land Use Allocation Sub-model		<8> Water use (s,y,lut)					
[9] Production Sub-model							
[10] Supplementary Intervention Sub-model							
[11] Economic Sub-model at Regional Level							
[12] Social Sub-model at Regional Level				<12> Effects on economic conditions at farm level (s,y)	<12> Effects on socio-economic conditions at farm level (s,y)		
[13] Environmental Impact Sub-model							
[14] Goal and Impact Analysis Sub-model							

<u>Note</u>: (s,y,lut,p,g) = per sub-unit or water management unit, per year, per land use type, per product, per goal

[8] Land Use Allocation Sub-model	[9] Production Sub-model	[10] Supplementary Intervention Sub-model	[11] Economic Sub-model at Regional Level	[12] Social Sub-model at Regional Level	[13] Environmental Impact Sub-model	[14] Goal & Impact Analysis Sub-model
<E> Current land use (s,lut) Current population (s)	<E> Current yield reduction by pests and diseases (s)	<E> Current land use (s) Current population (s)	<E> Current land use (s)	<E> Current land use (s) Current population (s)	<E> Current land use (s) Current population (s)	
						<G> Goals & indicators (y) Discount factor (g) Priority (g)
<1> Construction schedule (s,y) Land use allocation rule (s,y) Land use conversion rule (lut,lut) Water demand standard (s,y)	<1> Projected pest & disease control (s,y)	<1> Construction schedule (s,y) Rule in production allocation(p,y) Post-harvest losses (p,y) Rule in by-product generation (s,y) Material inputs for cultivation (lut)	<1> Construction schedule (s,y) Costs of water management measures (s,y) Mitigation costs (s,y) Cultivation costs (lut,y) Processing costs (p,y) Product prices (p,y) Discount rate	<1> Working days per labourer (s,y) Labour demand for cultivation (lut,y)	<1> Relationship between water conditions and malaria incidence Water quality standard for domestic use (s,y)	
					<2> Modified water level, salinity and pH (s,y)	
<3> Crop calendar (s,y,lut)	<3> Yield (s,y,lut)			<3> Crop calendar (s,y,lut)	<3> Crop calendar (s,y,lut)	
<6> Population & labour force (s,y)		<6> Population & labour force (s,y)		<6> Population & labour force (s,y)	<6> Population (s,y)	<6> Population & labour force (s,y)
<7> Weighting factor (s,y,lut)						
	<8> Area (s,y,lut)	<8> Area (s,y,lut)	<8> Area (s,y,lut)	<8> Area (s,y,lut)	<8> Area (s,y,lut)	<8> Area (s,y,lut)
		<9> Production (s,y,c)	<9> Production (s,y,c)	<9> Production (s,y,c)		<9> Production (s,y,c)
			<10> Exported production (s,y,c) By-products (s,y,c)	<10> By-products (s,y,c)	<10> Pesticide use (s,y)	
				<11> Income (s,y)		<11> Income (s,y) Regional economic indicators
						<12> Production distribution (s,y) Income distribution (s,y) Employment (s,y)
						<13> Malaria incidence (s,y) Minimum land cover in dry season (s,y) Total pesticide use (y) Population supplied with fresh water (s,y)
						<14> Scenario assessment

Four land use strategies, corresponding to four production orientations have been formulated:

1: Maximize rice production: rice production is the focus and the rice cropping system yielding the highest rice production is selected;

2: Maximize income from rice production: rice production is the focus, but the rice cropping system yielding the highest net income is selected;

3: Crop diversification: crops yielding the highest net income are selected.

4: Minimize effects of acid water: acid tolerant crops cultivated in areas of slightly and moderately active acid sulphate soils, and no land use changes are allowed on strongly active acid sulphate soils;

4.40 Twenty-eight development scenarios have been identified by combining the 7 construction schedules with the 4 land use strategies. These scenarios were compared with the 'zero' scenario, i.e. the "without case", in which the water conditions and the land use patterns are assumed to remain as they are now, with the exception that more land is allocated for specific use (housing, urban, roads, etc.), as a function of population growth rate.

IV.3 DEVELOPMENT OF CAILUP FOR THE QUAN LO PHUNG HIEP REGION

IV.3.1 Selection of tools for implementing CAILUP

4.41 The personal computer (PC) was selected for CAILUP for the Quan Lo Phung Hiep region because:

- The personal computer is becoming increasingly popular in planning institutes in Vietnam, including local planning departments. Larger computers (mini-computers or mainframes) are only available at a limited number of agencies;
- During recent years, the capacity of the PC hardware has been improved considerably in terms of speed, data storage, and graphical display while costs have decreased significantly.

4.42 The DOS environment is most suitable for CAILUP for the Quan Lo Phung Hiep region, because:

- The DOS environment is available on most personal computers in Vietnam, therefore exchange and integration of data is not a problem;
- Most planners at Vietnamese planning institutes are able to work with DOS;

- The DOS environment allows high speed data retrieval and calculation, in comparison to other environments like WINDOWS. This feature is important in view of the calculation requirements of CAILUP;
- Commercial software packages developed for the DOS environment provide adequate tools for programming, data management and graphical display;
- Other operation systems such as UNIX or ZENIX for PC's may provide a higher speed and a larger memory for the calculation than DOS, however DOS is more user-friendly and a large number of software packages are available.

4.43 Microsoft QuickBasic was selected as the programming language in CAILUP for the Quan Lo Phung Hiep region because:

- QuickBasic is a multipurpose language, but it is so simple and user-friendly that a version of it, QBasic, has been included in the DOS package;
- The Microsoft QuickBasic package provides a good environment for debugging in the interpreting mode. This feature is important for the programming of models, in particular with a large model that requires expanded memory;
- A QuickBasic program can be compiled and run as an executable programme;
- Programmes for menus, windows, mouse control, etc. are included in the Microsoft QuickBasic version 7.0 (also called Professional Development System (PDS) [Holzner, 1990]);
- Other models in the field of land use planning have been developed, using the FORTRAN or BASIC language. They could be more easily referred to by CAILUP if a closely related language had been used;
- Some models for the Quan Lo Phung Hiep region have been developed in the Microsoft QuickBasic 4.5 environment.

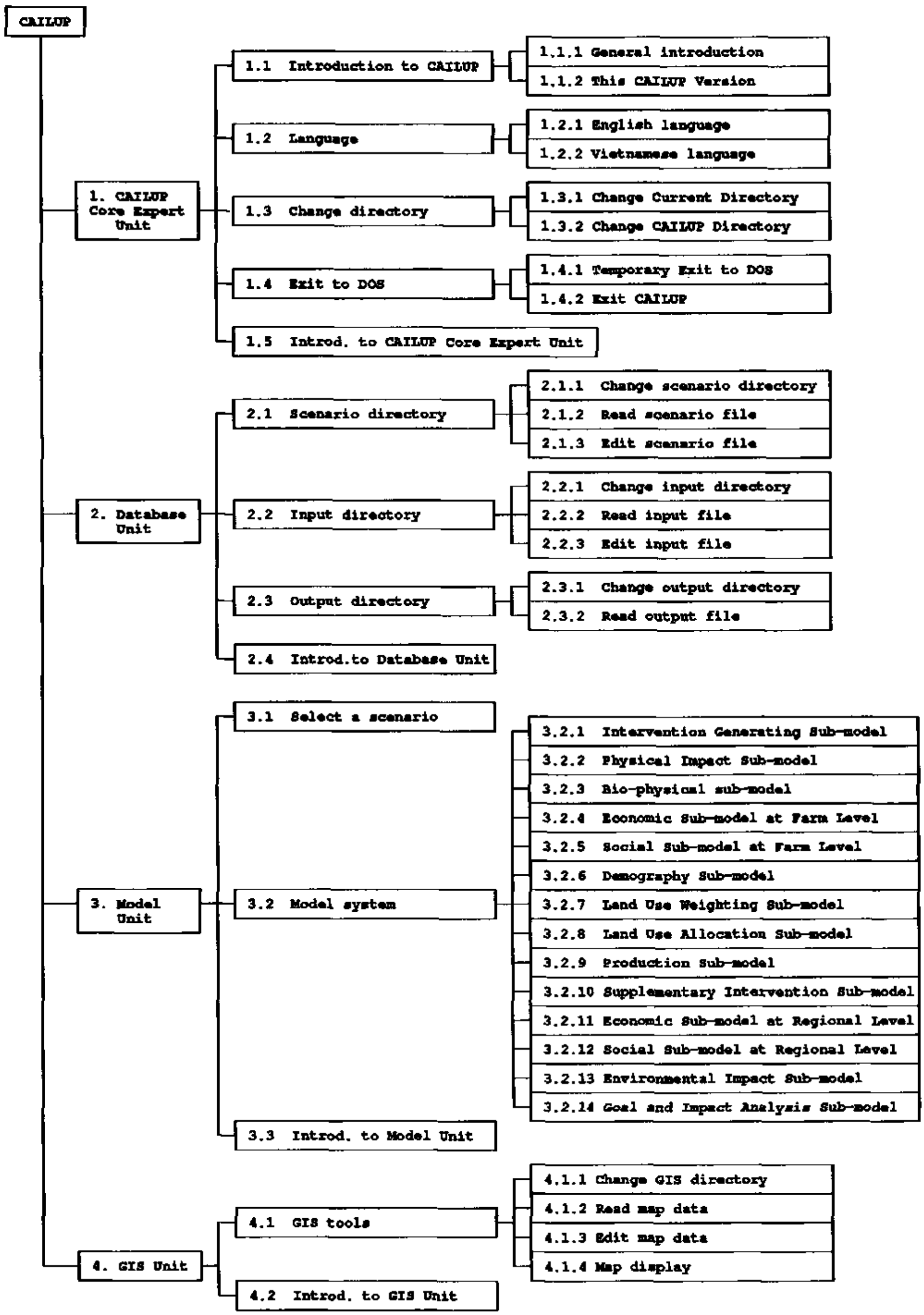
4.44 To apply the advantages of the available programmes, some additional tools are used in combination with CAILUP for the Quan Lo Phung Hiep region:

- EDIT.COM of MS-DOS, a programme available in the DOS environment that also uses the QBasic editor;
- LIST.COM version 7.7a, a non-commercial programme for reading data files.
- A worksheet software package, e.g. QUAPRO or LOTUS, with many economic functions, is used for data processing and graphical display.

IV.3.2 Core Expert Unit

4.45 The hierarchical menu system of the Core Expert Unit is described in Fig. 35.

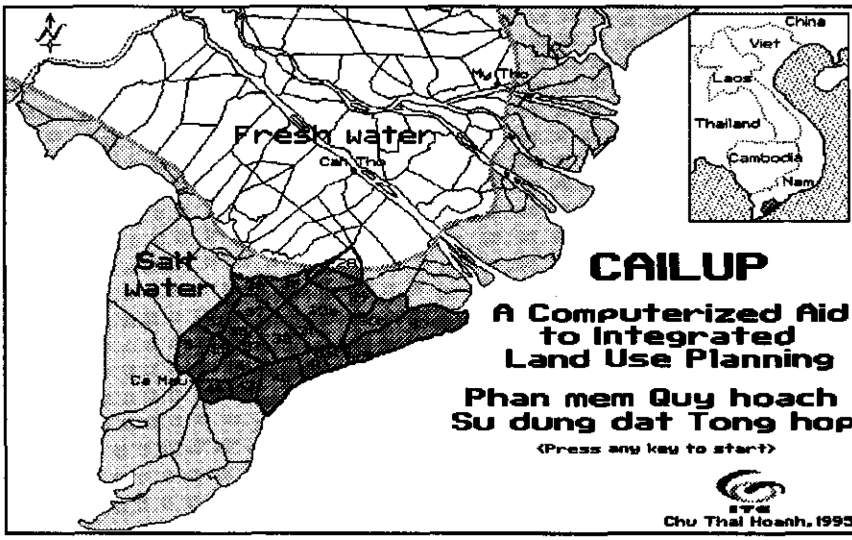
Figure 35: Menu system of CAILUP



4.46 Getting started with CAILUP:

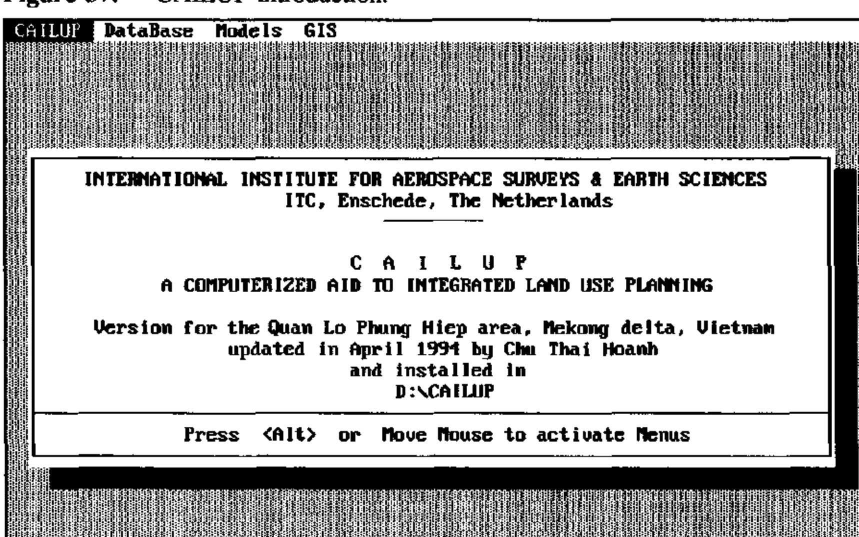
- CAILUP starts with a logo (Fig. 36).

Figure 36: CAILUP logo.



- An introduction to the current CAILUP version and a main menu system will appear after pressing any key (Fig. 37).

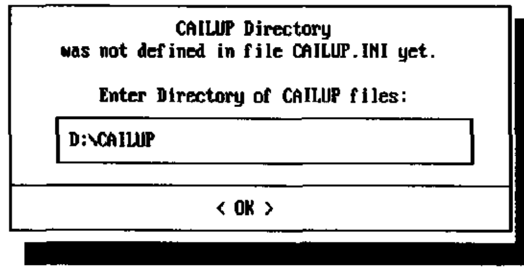
Figure 37: CAILUP introduction.



- In the first run, when the user has not defined the directory where CAILUP was installed, the model will ask for this information (Fig. 38).

- By pressing the <Alt> key, then the bold character or using arrow keys and <Enter>, or moving the mouse to a selection, the user can select one of the four items of the main menu at the top of the screen (Fig. 37).

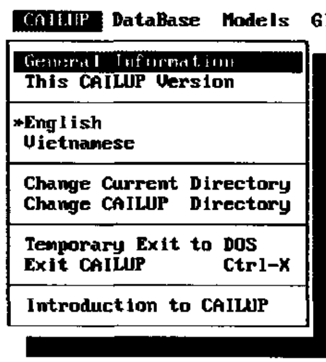
Figure 38: CAILUP directory.



4.47 "CAILUP" menu

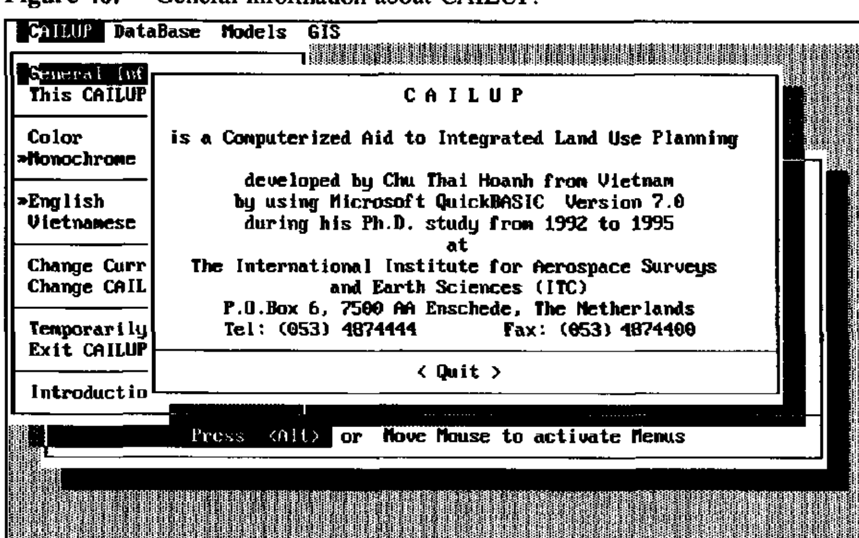
The "CAILUP" menu options are shown in Fig. 39.

Figure 39: "CAILUP" sub-menus.



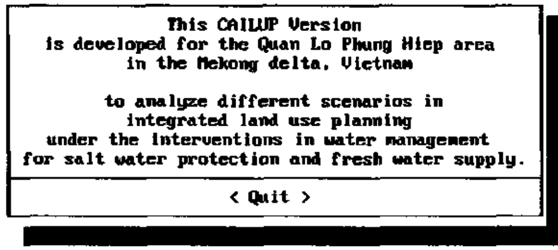
General Information: provides general information about CAILUP (Fig. 40).

Figure 40: General information about CAILUP.



This CAILUP Version:
for presenting the currently used CAILUP version (Fig. 41). Since different models can be developed for different objectives or study areas, but can be run in the same CAILUP environment, the user should pay attention to the version being used.

Figure 41: CAILUP version.



English: for selecting the English language for CAILUP.

Vietnamese: for selecting the Vietnamese language for CAILUP (Fig. 42). The selected language is indicated by a mark ».

Figure 42: CAILUP in the Vietnamese language.

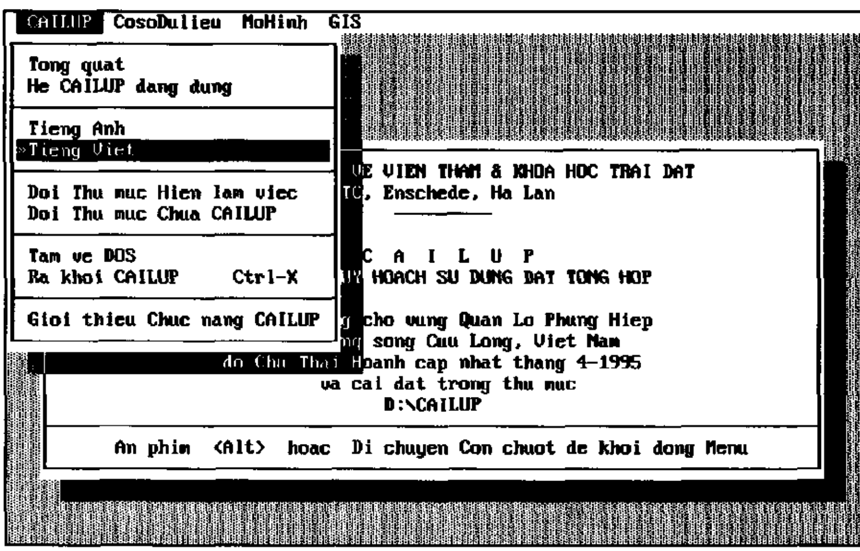
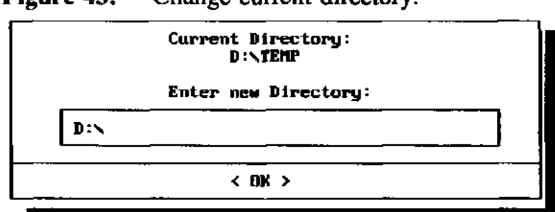


Figure 43: Change current directory.

Change Current Directory:
for changing the current working directory. This option allows the user to move the CAILUP set-up to another directory than that from which CAILUP was started (Fig. 43).



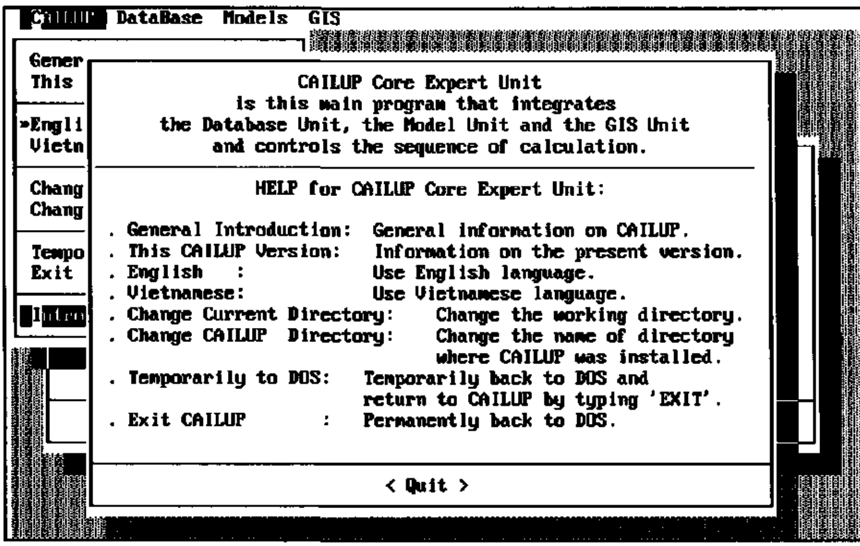
Change CAILUP Directory: for changing the directory in which CAILUP was installed. This option is required if different CAILUP versions or models are used.

Temporary Exit to DOS: for temporarily leaving CAILUP and returning to DOS. This option allows the user apply DOS commands or other programs in the DOS environment. By typing "EXIT", the program returns to CAILUP.

Exit CAILUP: for permanently returning to DOS. Ctrl-X is a shortcut key for this function.

Introduction to CAILUP Core Expert Unit: For introducing the general functions of this menu and giving a HELP on each item (Fig. 44).

Figure 44: Introduction to CAILUP Core Expert Unit.



4.48 <u>"Database" menu</u>

The Database menu options are shown in Fig. 45.

Scenario Directory: for changing the name of the directory containing the scenario definition files (Fig. 46).

Figure 46: Scenario directory.

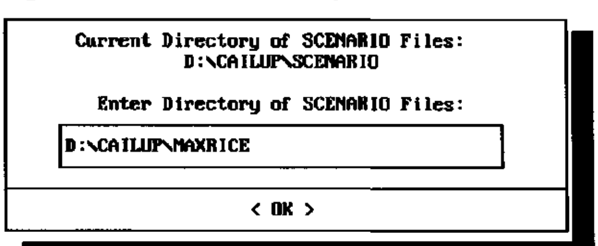
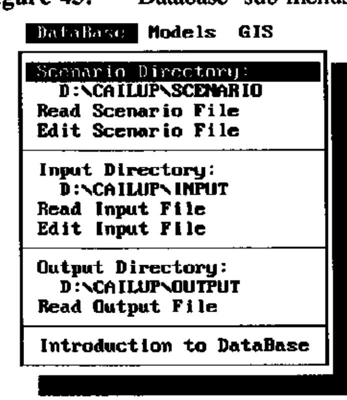


Figure 45: "Database" sub-menus.



Read Scenario File: for reading a scenario definition file. A description and an example of this file are presented in 4.52 and Appendix S1. The user can select a filename by typing into a query window (Fig. 47) and a list of files will be provided (Fig. 48). CAILUP links to LIST.COM for this function.

Figure 47: Scenario definition file.

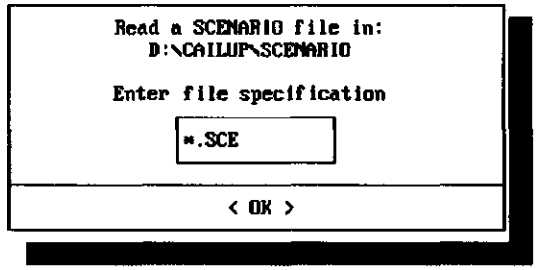
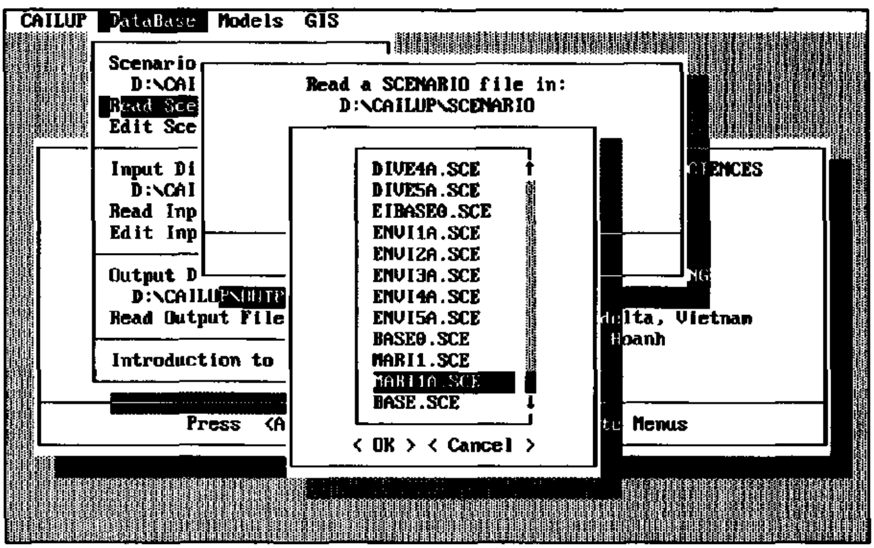


Figure 48: Read scenario definition file.



Edit Scenario File: for editing a scenario definition file. Selection of a filename is identical to the 'Read Scenario File' (Figs. 47 and 48). CAILUP links to EDIT.COM for this function.

Input Directory: for changing the name of the directory storing the input data files (similar to Scenario Directory, Fig. 46).

Read Input File: for reading an input file (similar to Read Scenario File, Figs. 47 and 48). An input file contains the various data required for execution of each sub-model. A detailed description of input data for each sub-model is presented in IV.3.5.

Edit Input File: for editing an input file (similar to Edit Scenario File).

Output Directory: for changing the name of the directory storing the output data files (similar to Scenario Directory, Fig. 46).

Read Output File: for reading an output file (similar to Read Scenario File, Figs. 47 and 48). An output file contains data calculated by each sub-model, that can be used as input for subsequent models. A detailed description of output data from each sub-model is presented in IV.3.5.

Introduction to DataBase Unit: for introducing the general functions of the DataBase Unit and for the provision of a HELP on each item (Fig. 49).

Figure 49: Introduction to the Database Unit.

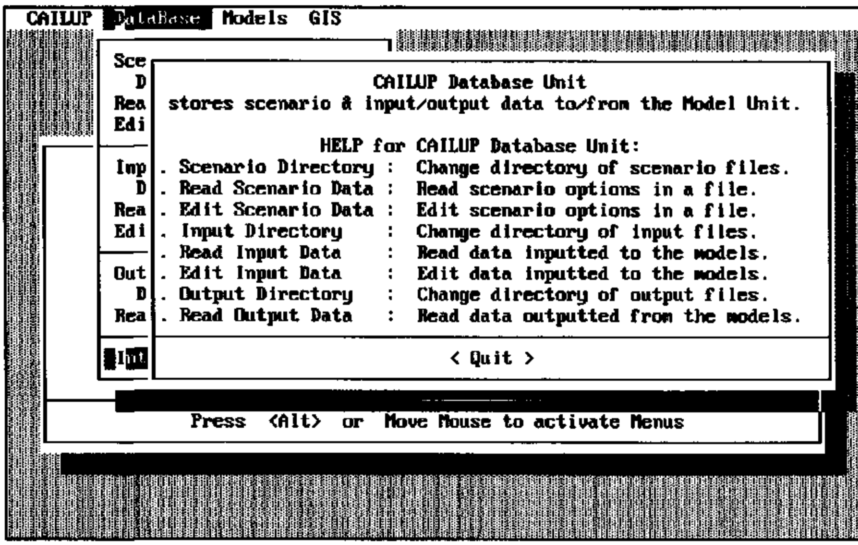
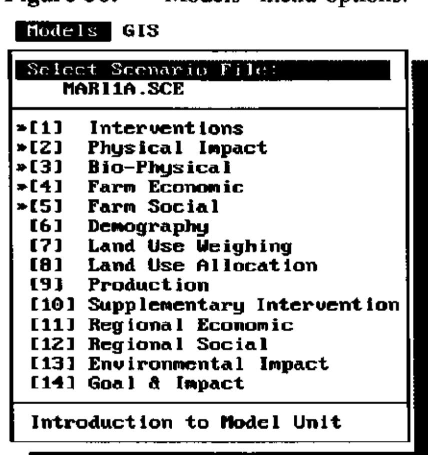


Figure 50: "Models" menu options.

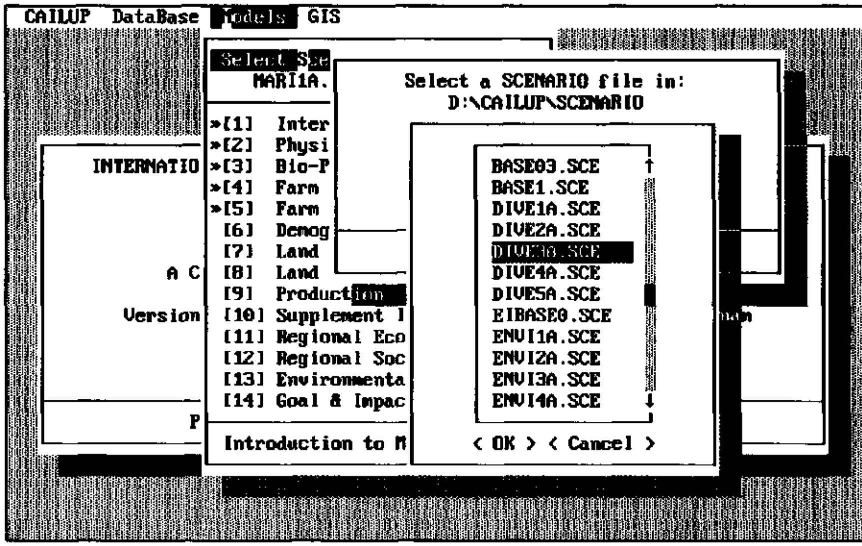


4.49 <u>"Models" menu</u>

The "Models" menu options are shown in Fig. 50.

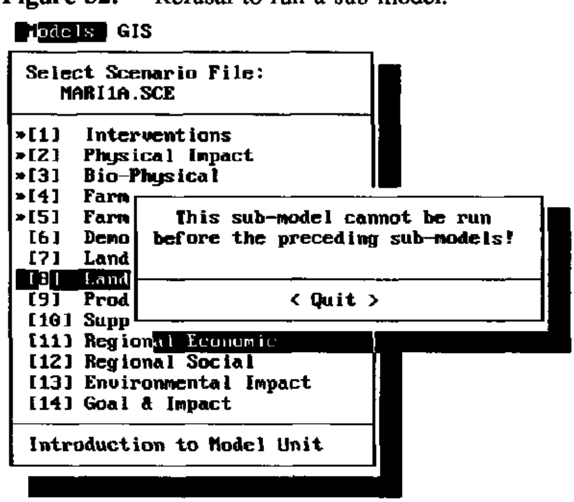
Select Scenario File: for selecting a scenario definition file in the scenario directory before running any model (Fig. 51). CAILUP controls the sequence of calculations, and shows a mark » next to the name of models already executed (Figs. 50 and 51).

Figure 51: Selection of a scenario file for models.



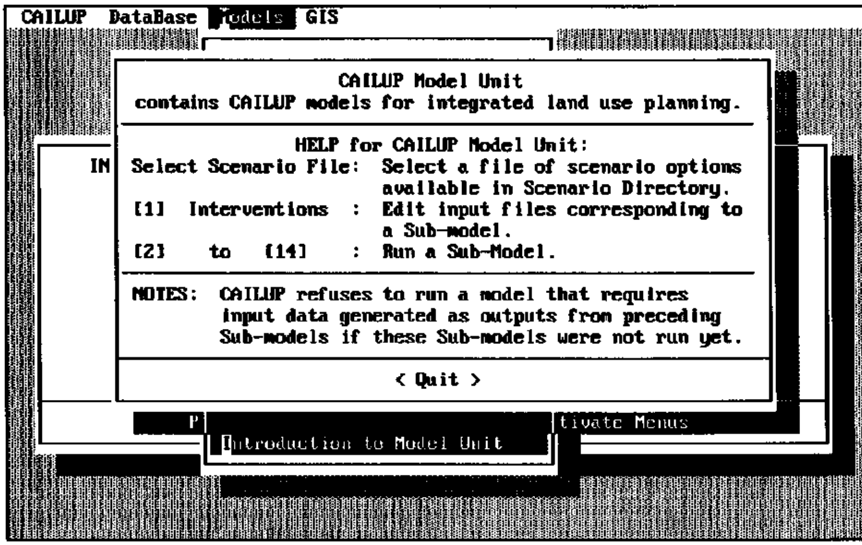
Sub-models [1] to [14]: for running a sub-model. CAILUP does not run a sub-model if preceding sub-models have not been run yet (Fig. 52).

Figure 52: Refusal to run a sub-model.



Introduction to Model Unit: for introducing the general functions of the Model Unit and giving a HELP on each item (Fig. 53).

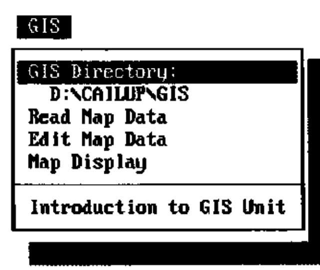
Figure 53: Introduction to the Model Unit.



4.50 "GIS" menu

The "GIS" menu options are shown in Fig. 54. Functions of the various items are:

Figure 54: "GIS" menu options.

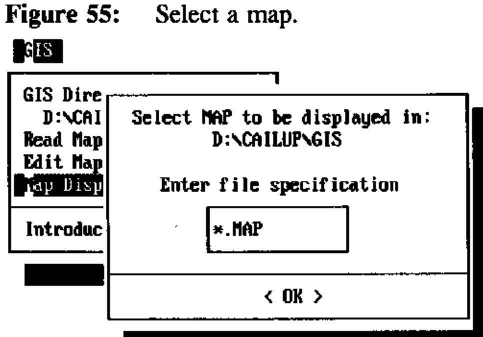


Read Map Data: for reading a map definition file that contains information on the base map and the input/output data to be shown. 'Read Map Data' is identical to 'Read Scenario File'. More details of map definition are discussed in IV.3.4.

Edit Map Data: for editing a map definition file. This function is identical to the 'Edit Scenario File'.

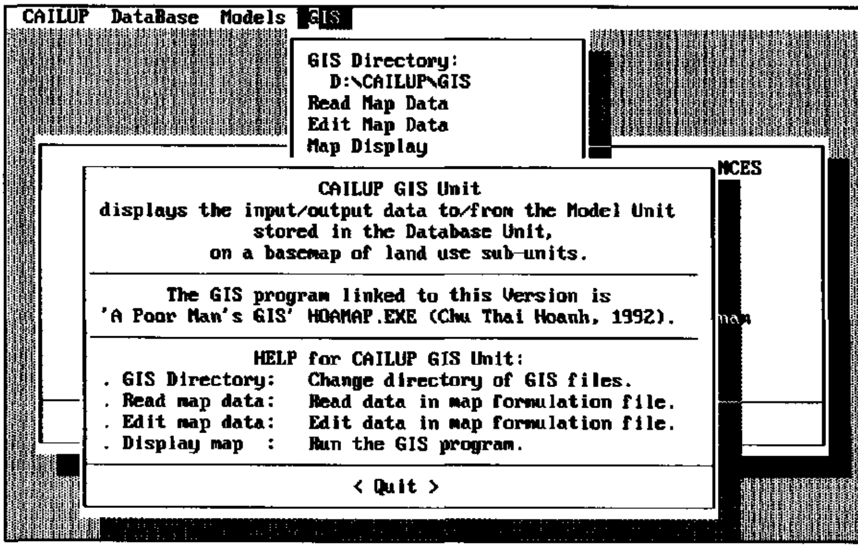
Map Display: for selecting a map (Fig. 55) to be shown on screen. The CAILUP version for the Quan Lo Phung Hiep region is linked to a simple GIS for this purpose (see 4.55).

Figure 55: Select a map.



Introduction to GIS Unit: for introducing the general functions of the GIS Unit and giving a HELP on each item (Fig. 56).

Figure 56: Introduction to the GIS Unit.



IV.3.3 Database Unit

4.51 The Database Unit of CAILUP for the Quan Lo Phung Hiep region has 3 components: Scenario Definition, Input Data and Output Data.

The Database Unit has a flexible structure: depending on the complexity of a scenario, data for each component can be stored in one or various directories that can be selected by the user, as explained in 4.48.

4.52 The Scenario Definition component consists of scenario definition files with extension ".SCE". Each scenario definition file contains information on the selected land use scenario and input/output filenames. An example of a scenario definition file is given in Appendix S1 (File MARI1.SCE).

4.53 The Input Data component contains input data in ASCII code for the Model Unit separately for each sub-model. Filenames are selected by the user; they should match with information in the corresponding scenario definition file. Some input data such as financial and economic data should be processed by worksheet or database software packages before being inputted in the models. These data can be stored in worksheet or database formats and converted to ASCII codes before input in the models.

As discussed in 3.14, in general, a relational database structure is applied for the input files: rows for spatial units (sub-unit, water management unit or region) per time interval (year, month, half a month) and columns for attributes. Integer or real values in input files are free format. Two special characters " & " and " ' " at the beginning of a line can be used to show remarks.

Examples of input data files for each sub-model are presented in Appendices S2 to S14.

4.54 The Output Data component contains output data from the Model Unit. Since large amounts of data are generated, two types of computer code are used:

i) Binary code for output data at sub-unit level that are exchanged among Sub-models;

ii) ASCII code for data at sub-unit level for selected years, and water management unit and the regional levels for all the years during the planning period. The user can select years with output data for sub-units for detailed analysis and mapping. Filenames are selected by the user, and a specific extension is given for each sub-model; e.g. scenario-name.S02, scenario-name.S03, etc. for sub-model [2], [3], etc.

Since the total time of a complete run on a 486 PC is approximately two hours (9 minutes per sub-model, on average), the data at sub-unit level in ASCII code (about 3 megabytes for one year for all sub-models together) can be deleted after analysis and mapping, and only data in binary code (about 4 Megabytes for 30 years for all sub-models) are stored. These data can be converted to data in ASCII code, if needed.

Examples of ASCII output data files are presented in Appendices S2 to S14.

IV.3.4 GIS Unit

4.55 The GIS Unit of CAILUP for the Quan Lo Phung Hiep region is a map display facility for spatial analysis. "A poor's man GIS" developed by Chu Thai Hoanh in 1992 is used for this purpose. This GIS software package comprises two main groups of functions:

i) A graphic editor for drawing a base map on screen and storing it in a graphic format;

ii) Display of output data at sub-unit level in different colours or patterns.

4.56 The GIS Unit consists of:

i) Map definition files, with functions similar to the scenario definition files, contain information about filenames of the base map, overlay map, sub-unit coordinates, label coordinates, and input or output data, to be displayed.

An example of a "map definition" file is given in Appendix S1 (File LANDUSE.MAP).

ii) Base map files containing data on a map of the Region with sub-unit boundaries. Local coordinates on screen of these sub-units and labels are stored in ASCII files.

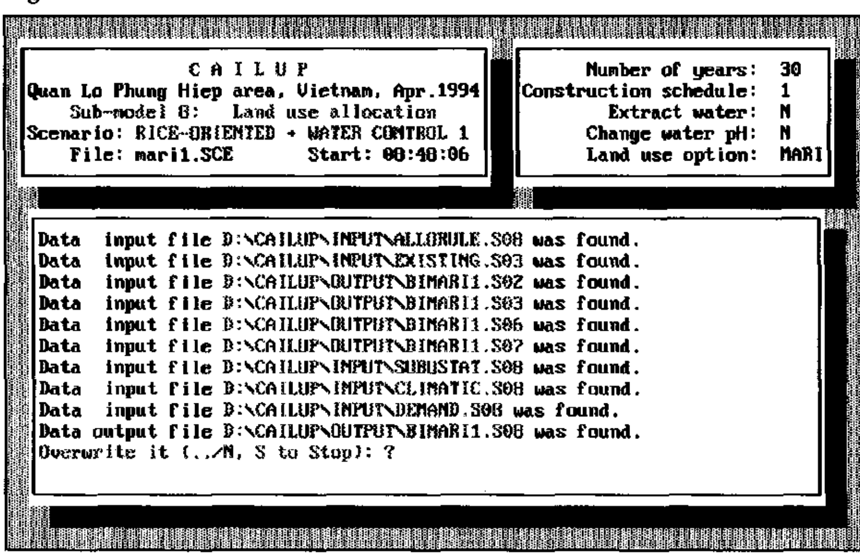
iii) Overlay map files containing data of a map with specific information such as canal network, roads, etc. superimposed on the data map displayed on screen. This option can be selected by the user.

IV.3.5 Model Unit

4.57 The mathematical model for the Quan Lo Phung Hiep region comprises 14 sub-models as discussed in III.2.4.C and the conceptual model is presented in IV.2.

4.58 Windows on the screen are used as a model-user interface. Sub-model [1] provides functions with various windows for editing scenario definition and input data files as presented in 4.60. Sub-models [2] to [14] start with three windows displaying the model title, the scenario and options, and the calculation sequence (Fig. 57).

Figure 57: Sub-model windows.



4.59 Main steps in the calculation sequence are displayed, so that the user can stop the model, temporarily exit to DOS for checking the output, then return to the model again to continue the calculation or terminate the model. When the calculations in a sub-model have been completed or are stopped by the user, the sub-model is ended and the system is connected to the CAILUP main program. The code of the completed sub-model is outputted to a file 'scenario-name.RUN' to inform the user and create the option for running the next sub-model from the CAILUP main program, as shown in Fig. 52.

4.60 Sub-model [1]: Intervention Generating

Function: Generate an intervention data set as input for the other sub-models.

Input data:

<G> Qualitative information from the conceptual model on goals and development issues as discussed in IV.2. This information has to be expressed in quantitative terms in the input files of other sub-models;

<E> Existing conditions in the Region as a reference for the selection of input data for other sub-models.

Output data:

<1> Interventions as input data for other sub-models. Examples of such input data in other sub-models are presented in Appendices S2 to S14.

Operation procedure:

The operation sequence in sub-model [1] is a simple procedure as shown in Fig. 58.

Main steps in the operation sequence are:

1) Start sub-model [1]: sub-model [1] is run directly in the environment of the CAILUP main program, i.e. it cannot be run independently without starting the main program. Sub-model [1] starts with a list of other sub-models (Fig. 59).

2) Select sub-model to be intervened: the user can select a sub-model to be intervened, from the list in Fig. 59.

Figure 58: Sequence of operations in sub-model [1].

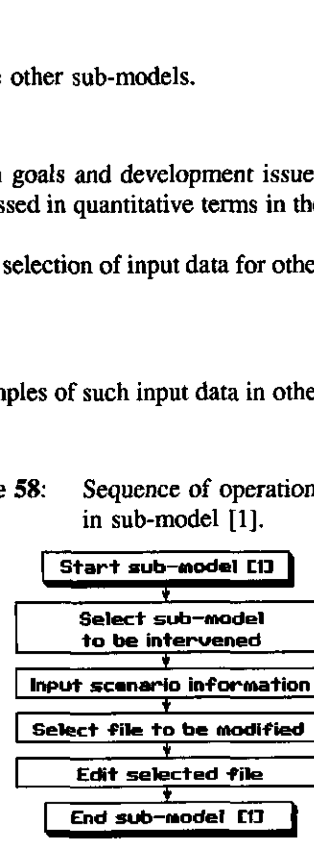
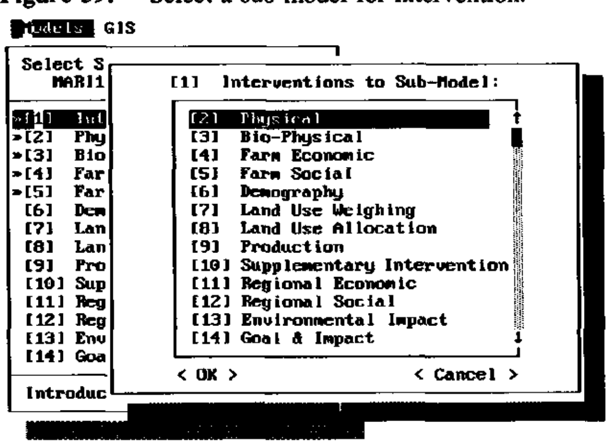


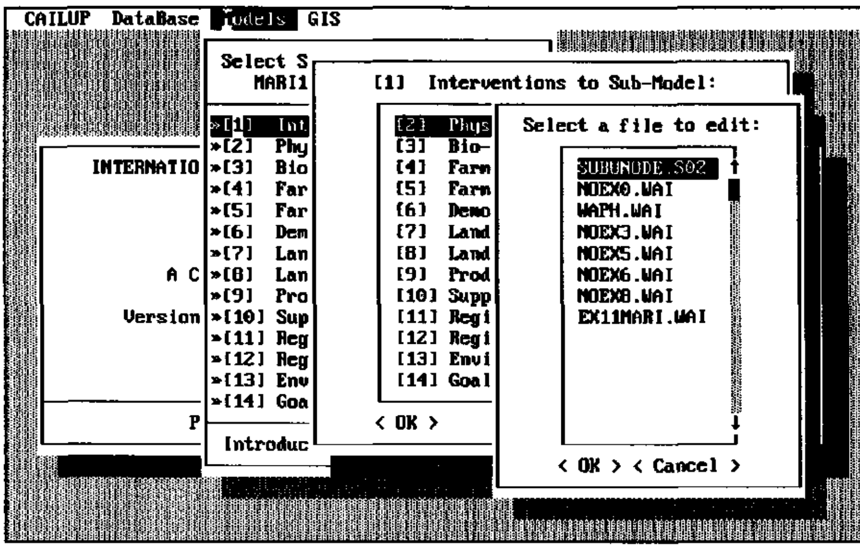
Figure 59: Select a sub-model for intervention.



3) Input scenario information: the names of input files corresponding to each sub-model are read from the selected scenario definition file (see 4.52).

4) Select a file to be modified: depending on the sub-model selected, a list of input files corresponding to that sub-model is provided (Fig. 60). The user can select the file to be modified.

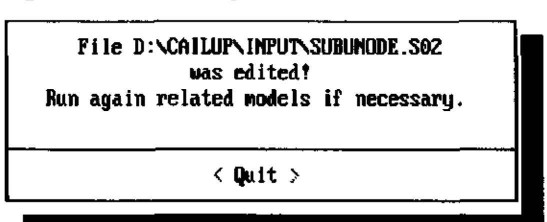
Figure 60: Select an input file.



5) Edit selected file: the selected file is edited by using EDIT.COM of DOS. A backup file is created before editing.

6) End sub-model [1] and connect to CAILUP main program: when editing is completed, sub-model [1] is ended and connection is made to the CAILUP main program with a warning, as shown in Fig. 61.

Figure 61: Warning on edited file.



4.61 Sub-model [2]: Physical Impact

Function: Predict physical conditions under the scenario selected. For the Quan Lo Phung Hiep region, sub-model [2] predicts the water conditions in each sub-unit with respect to three main factors: water level, salinity and pH, for different construction schedule options.

A water model for the Quan Lo Phung Hiep region:

Because of the complicated water regime in a delta with a dense network of rivers and canals fully under tidal influence, a hydraulic and salinity model is run separately to generate water data as input into sub-model [2] before starting CAILUP. Sub-model [2] transfers the water data from the hydraulic and salinity model scheme to sub-units and integrates these water data with the construction schedule of the water management system.

Several hydraulic and salinity models have been developed [Delft Hydraulics, 1989; van der Tuin, 1991; NEDECO, 1991a, 1991b, 1991c] to predict water level and salinity under a tidal regime. The VRSAP (Vietnam River Systems And Plains) model has been used for the Quan Lo Phung Hiep region. Details on this model can be found in the relevant references [Khue, 1991a, 1991b; ESSA et al., 1992b, 1992c; NEDECO 1991a, 1991b, 1991c, 1992a, 1992b, 1993b, 1993c]. The VRSAP model is a programme for mathematical modelling of one-dimensional hydrodynamic movement, transport and dispersion of mixed substances such as water and salt. An algorithm following an implicit finite difference method to solve the one-dimensional Saint-Venant equations and the advection-dispersion equation, is applied to a complex network of rivers, canals, and sewers. During its application for water resources planning and hydraulic design, it has been regularly refined. A recent version reprogrammed in QuickBasic 7.0 can be run on a microcomputer for a large scale network of about 1,500 segments, and is suitable for the Mekong Delta as a whole.

Input data required for the VRSAP model are:

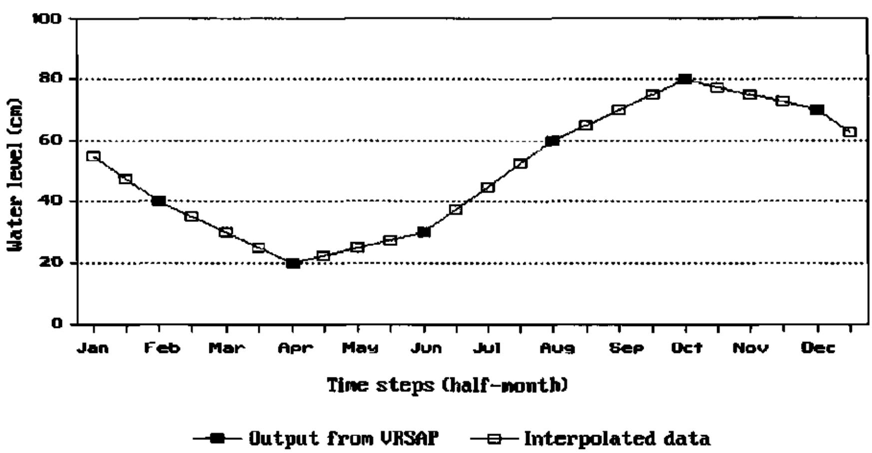
- Topographic data describing the river and canal system. The system is represented by a series of segments (each comprising a portion of a canal or river) separated by nodes and linked to plains (areas along the canal or river). Different types of hydraulic structures, e.g. dams, sluices, etc. can be included in the scheme.
- Hydrological and meteorological data comprising water level, discharge and salinity at boundary nodes and rainfall in fields.

Output data, including water levels and salinity at selected nodes, and flow at both ends of selected segments, can be presented in tabular form or displayed as a graph. In addition to simulating water conditions in the present canal and river network, the effects of interventions in the system (water extraction, canal excavation, building new hydraulic structures) and variations in water resources (changes in the natural flow from upstream) can be predicted by changing the topographic and hydrological input data.

As the canal and river system in the Mekong Delta is dense and interconnected, a hydraulic scheme for the Region must also cover the surrounding area, i.e. the complete Ca Mau peninsula of which it is a core zone (Fig. 28). The hydraulic scheme, comprising 372 segments, 455 nodes and 190 fields, is part of the Mekong Delta hydraulic scheme.

Hourly hydrological data from 44 water level stations, 19 discharge stations and 24 salinity stations, collected in the measurement campaigns in 1989-1990 have been used to calibrate the model. As discharge and salinity data are only available at distinct time intervals, the VRSAP model only generates data on water conditions at nodes and in plains at pre-selected periods (e.g. the first half of February, April, June, August, October and December), including averages of daily maximum and minimum water levels, daily average water level, and daily average salinity. Water conditions at other moments are obtained by linear interpolation in sub-model [2] as shown in Fig. 62.

Figure 62: Interpolation of water data.



Sub-model [2] has been designed in such a flexible way that it can be run in conjunction with different time steps in the VRSAP model. Obviously, if data are available, execution of the VRSAP model with shorter intervals may improve the prediction.

Assumptions on water pH in the Quan Lo Phung Hiep region:

In an area with acid sulphate soils, water pH in the canals usually decreases at the onset of the rainy season and then remains constant for one or two months, depending on rainfall. Changes in water pH may occur due to lowering of the water table in the acid sulphate soil area and the additional water extraction for agriculture after completion of the new water management system.

A model for the prediction of water pH for a complex canal system as that of the Region is not yet available. Existing models for acid sulphate soils mainly refer to the plot level and require detailed soil and groundwater data that are not available on a large scale.

A comprehensive model for acid sulphate soils, linking soil and water components at different spatial scales, is being developed by a Vietnamese modelling group headed Prof. Erik Eriksson from the University of Upsala, Sweden [Eriksson, 1991]. An operational version of that model is expected to be available in 1996. For the time being, water pH data from 14 stations in the Quan Lo Phung Hiep region, collected since 1988, have been used to characterize the water pH situation at different nodes in the hydraulic scheme.

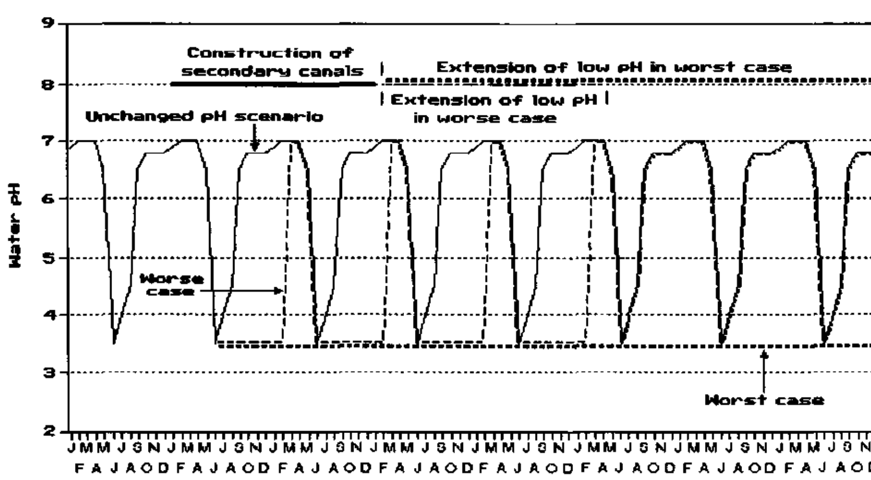
Assumptions have to be made about the variation in water pH under the influence of the water management system. Two water pH scenarios can be considered:

1/ *Unchanged water pH scenario*: water pH is assumed not to be affected by changes in water management.

2/ *Unfavourable water pH scenario*: water pH is assumed to be unfavourably affected by changes in water management. Field investigations have shown that during and following excavation of secondary canals, the water pH decreases due to acid water leaching from the disturbed soils.

In this scenario, for the period from the onset of the rainy season till a few months after its end (from June to January), water pH is set to the lowest observed value during the construction of secondary canals in the water management unit and this situation is maintained for some years. The period of low water pH in each year, and the number of years having that condition (according to field surveys, about 3 years), can be set by the user. In the worst case, low water pH will be a permanent condition (Fig. 63).

Figure 63: Effects of the construction of secondary canals on water pH in different scenarios.



Input data:

<E> Data on the present canal network, hydrological and meteorological conditions required for the VRSAP model. Water levels and salinity at nodes and in plains, generated in the VRSAP model, and water pH at nodes based on observed data are used as input data for this sub-model;

<1> Interventions with respect to the construction schedule of main sluices, main canals and secondary canals, assumptions about the variation in water pH;

<8> Water demand associated with future land use.

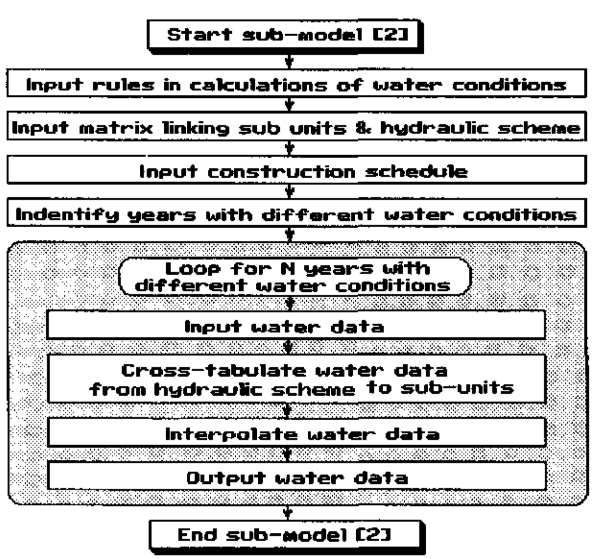
From data on water demand, the water volume extracted from the canals in each sub-unit is calculated and allocated to nodes in the hydraulic scheme. The VRSAP model is then run again to generate water level and salinity conditions under the new land use scenario. Changes in land use, causing significantly higher water extraction can only occur when the entire modified water management system has been implemented. A small change in water extraction causes a minor effect in the whole system. In practice, therefore, water data under the present extraction level can be used for the first few years of construction.

Output data:

<2> Water level, salinity and pH for each sub-unit at each time step in each year. To limit the size of the data file, only data from the years having different conditions than the preceding year are transferred to other sub-models.

Calculations: The main steps in the sequence of calculations are (Fig. 64):

Figure 64: Sequence of calculations in sub-model [2].



1) Start sub-model [2]: as described in 4.58.

2) Input rules in calculations of water conditions: these rules are applied to select water pH scenario as discussed above.

3) Input matrix linking sub-units and hydraulic scheme: a matrix, linking sub-units with the nodes and plains of the hydraulic scheme is used to transfer data from nodes and plains to the corresponding sub-units (File SUBUNODE.S02 in Appendix S2).

4) Input construction schedule (File CONSTRUC.SCH in Appendix S2).

5) Identify years with different water conditions: by analyzing the construction schedule, years with different water conditions (modified water level or salinity or pH in any sub-unit) are identified (Table 7).

Table 7: Effect of construction schedule on water conditions.

Year	Construction	Water conditions
1	Present water management system	Present water conditions
2	Completion of 3 main sluices	New water level, salinity and pH
3	Start of excavation of secondary canals in water management unit 1	New water pH
4	End of excavation of secondary canal in water management unit 1	Identical to previous year
5	Completion of 5 main sluices	New water level, salinity and pH
6	Start of excavation of secondary canals in water management unit N	New water pH
7	End of excavation of secondary canals in water management unit N	Identical to previous year
8	No construction work	Identical to previous year
9	End of the effect on water pH in unit N	New water pH
10	No construction work	Identical to previous year
...	...	...

6) Loop for N years with different water conditions:

6.1) Input water data: if a new water condition was identified in the year under consideration, data on water level and salinity (generated in the VRSAP model), and observed water pH at selected time steps are inputted (File NOEX0.S02 in Appendix S2). If the scenario of a change in water pH has been selected, new pH values are determined as discussed above.

6.2) Cross-tabulate water data from the hydraulic scheme to sub-units: input water data from nodes and fields in the hydraulic scheme are transferred to sub-units by using the linking matrix (File SUBUNODE.S02 in Appendix S2).

6.3) Interpolate water data: data at time steps not calculated by the VRSAP model are obtained by interpolation between the input data.

6.4) Output water data: data at all time steps in years with water conditions different from the preceding one are outputted to the binary and optional ASCII files (File MARI13.S02 in Appendix S2).

7) End sub-model [2], then connect to CAILUP main program as described in 4.59.

4.62 Sub-model [3]: Bio-Physical Sub-model for Agriculture, Fishery and Forestry

Function: Estimate yield for relevant land use types in agriculture (rice and upland crops), fisheries (shrimps, prawns and fish) and forestry (mangrove, melaleuca, eucalyptus and nipa palm).

Input data:
<E> Existing physical conditions such as soil type, elevation, etc.
<1> Selection of cropping calendars, pumping of water for early sowing, etc.
<2> Water level, salinity and pH.

Output data:
<3> Yield of all products.

For sensitivity analysis and calibration, information on effect of main factors on yield is also outputted, as in examples in Appendix S3 (Files MARI1.1HY, MARI1.BEA, MARI1.SPO and MARI1.FOR).

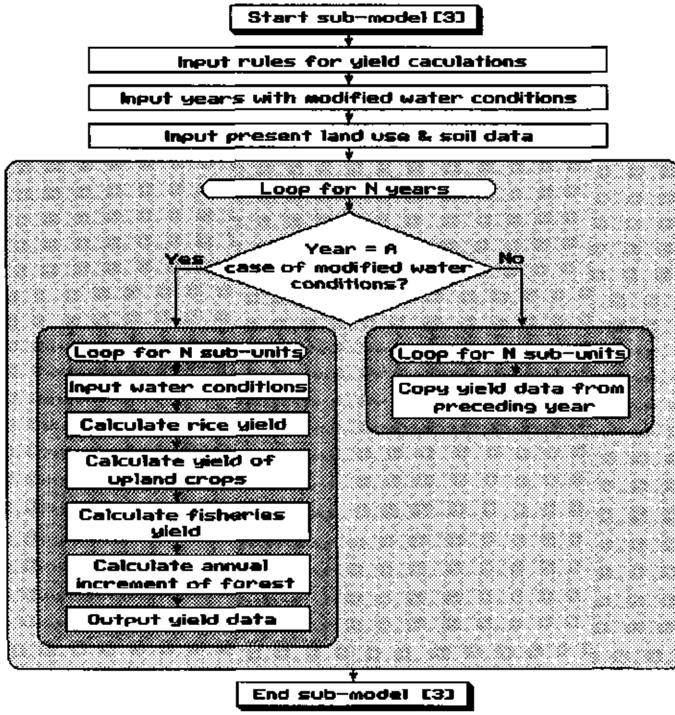
Calculations: In general, yield is expressed as a proportion of the maximum observed yield after reductions due to the effects of main physical factors such as soil type, water conditions, etc. as discussed in 3.29.

Notes:
i) In the following, the "effect of a factor on yield" means the proportion of the maximum yield after a yield-reduction due to the influence of that factor;

ii) In the equations of this sub-model, 't' stands for time step, 'st' for soil type, 'crop' for cropping calendar, 'sta' for crop stage, 'NSta' for number of crop stages, 'Nt' for number of time steps in a growth cycle, It and Ft for initial and final time step in a growth cycle, respectively.

The main steps in the sequence of calculations are (Fig. 65):

Figure 65: Sequence of calculations in sub-model [3].



1) Start sub-model [3]: as described in 4.58.

2) Input rules for yield calculations: rules for yield calculations deal with relations between physical conditions and yields, cropping calendars, pumping of water for early sowing, etc. (File AGRIRULE.S03 in Appendix S3).

3) Input years with modified water conditions from sub-model [2].

4) Input present land use and soil data (percentage of each soil type in each sub-unit (Files EXISTING.S03 and SOILTYPE.S03 in Appendix S3).

5) Loop for N years: two situations are possible:

- If a new water condition occurs in the year under consideration, a new yield level has to be calculated from *5.1*.
- If water conditions in a year are identical to those in the preceding year, yield calculation is not needed and a loop for all sub-units is performed to copy yield data from the preceding year.

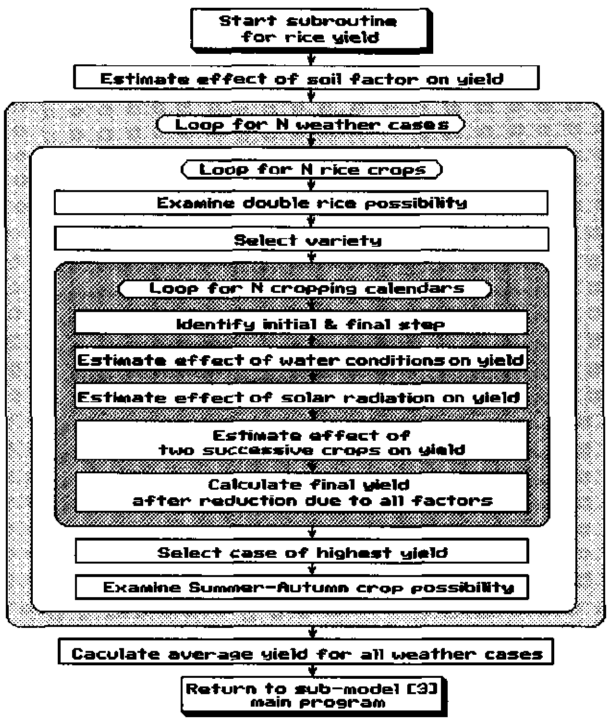
5.1) Loop for N sub-units:

5.1.1) Input water conditions (water level, salinity and pH) from sub-model [2].

Part I: Calculations of rice yield

5.1.2) Calculate rice yield: the main steps in the sequence of calculations are (Fig. 66):

Figure 66: Sequence of calculations for rice yields.



5.1.2a) Estimate the effect of the soil factor on yield: the effect of the soil factor on yield is calculated by aggregating the effects of all soil types on yield*, weighted for the area of each soil type in a sub-unit:

$$YSoil = \sum_{st=1}^{Nst} [YSt(st) * \frac{Area(st)}{TotArea}]$$

where: YSoil = the effect of soil factor on yield;
Nst = number of soil types;
YSt(st) = the effect of each soil type on yield;
Area(st) = area of each soil type in sub-unit (ha);
TotArea = total area of sub-unit (ha).

* The effect of each soil type on yield has been estimated by agronomists and soil scientists, based on experiments, yield inventories and field surveys [Sub-NIAPP, 1990].

5.1.2b) Loop for N weather cases: although normal weather conditions have been assumed in sub-model [2], two situations are considered to analyse the risk of rice yield reductions due to weather variations, both resulting in drought at the beginning of the rainy season:

- In favourable years, rainfall is regularly distributed and irrigation by canal water is not needed. Water quality in the field, therefore, is set to rain water quality (salinity = 0‰ and pH = 7), and is not a constraint in rice cultivation.
- In unfavourable years, rainfall is irregularly distributed at the beginning of the rainy season, irrigation by canal water is needed and water quality in the field is set to water quality in the canal.

More details on the field water quality in these situations are discussed in *5.1.2g*.

5.1.2c) Loop for N rice crop types: six types of rice crop are considered:

▸ Single rice crops:	- Traditional rice, one crop		(One Trad.)
	- High yielding rice, one crop		(One HY).
▸ Double rice crops:	- First crop:	Summer-Autumn rice	(SA)
	- Second crop:	Traditional rice	(2nd Trad.)
		High yielding rice	(2nd HY)
		Winter-Spring rice	(WS).

5.1.2d) Examine double rice possibility: double rice is only practised if yields for both crops exceeds 0 or a certain predetermined yield level (e.g. over inputs for cultivation expressed in rice equivalents). The SA version is considered first, and if it cannot be realized, the second crop is skipped.

5.1.2e) Select variety: two groups of rice varieties are considered:

- Traditional varieties, with an average cycle length of 11 time steps (165 days), including the nursery period. Depending on water conditions, farmers usually use varieties with an as long as possible cycle. However, because of salt water intrusion, harvesting should take place before the second half of February. These varieties are used as One Trad. and 2nd Trad. rice crop.
- High yielding varieties, with an average cycle length of 8 time steps (120 days). These varieties are used as One HY, SA, 2nd HY and WS rice crop.

5.1.2f) Loop for N cropping calendars: each rice crop has a number of cropping calendars as shown in Figs. 67 and 68.

Figure 67: Cropping calendars of single rice crops.

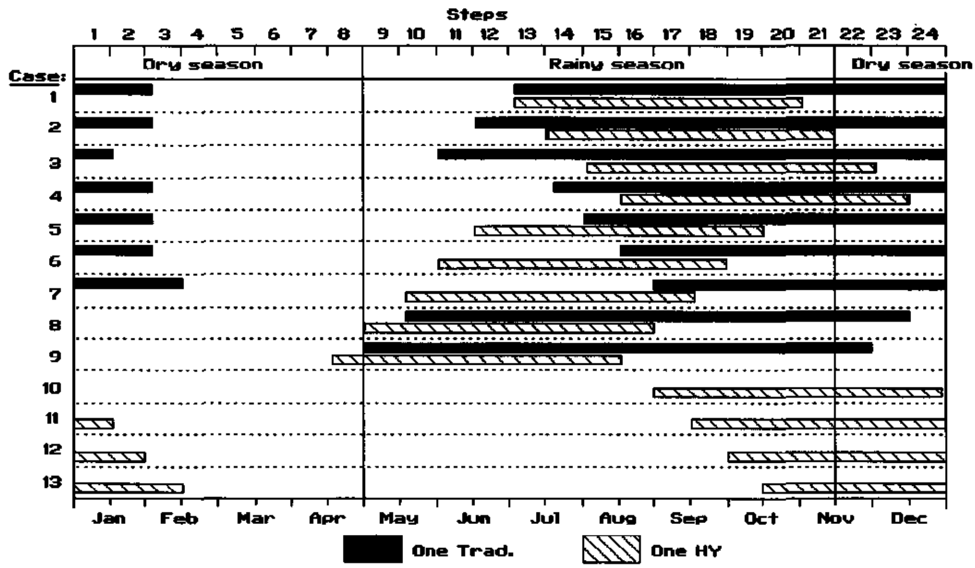
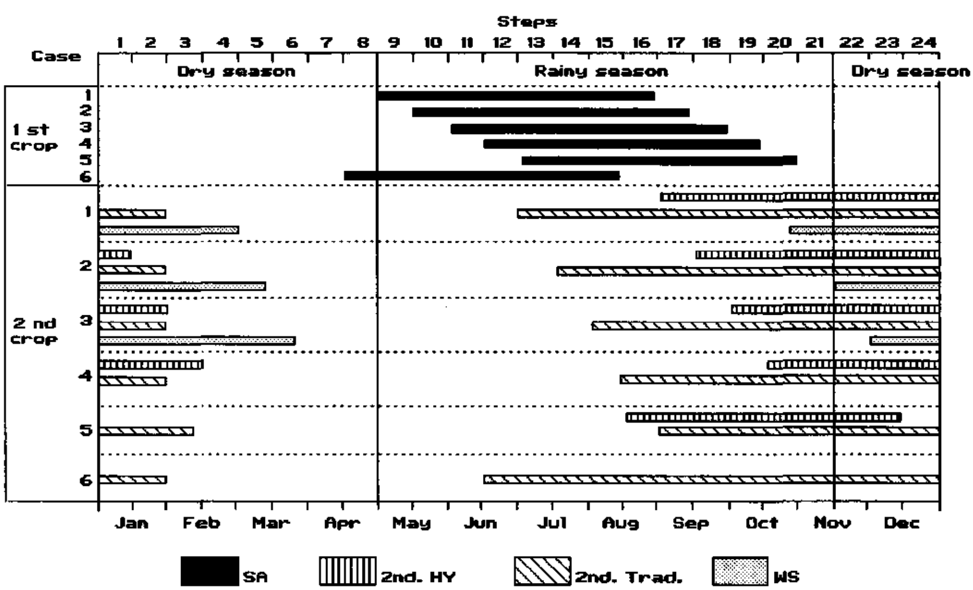


Figure 68: Cropping calendars of double rice crops.



The cropping calendars are given in order of priority by farmers based on the current water conditions. In the model, rice yields for all these cropping calendars are calculated and the crop with the highest yield is selected, except for the SA crop. Selection of the highest yielding first crop may limit the possibilities for the second crop, therefore, an option has been included to enable the user to simulate selections made by farmers. The options included for the SA crop are:

i) selecting the first cropping calendar with rice yield exceeding 0 or a certain predetermined level (see *5.1.2d*) (usually selected by inexperienced farmers); or

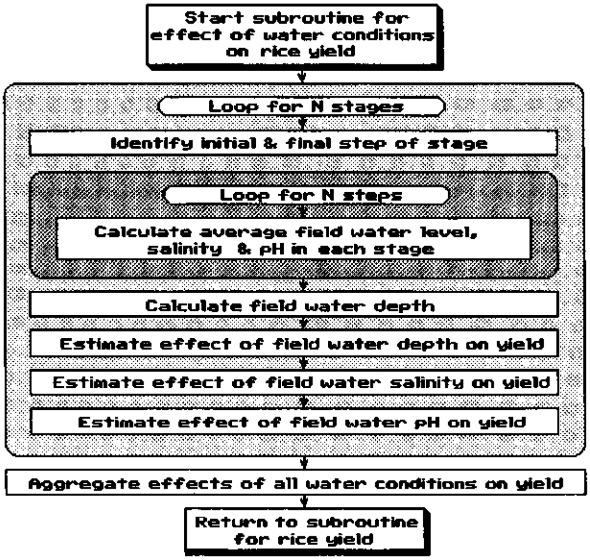
ii) selecting the cropping calendar giving the highest yield (experienced farmers).

Maximizing the total yield of both crops in case of double rice is not usually practised by farmers in the region, and is, therefore, not considered in the model.

5.1.2g) Identify initial and final step of the growth cycle: the initial and final time step of each cropping calendar are selected for the double rice crop. The 2nd HY crop can only be started after harvesting the SA crop. The 2nd Trad. crop is transplanted after harvesting of the SA crop, therefore it should be started 4 time steps before harvesting the SA crop.

5.1.2h) Estimate the effects of water conditions on yield: the main steps in the sequence of calculations are (Fig. 69):

Figure 69: Sequence of calculations to estimate the effect of water conditions on rice yield.



1/ *Loop for N stages*: the growth cycle of the rice crop is divided in three stages: seedling, tillering and yield formation.

1a/ *Identify initial and final step of the stage*: time steps for each stage are determined. For traditional varieties, the length of the tillering stage depends on the number of time steps available for this stage as mentioned in *5.1.2e*):

Tillering = (Initial - Final) - Seedling - YieldFormation

where:
- Tillering = length of tillering stage (in time steps of half a month);
- Initial = initial time step of the crop;
- Final = final time step of the crop;
- Seedling = length of the seedling stage (in time steps of half a month)
- YieldFormation = length of yield formation stage (in time steps of half a month).

1b/ *Loop for N time steps from the initial to the final step of each stage to calculate average field water level, salinity and pH:*

- For water level, two options have been included to calibrate the model:

  - If the quality of the irrigation and drainage system is poor, the field water level is assumed identical to the water level in representative plains from sub-model [2]:

$$FWL(sta) = [\sum_{t=It}^{Ft} PWL(t)] / Nt$$

where:
- FWL(sta) = field water level (cm);
- It and Ft = initial and final time step of the stage;
- PWL(t) = plain water level (cm) per time step from sub-model [2];
- Nt = number of time steps in the stage.

  - When the quality of the irrigation and drainage system has been improved by farmers, the field water level is close to the canal water level from sub-model [2]:

$$FWL(sta) = [\sum_{t=It}^{Ft} CWL(t)] / Nt$$

where:
- FWL(sta) = field water level (cm);
- CWL(t) = canal water level (cm) per time step from sub-model [2].

- For field water salinity and pH:

$$FWS(sta) = [\sum_{t=It}^{Ft} WSal(t)] / Nt$$

$$FWpH(sta) = [\sum_{t=It}^{Ft} WpH(t)] / Nt$$

where:
- FWS(sta), FWpH(sta) = field water salinity (‰) and field water pH, respectively;
- WSal(t), WpH(t) = water salinity (‰) and water pH, respectively, determined as follows:

- In the rainy season of favourable years:

$$WSal(t) = RWS \quad \text{and} \quad WpH(t) = RpH$$

where: RWS = rain water salinity (assumed at 0 ‰);
RpH = rain water pH (assumed at 7).

- In the rainy season of unfavourable years:
  - from the beginning to mid-July:

$$WSal(t) = CWS(t) \quad \text{and} \quad WpH(t) = CWpH(t)$$

where: CWS(t) and CWpH(t) = canal water salinity and pH per time step from sub-model [2].

  - for the remainder of the growth cycle:

$$WSal(t) = RWS \quad \text{and} \quad WpH(t) = RpH$$

where: RWS and RpH = rain water salinity and pH.

- In the dry season of both favourable and unfavourable years:

$$WSal(t) = CWS(t) \quad \text{and} \quad WpH(t) = CWpH(t)$$

where: CWS(t) and CWpH(t) as defined above.

Two exceptions are made:
- during the seedling stage before mid-July, leaching of acidity is needed, therefore: WpH(t) = CWpH(t)
- during the yield formation stage of traditional varieties (One Trad. and 2nd Trad. crops), irrigation by canal water is not required, therefore:

$$WSal(t) = RWS \quad \text{and} \quad WpH(t) = RpH$$

1c/ *Calculate field water depth*:

$$FWD(sta) = FWL(sta) - FElevation$$

where: FWD(sta) = field water depth (cm);
FWL(sta) = field water level calculated in step 1b/ (cm);
FElevation = field elevation of the sub-unit (cm).

Field elevation is set to the dominant elevation of the sub-unit.

To avoid salinity at the end of the growth cycle, Winter-Spring rice should be sown as early as possible. Farmers may pump water out of the fields before recession of the flood. If that technique is applied:

$$FWD(sta) = FWL(sta) - FElevation - Pump$$

where: Pump = reduction in water level by pumping (cm).

1d/ *Estimate the effect of field water depth on yield*: the effect of field water depth on rice yield YFWD(sta) [Sub-NIAPP, 1992, ESSA et al., 1992b] is shown in Figs. 70 and 71.

Figure 70: Effect of field water depth at different growth stages on yield of HY rice.

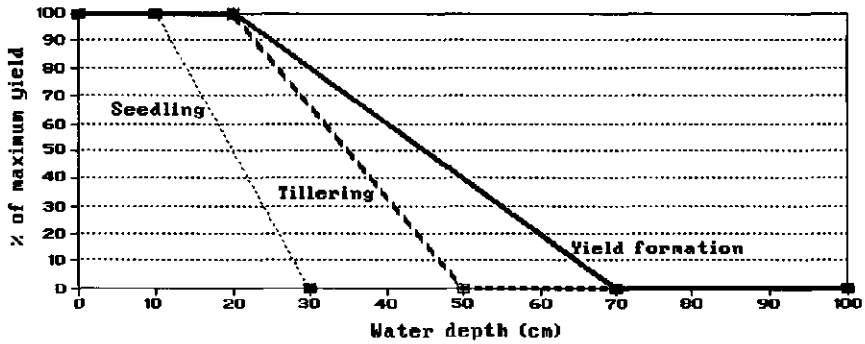
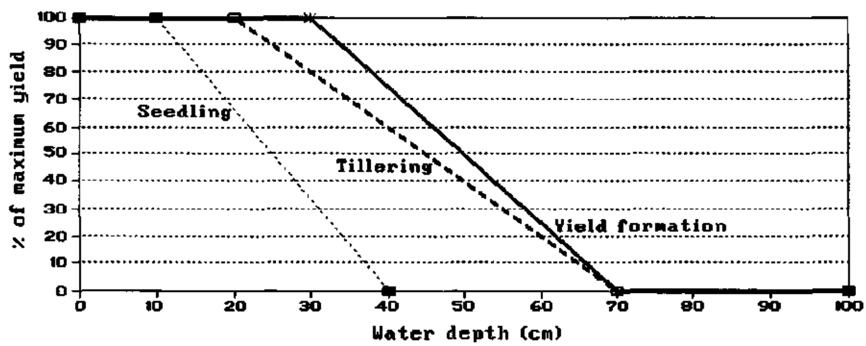


Figure 71: Effect of field water depth at different growth stages on yield of traditional rice.



1e/ *Estimate the effect of field water salinity on yield*: the effect of field water salinity on rice yield YFWS(sta) [Sub-NIAPP, 1992, ESSA et al., 1992b] is shown in Figs. 72 and 73.

Figure 72: Effect of field water salinity at all growth stages on yield of HY rice.

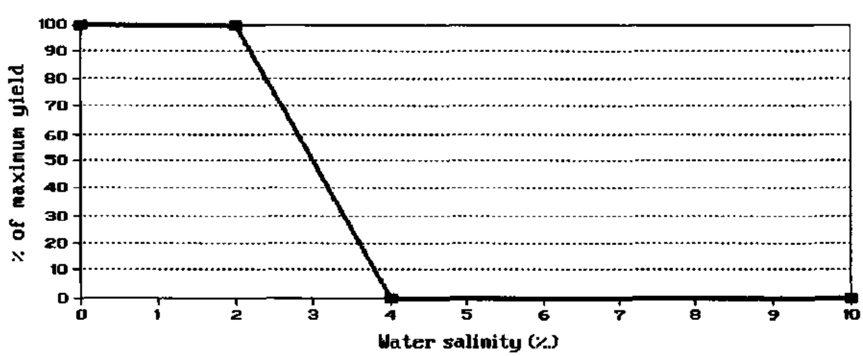
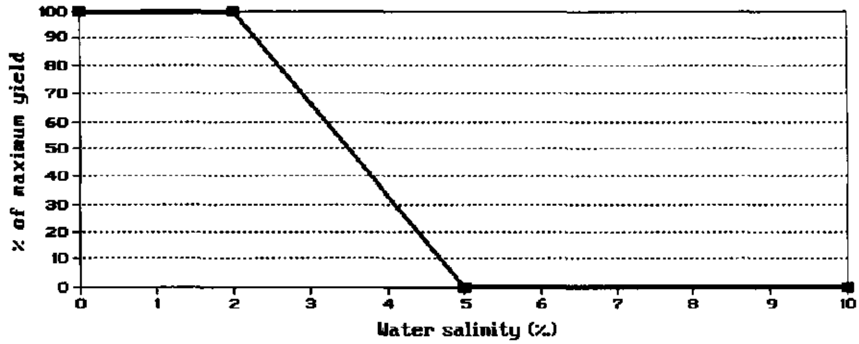


Figure 73: Effect of field water salinity at all growth stages on yield of traditional rice.



1f/ *Estimate the effect of field water pH on yield*: the effect of field water pH on rice yield YFWpH(sta) [Sub-NIAPP, 1992, ESSA et al., 1992b] is shown in Figs. 74 and 75.

Figure 74: Effect of field water pH at different growth stages on yield of HY rice.

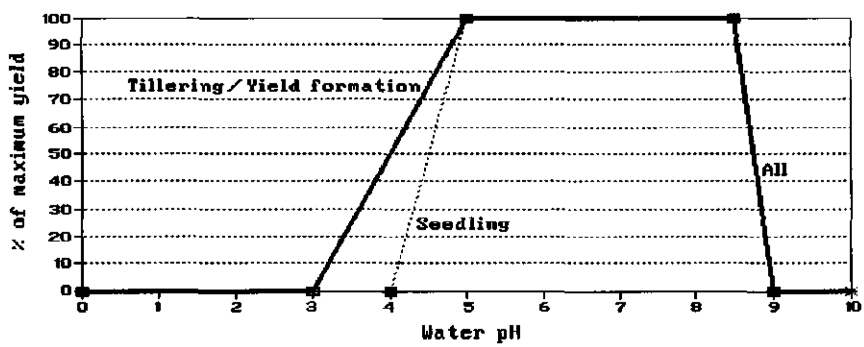
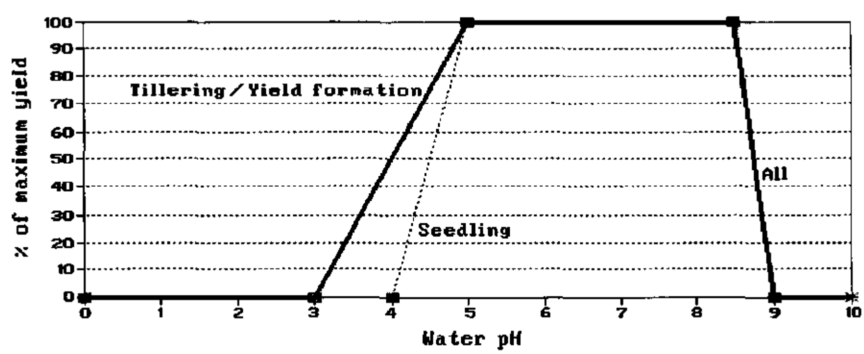


Figure 75: Effect of field water pH at different growth stages on yield of traditional rice.



2/ *Aggregate the effects of all water conditions on yield*: the effect of all water conditions on rice yield is estimated by applying the 'rule of the minimum'* based on the effect of field water depth, salinity and pH in all 3 stages of the growth cycle:

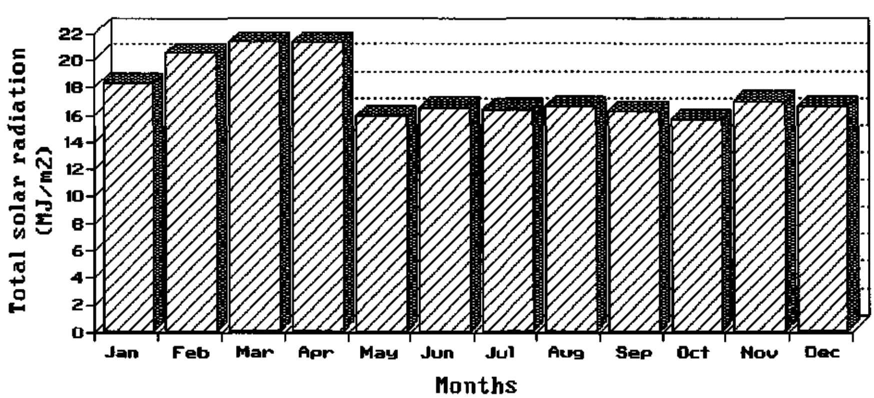
$$YWater(crop) = \operatorname*{Min}_{sta=1}^{NSta} [YFWD(sta), YFWS(sta), YFWpH(sta)]$$

where: YWater(crop) = the effect of water conditions on yield;
YFWD(sta) = the effect of field water depth on yield;
YFWS(sta) = the effect of field water salinity on yield;
YFWpH(sta) = the effect of field water pH on yield.

3/ *Return to subroutine for rice yield.*

5.1.2i) Estimate the effect of solar radiation on rice yield: higher yields can be achieved if the cropping calendar is shifted to the dry season with higher solar radiation (Fig. 76). Such a shift can be applied under modified water conditions. An empirical equation is applied in the model to estimate the effects of differences in solar radiation as a proportion of maximum observed yield [Sub-NIAPP, 1992, ESSA et al., 1992b]:

Figure 76: Monthly solar radiation at Ca Mau station.



First, total solar radiation during the growth cycle of each cropping calendar is calculated:

$$TotSolar(crop) = \sum_{t=It}^{Ft} SR(t)$$

where: TotSolar(crop) = total solar radiation during the growth cycle (MJ/m^2);
SR(t) = solar radiation per time step (MJ/m^2).

---

* Different parametric methods such as averages, addition, multiplication, exponent, etc. have been tested. In this case, the minimum value is most suitable in matching estimated yields with observed yields (see 3.29).

Subsequently, maximum total solar radiation for a given variety (traditional or high yielding) is selected:

$$\text{MaxTotSolar} = \max_{crop=1}^{NCrop} [\text{TotSolar(crop)}]$$

where: MaxTotSolar = maximum total solar radiation possible for a variety;
NCrop = number of cropping calendars possible for a variety.

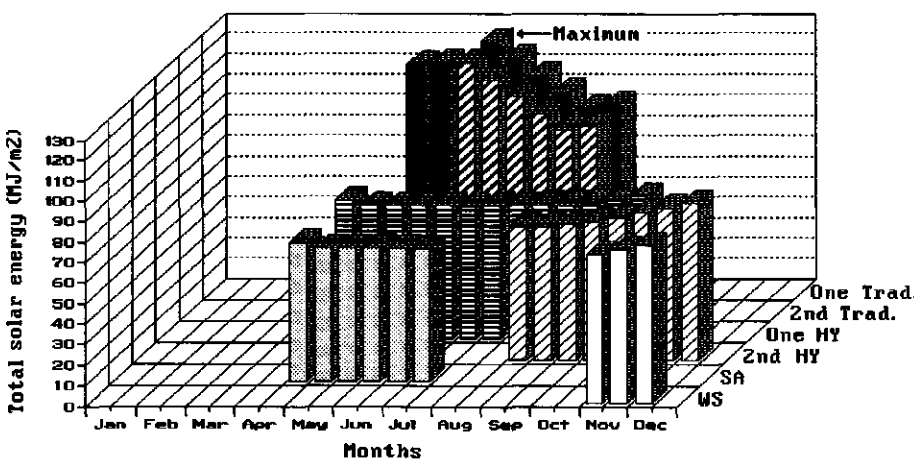
Finally, the effect of solar radiation on yield is calculated for each cropping calendar:

$$\text{YSolar(crop)} = \text{TotSolar(crop)} / \text{MaxTotSolar}$$

where: YSolar(crop) = the effect of solar radiation on yield.

For example, maximum total solar radiation for the traditional variety is that during the third cropping calendar of One Trad. crop (124 MJ/m², Fig. 77). Thus, for that crop growth cycle, the effect of solar radiation on rice yield is set at 1.

Figure 77: Total solar radiation during the growth cycle in relation to its start.



The effect of solar radiation on yield in the last 2nd Tra. cropping calendar is:

YSolar(last2ndTra.) = 89 / 124 = 0.72

For the HY variety, only solar radiation during the last 3 steps of the growth cycle (last step of the tillering stage and 2 steps of the yield formation stage, totalling 45 days) has a significant effect on rice yield.

5.1.2j) Estimate the effect of two successive crops on yield (YDouble(crop)): due to the buildup of pest populations, micronutrient depletion, etc. when two rice crops are grown in succession, yield of the 2nd crop is lower than that of a single crop with the identical weather and water conditions. Therefore, for the 2nd crop, a reduction of 0.1 for the HY variety and 0.2 for traditional varieties is applied (i.e. YDouble(crop) = 0.9 and 0.8 for 2nd HY and 2nd Trad., respectively).

5.1.2k) Calculate final yield after reduction due to all factors: a parametric method is applied to calculate final yield:

$$\text{Yield(crop)} = \text{MaxY} * \text{YSoil} * \text{YWater(crop)} * \text{YSolar(crop)} * \text{YDouble(crop)}$$

where: Yield(crop) = resulting yield (t/ha);
MaxY = maximum observed yield in the Region (t/ha);
YSoil, YWater(crop), YSolar(crop) and YDouble(crop) as defined above.

5.1.2l) Select case of highest yield: the highest yielding variant for each rice crop is selected:

$$\text{SelYield} = \max_{\text{crop}=1}^{\text{NCrop}} [\text{Yield(crop)}]$$

where: SelYield = yield (t/ha) of highest yielding variant;
NCrop = number of cropping calendars for a rice crop.

5.1.2m) Examine SA crop possibility: double rice can only be practised if yields in both crops exceed 0 or a certain predetermined level (see *5.1.2d*). If the 2nd crop (2ndTrad., 2nd HY or WS) cannot be cultivated, the double rice option is omitted.

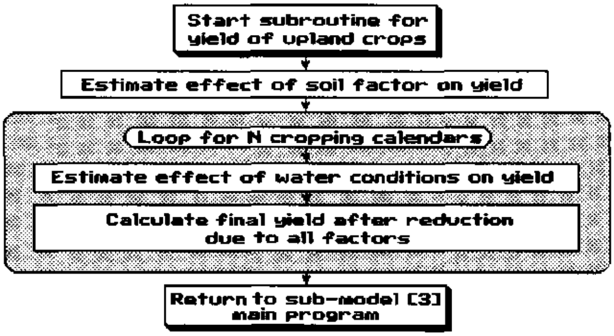
5.1.2n) Calculate average yield for all weather cases: in the Region, a frequency of drought at the beginning of the rainy season (e.g. once in every two years) has been observed. Therefore, rice yield is calculated as the weighted average of yields in favourable and unfavourable years. Since the frequency of drought is different in different water management units, the weighting factor varies among water management units.

5.1.2o) Return to sub-model [3] *main program*

Part II: Calculations of yield of upland crops

5.1.3) Calculate yield of upland crops: The main steps in the sequence of calculations are (Fig. 78):

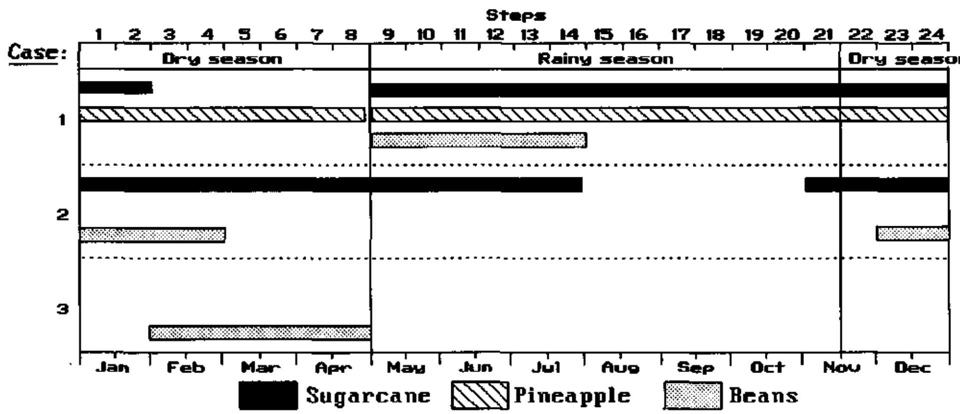
Figure 78: Sequence of calculations for yield of upland crops.



5.1.3a) Estimate the effect of the soil factor on yield: the effect of the soil factor on yield is calculated identically to that for rice (see *5.1.2a*).

5.1.3b) Loop for N cropping calendars: each upland crop has a different cropping calendar, as shown in Fig. 79:

Figure 79: Cropping calendars of upland crops.



Sugarcane: one crop cycle comprises three years, but within one growth period, two options are defined:
1. from early May to late January;
2. from early November to late July.

Pineapple: grown from the beginning of the rainy season (early May) and harvested every year during three years.

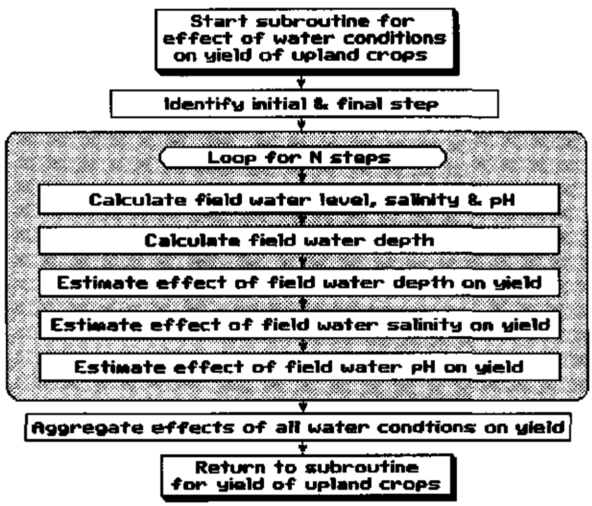
Beans: three cropping calendars of beans have been defined, alternating between rice crops:
1. Summer-Autumn (SA) from early May to late July;
2. Winter-Spring (WS) from early December to late February;
3. Spring-Summer (SS) from early February to late April.

5.1.3c) Estimate the effect of water conditions on yield: the main steps in the sequence of calculations are shown in Fig. 80.

Upland cropping calendars are not divided in stages as those for rice crops. Two procedures are applied:

- The first procedure is applied for 'perennial' upland crops (i.e. pineapple and sugarcane). Average water conditions during the complete growth cycle of one year are used to determine the effect of the water conditions on yield.
- The second procedure is applied for annual upland crops (i.e. beans). Since the growth cycle is short (6 time steps), the effect of water conditions is determined for each time step, and a final value is selected by applying the 'rule of the minimum':

Figure 80: Sequence of calculations to estimate the effect of water conditions on yield of upland crops.



1/ *Identify initial and final step*: the time period for each cropping calendar has been shown in *5.1.3b*.

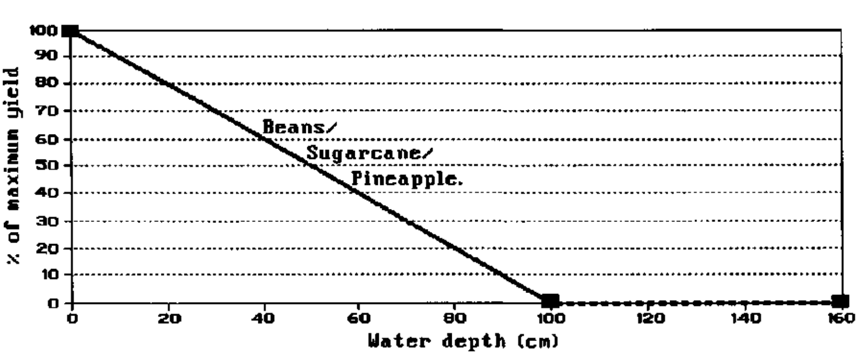
2/ *Loop for N time steps* from the initial to the final step of the cropping calendar.

2a/ *Calculate field water level, salinity and pH*: field water level, salinity and pH are calculated similarly to those for rice crops in *5.1.2h*.

2b/ *Calculate field water depth*: similarly to that for rice crops in *5.1.2h*.

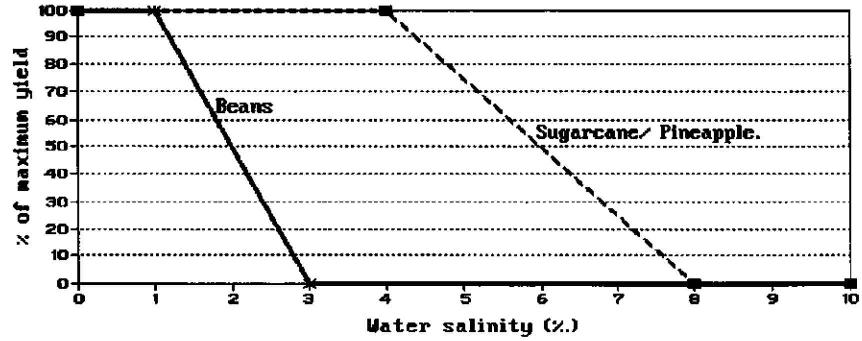
2c/ *Estimate the effect of field water depth on yield*: the effect of field water depth on the yield of upland crops [Sub-NIAPP, 1992, ESSA et al., 1992b], mainly due to the reduction in area as a result of the construction of raised beds, is shown in Fig. 81.

Figure 81: Effect of field water depth on yield of upland crops.



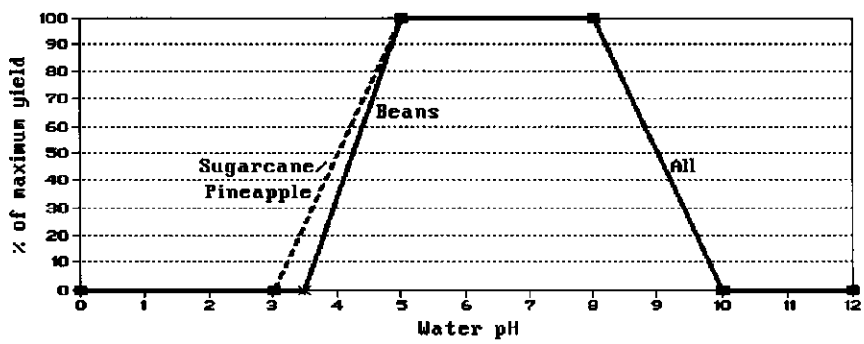
2d/ *Estimate the effect of field water salinity on yield*: the effect of field water salinity on the yield of upland crops [Sub-NIAPP, 1992, ESSA et al., 1992b] is shown in Fig. 82.

Figure 82: Effect of field water salinity on yield of upland crops.



2e/ *Estimate the effect of field water pH on yield*: the effect of field water pH on the yield of upland crops [Sub-NIAPP, 1992, ESSA et al., 1992b] is shown in Fig. 83.

Figure 83: Effect of field water pH on yield of upland crops.



3/ *Aggregate the effects of all water conditions on yield*: similarly to rice, the effects of all water conditions is determined on the basis of the 'rule of the minimum'.

5.1.3d) Calculate final yield after reduction due to all factors: a parametric method is applied to calculate the resulting yield:

$$\text{Yield(crop)} = \text{MaxY} * \text{YSoil} * \text{YWater(crop)}$$

where:	Yield(crop)	=	resulting yield (t/ha);
	MaxY	=	maximum observed yield in the Region (t/ha);
	YSoil	=	the effect of the soil factor on yield;
	YWater(crop)	=	the effect of water conditions on yield.

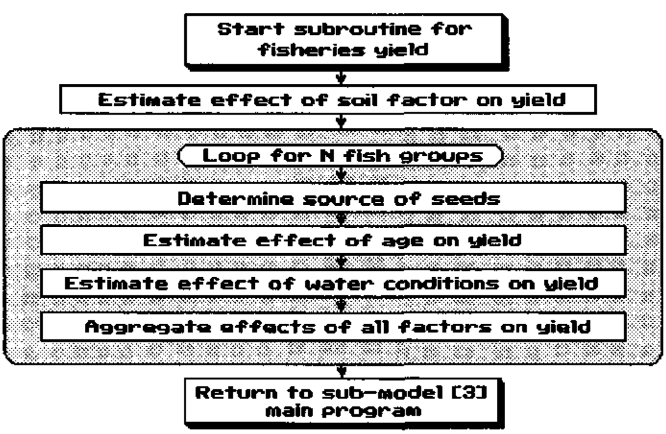
For sugarcane, the cropping calendar generating the highest yield is selected. For both sugarcane and pineapple, during a growth cycle of three years, the yield in the second year is highest, therefore a reduction of 0.2 is applied for the first and the third year.

5.1.3e) Return to sub-model [3] *main program*

Part III: Calculations of fisheries yield

5.1.4) Calculate fisheries yield: the sequence of calculations of fisheries yield is presented in Fig. 84.

Figure 84: Sequence of calculations for fisheries yield.



Rules applied in this sub-model to analyse the effect of physical factors on fisheries yield (File FISHRULE.S03 in Appendix S3) have been provided by specialists on fisheries [Can, 1992; ESSA et al., 1992b], and are based on data from field observations, experimental farms and literature.

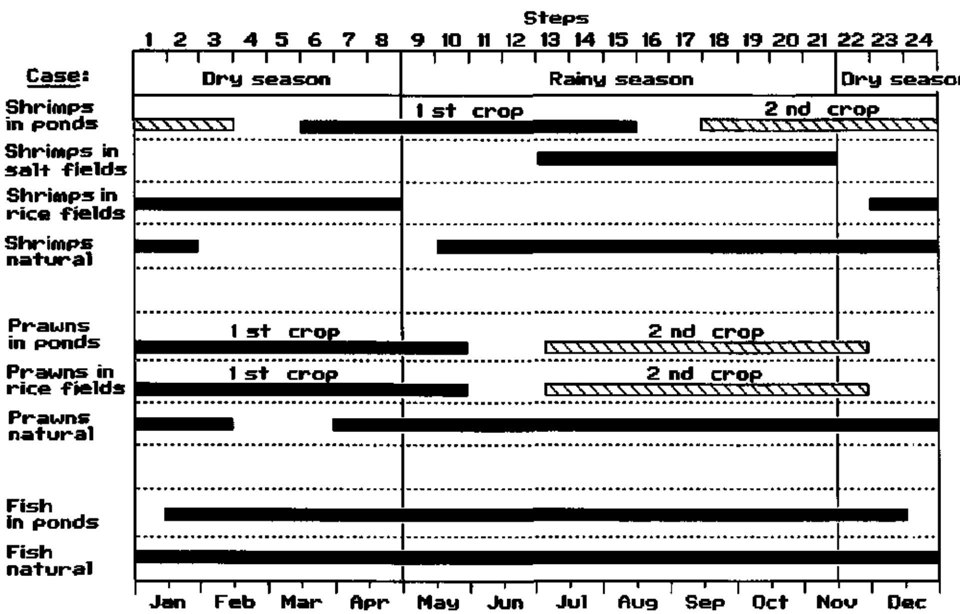
5.1.4a) Estimate the effect of the soil factor on yield: the effect of the soil factor on fisheries yield is calculated similarly to that for rice (see *5.1.2a*).

5.1.4b) Loop for N fish groups: twelve groups of aquatic species (including shrimps, prawns and fish) with different cropping calendars (Fig. 85) are considered:

Group 1: Shrimps in ponds, 1st crop, extensive
Group 2: Shrimps in ponds, 2nd crop, extensive
Group 3: Shrimps in salt fields, one crop, extensive
Group 4: Shrimps in rice fields, one crop, extensive
Group 5: Natural shrimps from catching

Group 6: Prawns in ponds, 1st crop, semi-intensive
Group 7: Prawns in ponds, 2nd crop, semi-intensive
Group 8: Prawns in rice fields, 1st crop, semi-intensive
Group 9: Prawns in rice fields, 2nd crop, semi-Intensive
Group 10: Natural prawns from catching
Group 11: Fish in ponds, full year (only freshwater fish is considered)
Group 12: Natural fish from catching

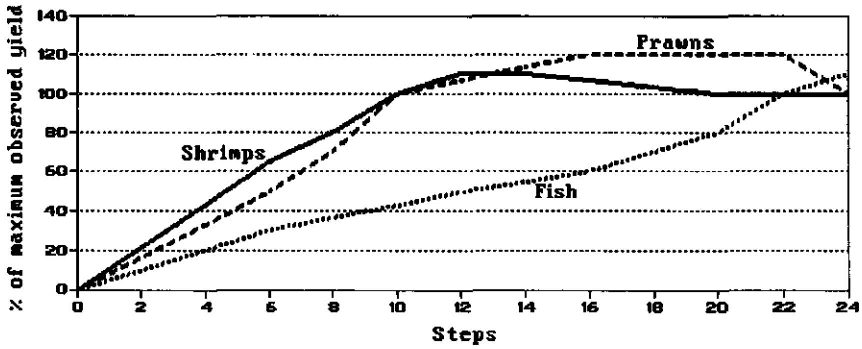
Figure 85: Cropping calendars of fisheries.



1/ *Determine source of seeds*: the source of seeds is one of the factors affecting fisheries yield. Two sources of seeds are distinguished in the region: natural seeds from rivers and canals, and seeds from hatcheries. For shrimps and prawns, the natural seed supply in each water management unit depends on distance from the breeding location, i.e. to the main estuaries. For fish, since many freshwater and brackish water species exist in the region, the natural seed supply is assumed to be abundant in all water management units.

2/ *Estimate the effect of age on yield*: fisheries products can be harvested at any time during the growing period, depending on water conditions. Realized yield, therefore, may not be potential yield. Relative yields as a function of the age of fish groups are given in Fig. 86.

Figure 86: Effect of age on fisheries yield.

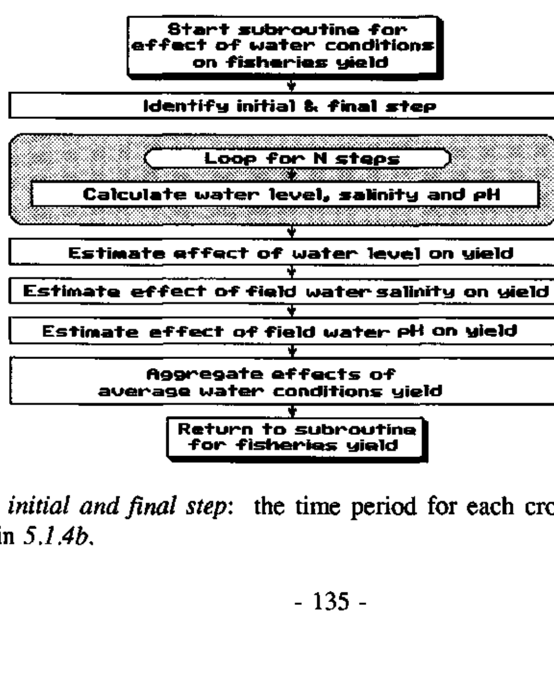


Note: Values below 100% are based on field survey data, values above 100% have been estimated.

Although the period for catching natural shrimps, prawns and fish may cover many time steps, a seasonal cycle for the first two species has been observed, i.e. the yield of these groups is affected by age. For the third species, fishes of different ages are caught throughout the year, and the effect of age on fish yield is incorporated in the maximum observed yield.

3/ *Estimate the effect of water conditions on fisheries yield*: the main steps in the sequence of calculations are shown in Fig. 87.

Figure 87: Sequence of calculations to estimate the effect of water conditions on fisheries yield.



3a/ *Identify initial and final step*: the time period for each cropping calendar has been shown in *5.1.4b*.

3b/ *Loop for N steps* from the initial to the final step to *calculate water level, salinity and pH*: two types of water conditions are considered in the model to estimate fisheries yield: extreme conditions and average conditions. Data on these conditions are selected or calculated from data generated by sub-model [2]:

$$MaxCWL = [\sum_{t=It}^{Ft} MCWL(t)] / Nt$$

where: MaxCWL = average maximum canal water level (cm);
MCWL(t) = maximum canal water level (cm) per time step from sub-model [2].

$$MaxFWL = [\sum_{t=It}^{Ft} MPWL(t)] / Nt$$

where: MaxFWL = average maximum field water level (cm);
MPWL(t) = maximum plain water level (cm) per time step from sub-model [2].

$$MinFWpH = \underset{t=It}{\overset{Ft}{Min}} [CWpH(t)]$$

where: MinFWpH = minimum field water pH;
CWpH(t) = canal water pH per time step from sub-model [2].

$$AvePWD = [\sum_{t=It}^{Ft} PWL(t)] / Nt - FElevation + PD$$

where: AvePWD = average pond water depth (cm);
PWL(t) = plain water level (cm) per time step from sub-model [2];
FElevation = dominant field surface elevation (cm) of sub-unit;
PD = pond depth (cm). A normal pond or ditch depth of 1.3 m is applied for ponds and ditches around rice fields (Fig. 88).

$$AveFWS = [\sum_{t=It}^{Ft} CWS(t)] / Nt$$

where: AveFWS = average field water salinity (‰);
CWS(t) = canal water salinity (‰) per time step from sub-model [2].

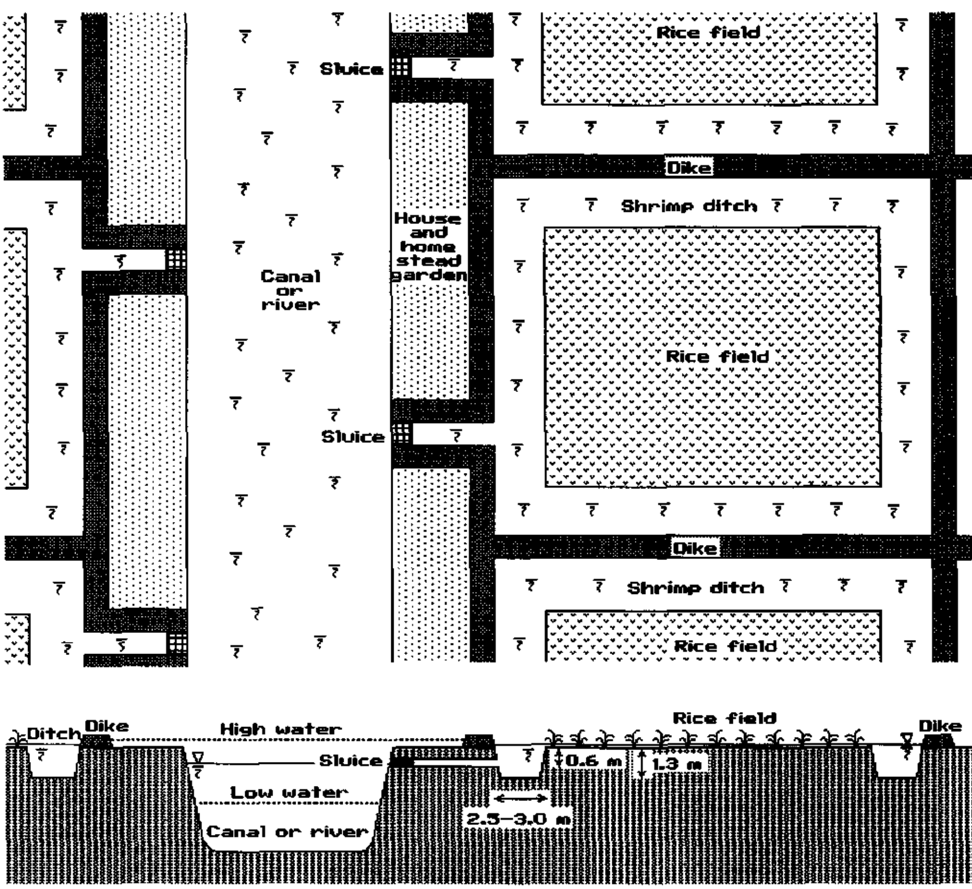
$$AveFWpH = [\sum_{t=It}^{Ft} CWpH(t)] / Nt$$

where: AveFWpH = average field water pH;
CWpH(t) = canal pH per time step from sub-model [2].

3c/ *Estimate the effect of water level on yield*: three effects of water level on fisheries yield are considered:

- Effect of average maximum canal water level (YMaxCWL): since water should enter the ponds or ditches by gravity, to collect natural seeds, two situations are distinguished:
  - if average maximum canal water level is below the elevation of the intake sluice (0.6 m below ground surface, as shown in Fig. 88), water cannot enter, i.e. cultivation is impossible (YMaxCWL = 0).
  - if average maximum canal water level exceeds the elevation of the intake sluice, cultivation is possible (YMaxCWL = 1)

Figure 88: Scheme of ditch system for combined shrimp-rice cultivation.

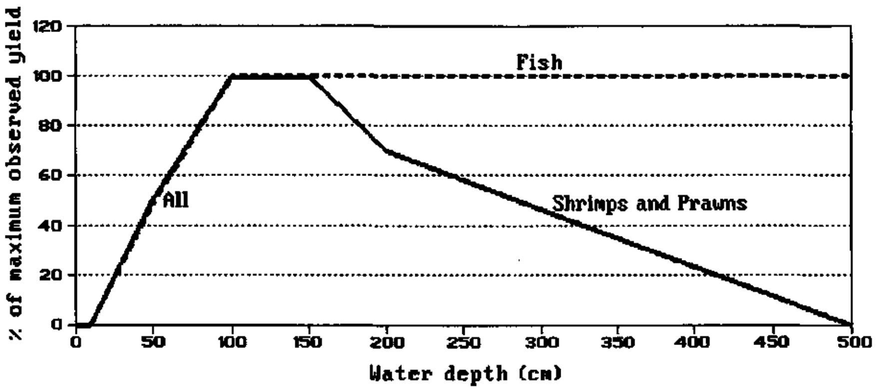


- Effect of average maximum field water level (YMaxFWL): in the combination of shrimp-rice or prawn-rice, a water layer of at least 10 cm is required on the rice field. Therefore, two situations are distinguished:

- if average maximum field water level is below 10 cm, cultivation is impossible (YMaxFWL = 0).
- if average maximum field water level exceeds 10 cm, cultivation is possible (YMaxFWL = 1).

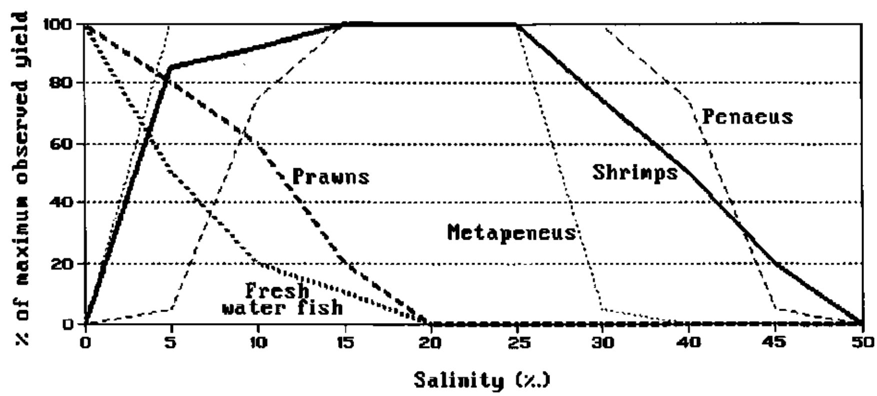
▸ Effect of average pond water depth (YAvePWD): this effect is illustrated in Fig. 89. In practice, if pond water depth exceeds 1 m, farmers usually operate the sluice to maintain optimum water depth, therefore in this case, YAvePWD = 1.

Figure 89: Effect of average pond water depth on fisheries yield.



3d/ *Estimate the effect of field water salinity on yield* (YAveFWS): the effect of field water salinity on fisheries yields is shown in Fig. 90.

Figure 90: Effect of water salinity on fisheries yield.



Notes on Fig. 90:

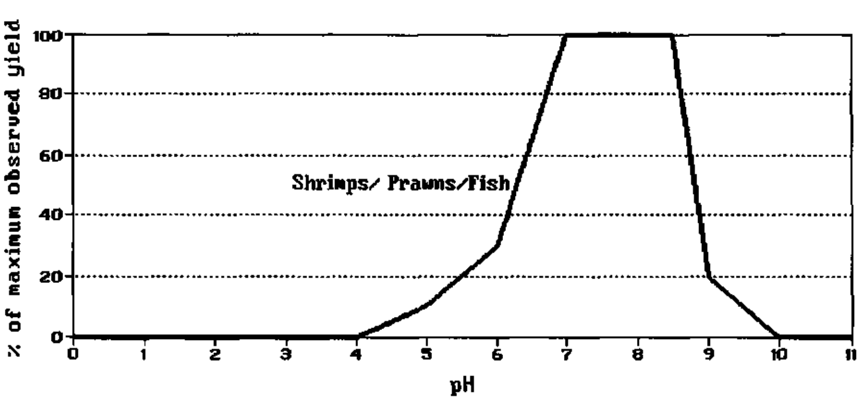
- Two major groups of shrimps are identified in the region: Penaeus (Penaeus indicus or Penaeus monodom), tolerant to high salinity and Metapenaeus (Metapenaeus ensis or Metapenaeus lysianassa) suitable for low salinity. As over 70% of the shrimps observed at 10 stations in the region belong to the 2nd group, a common curve indicating the effect of water salinity on shrimps has been included in Fig. 90.

- Since the high value fish species are freshwater species, only the effect of water salinity on these species is considered.

3e/ *Estimate the effect of field water pH on yield:* two effects of field water pH on fisheries yield are considered:

- Effect of minimum field water pH (YMinFWpH): if water pH at any time step drops below the lowest acceptable value (pH = 4 in Fig. 91), all fishes die, i.e. YMinFWpH = 0; otherwise, YMinFWpH = 1.
- Effect of average field water pH (YAveFWpH): this effect is shown in Fig. 91.

Figure 91: Effect of average field water pH on fisheries yield.



3f/ *Aggregate the effects of average water conditions on fisheries yield (YAveW):*

- For species reared in ponds, the effect of average water conditions is determined by the "rule of the minimum":

  YAveW = Min [YAvePWD, YAveFWS, YAveFWpH]

- For species grown in rice or salt fields, yield is only affected by salinity and pH:

  YAveW = Min [YAveFWS, YAveFWpH]

- For species from the natural catch:
  - natural shrimps or prawns are not affected by water level:

    YAveW = Min [YAveFWS, YAveFWpH]

  - natural fish is only affected by water pH (natural freshwater fish is replaced by brackish water fish if salinity increases):

    YAveW = YAveFWpH

3.g/ *Return to subroutine for fisheries yield.*

4/ Aggregate the effects of all factors on yield: each aquatic species lives in specific water conditions, hence separate calculations are required:

- Groups 1, 2, 6 and 7 (shrimps and prawns in ponds) are affected by all factors except maximum field water level:

$$\text{Yield} = \text{MaxY} * (\text{NSeed} + \text{ASeed}) * \text{YAge} * \text{YSoil} \\ * \text{YMaxCWL} * \text{YMinFWpH} * \text{YAveW}$$

where: Yield = final yield (kg/ha);
MaxY = maximum observed yield (kg/ha);
NSeed = natural seed supply (from 0 to 1);
ASeed = additional seed supply from hacheries (from 0 to 1);
YAge = the effect of age on yield;
YSoil = the effect of the soil factor on yield;
YMaxCWL, YMinFWpH, YAveW as defined above.

- Group 3 (shrimps in salt fields) is affected by all factors except the soil factor (soil quality already improved during salt production):

$$\text{Yield} = \text{MaxY} * (\text{NSeed} + \text{ASeed}) * \text{YAge} \\ * \text{YMaxCWL} * \text{YMinFWpH} * \text{YAveW}$$

- Groups 4, 8 and 9 (shrimps and prawns in rice fields) are affected by all factors except the soil factor (soil quality already improved during rice cultivation):

$$\text{Yield} = \text{MaxY} * (\text{NSeed} + \text{ASeed}) * \text{YAge} \\ * \text{YMaxCWL} * \text{YMinFWpH} * \text{YAveW}$$

- Groups 5 and 10 (natural shrimps and prawns) are not affected by extreme water conditions, i.e. maximum water level and minimum pH, as they can move along the canal to a suitable location during critical periods, and the soil factor (no effect of the soil type in the streambed on natural fisheries):

$$\text{Yield} = \text{MaxY} * \text{NSeed} * \text{YAge} * \text{YAveW}$$

- Group 11 (freshwater fish in ponds) are affected by all factors except the maximum water level, as demand of water exchange is not as high as for shrimps and prawns:

$$\text{Yield} = \text{MaxY} * (\text{NSeed} + \text{ASeed}) * \text{YAge} * \text{YMinFWpH} * \text{YAveW}$$

- Group 12 (natural fish) is only affected by average water conditions:

$$\text{Yield} = \text{MaxY} * \text{YAveW}$$

5.1.4c) Return to sub-model [3] main program.

Part IV: Calculations of annual increment in forest resource

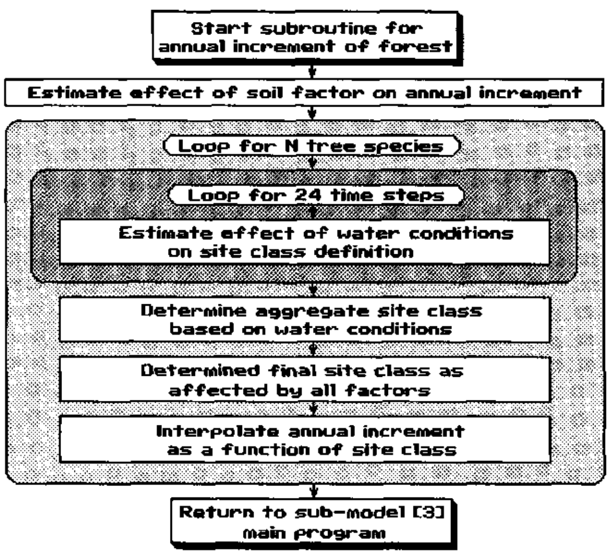
5.1.5) Calculate annual increment in forest resource: forest production (called 'annual increment' in the following) represents the annual increase in stand volume (m^3/ha/year) based on site class. Site class is defined as "a measure of the relative production capacity of a site for the crop or stand under study, based e.g. on volume or height, or the maximum mean annual increment that is attainable at a given age class" [FAO, 1984].

In this model, site class is determined by the physical conditions in each sub-unit in each year. Accumulated volume increment until forest harvest is referred to as forest yield and is calculated in sub-model {9}.

As for the calculation of agricultural yields and fisheries yields, rules applied in the model (File FORERULE.S03 in Appendix S3) to simulate the effect of physical factors on annual increments in forests, have been provided by foresters [Duyet, 1991; ESSA et al., 1992b] and are based on data from field observations, experimental farms or literature.

The main steps in the sequence of calculations are presented in Fig. 92.

Figure 92: Sequence of calculations for annual increments of forests.



5.1.5a) Estimate the effect of the soil factor on annual increment: the effect of the soil factor on site class of forest is calculated similarly to that on rice (see *5.1.2a*).

5.1.5b) Loop for N tree species: four tree species are considered in this sub-model: Melaleuca *(Melaleuca leucadendron)*, Eucalyptus *(Eucalyptus camadulensis)*, mangrove *(Rhizophora)* and nipa palm *(Nipa fruticans)*.

Each species has its specific annual increment for each site class (Figs. 93 to 96).

Figure 93: Yield of Melaleuca as a function of age, for different site classes.

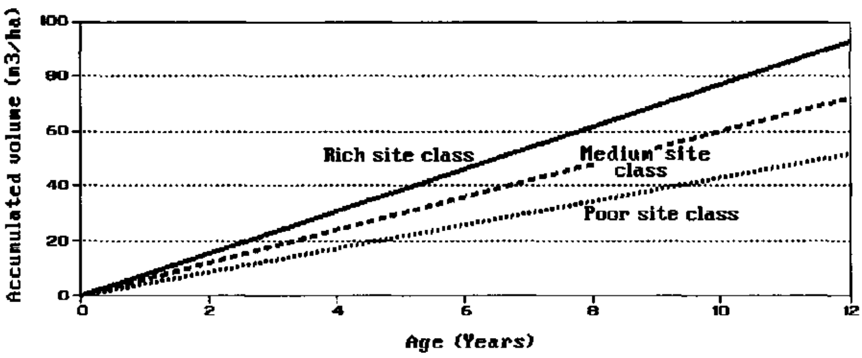


Figure 94: Yield of Eucalyptus as a function of age, for different site classes.

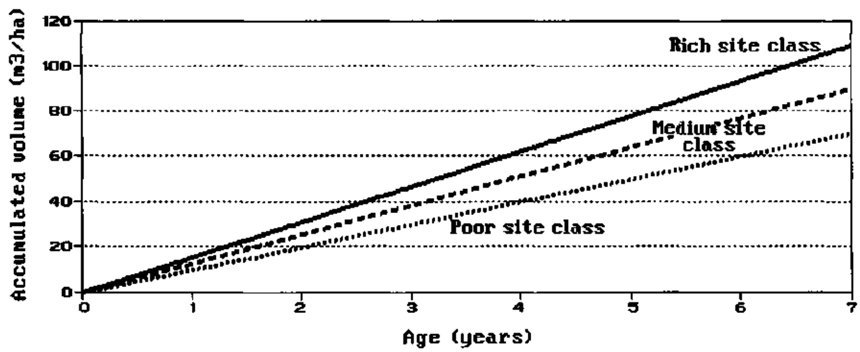


Figure 95: Yield of mangrove as a function of age, for different site classes.

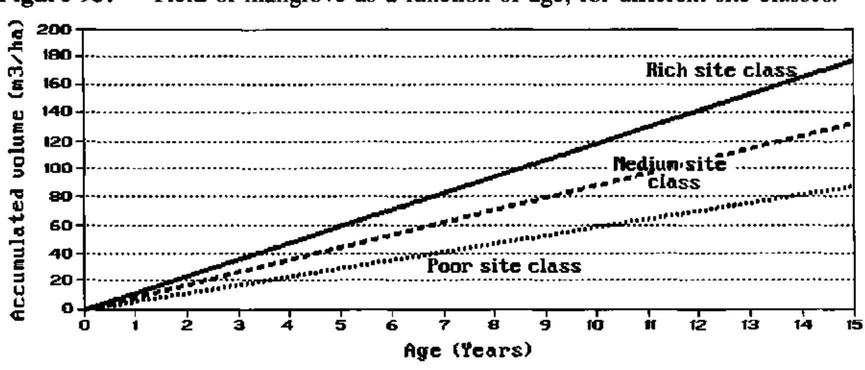
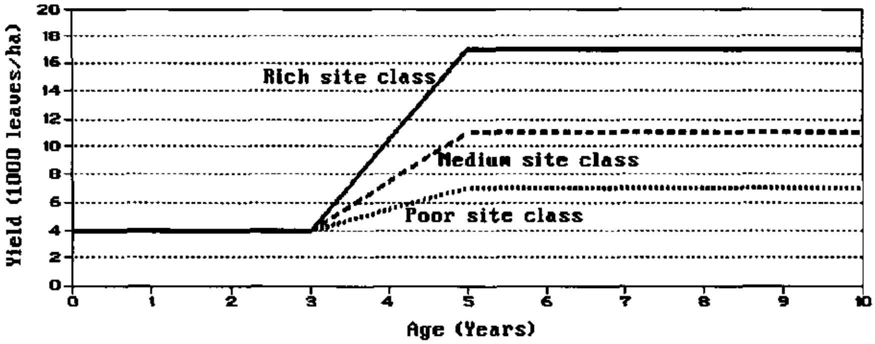


Figure 96: Yield of nipa palm as a function of age, for different site classes.



1/ *Loop for 24 time steps to estimate the effect of water conditions on site class definition of forest*: the effect of water conditions is determined over 24 time steps and aggregated for the annual site class. Then, a resulting site class based on water conditions and the soil factor is determined. Each tree species is affected by water conditions in a specific way (Table 8), hence for each species, specific criteria are applied:

Table 8: Effect of water conditions on site class determination for tree species.

Tree species	Water conditions	Poor site class	Medium site class	Rich site class
Melaleuca	Field water depth (m)	> 1	< 0.5	0.5 to 1
Eucalyptus	Depth of water table (m)	> 0	0 to -0.5	< -0.5
	Salinity (‰)	> 18	12 to 18	< 12
Mangrove	Field water depth (m)	> 1	0.5 to 1.0	< 0.5
	Salinity (‰)	< 20 or > 30	20 to 25	25 to 30
	Tide fluctuation (m)	< 0.5 or > 2.5	0.5 to 1.0 or 2.0 to 2.5	1.0 to 2.0
Nipa palm	Salinity (‰)	< 4 or > 18	12 to 18	4 to 12

- Melaleuca: site class of Melaleuca forest based on water conditions is determined by field water depth:

$$FWD(t) = CWL(t) - FElevation$$

where: FWD(t) = water depth (m) in Melaleuca forest;
CWL(t) = canal water level from sub-model [2];
FElevation = dominant field elevation (m) in sub-unit.

$$SCWat(t) = SCFWD(t)$$

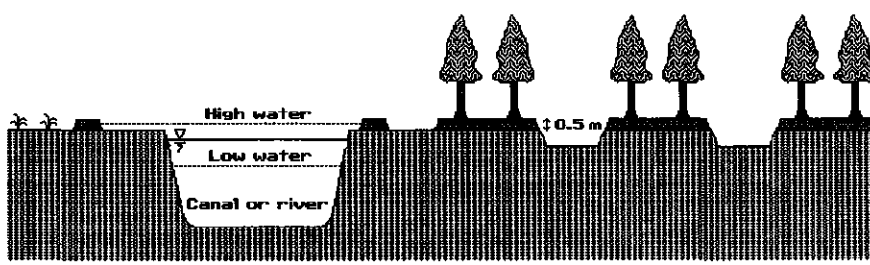
where: SCWat(t) = site class based on water conditions;
SCFWD(t) = site class based on field water depth.

- Eucalyptus: Eucalyptus is affected by the depth of the water table and salinity. Eucalyptus is grown on raised beds with a height of about 0.5 m above surface level (Fig. 97), therefore:

$$WTD(t) = CWL(t) - (FElevation + HRB)$$

where: WTD(t) = depth of water table (m) in Eucalyptus forest;
CWL(t) = canal water level from sub-model [2];
FElevation = dominant field elevation (m) in sub-unit;
HRB = height of raised beds (m).

Figure 97: Raised beds for Eucalyptus.



Since Eucalyptus forests are protected from salt water intrusion if possible, field water salinity is determined for two periods:

- In the dry season:

$$FWS(t) = CWS(t)$$

where: FWS(t) = water salinity (‰) in the Eucalyptus forest;
CWS(t) = canal water salinity from sub-model [2].

- In the rainy season:

$$FWS(t) = RWS$$

where: RWS = rain water salinity (assumed = 0 ‰).

Site class of Eucalyptus forest based on water conditions is determined as:

$$SCWat(t) = [SCDWT(t) + SCFWS(t)]/2$$

where: SCWat(t) = site class based on water conditions;
SCDWT(t) = site class based on depth of the water table;
SCFWS(t) = site class based on field water salinity.

- Mangrove: Mangrove is affected by field water depth, tide fluctuation and salinity:

$$FWD(t) = CWL(t) - FElevation$$

where: FWD(t) = field water depth (m) in the mangrove forest;
CWL(t) = canal water level from sub-model [2];
FElevation = dominant field elevation (m) in sub-unit.

$$FTF(t) = TF(t)$$

where: FTF(t) = tide fluctuation (m) in the mangrove forest;
TF(t) = tide fluctuation from sub-model [2].

$$FWS(t) = CWS(t)$$

where: FWS(t) = water salinity (‰) in the mangrove forest;
CWS(t) = canal water salinity (‰) from sub-model [2].

Site class of mangrove forests based on water condition is determined as:

$$SCWat(t) = [SCFWD(t) + SCFTF(t) + SCFWS(t)] / 3$$

where: SCWat(t) = site class based on water conditions;
SCFWD(t) = site class based on field water depth;
SCFTF(t) = site class based on tide fluctuation;
SCFWS(t) = site class based on field water salinity.

- Nipa palm: site class of nipa palm based on water conditions is only determined by water salinity:

$$FWS(t) = CWS(t)$$

where: FWS(t) = water salinity (‰) in the nipa palm area;
CWS(t) = canal water salinity (‰) from sub-model [2].

$$SCWat(t) = SCFWS(t)$$

where: SCWat(t) = site class based on water conditions;
SCFWS(t) = site class based on water salinity.

2/ *Determine aggregate site class based on water conditions*: site class values for each time step are aggregated to one annual value:

$$SCWatYear = [\sum_{t=1}^{Nt} SCWat(t)] / Nt$$

where: SCWatYear = site class based on all relevant water conditions.

3/ *Determine final site class as affected by all factors*:

- For Melaleuca, Eucalyptus and mangrove:

FinalSC = SCWatYear * SCSoil

where: FinalSC = final site class;
SCWatYear as defined above;
SCSoil = site class based on soil factor.

- For nipa palm: the effect of the soil factor on nipa palm is minor, therefore:

FinalSC = SCWatYear

4/ *Interpolate annual increment as a function of annual site class*: annual increment is derived from the graphs in Figs. 93 to 96.

An additional rule is applied for mangrove and nipa palm to simulate their occurrence in areas irrigated with fresh water part of the year: if salinity is low over a certain number of time steps in the year (for example, an annual average below 2 ‰ for mangrove and a six-month average below 4 ‰ for nipa palm), these tree species will die, i.e. annual increment = 0 and accumulated production = 0.

5.1.5c) Return to sub-model [3] *main program.*

5.1.6) Output yield data (Files MARI1.1HY, MARI1.BEA, MARI1.SPO and MARI1.FOR in Appendix S3).

5.2) Loop for N sub-units to copy yield data from the preceding year to the current year if water conditions are the same as those in the preceding year.

6) End of sub-model [3], then connect to CAILUP main program as described in 4.59.

4.63 Sub-model [4]: Economic Sub-model at Farm Level

Function: Estimate feasibility of land use types based on yields generated in sub-model [3] and economic criteria at farm level.

Input data:
<E> Existing financial conditions such as farm-gate prices, land use conversion and operation costs, level of income of representative households, etc.
<1> Interventions with respect to economic factors, such as taxes, credit availability, etc.
<3> Yields
<12> New financial data, if available.

Output data:
<4> Bio-physical/economic feasibility at farm level (File MARI16.S04 in Appendix S4).

Discussion on sub-model [4] for the Quan Lo Phung Hiep region:

1/ As in other economic analyses, assumptions are made in this sub-model to:
i) generalize rules that are diverse in the Region;
ii) test rules that are uncertain due to limited insight;
iii) analyze the effects of interventions.

2/ For the Quan Lo Phung Hiep region with small farm sizes and limited investment possibilities for farmers, different financial analyses are applied for specific land use types to simulate the selection process of the local farmers, based on the following assumptions:

- The financial analysis is applied for a typical household of 5.6 persons, comprising 2.5 labourers, and 1 hectare of land.
- Variations in financial values related to factors such as soil type, transport conditions, local markets, etc., are assumed to be negligible.
- For agricultural production, following the construction of main sluices, higher operational costs are assumed to result in better income. For fisheries and forestry production, costs are assumed to be identical in the 'without' and 'with' cases.
- For agricultural and fisheries production, the financial analysis is limited to a net income analysis. For forestry production, where income is only achieved after several years, a discounted cash flow analysis is applied to convert future benefits per unit of product into present value.

3/ The objective of sub-model [4] is to generate feasibilities of relevant land use types (relative values to compare between land use types) as a basis for land use allocation. The financial analysis is performed by using worksheet software packages before operating sub-model [4]. Examples of financial worksheets are given in Appendix S4 (File AGRIFI.WQ1 and FISHFI.WQ1).

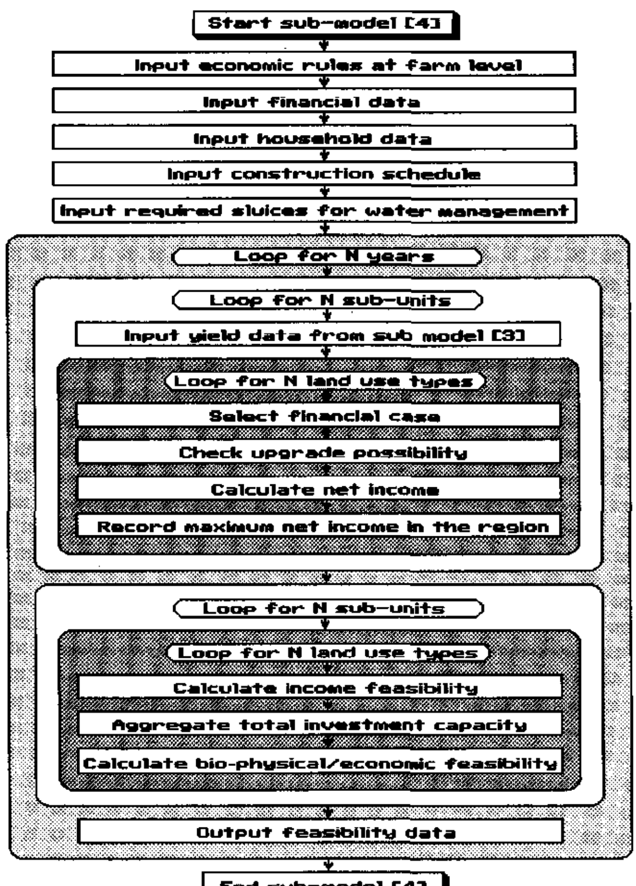
4/ A bio-physical/economic feasibility of each land use type is generated by integrating financial factors at farm level with the suitability of the land use type as expressed by the bio-physical yield from sub-model [3]. In the financial analysis, yield values in different physical units (tonnes of rice/ha, kg of shrimps/ha, m3 of wood/ha) are transformed into monetary values to make the land use types comparable.

Based on these monetary values, feasibility is determined for each land use type in several steps. First, it is expressed as a ratio of the maximum income from all land use types in each year. Subsequently, it is refined through various filters in sub-model [4] or in subsequent sub-models: investment capacity, social issues at farm level, government policy, etc., before being applied as a weighting factor for land allocation. The quality of each filter, fine or coarse, depends on the level of analysis, and can be improved through better understanding and more available data.

5/ Two main factors are considered in this sub-model:
i) feasibility of each land use type with respect to net income of the farmer;
ii) the investment capacity of the farmer for a land use type.

Calculations: The main steps in the sequence of calculations are (Fig. 98):

Figure 98: Sequence of calculations in sub-model [4].



1) Start sub-model [4]: as described in 4.58.

2) Input economic rules at farm level: the characteristics of household types, such as income, investment capacity, credit support, etc. are derived from social and economic surveys, local inventories and reports (Files FARMRULE.S04 in Appendix S4).

3) Input financial data: outputs from the financial analyses of each cropping pattern for 'without' and 'with' cases are compiled (File FINAN.S04 in Appendix S4). Some assumptions should be made in generating these input data:

- Required capital for cultivation:

$$\text{ReqCap} = \text{ConvCost} + (\text{OpeCost} * \text{WorkRatio})$$

where: ReqCap = required capital (VN Dong/ha);
ConvCost = land use conversion costs (VN Dong/ha);
OpeCost = operation costs (VN Dong/ha);
WorkRatio = ratio of working capital to operation costs.

Operation costs do not include family labour costs (considered a part of the farmers income). The ratio of working capital to operation costs is assumed 0.5 for annual crops and 1 for crops with cycles longer than one year, such as sugarcane and pineapple or forestry.

- Capital intensity for cultivation:

$$\text{CapInt} = \text{ReConvCost} + \text{OpeCost}$$

where: CapInt = capital intensity (VN Dong/ha);
ReConvCost = repayment for land use conversion costs (VN Dong/ha);
OpeCost = operation costs (VN Dong/ha).

Repayment for land use conversion costs is calculated, based on land use conversion costs, rate of interest and repayment period, assuming that farmers incur debts for investment. Different rates of interest and different repayment periods can be tested. The official interest rates applied by commercial banks usually range from 2.85 to 4.5% per month, but farmers usually pay 30 to 50% per three months to private lenders when borrowing money for seeds, fertilizer, etc. [NEDECO, 1991d]. For land use conversion costs, a rate of interest of 24% per year during 10 years is assumed for agriculture and fisheries, but no interest is considered for forestry since income per hectare from forest production is so low that farmers are assumed to invest their own capital only, in this production. For the currently cultivated area, no land use conversion costs apply.

- Farm gate prices: real prices are applied for the past and the current year. For subsequent years, prices are assumed to be the same or they can be defined as a function of demand and supply derived from sub-models [11] and [12] (Economic and Social Sub-models at Regional Level).

- Taxes: defined as a fraction of gross income (6% for all agricultural and fisheries production and 0% for forestry production). These values can be adjusted for modified tax policies.

4) Input household data: based on the current conditions (1990), households in the region are classified into 5 income groups with respect to average annual income per capita:

- Rich: > 1,000,000 VN Dong (or 1,000 kg rice);
- Well-to-do: from 700,000 to 1,000,000 VN Dong;
- Medium: from 500,000 to 700,000 VN Dong;
- Poor: from 300,000 to 500,000 VN Dong;
- Very poor: < 300,000 VN Dong;

The investment capacity of each household is assumed to be proportional to its income, i.e. it varies per household group (File FARMRULE.S04 in Appendix S4). Data on household groups at village level are available only for part of the Region. A classification of sub-units is, therefore, required to determine sub-unit investment level. The distribution of household groups in each sub-unit is based on the general distribution in the Region (File HOUSE.S04 in Appendix S4).

The effect of a credit support system is considered by assuming that credit support is available for a certain fraction of the households (File HOUSE.S04 in Appendix S4) to upgrade one grouping level. Different rates of credit support (e.g. 30% of households in the 'without' case and 50% of households in the 'with' case) and different support strategies (support to either the 'poor' or the 'medium' sub-unit) can be tested to analyze the effect of credit support on the bio-physical/economic feasibility.

5) Input construction schedule: financial values of the 'without' case are applied to a sub-unit when the main sluices relating to that sub-unit have not been completed, and vice versa (File CONSTRUC.SCH in Appendix S2).

6) Input required sluices for water management: certain main sluices are required to change water conditions in each sub-unit. These requirements are defined by water resources planners (File SUBUNODE.S02 in Appendix S2).

7) Loop for N years:

7.1) Loop for N sub-units:

7.1.1) Input yield data from sub-model [3]

7.1.2) Loop for N land use types:

7.1.2a) Select financial case: if the construction of main sluices required for changing water conditions in one sub-unit has been completed, financial values for the 'with' case are applied, otherwise values for the 'without' case are used.

7.1.2b) Check upgrade possibility: capital formation is taken into account by assuming that after a number of years, households in a certain income group can be upgraded to a higher income group. The number of years varies for the various income groups (for the richer group, capital formation is assumed to proceed faster) and for the 'without' or 'with' case (faster in the 'with' case).

7.1.2c) Calculate net income: net income per ha is calculated by the following formula:

$$\text{NetInc} = [(\text{Yield} * \text{FGPrice}) * (1 - \text{Tax})] - \text{CapInt}$$

where:
- NetInc = net income (VN Dong/ha);
- Yield = yield (t/ha or kg/ha or m^3/ha);
- FGPrice = farm gate price (VN Dong/t or VN Dong/kg or VN Dong/m^3);
- Tax = rate of taxes as discussed above;
- CapInt = capital intensity (VN Dong/ha).

Net income is calculated for two situations: 'without' land use conversion costs (NetIncWithout) for currently cultivated areas and 'with' land use conversion costs (NetIncWith) for newly cultivated areas. Average net income from each land use type is calculated:

$$\text{AveNetInc} = \frac{[(\text{NetIncWithout} * \text{CurArea}) + (\text{NetIncWith} * (\text{CulArea} - \text{CurArea})]}{\text{CulArea}}$$

where:
- AveNetInc = average net income (VN dong/ha);
- NetIncWithout = net income 'without' land use conversion costs (VN Dong/ha);
- CurArea = current cultivated area (ha);
- NetIncWith = net income 'with' land use conversion costs (ha);
- CulArea = cultivable area (ha), calculated as:

$$\text{CulArea} = \text{TotArea} - \text{ASpec} - \text{AGard} - \text{AWat}$$

where:
- TotArea = total area of sub-unit (ha);
- ASpec = area for specific uses (ha);
- AGard = area of homestead gardens (ha);
- AWat = area of water surfaces (ha).

7.1.2d) Record maximum net income in the Region: to analyze the distribution of the feasibility of each land use type in the region, the feasibility in each year is expressed as the ratio of net income from that land use type to maximum net income from among all land use types in that year. Maximum value of net income (MaxNetInc), therefore, is traced during the loops of sub-units and land use types.

7.2) Loop for N sub-units, then Loop for N land use types:

7.2.a) Calculate income feasibility:

$$\text{NetIncFea} = \text{AveNetInc} / \text{MaxNetInc}$$

where:
- NetIncFea = net income feasibility of a land use type;
- AveNetInc = average net income (VN Dong/ha);
- MaxNetInc = maximum net income (VN dong/ha) in the Region from among all land use type.

7.2.b) Aggregate total investment capacity: for each sub-unit, the capacity of investment into a land use type is expressed as the fraction of the number of households able to invest into that land use type, subject to the condition:

$$InvCap = \sum_{g=1}^{NG} [GFract(g)]$$

where: InvCap = investment capacity (without credit);
NG = number of income groups (= 5 in the Region);
GFract(g) = fraction of number of households in the income group (g) having an investment capacity of ≥ the required capital;

Investment capacity will increase in the future when households are upgraded (see *7.1.2b*). If credit support is available, total investment capacity also increases:

$$TotInvCap = InvCap + [GFract(g-1) * CredFract]$$

where: TotInvCap = total investment capacity;
g = the lowest income group having an investment capacity of ≥ the required capital;
GFract(g-1) = fraction of the number of households in the income group (g-1) (e.g. if (g) is 'medium' group, then (g-1) is 'poor' group);
CredFract = fraction of number of households in income group (g-1) receiving credit support.

7.2.c) Calculate bio-physical/economic feasibility:

$$BEF = NetIncFea * TotInvCap$$

where: BEF = bio-physical/economic feasibility.

7.3) Output feasibility data: data on net income and feasibility are outputted (File MARI16.S04 in Appendix S4).

8) End of sub-model [4], then connect to CAILUP main program as described in 4.59.

4.64 Sub-model [5]: Social Sub-model at Farm Level

Function: Estimate final selection of land use types by farmers, based on bio-physical/economic feasibility and social criteria at farm level.

Input data:
<E> Household income groups, family labour requirements for cultivation, etc.
<1> Preferences of farmers or the local population
<4> Net income and bio-physical/economic feasibility
<12> New social data, if available.

Output data:
<5> Integrated feasibility of each land use type (File MARI16.S05 in Appendix S5).

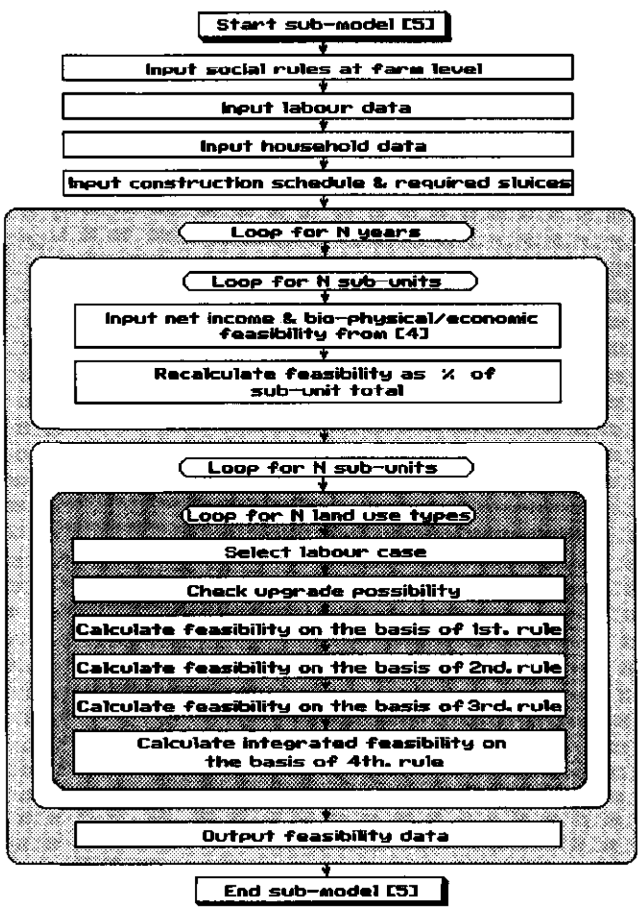
Discussion on sub-model [5] for the Quan Lo Phung Hiep region:

1/ This sub-model assumes that the prediction of prices based on market demand and the dissemination of economic information to farmers are imperfect. Therefore, farmers cannot select land use types by maximizing a goal such as net income. Consequently, whenever a land use type has a bio-physical/economic feasibility exceeding 0, it will be practised somewhere. The area of each land use type in the total area of a sub-unit is assumed to be proportional to its feasibility, i.e. in this sub-model, feasibility is a relative value considered in the context of a sub-unit and not for the whole region as in sub-model [4].

2/ This sub-model comprises four relevant social rules (see *6.2.c*, *d*, *e* and *f* in Calculations). The preference of the local population among products (income elasticity of demand) is expressed by a preference value that depends on income, i.e. varies with income group.

Calculations: The main steps in the sequence of calculations are (Fig. 99):

Figure 99: Sequence of calculations in sub-model [5].



1) Start sub-model [5]: as described in 4.58.

2) Input social rules at farm level: social data required for sub-model [5] are priority of land use, preference in product consumption of each income group, etc. (File FARMRULE.S05 in Appendix S5).

3) Input labour data: family labour-days required for each land use type in 'without' and 'with' cases have been estimated in the financial analysis in sub-model [4] (File FINAN.S04 in Appendix S4).

4) Input household data (File HOUSE.S04 in Appendix S4).

5) Input construction schedule and required sluices as in sub-model [4] (Files CONSTRUC.SCH and SUBUNODE.S02 in Appendix S2).

6) Loop for N years:

6.1) Loop for N sub-units:

6.1a) Input net income and bio-physical/economic feasibility from sub-model [4].

6.1b) Recalculate the feasibility as a percentage of sub-unit total: in this sub-model, the feasibility is recalculated as fraction of the sub-unit total:

$$NBEF(i) = BEF(i) / [\sum_{lut=1}^{NP} BEF(lut)]$$

where:
- NBEF(i) = new bio-physical/economic feasibility of land use type (i);
- BEF(i), BEF(lut) = bio-physical/economic feasibility of land use types (i) and (lut), respectively, from sub-model [4];
- NP = total number of productive land use types;
- lut = productive land use type.

The same calculation for feasibility is repeated following application of each social rule in steps *6.2c*, *6.2d*, *6.2e* and *6.2f*.

6.2) Loop for N sub-units, then Loop for N land use types:

6.2a) Select the labour case: if the construction of main sluices required for changing the water conditions in a given sub-unit has been completed, labour values for the 'with' case are applied, otherwise values for the 'without' case are used.

6.2b) Check upgrade possibility: as in sub-model [4], after some years, households in a certain income group can be upgraded to a higher income group (e.g. from the 'poor' group to the 'medium' group).

6.2c) Calculate feasibility on the basis of the 1st rule: the first social rule assumes that:

a- Land use types are ranked according to the priority of farmers, based on their requirements for investment, labour, cultivation techniques, etc.

b- A competitive relationship exists among different land use types. Therefore, if the increment in net income from a land use type (i) compared with that from the next higher priority (j) is less than or equal to a threshold increment, land use type (i) will be converted to land use type (j) (e.g. if the increment in net income associated with replacement of single rice by double rice is marginal, farmers prefer the single crop because of its lower inputs):

If [NetInc(i) - NetInc(j)]/NetInc(i) ≤ TIncrement(ij), then:

$$\mathrm{Feas1}(j) = \mathrm{NBEF}(j) + \mathrm{NBEF}(i) \quad \text{and} \quad \mathrm{Feas1}(i) = 0$$

where:

NetInc(i), NetInc(j)	=	net income (monetary units/ha) from land use types (i) and (j), respectively, generated in sub-model [4];
TIncrement(ij)	=	threshold increment to convert from (i) to (j);
Feas1(i), Feas1(j)	=	feasibilities of land use types (i) and (j), respectively, after application of the 1st social rule.

The threshold increment depends on land use types (i) and (j) (e.g. the value for selection between single rice and double rice is higher than for selection between two double rice cropping patterns). Similarly, the value for selecting between fisheries and agriculture is higher than that among various agricultural cropping patterns.

6.2d) Calculate feasibility on the basis of the 2nd rule: the second social rule is based on the assumption that farmers only practice a land use type if net income per labour-day exceeds a minimum value ('desired income' per family labour-day). That value varies among income groups: a rich farmer requires a higher income per labour-day than a poor farmer. A loop for all household groups is performed:

$$\mathrm{TotSel}(i) = \sum_{g=1}^{NG} [\mathrm{GFract}(g) * \mathrm{Sel}(g)]$$

where:

TotSel(i)	=	fraction of all households selecting land use type (i) over all households in the sub-unit;
NG	=	number of income groups (= 5 in the Region);
g	=	income group;
GFract(g)	=	fraction of number of households in income group (g) in the total number of households in sub-unit;
Sel(g)	=	a factor reflecting the selection of land use type (i) by income group (g): Sel(g) = 1 if [NetInc(i)/FamLab(i)] ≥ DInc(g); Sel(g) = 0 if [NetInc(i)/FamLab(i)] < DInc(g);
NetInc(i)	=	net income (monetary units/ha) from land use type (i) generated in sub-model [4];
FamLab(i)	=	family labour-days required for land use type (i);
DInc(g)	=	'desired income' per family labour-day of income group (g);

and: $Feas2(i) = Feas1(i) * TotSel(i)$

where: Feas2(i) = feasibility of land use type (i) after application of the 1st and 2nd social rule.

6.2e) Calculate feasibility on the basis of the 3rd rule: the third social rule assumes that a preference among products in each production system exists, based on the storage and processing capacity at farm level. The feasibility of each land use type is modified by multiplying with a preference value, but the total feasibility in each production system remains unchanged:

$$Feas3(i) = [Feas2(i) * Pref(i) * \sum_{lut=1}^{NP} Feas2(lut)] / \sum_{lut=1}^{NP} [Feas2(lut) * Pref(lut)]$$

where: Feas3(i) = feasibility of land use type (i) after application of the 1st, 2nd and 3rd social rule;
NP = number of land use types in a production system;
lut = land use type;
Pref(i), Pref(lut) = preference value of land use types (i) and (lut), respectively.

Preference values can be equal to 1 if there is no preference or the preference is not clear (e.g. among fisheries products).

6.2f) Calculate integrated feasibility on the basis of the 4th rule: the fourth social rule assumes that traditional rice is preferred by the local population to high yielding rice. Part of the area of high yielding rice, therefore, is converted to traditional rice. The feasibility of rice land use types is recalculated with a preference value between two varieties:

$$InFe(i) = [Feas3(i) * RPref(i) * \sum_{lut=1}^{NRice} Feas3(lut)] / \sum_{lut=1}^{NRice} [Feas3(lut) * RPref(lut)]$$

where: InFe(i) = integrated feasibility of rice land use type (i) after application of all four social rules;
RPref(i), RPref(lut) = preference value of rice land use types (i) and (lut) based on variety, respectively;
NRice = number of rice land use types.

For the non-rice land use types, the integrated feasibility is the feasibility after application of the 3th social rule:

$$InFe(i) = Feas3(i)$$

6.3) Output feasibility data: data on integrated feasibility are outputted.

7) End of sub-model [5], then connect to CAILUP main program as described in 4.59.

4.65 Sub-model [6]: Demography

Function: Estimate population and available labour force.

Input data:
<E> Existing demographic situation: population, type (rural or urban), percentage of labour force engaged in agricultural activities, etc.
<1> Projection of population growth by birth control program, fraction of urban population in the total population, migration possibilities, etc.
<4> Net income
<5> Integrated feasibility

Output data:
<6> Population and labour force (File MARI11.S06 in Appendix S6).

Discussion on sub-model [6] for the Quan Lo Phung Hiep region:

A variety of population forecasting techniques exists varying from relatively simple to complex [Conyers & Hills, 1984, FAO, 1991b]. Main factors taken into account in these techniques are fertility, mortality and migration rates.

Sub-model [6] deals with three main issues:
(i) population growth;
(ii) redistribution of the population in the Region due to urbanization;
(iii) redistribution of the population as a consequence of water management.

Sub-model [6] focuses on the second and third issue, and has been developed on the basis of the following assumptions:

1/ *Population growth:* population growth originates from two sources: natural growth (fertility - mortality) and 'external migration' (i.e. migration from/to outside). Projected rates of natural growth and external migration are derived from targets of population control programmes. Rates of natural growth are assumed to be equal for all water management units. Rates of external migration to various water management units are different, therefore a spatial-temporal adjustment coefficient is used to allocate total external migration to each unit.

2/ *Redistribution of the population due to urbanization:* the total urban population is defined as a proportion of the total population and derived from urbanization studies [NEDECO, 1993c]. Assuming that no new urban centres will be created in the future, movement of people from rural sub-units to urban sub-units is controlled by administrative regulations (e.g. movement to main towns is only possible within a district or a province as expressed in a matrix of migration possibilities (File MIGRAT.S06 in Appendix S6).

In the Lewis-Fei-Ranis model [Todaro, 1982, 1992], it is assumed that urban wages would have to be at least 30% higher than average rural income to induce workers to migrate from their home areas. However, in the 'expected income' model [Todaro, 1982, 1992] it is pointed out that the decision to migrate depends on 'expected' rather than actual urban-rural wage differentials. Since data on urban income are not available and there is no promising off-farm income in rural sub-units in the Region, the number of people migrating from rural sub-units to an urban sub-unit is assumed inversely proportional to income from land use in each sub-unit: when income is low, more people will migrate (see Calculations for details).

3/ *Redistribution of the population in rural areas as a consequence of water management:* a relevant effect of interventions in water management is the increase in income from land use. Consequently, inhabitants from other rural sub-units will migrate to these sub-units, particularly from areas with many natural constraints, similar the urbanization process. The number of persons moving between two rural sub-units is assumed to be controlled by:

- administrative regulations (e.g. movement is possible only between two adjacent sub-units or among sub-units in the same district) and social conditions (Khmer people living on the sand ridges or high tidal flats are not willing to move to the inundated area) as expressed in a matrix of migration possibilities (File MIGRAT.S06 in Appendix S6);

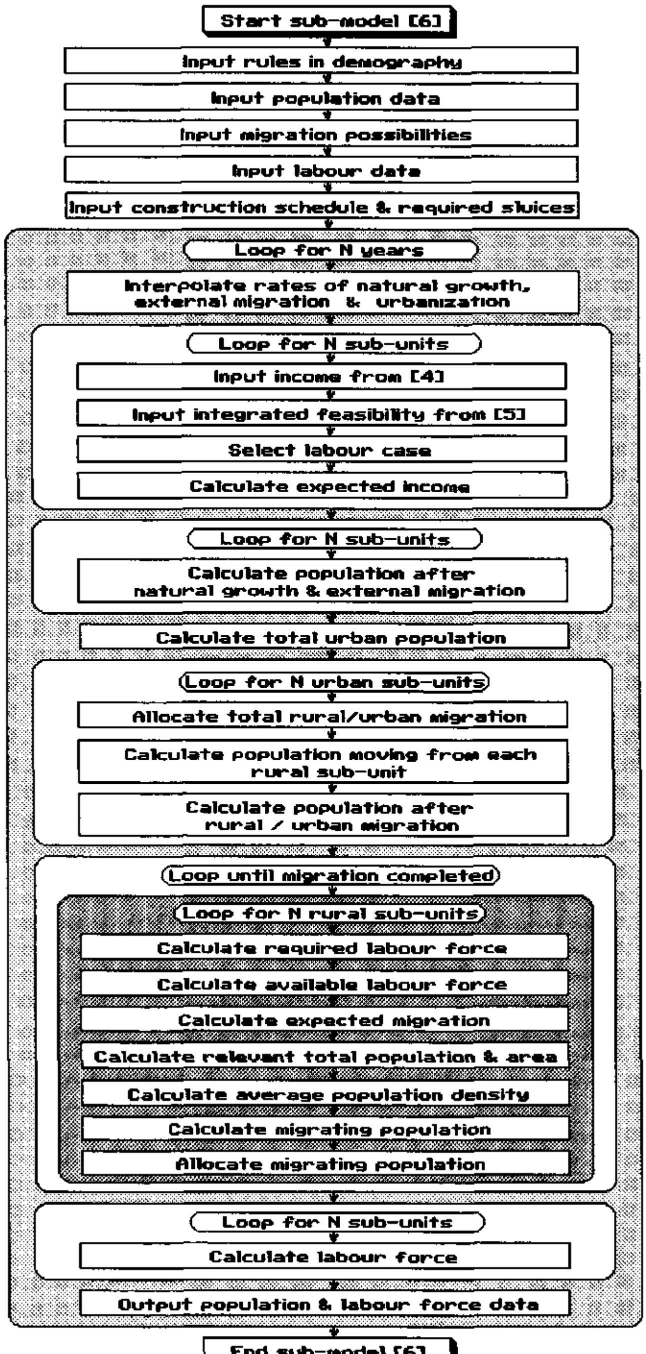
- the difference between the expected income in the sub-unit of destination and the current income in the sub-unit of origin. For rural/urban migration, a differential of 30% is assumed by Lewis [Todaro, 1982, 1992], therefore for rural/rural migration, it should be higher because of less attractive facilities in the rural areas;

- the difference in job opportunities in the sub-unit of destination and the sub-units of origin. In urban/rural migration, Todaro [Todaro, 1982, 1992] assumed that migration rates in excess of urban job opportunity growth rates are not only possible but rational. However, in rural/rural migration, assuming that people are only willing to move to new areas if job opportunities there are better, migration is assumed to stop when the labour force available for land use per hectare of cultivable land in the sub-unit of destination is equal to that in all relevant sub-units;

- only a proportion of the population making the final decision in migration, reflecting effects of other factors such as resettlement support by the Government, communication facilities, etc.

Calculations: The main steps in the sequence of calculations are (Fig. 100):

Figure 100: Sequence of calculations in sub-model [6].



1) Start sub-model [6]: as described in 4.58.

2) Input rules in demography: rules in demography comprise rates of population growth and external migration, difference in income causing migration, percentage of the population making final decision to migrate, etc. (File POPURULE.S06 in Appendix S6).

3) Input population data: present population, sub-unit type (urban or rural) (File EXISTING.S03 in Appendix S3).

4) Input migration possibilities: possibilities of migration from rural sub-units to urban sub-units and among rural sub-units are defined in a matrix with different codes for different migration types (File MIGRAT.S06 in Appendix S6):

- 0 for no migration
- 1 for migration between two rural sub-units
- 2 for migration to district towns
- 3 for migration to provincial towns

5) Input labour data: numbers of labour-days required for each cropping pattern in the 'without' and 'with' cases have been estimated in the financial analysis in sub-model [4] (File FINAN.S04 in Appendix S4).

6) Input construction schedule and required sluices as in sub-model [4] (Files CONSTRUC.SCH and SUBUNODE.S02 in Appendix S2).

7) Loop for N years:

7.1) Interpolate rates of natural growth, external migration and urbanization: the projected natural growth rate (fertility - mortality) and net rate of external migration at a number of target years as consequences of birth control and urbanization programmes, are selected. Rates of natural growth and external migration are interpolated from projected values between two target years.

7.2) Loop for N sub-units:

7.2a) Input income from sub-model [4].

7.2b) Input integrated feasibility from sub-model [5].

7.2c) Select the labour case: if the construction of main sluices required for changing the water conditions in one sub-unit has been completed, labour values for the 'with' case are applied, otherwise values of the 'without' case are used.

7.2d) Calculate expected income: expected income is calculated by aggregating income and integrated feasibility:

$$ExpInc(s,y) = \sum_{lut=1}^{NP} [NetInc(s,y,lut) * InFe(s,y,lut)]$$

where: ExpInc(s,y) = expected income (VN Dong/ha) from land use in sub-unit (s) in year (y);

NP	=	number of productive land use types;
lut	=	land use type;
NetInc(s,y,lut)	=	net income (VN Dong/ha) from sub-model [4];
InFe(s,y,lut)	=	integrated feasibility from sub-model [5].

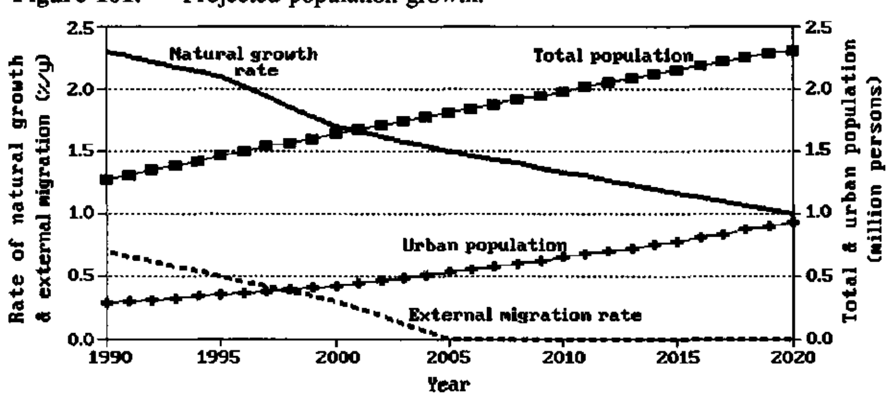
7.3) Loop for N sub-units to calculate population after natural growth and external migration: the "modified exponential" method [Conyers & Hills, 1984] is applied in this sub-model to estimate the population in each year:

$$NEPopu(s,y) = Popu(s,y-1) * [1 + NGRate(y)] * [1 + RExt(y)]$$

where:	NEPopu(s,y)	=	population (persons) in sub-unit (s) after natural growth and external migration in year (y);
	Popu(s,y-1)	=	population (persons) in sub-unit (s) in year (y-1);
	NGRate(y)	=	natural growth rate in year (y);
	RExt(y)	=	rate of external migration in year (y).

7.4) Calculate total urban population: the population in all urban sub-units is assumed to increase each year at the same rate, from three sources: natural growth, external migration, and migration from rural areas to urban areas. Total rural/urban migration, therefore, is the difference between projected urban population and projected urban population after natural growth and external migration (Fig. 101).

Figure 101: Projected population growth.



Total projected urban population is estimated as a proportion of the total population:

$$TotUrPopu = TotPopu(y) * UrFract(y)$$

where:	TotUrPopu(y)	=	total urban population (persons) in the Region in year (y);
	TotPopu(y)	=	total population in year (y);
	UrFract(y)	=	projected fraction of urban population in the total population.

Urban population increase by natural growth and external migration is estimated by the "modified exponential" method:

$$TotUrNEPopu(y) = TotUrPopu(y-1) * [1 + NGRate(y)] * [1 + RExt(y)]$$

where: TotUrNEPopu(y) = total urban population (persons) in year (y) after natural growth and external migration;
TotUrPopu(y-1) = total urban population (persons) in year (y-1);
NGRate(y) = natural growth rate in year (y);
RExt(y) = rate of external migration in year (y).

7.5) Loop for N urban sub-units:

7.5a) Allocate total rural/urban migration to each urban sub-unit:

$$RUMig(u,y) = NEPopu(u,y) * [TotUrPopu(y) / TotUrNEPopu(y)]$$

where: RUMig(u,y) = number of persons migrating to urban sub-unit (u) in year (y);
NEPopu(u,y) = population (persons) in urban sub-unit (u) in year (y) after natural growth and external migration;
u = urban sub-unit.

7.5b) Calculate population moving from each rural sub-unit: the number of persons migrating from rural sub-units to an urban sub-unit is assumed to be weighted on expected income in rural sub-units:

$$Mig(r,u,y) = RUMig(u,y) * ExpInc(r,y) / [\sum_{k=1}^{NRSub} ExpInc(k,y)]$$

where: Mig(r,u,y) = number of persons migrating from rural sub-unit (r) to urban sub-unit (u) in year (y);
u = urban sub-unit;
r,k = rural sub-units;
RUMig(u,y), ExpInc(r,y) and ExpInc(k,y) as calculated in *7.5a* and *7.2d*;
NRSub = number of rural sub-units from where migration to the urban sub-unit (u) is possible.

7.5c) Calculate population after rural/urban migration: for urban sub-unit (u):

$$Popu(u,y) = NEPopu(u,y) + \sum_{r=1}^{NRSub} Mig(r,u,y)$$

where: Popu(u,y) = population (persons) in year (y);
NEPopu(u,y) = population (persons) after natural growth and external migration.

For each relevant rural sub-unit (r):

$$RUPopu(r,y) = NEPopu(r,y) - Mig(r,u,y)$$

where: RUPopu(r,y) = population (persons) in rural sub-unit (r) in year (y) after rural/urban migration.

7.6) Loop until migration among rural sub-units completed:

Loop for N rural sub-units: assuming that first a sub-unit of destination receives emigrants from the poorest emigration sub-unit, the calculation is repeated with the new labour force per hectare of cultivable land until migration between rural sub-units is completed.

7.6a) Calculate required labour force: in this sub-model, the area of each land use type is assumed to be weighted for the integrated feasibility from sub-model [5]. The labour force required for land use is estimated:

$$ReqLab(s,y) = \sum_{lut=1}^{NP} \left[Lab(y,lut) * CulArea(s,y) * InFe(s,y,lut) / [\sum_{i=1}^{NP} InFe(s,y,i)] \right]$$

where: ReqLab(s,y) = required labour force (labour-days) for all productive land use types in sub-unit (s) in year (y);
NP = number of productive land use types;
lut, i = land use types;
Lab(y,lut) = number of labour-days required for land use type (lut);
CulArea(s,y) = cultivable area (ha) as calculated in sub-model [4] (total area minus areas for specific uses, homestead gardens and water surface). For the first run of the model, current land use areas are used. New areas from sub-model [8] can be used if a return from the following sub-models is needed to adjust for the effects of new land uses on migration.
InFe(s,y,lut), InFe(s,y,i) = integrated feasibility from sub-model [5].

7.6b) Calculate available labour force: the degree of participation in the labour force and the percentage engaged in land use (from age 15 to 60) of the total population have been estimated from several social studies [Thu, 1991, NEDECO, 1991e] and are assumed equal in all sub-units in each year, hence the available labour force is:

$$AvaiLab(s,y) = Popu(s,y-1) * RLab(y) * RLULab(y) * NWDay(y)$$

where: AvaiLab(s,y) = available labour force (labour-days) for land use in sub-unit (s) in year (y);
Popu(s,y-1) = population (persons) in year (y-1);
RLab(y) = fraction of the labour force in the total population in year (y) (e.g. 0.45 in the Region);
RLULab(y) = fraction of the labour force engaged in land use in the total labour force in year (y) (e.g. 0.75 in rural sub-units);
NWDay(y) = number of working days in a year (labour-days).

7.6c) Calculate expected migration:

$$ExpMig(s,y) = [ReqLab(s,y) - AvaiLab(s,y)] / RLULab(y) / RLab(y)$$

where: ExpMig(s,y) = expected migration (persons).

7.6d) Calculate relevant total population and total cultivable area in the rural/rural migration: a rural sub-unit (i) is involved in migration to another rural sub-unit (r), if the following conditions are satisfied:

i) Migration from (i) to (r) is possible under current administrative regulations and social conditions (see 4/ in Discussions);

ii) The difference in expected incomes exceeds a threshold value:

$$\frac{ExpInc(r,y) - ExpInc(i,y)}{ExpInc(i,y)} \geq ExpDiff$$

where: ExpInc(r,y), ExpInc(i,y) as calculated in *7.2d*;
ExpDiff = expected difference in income.

iii) Expected migration in (r) greater than expected migration in (i):

$$ExpMig(r,y) > ExpMig(i,y)$$

Then, the relevant total population and total cultivable area in the rural/rural migration are:

$$TotMig = RUPopu(r,y) + \sum_{i=1}^{NRSub} RUPopu(i,y)$$

$$TotCulArea = CulArea(r,y) + \sum_{i=1}^{NRSub} CulArea(i,y)$$

where: TotMig = relevant total population (persons) including the rural/rural migration to sub-unit (i) in year (y);
RUPopu(r,y), RUPopu(i,y) = population (persons) after rural/urban migration calculated in *7.5c*;
r, i = rural sub-units;
NRSub = number of rural sub-units satisfying the above conditions;
TotCulArea = relevant total cultivable area (ha).

7.6e) Calculate average population density:

$$Density = TotMig / TotCulArea$$

where: Density = average population density in sub-unit (r) and relevant sub-units (i).

7.6f) Calculate migrating population:

$$Migi = [CulArea(r,y) * Density] - RUPopu(r,y)$$

where: Migi = population (persons) migrating to sub-unit (r).

7.6g) Allocate migrating population to relevant rural sub-units:

For each relevant sub-unit (i):

$$Mig(i,y) = ExpMig(i,y) * [Migi / TotMig] * Decide(y)$$

where: Mig(i,y) = population (persons) migrating from sub-unit (j) to (i);
Decide(y) = fraction of the population deciding to migrate.

The fraction of the population deciding to migrate reflects the effect of other factors such as government support, conservative character, etc. In addition, an upper limit (e.g. 2% of the total population) is the maximum population migrating from a sub-unit. These fractions are adjusted in model calibration.

Populations in sub-unit (r) and each relevant sub-unit (i) are:

$$Popu(r,y) = RUPopu(r,y) + \sum_{i=1}^{NRSub} Mig(i,y)$$

$$Popu(i,y) = RUPopu(i,y) - Mig(i,y)$$

where: Popu(r,y), Popu(i,y) = populations (persons) in sub-unit (r) and (i) in year (y).

7.7) Loop for N sub-units to calculate labour force for land use:

$$LabFor(s,y) = Popu(s,y) * RLab(y)$$

$$LabForLU(s,y) = LabFor(s,y) * RLULab(y)$$

where: LabFor(s,y) = labour force (persons) in sub-unit (s) in year (y);
LabForLU(s,y) = labour force (persons) for land use in sub-unit (s) in year (y).

7.8) Output population and labour force data (File MARI11.S06 in Appendix S6).

8) End of sub-model [6], then connect to CAILUP main program as described in 4.59.

4.66 Sub-model [7]: Land Use Weighting

Function: Generate weighting factors to allocate land resources to each land use type.

Input data:

- <E> Current area of each land use type
- <1> Government policy factors
- <3> Yields
- <5> Integrated feasibilities
- <6> Population dynamics

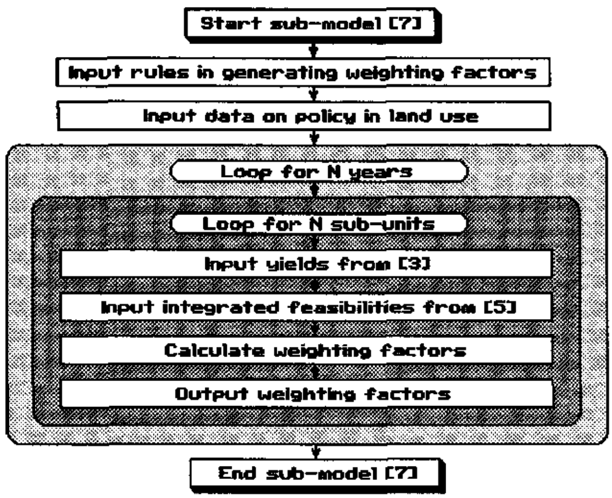
Current area <E> and population <6> are only used as references in the selection of government policy factors.

Output data:

<7> Weighting factors for each land use type.

Calculations: The main steps in the sequence of calculations are (Fig. 102):

Figure 102: Sequence of calculations in sub-model [7].



1) Start sub-model [7]: as described in 4.58.

2) Input rules in generating weighting factors: one, two or all three factors: integrated feasibilities, policy factor and yields can be selected to generate weighting factors. (File WEIGRULE.S07 in Appendix S7).

3) Input data on policy in land use: government policy on land use is expressed by a 'score' for each land use type in each water management unit. Different policies can be applied in different years, e.g. before, during and after construction of the new water management system. (File WEIGVALU.S07 in Appendix S7).

4) Loop for N years, then
Loop for N sub-units:

4.1) Input yields from sub-model [3].

4.2) Input integrated feasibilities from sub-model [5].

4.3) Calculate weighting factors:

- For productive land use types, weighting factors are:

$$Weig(s,y,lut) = InFe(s,y,lut) * PoFa(s,y,lut)$$

where: Weig(s,y,lut) = weighting factor for land use type (lut) in sub-unit (s) in year (y);
InFe(s,y,lut) = integrated feasibility from sub-model [5];
PoFa(s,y,lut) = policy factor.

In a food-oriented scenario, rice crops with high yield are preferred although their integrated feasibility may be low. Then, weighting factors of rice crops are adjusted by yield values:

$$Weig(s,y,r) = Weig0(s,y,r) * Yield(s,y,r) * \frac{\sum_{lut=1}^{NRice} Weig0(s,y,lut)}{\sum_{lut=1}^{NRice} [Weig0(s,y,lut) * Yield(s,y,lut)]}$$

where:

Weig(s,y,r)	=	weighting factor for rice land use type (r);
r, lut	=	rice land use type;
Weig0(s,y,r), Weig0(s,y,lut)	=	weighting factor of land use types (r) and (lut), respectively as calculated in the above equation;
Yield(s,y,r), Yield(s,y,lut)	=	rice yield (t/ha) of (r) and (lut);
NRice	=	number of rice land use types taken into account in the adjustment.

▸ For non-productive land use types (specific uses, homestead gardens), weighting factors are equal to policy factors (a ratio of increase in area per capita of these land use types to the area per capita in the preceding year, see 4.67 for details).

4.4) Output weighting factors (File MARI16.S07 in Appendix S7).

5) End of sub-model [7] *and connect to CAILUP main program*: as described in 4.59.

4.67 Sub-model [8]: Land Use Allocation

Function: Generate the area to be allocated to each land use type and the water volume extracted from the water management system.

Input data:

<E> Current area of each land use type and present population
<1> Land use conversion, water demand, etc.
<3> Selected cropping calendars
<6> Population dynamics
<7> Weighting factors

Output data:

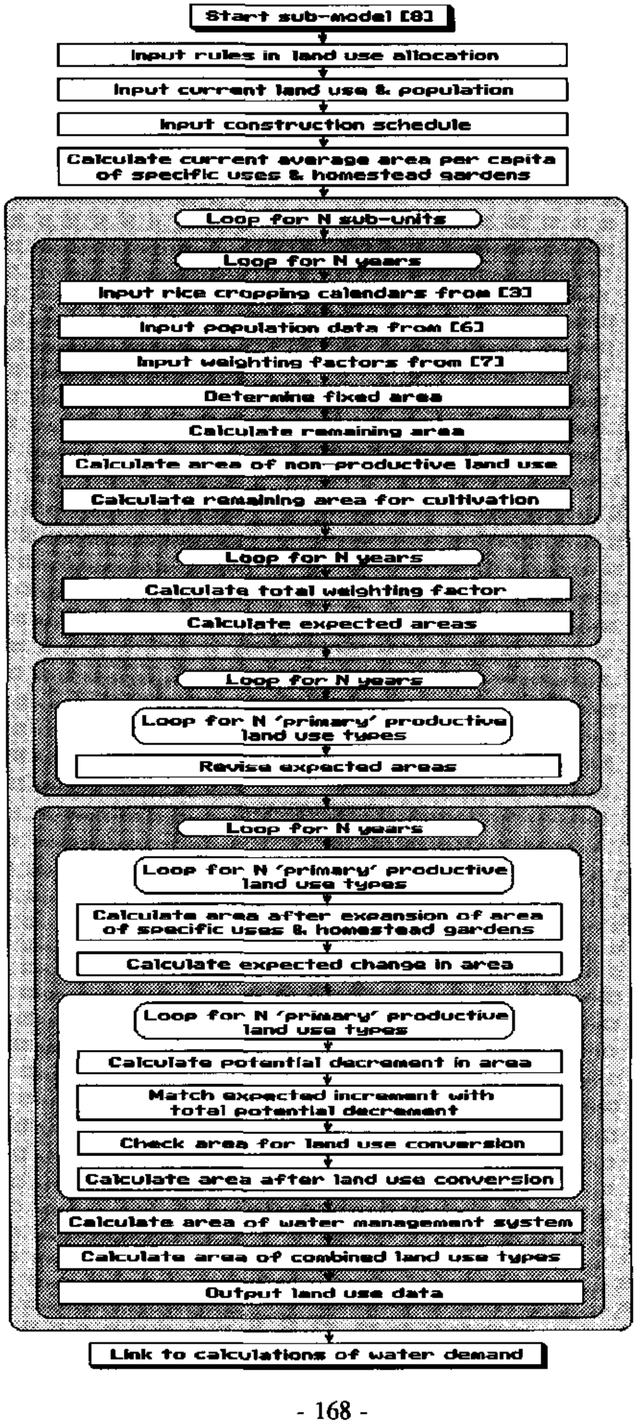
<8> A resource use plan comprising land and water resource allocation.

Calculations: In the equations in this sub-model, (s,y,lut) refers to land use type (lut) in sub-unit (s) in year (y). The calculations are divided in two parts: land use allocation and water resource allocation.

Part I: Land use allocation

The main steps in the sequence of calculations are (Fig. 103):

Figure 103: Sequence of calculations in sub-model [8].



1) Start sub-model [8]: as described in 4.58.

2) Input rules in land use allocation: possibilities for land use conversion, cultivation period, fraction of cultivated land occupied by the water management system, etc. (File ALLORULE.S08 in Appendix S8).

3) Input current land use and population (File EXISTING.S03 in Appendix S3).

4) Input construction schedule (File CONSTRUC.SCH in Appendix S2).

5) Calculate current average area per capita of specific uses and homestead gardens: for urban sub-units:

$$AASU = [\sum_{s=1}^{NUSub} Area(s,0,speci)] / [\sum_{s=1}^{NUSub} Popu(s,0)]$$

$$AAGU = [\sum_{s=1}^{NUSub} Area(s,0,gard)] / [\sum_{s=1}^{NUSub} Popu(s,0)]$$

where:
- AASU = present average area (ha/urban capita) of specific uses;
- NUSub = number of urban sub-unit;
- Area(s,0,speci) = current area (ha) of specific uses in year 0;
- Popu(s,0) = current population (persons) in year 0;
- AAGU = average area (ha/urban capita) of homestead gardens;
- Area(s,0,gard) = current area (ha) of homestead gardens in year 0.

Similar calculations are carried out for current average area of specific uses (AASR) and homestead gardens (AAGR) in rural sub-units.

6) Loop for N sub-units:

6.1) Loop for N years:

6.1a) Input rice cropping calendars from sub-model [3].

6.1b) Input population data from sub-model [6].

6.1c) Input weighting factors from sub-model [7].

6.1d) Determine fixed area: the area of salt fields is assumed to be fixed during the planning period:

$$Area(s,y,salt) = Area(s,0,salt)$$

where:
- Area(s,y,salt) = area (ha) of salt fields;
- Area(s,0,salt) = current area (ha) of salt fields (in year 0).

6.1e) Calculate remaining area:

$$RemArea(s,y) = TotArea(s) - Area(s,y,salt)$$

where:
- RemArea(s,y) = remaining area (ha);
- TotArea(s) = total area (ha) of sub-unit (s).

6.1f) Calculate area of non-productive land use types:

- For urban sub-units:

$$\text{Area}(s,y,\text{speci}) = \text{Area}(s,y-1,\text{speci}) + \text{AASU} * \text{Wei}(s,y,\text{speci}) * \text{Max}[(\text{Popu}(s,y) - \text{Popu}(s,y-1)), 0]$$

$$\text{Area}(s,y,\text{gard}) = \text{Area}(s,y-1,\text{gard}) + \text{AAGU} * \text{Wei}(s,y,\text{gard}) * \text{Max}[(\text{Popu}(s,y) - \text{Popu}(s,y-1)), 0]$$

where: Area(s,y,speci), Area(s,y-1,speci) = area (ha) of specific uses in years (y) and (y-1), respectively;
Area(s,y,gard), Area(s,y-1,gard) = area (ha) of homestead gardens;
Wei(s,y,speci), Wei(s,y,gard) = weighting factors of specific uses and homestead gardens from sub-model [7], as fractions of AASU and AAGU, respectively;
Popu(s,y), Popu(s,y-1) = population (persons).

- Similar calculations are carried out for the rural sub-units.

- Part of the uncultivated land can be used for nature reserve:

$$\text{Area}(s,y,\text{uncul}) = \text{Area}(s,y-1,\text{uncul}) * \text{Wei}(s,y,\text{uncul})$$

where: Area(s,y,uncul), Area(s,y-1,uncul) = area (ha) of uncultivated land;
Wei(s,y,uncul) = weighting factor from sub-model [7], as a fraction of area of uncultivated land in year (y-1).

6.1g) Calculate remaining area for cultivation:

$$\text{CulArea}(s,y) = \text{RemArea}(s,y) - \text{Area}(s,y,\text{speci}) - \text{Area}(s,y,\text{gard}) - \text{Area}(s,y,\text{uncul}) - \text{Area}(s,y-1,\text{water})$$

where: CulArea(s,y) = area (ha) for cultivation;
Area(s,y-1,water) = area (ha) of water surface in canals and rivers in year (y-1). Expansion of this area depends on the allocation of other land use types.

6.2) Loop for N years:

6.2a) Calculate total weighting factor: since the land resource is first allocated to land use types that require a separate land area (hereafter called 'primary' productive land use types), the total weighting factor does not include combined land use types such as shrimps in rice fields, beans in rotation with rice, etc.

$$\text{TotWeig}(s,y) = \sum_{lut=1}^{NPP} \text{Weig}(s,y,lut)$$

where: TotWeig(s,y) = total weighting factor;
NPP = number of 'primary' productive land use types;
Weig(s,y,lut) = weighting factor from sub-model [7].

6.2b) Loop for N 'primary' productive land use types to calculate expected areas:

$$ExpArea(s,y,lut) = CulArea(s,y) * Weig(s,y,lut) / TotWeig(s,y)$$

where: ExpArea(s,y,lut) = expected area (ha);
Weig(s,y,lut) = weighting factor from sub-model [7].

6.3) Loop for N years, then
Loop for N 'primary' productive land use types to revise the expected areas:

6.3a) Revise expected areas for land use types refering to crops with a long growth cycle: some of the land use types refer to crops with a long growth cycle (e.g. 3 years for pineapple or 8 years for Melaleuca forest). The expected areas of these land use types should be matched with land use conversions in the past and the possibilities in the future.

Match with area converted in the past:

$$ExpArea(s,y,lut) \geq \sum_{i=1}^{GC(lut)} [ExpArea(s,i,lut) - ExpArea(s,i-1,lut)]$$

and with possibilities in the future:

$$ExpArea(s,y,lut) \leq \min_{i=y+1}^{y+GC(lut)} [ExpArea(s,i,lut)]$$

where: ExpArea(s,y,lut) = expected area (ha);
GC(lut) = duration (y) of the growth cycle;
i = year number in growth cycle.

6.3b) Revise expected areas of 'primary' productive land use types requiring completion of the on-farm system:

- Before construction of the on-farm system, the area cannot be expanded:

$$ExpArea(s,y,lut) = ExpArea(s,y-1,lut)$$

- During construction of the on-farm system:

$$ExpArea(s,y,lut) \leq ExpArea(s,y-1,lut) + [(ExpArea(s,yf(s),lut) - ExpArea(s,yi(s),lut)) / (yf(s) - yi(s)+1)]$$

where: yf(s), yi(s) = final and initial years of the construction period of the on-farm system;
(yf(s)-yi(s)+1) = construction period.

6.4) Loop for N years to calculate area subject to land use conversion:

6.4.1) Loop for N 'primary' productive land use types:

6.4.1a) Calculate the area of each land use type after expansion of the area of specific uses and homestead gardens:

$$\text{DemLand}(s,y) = [\text{Area}(s,y,\text{speci}) + \text{Area}(s,y,\text{gard})] - [\text{Area}(s,y-1,\text{speci}) + \text{Area}(s,y-1,\text{gard})]$$

where: DemLand(s,y) = demand for land (ha) for expansion of the area of specific uses and homestead gardens.

The area converted from each 'primary' productive land use type to specific uses and homestead gardens in year (y) is assumed to be proportional to the area of that land use type in year (y-1):

$$\text{RedArea}(s,y,\text{lut}) = \text{Area}(s,y-1,\text{lut}) * [1 - (\text{DemLand}(s,y) / \sum_{i=1}^{NPP} \text{Area}(s,y-1,i))]$$

where: RedArea(s,y,lut) = area (ha) after reduction due to expansion of the area of specific uses and homestead gardens;
Area(s,y-1,lut), Area(s,y-1,i) = area (ha) of land use types (lut) and (i) in year (y-1), respectively;
NPP = number of 'primary' productive land use types;
i = land use type.

6.4.1b) Calculate expected change (increment/decrement) in area:

$$\text{ExpChange}(s,y,\text{lut}) = \text{ExpArea}(s,y,\text{lut}) - \text{RedArea}(s,y,\text{lut})$$

where: ExpChange(s,y,lut) = expected change (ha) in area.

If the expected change is positive or negative, an increment or a decrement in area is required in year (y).

6.4.2) Loop for N 'primary' productive land use types with increment in area: the expected increment in area of a land use type (lut) is taken from the total potential decrement in area of all land use types (i) that can be converted to (lut).

6.4.2a) Calculate potential decrement in area:

$$\text{PotDec}(s,y,\text{lut}) = \sum_{i=1}^{NPlut} \text{ExpChange}(s,y,i) \qquad \text{with ExpChange}(s,y,i) < 0$$

where: PotDec(s,y,lut) = total potential decrement (ha) in area of all land use types that can be converted to (lut);
NPlut = number of land use types that can be converted to (lut);
i = land use type.

6.4.2b) Match expected increment with total potential decrement: Loop for N 'primary' productive land use types that can be converted to land use type (lut):

Three situations are considered:

1/ *ExpChange(s,y,lut) >= -PotDec(s,y,lut) > 0*: the total potential decrement is insufficient to satisfy the demand for land use type (lut), then all decrements in land use types (i) are converted to land use type (lut):

$$\text{ConvArea}(s,y,i,lut) = -\text{ExpChange}(s,y,i)$$

where: ConvArea(s,y,i,lut) = area (ha) converted from land use type (i) to (lut).

2/ *ExpChange(s,y,lut) < -PotDec(s,y,lut)*: the potential decrement exceeds the demand for land use type (lut), then land is converted in proportion to the potential decrement in each land use type (i):

$$\text{ConvArea}(s,y,i,lut) = \text{ExpChange}(s,y,lut) * \text{ExpChange}(s,y,i) / \text{PotDec}(s,y,lut)$$

3/ *ExpChange(s,y,lut) > 0 but PotDec(s,y,lut) = 0*: no decrements in other land use types are expected. The increment in area of a land use type (lut) is, therefore, distributed over all land use types (i). Subsequently, the deficit in area of land use types (i) will be converted from other land use types in *6.4.2e*.

3.a/ *Calculate potential area* that can be converted to land use type (lut):

$$\text{PotArea}(s,y,lut) = \sum_{i=1}^{NPlut} \text{RedArea}(s,y,i)$$

where: PotArea(s,y,lut) = total potential area (ha) of all land use types that can be converted to (lut);
NPlut = number of land use types that can be converted to (lut);
i = land use type.

3.b/ *Match expected increment of land use type (lut) with the total potential area*: three situations similar to those in *6.4.2b 1/ 2/* and *3/* are considered:

i/ *ExpChange(s,y,lut) >= PotArea(s,y,lut) > 0*: total potential area is insufficient to meet the demand for (lut), then:

$$\text{ConvArea}(s,y,i,lut) = -\text{RedArea}(s,y,i)$$

ii/ *ExpChange(s,y,lut) < PotArea(s,y,lut)*:

$$\text{ConvArea}(s,y,i,lut) = \text{ExpChange}(s,y,lut) * \text{RedArea}(s,y,i) / \text{PotArea}(s,y,lut)$$

iii/ *PotArea(s,y,lut) = 0*: no land available for the increment in land use type (lut), i.e. ExpChange(s,y,lut) = 0.

6.4.2c) Check the area for land use conversion:

Loop for N 'primary' productive land use types: when the calculation of all land use conversions is completed, the area converted from each land use type is verified:

$$\text{TotConv}(s,y,i) = \sum_{lut=1}^{NPP} \text{ConvArea}(s,y,i,lut)$$

where: TotConv(s,y,i) = total area (ha) converted from land use type (i);
NPP = number of 'primary' productive land use types.

If TotConv(s,y,i) > RedArea(s,y,i), then adjustment is needed for all cases of conversion from land use type (i):

$$\text{ConvArea}(s,y,i,lut) = \text{OldConvArea}(s,y,i,lut) * \text{RedArea}(s,y,i) / \text{TotConv}(s,y,i)$$

where: ConvArea(s,y,i,lut) = converted area (ha) from land use type (i) to (lut) after adjustment;
OldConvArea(s,y,i,lut) = ConvArea(s,y,i,lut) as calculated in *6.4.2b* (i.e. before adjustment).

6.4.2d) Calculate the area after land use conversion: Loop for N 'primary' productive land use types:

$$\text{Area}(s,y,lut) = \text{RedArea}(s,y,lut) + \sum_{i=1}^{NPP} \text{ConvArea}(s,y,i,lut)$$

where: Area(s,y,lut) = area (ha) of land use type (lut);
NPP = number of 'primary' productive land use types;
i = land use type.

6.4.2e) Loop for N 'primary' productive land use types to repeat the conversion procedure if needed: after land use conversion, the expected change is recalculated on the basis of the new area:

$$\text{ExpChange}(s,y,lut) = \text{ExpArea}(s,y,lut) - \text{RedArea}(s,y,lut)$$

where: ExpChange(s,y,lut) = expected change (ha) in area.

If the expected change in area of any land use type > 0, i.e. expansion in area of that land use type is still expected, the calculation returns to step *6.4.2a* with Area(s,y,lut) (newly calculated in *6.4.2d*) replacing RedArea(s,y,lut).

6.4.3) Calculate the new area of water management system and of canal water surface: Loop for N 'primary' productive land use types:

Part of the cultivated land is used for the new water management system, therefore:

$$\text{WMSArea}(s,y,lut) = \text{Area}(s,y,lut) * \text{Wei}(s,y,water) * \text{WMSFract}(y) / (yf(s) - yi(s) + 1)$$

where: WMSArea(s,y,lut) = area (ha) of water management system in area of land use type (lut);
Area(s,y,lut) as calculated in *6.4.2d*;
Wei(s,y,water) = weighting factor of water management system from sub-model [7], reflecting the policy with respect to expansion of the water management system in cultivated land;
WMSFract(y) = fraction of cultivated land occupied by water management system;
yf(s), yi(s) = initial and final year of the construction period.

In the new water management system, the area of canal water surface is:

$$\text{WArea}(s,y,lut) = \text{WMSArea}(s,y,lut) * \text{WFract}(y)$$

where: WArea(s,y,lut) = area (ha) of canal water surface;
WFract(y) = fraction of canal water surface area in the water management system.

Cultivated area of each (lut), therefore, decreases:

$$\text{Area}(s,y,lut) = \text{OldArea}(s,y,lut) - \text{WMSArea}(s,y,lut)$$

where: Area(s,y,lut) = area (ha) of land use type (lut);
OldArea(s,y,lut) = Area(s,y,lut) calculated in *6.4.2* (i.e. before the reduction due to the new water management system).

while area of canal water surface and specific uses increases:

$$\text{Area}(s,y,water) = \text{Area}(s,y-1,water) + \sum_{lut=1}^{NPP} \text{WArea}(s,y,lut)$$

$$\text{Area}(s,y,speci) = \text{OldArea}(s,y,speci) + \sum_{lut=1}^{NPP} [\text{WMSArea}(s,y,lut) - \text{WArea}(s,y,lut)]$$

where: Area(s,y,water), Area(s,y-1,water) = area (ha) of canal water surface;
NPP = number of 'primary' productive land use types;
Area(s,y,speci) = area (ha) of specific uses;
OldArea(s,y,speci) = Area(s,y,speci) calculated in *6.1f* (i.e. before the increase due to the new water management system).

6.4.4) Calculate area of combined land use types:

$$\text{Area}(s,y,nipa) = \text{Area}(s,y,water) * \text{Weig}(s,y,nipa)$$

$$\text{Area}(s,y,shsa) = \text{Area}(s,y,salt) * \text{Weig}(s,y,shsa)$$

$$\text{Area}(s,y,shri) = [\text{Area}(s,y,onetra) + \text{Area}(s,y,oneHY)] * \text{Weig}(s,y,shri)$$

$$\text{Area}(s,y,prri) = [\text{Area}(s,y,onetra) + \text{Area}(s,y,SAtra)] * \text{Weig}(s,y,prri)$$

where: Area(s,y,nipa), Area(s,y,shsa), Area(s,y,shri) and Area(s,y,prri) = area (ha) of nipa palm, shrimps in salt fields, shrimps in rice fields and prawns in rice fields, respectively;
Area(s,y,water), Area(s,y,salt) = area (ha) of water surface and salt fields, respectively as calculated in *6.4.3* and *6.1d*;
Area(s,y,onetra), Area(s,y,oneHY) and Area(s,y,SAtra) = area (ha) of single traditional rice, single high yielding rice and Summer-Autumn + 2nd traditional rice, respectively;
Weig(s,y,nipa), Weig(s,y,shsa), Weig(s,y,shri) and Weig(s,y,prri) = weighting factors for nipa palm, shrimps in salt fields, shrimps in rice fields and prawns in rice fields from sub-model [7].

Beans are only cultivated in rice fields if their cropping calendar does not overlap with the rice cropping calendar:

$$Area(s,y,beanSA) = [\sum_{i=1}^{NRice} Area(s,y,i)] * Wei(s,y,beanSA)$$

where: Area(s,y,beanSA) = area (ha) of Summer-Autumn beans;
NRice = number of rice land use types with cropping calendars not overlapping the cropping calendar of Summer-Autumn beans;
i = rice land use type;
Wei(s,y,beanSA) = weighting factor for Summer-Autumn beans from sub-model [7].

Similar calculations are applied for Winter-Spring and Spring-Summer beans.

6.4.5) Output land use data: data on land use area (File MARI1.S08 in Appendix S8) and areas converted among land use types are outputted.

7) Link to calculations of water demand.

Part II: Calculations for water demand

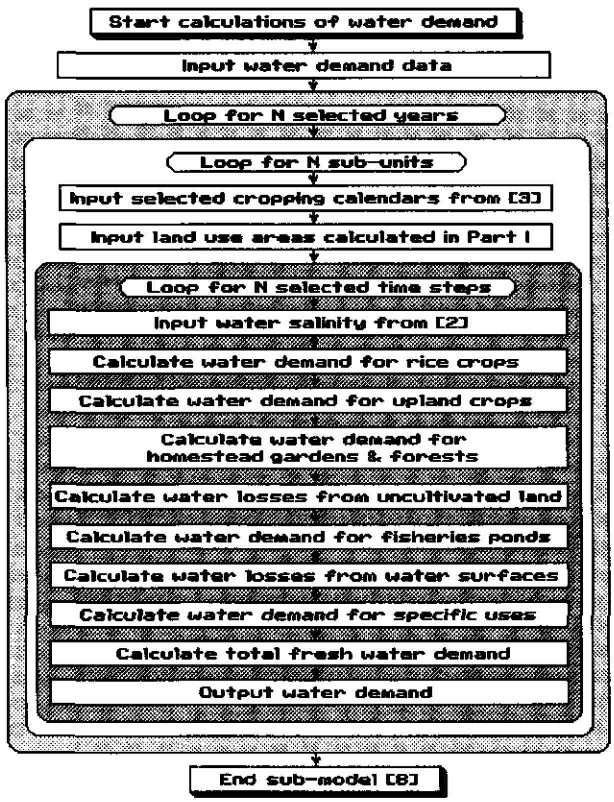
Following the allocation of land to all land use types, water resource allocation, based on water demand in each sub-unit, is considered a prerequisite for the implementation of the selected scenario. Data on water demand are transferred to the hydraulic and salinity model to examine whether improvement of the canal systems is necessary for irrigation purposes, or for controlling the salt water intrusion in the surrounding areas. With respect to water resource allocation, two zones are distinguished in the study region:

1/ In the first zone, canal water is of low salinity ("fresh water") and can be used for irrigation of the relevant agricultural land use types and to some extent, for specific uses. Water management measures such as expansion of canals can be applied to satisfy the water demand in this zone.

2/ In the second zone, the salinity of canal water exceeds the irrigation criterion for agriculture. Irrigation of rice and upland crops with this water would cause yield reductions as calculated in sub-model [3]. However, canal water is also used for other purposes such as irrigation of scattered trees and forests, fisheries (shrimps) ponds, reeds and sedges in uncultivated land. Fresh water is only supplied for specific uses and originates from other sources, such as rain water storage or groundwater.

The main steps in the sequence of calculations are (Fig. 104):

Figure 104: Sequence of calculations for water demand.



8) *Input water demand data*: data required for water demand calculations comprise:

- Data on Penman potential evapotranspiration and rainfall at two and four stations, respectively [NEDECO, 1991c] (File CLIMATE.S08 in Appendix S8).

- Codes of climatic stations pertaining to each sub-unit (File SUBUSTAT.S08 in Appendix S8) defined by applying the Thiessen method [Chow et al., 1988].

- Water demand characteristics: crop factors for rice crops, upland crops, perennial trees and forests, and grass in uncultivated land, evaporation from surface water in canals and rivers, replenishment water for fisheries ponds, and water demand for specific uses (domestic use, industry, public use, etc.) (File DEMAND.S08 in Appendix S8).

9) Loop for N selected years, then
Loop for N sub-units: only data for selected steps in certain years are calculated and transferred to the hydraulic and salinity model.

9.1) Input selected cropping calendars from sub-model [3].

9.2) Input land use areas calculated in Part I of this sub-model.

9.3) Loop for N selected time steps:

9.3a) Input water salinity from sub-model [2].

9.3b) Calculate water demand for rice land use types: the FAO method [Brouwer & Heibloem (1986), Doorenbos & Pruitt (1992), Smith (1992)] is applied to calculate the irrigation demand at each time step for each rice land use type:

$$IRR(t,lut) = Kc(t,lut) * ETo(t) + Perc - [P(t) * Pe] + Sat(t,lut) + [WLa(t,lut) / 2]$$

where: IRR(t,lut) = irrigation demand (m) at time step (t);
Kc(t,lut) = crop factor for rice;
ETo(t) = reference crop evapotranspiration (m);
Perc = percolation (m);
P(t) = rainfall (m);
Pe = effective rainfall coefficient;
Sat(t,lut) = amount of water (m) needed to saturate the soil for land preparation in the initial time step.
For other time steps, Sat(t,lut) = 0;
WLa(t,lut) = water layer (m) established during the two steps following the initial step. For other time steps, WL(t,lut) = 0.

Total water demand for rice land use types is:

$$WDRice(s,y,t) = [\sum_{lut=1}^{NRice} (IRR(t,lut) * Area(s,y,lut))] * IRRe$$

where: WDRice(s,y,t) = water demand (m^3) for rice land use types in time step (t);
Area(s,y,lut) = area (m^2) of rice land use type as calculated in Part I;
NRice = number of rice land use types;
IRRe = irrigation efficiency.

9.3c) Calculate water demand for upland crops (WDUpland(s,y,t): the equations applied for rice are also used for sugarcane, pineapple and beans, except that the water layer WL(t,lut) is not needed.

9.3d) Calculate water demand for homestead gardens and forests (WDForest(s,y,t)): calculations similar to those for rice land use types are applied, except that water for saturation Sat(t,lut) and the water layer WL(t,lut) is not needed.

9.3e) Calculate water losses from uncultivated land (WLUncul(s,y,t)): uncultivated land is covered by reeds and sedges. Calculations similar to those for homestead gardens and forests are applied.

9.3f) Calculate water demand for fisheries ponds: water demand for fisheries ponds comprises two components: evaporation from surface water and water for regular replenishment.

$$WDFish(s,y,t) = (Evapo(t) + Reple(t)) * \sum_{lut=1}^{NFish} Area(s,y,lut)$$

where:
- WDFish(s,y,t) = water demand (m^3) for fisheries ponds in time step (t);
- Evapo(t) = evaporation (m) from surface water;
- Reple(t) = water for replenishment (m);
- NFish = number of land use types of fisheries ponds;
- Area(s,y,lut) = area (m^2) of fisheries (shrimps, prawns or fish) ponds calculated in Part I of this sub-model.

9.3g) Calculate water losses from water surfaces:

$$WLoss(s,y,t) = Evapo(t) * Area(s,y,water)$$

where:
- WLoss(s,y,t) = total water loss (m^3) from water surfaces of canals and rivers in time step (t);
- Area(s,y,water) = area (ha) of water surfaces of canals and rivers.

9.3h) Calculate water demand for specific uses:

$$WDSpec(s,y,t) = Popu(s,y) * SWR(y)$$

where:
- WDSpec(s,y,t) = water demand (m^3) in time step (t);
- Popu(s,y) = population (persons);
- SWR(y) = standard water requirement (m^3/capita). Different standards are applied for the urban and the rural population.

9.3i) Calculate total fresh water demand: if water salinity in the sub-unit is below the salinity threshold for irrigation:

$$TotWD(s,y,t) = WDRice(s,y,t) + WDUpland(s,y,t) + WForest(s,y,t) + WLUncul(s,y,t) + WDFish(s,y,t) + WDSpec(s,y,t) + WLoss(s,y,t)$$

otherwise:

$$TotWD(s,y,t) = WDSpec(s,y,t)$$

9.3j) Output water demand (File MARI18.W08 in Appendix S8).

10) End of sub-model [8], then connect to CAILUP main program as described in 4.59.

4.68 Sub-model [9]: Production

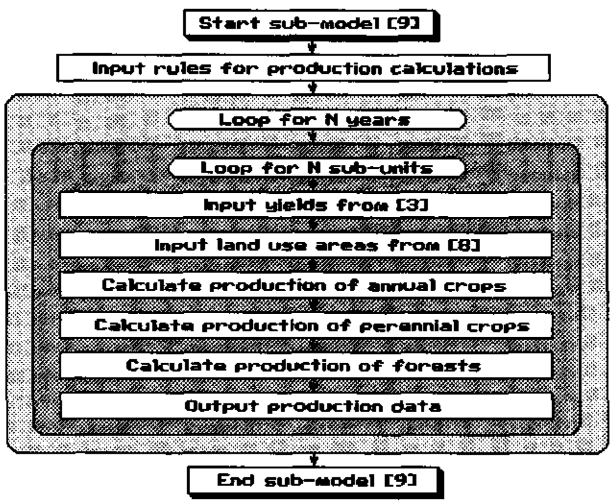
Function: Generate the production from each land use type.

Input data:
<E> Current area of land use type and present population
<1> Interventions in pest and disease control, improvement of input supply
<3> Yields
<8> Area of each land use type.

Output data:
<9> Production of each product.

Calculations: In the equations in this sub-model, (s,y,lut) refers to land use type (lut) in sub-unit (s) in year (y). The main steps in the sequence of calculations are (Fig. 105):

Figure 105: Sequence of calculations in sub-model [9].



1) Start sub-model [9]: as described in 4.58.

2) Input rules for production calculations: rules for production calculations deal with yield reductions due to the effect of pests and diseases, the level of pests and diseases in each year during the planning period and yield reductions due to the delay in supplying input materials. (File PRODRULE.S09 in Appendix S9).

3) Loop for N years, then
Loop for N sub-units:

3.1) Input yields from sub-model [3].

3.2) Input land use areas from sub-model [8].

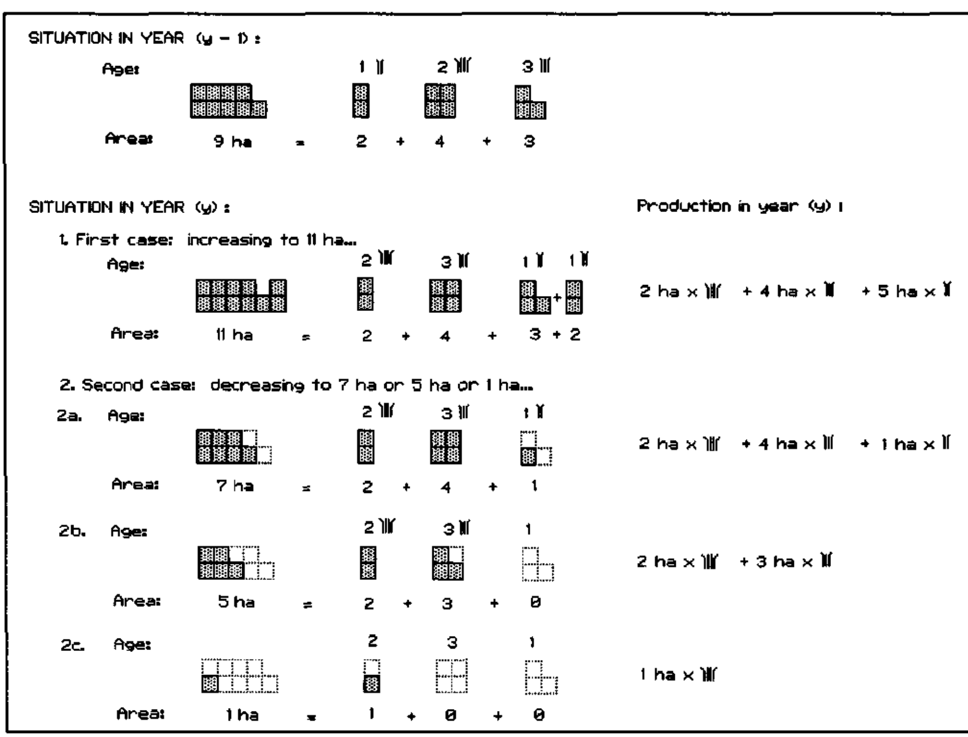
3.3) Calculate production of annual crops: production of annual crops such as rice, beans, shrimps, prawns and fish is:

$$Prod(s,y,lut) = Area(s,y,lut) * Yield(s,y,lut) * (1 - PeEff(y,lut)) * (1 - InEff(y,lut))$$

where: Prod(s,y,lut) = production (tonnes or kg);
Area(s,y,lut) = area (ha) from sub-model [8]. For combined crops of rice with shrimps or prawns, the area of rice crops is reduced by a fraction (e.g. 0.1), representing the area of ditches around rice fields;
Yield(s,y,lut) = yield (t/ha or kg/ha) from sub-model [3];
PeEff(y,lut) = a fractional yield reduction due to the effects of pests and diseases. Three levels of pest incidence (low, medium and high, corresponding to different yield losses) are considered for different risk analyses (see 3.41);
InEff(y,lut) = a fractional yield reduction due to a delay in supplying input materials. This factor reflects a gap between expected (attainable) production based on yields from sub-model [3] and recorded (actual) yields, and is used as a spatial-temporal adjustment coefficient during model calibration.

3.4) Calculate production of perennial crops: perennial crops (sugarcane and pineapple), are harvested annually. The dynamics of perennial crops is illustrated in Fig. 106.

Figure 106: Example of the dynamics of perennial crops.



3.4a) Loop for N years representing the duration of the growth cycle to calculate area of each age class:

- In the first year, the total area is assumed to be evenly distributed over the age classes:

$$AArea(s,y,a,lut) = Area(s,0,lut) / GC(lut)$$

where:			
where:	AArea(s,y,a,lut)	=	area (ha) of age class (a);
	a	=	age class, varying from (1) to GC(lut);
	Area(s,0,lut)	=	current area (ha) in year 0;
	GC(lut)	=	duration (y) of the growth cycle.

- In the other years:
  - Shift the areas by one age class:

$$AArea(s,y,a,lut) = AArea(s,y-1,a-1,lut)$$

  - Calculate the change in area:

$$Change(s,y,lut) = Area(s,y,lut) - Area(s,y-1,lut)$$

where:	Change(s,y,lut)	=	change in area from year (y-1) to year (y);
	Area(s,y,lut), Area(s,y-1,lut)	=	area (ha) from sub-model [8].

  - If the change in area is positive, the crop is replanted in the area of the oldest age class in year (y-1), i.e. entered in the first age class in year (y) (Case 1 in Fig. 106):

$$AArea(s,y,1,lut) = AArea(s,y-1,GC(lut),lut) + Change(s,y,lut)$$

where:	AArea(s,y,1,lut)	=	area (ha) of first age class in year (y);
	AArea(s,y-1,GC(lut),lut)	=	area (ha) of oldest age class in year (y-1).

  - If the change in area is negative, i.e. if land is required for other land use types, the crop is not replanted (Case 2a in Fig. 106). If the required land exceeds the area of the oldest age class in year (y-1)*, the required area is assumed to be converted from the next oldest age class (GC(lut)-1, GC(lut)-2, etc. in year (y-1), until no land is required (Case 2b and 2c in Fig. 106).

---

* Although this situation is normally avoided as discussed in 4.67, it still occurs to a limited extent in the Region.

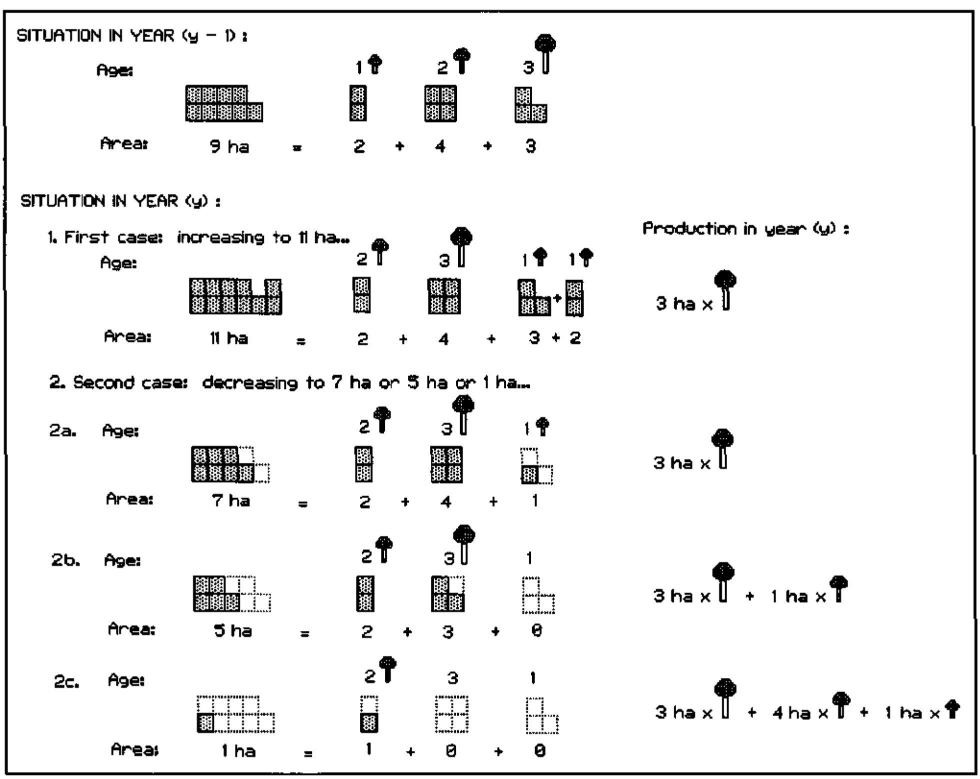
3.4b) Calculate production: the production of land use types of perennial crops is calculated by a formula similar to that for annual crops:

$$Prod(s,y,lut) = \sum_{a=1}^{GC(lut)} [AArea(s,y,a,lut) * Yield(s,y,a,lut) * (1 - PeEff(y,lut))]$$

where: Prod(s,y,lut) = production (tonnes);
GC(lut) = duration of the growth cycle (years);
a = age class;
Yield(s,y,a,lut) = yield (t/ha) of age class (a) from sub-model [3];
PeEff(y,lut) = fractional yield reduction due to the effects of pests and diseases.

3.5) Calculate production of forests: forests, such as Melaleuca, mangrove or Eucalyptus, are harvested after a complete growth cycle, except when they are replaced by new plantings. The dynamics of forests, therefore, is slightly different from those of other perennial crops. The dynamics of forests is illustrated in Fig. 107.

Figure 107: Example of the dynamics of forests.



3.5a) Loop for N years representing the duration of the growth cycle to calculate the harvested area of each age class and youngest harvested age class (HArea(s,y,a,lut) and Ya). Calculation sequences are similar to those for perennial crops by assuming that:

- In year (y) only forests at the end of their cycle (age class GC(lut) in year y-1) are harvested and forests are replanted if the area is available (Case 1 in Fig. 107);

- If the land is needed for other land use types, areas harvested are not replanted (Case 2a in Fig. 107);

- If the required land exceeds the size of the area harvested (see footnote * in *3.4a*), the next oldest age classes GC(lut)-1, GC(lut)-2, etc. in year (y-1) are harvested successively until the requirement is satisfied. The youngest harvested age class (Ya) is the age of oldest age class to be harvested in that case;

- Illegal harvest is already included in the change in area from year (y-1) to year (y).

3.5b) Loop for N years representing the duration of the growth cycle to calculate accumulated volume of each age class:

$$\mathrm{AVol}(s,y,a,lut) = \sum_{i=1}^{a} \mathrm{AnInc}(s,y-a+i,lut)$$

where: AVol(s,y,a,lut) = accumulated volume (m^3/ha) in age class (a);
i = year, from (1) to (a);
AnInc(s,y-a+i,lut) = annual increment (m^3/ha) in year (y-a+i) from sub-model [3].

3.5c) Calculate production of forests:

$$\mathrm{Prod}(s,y,lut) = \sum_{a=GC(lut)}^{Ya} [\mathrm{HArea}(s,y,a,lut) * \mathrm{AVol}(s,y,a,lut)]$$

where: Prod(s,y,lut) = production (m^3);
Ya = youngest harvested age class (years) identified in *3.5a*;
CG(lut) = duration of the growth cycle (y);
a = age class;
HArea(s,y,a,lut), AVol(s,y,a,lut) as calculated in *3.5a* and *3.5b*.

Nipa palm has been growing or was planted for many years in the Region and is harvested annually. Therefore, its yield is assumed to be a function of site class estimated in sub-model [3] and not of age class. Calculations of nipa palm production are identical to those for annual crops in *3.3*).

3.6) Output production data. (File MARI16.S09 in Appendix S9).

4) End of sub-model [9], then connect to CAILUP main program as described in 4.59.

4.69 Sub-model [10]: Supplementary interventions

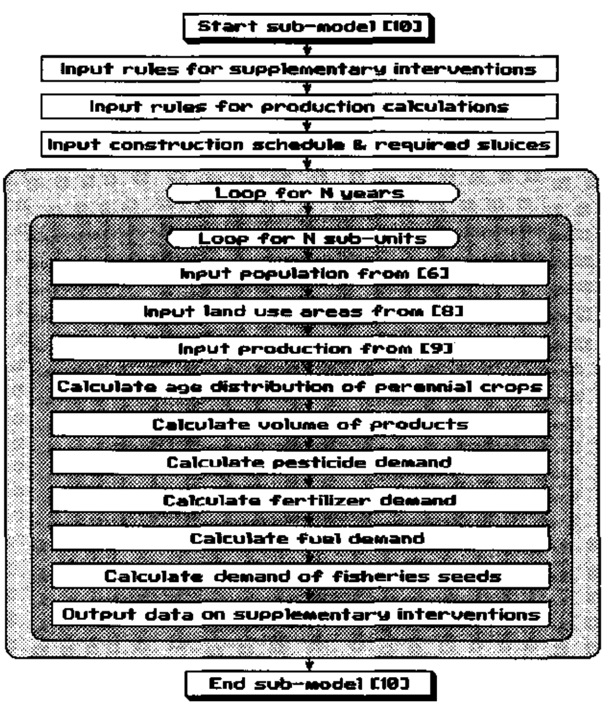
Function: Generate data on volume of products used for different purposes, production of livestock as by-products from rice production and materials required to support the selected scenario.

Input data:
<E> Current land use area and present population
<1> Pest and disease control, demand of products per capita, pig and duck raising
<6> Population dynamics
<8> Land use areas in each year
<9> Production from land use types

Output data:
<10> Volume of products to be processed for local consumption, exported/imported from/to the region, production of pigs and ducks, volume of materials such as fertilizer, pesticides, fuel, etc. required for the selected scenario.

Calculations: In the equations in this sub-model, (s,y,lut,p) refers to product (p) and land use type (lut) in year (y) and in sub-unit (s). The main steps in the sequence of calculations are (Fig. 108):

Figure 108: Sequence of calculations in sub-model [10].



1) Start sub-model [10]: as described in 4.58.

2) Input rules for supplementary interventions: rules for supplementary interventions deal with the demand for primary products per capita, post-harvest losses, quantity of by-products from rice production, etc.; (File SUPPRULE.S10 in Appendix S10).

3) Input rules for production calculations: Pest and desease incidence levels in each year during the planning period are needed for calculations of pesticide demand (File PRODRULE.S09 in Appendix S9).

4) Input construction schedule and required sluices: these data are needed to specify the 'without' or 'with' case in the calculations of demand of input materials (Files CONSTRUC.SCH and SUBUNODE.S02 in Appendix S2).

5) Loop for N years, then
Loop for N sub-units:

5.1) Input population from sub-model [6].

5.2) Input land use areas from sub-model [8].

5.3) Input production of each product from sub-model [9].

5.4) Calculate the age distribution of perennial crops: as different amounts of fertilizers are used for perennial crops of different ages, calculations as in sub-model [9] (see 4.68) are applied to calculate the age distribution of these crops.

5.5) Calculate the volume of products used for different purposes: products from the region are used for two major purposes: local consumption (in each sub-unit or in the Region) and export. Export here means transported out of the sub-unit for redistribution in the Region (export at sub-unit level), or out of the Region for redistribution in the country and for export to other countries (export on regional basis). If the demand for certain products in a sub-unit is higher than the supply, import is needed. Import here means transported from outside the sub-unit, possibly from other sub-units, or from other regions in the country or from other countries.

Four characteristics are calculated for main products such as rice, sugarcane, pineapple, wood, shrimps, prawns and fish: total production, local consumption and production of by-products, imported/exported volume, and redistributed volume within the region.

1/ Calculation of total production:

- For rice, beans, shrimps, prawns, fish and wood (Melaleuca, mangrove and Eucalyptus):

$$\mathrm{TotProd}(s,y,p) = [\sum_{lut=1}^{NPp} \mathrm{Prod}(s,y,lut)] * [1 - \mathrm{PoLoss}(y,p)]$$

where: TotProd(s,y,p) = total production (tonnes, kg or m^3);

NPp	=	number of land use types producing a certain product (p);
Prod(s,y,lut)	=	production (tonnes, kg or m^3) from sub-model [9];
PoLoss(y,p)	=	fraction of post-harvest losses in total production.

- For sugarcane, pineapple and nipa palm:

$$TotProd(s,y,p) = Prod(s,y,lut)] * [1 - PoLoss(y,p)]$$

where:

TotProd(s,y,p)	=	total production (tonnes or number of leaves);
Prod(s,y,lut)	=	production (tonnes or leaves) from sub-model [9];
PoLoss(y,p)	=	fraction of post-harvest losses in total production.

2/ Calculation of local consumption and production of by-products: the general equation applied for all products is:

$$PopuCon(s,y,p) = Popu(s,y) * Demand(y,p)$$

where:

PopuCon(s,y,p)	=	consumption (tonnes, kg or m^3) of the local population;
Popu(s,y)	=	population (persons) from sub-model [6];
Demand(y,p)	=	demand (t/capita, kg/capita or m^3/capita)

For products other than rice, PopuCon(s,y,p) is the total local consumption LocCon(s,y,p). Rice is not only used for human consumption, hence additional calculations are required:

- The local population uses the major part (approximately 85%) of the rice unsuitable for human consumption (locally called 'bad' rice), broken rice and bran, for pig raising. Therefore pork is considered a main by-product, closely related to rice production [Sub-NIAPP, 1992]. The remainder is used for activities such as raising chickens, ducks, fish in ponds, etc.

$$RicePig(s,y) = TotProd(s,y,rice) * (UnFract + BkFract + BrFract)$$

$$TotProd(s,y,pig) = RicePig(s,y) * RicePigProp / PigFact$$

where:

RicePig(s,y)	=	rice (tonnes) for pig raising and other similar activities;
TotProd(s,y,rice)	=	total rice production (tonnes);
UnFract	=	fraction of 'bad' rice;
BkFract	=	fraction of broken rice;
BrFract	=	fraction of bran;
TotProd(s,y,pig)	=	total production (tonnes) of pork;
RicePigProp	=	proportion of 'bad' and broken rice, and bran used for pig raising;
PigFact	=	conversion factor (tonnes of rice per tonne of pork).

- Rice for pigs and other activities is added to local human consumption:

$$LocCon(s,y,rice) = PopuCon(s,y,rice) + RicePig(s,y)$$

where: LocCon(s,y,rice) = total local consumption of rice (tonnes).

▸ Duck is another main by-product from rice production [Sub-NIAPP, 1992]. Young ducks are fed at the farm till up to 30 days of age, then released in newly harvested rice fields to eat the residual rice and clearing the fields from insects. Obviously, rice cultivation combined with shrimps or prawns cannot be combined with duck rearing.

$$NDuck(s,y) = \left[\left(\sum_{lut=1}^{NRice} Area(s,y,lut) \right) - \left(\sum_{lut=1}^{NRiceFish} Area(s,y,lut) \right) \right] * DuckRate * DuckProp$$

$$TotProd(s,y,duck) = NDuck(s,y) * DuckWeight$$

where: NDuck(s,y) = number of ducks (animals);
NRice = number of rice land use types;
Area(s,y,lut) = area (ha) from sub-model [8];
NRiceFish = number of shrimp-rice and prawn-rice land use types;
DuckRate = number of ducks (animals) per hectare of rice fields;
DuckProp = proportion of rice fields having duck raising.
TotProd(s,y,duck) = total production (tonnes) of duck;
DuckWeight = average weight (tonnes) per duck.

3/ Calculation of imported/exported volume:

$$ImExVol(s,y,p) = TotProd(s,y,p) - LocCon(s,y,p)$$

where: ImExVol(s,y,p) = imported/exported volume (tonnes, kg or m^3).

If the value is positive, products are exported; in the reverse case, import is needed to satisfy local demands. Imported/exported volume to/from the Region is calculated by aggregating data of all sub-units.

Production of nipa palm, currently used as construction material for housing, is negatively affected by the protection against salt water intrusion, therefore alternative materials should be supplied. The production gap, compared to the 'without' situation (i.e. a constant production equal to that in year 0) is calculated each year:

$$NipaLoss(s,y) = TotProd(s,0,nipa) - TotProd(s,y,nipa)$$

where: NipaLoss(s,y) = losses (number of leaves) in production of nipa palm;
TotProd(s,0,nipa), TotProd(s,y,nipa) = total production (leaves) of nipa palm in year (0) and year (y), respectively, as calculated in 1/.

5.6) Calculate pesticide demand: annual pesticide demand per sub-unit is the sum of pesticide demand for each agricultural crop defined as a function of the levels of pest incidence in each year:

$$PestDem(s,y) = \sum_{lut=1}^{NALut} [Area(s,y,lut) * PestHa(PestLevel(y),lut)]$$

where: PestDem(s,y) = pesticide demand (kg);

NALut	=	number of agricultural land use types;
Area(s,y,lut)	=	area (ha) from sub-model [8];
PestHa(PestLevel(y),lut)	=	pesticide demand (kg) per ha corresponding to level of pest incidence;
PestLevel(y)	=	pest incidence as used in sub-model [9].

5.7) Calculate fertilizer demand: as under modified water conditions after construction of the main sluices, fertilizer application to agricultural crops changes, 'without' and 'with' cases are distinguished in calculating fertilizer demand.

$$FerDem(s,y) = \sum_{lut=1}^{NP} [Area(s,y,lut) * FerHa(wm,lut)]$$

where:

FerDem(s,y)	=	fertilizer demand (tonnes);
NP	=	number of productive land use types;
Area(s,y,lut)	=	area (ha) from sub-model [8];
FerHa(wm,lut)	=	fertilizer demand (tonnes) per hectare per water management situation;
wm	=	water management case ('without' or 'with' new water management system).

5.8) Calculate fuel demand: demand for fuel, the main energy source for cultivation (e.g. for water pumping, threshing, etc.), is assumed identical for the 'without' and 'with' cases and is estimated for all crops.

$$FuelDem(s,y) = \sum_{lut=1}^{NP} [Area(s,y,lut) * FuelHa(lut)]$$

where:

FuelDem(s,y)	=	fuel demand (litres);
FuelHa(lut)	=	fuel demand (litres) per hectare.

5.9) Calculate demand of fisheries seeds from hacheries: in addition to natural seeds originating from canals and rivers, seeds from hatcheries are needed for fisheries ponds:

$$SeedDem(s,y) = \sum_{lut=1}^{NFish} [Area(s,y,lut) * SeedHa(lut)]$$

where:

SeedDem(s,y)	=	total seed demand (number of seeds) from hacheries;
NFish	=	number of aquacultural land use types;
SeedHa(lut)	=	seed demand (number of seeds) from hacheries per hectare.

5.10) Output data on supplementary interventions (Files MARI18.P10, MARI18.E10, MARI18.F10, MARI18.U10 in Appendix S10).

6) End of sub-model [10], then connect to CAILUP main program as described in 4.59.

4.70 Sub-model [11]: Economic Sub-model at Regional Level

Function: Estimate economic and financial indicators of the selected scenario at regional level.

Input data:
<E> Current land use areas and present population
<1> Modified prices, taxes, operation and maintenance costs, administrative costs, etc.
<8> Land use areas and land use conversion in each year
<9> Production from land use types
<10> Total production of by-products

Output data:
<11> Economic or financial indicators at regional level

Discussion on sub-model [11] for the Quan Lo Phung Hiep region:

1/ This sub-model is based on economic analysis for water management projects and generates:

- Economic indicators to assess the economic return from investment in water management. Opportunity costs and economic prices are applied in estimating costs of all activities and revenues from the production of all products;
- Financial data to analyze the allocation of budgets during the planning period, an option in application of this sub-model. In this case, financial prices are applied.

2/ The outputs from the economic calculations are generated for two situations: 'without processing' and 'with processing' of products (see 4.31) and for two areas: the Region and the Inside (see 4.35).

Calculations: In the equations in this sub-model, (s,y,lut,p) refers to sub-unit (s) in year (y) for land use type (lut) and product (p).

The main steps in the sequence of calculations are (Fig. 109):

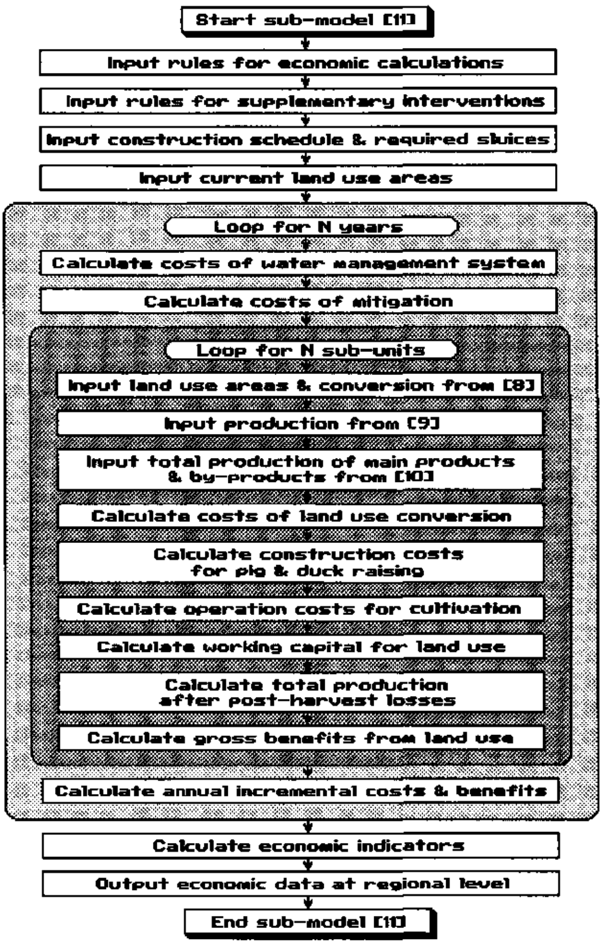
1) Start sub-model [11]: as described in 4.58.

2) Input rules for economic calculations: rules in economic calculations at regional level deal with costs of all components of the water management system, costs of mitigation, cultivation costs and prices of products (File ECORULE.S11 in Appendix S11).

3) Input rules for supplementary interventions: post-harvest losses as used in sub-model [10] are applied (File SUPPRULE.S10 in Appendix S10).

4) Input construction schedule and required sluices: these data are needed to specify the 'without' or 'with' case in the calculations of costs (Files CONSTRUC.SCH and SUBUNODE.S02 in Appendix S2).

Figure 109: Sequence of calculations in sub-model [11].



5) Input current land use areas (File EXISTING.S03 in Appendix S3).

6) Loop for N years

6.1) Calculate annual costs of the water management system: the water management system consists of:

i) Main sluices for protection against salt water intrusion;
ii) Main canals for irrigation and drainage, including canals for extracting fresh water from the Bassac river upstream of the Region. Costs of canals linking to the Bassac river are shared with the upstream regions;
iii) Secondary canals;
iv) Secondary sluices and on-farm systems;
v) Improvement of rural roads connected with the water management system.

Costs of each component (c) in year (y) consist of:

$$Cons(y,c) = TotCons(c) / NConsYear(c)$$

where:
- Cons(y,c) = annual construction costs (US$) during the construction period of component (c). Outside of this period, Cons(y,c) = 0;
- TotCons(c) = total construction costs (US$);
- NConsYear(c) = number of years of construction period.

$$O\&M(y,c) = [\sum_{t=1}^{y} Cons(t,c)] * O\&MRatio(c)$$

where:
- O&M(y,c) = annual operation and maintenance costs (US$);
- t = year number from the initial year of the construction period;
- O&MRatio(c) = ratio of annual O&M costs to annual construction costs.

$$Rep(y,c) = [\sum_{t=1}^{y} Cons(t,c)] * RepRatio(c)$$

where:
- Rep(y,c) = annual replacement costs (US$);
- t = year number from the initial year of the construction period;
- RepRatio(c) = ratio of annual replacement costs to annual construction costs.

$$Adm(y,c) = O\&M(y,c) * AdmRatio(c)$$

where:
- Adm(y,c) = annual administrative costs (US$);
- AdmRatio(c) = ratio of annual administrative costs to annual O&M costs.

For main sluices, O&M, replacement and administrative costs are only incurred after the construction has been completed, while for other components, they are incurred immediately after the start of the construction.

6.2) Calculate costs of mitigation:

i) Mitigation costs for the transportation system comprise costs for:

- Additional excavation to maintain the present navigation capacity of canals in the Inside, as the new water management system results in lower water levels in these canals.
- Construction of a transitional port at Ca Mau to maintain the access to the Region through the Quan Lo - Phung Hiep canal which will be blocked by a main sluice.
- Protecting the highway along canals downstream of the main sluices since closing of these sluices causes higher water levels in these canal sections during flood tide.

These items are considered integral components of the water management system. Their costs are also separated into construction, O&M, replacement and administrative costs.

ii) Mitigation for losses in nipa palm production: the shadow price of nipa palm leaves is applied in calculation of the economic losses in nipa palm production due to the construction of the new water management system.

$$NipaCost(y) = \sum_{s=1}^{NSub} [NipaLoss(s,y) * LeafPrice]$$

where: NipaCost(y) = cost (US$) of mitigation for nipa palm losses;
NSub = number of sub-units in the Region;
NipaLoss(s,y) = number of lost leaves from sub-model [10];
LeafPrice = price (US$) per nipa palm leaf, calculated as:

$$LeafPrice = HouseCost / NLHouse$$

where: HouseCost = costs (US$) of substitute materials for housing;
NLHouse = number of nipa palm leaves per house.

6.3) Loop for N sub-units:

6.3a) Input land use areas and land use conversion from sub-model [8].

6.3b) Input production from each land use type from sub-model [9].

6.3c) Input total production of main products and by-products from sub-model [10].

6.3d) Calculate costs of land use conversion: conversion costs for each land use type are estimated for a base case of conversion from uncultivated land. An adjustment coefficient is applied for the conversion from other land use types (File ECORULE.S11 in Appendix S11).

$$Conv(s,y) = \sum_{lut=1}^{NP} [\sum_{i=1}^{NP} (ConvArea(s,y,i,lut) * ConvHa(lut) * AdjCoeff(i,lut))]$$

where: Conv(s,y) = conversion costs (US$);
NP = number of productive land use types;
ConvArea(s,y,i,lut) = area (ha) converted from land use type (i) to (lut);
ConvHa(lut) = conversion costs (US$/ha) from uncultivated land to land use type (lut);
AdjCoeff(i,lut) = adjustment coefficient for conversion from land use type (i) to land use type (lut).

6.3e) Calculate construction costs for pig and duck raising:

$$PDCons(s,y) = [TotProd(s,y,pig) - TotProd(s,y-1,pig)] * PigCons + [TotProd(s,y,duck) - TotProd(s,y-1,duck)] * DuckCons$$

where: PDCons(s,y) = construction costs (US$) for pig and duck raising;
TotProd(s,y,pig), TotProd(s,y-1,pig), TotProd(s,y,duck) and TotProd(s,y-1,duck) = total production (tonnes) of pigs and ducks in year (y) and year (y-1), respectively, from sub-model [10];
PigCons, DuckCons = construction costs (US$) per tonne of meat for pig and duck raising, respectively.

6.3f) Calculate operation costs for cultivation:

▸ Operation costs for land use types with annual crops:

$$AOpe(s,y) = \sum_{lut=1}^{NPA} [Area(s,y,lut) * OpeHa(wm,lut)]$$

where: AOpe(s,y) = operation costs (US$) for annual crops;
NPA = number of land use types of annual crops;
Area(s,y,lut) = area (ha) from sub-model [8];
OpeHa(wm,lut) = operation costs (US$) per hectare;
wm = water management case ('without' or 'with' construction of the new water management system).

▸ Annual operation costs for land use types with perennial crops and forests: since different operation costs can be applied for perennial crops (sugarcane, pineapple) and forests of different ages, the area of these crops is subdivided according to age classes, as calculated in sub-model [9] (see 4.68).

$$POpe(s,y) = \sum_{lut=1}^{NPPF} [\sum_{a=1}^{GC(lut)} (Area(s,y,a,lut) * OpeHa(wm,a,lut))]$$

where: POpe(s,y) = operation costs (US$) for perennial crops and forests;
NPPF = number of land use types for perennial crops and forests;
GC(lut) = duration (y) of the growth cycle;
a = age class;
Area(s,y,a,lut) = area (ha) of age class (a) from sub-model [9];
OpeHa(wm,a,lut) = operation costs (US$) per hectare for age class (a);
wm = water management case.

▸ Operation costs for pig and duck raising:

$$PDOpe(s,y) = [TotProd(s,y,pig) * OpePig] + [TotProd(s,y,duck) * OpeDuck]$$

where: PDOpe(s,y) = operation costs (US$) for pig and duck raising;
TotProd(s,y,pig), TotProd(s,y,duck) = total production (tonnes) of pig and duck from sub-model [10];
OpePig, OpeDuck = operation costs (US$) per tonne meat of pigs and ducks, respectively.

6.3g) Calculate working capital for land use:

▸ Working capital is estimated as a fraction of the operation costs and also depends on land use conversion:

$$WCap(s,y) = \sum_{lut=1}^{NP} [\sum_{i=1}^{NP} (ConvArea(s,y,i,lut) * Diff(wm,i,lut))]$$

where: WCap(s,y) = working capital (US$);
NP = number of productive land use types;
i = land use type;
ConvArea(s,y,i,lut) = area (ha) converted from land use type (i) to land use type (lut);
wm = water management case;
Diff(wm,i,lut) = difference in working capital (US$) per ha between land use type (i) and land use type (lut), calculated as:

$$Diff(wm,i,lut) = [OpeHa(wm,lut) * Fract(lut)] - [OpeHa(wm,i) * Fract(i)]$$

where: OpeHa(wm,lut), OpeHa(wm,i) = operation costs (US$) per ha of land use types (lut) and (i), respectively. If land use conversion includes perennial crops, OpeHa(wm,1,lut) and/or OpeHa(wm,1,i) in the first year of the growth cycle are used;
Fract(lut), Fract(i) = working capital as a fraction of operation costs for land use type (lut) and (i), respectively.

Working capital of a land use type, therefore, can be negative in a certain year if land is converted from a type with high working capital to another with low working capital.

- Working capital for pig and duck raising:

$$PDWCap(s,y) = [(TotProd(s,y,pig) - TotProd(s,y-1,pig)) * OpePig * Fract(pig)] + [(TotProd(s,y,duck) - TotProd(s,y-1,duck)) * OpeDuck * Fract(duck)]$$

where: PDWCap(s,y) = annual operation costs (US$) for pig and duck raising;
TotProd(s,y,pig), TotProd(s,y-1,pig), TotProd(s,y,duck) and TotProd(s,y-1,duck) = total production (tonnes) of pigs and ducks in year (y) and year (y-1);
OpePig, OpeDuck = operation costs (US$) per tonne meat of pigs and ducks, respectively;
Fract(pig), Fract(duck) = working capital as a fraction of operation costs for pig and duck raising, respectively.

- Aggregated working capital during the planning period, if positive, is assumed to be recovered by the end of the planning period.

6.3h) Calculate total production after post-harvest losses: calculations identical to those in sub-model [10] (see 4.69) are carried out to calculate total production of each product after post-harvest losses (TotProd(s,y,p)) from production of each land use type generated in sub-model [9].

6.3i) Calculate gross benefits: gross benefits are calculated for two situations:

- 'Without' processing:

$$GBWo(s,y) = \sum_{p=1}^{NProd} [TotProd(s,y,p) * FGPrice(p)]$$

where: GBWo(s,y) = gross benefits (US$) 'without' processing;
NProd = number of products;
TotProd(s,y,p) = total production (tonnes, kg or m^3) from sub-model [10];
FGPrice(p) = farm-gate price (US$) per tonnes, kg or m^3.

- 'With' processing:

$$GBWi(s,y) = \sum_{p=1}^{NProd} [TotProd(s,y,p) * ProcFract(p) * ProcPrice(p)]$$

where: GBWi(s,y) = gross benefits (US$) 'with' processing;
NProd = number of products;
TotProd(s,y,p) = total production (tonnes, kg or m^3) as calculated in *6.3h*;
ProcFract(p) = fraction of processed product in total production;
ProcPrice(p) = price (US$) per tonne, kg or m^3 of processed product.

$$ProcCost(s,y) = \sum_{p=1}^{NProd} [TotProd(s,y,p) * ProcUnit(p)]$$

where: ProcCost(s,y) = processing costs (US$);
NProd = number of products;
TotProd(s,y,p) = total production (tonnes, kg or m^3) from sub-model [10];
ProcUnit(p) = processing costs (US$) per unit of original product.

6.4) Calculate annual incremental costs and benefits

- 'Without' processing:

$$CostWo(y) = [\sum_{c=1}^{NC} (Cons(y,c) + O\&M(y,c) + Rep(y,c) + Adm(y,c))] + [NipaCost(y)]$$
$$+ [\sum_{s=1}^{NSub} (Conv(s,y) + PDCons(s,y) + AOpe(s,y) + POpe(s,y) + PDOpe(s,y) + WCap(s,y) + PDWCap(s,y))]$$

where: CostWo(y) = total costs (US$) of the selected scenario 'without' processing;
NC = number of components in the new water management system, including mitigation for transport;
c = component in the new water management system;
Cons(y,c), O&M(y,c), Rep(y,c) and Adm(y,c) as calculated in *6.1* and *6.2*.
NipaCost(y) as calculated in *6.2*;
NSub = number of sub-units in the Region;
Conv(s,y), PDCons(s,y), AOpe(s,y), POpe(s,y), PDOpe(s,y), WCap(s,y) and PDWCap(s,y) as calculated in *6.3d, 6.3e, 6.3f* and *6.3g*.

- 'With' processing:

$$\text{CostWi}(y) = \text{CostWo}(y) + \sum_{s=1}^{NSub} \text{ProcCost}(s,y)$$

where: CostWi(y) = total costs (US$) of the selected scenario 'with' processing;
ProcCost(s,y) as calculated in *6.3i*.

- All costs and benefits are calculated for a base case ('without' construction of the new water management system (see 4.40)) before performing calculations for the selected scenario. Then:

$$\text{IncCostWo}(y) = \text{CostWo}(y) - \text{CostWoBase}(y)$$

where: IncCostWo(y) = incremental costs (US$) 'without' processing;
CostWoBase(y) = total costs (US$) for the base case 'without' processing.

$$\text{IncGBWo}(y) = \sum_{s=1}^{NSub} [\text{GBWo}(s,y)] - \sum_{s=1}^{NSub} [\text{GBWoBase}(s,y)]$$

where: IncGBWo(y) = incremental gross benefits (US$) 'without' processing;
GBWoBase(s,y) = gross benefits (US$) for the base case 'without' processing.

$$\text{IncNBWo}(y) = \text{IncGBWo}(y) - \text{IncCostWo}(y))$$

where: IncNBWo(y) = incremental net benefits (US$) 'without' processing.

- Similar calculations are applied for the 'with' processing situation.

7) Calculate economic indicators for the selected scenario: indicators are calculated with various discount rates for two situations: 'without' processing and 'with' processing and for two areas: the Region as a whole and the Inside.

$$\text{NPV} = \sum_{y=1}^{NY} (\text{IncNBWo}(y) / (1 + \text{DR})^y)$$

$$\text{B/C ratio} = [\sum_{y=1}^{NY} (\text{IncGBWo}(y) / (1 + \text{DR})^y)] / [\sum_{y=1}^{NY} (\text{IncCostWo}(y) / (1 + \text{DR})^y)]$$

$$\text{N/K ratio} = [\sum_{y=T}^{NY} (\text{IncNBWo}(y) / (1 + \text{DR})^y)] / [\sum_{y=1}^{T-1} (\text{IncNBWo}(y) / (1 + \text{DR})^y)]$$

$$\text{IRR} = \text{DR with } [\sum_{y=1}^{NY} (\text{IncNBWo}(y) / (1 + \text{DR})^y)] = 0$$

$$\text{PB} = \text{The first year FY when } [\sum_{y=1}^{FY} \text{IncNBWo}(y)] > 0$$

where: NPV = net present value (US$) of the selected scenario;
B/C ratio = benefit-cost ratio;
N/K ratio = net benefit-investment ratio;
IRR = internal rate of return;
PB = payback period;
NY = number of years in the planning period;
IncNBWo(y), IncGBWo(y) and IncCostWo(y) as calculated in *6.4*;
DR = discount rate;
T = year when incremental net benefits IncNBWo(y) have turned positive.

NPV, IRR and B/C ratio are often used in economic analysis of investment projects, and N/K ratio can be used for ranking the projects [Gittinger, 1982]. The payback period is not a convenient indicator for the assessment of water management projects because it is an undiscounted measure of project worth and earnings after the payback period has not been taken into account [Gittinger, 1982]. Despite these disadvantages, it is often used by local authorities, in particular in financial analysis.

8) Output economic data at regional level: (Files MARI1.S11 and MARI12.S11 in Appendix S11).

9) End of sub-model [11], then connect to CAILUP main program as described in 4.59.

4.71 Sub-model [12]: Social Sub-model at Regional Level

Function: Estimate per capita income and production, and employment generated from land use in the region.

Input data:

<E> Current land use areas
<1> Number of working days per labourer, labour requirements for land use, etc.
<3> Selected cropping calendars
<6> Population dynamics and labour force
<8> Land use areas and land use conversion in each year
<9> Production from land use types
<10> Production of by-products
<11> Costs and benefits in land use

Output data:

<12> Socio-economic indicators at sub-unit level and at regional level.

Discussion on sub-model [12] for the Quan Lo Phung Hiep region:

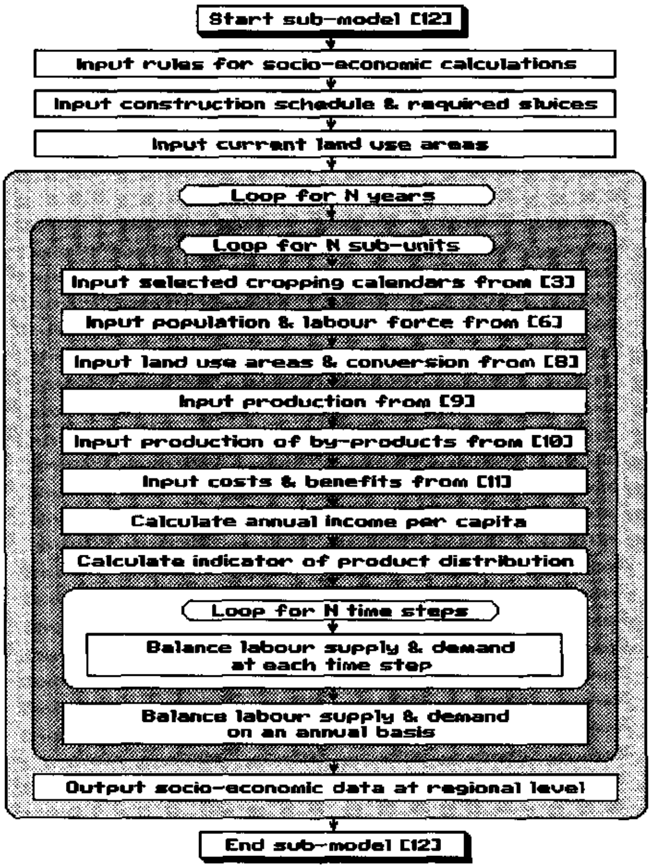
1/ Distribution of income, production of rice and employment generation are major socio-economic issues related to land use in the region. Income and production per capita are calculated at sub-unit level and compared to the averages for the Region as a whole.

2/ Employment is balanced with labour force available for land use. Employment is calculated per production system for two types of labourer: skilled and unskilled. Education programmes will be needed as a supplementary intervention, if the demand for skilled labourer for a certain crop exceeds the supply, in particular after construction of the new water management system.

<u>Calculations</u>: in the equations in this sub-model, (s,y,t,lut,p) refers to sub-unit(s) in year (y) at time step (t) of land use type (lut) and product (p).

The main steps in the sequence of calculations are (Fig. 110):

Figure 110: Sequence of calculations in sub-model [12].



1) Start sub-model [12]: as described in 4.58.

2) Input rules for socio-economic calculations: rules in socio-economic calculations at regional level refer to number of working days per labourer, labour requirements for land use conversion and cultivation, etc. (File SOCIRULE.S12 in Appendix S12).

3) Input construction schedule and required sluices: these data are needed to identify the 'without' or 'with' cases to be applied in calculations of labour requirements (Files CONSTRUC.SCH and SUBUNODE.S02 in Appendix S2).

4) Input current land use areas (File EXISTING.S03 in Appendix S3).

5) Loop for N years:

5.1) Loop for N sub-units:

5.1a) Input selected cropping calendars from sub-model [3].

5.1b) Input population and labour force from sub-model [6].

5.1c) Input land use areas and land use conversion from sub-model [8].

5.1d) Input production from sub-model [9].

5.1e) Input production of by-products from sub-model [10];

5.1f) Input costs and benefits from sub-model [11].

5.1g) Calculate annual income per capita: annual income per capita in each sub-unit and its ratio to average income in the Region (as a measure of income distribution) are calculated for both, 'without' and 'with processing'.

- Income per capita 'without' processing:

$$IncWo(s,y) = [GBWo(s,y) - CostWo(s,y)] / Popu(s,y)$$

where:
- IncWo(s,y) = income (US$) per capita 'without' processing;
- GBWo(s,y) = gross benefits (US$) 'without' processing from sub-model [11];
- Popu(s,y) = population (persons) from sub-model [6];
- CostWo(s,y) = total costs (US$) 'without' processing, calculated as:

$$CostWo(s,y) = Conv(s,y) + PDCons(s,y) + AOpe(s,y) + POpe(s,y) + PDOpe(s,y) + WCap(s,y) + PDWCap(s,y)$$

where:
- Conv(s,y) = costs (US$) of land use conversion from sub-model [11];
- PDCons(s,y) = construction costs (US$) for pig and duck raising from sub-model [11];
- AOpe(s,y) = operation costs (US$) for annual crops from sub-model [11];
- POpe(s,y) = operation costs (US$) for perennial crops and forests from sub-model [11];
- PDOpe(s,y) = operation costs (US$) for pig and duck raising from sub-model [11];
- WCap(s,y) = working capital (US$) for cultivation from sub-model [11];
- PDWCap(s,y) = working capital (US$) for pig and duck raising from sub-model [11].

- Income per capita 'with' processing:

$$IncWi(s,y) = [GBWi(s,y) - (CostWo(s,y) + ProcCost(s,y))] / Popu(s,y)$$

where:
- IncWi(s,y) = income (US$) per capita 'with' processing;
- GBWi(s,y) = gross benefits (US$) 'with' processing from sub-model [11];
- ProcCost(s,y) = processing costs (US$) from sub-model [11].
- Popu(s,y) = population (persons) from sub-model [6].

5.1h) Calculate indicator of product distribution: calculations identical to those in sub-model [10] are carried out (see 4.69) to calculate total production of each product after post-harvest losses (TotProd(s,y,p)) from production of each land use type, generated by sub-model [9]. The ratio of production per capita in each sub-unit to the average for the Region is used to illustrated the distribution of a product in the Region:

$$\text{ProdRatio}(s,y,p) = \frac{\text{TotProd}(s,y,p) / \text{Popu}(s,y)}{[\sum_{i=1}^{NSub} \text{TotProd}(i,y,p)] / [\sum_{i=1}^{NSub} \text{Popu}(i,y)]}$$

where: ProdRatio(s,y,p) = ratio of production (p) per capita in sub-unit (s) to the average in the Region;
TotProd(s,y,p) = total production (tonnes, kg or m^3);
Popu(s,y) = population (persons) from sub-model [6];
NSub = number of sub-units in the Region;
i = sub-unit.

5.1i) Loop for N time steps to balance labour supply and demand at each time step: the following calculations are applied for both skilled and unskilled labour.

1/ Calculate labour requirements for land use conversion: the number of labour-days/ha required for land use conversion from any given land use type to another, is given in a matrix (File SOCIRULE.S12 in Appendix S12). For each time step during the land use conversion period (usually at the beginning and the end of the rainy season), labour requirements for land use conversion are calculated:

$$\text{ConvLab}(s,y,t) = \sum_{lut=1}^{NP} [\sum_{i=1}^{NP} (\text{ConvArea}(s,y,i,lut) * \text{ConvHa}(i,lut))] / \text{NTT}(lut)$$

where: ConvLab(s,y,t) = labour requirements (labour-days) for land use conversion;
t = time step in the period when conversion to land use type (lut) is possible;
NP = number of productive land use types;
ConvArea(s,y,i,lut) = area (ha) converted from land use type (i) to (lut) from sub-model [8];
ConvHa(i,lut) = labour requirements (labour-days) per ha for conversion from land use type (i) to (lut);
NTT(lut) = number of time steps in the conversion period.

2/ Calculate labour requirements for land use operations:

- Labour requirements for operation of annual crops:

$$\text{AOpeLab}(s,y,t) = \sum_{lut=1}^{NPA} [\text{Area}(s,y,lut) * \text{OpeLabHa}(wm,t,lut)]$$

where: AOpeLab(s,y,t) = labour requirements (labour-days) for operation of annual crops;

t	=	time step in selected cropping calendar of land use type (lut) from sub-model [3];
NPA	=	number of land use types of annual crops;
Area(s,y,lut)	=	area (ha) of land use type (lut) from sub-model [8];
OpeLabHa(wm,t,lut)	=	labour requirements (labour-days) per hectare for operation in time step (t);
wm	=	water management case ('without' or 'with' new water management system).

- Labour requirements for operation of perennial crops and forests:

$$POpeLab(s,y,t) = \sum_{lut=1}^{NPPF} [\sum_{a=1}^{GC(lut)} (Area(s,y,a,lut) * OpeLabHa(wm,a,t,lut))]$$

where:

POpeLab(s,y,t)	=	labour requirements (labour-days) for perennial crops and forests;
NPPF	=	number of land use types for perennial crops and forests;
GC(lut)	=	duration (y) of the growth cycle;
a	=	age class;
Area(s,y,a,lut)	=	area (ha) of age class (a) of land use type (lut) as calculated in sub-model [9];
OpeLabHa(wm,a,t,lut)	=	labour requirements (labour-days) per hectare for operation in time step (t) of age class (a).

- Labour requirements for pig and duck raising:

$$PDLab(s,y,t) = [TotProd(s,y,pig) * LabPig] + [TotProd(s,y,duck) * LabDuck]$$

where: PDLab(s,y,t) = labour requirements (labour-days) for pig and duck raising;
TotProd(s,y,pig), TotProd(s,y,duck) = total production (tonnes) of pigs and ducks, respectively;
LabPig, LabDuck = labour requirements (labour-days) per tonne of meat for pigs and ducks.

3/ Balance labour supply and demand in each time step:

$$LabBal(s,y,t) = [LabForce(s,y) * NDay(t)] - [ConvLab(s,y,t) + AOpeLab(s,y,t) + POpeLab(s,y,t) + PDLab(s,y,t)]$$

where:

LabBal(s,y,t)	=	labour balance (labour-days) in time step (t) (positive value: surplus, negative value: shortage of labour);
LabForce(s,y)	=	potential labour force (labourers) engaged in land use from sub-model [6];
NDay(t)	=	number of days in time step (t);

ConvLab(s,y,t), AOpeLab(s,y,t), POpeLab(s,y,t) and PDLab(s,y,t) = labour requirements (labour-days) for each item as calculated in *5.1i 1/* and *2/*.

5.1j) Balance labour supply and demand on an annual basis:

$$\text{AnnuLabBal}(s,y) = [\text{LabForce}(s,y) * \text{NWKDay}(y)] - \sum_{t=1}^{NT} [\text{ConvLab}(s,y,t) + \text{AOpeLab}(s,y,t) + \text{POpeLab}(s,y,t) + \text{PDLab}(s,y,t)]$$

where: AnnuLabBal(s,y) = annual labour balance (labour-days) (positive value: surplus, negative value: shortage of labour);
LabForce(s,y) = potential labour force (labourers) engaged in land use from sub-model [6];
NWKDay(y) = number of working days per labourer in a year;
NT = number of time steps in a year;
ConvLab(s,y,t), AOpeLab(s,y,t), POpeLab(s,y,t) and PDLab(s,y,t) = labour requirements (labour-days) for each item calculated in *5.1i*.

5.2) Output socio-economic data at regional level: (Files MARI13.I12, MARI13.C12 and MARI13.E12 in Appendix S12).

6) End of sub-model [12], then connect to CAILUP main program as described in 4.59.

4.72 Sub-model [13]: Environmental impact

Function: Estimate values of specific environmental impact indicators.

Input data:
<E> Current land use areas
<1> Standards in water quality for domestic use, level of malaria incidence
<2> Water quality
<3> Selected cropping calendars
<6> Population dynamics
<8> Land use areas in each year
<10> Total pesticide and fertilizer use

Output data:
<13> Values of indicators for specific environmental impacts, required for evaluation of the selected scenario.

Discussion on sub-model [13] in the Quan Lo Phung Hiep region:

1/ This sub-model deals with specific environmental impacts in the Region, associated with construction of the new water management system and the associated land use changes. However, current knowledge is often insufficient for accurate prediction of many environmental impacts such as changes in properties of certain soil types, effects of pesticide use on the habitat, changes in aquatic populations due to irrigation, etc. Thematic studies are required for modelling these impacts. This sub-model focuses on the impact on human living conditions.

2/ Four issues related to environmental impact in the Region are considered:

a. Due to shortage of fresh water in the region, surface water is used for many purposes. The local population considers improvement of the water quality for domestic use, in particular with respect to salinity and pH, an important objective. In this sub-model, water quality is compared with standards to identify the effect of the new water management system on the supply of fresh water for domestic use.

b. Increasing surface water use may cause spreading of waterborne diseases. In this sub-model, the impact of the new water management system on the incidence of malaria is estimated as an example for this issue.

c. The main soil types in the Region are acid sulphate and saline soils. To limit salinization effects from saline soils and oxidation of the pyrite layer in acid sulphate soils, a water layer associated with crop cultivation is required. Land cover, in particular a vegetation cover in the dry season, also provides a favourable environment for human life. Hence, increased land cover in the dry season is an environmental objective of land use planning in the Region. Therefore, this sub-model generates data on land cover for each sub-unit at each time step.

d. Application of pesticides and fertilizer for agriculture is another environmental issue in the Region, in particular with respect to the effect of pesticide residues in aquatic population and eutrophication of coastal areas. Current knowledge and data on these impacts are inadequate for simulation modelling. This sub-model generates data on total pesticide and fertilizer use over the planning period, as indicators for these effects.

<u>Calculations</u>: The main steps in the sequence of calculations are (Fig. 111):

1) Start sub-model [13]: as described in 4.58.

2) Input rules for environmental impacts: rules for environmental impacts refer to standards of water quality for domestic use, relationships between water salinity and levels of malaria incidence, etc. (File ENVIRULE.S13 in Appendix S13).

3) Loop for N years, then
Loop for N sub-units:

3.1) Input water quality from sub-model [2].

3.2) Input selected cropping calendars from sub-model [3].

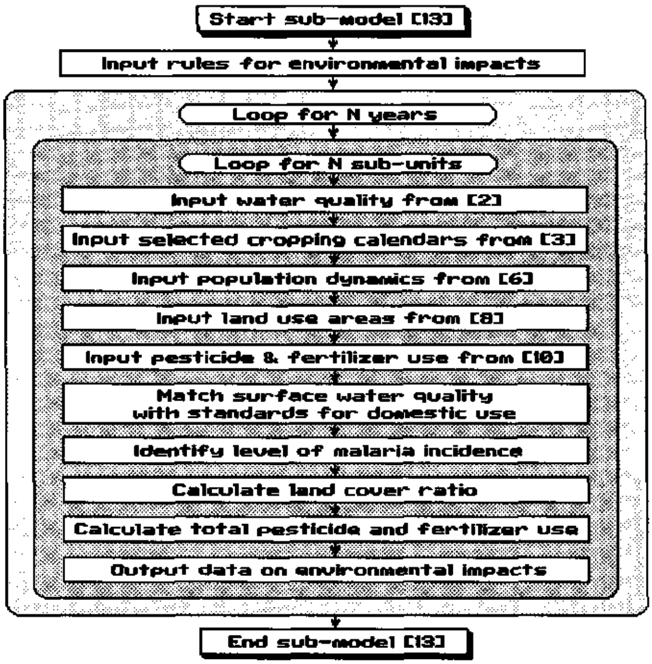
3.3) Input population and labour force from sub-model [6].

3.4) Input land use areas from sub-model [8].

3.5) Input total pesticide and fertilizer use from sub-model [10];

3.6) Match surface water quality with standards for domestic use: salinity and pH are two factors considered in sub-model [13]. For drinking water, salinity should be below 0.5 ‰ and pH between 6.5 and 7.5. For domestic use, in particular in the areas intruded by salt water, the local population has to accept to salinity levels up to 1 ‰.

Figure 111: Sequence of calculations in sub-model [13].



Surface water quality in each time step is compared with these standards to determine whether they are met. If these standards are met at all time steps in a year, surface water may be supplied for domestic use. Otherwise, other fresh water sources (stored rainwater or groundwater) should be used during particular time steps or year-round.

3.7) Identify the level of malaria incidence: based on observations by the public health institute, three levels of incidence of malaria (fresh water species, dominant in the area) have been identified as a function of surface water salinity (Table 9):

Table 9: Relation between surface water salinity and incidence of malaria

Salinity level (‰)	0 to 0.6	0.6 to 4.0	> 4.0
Incidence level	High	Medium	Low

The level of malaria incidence at each time step can thus be derived from the salinity level.

3.8) Calculate land cover ratio: ratio of land cover to the total area is calculated for each time step:

$$LCRatio(s,y,t) = [Area(s,y,speci) + Area(s,y,gard) + Area(s,y,water) + \sum_{lut=1}^{NP} (Area(s,y,lut) * Pres(t,lut))] / TotArea(s)$$

where: LCRatio(s,y,t) = land cover ratio in time step (t) of sub-unit (s) in year (y);

Area(s,y,speci), Area(s,y,gard), Area(s,y,water) = area (ha) of specific uses, homestead gardens and surface water in canals and rivers from sub-model [8];
NP = number of productive land use types;
lut = land use type;
Area(s,y,lut) = area (ha) from sub-model [8];
TotArea(s) = total area (ha);
Pres(t,lut) = presence of a crop in land use type (lut) at time step (t). Pres(t,lut) = 1 when (t) is within the selected cropping calendar from sub-model [3], otherwise Pres(t,lut) = 0.

3.9) Calculate total pesticide and fertilizer use:

$$\text{TotPest(s,y)} = \sum_{i=1}^{y} \text{PestDem(s,y)} \qquad \text{and} \qquad \text{TotFert(s,y)} = \sum_{i=1}^{y} \text{FertDem(s,y)}$$

where: TotPest(s,y), TotFert(s,y) = cumulative pesticide (kg) and fertilizer (tonnes) use in sub-unit (s) from year (1) to year (y);
i = year, from year (1) to year (y);
PestDem(s,y), FertDem(s,y) = pesticide (kg) and fertilizer (tonnes) demand in sub-unit (s) in year (y), from sub-model [10].

Distribution of these indicators in the region allows identification of the sub-units where the impact of pesticides and fertilizer on the environment needs to be monitored and controlled.

4) Output data on environmental impacts: (File MARI11.S13 in Appendix S13).

5) End of sub-model [13], then connect to CAILUP main program as described in 4.59.

4.73 Sub-model [14]: Goal and Impact Analysis

Functions:
- Aggregate land use area, production, socio-economic achievements, and impacts (subsequently referred to as impact values) from sub-unit level to water management unit and regional levels, for analysis and reporting.
- Compare achievements and impacts of the selected scenario with the values of goal indicators to calculate scores for ranking of land use scenarios.

Input data:
<G> Target values of goal indicators and parameters used in goal and impact analysis
<6> Population dynamics and labour force
<8> Land use areas
<9> Production from land use
<11> Economic indicators at regional level
<12> Social indicators at regional level
<13> Indicators of environmental impacts

Output data:
<14> Production, area and yield, socio-economic and environmental impact indicators at water management unit and regional levels; scores for ranking of the selected scenario.

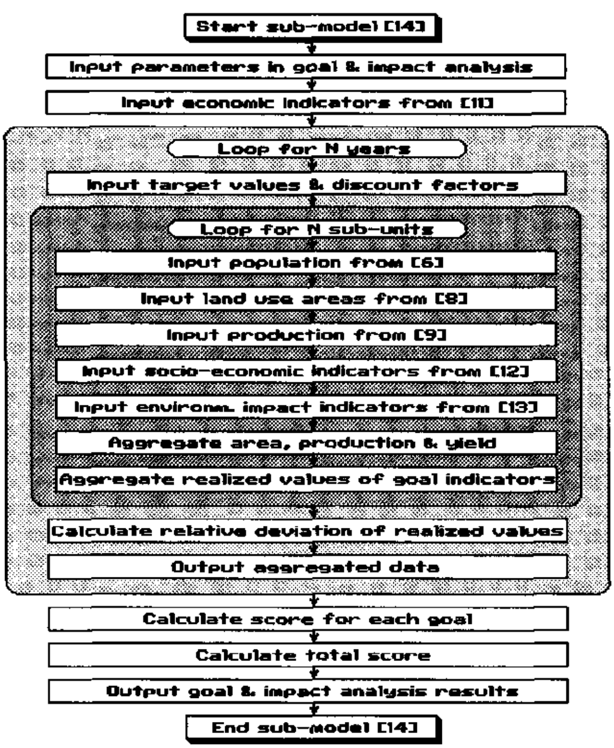
Discussion on sub-model [14] for the Quan Lo Phung Hiep region:

1/ As introduced in 4.30, achievements of development goals in the Region are characterized by the values of food production, economic, socio-economic and environmental impact indicators. Depending on the objectives of development, different priorities may be given to different goals, as discussed in 3.46. Positive priority values are assigned to indicators for which 'higher is better', such as total food production, income per capita, benefit-cost ratio, etc., and negative values to indicators for which 'lower is better', such as total pesticide use, proportion of the population with a low income, etc. A zero value implies that the indicator is not taken into account in evaluation of the selected scenario.

2/ Similar to the calculations in the Economic Sub-model [11] at Regional Level, goals and impacts are analyzed for two situations: 'without' and 'with' processing of products, and for two areas: the entire Region and the Inside.

Calculations: The main steps in the sequence of calculations are (Fig. 112):

Figure 112: Sequence of calculations in sub-model [14].



1) Start sub-model [14]: as described in 4.58.

2) Input parameters in goal and impact analysis: parameters in goal and impact analysis deal with the selected economic discount rate and priority of goals (File GOALRULE.S14 in Appendix S14).

3) Input economic indicators from sub-model [11].

4) Loop for N years:

4.1) Input target values and discount factors during the planning period (File GOALRULE.S14 in Appendix S14).

4.2) Loop for N sub-units to aggregate land use area, production, socio-economic achievements, and values of environmental impact indicators, from sub-unit level to water management unit and regional level:

4.2a) Input population from sub-model [6].

4.2b) Input land use areas from sub-model [8].

4.2c) Input production from sub-model [9].

4.2d) Input socio-economic indicators from sub-model [12].

4.2e) Input environmental impact indicators from sub-model [13];

4.2f) Aggregate area, production and yield from sub-unit level to water management unit and regional level for spatial analysis and reporting.

4.2g) Aggregate realized values of goal indicators from sub-unit level to water management unit and regional level. Realized values of goal indicators comprise:

- total rice production from sub-model [9];
- economic indicators at regional level such as NPV, IRR, etc., from sub-model [11];
- rice production per capita from sub-model [12];
- rice distribution (ratio of rice per capita in each sub-unit to the average for the Region) from sub-model [12];
- income per capita from sub-model [12];
- income distribution (similar to rice distribution) from sub-model [12];
- employment generation and balance of labour supply and demand from sub-model [12];
- minimum land cover ratio in the dry season from sub-model [13];
- total pesticide use from sub-model [13].
- proportion of the population supplied with surface fresh water determined as:

$$WSProp(y) = \left[\sum_{s=1}^{NSub} (Popu(s,y) * WSPoss(s,y)) \right] / \left[\sum_{s=1}^{NSub} Popu(s,y) \right]$$

where: WSProp(y) = proportion of the population supplied with surface fresh water in the Region in year (y);

NSub	=	number of sub-units in the Region;
s	=	sub-unit;
Popu(s,y)	=	population (persons) from sub-model [6];
WSPoss(s,y)	=	possibility of water supply by surface water in sub-unit (s) in year (y), from sub-model [13].

These calculations are applied to each water management unit in the Region.

4.3) Calculate relative deviation of realized values: the relative deviation of realized values from targets at regional level, is calculated for each year:

$$RDev(g,y) = [RVal(g,y) - Goal(g,y)] / Goal(g,y)$$

where:	RDev(g,y)	=	relative deviation of realized value from goal (g) in year (y);
	RVal(g,y)	=	realized value of goal (g) in year (y) (in units of that goal);
	Goal(g,y)	=	target value of goal (g) in year (y);

4.4) Output aggregated data (Files MARI1.I14 and MARI1.P14 in Appendix S14).

5) Calculate score for each goal: as discussed in 3.46, depreciation with a variable discount rate is applied in calculating the score for each goal:

$$GScore(g) = Prior(g) * \sum_{y=1}^{NY} [RDev(g,y) * DFact(g,y)]$$

where:	GScore(g)	=	score of goal (g);
	Prior(g)	=	priority of goal (g);
	NY	=	number of years in planning period;
	y	=	year;
	DFact(g,y)	=	discount factor for goal (g).

6) Calculate total score for ranking of the selected scenario:

$$TotScore = \sum_{g=1}^{NG} GScore(g)$$

where:	TotScore	=	total score;
	NG	=	number of goals;
	g	=	goal.

7) Output goal and impact analysis results (File MARI1.S14 in Appendix S14).

8) End of sub-model [14], then connect to CAILUP main program as described in 4.59.

IV.4 APPLICATIONS OF CAILUP FOR THE QUAN LO PHUNG HIEP REGION

IV.4.1 Calibration of CAILUP for the Quan Lo Phung Hiep region

4.74 The aim of calibration is to improve parameter estimation [Jørgensen, 1994] by determining values that best match model outputs with actual data. Actual data for CAILUP are defined as observed data, i.e. 'point' data from a survey at small scale, or inventory data, i.e. data regularly collected at large scale, spatially and temporally. Some sub-models are not subjected to calibration, such as sub-model [1] (used as a tool for generating input data to other sub-models) sub-models [11] and [12] (generating values for economic and socio-economic indicators in the Region), and sub-models [13] and [14] (integrating data from other sub-models).

4.75 Some specific remarks on the calibration of CAILUP:

i) Actual data are evidently not available for some types of intermediate outputs such as bio-physical/economic feasibility from the Economic Sub-model at Farm Level [4], weighting factors from the Land Use Weighting Sub-model [7], etc. Therefore, in calibrating these sub-models, an attempt has been made to generate values that are proportional with actual land use areas. Output values are verified indirectly in the subsequent sub-model. For example, the weighting factors in sub-model [7] are indirectly evaluated by the differences between outputs from the Land Use Allocation Sub-model [8] and actual data from the inventories.

ii) Actual data are available for verification of other model outputs (e.g. water level from the Physical Impact Sub-model [2], crop yields in the Bio-Physical Sub-model [3], etc.). A sub-model is considered one component of a series of sub-models (e.g. from the Bio-physical Sub-model [3] to the Land Use Allocation Sub-model [8]). Calibration is not restricted to matching outputs from a specific sub-model with actual data, but includes matching the final outputs of a series with actual data for this series. Therefore, calibration of a sub-model may be repeated. First, initial outputs that best match the actual data of a sub-model are generated and transferred to other sub-models. Subsequently, the whole series is recalibrated to match the final outputs of the series with actual data.

The procedure of calibration of single sub-models, followed by that of a series, is helpful if actual data for a sub-model are limited. It also helps to identify problems in data aggregation (see 3.29) and error propagation among sub-models.

iii) In calibrating of the CAILUP model, attention is also paid to spatial and temporal aspects. Calibration does not only aim at matching model outputs with actual data at the sub-unit level in a given year, but also at the water management unit level and for the entire Region during the whole period for which actual data are available. For regional planning, the latter two levels, i.e. the water management unit and the Region, are the major focus, indeed. Actual data may not be available for verification of certain outputs, therefore 'expert knowledge' collected in field surveys is also used for model calibration.

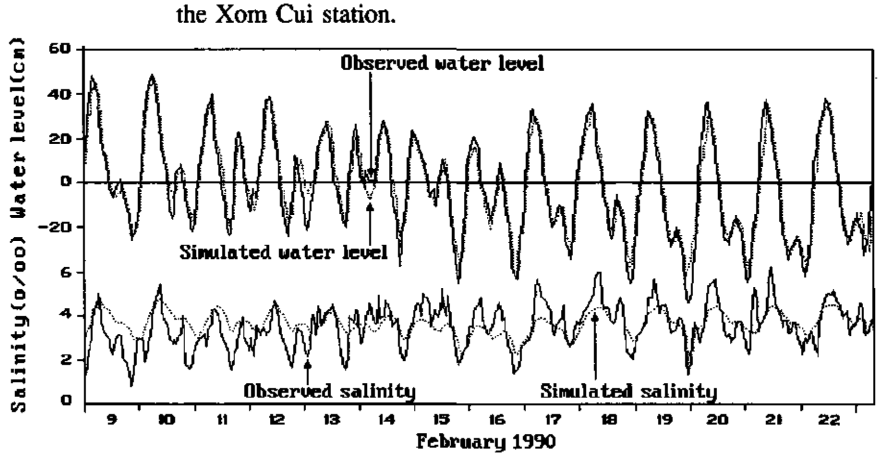
4.76 Data used for calibration of CAILUP for the Quan Lo Phung Hiep region are:

- Data on water conditions in 1989-1990, used for sub-model [2];
- Data on rice yields at village level, and on non-rice yields at district level from 1986 to 1990, used for sub-model [3];
- Data on population and land use areas in 1985 and 1990 at village level, used for sub-models [6], [7] and [8];
- Data on production at district level from 1985 to 1990, used for sub-models [9] and [10].

Actual data at village and district levels have been disaggregated to sub-unit and water management unit level, respectively. The procedure of calibration followed the sequence of model operations described in 3.30. Population and land use in 1985 at the sub-unit level were used as initial conditions. The aim of calibration was to match model outputs at the water management unit level with actual data from 1986 to 1990.

4.77 As discussed in 4.61, the VRSAP hydraulic and salinity model was calibrated to generate data on water conditions for the Physical Impact Sub-model [2]. An example of water level and salinity simulated by the VRSAP model and observed in the hydrological measurement campaign in 1990 is given in Fig. 113.

Figure 113: Comparison of simulated and observed water level and salinity at the Xom Cui station.



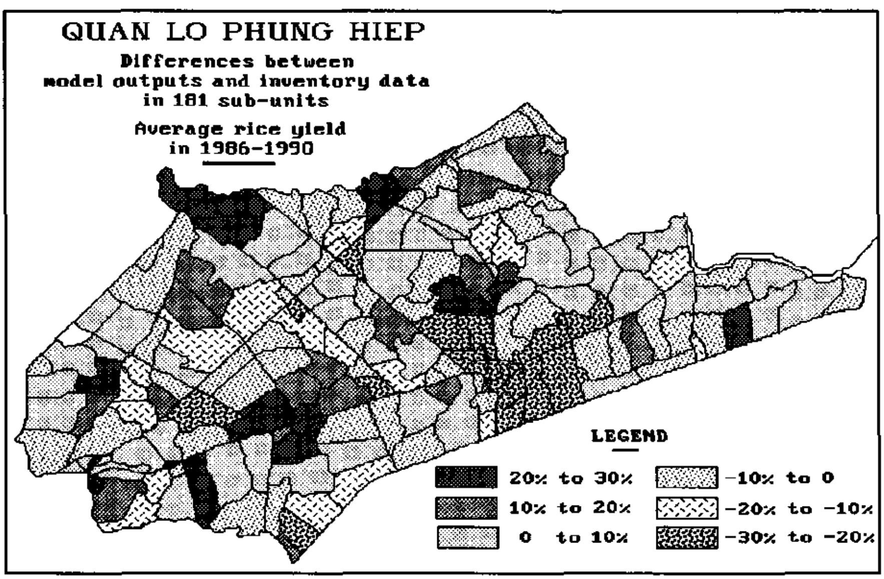
4.78 The simulated outputs from the Bio-physical Sub-model [3] were calibrated by adapting some spatial and temporal coefficients, e.g. those related to local weather, represented by the percentage of unfavourable years in rice yield calculations, or to irrigation capacity of small creaks, represented by the selection of canal and plain water levels in yield simulations (see 4.62).

Problems of data aggregation may also be identified by comparing model outputs with actual data. For example, according to the inventory, sugarcane was successfully grown in a limited area (on sand ridges with high elevations), while simulated yields were negligible due to inundation (as a result of using the dominant elevation in a sub-unit, see 3.29).

Spatial and temporal variations in the real world may also lead to differences between model outputs and observed data in certain years. For example, the actual rice yield in a year with specific weather conditions may be different from the simulated yield that is based on average conditions. Moreover, the simulated yield is considered an attainable yield expected by farmers, under average weather and water conditions, and for specific soil management and cultivation techniques. Effects of factors leading to yield reduction such as pests and diseases or to a delay in supplying input materials, have not been taken into account here, but are only considered in the Production Sub-model [9].

A comparison of simulated and actual yields is shown in Fig. 114.

Figure 114: Comparison between simulated yields and actual data.

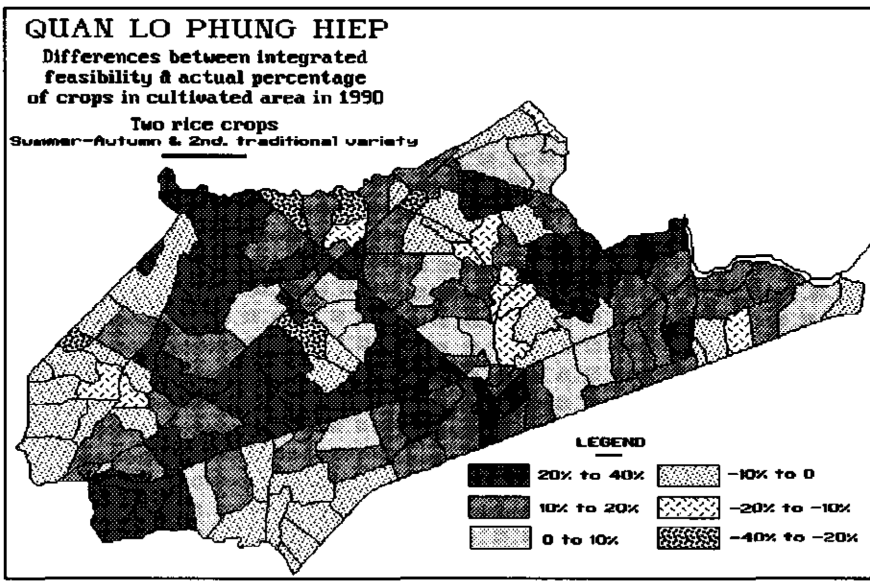


4.79 Actual data on the bio-physical/economic feasibility generated in the Economic Sub-model at Farm Level [4] are of course not available. The aim of calibration, therefore, was to generate values that are proportional with the areas of land use types in each sub-unit. Data used in the financial analysis, e.g. the amount of input materials, the number of hired labourers, rate of interest, etc. (see 4.63) were revised and adjusted to guarantee that farmers attain a certain net income from the yield simulated in sub-model [3].

4.80 Calibration of the Socio-economic Sub-model at Farm Level [5] was similar to that of sub-model [4]. Data on preferences in the social rules (see 4.64) were adjusted to generate the integrated feasibility with the same purpose as in 4.79.

An example of the spatial distribution of the integrated feasibility of two rice crops (Summer-Autumn and 2nd traditional variety) in comparison with their actual areas, is shown in Fig. 115.

Figure 115: Comparison of calculated integrated feasibility and percentage of actual area.

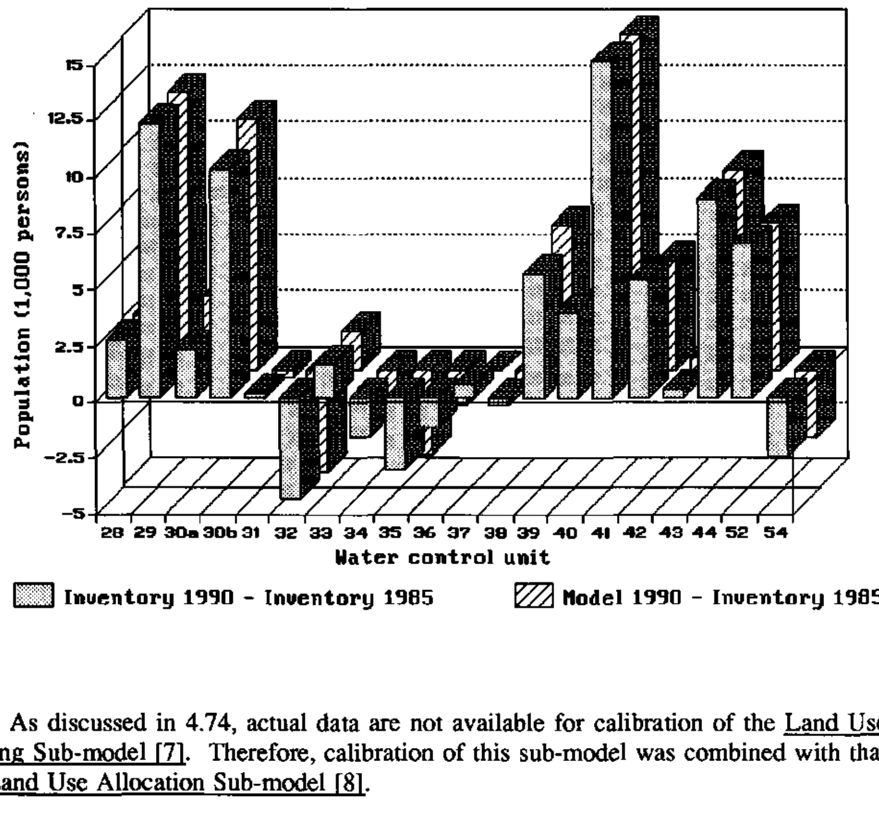


The observed differences reflect different effects from Government policies and factors other than those considered in sub-models [4] and [5], on the selection of land use by farmers in the various sub-units in the Region.

4.81 The Demography Sub-model [6] was calibrated by adjusting the distribution of emigration over the water management units, the matrix of migration possibilities and the proportion underlying the decision to migrate (see 4.65). Calculated migration among sub-units is also affected by the integrated feasibility from sub-model [5], therefore, calibration of this sub-model should be carried out in series as discussed in 4.74.

A comparison of model output with actual data on population increase is shown in Fig. 116.

Figure 116: Comparison between population increase simulated by CAILUP and that from the inventory.



4.82 As discussed in 4.74, actual data are not available for calibration of the Land Use Weighting Sub-model [7]. Therefore, calibration of this sub-model was combined with that of the Land Use Allocation Sub-model [8].

First, weighting values of non-productive land use types (specific uses, homestead gardens and uncultivated land) were adjusted by modifying policy factors (see 4.66) to match calculated areas of these land use types with actual data. Then, policy factors of 'primary' productive land use types, and finally those of combined productive land use types were adjusted in combination with the integrated feasibilities from sub-model [5] to generate weighting values for land use allocation.

Outputs and actual data on land use areas are compared in Table 10. Aggregation from sub-unit level to both water management unit and district level for comparison, may help in identifying which sub-units need to be reconsidered.

Table 10: Comparison between the areas (ha) of relevant land use types from sub-model [8] and those from the 1990 inventory.

No	Water manag. unit or District	Single rice			Double rice			Sugarcane and pineapple			Forests			Shrimp		
		Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.
1	28	7203	6437	766	4409	3975	434	256	229	27	75	66	9	0	173	-173
2	29	18294	17259	1035	6043	5712	331	138	132	6	3051	2803	248	1354	1284	70
3	30a	22777	21842	935	13645	13079	566	76	73	3	313	308	5	0	0	0
4	30b	20563	20099	464	15486	15153	333	0	0	0	0	0	0	3302	3222	80
5	31	15020	15045	-25	14589	14611	-22	107	105	2	0	0	0	57	58	-1
6	32	14016	13696	320	13949	13632	317	167	165	2	171	165	6	342	339	3
7	33	5220	5612	-392	3244	3493	-249	3	15	-12	0	0	0	545	580	-35
8	34	6970	6455	515	2518	2336	182	12	11	1	0	0	0	4244	4040	204
9	35	7216	7135	81	4938	4874	64	239	235	4	212	213	-1	0	0	0
10	36	8915	9778	-863	1654	1814	-160	1976	2169	-193	0	0	0	0	0	0
11	37	4109	4032	77	2347	2297	50	1239	1219	20	231	252	-21	0	0	0
12	38	2543	3218	-675	1015	1293	-278	77	124	-47	70	153	-83	30	764	-734
13	39	7434	7241	193	1617	1533	84	0	11	-11	0	0	0	2251	2714	-463
14	40	27350	26059	1291	20859	19876	983	3	0	3	2583	2811	-228	8314	10947	-2633
15	41	9654	10320	-666	8399	8975	-576	0	0	0	2662	2872	-210	4672	4943	-271
16	42	13744	13893	-149	9465	9567	-102	0	0	0	2020	2400	-380	4376	4405	-29
17	43	8785	9158	-373	2912	3123	-211	0	0	0	0	0	0	2969	3049	-80
18	44	8173	7790	383	4451	4248	203	0	0	0	0	0	0	175	166	9
19	52	6820	5683	1137	2636	2195	441	211	174	37	216	182	34	0	787	-787
20	54	14437	13683	754	972	1633	-661	0	0	0	63	62	1	511	807	-296
1	My Tu	10163	7997	2166	5251	4640	611	262	225	37	1778	2649	-871	87	193	-106
2	Thanh Tri	29508	28082	1426	15545	13110	2435	230	270	-40	1433	741	692	888	86	802
3	My Xuyen	16195	16939	-744	10887	7786	3101	49	0	49	193	0	193	2428	4350	-1922
4	Vinh Chau	22082	21440	642	16641	16065	576	3	0	3	2165	1670	495	6100	8904	-2804
5	Bac Lieu	7140	6727	413	5551	5757	-206	3	0	3	522	1272	-750	2823	2549	274
6	Ca Mau	10701	11287	-586	4963	4641	322	0	0	0	0	0	0	2191	742	1449
7	Hong Dan	35190	32795	2395	20640	19561	1079	3524	3914	-390	561	570	-9	294	1200	-906
8	Vinh Loi	33708	35741	-2033	27621	33545	-5924	142	0	142	2646	2741	-95	5409	4614	795
9	Gia Rai	39565	40346	-781	24103	23953	150	80	79	1	2089	2400	-311	11318	11558	-240
10	Thoi Binh	20274	19586	688	2081	3076	-995	211	0	211	120	62	58	1604	4082	-2478
11	Vinh Thuan	4717	3495	1222	1865	1285	580	0	174	-174	160	182	-22	0	0	0
	Total	229243	224435	4808	135148	133419	1729	4504	4662	-158	11667	12287	-620	33142	38278	-5136
	Difference (%)			2			1			-3			-5			-13

Notes: Model = Model output, Inven = Inventory data, Dif. = Model output - Inventory

Table 10: Comparison between the areas (ha) of relevant land use types from sub-model [8] and those from the 1990 inventory (continued).

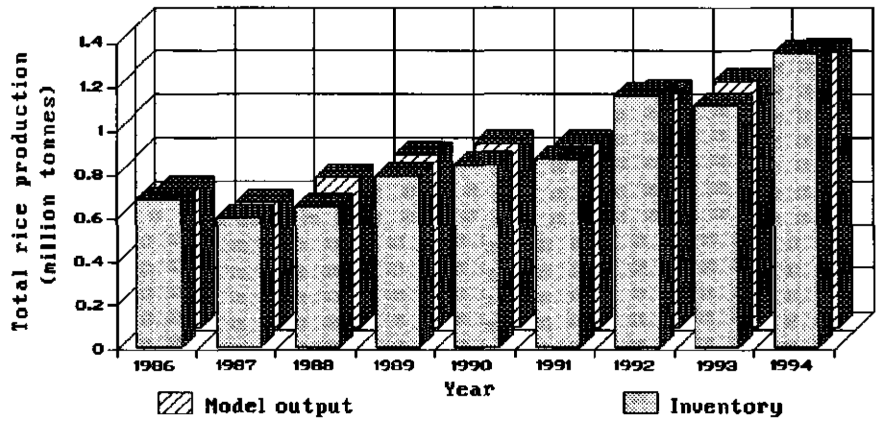
No.	Water manag. unit or District	Fish ponds			Canals and rivers			Uncultivated land			Specific uses			Homestead gardens		
		Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.
1	28	1	1	0	851	851	0	1465	1478	-13	882	1527	-645	1945	1971	-26
2	29	38	36	2	2539	2498	41	2984	2956	28	2463	3628	-1165	1981	2230	-249
3	30a	123	116	7	2931	2875	56	2881	2820	61	2560	3457	-897	1869	2128	-259
4	30b	173	168	5	1342	1314	28	1243	1254	-11	2993	3531	-538	3125	3070	55
5	31	264	261	3	925	934	-9	1446	1430	16	1438	1261	177	1268	1431	-163
6	32	0	490	-490	1422	1554	-132	2217	2218	-1	1674	1191	483	1621	1876	-255
7	33	0	211	-211	2041	1970	71	1650	1686	-36	1300	645	655	828	868	-40
8	34	0	490	-490	1986	2028	-42	2937	2911	26	954	1097	-143	1311	1433	-122
9	35	216	211	5	517	517	0	1901	1874	27	1174	1372	-198	1222	1175	47
10	36	175	192	-17	279	276	3	4217	4231	-14	1158	750	408	1893	1173	720
11	37	0	115	-115	114	116	-2	8477	8552	-75	568	494	74	1194	1162	32
12	38	0	86	-86	2085	2485	-400	6147	6054	93	1297	322	975	1917	954	963
13	39	0	57	-57	2187	2161	26	2334	2389	-55	1519	1142	377	1664	1807	-143
14	40	14	213	-199	4613	4596	17	6146	5994	152	5550	6693	-1143	3382	3669	-287
15	41	1	151	-150	5470	5501	-31	756	751	5	3097	1548	1549	742	949	-207
16	42	0	627	-627	3202	3167	35	2726	2683	43	4354	3086	1268	1915	2070	-155
17	43	0	237	-237	946	946	0	2131	2126	5	938	745	193	2303	1787	516
18	44	0	108	-108	617	617	0	637	641	-4	869	1048	-179	2012	2112	-100
19	52	4	3	1	220	220	0	5815	5827	-12	1565	2502	-937	1101	892	209
20	54	0	19	-19	966	1105	-139	3704	3670	34	1022	1024	-2	2317	2275	42
1	My Tu	11	0	11	1097	1020	77	2060	2640	-580	1322	2041	-719	2339	2564	-225
2	Thanh Tri	285	60	225	4603	4870	-267	5570	4691	879	3555	5876	-2321	2619	2814	-195
3	My Xuyen	105	121	-16	1105	935	170	1232	900	332	2265	3380	-1115	2373	2310	63
4	Vinh Chau	7	170	-163	4089	3271	818	4723	5415	-692	4231	6018	-1787	2801	3252	-451
5	Bac Lieu	9	80	-71	806	1759	-953	1632	768	864	2278	1355	923	885	680	205
6	Ca Mau	0	129	-129	1974	2048	-74	1859	1147	712	1877	2072	-195	2891	3628	-737
7	Hong Dan	383	1098	-715	4017	5807	-1790	22317	22349	-32	5218	3225	1993	7000	5484	1516
8	Vinh Loi	205	320	-115	7143	6863	280	1954	1900	54	5531	3496	2035	3179	3866	-687
9	Gia Rai	0	1781	-1781	8175	7492	683	9351	10519	-1168	7778	5667	2111	7044	6550	494
10	Thoi Binh	0	33	-33	2072	1511	561	7134	6821	313	2030	1638	392	3576	3233	343
11	Vinh Thuan	4	0	4	172	155	17	3982	4395	-413	1290	2295	-1005	903	651	252
	Total	1009	3792	-2783	35253	35731	-478	61814	61545	269	37375	37063	312	35610	35032	578
	Difference (%)			-73			-1			0			1			2

Notes: Model = Model output, Inven = Inventory data, Dif. = Model output - Inventory

The relative difference between calculated areas and inventory data on fish ponds is so very high, because small fish ponds in homestead gardens were included in the inventory while only large fish ponds with viable economic returns were taken into account in the CAILUP model.

4.83 The Production Sub-model [9] was calibrated by modifying the spatial and temporal adjustment coefficients describing the effects of pests and diseases and of delay in supplying input materials (see 4.68). Model outputs and actual data are compared in Fig. 117.

Figure 117: Comparison between regional rice production simulated by CAILUP and that from the 1994 inventory.



Note: Outputs in 1986-1990 have been established after calibration, while those in 1991-1994 are from validation (see 4.86).

4.84 Values of demand per capita for local consumption and of factors dealing with pig and duck raising (see 4.69) were adjusted in the calibration of the Supplementary Intervention Sub-model [10], to match the calculated production of pigs and ducks with actual data.

IV.4.2 Validation of CAILUP for the Quan Lo Phung Hiep region

4.85 The aim of validation is to compare model behaviour with available data over the range of represented conditions [Jørgensen, 1994]. Actual data at district level from 1991 to 1994, not used for model development and calibration, are available for model validation. Government policies and hence socio-economic conditions in the Region changed during that period, therefore model parameters were adapted accordingly. Water conditions and the associated land uses at the eastern side of the Region changed as a result of the completion of three sluices under the new water management system.

4.86 Population and land use in 1990 were used as initial conditions in model validation. Values of parameters such as rate of migration, policy factors, etc. were adjusted to represent actual conditions for the 1990-1994 period. The procedure of validation is identical to that of calibration. Examples of comparison between model outputs and inventory data on land areas and production are given in Table 11 and Fig. 117.

Table 11: Comparison between total areas (ha) of relevant land use types from sub-model [8] and those from the 1994 inventory.

Single rice			Double rice			Sugarcane and pineapple			Forests			Shrimp		
Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.
223764	214461	9303 (4%)	167730	166039	1691 (1%)	8140	8425	-285 (-3%)	15255	16261	-1006 (-6%)	33779	37450	-3671 (-10%)

Fish ponds			Canals and rivers			Uncultivated land			Specific uses			Homestead gardens		
Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.	Model	Inven	Dif.
2470	6266	-3796 (-61%)	41647	42457	-809 (-2%)	24724	25444	-720 (-3%)	40678	38867	1811 (5%)	38874	39698	-824 (-2%)

IV.4.3 Evaluation of development scenarios

4.87 Twenty eight development scenarios have been identified by combining 7 construction schedules of the water management system with 4 land use strategies (see 4.39 and 4.40). Water conditions and land use in 1990 were used as initial conditions. The values of parameters and of adjustment coefficients determined in the model calibration and validation were used for all scenarios, except for the construction schedule of the new water management system (Table 12), and also except policy factors.

Table 12: Construction periods (in years) of the new water management system.

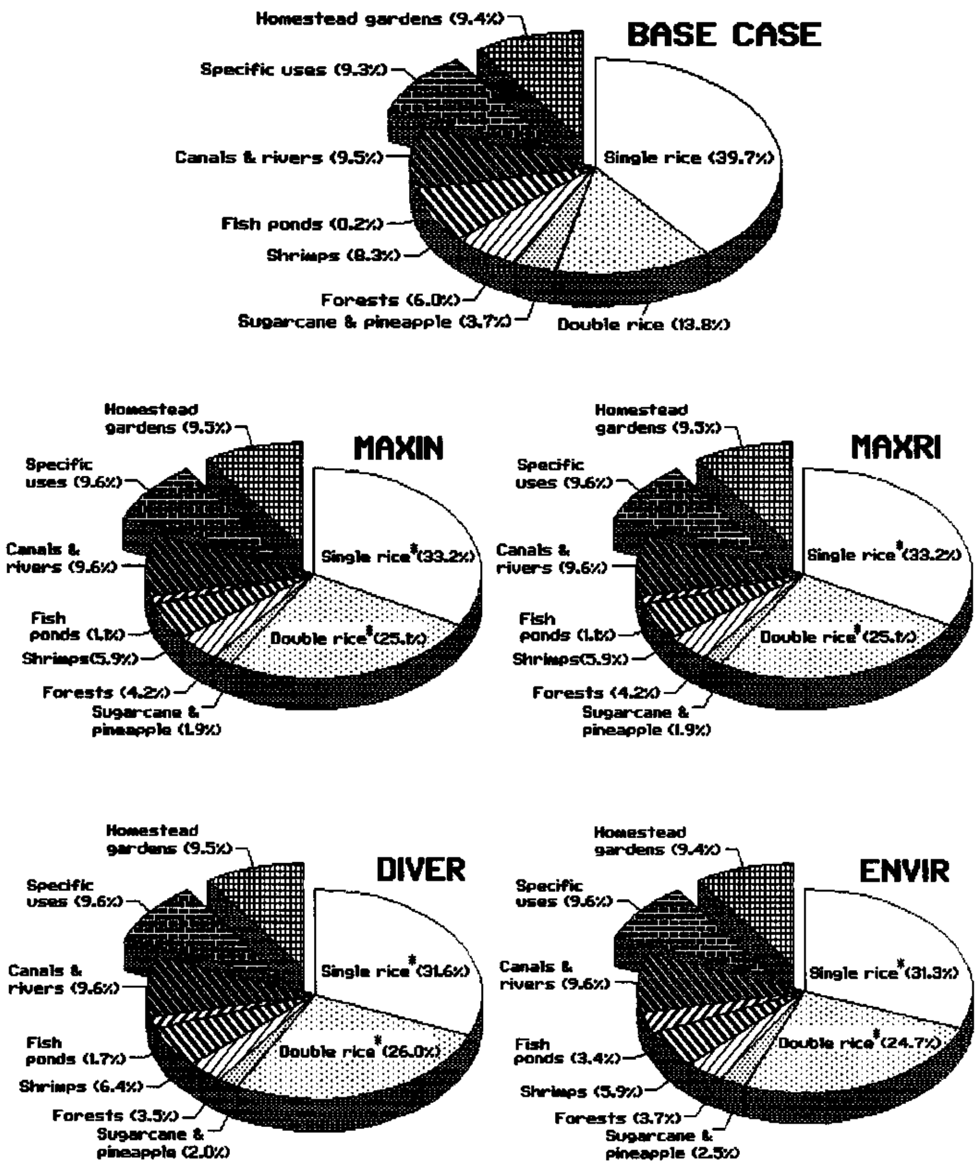
Construction schedule	Main features	Investment sources	Main sluices & main canals	Secondary canals	On-farm systems
A (SEQ7)	- Main sluices built sequentially from east to west over 7 years	Internal	7	9	9
B (SIM5)	- Main sluices built simultaneously in two provinces over 5 years	External	5	5	5
C (SIM7)	- As B, but over 7 years	Internal	7	9	9
D (ASS7)	- As A, with early construction of secondary canals in acid sulphate soil areas	Internal	7	8	9
E (ASS5)	- As B for main sluices and D for secondary canals	External	5	3	5
F (SEP10)	- Construction work separated in 2 parts and completed in 10 years	Internal	10	12	12
G (SEP17)	- Construction work separated in 3 parts and completed in 17 years	Internal	17	17	17

Notes: With external investment funds (e.g. a loan from international financing agencies), construction of all components in many water management units can be started and also completed simultaneously.

The values of policy factors in sub-model [7] were adjusted for each land use strategy. Parameter values were derived from other studies (see 4.2) for projections on population in sub-model [6], demand for main products per capita in sub-model [10], costs of the water management system and other activities in sub-model [11], factors relating to environmental impacts in sub-model [13], target values of goal indicators in sub-model [14], etc.

A summary of land use areas in year 20 for construction schedule ASS7 is presented in Fig. 118 and Table 13.

Figure 118: Allocation of land resources in year 20 for different land use strategies combined with construction schedule ASS7.



* Among scenarios, total areas of single rice and double rice crops are almost the same, but varieties and cropping calendars are different.

Table 13: Areas (ha) of relevant land use types in year 20 (construction schedule ASS7).

Land use strategy	Main features	Single rice*	Double rice*	Sugarcane & pineapple	Forests	Shrimps	Fish ponds	Canals & rivers	Specific uses	Homestead gardens
0: BASE	'Without' water management system	185626	64417	17338	28140	38683	952	44419	43420	44020
1: MAXIN	Maximize income from rice production	153551	115828	8731	19182	27139	4883	44409	44325	43996
2: MAXRI	Maximize rice production	153554	115830	8732	19182	27139	4883	44409	44319	43996
3: DIVER	Diversification based on income	146141	120368	9214	16405	29716	7661	44409	44304	43996
4: ENVIR	Minimize effects of acid water	144412	114181	11469	16930	27138	15483	44571	44310	43547

Note: * See footnote in page 220.

4.88 Sub-models [2] to [11] were applied for a base case, i.e. 'without' construction of the new water management system. Current water conditions were assumed to be maintained throughout the planning period. Land use changes in this base case are mainly due to expansion of areas for specific uses and homestead gardens as a result of population growth, and improvement in investment capacity of farmers. Policy factors were identical to those used in model validation.

In this case, rice production increases from 0.7 million tonnes in year 1 (1991) to 1.2 million tonnes in year 4 (1994) and fluctuates around this level in the course of the planning period due to different levels of pest and disease occurence in various years.

4.89 Target values of the goal indicators were only defined by decision-makers for target years, i.e. at five-year intervals, before and after completion of the new water management system, and at the end of the time horizon (year 30). Target values for other years were obtained by linear interpolation between values in these target years. Two economic indicators usually considered by decision-makers in the Region, i.e. B/C ratio and IRR with a discount rate of 12%/y, were used in ranking the scenarios. All goals were assumed equally important in priority setting, and a discount rate of 2%/y was applied for all indicators other than the economic ones.

4.90 Table 14 presents an example of target values, realized values and their relative deviation from the targets for the entire Region in scenario ASS7-MAXIN, combining construction schedule ASS7 with land use strategy MAXIN.

Table 14: Target values, realized values and their relative deviation from targets for scenario ASS7-MAXIN.

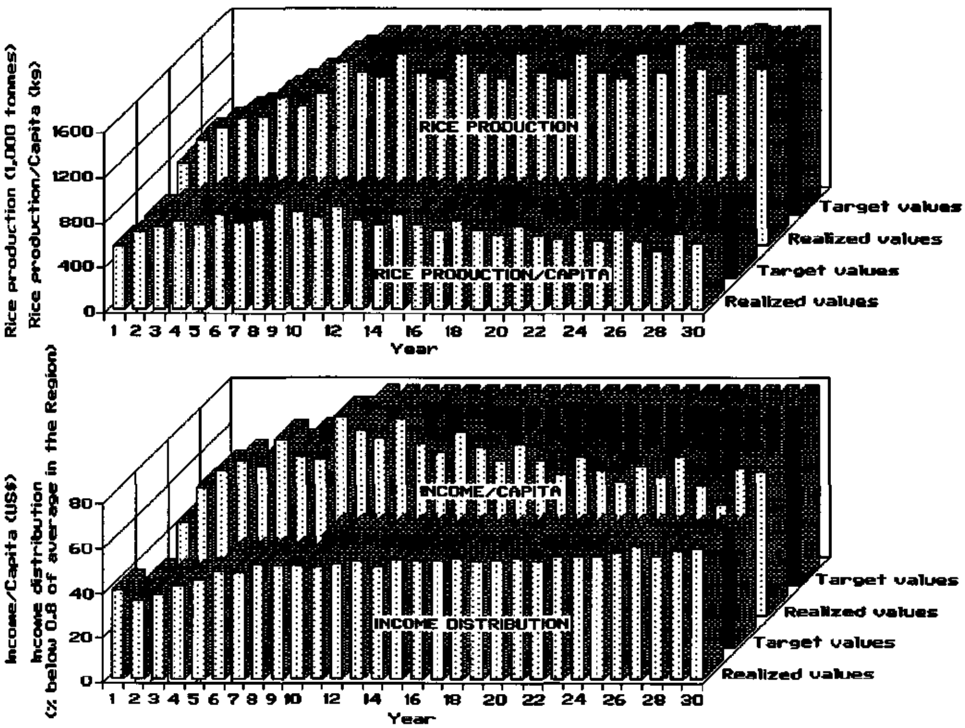
Goal indicators		Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Rice production (1,000 tonnes)	G	700	800	900	1000	1100	1200	1300	1400	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	R	739	943	1046	1139	1149	1325	1246	1350	1631	1542	1493	1709	1538	1490	1706	1536	1488	1704	1535	1487	1703	1534	1487	1703	1534	1799	1575	1352	1800	1577
	D	6	18	16	14	4	10	-4	-4	9	3	0	14	3	-1	14	2	-1	14	2	-1	14	2	-1	14	2	20	5	-10	20	5
Rice production /capita (kg)	G	550	600	650	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700
	R	558	687	733	769	749	835	761	800	939	864	815	910	799	754	843	742	702	786	693	657	737	651	618	694	614	707	608	513	671	579
	D	1	15	13	10	7	19	9	14	34	23	16	30	14	8	20	6	0	12	-1	-6	5	-7	-12	-1	-12	1	-13	-27	-4	-17
Rice distribution (% below 0.6 of average in the Region)	G	20	20	20	20	30	30	30	30	30	40	40	40	40	40	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
	R	19	21	22	26	29	33	33	36	36	36	39	39	40	39	40	41	41	41	42	42	44	43	44	45	45	44	45	46	46	47
	D	-5	7	11	32	-2	9	11	19	21	-9	-4	-2	0	-3	-11	-10	-10	-10	-7	-8	-3	-4	-2	-1	0	-1	0	2	2	5
Income per capita (US$)	G	40	45	50	55	60	65	70	75	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
	R	42	57	65	69	67	78	71	70	89	83	79	88	77	73	82	75	69	76	69	63	71	65	60	67	62	71	58	50	66	65
	D	5	27	30	25	12	20	1	-7	11	4	-1	10	-4	-9	3	-6	-14	-5	-14	-21	-11	-19	-25	-16	-23	-11	-28	-38	-18	-19
Income distribution (% below 0.8 of average in the Region)	G	30	30	30	30	40	40	40	40	40	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	R	39	35	37	42	44	48	47	51	51	51	50	51	53	50	53	52	52	54	53	53	54	53	54	55	54	57	59	55	57	58
	D	31	15	24	38	11	19	19	29	27	1	1	3	5	0	6	5	4	7	5	6	7	6	8	10	9	13	18	10	14	17
Employment (million labour-days)	G	60	60	60	60	60	65	65	65	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
	R	45	48	49	51	53	57	57	62	65	67	65	68	65	65	68	65	64	68	65	65	68	65	65	68	65	69	66	63	69	67
	D	-24	-21	-19	-15	-12	-12	-12	-5	-7	-5	-8	-3	-7	-8	-3	-7	-8	-4	-7	-8	-3	-7	-8	-3	-7	-1	-5	-9	-1	-5
% of total population supplied with fresh surface water	G	0	0	0	0	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
	R	0	0	0	0	11	12	12	16	16	16	15	15	15	15	15	15	15	15	15	14	14	14	14	14	14	14	14	13	13	13
	D	0	0	0	0	-22	-14	-14	13	12	11	10	9	9	8	7	6	5	5	4	3	2	1	1	-1	-1	-2	-4	-4	-5	-6
% land cover in total area in dry season	G	30	30	30	30	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
	R	31	31	32	34	35	36	36	37	37	38	38	38	38	38	38	38	38	38	38	39	39	39	39	39	39	39	39	39	39	39
	D	2	4	7	12	-1	1	3	4	6	8	9	9	9	9	9	9	9	10	10	10	10	10	10	11	11	11	11	11	12	12
Total pesticide use (1,000 tonnes)	G	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
	R	0.4	0.6	1.0	1.4	1.9	2.4	3.2	4.2	4.8	5.7	6.7	7.3	8.2	9.2	9.8	10.7	11.7	12.3	13.2	14.2	14.9	15.8	16.8	17.4	18.3	18.7	19.6	20.8	21.3	22.1
	D	-27	-35	-33	-32	-22	-19	-8	4	6	13	21	22	26	31	31	34	38	37	39	42	42	43	46	45	46	44	45	49	47	47

B/C ratio	G	1.2	IRR (%)	G	12.0
	R	1.9		R	32.4
	D	63		D	170

Notes: G = Target value, R = Realized value
D = Relative deviation (%) of realized value from target

In this scenario, the goal of increasing rice production to approximately double that in year 1 (0.7 million tonnes) after completion of the new water management system, can be achieved in years without high incidence of pests and diseases (Fig. 119).

Figure 119: Rice production and income in scenario ASS7-MAXIN.



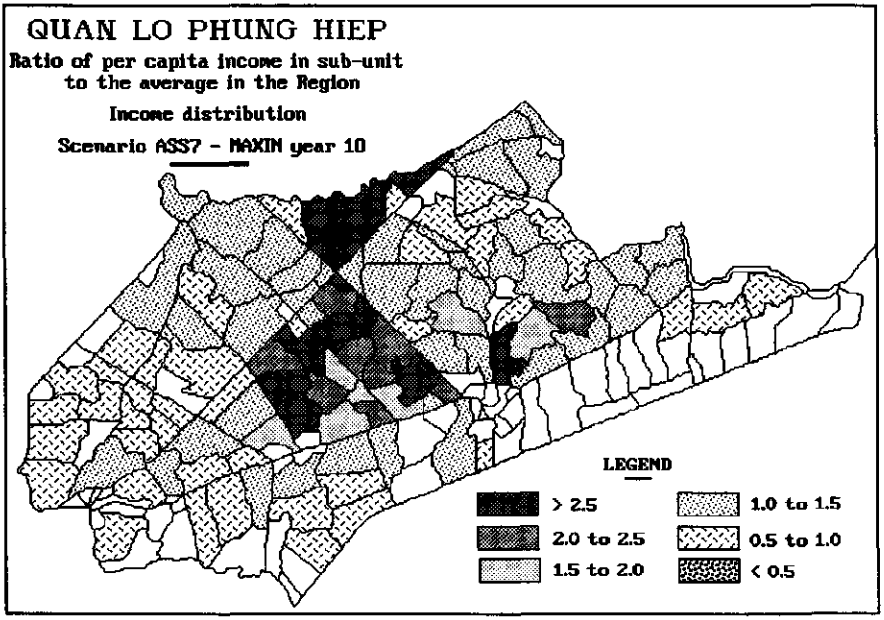
Although rice production per capita in the Region in year 1 (550 kg) exceeds the demand per capita for local consumption (estimated at 235 kg), increasing rice production per capita is still a goal because it represents the main source of income to farmers and it is unequally distributed in the Region. The goal of increasing rice production per capita from 550 kg in year 1 to 700 kg under the new water management system, can be realized until year 18 (Fig. 119). Subsequently, population growth exceeds the increase in production, so that per capita availability gradually decreases. Possible solutions could be:

i) increasing rice production from year 18 by expansion of the irrigated areas outside the central part;
ii) introducing new high yielding varieties;
iii) intensifying the current birth control programme.

Since sub-units with favourable soil and water conditions will develop faster then the others, differences in per capita availability among sub-units increase with the increase in rice production in the Region. Target values, therefore, are higher following construction of the new water management system (Table 14). The percentage of the population with a per capita availability below 0.6* times the average in the Region is used as an indicator for the goal of equity in food availability. The goal of limiting this percentage to below 45% after completion of the new water management system can be attained in this scenario (Table 14).

A similar situation exists for the goals of increasing income per capita and equity in income (Fig. 119). The percentage of the population with an income below 0.8* times the average in the Region, will be about 51 in year 10, very close to the target value of 50%. The spatial distribution of income per capita in the Region in this year is shown in Fig. 120.

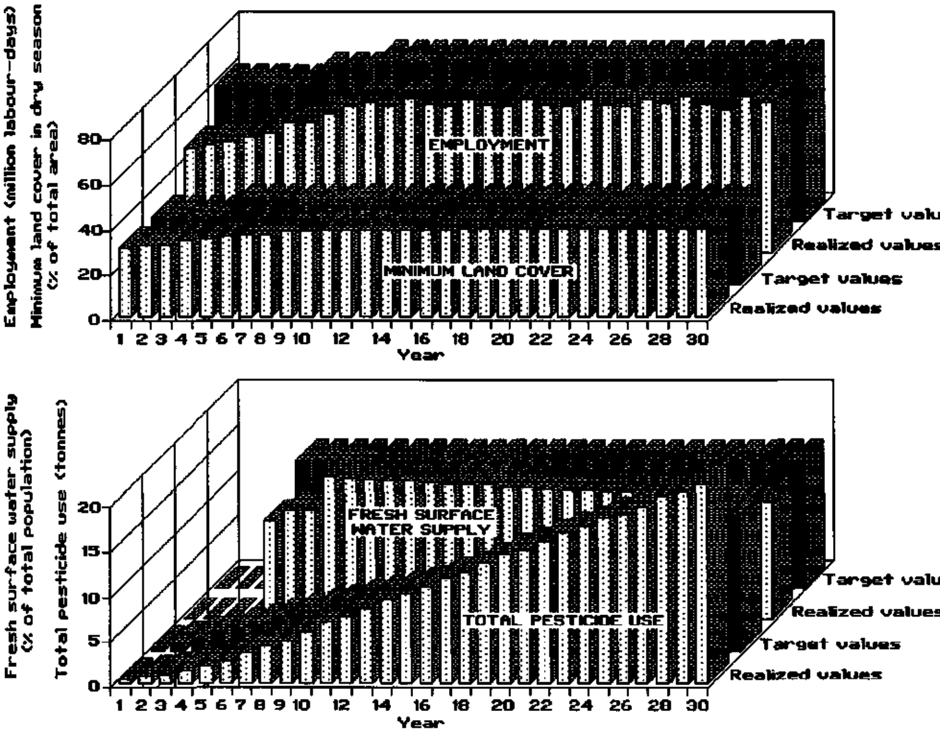
Figure 120: Calculated distribution of per capita income in the Region in year 10.



* No objective criterion is available in selecting this value. It is based on fluctuations in the indicator value around the average and the development situation in the region.

On the other hand, the target value for employment generation cannot be realized (Fig. 121), as this was set high at 50% of the available labour force for land use (Table 14).

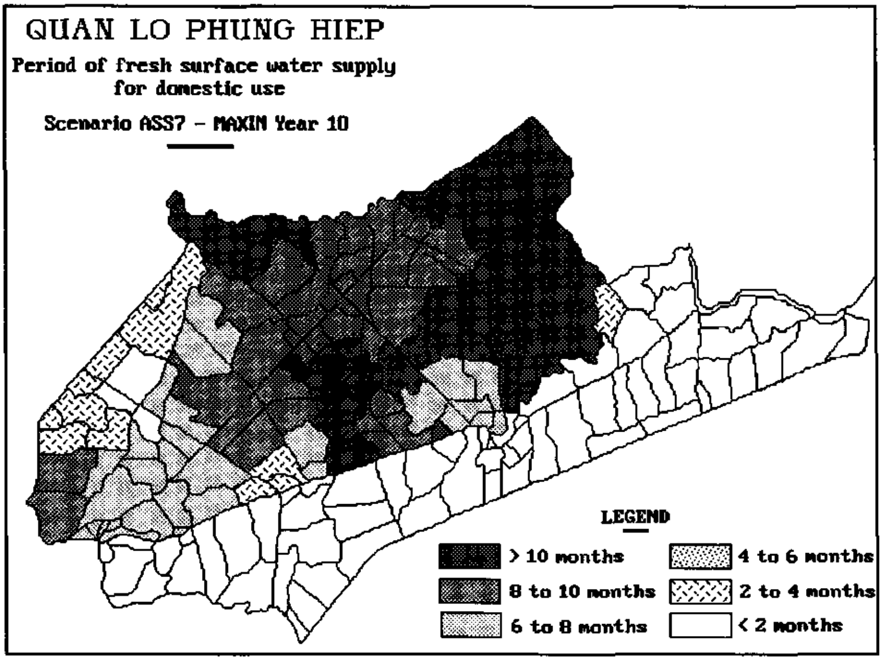
Figure 121: Employment, land cover, water supply and pesticide use in scenario ASS7-MAXIN.



Since not many crops are cultivated during the dry season, due to limited fresh water availability, minimum land cover in the dry season does not increase significantly in this scenario (Fig. 121).

The objective of protection from salt water is mainly to extend the period of low salinity into the dry season, for agriculture. Year-round protection requires building sluices at the west side of the Region at very high costs, therefore it is not considered for the coming 30 years. The goal of increasing the proportion of the population supplied with fresh surface water is set at only 14%, representing the population in the north-east of the Region (Fig.122). The realized value is at maximum 16% in year 8, when the construction of main sluices is completed (Table 14 and Fig. 121).

Figure 122: Fresh surface water supply for domestic use in year 10, scenario ASS7-MAXIN.



Annual pesticide use in the Region is targeted at below 500 tonnes, to limit negative impact on the environment. 'Cumulative total pesticide use' was selected as the indicator for the goal of limiting pesticide use, because some types of pesticide can leave residues in the environment and in aquatic animals. In this scenario, where the focus is on rice production, this goal cannot be attained after completion of the new water management system (Fig. 121).

4.91 Scores for 28 development scenarios, calculated in sub-model [14] are presented in Table 15.

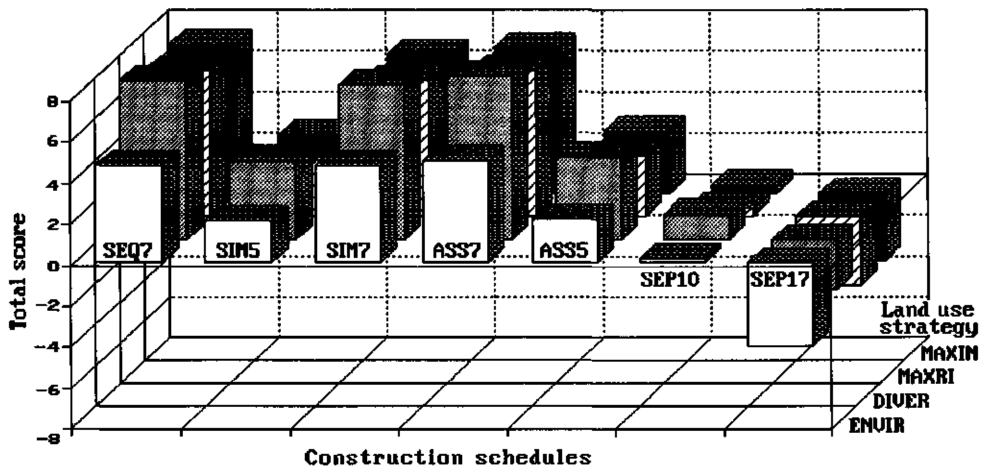
Table 15: Scores for 28 development scenarios.

Scenario	Rice production	Rice per capita	Rice distribution	Income per capita	Income distribution	Employment generation	Fresh surface water supply	Minimum land cover	Total pesticide use	B/C ratio	IRR	Total	Rank
SEQ7-MAXIN	1.5	1.2	-0.7	1.3	0.4	-2.0	3.9	1.7	-2.9	0.7	2.1	7.2	1
SIM5-MAXIN	0.6	0.4	-1.6	0.7	-0.6	-3.0	4.6	2.0	-2.0	0.5	1.2	2.8	5
SIM7-MAXIN	1.5	1.2	-0.5	0.7	0.8	-1.6	4.1	2.2	-2.8	0.3	1.0	6.7	3
ASS7-MAXIN	1.5	1.1	-0.3	1.3	0.4	-2.0	4.1	1.7	-2.9	0.6	1.7	7.1	2
ASS5-MAXIN	0.6	0.3	-1.4	0.7	-0.3	-3.0	4.7	2.1	-2.0	0.4	1.0	3.0	4
SEP10-MAXIN	0.2	-0.2	-0.5	-0.8	0.5	-2.7	2.9	1.9	-1.2	0.1	0.4	0.4	6
SEP17-MAXIN	0.2	-0.1	-0.7	-0.3	0.0	-2.6	-1.0	1.5	-1.8	0.5	1.0	-3.3	7
SEQ7-MAXRI	1.5	1.2	-0.7	1.3	0.4	-2.0	3.9	1.7	-3.1	0.7	2.1	7.1	1*
SIM5-MAXRI	0.7	0.4	-1.6	0.7	-0.6	-3.0	4.6	2.0	-2.2	0.4	1.2	2.7	5
SIM7-MAXRI	1.5	1.2	-0.6	0.7	0.8	-1.6	4.1	2.2	-3.0	0.3	1.0	6.6	3
ASS7-MAXRI	1.5	1.2	-0.3	1.3	0.4	-2.0	4.1	1.7	-3.1	0.6	1.7	7.1	1*
ASS5-MAXRI	0.6	0.4	-1.5	0.7	-0.3	-3.0	4.7	2.1	-2.1	0.4	1.1	2.9	4
SEP10-MAXRI	0.2	-0.1	-0.5	-0.8	0.5	-2.7	2.9	1.9	-1.4	0.1	0.4	0.4	6
SEP17-MAXRI	0.3	-0.1	-0.7	-0.2	0.0	-2.6	-1.0	1.5	-2.0	0.5	1.0	-3.4	7
SEQ7-DIVER	1.3	1.1	-1.3	1.3	0.2	-1.5	3.9	2.5	-2.5	0.6	2.1	7.7	2
SIM5-DIVER	0.5	0.2	-2.3	0.6	-1.1	-2.2	4.6	3.1	-1.2	0.4	1.2	3.8	5
SIM7-DIVER	1.3	1.0	-0.9	0.6	0.6	-1.1	4.1	3.0	-2.4	0.3	1.0	7.5	3
ASS7-DIVER	1.3	1.0	-0.8	1.2	0.3	-1.5	4.1	2.6	-2.5	0.6	1.7	7.9	1
ASS5-DIVER	0.5	0.2	-2.2	0.6	-0.9	-2.2	4.7	3.1	-1.1	0.3	1.0	4.0	4
SEP10-DIVER	0.0	-0.3	-1.1	-0.9	0.3	-2.2	2.9	2.7	-0.6	0.0	0.3	1.2	6
SEP17-DIVER	0.1	-0.2	-1.2	-0.3	-0.2	-2.1	-1.0	2.3	-1.3	0.4	1.0	-2.5	7
SEQ7-ENVIR	0.8	0.5	-1.4	-0.4	1.0	-1.8	3.9	2.9	-2.3	0.2	1.2	4.7	2*
SIM5-ENVIR	0.1	0.0	-1.5	-1.1	0.7	-2.2	4.6	3.1	-2.0	0.0	0.5	2.0	5
SIM7-ENVIR	0.8	0.5	-1.4	-1.2	1.5	-1.2	4.1	3.3	-2.2	0.0	0.3	4.7	2*
ASS7-ENVIR	0.7	0.5	-1.1	-0.6	1.3	-1.6	4.1	2.9	-2.3	0.1	0.8	4.9	1
ASS5-ENVIR	0.1	-0.1	-1.6	-1.1	0.7	-2.2	4.7	3.2	-1.9	-0.1	0.3	2.1	4
SEP10-ENVIR	-0.3	-0.5	-0.8	-2.0	1.3	-2.3	2.9	3.0	-1.0	-0.1	0.0	0.2	6
SEP17-ENVIR	-0.2	-0.5	-1.0	-1.6	0.9	-2.2	-1.0	2.6	-1.5	0.1	0.5	-4.1	7

Notes: * These two scenarios have the same rank because their total scores are equal.

Total scores for the various scenarios are compared in Fig. 123. Among construction schedules, ASS7 and SEP17 have the highest and lowest total score, respectively. Among land use strategies, DIVER and ENVIR have the highest and lowest total score, respectively.

Figure 123: Total scores for all 28 scenarios.



Single scores for each of the goals show that schedules with short construction periods, such as SIM5 and ASS5 not always lead to high values of indicators for economic returns (B/C ratio and IRR) and production, since investments in land use conversion by farmers are not in harmony with those for water management implemented by the Government. Hence, during the first few years, the cultivated area decreases due to expansion of the new water management system, while benefits from the system are only realized after land use conversion. This indicates that integrated planning for land use and water management in the Region is essential.

Conflicts among goals are also illustrated in Table 15, e.g. a scenario may have a high score for rice production but a low value for income per capita. Construction schedule ASS7 has the highest total score in combination with most land use strategies (except with MAXIN: its total score is slightly lower than that for schedule SEQ7). It also may help to avoid the risk of low pH in the acid sulphate soil area at the west side of the Region (see 4.100), and to promote equity in the distribution of rice production and income in the Region, since water conditions in the less endowed areas will be improved earlier. It also meets an institutional requirement, i.e. the construction of the new water management system starts in both provinces under a limited budget from the Government.

Table 15 also illustrates the ranking order among four land use strategies combined with all construction schedules. Rice-oriented strategies such as MAXIN or MAXRI lead to high scores for rice production, B/C ratio and IRR. Strategy DIVER does not provide significantly higher scores for the B/C ratio and IRR than strategies MAXIN and MAXRI, but it has the highest total score because of its high score for minimum land cover, as more crops are cultivated in the dry season in this scenario. Strategy ENVIR has the highest score for minimum land cover and income distribution, but low scores for rice production, rice per capita, B/C ratio and IRR lead to the lowest total score, in particular when combined with construction schedules SEP10 and SEP17.

4.92 'With' processing of main products, the total score for each scenario increases due to higher B/C ratio and IRR compared to 'without' processing. The B/C ratio, IRR and total score 'without' and 'with' processing for 7 scenarios representing land use strategy MAXIN for both the Region as a whole and the Inside separately, are given in Table 16.

Table 16: B/C ratio and IRR for the entire Region and the Inside 'without' and 'with' processing.

Scenario	For the entire Region								For the Inside			
	'Without' processing				'With' processing				'Without' processing		'With' processing	
	B/C ratio	IRR (%)	Total score	Rank	B/C ratio	IRR (%)	Total score	Rank	B/C ratio	IRR (%)	B/C ratio	IRR (%)
SEQ7-MAXIN	2.0	36.7	7.2	1	2.3	39.5	7.9	3	1.8	31.6	2.0	35.6
SIM5-MAXIN	1.7	26.8	2.8	5	2.0	29.5	3.3	5	1.6	26.4	1.8	29.8
SIM7-MAXIN	1.6	23.9	6.7	3	1.8	29.1	8.0	1	1.7	27.0	1.9	32.5
ASS7-MAXIN	1.9	32.4	7.1	2	2.2	35.1	8.0	1	1.8	27.9	2.0	31.4
ASS5-MAXIN	1.7	24.6	3.0	4	1.9	27.0	3.5	4	1.6	24.1	1.8	27.1
SEP10-MAXIN	1.8	23.8	0.4	6	2.0	25.4	1.3	6	1.6	22.4	1.8	24.9
SEP17-MAXIN	1.3	16.5	-3.3	7	1.5	19.8	-2.7	7	1.4	19.6	1.6	23.4

4.93 After completion of the new water management system, rice production per capita and income per capita in the Inside are approximately 30% higher than those for the entire Region. If all costs of the new water management system would be covered by the Inside as a project area, the B/C ratio and IRR for the Inside would be lower than those for the entire Region (Table 16), because shrimp production will not be possible in the Inside after the construction of sluices. Land use strategy in the Region as a whole is to allocate more land to shrimp raising in the coastal areas (not belonging to the Inside) to mitigate losses in shrimps in the Inside, therefore the B/C ratio and IRR for the entire Region are higher. However, the values of the economic indicators for the Inside are still high enough to consider the new water management system as a promising project in terms of economic returns.

IV.4.4 Sensitivity analysis

4.94 The aims of sensitivity analyses are:

i) To provide a measure of the sensitivity of the outputs of greatest interest in the model to either parameters, functions or sub-models [Jørgensen, 1994]. The major outputs from CAILUP are values of goal indicators and the total score from sub-model [14].

ii) To analyse the impact of changes in values of inputs on model outputs [Turban, 1993]. The model contains many parameters, therefore only changes in those parameters having a very strong effect on model outputs were considered. The variation in some parameters can be estimated on the basis of levels and frequencies of variation in actual data (drought, rice price), while that in others can only be determined on the basis of values from various assumptions (water pH, population growth rate).

The discussion on sensitivity analysis focuses on values of goal indicators and the total scores by comparison with their values generated in the evaluation of development scenarios (subsequently referred to as 'normal' situation). Construction schedule ASS7, a schedule with great attention from decision makers because of the reasons discussed in 4.91, has been selected for illustration of the results. Modified parameters were also applied in the base case of 'without' construction of the new water management system.

4.95 The first aim of sensitivity analysis received attention during development, calibration and validation of each sub-model as shown in Fig. 5. For example, different values of soil and water factors, and different parametric methods (addition, multiplication, exponent, minimum value, etc.) were tested in sub-model [3] for yield estimation, and those leading to the best match between model outputs and actual data were selected. The second aim of sensitivity analysis is emphasized in CAILUP applications and discussed in the following.

4.96 The effect of water extraction on land use in the Region was analysed by comparison of outputs from the run 'without' water extraction with a rerun 'with' water extraction. Since rice cropping calendars in the Region can be adjusted to periods with suitable water conditions (see sub-model [3] in 4.62), only 0.5% of the area, approximately 500 ha, of double rice crops has to be changed to single rice or other land use types. This effect is not significant in determining the total score. The small difference between two runs 'without' and 'with' water extraction also reflects the attempt in formulation of land use strategies, at limiting water extraction in the dry season, e.g. by limiting the area of Winter-Spring rice crop.

4.97 Pig and duck raising is an important activity associated with rice production. For example, without these activities, the B/C ratio and IRR in scenario ASS7-MAXIN are as low as 0.4 and 2.5%, respectively (compared with 1.9 and 32.4% in the 'normal' situation in Table 14), causing a reduction in the total score from 7.1 to -7.3. These values indicate that these activities associated with rice production may be also important in justifying the construction of the new water management system.

4.98 Pest and disease outbreaks often occur at different locations in the Region. The model was applied for a 'worst' case, assuming that the incidence of pest and disease outbreaks will be high during the first ten years, medium in the middle 10 years and low in the last 10 years. Scores for 7 scenarios representing land use strategy MAXIN are presented in Table 17.

Table 17: Scores in the 'worst' case of pest and disease outbreak.

Scenario	Rice production	Rice per capita	Rice distribution	Income per capita	Income distribution	Employment generation	Fresh surface water supply	Minimum land cover	Total pesticide use	B/C ratio	IRR	Total	Rank
SEQ7-MAXIN(p)	0.7	0.0	-0.7	-1.2	0.3	-1.9	3.9	1.7	-16.7	0.6	1.5	-11.7	3
SIM5-MAXIN(p)	-0.2	-0.8	-1.5	-1.8	-0.7	-2.9	4.6	2.0	-15.5	0.3	0.8	-15.6	5
SIM7-MAXIN(p)	0.7	0.0	-0.6	-1.8	0.9	-1.6	4.1	2.2	-16.4	0.2	0.7	-11.5	2
ASS7-MAXIN(p)	0.7	0.0	-0.4	-1.2	0.4	-1.9	4.1	1.7	-16.6	0.5	1.3	-11.4	1
ASS5-MAXIN(p)	-0.2	-0.8	-1.4	-1.9	-0.4	-2.9	4.7	2.1	-15.5	0.3	0.7	-15.3	4
SEP10-MAXIN(p)	-0.5	-1.1	-0.7	-3.1	0.7	-2.6	2.9	1.9	-14.1	0.0	0.8	-16.2	6
SEP17-MAXIN(p)	-0.4	-1.1	-0.6	-2.5	0.0	-2.5	-1.0	1.5	-15.0	0.4	0.3	-20.5	7

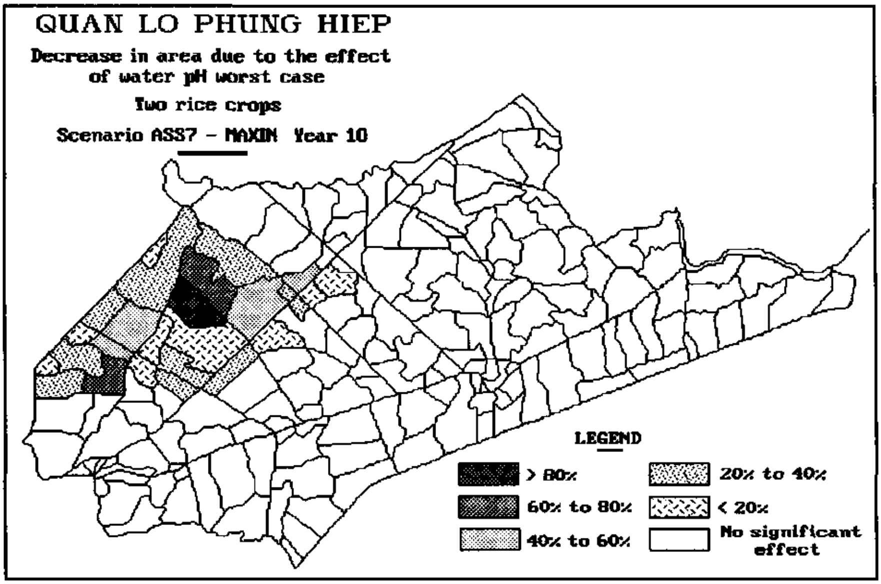
The total scores in this situation are lower than those in the 'normal' situation (Table 15) due to lower scores for rice production, income, B/C ratio, IRR, and especially for total pesticide use, since pesticides are required in the earlier stages of the planning period. Construction schedules ASS7 and SEP17 remain at the highest and lowest ranks, respectively.

4.99 Droughts, causing significant yield reductions in double rice cropping, and tc a lesser extent in single rice crops, were observed once every two years during 1980-1990. In a high risk case, this effect is assumed more serious than in the 'normal' situation. The proportion of unfavourable years used in the rice yield estimation (see sub-model [3] in 4.62) is assumed to increase from 20 to 30%, on average for the entire Region. The decrease in total rice production in scenario ASS7-MAXIN goes down from 11% in year 1 to 3% in year 8 after completion of the new water management system. The total score decreases from 7.4 in the 'normal' situation, to 5.6.

Obviously, any phenomenon causing reductions in rice yield leads to a decrease in scores, with a strong reduction in land use strategies MAXRI, MAXIN, and less in DIVER and ENVIR. Nevertheless, scenario ranks hardly change because in all scenarios rice production contributes approximately 75% to total income, and up to 90% if income from pig and duck production is included to the income.

4.100 A fall in water pH in the acid sulphate soil area is an important environmental issue in the Region (see sub-model [2] in 4.61). In the 'worst' case, water pH is assumed constant at the minimum observed value over the planning period. Its effect on land use is evident at the west side of the Region, as shown in Fig. 124.

Figure 124: Effect of water pH in 'worst' case.



Total scores of the scenarios for strategy MAXIN are presented in Table 18.

Table 18: Scores in the 'worst' case of water pH change.

Scenario	Rice production	Rice per capita	Rice distribution	Income per capita	Income distribution	Employment generation	Fresh surface water supply	Minimum land cover	Total pesticide use	B/C ratio	IRR	Total	Rank
SEQ7-MAXIN(pH)	0.9	0.7	-0.4	0.7	0.1	-2.5	3.8	1.7	-2.4	0.6	1.8	5.0	2
SIM5-MAXIN(pH)	-0.9	-1.1	-1.7	-0.6	-0.2	-4.2	4.6	2.4	0.2	0.1	0.3	-1.9	6
SIM7-MAXIN(pH)	0.9	0.6	-0.6	0.6	0.6	-2.5	4.1	1.8	-2.1	0.5	1.2	4.6	3
ASS7-MAXIN(pH)	1.0	0.7	-0.4	0.8	0.8	-2.4	3.9	1.7	-2.4	0.6	1.6	5.1	1
ASS5-MAXIN(pH)	-0.9	-1.1	-1.7	-1.1	-0.2	-4.2	4.6	2.4	0.3	0.1	0.3	-1.5	5
SEP10-MAXIN(pH)	-0.2	-0.4	-0.7	-1.1	0.4	-3.2	2.8	1.7	-0.9	0.1	0.4	-1.0	4
SEP17-MAXIN(pH)	-0.8	-1.1	-1.1	-1.3	0.1	-4.0	-2.5	0.9	-0.4	0.6	0.8	-8.8	7

In this 'worst' case, most individual goal scores and the total score are lower than those for the 'normal' situation (Table 15), except for total pesticide use.

4.101 The <u>rice price</u> declined in the international market during the last 20 years [Rosegrant & Pingali, 1994]. A reduction of approximately 5% per year was recorded over the period 1980-1990. Values of economic indicators and scores were analysed with the assumption of a rice price decline as over 1980-1990, during the first ten years of the planning period. The B/C ratio, IRR and the total score of four scenarios in the construction schedule ASS7 are presented in Table 19.

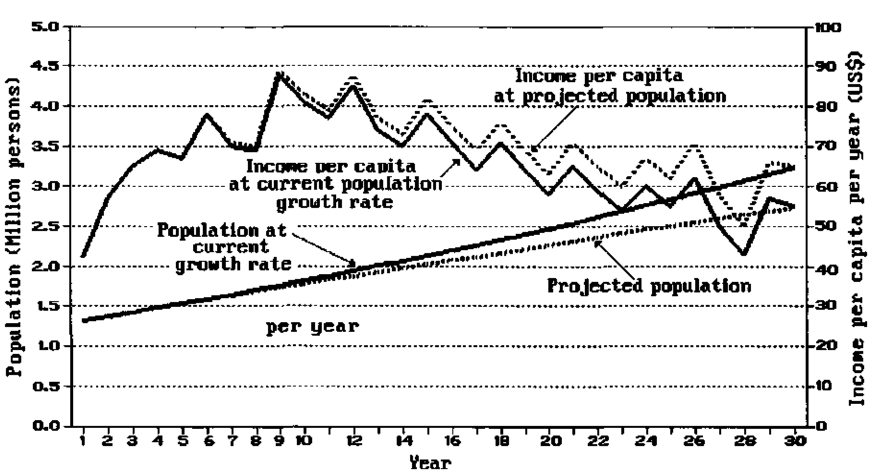
Table 19: Values of economic indicators and total scores under modified rice prices.

Scenario	Current price of rice			Reduced price of rice		
	B/C ratio	IRR (%)	Total score	B/C ratio	IRR (%)	Total score
ASS7-MAXIN	1.9	32.4	7.1	0.9	8.3	-6.2
ASS7-MAXRI	1.9	32.5	7.1	0.9	8.3	-6.2
ASS7-DIVER	1.9	32.3	7.9	0.9	8.4	-5.7
ASS7-ENVIR	1.3	22.2	4.9	0.6	0.0	-7.5

Table 19 indicates that economic returns under the new water management system very much depend on rice production. Similarly to the other effects on rice production, the effect of a decline in rice price is less in land use strategies DIVER and ENVIR than in the two others.

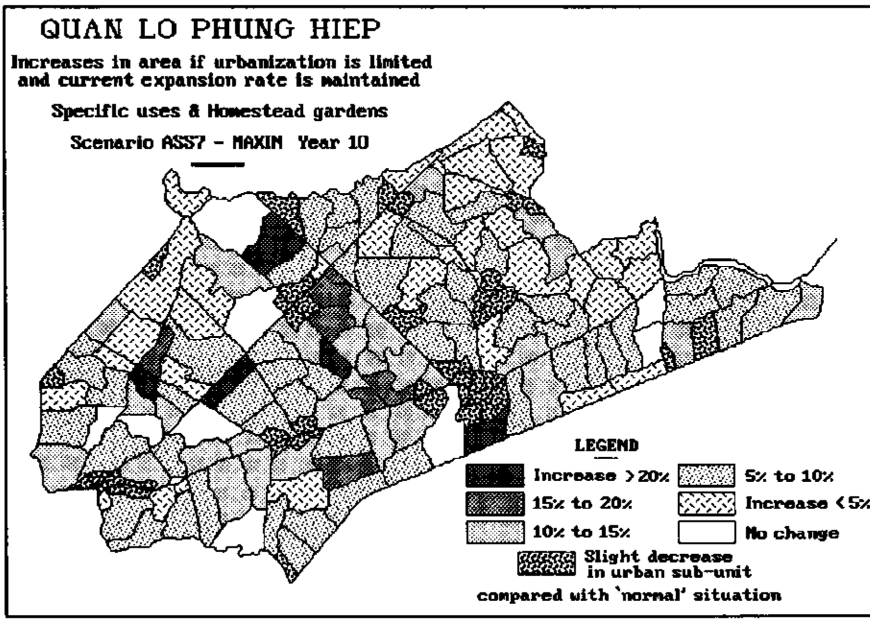
4.102 Since many indicators of development goals are related to population size, such as rice production and income per capita, fresh surface water supply, etc., the model was also applied to analyse the effects of population growth and migration policy. A situation in which the current population growth rate is maintained during the planning period is compared with the 'normal' situation in Fig. 125, for scenario ASS7-MAXIN. The total score in this scenario decreases from 7.1 in the 'normal' situation to 5.5 due to low scores for rice production and income per capita.

Figure 125: Effect of population growth on income per capita.



Urban population is projected to increase from 22% of the total population in year 1 to 40% in year 30. If migration to urban sub-units is limited to half the projected value and area of specific uses and homestead gardens per capita keep expanding at a rate as during 1990-1994, the areas of these land use types will increase as shown in Fig. 126.

Figure 126: Changes in areas of specific uses and homestead gardens under limited urbanization.



Compared with the 'normal' situation for scenario ASS7-MAXIN, rice area and production will decrease by approximately 25,000 ha and 200,000 tonnes, respectively, in year 20. Scores on rice production, rice and income per capita, and employment decrease, but scores on rice and income distribution, water supply and total pesticide use increase, resulting in a total score of 7.6 compared with 7.1 in the 'normal' situation. Changes in values for other scenarios are similar.

4.103 Different policy views can be taken into account by modifying priority and/or discount factors assigned to each goal. Scores and ranks for four scenarios for the construction schedule ASS7, with different priority settings are shown in Table 20.

Table 20: Scores and ranks for scenarios with different priority settings.

Scenario	'Normal' situation (P0)		Only rice production (P1)		Rice/capita & Income/capita (P2)		Rice distribution & Income distribution (P3)		Fresh surface water supply Minimum land cover & Total pesticide (P4)		B/C ratio & IRR (P5)		All goals, with a negative discount rate (-10%/y from year 10) for rice production & rice/capita (P6)	
	TS	R	TS	R	TS	R	TS	R	TS	R	TS	R	TS	R
ASS7-MAXIN	7.2	2	1.5	1	2.4	2	0.0	3	2.9	3	2.3	1	7.0	2
ASS7-MAXRI	7.1	3	1.5	1	2.5	1	0.1	2	2.7	4	2.3	1	7.2	1
ASS7-DIVER	7.9	1	1.3	3	2.3	3	-0.6	4	4.1	2	2.3	1	6.1	3
ASS7-ENVIR	4.9	4	0.7	4	-0.1	4	0.2	1	4.7	1	1.0	4	-0.2	4

<u>Notes</u>:

TS = Total score
R = Rank
(P0) = 'Normal' situation in which all goals are taken into account as given in 4.89.
(P1) = Only rice production is considered, in views of its contribution of food to the country.
(P2) = Only the increase in food and income per capita are taken into account.
(P3) = Only social issues, i.e. distribution of food and income, are considered.
(P4) = Only three indicators dealing with environmental impacts are considered.
(P5) = Only economic indicators are taken into account.
(P6) = All goals are taken into account, with the additional consideration that according to the national development plan, from year 10 onwards, the annual increment in food production in the country will be lower than the population growth rate, hence food demand by the country on the Region becomes important (see 3.46).

4.104 Taking into account development objectives and possible impacts of the new water management system on the bio-physical and socio-economic conditions, and also considering institutional issues in the Region, <u>construction schedule</u> ASS7 was selected. Three main sluices at the east side were completed in 1993. In 1995, construction of three others has been started. Secondary canals have been excavated at the west side of the Region, as planned.

Since each land use strategy has the highest score for at least one of the goals in the situations considered, selection of a <u>land use strategy</u> is more difficult than that of a construction schedule.

Rice-oriented strategies (MAXIN and MAXRI) satisfy the demands by the country on the Region, but lead to high risks of monoculture, and provide a relatively low income that is difficult to increase. Diversification (DIVER) may limit the risk of economic losses in rice production, but requires much effort in activities such as capital formation for investment, marketing, trading, etc., that are new to the local population. Minimizing the effect of acid water (ENVIR) is a cautious strategy that leads to a better situation in environmental protection, and food and income distribution, but cannot satisfy the demand for production and is difficult to implement under the dynamic conditions of the free-market system.

Therefore, although the decision on the construction of the new water management system reflects a rice-oriented land use strategy in the Region, attention is also paid by the local population to crops other than rice, in particular outside the area protected from salt water.

CHAPTER V CONCLUSIONS AND RECOMMENDATIONS

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

5.1 The first part of this Chapter presents a preliminary evaluation of CAILUP as conclusions of the study. The results in Chapters II, III and IV are discussed against the background of the two objectives of the study formulated in Chapter I:

(i) *to develop and implement a method and corresponding software system for integrated land use planning at regional level in irrigated areas;*

(ii) *to test the method and the system in the Quan Lo Phung Hiep region.*

Challenges and recommendations in development and applications of CAILUP based on experiences during the study are discussed in the second part of this Chapter.

V.1 PRELIMINARY EVALUATION OF CAILUP - CONCLUSIONS

5.2 Discussions in the preceding chapters, in particular Chapter IV, indicate that <u>integration in land use planning</u>, including land and water resources, is essential. 'Biodiversity' leads to a large number of land use types with various cultivation techniques, while 'sociodiversity' results in a variety of socio-economic objectives and preferences. The more diverse the land use pattern, the more important integration in planning and management.

CAILUP can help in integration in multi-level and multi-sectoral planning, integration between bio-physical and socio-economic factors, between local expertise and international expertise, and between computer technology and land use planning.

5.3 Integration in land use planning can be realized through <u>simulation modelling</u> (Chapters III and IV). An 'ideal' model is a copy of the real world, as a physical model at scale 1:1 or a prototype. Such a model, however, is impossible to achieve at regional level. In CAILUP, simulation implies development of a model and study of its behaviour and modelling implies simplification of reality in accordance with its philosophy. The main aim in model development is to incorporate all relevant factors in a structure (both temporal and spatial) that resembles reality.

CAILUP starts from a key intervention dealing with one factor, and is then expanded with more interaction factors to analyze its impact in the entire region. The various types of integration indicated above are gradually implemented during the development of the model. This type of simulation modelling increases insight in behaviour of the farmers who, better than any specialist, know why, where, when and how to apply different techniques under the local bio-physical and socio-economic conditions. This behaviour is described in sub-models [3], [4] and [5] of CAILUP. Knowledge from other sources, e.g. national and international experts, can be included to analyse the scope for improvements in management at farm level and regional level.

5.4 Development of '<u>building blocks</u>' is a suitable technique in developing CAILUP, as described in Chapters III and IV. First, main blocks and their relationships are identified and a frame is established to link all the blocks. A simple structure for each block is formulated and gradually more details are included, which, however, are always considered in the context of the whole system.

Some analysts are afraid that by applying this method, the risk exists that if one block is 'weak', the whole system may fail. However, CAILUP is also a learning tool. As illustrated in Chapter IV, 'weak' blocks, formulated on the basis of current knowledge and available data, are also incorporated in CAILUP, rather than being ignored with the consequence of an incomplete system comprising only 'strong' blocks. CAILUP thus also serves to identify knowledge and information gaps, and to limit inconsistencies in the level of detail of various components, that may occur when existing models for single disciplines are simply linked.

5.5 CAILUP has been developed for the purpose of <u>exploration of possibilities</u> rather than for prediction. As illustrated in Chapter IV, it is a tool to answer 'what-if' questions in support of planning and management, and not to answer the question 'what is going to happen'. The 'what-if' questions are related to the impacts of the key intervention and possible supplementary interventions.

5.6 Any method requires <u>suitable conditions</u> for its successful applications. To develop and apply CAILUP in a regional study as in the example of the Quan Lo Phung Hiep region (Chapter IV), the components listed below are required. These components are classified into two groups:

(a) essential components, i.e. components that are indispensable in the development and applications of CAILUP;

(b) optional components, i.e. components that contribute to improvement of the quality, and extension of the capabilities of CAILUP.

Human resources:

- <u>Farmers</u> (a) living in the region, understanding the local conditions, whose knowledge can be relied upon in the course of the study;
- A <u>multisectoral planning team</u> (a) with proper coordination and sufficient knowledge of both bio-physical and socio-economic conditions in the region. Planners from the sector responsible for the key intervention will play the role of generalists and coordinators in the study;
- <u>Modellers</u> (a) able to translate conceptual models developed by the planning team into mathematical models and computer programmes;

- Decision makers (a) familiar with the development plan of the country and the region, and prepared to apply CAILUP as a decision and management support system;
- International experts (b) with knowledge in specific disciplines and insight in the relevant issues in the region.

Data and information:

- Data on current bio-physical and socio-economic conditions (a) such as climate, land, water, population, household groups, farmers' preferences, etc.
- Data on current land use (a) such as land use types, crop requirements, cultivation techniques, production, etc.
- Information on the key and supplementary interventions in the region and development plans for the country and for surrounding regions (a).
- Information on existing models (b).

Hardware and software packages:

- Computers* (a) and peripherals (b) such as printers, digitizers, etc.
- Worksheet, programming and GIS software packages* (a) suitable for application by the modellers and the planning team.
- Existing models (b) relevant to the problems in the region.

5.7 In summary, the two objectives of the study have been attained. Taking into account major issues in land use planning methodology, the CAILUP was developed to facilitate integration in land use planning. A corresponding software system was developed and tested successfully for the Quan Lo Phung Hiep region with its specific bio-physical and socio-economic conditions.

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* No specific computers, programming languages and software packages are recommended, as CAILUP is developed on the basis of local conditions. Obviously, modern hardware and powerful software packages may facilitate the development and applications of CAILUP. However, the local capabilities, in terms of knowledge and facilities for operation and maintenance, and specifications of hardware and software packages, should match.

V.2 CHALLENGES IN DEVELOPMENT AND APPLICATIONS OF CAILUP - RECOMMENDATIONS

5.8 Although the above requirements (5.6) have been fulfilled, development and applications of CAILUP are still confronted with many challenges. These challenges refer to three main issues: integration (5.9 to 5.12), modelling (5.13 to 5.20) and applications (5.21 to 5.24). However, this classification is relative as some challenges refer to two or all three issues (e.g. 5.9, 5.12, 5.13, 5.16, 5.17) and are associated (e.g. 5.8 and 5.9; 5.8, 5.10, 5.12 and 5.13; 5.9, 5.17 and 5.18; 5.22 and 5.23, etc.).

Each challenge derives from the existence of two alternatives.

5.9 *'Single'* versus *'multi'*: this challenge refers to the tension between single disciplinary versus multidisciplinary, single sectoral versus multisectoral and single level (farm, regional, national, etc.) versus multilevel studies. Although development of 'building blocks' is a suitable technique for CAILUP, two directions are possible in its development and refinement: expansion ('multi') or intensification ('single'). This challenge is identical to that of allocating a limited resource to many users, or concentrating on one or a small number of users. In the past few decades, many 'single' models have been developed by specialists, therefore 'multi' models developed by generalists are required to integrate these 'single' models.

5.10 *'Bio-physical'* versus *'socio-economic'*: CAILUP is developed to integrate knowledge and insight in the bio-physical and socio-economic realms. These two realms can be compared with the 'body' and the 'mind' of a person, i.e. they require different methods for survey, study and management, but functionally they are always integrated. Current knowledge on the interactions among factors in each realm and in particular on the interactions among factors in the two different realms is still limited. A challenge for CAILUP is to avoid bias in integration, so that relevant factors in both realms and their interactions are included in the model in a well-balanced way.

5.11 *'Local'* versus *'global'*: depending on the objectives of application, two directions can be distinguished in developing a model:

(i) Focus on generally valid factors and interactions so that the model can be 'globally' used, as most of the model introduced in 2.20. Applications of such models are faced with the problem of specificity represented by local conditions.

(ii) Focus on factors and interactions for a specific case, so that the model can be used 'locally'. With the current widespread availability of computers, a large number of models with local names or even 'noname' are being developed by modellers in many countries.

For the first type, attempts have been made to increase the flexibility of the model by including as much as possible local factors and interactions, so that the model can be applied for various situations.

For the second type, although the model is developed and applied for a specific case, the modeller in many cases also has the intention to apply it for other cases without or with minor modifications.

A possible solution is to break up the model in small sub-models and modules so that the model can easily be adapted by adding a new module or replacing an existing module by a more appropriate version. However, implementation of this option is often difficult in reality. First, 'local' and 'global' factors and interactions have not been not explicitly distinguished by the modeller during model development, but are usually detected during model application. To increase the flexibility of a model, therefore requires efforts in reprogramming. Secondly, many models are provided in the form of compiled executable files, thus making it impossible to adapt them to local conditions.

5.12 *'Aggregation'* versus *'disaggregation'*: as discussed in 3.29, although aggregation may cause error, it cannot be avoided in regional planning, since point data have to be aggregated to area data. On the other hand, some types of data are only available at a higher spatial or temporal level than the lowest level applied in the calculations, e.g. at regional level or district level while calculations are performed at village level. In practice, therefore although disaggregation is avoided as much as possible, it may still be needed. A challenge is to determine a lowest level, so that all data can be aggregated or disaggregated to that level and errors caused by aggregation or disaggregation are minimized.

5.13 *'Simple'* versus *'complex'*: a model is a simplification of reality. If two models can be applied and provide the same output, a practical user, such as a manager, prefers the simple one, but others, such as many research scientists, may prefer the complexer one because:

(i) they think that complex models are more appropriate representations of the real world;
(ii) complex models can be applied to analyse more possibilities;
(iii) there is a preference of complexity in model application similar to the 'love of long words and complex structures' in using language.

A challenge in modelling is to identify the limit of 'simplicity' that still meets the demands of model application, but provides enough the 'complexity' to express the perceptions of users.

5.14 *'Explanatory'* versus *'descriptive'*: most models start from a descriptive version in which inputs and outputs are linked through a black-box. With increasing knowledge, the black-box is opened and the model is refined. Inside the black box, the modeller may find many black sub-boxes. Factors within these black sub-boxes and their interactions are included in a new version that is less 'black' (descriptive) and more 'white' (explanatory). Such cycles are continuously repeated during model refinement. However, the number of black sub-boxes is so large that a completely explanatory version, though ideal, will never be attained. A similar situation occurs when a model is expanded by adding new black boxes for explanation of relations among some factors. A challenge in modelling is to determine when the purpose of modelling has been attained and the cycle of opening and linking black boxes can cease.

5.15 *'Static'* versus *'dynamic'*: a dynamic process can simply be described by compiling a number of static states into a temporal sequence, as applied in animation techniques. In land use planning, the situation is more complex, as illustrated in Chapter IV. For example, not one, but many opportunities can be opened from a new static state in land use; to attain sustainable development, decisions in land use in any given year are based on the states in many years, rather than on only that in the preceding year.

5.16 *'Exact'* versus *'approximate'*: a model dealing with bio-physical processes usually requires exact data from intensive surveys and experiments, but a model dealing with socio-economic processes is usually based on approximate data from sampling, interviews and expert knowledge. A challenge in integration of these two types of processes is to decide which data can be used as inputs and which data have to be updated.

5.17 *'Quantitative'* versus *'qualitative'*: quantitative data are preferred in modelling as they are easily used. However, quantitative data are not always available, in particular those originating from 'expert knowledge'. A conceptual model is used to deal with qualitative data, but that is an abstract object that can hardly be used as means of communication among scientists, although it can be represented in various formats as pictures, flow charts, formulae, etc. An attempt has been made to convert qualitative data to quantitative data for mathematical modelling, by applying conventions for classification at international, national or local levels. Units such as kilogramme, meter and the Richter's earthquake scale are examples of international conventions. Soil or household group classifications as in Chapter IV represents national and local conventions. Conversion of qualitative data into quantitative data remains a major challenge in modelling.

5.18 *'Verifiable'* versus *'speculative'*: one type of models deals with repeatable or recurring systems, i.e. the same inputs, relations among components and outputs can be observed at different locations and times, such as the physical and bio-physical sub-models in CAILUP. Following model calibration, experimentation is possible to generate data for validation. Another type of models refers to unique systems and experimentation is impossible, such as the demography and socio-economic sub-models in CAILUP. Only a limited number of verifiable sub-models can be 'really' validated on the basis of observed data. Other speculative models are validated on the basis of expert knowledge. Integration of these two types is a challenge for planning models.

5.19 *'Single' operation* versus *'interactive' operations*: normally, users prefer models that generate final outputs after a single operation. However, for a planning tool such as CAILUP, interactive operations (see 3.31) are required. A larger number of iterations may cause difficulties to the user, in particular if a large data volume has to be analysed to limit error propagation, before starting a new iteration. Design of an interactive model suitable for the purpose of application is a challenge in modelling for planning.

5.20 *'Transparent'* versus *'opaque'*: a system like CAILUP requires a model so transparent that the user can easily understand input data, trace calculation sequences and analyse output data. On the other hand, the user prefers a system with fast calculations (no internal checks) and not requiring much effort in preparing input data and in analysing output data. The choice between a (more) transparent and opaque character is always a challenge in modelling.

5.21 *'Research'* versus *'management'*: many models have been developed as a scientific tool for research purposes to increase understanding, but planning requires readily applicable models. Selecting the purpose: research or management, is a challenge in modelling. However, during applications and after refinements, a research model may become a management tool and a management model may also be used in research. So, distinction between 'research' or 'management' may be only valid during model development.

5.22 *'Subjective'* versus *'objective'*: a model should simulate what happens in reality, therefore its outputs should be independent of the modeller and the user. Nevertheless, it is a simplification of reality in accordance with the explicit purpose formulated by the modeller. Parameters can be adjusted to generate outputs within a range accepted in model calibration, although they may fall out of the observed range. Model outputs are, more or less, subjective to the modeller and the user. Limiting the subjectivity of modeller and user is a challenge in modelling.

5.23 *'Short-term'* versus *'long-term'*: incorporation of short-term and long-term objectives, which are often contradictory, should be implemented in land use planning. A challenge in the application of CAILUP is the taking into account of the conflicts between short-term and long-term objectives in evaluation of development scenarios.

5.24 *'Explorative'* versus *'prospective'*: as discussed in 5.6, CAILUP is developed for explorative studies rather than for prospective studies. In practice, these studies can be considered different phases in a sequence comprising explorative, prospective and instrument studies. Data used as inputs in an explorative study in which various scenarios are examined, as illustrated in Chapter IV, refer to many preceding prospective studies such as those on population projection, national development plan, sectoral plans, etc. The explorative study will be followed by other prospective studies in which a highly probable scenario will be identified, to formulate an action plan, and subsequently instrument studies in which instruments to implement the plan, are selected. These selected instruments then serve as the key interventions in a new explorative study, and the sequence will be repeated towards the future.

5.25 The final conclusion, and also recommendation is that the above alternatives in each challenge always show a cyclic behaviour in which at any point in model development, a choice is being made for one alternative. For all the challenges, there is also a cycle in which one challenge becomes dominant and is the main subject of many studies during a number of years. The attempt of development and application of CAILUP in further studies is not to avoid these challenges, but to develop and apply a system adapted to these cycles.

Chapter V

APPENDICES

S1: **Examples for scenario and map definition**

S2: **Examples of input and output data of the Physical-Impact Sub-model [2]**

S3: **Examples of input and output data of the Bio-physical Sub-model [3]**

S4: **Examples of input and output data of the Economic Sub-model at Farm Level [4]**

S5: **Examples of input and output data of the Social Sub-model at Farm Level [5]**

S6: **Examples of input and output data of the Demography Sub-model [6]**

S7: **Examples of input and output data of the Land Use Weighting Sub-model [7]**

S8: **Examples of input and output data of the Land Use Allocation Sub-model [8]**

S9: **Examples of input and output data of the Production Sub-model [9]**

S10: **Examples of input and output data of the Supplementary Intervention Sub-model [10]**

S11: **Examples of input and output data of the Economic Sub-model at Regional Level [11]**

S12: **Examples of input and output data of the Social Sub-model at Regional Level [12]**

S13: **Examples of input and output data of the Environmental Impact Sub-model [13]**

S14: **Examples of input and output data of the Goal and Impact Analysis Sub-model [14]**

Appendices

Appendix S1: Examples for scenario and map definition.

File: MARI1.SCE (Example of a scenario definition file).

```
' ==============================================================================
' DATA ON SCENARIO DEFINITION FOR CAILUP FOR QUAN LO PHUNG HIEP REGION
' Last updated:  20 December 1995   by:  Chu Thai Hoanh
' ==============================================================================
' SCENARIO NAME
' ------------------------------------------------------------------------------
  RICE-ORIENTED + CONSTRUCTION SCHEDULE 1

' ------------------------------------------------------------------------------
' GENERAL INFORMATION TO ALL SUB-MODELS
' ------------------------------------------------------------------------------
' Number of years to be simulated
' ------------------------------------------------------------------------------
  30
' ------------------------------------------------------------------------------
' Construction schedule No.
' ------------------------------------------------------------------------------
  1
' ------------------------------------------------------------------------------
' Land use scenario (maximum 4 characters)
' ------------------------------------------------------------------------------
  MARI
' ------------------------------------------------------------------------------
' Extract fresh water for cultivation (Y/N)
' ------------------------------------------------------------------------------
  Y
' ------------------------------------------------------------------------------
' Change water pH (Y/N)
' ------------------------------------------------------------------------------
  N
' ------------------------------------------------------------------------------
' Input file for construction schedule
' ------------------------------------------------------------------------------
  CONSTRUC.SCH

' ------------------------------------------------------------------------------
' SPECIFIC INFORMATION TO EACH SUB-MODEL
'
' SUB-MODEL 2:  PHYSICAL IMPACT
' ------------------------------------------------------------------------------
' Rules of water variations.
' ------------------------------------------------------------------------------
  WARULE.S02
' ------------------------------------------------------------------------------
' Input data file to link nodes, fields to sub-units
' ------------------------------------------------------------------------------
  SUBUNODE.S02
' ------------------------------------------------------------------------------
' Number of cases with different water conditions
' ------------------------------------------------------------------------------
  6
' ------------------------------------------------------------------------------
' Year and input file of each case
' Year     Water level  Water pH   Number of
'         and salinity             sluices
' ------------------------------------------------------------------------------
   1,   NOEX0.WAI,     WApH.WAI,     0
   3,   NOEX3.WAI,     WApH.WAI,     3
   5,   NOEX5.WAI,     WApH.WAI,     6
...
```

File: LANDUSE.MAP (Example of a map definition file).

```
' ==============================================================================
' LAND USE MAP OF QUAN LO PHUNG HIEP REGION
' Last updated:  15 December 1995   by:  Chu Thai Hoanh
' ==============================================================================
' MAP NAME
' ------------------------------------------------------------------------------
  QUAN LO PHUNG HIEP
' ------------------------------------------------------------------------------
' LOCATION (x,y) AND COLOUR OF MAP NAME IN SCREEN (WIDTH 80, 43)
' ------------------------------------------------------------------------------
  10 4                  4
' ------------------------------------------------------------------------------
' INFORMATION ON BASE MAP
' ------------------------------------------------------------------------------
' File name
  QLPHBASE
' Single colour  (=1)   or multicolour  (>1)
  1
' Colour code of base map (any number if multicolour)
  6
' ------------------------------------------------------------------------------
' FILENAME OF OVERLAY MAP   (0 if no need)
' ------------------------------------------------------------------------------
  0
' ------------------------------------------------------------------------------
' FILENAME OF MAPPING UNITS
' Data structure in this file is:  No.,x,y, Unit name
' ------------------------------------------------------------------------------
  QLPH.XY
' ------------------------------------------------------------------------------
' FILENAME OF UNIT LABELS   (0 if no need)
' Data structure in this file is:   No.,x,y, Unit label
' ------------------------------------------------------------------------------
  QLPHWMU.XY
' ------------------------------------------------------------------------------
' LOCATION (x,y) OF LEGEND  (Maximum 80, 43)
' ------------------------------------------------------------------------------
  48     47
' ------------------------------------------------------------------------------
' NUMBER OF DATA FILES
' ------------------------------------------------------------------------------
  5
' ------------------------------------------------------------------------------
' INFORMATION ON DATA FILE 1
' ------------------------------------------------------------------------------
' Filename
  C:\CAILUP\INPUT\EXISTING.S03
' Name of Data type
  CURRENT LAND USE
' Colour code of this name
  14
' Total number of data type
  32
' Colour code of data type name on screen
  2
' ------------------------------------------------------------------------------
' No. DATA NAME                         TYPE          UNIT        DISPLAY
'                                    (0=character)             (0=no displayed)
'                                    (1=numeric)                (1=displayed)
' ------------------------------------------------------------------------------
  1,  Sub-unit,                          1,             ,            0
  2,  Water management unit,             1,             ,            0
  3,  Total area,                        1,           ha,            1
  4,  Single traditional rice,           1,           ha,            1
...
```

Appendix S2: Examples of input and output data of the Physical-Impact Sub-model [2]

File: CONSTRUC.SCH (Example of input data on construction schedules)

```
' ===============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Physical Impact Sub-model [2]
' CONSTRUCTION SCHEDULES
' Last updated:  20 November 1992   by:  Truong Tien Dung
' (Data from the Institute for Hydraulic Construction Survey and Design)
' ===============================================================================
'                                      OPTION 1                      OPTION  2           ...
' No.        Items                Start         End             Start        End
'                            quarter year quarter year  quarter year quarter year
' -------------------------------------------------------------------------------
' MAIN SLUICES & CANALS
  1 , My Phuoc,                   1       1      8       2      1       1      6       2   ...
  2 , Cai Trau,                   5       2      8       2      3       1      6       2   ...
...
' -------------------------------------------------------------------------------
' SECONDARY SLUICES & ON-FARM SYSTEMS (in 20 water management units)
  1 ,         28               ,  1       1     10       3      1       1      8       2   ...
  2 ,         29               ,  1       1     10       3      1       1      8       2   ...
...
```

File: SUBUNODE.S02 (Example of a matrix linking sub-units to nodes and fields)

```
' ===============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Physical Impact Sub-model [2]
' MATRIX LINKING SUB-UNITS TO NODES AND PLAINS OF THE WATER SCHEME
' AND LIST OF REQUIRED SLUICES TO PROTECT FROM SALT WATER FOR EACH SUB-UNIT
' Last updated:  20 December 1993   by:  the Hydraulic and Salinity Modelling Group
' Notes on required sluices:  0 = no need for this sub-unit
'                             1 = need this sluice to protect for sub-unit
'                             2 = outside the sluice system, not protected
' Abbreviations:            Sub = sub-unit         WMU = Water management unit
' ===============================================================================
' Sub WMU    Province  District   Village     Node Plain             Sluices
'                                                          S1   S2   S3   S4   S5   S6   S7...
' -------------------------------------------------------------------------------
  1,  28,        HG,     MY TU,  Long Hung,   75   12      1    0    0    0    0    0    0...
  2,  28,        HG,     MY TU,  Hung Phu,    76   12      1    1    0    0    0    0    0...
...
```

File: WARULE.S02 (Example of input data on rules in variation of water conditions)

```
' ===============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP AREA - Physical Impact Sub-model [2]
' RULES IN VARIATION OF WATER CONDITIONS
' Last updated:  27 June 1994   by:  Chu Thai Hoanh
' ===============================================================================
' Number of years in which water pH is low (in worst case, 1000 years)
' -------------------------------------------------------------------------------
  3
' -------------------------------------------------------------------------------
' Last step of low water pH   (> 24 if the effect lasts to the next year)
' -------------------------------------------------------------------------------
  26
```

File: NOEX0.S02 (Example of input data on current water level and salinity)

```
' ===============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP AREA - Physical Impact Sub-model [2]
' WATER LEVEL AND SALINITY WITHOUT SLUICES OR ADDITIONAL WATER EXTRACTION
' Last updated:  24 January 1994   by:  the Hydraulic and Salinity Modelling Group
' (Water level and salinity data extracted from outputs of VRSAP model, pH is observed).
=================================================================================
' Step      Node (N)       Code        Water level (cm)      Average             pH
'        or Plain (P)              Max.   Min.  Average   Salinity (o/oo)
' -------------------------------------------------------------------------------
   3,         N,            126     48    -42     -1          9.9              6.9
   3,         N,            134     47    -41     -1         15.2              7.0
...
```

File: MARI13.S02 (Example of output data on water conditions)

```
' ************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP AREA - Physical Impact Sub-model [2]
' WATER CONDITIONS                                 Generated at 18:12:16 on 06-01-1994
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No
' ************************************************************************************
' Sub-unit  Year  Step  CanalWL  MaxCanalWL  PlainWL  PlainMaxWL  Tide  Salinity    pH
' ------------------------------------------------------------------------------------
     1        1     3     24        81         34         37      132     1.0       7.1
     2        1     3     24        75         34         37      125     1.8       7.1
...
```

Appendix S3: Examples of input and output data of the Bio-physical Sub-model [3]

File: EXISTING.S03 (Example of input data on current land use)

```
' ====================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP AREA - Bio-physical Sub-model [3]
' LAND USE AREA IN 1990
' Last updated:  27 January 1992    by:  Le Khanh Chien
' (Data from the Mekong Delta Water Resources Planning Office)
' Abbreviations:                    OneTra = Single traditional rice
' Sub     = Sub-unit                OneHY  = Single high yielding rice
' WMU     = Water management unit   SATra  = Double rice, Summer-Autumn and traditional
' Prov    = Province                SAHY   = Double rice, Summer-Autumn and high yielding
' Dist    = District                SAWS   = Double rice, Summer-Autumn and Winter-Spring
' Total   = Total area              SA     = Summer-Autumn rice
' Popu    = Population (persons)    2ndTra = Second traditional rice
' PType   = Population type         2ndHY  = Second high yielding rice
' Elev    = Elevation (cm)          WS     = Winter-Spring rice
' BeanWS = Winter-Spring beans      ShPo   = Shrimps in ponds         Mela = Melaleuca
' BeanSS = Spring-Summer beans      ShRi   = Shrimps in rice fields   Mang = Mangrove
' BeanSA = Summer-Autumn beans      ShSa   = Shrimps in salt fields   Euca = Eucalyptus
' Sugar  = Sugarcane                ShNa   = Shrimps in canals        Nipa  = Nipa palm
' Sugar1 = Sugarcane, 1st year      PrPo1  = Prawns in ponds, one crop
' Sugar2 = Sugarcane, 2nd year      PrPo2  = Prawns in ponds, two crops
' Sugar3 = Sugarcane, 3rd year      PrRi1  = Prawns in rice fields, one crop
' Pine    = Pineapple               PrRi2  = Prawns in rice fields, two crops
' Pine1   = Pineapple, 1st year     PrNa   = Prawns in canals
' Pine2   = Pineapple, 2nd year     FiPo   = Fish pond
' Pine3   = Pineapple, 3rd year     FiNa   = Fish in canals
' Note:  All land use areas are in hectares.   Population type:  R = Rural, U = Urban
'=====================================================================================
' Sub WMU  Prov   Village      Popu  PType   Elev  Total OneTra  OneHY  SATra SAHY ...
'=====================================================================================
  1,  28,   HG, Long Hung,    4115,   R,      30    1368   232    363    155    0  ...
  2,  28,   HG,  Hung Phu,   10759,   R,      35    3698   638    888    266    0  ...
...
```

File: SOILTYPE.S03 (Example of input data on soil types)

```
' ====================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP AREA - Bio-physical Sub-model [3]
' PERCENTAGE OF SOIL TYPE IN EACH SUB-UNIT
' Last updated:  20 August 1991    by:  Tran Van Khanh
' (Data from the Sub-Institute for Agricultural Planning and Projection)
' Abbreviations:          Sub = Sub-unit     WMU = Water management unit
' Soil classification:
'           Vietnamese                  FAO-UNESCO               USDA
' Cz = Raised ridge sandy soils      Haplic aenosols         Fluventic tropopsamment
' Mm = Saline mangrove soils         Gleyic solonchaks       Salic hydraquents
'...
' ====================================================================================
' Sub     Village    Dominant soil type        Types:    1     2     3     4    5     6    ...
'                       (Symbol)                 (%)      Cz    Mm    Mn    M    Mi  SplMm ...
' ------------------------------------------------------------------------------------
    1,  Long Hung,        Sj2,                         0.0   0.0   0.0   0.0  0.0   0.0   ...
    2,  Hung Phu,         Sj2,                         0.0   0.0   0.0   0.0  0.0   0.0   ...
...
```

File: AGRIRULE.S03 (Example of input data on rules in agricultural yield)

```
' ============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' RULES IN AGRICULTURAL YIELD       Last updated:  30 November 1991   by:  Nguyen Manh Hung
' (Data from the Sub-Institute for Agricultural Planning and Projection)
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' ============================================================================
' RICE CROPS
' ============================================================================
' Maximum observed rice yield (t/ha):  HY (high yielding) varieties  Traditional varieties
' ----------------------------------------------------------------------------
                                                   7                      5
' ----------------------------------------------------------------------------
' Input for cultivation:  SA  2ndHY  2ndTra  WS  OneHY  OneTra (in rice equivalent t/ha)
' (= 0 to generate all low yield values)
' ----------------------------------------------------------------------------
                         1.8   1.8    1.3   1.8   1.8    1.3
' ----------------------------------------------------------------------------
' Crop length        HY: 8 steps                    Traditional (normal case): 11 steps
'         Seedling  Tillering  Yield formation    Seedling  Tillering  Yield formation
' ----------------------------------------------------------------------------
              2         3          3                 5          4          2
' ----------------------------------------------------------------------------
' Effect of water depth on yield of HY variety
'          Seedling stage           Tillering stage        Yield formation stage
' ----------------------------------------------------------------------------
  x cm,   0    10    30  1000        0   20    50  1000        0   20    70  1000
  y,      1     1     0     0        1    1     0     0        1    1     0     0
' ----------------------------------------------------------------------------
' Number of SA crop cases,  initial and final steps of each case  (in priority order)
'                           Case 1      Case 2    Case 3     Case 4     Case 5     Case 6
' ----------------------------------------------------------------------------
              6              9  16      10  17     11  18     12  19     13  20     8  15
...
' ----------------------------------------------------------------------------
' Percentage of unfavourable years for production
' WMU:          28 29 30a 30b 31 32 33 34 35 36 37 38 39 40 41 42 43 44 52 54
' ----------------------------------------------------------------------------
  For SA rice, 40 35  30  20 10 15 15 20 15 15 15 10 15 10  5 25 20 20 10  5
...
' ----------------------------------------------------------------------------
' Effect of soil factor on rice yield
'   Cz     Mm     Mn     M     Mi   Sp1Mm Sp2Mm  Sp1M  Sp2M  Sj1M  Sj2M    Sj1   Sj2    TS
' ----------------------------------------------------------------------------
  0.7     0     0.8    0.8    1     0     0     0.8   0.8    0.6   0.8    0.6   0.8    0.5
...
' ============================================================================
' 1. SUGARCANE      2. PINEAPPLE      3. BEANS
' ============================================================================
' Yield of sugarcane and pineapple in each year as proportion of maximum observed yield
'                                   1st year      2nd year      3rd year
' ----------------------------------------------------------------------------
                                      0.8           1.0           0.8
' ----------------------------------------------------------------------------
' Maximum observed yield (t/ha)    Sugarcane     Pineapple       Beans
' ----------------------------------------------------------------------------
                                      80            30             2
' ----------------------------------------------------------------------------
' Input for cultivation:  Sugarcane  Pineapple    Beans (in product equivalent t/ha)
' (= 0 to generate all low yield values)
' ----------------------------------------------------------------------------
                               0         0        0
' ----------------------------------------------------------------------------
' Crop length (by steps)        Sugarcane    Pineapple     Beans
' (sugarcane: 22 steps, but effect of water conditions only significant in initial 18 steps)
' ----------------------------------------------------------------------------
                                  18          24            6
' ----------------------------------------------------------------------------
' Effect of water depth on yield of upland crops (due to loss of land between raised beds)
'         Sugarcane                      Pineapple                      Beans
' ----------------------------------------------------------------------------
  x cm,   0    50    70   1000        0   50    70   1000        0   50    70   1000
  y,      1   0.5   0.3      0        1  0.5   0.3      0        1  0.5   0.3      0
...
```

File: FISHRULE.S03 (Example of input data on rules in fisheries yield)

```
' ==========================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' RULES IN FISHERIES YIELD          Last updated:  20 January 1992   by:  Tran Duc Can
' (Data from the Institute for Aquaculture Research No.II)
' ==========================================================================
' Fish group  1:   ShPo1 = Shrimps in ponds, 1st crop,  extensive
' Fish group  2:   ShPo2 = Shrimps in ponds, 2nd crop,  extensive
' Fish group  3:   ShSa  = Shrimps in salt fields, one crop, extensive
' Fish group  4:   ShRi  = Shrimps in rice fields, one crop, extensive
' Fish group  5:   ShNa  = Shrimps in canals (natural conditions)
' Fish group  6:   PrPo1 = Prawns in ponds, 1st crop, semi-intensive
' Fish group  7:   PrPo2 = Prawns in ponds, 2nd crop, semi-intensive
' Fish group  8:   PrRi1 = Prawns in rice fields, 1st crop, semi-intensive
' Fish group  9:   PrRi2 = Prawns in rice fields, 2nd crop, semi-intensive
' Fish group 10:   PrNa  = Prawns in canals (natural conditions)
' Fish group 11:   FiPo  = Fish in ponds, full year (only fresh water fish is considered)
' Fish group 12:   FiNa  = Fish in canals (natural conditions)
' --------------------------------------------------------------------------
' Maximum observed yield of fish groups (kg/crop-ha of water surface)
' ShPo1  ShPo2  ShSa  ShRi  ShNa  PrPo1  PrPo2  PrRi1  PrRi2  PrNa  FiPo  FiNa
' --------------------------------------------------------------------------
  250    250    170   220    30    700    700    250    250    10   4000   50
' --------------------------------------------------------------------------
' Natural source of shrimp seeds in water management units
'  28   29  30a 30b  31  32  33  34  35  36  37  38  39  40  41  42  43  44  52  54
' --------------------------------------------------------------------------
  0.1 0.4  0.4 0.7  0.6 0.4 0.7 0.7 0.3 0.6 0.4 0.2 0.2 0.8 0.7 0.9 1.0 1.0 0.2 0.2
' --------------------------------------------------------------------------
' Initial and final steps in cropping calendars of fisheries
' ShPo1  Shpo2    ShSa    ShRi    ShNa  PrPo1  PrPo2  PrRi1  PrRi2   PrNa   Fipo   FiNa
' --------------------------------------------------------------------------
  6 15   18 27  13 21  23 32  10 26  13 22   1 10  13 22   1 10  17 27   2 23   1 24
' --------------------------------------------------------------------------
' Depth of water intake below ground surface (cm)
' Shpo1  Shpo2  ShSa   ShRi    ShNa  PrPo1  PrPo2  PrRi1  PrRi2  PrNa   FiPo   FiNa
' --------------------------------------------------------------------------
  50     50     60     60      0     50     50     60     60      0      0      0
' --------------------------------------------------------------------------
' Required average high water level in rice field for shrimps and prawns (cm)
' --------------------------------------------------------------------------
  5
' --------------------------------------------------------------------------
' Pond depth in relation to ground surface (cm)
' --------------------------------------------------------------------------
  130
' --------------------------------------------------------------------------
' Yield of shrimps by age   (Values < 1 are from farm records,  > 1 are estimated)
' --------------------------------------------------------------------------
   x steps,  0     6     8     10     12     14     20
   y,        0  0.65  0.80    1.0    1.1    1.1    1.0
...
```

File: FORERULE.S03 (Example of input data on rules in forest production)

```
' ==========================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' RULES IN FORESTRY PRODUCTION
' Last updated:  02 January 1992    by:  Nguyen Van Duyet
' (Data from the Sub-Institute for Forest Inventory and Planning)
' ==========================================================================
' Annual yield:   Melaleuca          Mangrove             Eucalyptus            Nipa palm
'               (m3/ha-year)       (m3/ha-year)          (m3/ha-year)       (leaves/ha-year)
' Site class: Poor Medium Rich   Poor Medium Rich    Poor Medium Rich    Poor Medium Rich
' --------------------------------------------------------------------------
  x class,      1     2     3      1     2     3      1     2     3      1     2     3
  y,          4.3   6.0   7.7    5.8   8.8  11.8   10.0  12.8  15.6   7000 11000 17000
' --------------------------------------------------------------------------
' Effect of water depth on site class of Melaleuca    and mangrove
'                Medium        Rich        Poor          Rich       Medium       Poor
'
' --------------------------------------------------------------------------
  Water depth (m),        0.5         1.0                          0.5          1.0
...
```

File: MARI1.1HY (Example of output data for rice yield)

```
' ***************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' SINGLE HIGH YIELDING RICE                            Generated at 18:04:56 on 06-30-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes  Water pH change: Yes  Year: 1  Maximize SA rice: Yes  Pump WS: Yes
' Abbreviations: Sub = Sub-unit WL = Water level (cm)  Soil  = Effect of soil factor
' WMU   = Water manag. unit     Sa = Water salinity (‰) Water = Effect of water conditions
' It    = Initial time step     pH = Water pH           Solar = Effect of solar radiation
' Ft    = Final time step       %Y = % after reduction  Two crop = Effect of two
' Yield = Crop yield (t/ha)  Final = Effect of all factors          consecutive crops
' Case  = Unfavourable (U) or Favourable (F) weather conditions
' ***************************************************************************************
' Sub WMU  Village  Case          Seedling...              Soil Water Solar Two  Final Yield
'                          It St WL  %Y  Sa   %Y  pH  %Y...                      crop
' ---------------------------------------------------------------------------------------
   1, 28, Long Hung,  U,  14 21  5 100  0.0 100 7.0 100      75    74    76   100    39   2.8
   1, 28, Long Hung   F,  14 21  5 100  0.0 100 7.0 100      75    74    76   100    39   2.8
...
```

File: MARI1.BEA (Example of output data for yield of beans)

```
' ***************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' YIELD OF BEANS                                       Generated at 18:04:56 on 06-30-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes          Water pH change: Yes       Year: 1
' Abbreviations:  see file MARI1.1HY above.
' ***************************************************************************************
' Sub WMU  Village                       Summer-Autumn                               ...
'                      It Ft    WL  %Y  Sa   %Y  pH  %Y  Soil Water Final Yield
' ---------------------------------------------------------------------------------------
   1, 28, Long Hung,   9 14     9  88  0.0 100 7.1 100    54   88    48     1.0  ...
   2, 28, Hung Phu,    9 14     4  95  0.0 100 7.1 100    56   95    53     1.1  ...
 ...
```

File: MARI1.SPO (Example of output data for shrimp yield)

```
' ***************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' SHRIMPS IN PONDS AND SALT FIELDS                    Generated at 20:26:31 on 07-18-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes          Water pH change: Yes        Year: 1
' Abbreviations:             WL = Water level (cm)            %Y = % yield after reduction
' Sub = Sub-unit            Sa = Water salinity (‰)       Wat = Effect of aver.water conditions
' WMU = Water man.unit       pH = Water pH                  Soil = Effect of soil factor
' It  = Initial step     MinpH = Minimum water pH        Final = Effect of all factors
' Ft  = Final step       Depth = Pond water depth (cm) Yield = Yield of shrimp (kg/ha)
' ***************************************************************************************
' Sub WMU  Village  Source SHRIMPS IN PONDS, 1st CROP  (Effect of age = 100%)          ...
'                 of seeds Soil WL  %Y  Sa  %Y  pH  %Y Wat MinpH %Y Depth %Y Final Yield
' ---------------------------------------------------------------------------------------
   1, 28, Long Hung,  10      62 137 100 1.0  16 7.2 100  16  7.1 100  -38 100   1    3 ...
   2, 28,  Hung Phu,  10      64 132 100 1.4  24 7.2 100  24  7.1 100  -24 100   2    4 ...
...
```

File: MARI1.FOR (Example of output data for forest yield)

```
' ***************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Bio-physical Sub-model [3]
' FOREST PRODUCTION                                    Generated at 20:26:31 on 07-18-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes          Water pH change: Yes        Year: 1
' Abbreviations:
' Sub = Sub-unit  Soil = Effect of soil factor         WL  = Site class by water depth
' WMU = Water     Water = S.class by water conditions  Sal = Site class by salinity
'      man.unit  Final = Site class by all factors    Tide = Site class by tide fluctuation
' Yield = Annual increment (m3/ha/year)  Notes:  Site classes: 1 = Poor 2 = Medium 3 = Rich
' ***************************************************************************************
' Sub WMU  Village          MELALEUCA                    EUCALYPTUS                NIPA  PALM
'                    Soil Water Final Yield   WL Sal Soil Water Final Yield  Sal  Yield
' ---------------------------------------------------------------------------------------
   1, 28, Long Hung, 100  2.0    2.0     6.0   1.4 3.0 100    2.2    2.2  13.3   0.0    0
   2, 28,  Hung Phu, 100  2.0    2.0     6.0   1.6 3.0 100    2.3    2.3  13.6   0.0    0
 ...
```

Appendix S4: Examples of input and output data of the Economic Sub-model at Farm Level [4]

File: AGRIFI.WQ1 (Example of a worksheet for financial analysis for agricultural production)

ECONOMIC STUDIES FOR QUAN LO PHUNG HIEP REGION
FINANCIAL ANALYSIS FOR RICE CROPS (1 ha/year)
Last updated: 20 July 1995 by: Chu Thai Hoanh
(Data from the Sub-Institute for Agricultural Planning and Projection and ESSA Ltd., updated with prices in NEDECO reports)
Abbreviations: see file EXISTING.S03 in Appendix S3

I. Land use conversion costs from uncultivated land (1,000 VN Dong/ha)
Note: All labourers are hired

Item	Without water management system						With water management system					
	One Trad	One HY	SA	2nd Trad	2nd HY	WS	One Trad	One HY	SA	2nd Trad	2nd HY	WS
1. Topographic survey	2.50	2.50	1.25	1.25	1.25	1.25	2.50	2.50	1.25	1.25	1.25	1.25
2. Soil survey	1.50	1.50	0.75	0.75	0.75	0.75	1.50	1.50	0.75	0.75	0.75	0.75
3. Feasibility study	2.50	2.50	1.25	1.25	1.25	1.25	2.50	2.50	1.25	1.25	1.25	1.25
4. Relocation survey	0.50	0.50	0.25	0.25	0.25	0.25	0.50	0.50	0.25	0.25	0.25	0.25
5. Land clearing	1500	1500	750	750	750	750	1500	1500	750	750	750	750
6. Excavation/road level 2	60	60	30	30	30	30	60	60	30	30	30	30
7. Excavation/road level 3	120	120	75	75	75	75	120	120	75	75	75	75
8. Levelling	500	500	400	400	400	400	500	500	400	400	400	400
Total	2187	2187	1259	1259	1259	1259	2187	2187	1259	1259	1259	1259

II. Operating quantities & costs (1,000 VN Dong/ha)
Notes: - All labour farmer's family except those for threshing
- Hired labours are paid by rice equivalent for threshing
- No cost for renting land - Cost-Fami. = Costs excluding family labour

Item	Unit	Unit price	Without water management system									
			OneTrad			OneHY			Summer-Autumn			...
			Quantity	Cost	Cost-Fami.	Quantity	Cost	Cost-Fami.	Quantity	Cost	Cost-Fami.	
A. MATERIALS COSTS												
1. Seed	kg	1	100	100	100	150	150	150	180	180	180	...
2. Fertilizer												
- Urea	kg	2.3	33	76	76	50	115	115	33	76	76	...
- DAP	kg	4	0	0	0	17	68	68	17	68	68	...
- NPK 16-16-8	kg	2.8	0	0	0	0	0	0	17	48	48	...
3. Pesticide+Herbicide												
- Pesticide	bottle	8	6	48	48	6	48	48	6	48	48	...
- Herbicide	kg	20	1	20	20	1	20	20	1	20	20	...
4. Pumping for irrigation												
- Fuel	litre	2	0	0	0	0	0	0	30	60	60	...
- Pumping cost	kg	1	0	0	0	0	0	0	55	55	55	...
5. Land Preparation												
- Tilling (2 times)	kg	1	200	200	200	200	200	200	220	220	220	...
B. LABOUR COSTS												
6. Seed soaking+broadcasting	man-day	10	1	10	0	2	20	0	2	20	0	...
7. Field clearing+levelling	man-day	10	10	100	0	10	100	0	10	100	0	...
8. Growing Season												
- Field work+weeding	man-day	10	20	200	0	30	300	0	30	300	0	...
- Fertilizing (3 times)	man-day	10	1	10	0	3	30	0	3	30	0	...
- Spraying (2 times)	man-day	10	1	10	0	2	20	0	2	20	0	...
9. Harvesting												
- Cutting+gathering	man-day	10	15	150	0	20	200	0	20	200	0	...
- Threshing	kg	1	125	125	125	200	200	200	150	150	150	...
- Drying+storing	man-day	10	3	30	0	5	50	0	4	40	0	...
- Transportation	man-day	10	3	30	0	5	50	0	4	40	0	...
C. OTHER COSTS												
10. Water charge	kg	1	0	0	0	0	0	0	20	20	20	...
11. Agricultural Tax	6% yield											
Total operating costs				1149	549		1611	801		1735	945	...
Total labour-days			54			77			75			
Total family labour-days			54			77			75			

File: FISHFI.WQ1 (Example of a worksheet for financial analysis for fisheries production)

ECONOMIC STUDIES FOR QUAN LO PHUNG HIEP REGION
FINANCIAL ANALYSIS FOR FISHERIES (1 ha/year)
Last updated: 20 July 1995 by: Chu Thai Hoanh
(Data from the Institute for Aquaculture Research No.II, ESSA Ltd. and NEDECO)
Abbreviations: see file EXISTING.S03 in Appendix S3

I. Land use conversion costs from uncultivated land (1,000 VN Dong/ha)
Note: - All labour is hired 'Without' & 'with' water management system

Item	ShPo	Shri	ShSa	ShNa	PrPo1	PrPo2	PrRi1	PrRi2	PrNa	FiPo	FiNa
1. Pre-construction	149	124	99	0	495	0	124	0	0	495	0
2. Access road construction	99	413	165	0	660	0	413	0	0	660	0
3. Land clearing	198	83	66	0	330	0	83	0	0	330	0
4. Dike construction	2871	1238	1650	0	9405	0	1238	0	0	9405	0
5. Drainage ditch excavation	248	1238	330	0	1155	0	1238	0	0	1155	0
6. Housing	495	413	330	0	1650	0	413	0	0	1650	0
7. Gate construction	891	413	495	0	1815	0	413	0	0	1815	0
8. Irrigation canal	0	0	0	0	825	0	0	0	0	825	0
9. Levelling	0	206	165	0	165	0	206	0	0	165	0
Total	4950	4125	3300	0	16500	0	4125	0	0	16500	0

II. Operating quantities & costs (1,000 VN Dong/ha) (for both 'without' and 'with' cases
Notes: - Skilled and unskilled labour are from farmer's family for one crop/year
- Specialists are hired Cost-Family = Costs excluding family labour force

Item	Unit	Unit price	ShPo Quantity	ShPo Cost	ShPo Cost-Family	ShRi Quantity	ShRi Cost	ShRi Cost-Family	...
1. Equipment	lump sum			660	660		124	124	...
2. Fuel & Oil	litres	2.0	80	160	160	60	120	120	...
3. Seeds for shrimps	1000 seeds	210.0	0	0	0	0	0	0	...
for prawns	1000 seeds	50.0							
for fish	1000 seeds	33.0							
4. Fertilizer	kg	4.0	0	0	0	10	40	40	...
5. Feed: low protein	kg	0.8	0	0	0	120	96	96	...
medium protein	kg	2.0	0	0	0	0	0	0	...
high protein	kg	3.0	0	0	0	0	0	0	...
6. Pesticides/Lime	kg	0.4	0	0	0	400	160	160	...
7. Maintenance	lump sum			990	990		495	495	...
8. Labour: Skilled	man-day	10.0	20	200	0	20	200	0	...
9. Labour: Unskilled	man-day	5.0	180	900	0	60	300	0	...
10. Labour: Specialist	man-day	10.0	10	100	100	10	100	100	...
11. Taxes (% of gross income)									
12. Housing	lump sum			84	84		84	84	...
Total operating costs				3094	1994		1718	1218	...
Total labour-days			210			90			
Total family labour-days			200			80			

File: FINAN.S04 (Example of input data for financial analysis)

' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Farm Level [4]
' **FINANCIAL ANALYSIS** (ha/year) Original worksheet file: FINAN.WQ1
' Last updated: 29 July 1995 by: Chu Thai Hoanh
' (Data from planning institutes and ESSA Ltd., updated with prices from NEDECO reports)
' Abbreviations: see file EXISTING.S03 in Appendix S3
' Note: Case=0: without, Case=1: with water management system Unit: 1,000 VN Dong/ha-year

' Item	Year	Case	OneTra	OneHY	SA	2ndTra	2ndHY	WS	...
' Yield unit:			tonne	tonne	tonne	tonne	tonne	tonne	
Number of years,	2								
'Land use conversion costs,	1	0	2187	2187	1259	1259	1259	1259	...
'Operational costs (excluding tax),	1	0	549	801	945	542	786	1150	...
'Percentage of working capital,	1	0	50	50	50	50	50	50	...
Required capital,	1	0	2492	2608	1752	1550	1672	1854	...
'Interest (%/year),	1	0	24	24	24	24	24	24	...
'Repayment period (years),	1	0	10	10	10	10	10	10	...
'Annual repayment for conversion costs,	1	0	594	594	342	342	342	342	...
Capital intensity (Repayment+Operation,	1	0	1203	1435	1327	924	1168	1532	...
Farm-gate price,	1	0	1000	1000	1000	1000	1000	1000	...
Tax (% gross income),	1	0	6	6	6	6	6	6	...
Family labour (labour-day),	1	0	54	77	75	78	110	77	...

...

File: FARMRULE.S04 (Example of input data on economic rules at farm level)

```
' ===========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Farm Level [4]
' RULES IN ECONOMICS AT FARM LEVEL
' Last updated:   20 July 1995    by:    Chu Thai Hoanh
' (Data from the Institute of Hygiene and Public Health and NEDECO)
' ===========================================================================================
' Percentage of household groups in different sub-unit investment levels
' Sub-unit level  /  Household groups:  Rich   Well-to-do  Medium  Poor   Very poor
' -------------------------------------------------------------------------------------------
  Rich level,                           30     30          20      17     3
  Well-to-do level,                     17     30          30      20     3
  Medium level,                         16     18          31      32     3
  Poor level,                           1      5           22      52     20
  Very poor level,                      0      3           19      49     29
' -------------------------------------------------------------------------------------------
' Investment capacity of household group (1,000 VN Dong)
' Year      Rich  Well-to-do  Medium   Poor  Very poor
' -------------------------------------------------------------------------------------------
  Number of subsequent years,  4
   1       45240     15080      9048     4524      2262
   2       58812     19604     11762     5881      2941
;..
' -------------------------------------------------------------------------------------------
' Number of years required to upgrade household group with respect to capital formation
'           Without water management system              With water management system
'   Rich  Well-to-do  Medium  Poor  Very poor     Rich  Well-to-do  Medium  Poor  Very poor
' -------------------------------------------------------------------------------------------
    0         5         6      7      8           0        3          4      5       6
' -------------------------------------------------------------------------------------------
' Percentage of households getting credit support:  Without case    With case
' -------------------------------------------------------------------------------------------
                                                     30              50
```

File: HOUSE.S04 (Example of input data on household groups)

```
' ===========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Farm Level [4]
' SUB-UNIT INVESTMENT LEVEL
' Last updated:    20 July 1995         by:    Chu Thai Hoanh
' (Data based on planners' knowledge)
' ===========================================================================================
' Sub WMU Province   District    Village    Sub-unit level  Credit support (0=No, 1=Yes)
'                                                           Without case  With case
' -------------------------------------------------------------------------------------------
   1, 28,   HG,       MY TU,   Long Hung,       2              0             0
   2, 28,   HG,       MY TU,    Hung Phu,       2              0             1
   ...
```

File: MARI16.S04 (Example of output data on bio-physical/economic feasibility)

```
' *******************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Farm Level [4]
' BIO-PHYSICAL/ECONOMIC FEASIBILITY                 Generated at 21:52:14 on 08-02-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes   Water pH change: No          Year: 6
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' Unit of net income: 1,000 VN Dong/ha/year,    Feasibility & capacity: %
' *******************************************************************************************
' Sub WMU  Village                 Item               OneTra  OneHY  SATra  SAHY   SAWS ...
'                                        Yield unit:  tonne   tonne  tonne  tonne  tonne ...
' -------------------------------------------------------------------------------------------
  1, 28, Long Hung, Yield,                              3.1     4.1    7.0    6.3    9.3 ...
                    Net income,                        1897    2665   4749   3805   6441 ...
                    Income feasibility,                15.6    22.0   39.2   31.4   53.1 ...
                    Investment capacity,              100.0   100.0   97.0   97.0   97.0 ...
                    Bio-phys./econ. feasibility,       15.6    22.0   38.0   30.4   51.5 ...
...
```

Appendix S5: Examples of input and output data of the Social Sub-model at Farm Level [5]

File: FARMRULE.S05 (Example of input data on social rules at farm level)

```
' ==========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Social Sub-model at Farm Level [5]
' ECONOMIC AND SOCIAL RULES AT FARM LEVEL
' Last updated:    08 August 1995    by:  Chu Thai Hoanh
' (Data based on planners' knowledge)
'==========================================================================================
' 1st RULE:  Priority if difference in net income is minor
' OneTra OneHY SATra SAHY SAWS Sugar Pine Euca Mang Mela ShPo ShSa ShRi PrPo1 PrPo2 ...
' ------------------------------------------------------------------------------------------
   1      2     3    4    5     6     7   10    9    8   12    0    0    13    14  ...
' ------------------------------------------------------------------------------------------
' Percentage of difference below which a higher priority type will be selected
' OneTra OneHY SATra SAHY SAWS Sugar Pine Euca Mang Mela ShPo ShSa ShRi PrPo1 PrPo2 ...
'-------------------------------------------------------------------------------------------
    0     2     2    2    5     5     5    5    5    5    5    0    5    5     5     5
' ------------------------------------------------------------------------------------------
' 2nd RULE:  Limit of income per capita (1,000 VN Dong) below which farmer will not accept
' ------------------------------------------------------------------------------------------
  Number of subsequent years,    4
' Year  Rich group  Well-to-do  Medium  Poor    Very poor
   1        15         12          9      6       3
   2        20         16         12      8       4
   3        25         20         15     10       5
   4        29         24         18     12       6
' ------------------------------------------------------------------------------------------
' 3rd RULE:  Preference value (%) of agricultural products
' based on consumption preference, farm storage and local processing facilities
'                    Rich group  Well-to-do  Medium   Poor   Very poor
' ------------------------------------------------------------------------------------------
  Rice,                 100         100        100     100      100
  Sugarcane,            70           60         50      40       30
  Pineapple,            40           35         30      25       20
;...
' ------------------------------------------------------------------------------------------
' 4th RULE:  Preference values of traditional rice and HY rice
' based on preference in rice consumption
'                       Rich group  Well-to-do  Medium   Poor  Very poor
' ------------------------------------------------------------------------------------------
  Traditional rice,       100         100         100     100     100
  HY rice,                 70          80          90     100     100
```

File: MARI16.S05 (Example of output data on integrated feasibility)

```
'******************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Social Sub-model at Farm Level [5]
' INTEGRATED FEASIBILITY                              Generated at 09:20:36 on 08-08-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes         Water pH change: No         Year: 6
' Notes: BEF  = Bio-physical/economic feasibility (% of total in sub-unit)
'        1st  = Feasibility after 1st rule (priority with minor income difference)
'        2nd  = Feasibility after 2nd rule (minimum income per family labour-day)
'        3rd  = Feasibility after 3rd rule (preference in each production system)
'        InFe = Integrated feasibility after 4th rule
'                                         (preference traditional rice and HY rice)
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' Unit:  % of total in sub-unit
'******************************************************************************************
' Sub WMU   Village      OneTra  OneHY  SATra  SAHY   SAWS   Sugar   Pine    Euca   Mang ...
'-------------------------------------------------------------------------------------------
   1, 28, Long Hung, BEF,  8.1   11.3   20.2   16.2   27.3    8.6    6.1     0.8    0.0 ...
                     1st,  8.1   11.3   20.2   16.2   27.3    8.6    6.1     0.8    0.0 ...
                     2nd,  8.6   12.1   21.6   17.3   29.3    6.5    4.6     0.0    0.0 ...
                     3rd,  9.0   12.7   22.7   18.1   30.7    4.8    1.9     0.0    0.0 ...
                    InFe, 11.3   11.1   28.2   15.8   26.8    4.8    1.9     0.0    0.0 ...
...
```

Appendix S6: Examples of input and output data of the Demography Sub-model [6]

File: POPURULE.S06 (Example of input data on rules in demography)

```
' ==========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Demography Sub-model [6]
' RULES IN DEMOGRAPHY
' Last updated:  10 August 1995    by:  Chu Thai Hoanh
' (Data from the Institute of Hygiene and Public Health, ESSA Ltd. and NEDECO)
' ==========================================================================================
' Projection in demography
' ------------------------------------------------------------------------------------------
  Number of subsequent years,    5                              0      5      10     25     60
  Projected natural growth rate (%),                           2.3    2.1    1.7    1.5     0
  Projected rate of immigration (%),                           1.5    1.7    1.0    0.4    0.0
  Projected urban/total ratio (%),                            21.7    23     26     36     66
  Maximum number of working days per year,                     305    305    305    305    305
  % total labourers in total population,                        47     47     47     47     47
  % rural labourers for land use in total labour force,         75     75     75     75     75
  % urban labourers for land use in total labour force,         15     15     15     15     15
' ------------------------------------------------------------------------------------------
' Percentage of migration from outside to each water management unit
' WMU: 28  29  30a 30b 31  32  33  34  35   36  37  38  39  40  41  42  43  44  52  54
' ------------------------------------------------------------------------------------------
  Number of subsequent years,      3
   1   -1   2   2 -20 -10  -7   0   2 -17  -10   2  16  25  40  10   2  15  20   6  23
   5   -1   2   2 -20 -10  -7   0   2 -17  -10   2  16  25  40  10   2  15  20   6  23
  10    0   2   2   0   2   2   0   2   2    0   2   2  20  10   2   0   2  20   0  30
' ------------------------------------------------------------------------------------------
' Percentage of difference in income causing desire of migration among rural sub-units
' ------------------------------------------------------------------------------------------
  Number of subsequent years,   5,                              0      5      10     25     60
  Percentage of difference in income,                           0      0      10     10     50
' ------------------------------------------------------------------------------------------
' Migration among rural sub-units
' ------------------------------------------------------------------------------------------
  Number of subsequent years,    5,                             0      5      10     25     60
  Percentage deciding to migrate,                              20     20      20     30     30
  Maximum migration (%) from one sub-unit to another,         0.3    0.3     0.3    0.3    0.3
```

File: MIGRAT.S06 (Example of input data on migration possibilities)

```
' ==========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Demography Sub-model [6]
' MATRIX OF POPULATION MIGRATION POSSIBILITIES
' Last updated:  14 August 1995   by:  Chu Thai Hoanh
' Notes:    0 = No migration    1 = Migration possible between adjacent sub-units
' 2 = Migration possible from rural sub-unit to urban district sub-unit
' 3 = Migration possible from rural/urban district sub-units to urban provincial sub-units
' ==========================================================================================
'                        Sub: 1 2 3 4 5 6 7 8 9 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 ... 1 1 1 1 1 1 1
'                                               0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 ... 7 7 7 7 7 8 8
'                                                                                ... 5 6 7 8 9 0 1
' Sub      Village           Migration possibility
' ------------------------------------------------------------------------------------------
  1 , Long Hung             , 1 1 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 ... 0 0 0 0 0 0 0
  2 , Hung Phu              , 1 1 2 1 1 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 ... 0 0 0 0 0 0 0
...
```

File: MARI11.S06 (Example of output data on population)

```
' ******************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Demography Sub-model [6]
' POPULATION DYNAMICS (persons)                    Generated at 13:13:46 on 08-17-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No
' Abbreviations: Sub = Sub-unit    WMU = Water management unit   Popu = Present population
'              P.type = Population type (U = urban, R = rural)
' ******************************************************************************************
'Sub WMU  Village    Popu P.type   Changes                        Year 1     2     3     4  ...
' ------------------------------------------------------------------------------------------
  1, 28, Long Hung, 4115, R, After natural growth & emigration   4235  4207  4247  4294 ...
                             After rural/urban migration         4225  4195  4239  4285 ...
                             After rural/rural migration         4091  4133  4182  4224 ...
...
```

Appendix S7: Examples of input and output data of the Land Use Weighting Sub-model [7]

File: WEIGRULE.S07 (Example of input data on rules in generating weighting factors)

```
'==============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Weighting Sub-model [7]
' RULES IN LAND USE WEIGHTING
' Last updated:   26 August 1995  by:   Chu Thai Hoanh
'==============================================================================
' Select factors to generate weighting factors:  0 = not selected     1 = selected
'      Bio-physical yield      Integrated feasibility      Government policy
'------------------------------------------------------------------------------
              0                          1                         1
'------------------------------------------------------------------------------
' If yield factor is selected, which crop yield is used:   0 = not used     1 = used
' OneTra OneHY SATra SAHY  SAWS  Sugar Pine  Euca   Mang  Mela  ShPo  ShSa  ShRi  PrPol ...
'------------------------------------------------------------------------------
    1     1     1     1     1     0     0     0     0     0     0     0     0     0    ...
```

File: WEIGVALU.S07 (Example of input data on Government policy factors)

```
' ==============================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Weighting Sub-model [7]
' GOVERNMENT POLICY
' Last updated:   26 August 1995  by:   Chu Thai Hoanh
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' Notes:  Inside  = Area will be protected from salt water and irrigated with fresh water
'         Outside = Area will not be protected and irrigated
' ==============================================================================
  Number of subsequent years,  3
  Year,            1
'------------------------------------------------------------------------------
' Government policies:
' Starting the construction of water management system
' Agriculture:  More double rice in fresh water areas, sugarcane in low salinity areas,
'               pineapple in acid sulphate soil areas, little beans.
' Aquaculture:  Start limiting shrimp ponds and shrimp-rice inside, few prawn ponds
'               and prawn-rice inside; maximize fish pond.
' Forestry   :  Maximize mangrove outside, Melaleuca inside.  Limit Eucalyptus in view of
'               environmental impact.
' Others     :  Uncultivated land not reserved.  Water, specific and homestead gardens
'               not limited.  Nipa palm not limited.
'------------------------------------------------------------------------------
' WMU  OneTra OneHY SATra SAHY  SAWS  Sugar Pine  Euca   Mang Mela  ShPo  ShSa  ShRi...
'------------------------------------------------------------------------------
   28 ,  100   100   100   100   100   100    50    50    80   100    50     0    50 ...
   29 ,  100   100   100   100   100   100    50    50    80   100    50     0    50 ...
...
```

File: MARI16.S07 (Example of output data on weighting factors)

```
'*******************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Weighting Sub-model [7]
' WEIGHTING FACTORS                                Generated at 10:27:29 on 09-03-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No       Year:  6
' Abbreviations:  see file EXISTING.S03 in Appendix S3
'*******************************************************************************
'------------------------------------------------------------------------------
' Sub WMU    Village     OneTra OneHY SATra SAHY  SAWS  Sugar Pine  Euca   Mang Mela  ShPo...
'------------------------------------------------------------------------------
   1, 28,  Long Hung,     5.6   5.2  16.0   7.2  17.9   2.8   0.6   0.0   0.0   0.0   0.0...
   2, 28,   Hung Phu,     5.8   4.9  15.5  10.5  16.5   4.3   0.9   0.0   0.0   0.0   0.0...
 ...
```

Appendix S8: Examples of input and output data of the Land Use Allocation Sub-model [8]

File: ALLORULE.S08 (Example of input data on rules in land use allocation)

```
' ================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Allocation Sub-model [8]
' RULES IN LAND USE ALLOCATION
' Last updated:   6 September 1995  by:   Chu Thai Hoanh
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' ================================================================================
' Possibility of land use conversion and total labour-days required
' From  To --->             Notes: -1 = Conversion is impossible
' |                                 0 = Conversion does not require labour
' |                                 N = Not considered
' V            OneTra OneHY SATra SAHY  SAWS  Sugar Pine  Euca  Mang Mela ShPo ShSa ShRi ...
'--------------------------------------------------------------------------------
 1, OneTra,      0     219   252   252   252  669   669   536  104  103  446   N   371
 2, OneHY,     219       0   252   252   252  669   669   536  104  103  446   N   371
 3, SATra,     219     219     0   252   252  669    -1    -1   -1   -1  446   N    -1
...

' --------------------------------------------------------------------------------
' Expected number of years to apply one land use type before conversion to another
' = 1 for annual crops, > 1 for perennial crops or forest or high investment land use types
' OneTra OneHY SATra SAHY  SAWS Sugar Pine  Euca  Mang Mela ShPo ShSa ShRi PrPo1 PrPo2 ...
' --------------------------------------------------------------------------------
   1     1     1     1     1     3     3     7   12     8    5    1    5    5     5  ...
' --------------------------------------------------------------------------------
' Expansion of areas of water management system and specific uses
' --------------------------------------------------------------------------------
  Number of subsequent years,  4
  Year,                                                    1     5    10    15
  Percentage of water management system in cultivated land,  5     5     5     5
  Percentage of water surface in new water management system, 75    65    50    30
  Percentage of area for specific uses for newcomers/capita,  35    15     5     5
' (compared with present area per capita)
...
```

File: MARI1.S08 (Example of output data on land use allocation in each sub-unit)

```
' ********************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Allocation Sub-model [8]
' LAND USE AREAS IN EACH SUB-UNIT                 Generated at 09:10:25 on 09-29-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No        Year: 10
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' ********************************************************************************
' Sub WMU   Village     OneTra OneHY SATra  SAHY  SAWS Sugar  Pine  Euca   Mang Mela ...
' --------------------------------------------------------------------------------
   1, 28,  Long Hung,    101    87   293    82   318    27     5     0      0    1 ...
   2, 28,   Hung Phu,    210   164  1106     0   591   109    21     0      0    1 ...
...
```

File: SUBUSTAT.S08 (Example of the matrix linking sub-units and climatic stations)

```
' ================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Allocation Sub-model [8]
' MATRIX LINKING SUB-UNITS TO CLIMATIC STATIONS FOR WATER DEMAND CALCULATIONS
' ================================================================================
' Evaporation stations:  1 = Soc Trang    Rainfall stations:  1 = Soc Trang    3 = Bac Lieu
'                        2 = Ca Mau                           2 = Ca Mau       4 = Vi Thanh
' --------------------------------------------------------------------------------
' Sub WMU  Province  District   Village    Evaporation station  Rainfall station
' --------------------------------------------------------------------------------
   1, 28,     HG,     MY TU,   Long Hung,          1                   1
   2, 28,     HG,     MY TU,    Hung Phu,          1                   3
...
```

File: CLIMATE.S08 (Example of input data on climatic conditions)

```
' ====================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Allocation Sub-model [8]
' CLIMATIC DATA FOR CALCULATIONS OF WATER DEMAND
' Last updated:  30 January 1995   by:  Nguyen Viet Dong
' (Date from the Sub-Institute for Water Resources Planning and Management)
' ====================================================================================
' Evapotranspiration Penman (mm) in each time step
'          Step:  1        2       3       4       5       6       7       8       9      10  ...
' ------------------------------------------------------------------------------------
  Number of stations,    2
  SOC TRANG,      69.0   77.0    87.5    90.5    98.0    96.0    99.0    94.0    79.5    70.5 ...
  CA MAU,         70.0   74.0    80.0    83.0    90.0    88.0    89.0    87.0    72.5    67.5 ...
' ------------------------------------------------------------------------------------
' Rainfall (mm) in each time step
'          Step:  1        2       3       4       5       6       7       8       9      10  ...
' ------------------------------------------------------------------------------------
  Number of stations,    4
  SOC TRANG,       0.0    0.0     0.0     0.0     0.0     3.0     0.0    48.8    39.4    96.2 ...
  BAC LIEU,        0.0   17.2     0.0     0.0     0.0     0.0     9.4    10.3    61.5    46.2 ...
...
```

File: DEMAND.S08 (Example of input data on water demand per land use type)

```
' ====================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Allocation Sub-model [8]
' WATER DEMAND                        Last updated:  20 October 1994    by:  Chu Thai Hoanh
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' ====================================================================================
' Kc FOR RICE WITH DIFFERENT CROPPING PATTERNS (from NEDECO, Working Paper 3, 1991)
' Crops,  Number of time steps  Kc values in each step
' ------------------------------------------------------------------------------------
  WS rice,                 8      0.71  0.70  0.85  0.97  1.16  1.05  1.00  0.82
  OneHY or SA or 2dnHY,    8      0.70  0.70  0.70  0.98  1.08  1.03  1.03  0.95
  OneTra or 2ndTra,        9      0.70  0.70  0.70  0.98  1.08  1.08  1.03  1.03  0.95
                          10      0.70  0.70  0.70  0.98  1.08  1.08  1.03  1.03  0.95  0.95
...
' ------------------------------------------------------------------------------------
'  Effective rainfall coefficient   Percolation (mm/time step)   Irrigation efficiency
' ------------------------------------------------------------------------------------
                0.85                            0                             0.8
' ------------------------------------------------------------------------------------
' Water layer (mm) in 2 first steps   and   water (mm) for soil saturation in initial step
' OneTra OneHY  SA  2ndTra 2ndHY  WS           OneTra OneHY  SA  2ndTra 2ndHY  WS
' ------------------------------------------------------------------------------------
  100      50   50   100    50    50              50    100  100    0      0     0
' ------------------------------------------------------------------------------------
' Evaporation (mm/day)  and  water replenishment (m3/day-ha) for fisheries ponds
' ------------------------------------------------------------------------------------
      5                                 55
' ------------------------------------------------------------------------------------
' Water supply criteria               Urban population            Rural population
' ------------------------------------------------------------------------------------
 Number of subsequent years, 4         1    10    20    50          1    10    20    50
 Water supplied (l/capita-day),       40   100   120   140         40    50    50    50
```

File: MARI18.W08 (Example of output data on water demand per sub-unit)

```
' ************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Land Use Allocation Sub-model [8]
' WATER DEMAND (m3/sec)                         Generated at 13:05:52 on 10-26-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No       Year:  8
' Abbreviations:      Sub = Sub-unit      WMU = Water management unit     ST = Time step
' Rice   = Water demand for rice crops              Upland = Water demand for upland crops
' Peren  = W.demand for perennial crops and forests Fish   = Water demand for fisheries
' Uncul  = Water losses from uncultivated land      Speci  = Water demand for specific uses
' Water  = Water losses from water surface          Sali   = Water salinity
' Total  = Total water demand                       Fresh  = Total fresh water demand
' ************************************************************************************
' Sub WMU  Village     ST  Rice Upland Peren Uncul  Fish Speci Water Sali  Total   Fresh
' ------------------------------------------------------------------------------------
  1, 28, Long Hung,    3    0.38  0.11  0.07  0.00  0.00  0.00  0.06  1.1   0.63    0.63
  2, 28,   Hung Phu,   3    0.79  0.32  0.14  0.00  0.00  0.01  0.30  0.9   1.54    0.01
...
```

Appendix S9: Examples of input and output data of the Production Sub-model [9]

File: PRODRULE.S09 (Example of input data on rules for production)

```
' ==========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Production Sub-model [9]
' RULES IN PRODUCTION CALCULATION
' Last updated:   31 October 1994   by:   Chu Thai Hoanh
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' ==========================================================================================
' Percentage of shrimp/prawn ditches in rice field
' ------------------------------------------------------------------------------------------
                      10
' ------------------------------------------------------------------------------------------
' Age (years) when forest is harvested:     Eucalyptus     Mangrove     Melaleuca
' ------------------------------------------------------------------------------------------
                                                7             12           8
' ------------------------------------------------------------------------------------------
' Effect of pests on yield of rice crop (percentages of remaining yield)
'               Low     Medium      High
' ------------------------------------------------------------------------------------------
  OneTra,       100       90         60
  OneHY,        100       80         60
  SA,           100       80         60
'...
' ------------------------------------------------------------------------------------------
' Level of pests during N years      0 = Low    1 = Medium    2 = High
' Crop     Year: 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23  ...
' ------------------------------------------------------------------------------------------
  OneTra,        0  1  2  0  1  2  0  1  2  0  1  2  0  1  2  0  1  2  0  1  2  0  1  ...
  OneHY,         1  2  0  1  2  0  1  2  0  1  2  0  1  2  0  1  2  0  1  2  0  1  2  ...
...
```

File: MARI16.S09 (Example of output data on production in each sub-unit)

```
' *****************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Production Sub-model [9]
' PRODUCTION AT SUB-UNIT LEVEL                       Generated at 17:29:34 on 11-04-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No       Year: 6
' Abbreviations:  see file EXISTING.S03 in Appendix S3.
' *****************************************************************************************
'Sub WMU   Village       OneTra   OneHY    SA    2ndTra   2ndHY    WS    Sugar    Pine  BeanSA...
'                        tonne    tonne  tonne   tonne    tonne  tonne  tonne    tonne tonne ...
'------------------------------------------------------------------------------------------
  1,   28, Long Hung,     193      369    2878     487     185   1706     868      57      0 ...
  2,   28,  Hung Phu,     426      706    7350    2061       0   3207    3700     269      0 ...
...
```

Appendix S10: Examples of input and output data of the Supplementary Intervention Sub-model [10]

File: SUPPRULE.S10 (Example of input data on rules for supplementary interventions)

```
' ===============================================================================
' INPUT TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Supplementary Intervention Sub-model [10]
' RULES IN SUPPLEMENTARY INTERVENTIONS
' Last updated:   06 November 1994   by:   Chu Thai Hoanh
' (Data from: - NEDECO, 1991: Identification of National & Export Markets and Constraints
'             - NEDECO, 1991: Technical report on price structures and market prospects of
'               major agricultural products in the Mekong delta
'             - Sub-NIAPP, 1992: Information and data in relation to Agriculture involved
'               in the study for the project of integrated development of the QLPH region)
' ===============================================================================
' Projection of local consumption per capita per year
' Notes:  Sugar production         = 10% of sugarcane production
'         Milled rice production = 63.8% of production of rice (or paddy)
' Year  Rice    Sugar  Pineapple  Beans  Wood  Shrimps Prawns  Fish   Pork   Duck
'        kg      kg        kg      kg     m3     kg      kg     kg     kg     kg
' -------------------------------------------------------------------------------
  Number of subsequent years,   5
   1    235     60         0        2    0.3     0       0     18     5.0    1.0
   5    240     90         0       10    0.3     0       0     27     7.7    1.5
...
' -------------------------------------------------------------------------------
' Percentage of post-harvest losses
' Year  Rice  Sugarcane  Pineapple  Beans  Wood  Shrimps Prawns Fish
' -------------------------------------------------------------------------------
  Number of subsequent years,   4
   1     15      20         30        10     0      30     30     20
  10      5      10         15         5     0      15     15     10
...
' -------------------------------------------------------------------------------
' Percentage of rice used for pig raising and similar activities
' Rice unsuitable for human consumption    Broken rice  Bran
' -------------------------------------------------------------------------------
                       5                            5        8
' -------------------------------------------------------------------------------
' Required rice (tonne) per tonne of pork
' -------------------------------------------------------------------------------
  4
' -------------------------------------------------------------------------------
' Average number of ducks per hectare of rice crops
' -------------------------------------------------------------------------------
  50
' -------------------------------------------------------------------------------
' Percentage of rice field used for duck rearing (%)
' -------------------------------------------------------------------------------
  Number of subsequent years,   5,              1     5     10     20     30
  Percentage,                                  15    15     15     15     15
' -------------------------------------------------------------------------------
' Average weight of one duck (kg)
' -------------------------------------------------------------------------------
  1.5
' -------------------------------------------------------------------------------
' Pesticides for agricultural crops (in kg/ha equivalence of highly concentrated liquid form)
' for both cases of 'without' and 'with' water management system
' (Case 0 = Low      1 = Medium       2 = High pest outbreak)
' Cases    OneTra  OneHY    SA   2ndTra  2ndHY  WS    Sugar1 Sugar2 Sugar3  Pine1 Pine2 ...
' -------------------------------------------------------------------------------
   0         0.7    1.4    1.4    0.7    1.4   1.7     0      0      0       2     2
   1         1.4    2.7    2.7    1.4    2.7   3.4     0      0      0       2     2
   2         2.0    4.0    4.0    2.0    4.0   5.0     0      0      0       2     2
' -------------------------------------------------------------------------------
' Fertilizers for agricultural crops (kg/ha) ('without' water management system)
'                        OneTra  OneHY   SA  2ndTra  2ndHY   WS   Sugar1 Sugar2 Sugar3...
' -------------------------------------------------------------------------------
  Urea              ,     33      50     33    33     50     50    250    250    250  ...
  DAP               ,      0      33     17     0     17     17      0      0      0  ...
  NPK               ,      0       0     17     0      0     17      0      0      0  ...
  Potassium         ,      0       0      0     0      0      0    200    200    200  ...
  Supper phosphate,        0       0      0     0      0      0      0      0      0  ...
...
```

File: MARI18.P10 (Example of output data on products used in each sub-unit)

```
' ***************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Supplem. Intervention Sub-model [10]
' DISTRIBUTION OF PRODUCTION                        Generated at 18:24:24 on 11-10-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No      Year: 8
' ***************************************************************************************
' Sub WMU  Village         Item              Rice   Sugarcane Pineapple  Beans     Wood   ...
'                                            tonne    tonne     tonne    tonne      m3    ...
'-----------------------------------------------------------------------------------------
   1, 28, Long Hung, Total production,       3810     1083       75        38        0    ...
                     Local consumption,      1778      496        0        62     1306    ...
                     Import or export,       2032      587       75       -24    -1306    ...
...
```

File: MARI18.E10 (Example of output data on pesticides used in each sub-unit)

```
' ***************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Supplem. Intervention Sub-model [10]
' PESTICIDES USED IN EACH SUB-UNIT (kg)             Generated at 18:24:26 on 11-10-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1  (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No        Year: 8
' Abbreviations:  see file EXISTING.S03 in Appendix S3.
' ***************************************************************************************
' Sub WMU   Village     Total  OneTra OneHY   SA    2ndTra  2ndHY   WS    Sugar1 Sugar2...
'-----------------------------------------------------------------------------------------
   1, 28,  Long Hung,   5926    143    352   2800    414    332   1605     0       0  ...
   2, 28,   Hung Phu,  13601    301    668   6936   1582      0   3020     0       0  ...
...
```

File: MARI18.F10 (Example of output data on fertilizer used in each sub-unit)

```
' ***************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Supplem. Intervention Sub-model [10]
' FERTILIZERS USED IN EACH SUB-UNIT (tonne)         Generated at 18:24:28 on 11-10-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1  (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No        Year: 8
' Abbreviations:  see file EXISTING.S03 in Appendix S3
' ***************************************************************************************
' Sub WMU   Village           Types        Total  OneTra OneHY   SA    2ndTra 2ndHY   WS  ...
'-----------------------------------------------------------------------------------------
   1, 28,  Long Hung, Urea,                 82       3      4     30     10     4     18  ...
                      DAP,                  49       2      3     23      5     3     13  ...
                      NPK,                  25       0      1     12      0     1      5  ...
                      Potassium,             7       0      0      0      0     0      0  ...
                      Supper phosphate,      2       0      0      0      0     0      0  ...
...
```

File: MARI18.U10 (Example of output data on fuel used in each sub-unit)

```
' ***************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Supplem. Intervention Sub-model [10]
' FUEL USED IN EACH SUB-UNIT (litres)               Generated at 18:24:36 on 11-10-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes       Water pH change: No      Year: 8
' Abbreviations:   see file EXISTING.S03 in Appendix S3
' ***************************************************************************************
' Sub WMU   Village     Total   OneTra   OneHY    SA    2ndTra   2ndHY    WS   Sugar  Pine ...
'-----------------------------------------------------------------------------------------
   1, 28,  Long Hung,  76890     0        0     42000    0        0    25680   0     150 ...
   2, 28,  Hung Phu,  192690     0        0    104040    0        0    48320   0     710 ...
...
```

Appendix S11: Examples of input and output data of the Economic Sub-model at Regional Level [11]

File: ECORULE.S11 (Example of input data in economic analysis at regional level)

```
' ==========================================================================================
' INPUT TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Regional Level [11]
' RULES AND DATA IN ECONOMIC ANALYSIS AT REGIONAL LEVEL
' Last updated:   14 November 1994     by:    Chu Thai Hoanh
'
' ==========================================================================================
' CONSTRUCTION COSTS OF WATER MANAGEMENT SYSTEMS          (1,000 US$)
' No.          Main sluices and main canals                    Costs
' ------------------------------------------------------------------------------------------
  1 ,             My Phuoc sluice,                               1824
  2 ,             Cai Trau sluice,                                619
...
  Dredging of main canals,                                     10673
  Excavation of main canals,                                   12635
  Excavation of irrigation canals from the Bassac river,       21250
' ------------------------------------------------------------------------------------------
' WMU      2ndary canals  2ndary sluices & on-farm systems  Rural roads
' ------------------------------------------------------------------------------------------
   28,          260                     2149                          1073
   29,         2834                     2935                          1061
...
' ------------------------------------------------------------------------------------------
' Other costs (Operation & Maintenance and Replacement costs as % of construction costs)
'              (Administrative costs as % of O&M costs)
'                                                O&M     Replacement  Administrative costs
' ------------------------------------------------------------------------------------------
  Main sluices,                                  1.0       0.8                 5.0
  Main canals,                                   5.0       0.0                 5.0
  Secondary canals,                              5.0       0.0                 5.0
  Secondary sluices & on-farm systems,          10.7       2.7                 5.0
  Rural roads,                                  10.7       0.0                 5.0
' ------------------------------------------------------------------------------------------
' Costs of mitigation activities  (1,000 US$)  Construction    O&M  Replac. Administrative
' ------------------------------------------------------------------------------------------
  Additional dredging of the Phung Hiep canal,      1109       5.0    0.0          5.0
  Ca Mau port,                                      1000       1.0    0.8          5.0
  Protection of the 1st National Highway,           2400      10.7    2.7          5.0
' ------------------------------------------------------------------------------------------
' Number of cases and  discount rate (%)
' ------------------------------------------------------------------------------------------
  5                    8  10   12   14 16

' ==========================================================================================
' ECONOMIC ANALYSIS (for 1 ha/year)                 Exchange rate (1991):   8250 VN Dong/US$
' Notes: - Case = 'Without' (0) or 'with' (1) new water management
'        - 'Basic' land use conversion costs = Costs for conversion from uncultivated land
'        - Percentage after processing: main products + by-products (in price equivalence)
' Abbreviations:   see file EXISTING.S03 in Appendix S3
' ==========================================================================================
'              Items                   Year Case OneTra  OneHY   SA   2ndTra  2ndHY ...
'                              Yield unit:       tonne  tonne  tonne tonne   tonne  ...
' ------------------------------------------------------------------------------------------
  Basic land use conversion costs,        1   0 265.09 265.09 152.55 152.55 152.55  ...
  Operating costs,                        1   0 104.06 147.14 163.23 116.38 166.77  ...
  Percentage of working capital,          1  0      50     50     50     50     50  ...
  Farm-gate price,                        1   0 103.00 100.00 100.00 103.00 100.00  ...
  Percentage of product after processing, 1  0      75     75     75     75     75  ...
  Price of processed product,             1  0     230    200    200    230    200  ...
  Processing cost (per unit of product),  1  0      40     40     40     40     40  ...
...
' ==========================================================================================
' LAND CONVERSION POSSIBILITY AND COSTS
' Possibility and costs (as percentage of 'basic' conversion costs above)
' From  To --->       Notes: -1 = Conversion is impossible              N = not considered
'  |                          0 = Conversion does not require costs
'  V            OneTra OneHY SATra SAHY  SAWS Sugar Pine  Euca  Mang Mela ShPo ShSa ShRi ...
' ------------------------------------------------------------------------------------------
1, OneTra,        0      0    13    13    13   60    60    50    0    0   100   N   100  ...
2, OneHY,         0      0    13    13    13   60    60    50    0    0   100   N   100  ...
3, SATra,         0      0     0    13    13   60    60    50    0    0   100   N    -1  ...
...
```

File: MARI1.S11 (Example of output data from economic analysis at regional level)

```
'*****************************************************************************************
' OUTPUT FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Regional Level [11]
' ECONOMIC DATA                                Generated at 12:50:30 on 11-29-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1  (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No
' Abbreviations:  Cost   = Construction costs       O&M  = Operation and maintenance costs
'                 Replac = Replacement costs        Admin = Administration costs
'                 Mitiga = Mitigation for transportation & for nipa palm
'*****************************************************************************************
' ECONOMIC DATA AT REGIONAL LEVEL  (1,000 US$)
' FOR THE ENTIRE REGION
' Year          TOTAL                         Main sluices              Main canal dredging     ...
'        Cost    O&M  Replac  Admin     Cost  O&M  Replac Admin    Cost  O&M  Replac Admin ...
'-----------------------------------------------------------------------------------------
   1    16804  1417   244     71       1443   0      0      0        0    0       0     0  ...
   2    31132  3728   584    186       2062  35     28      2     1779   89       0     4  ...
'...
'-----------------------------------------------------------------------------------------
' Year            Items                  TOTAL  OneTra OneHY    SA   2ndTra  2ndHY    WS ...
'-----------------------------------------------------------------------------------------
   1, Land use conversion costs   ,  19135   2888   7555    134     121      5       8 ...
   1, Working capital             ,   1979   -809   -436    132     376     31      43 ...
   1, Operation costs             ,  80534  11199  20618   3457    2498     65     100 ...
   1, Benefits without processing, 141878  30807  53220   6802    4229     54     206 ...
   1, Benefits with processing    , 229974  51584  79844  10204    7078     82     309 ...
   1, Processing costs            ,  55435   8970  15971   2042    1228     17      62 ...
'...
'-----------------------------------------------------------------------------------------
' CALCULATIONS OF ECONOMIC INDICATOR  (1,000 US$)
'-----------------------------------------------------------------------------------------
'                   WITH WATER MANAGEMENT SYSTEM        ... Incre-    Incre-    Increm.   Increm.
' Year Water   Miti- Landuse  Work.  Landuse Benefit ... mental    mental    benefit   benefit
'      manag. gation constr. capital operat.   no     ... benefit   benefit   - cost    - cost
'       cost   cost    cost            cost   process ... without    with     without    with
'                                                        process.  process.  process.  process.
'-----------------------------------------------------------------------------------------
   1   18536      0   19135    1979   80534  141878 ...  4136      5626    -15348    -14004
   2   35630    277    4204    1985   84265  149155 ...   898       300    -34688    -34005
'...
'-----------------------------------------------------------------------------------------
' ECONOMIC INDICATORS  WITHOUT PROCESSING                 WITH PROCESSING
' Discount       NPV      BC ratio   N/K ratio        NPV     B/C ratio   N/K ratio
' rate (%)   (1,000 US$)                          (1,000 US$)
'-----------------------------------------------------------------------------------------
      8       152022       1.26        0.69          266758      1.33         2.09
     10        93887       1.20        0.62          184461      1.28         1.87
     12        53584       1.13        0.56          126483      1.23         1.69
     14        25291       1.07        0.52           84979      1.19         1.55
     16         5231       1.02        0.48           54846      1.14         1.44
'            IRR(%)  Payback period (years)        IRR(%)  Payback period (years)
             16.66          11                      22.79           9
'=========================================================================================
' FOR THE INSIDE
...
```

File: MARI12.S11 (Example of output data from economic analysis at sub-unit level)

```
'*****************************************************************************************
' OUTPUT FOR QUAN LO PHUNG HIEP REGION - Economic Sub-model at Regional Level [11]
' ECONOMIC DATA FOR PRODUCTION (1,000 US$)       Generated at 12:32:40 on 11-29-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No        Year: 2
' Abbreviations:   see file EXISTING.S03 in Appendix S3
'*****************************************************************************************
' Sub WMU  Village              Items              OneTra OneHY  SA  2ndTra 2ndHY    WS ...
'-----------------------------------------------------------------------------------------
  1,  28, Long Hung, Land use conversion costs,      0      0    3      1     0       2 ...
                     Operation costs,               21     47   32     26     0      37 ...
                     Working capital,                0      0    2      3     0      11 ...
                     Benefits without processing,   42     90  128     41     0      75 ...
                     Benefits with processing,      71    135  192     69     0     113 ...
                     Processing costs,              12     27   38     12     0      23 ...
...
```

Appendix S12: Examples of input and output data of the Social Sub-model at Regional Level [12]

File: SOCIRULE.S12 (Example of input data in socio-economic analysis)

```
' ===============================================================================
' INPUT TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Social Sub-model at Regional Level [12]
' RULES AND DATA IN SOCIO-ECONOMIC ANALYSIS AT REGIONAL LEVEL
' Last updated:   01 December 1994   by:   Chu Thai Hoanh
' ===============================================================================
' Projection of number of working days in a year of one labourer
' -------------------------------------------------------------------------------
  Number of subsequent years,  5          0       5       10       25       30
  Number of working days per year,       305     305     305      305      305
' -------------------------------------------------------------------------------
' Required labour-days/day for each rice crop in each step
' -------------------------------------------------------------------------------
  Single rice - traditional variety:   Number of cropping calendars,    5
  Number of steps (step 0 for land preparation & last step for post-harvest),   13
  Steps,                           0   1   2   3   4   5   6   7   8   9  10  11  12
  Without case:  Skilled labour,   6   6   6   6   4   2   1   1   1   1   1   1   1
                 Unskilled labour, 3   3   2   1   2   2   2   2   1   1   1  12  13
  With case:     Skilled labour,   6   6   6   6   4   2   1   1   1   1   1   1   1
                 Unskilled labour, 3   3   2   1   2   2   2   2   1   1   1  12  13
'...
' -------------------------------------------------------------------------------
' Periods suitable for land use conversion  (initial and final time steps of each period)
' -------------------------------------------------------------------------------
  Number of periods, 2                             9  16        23  26
' -------------------------------------------------------------------------------
' LABOUR-DAYS REQUIRED FOR LAND USE CONVERSION
' Possibility, skilled and unskilled labour-days required for land use conversion
' From  To --->     Notes: -1 = Conversion is impossible            N = Not considered
' |                         0 = Conversion does not require labourer
' V                     OneTra OneHY SATra SAHY  SAWS  Sugar Pine  Euca  Mang Mela ...
' -------------------------------------------------------------------------------
 1, OneTra, Skilled,      0      0     0     0     0     0     0     0     0    0   ...
 1, OneTra, UnSkilled,    0      0    33    33    33   450   450   317     0    0   ...
 2, OneHY,  Skilled,      0      0     0     0     0     0     0     0     0    0   ...
 2, OneHY,  UnSkilled,    0      0    33    33    33   450   450   317     0    0   ...
...
```

File: MARI13.I12 (Example of output data on income and production per capita)

```
'********************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Social Sub-model at Regional Level [12]
' INCOME AND PRODUCTION PER CAPITA                Generated at 10:57:18 on 12-06-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No       Year: 3
' Notes:  % average = Percentage compared with average in the Region
'********************************************************************************
' Sub WMU   Village     Income  (US$)      %      Income (US$)   %       Rice (kg)      %    ...
'                       no processing  average   with proc. average                 average
'--------------------------------------------------------------------------------
   1, 28, Long Hung,     60.2          132        101.8        222     1316         159   ...
   2, 28, Hung Phu,      78.5          172        119.7        262     1310         158   ...
...
```

File: MARI13.C12 (Example of output data on employment)

```
'********************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Social Sub-model at Regional Level [12]
' EMPLOYMENT IN EACH STEP BY PRODUCT (Labour-days)  Generated at 10:55:46 on 12-06-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1  (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No       Year: 3
'********************************************************************************
' Sub WMU   Village    Product   Labour type  Step 1    2      3      4     5      6  ...
'--------------------------------------------------------------------------------
   1, 28,   Long Hung, Rice,       Skilled,     2440   2440   2060   1500   380    380 ...
                       Rice,       Unskilled,   5080   7320   4300   1500  1500   5620 ...
                       Sugarcane,  Skilled,      120    120    120    120   120    120 ...
                       Sugarcane,  Unskilled,    890    890    150    150   150    150 ...
...
```

File: MARI13.E12 (Example of output data on labour force balance)

```
'*****************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Social Sub-model at Regional Level [12]
' EMPLOYMENT (1.000 labour-days)                         Generated at 10:51:44 on 12-06-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes          Water pH change: No        Year: 3
' Notes: LU labour              = Labour engaged in land use
'        Available lab.-days    = Annual labour-days available for land use
'        Required lab.-days     = Annual labour-days required for land use
'        Annual balance         = Annual available minus annual required labour-days
'        Skilled                = Skilled labour-days required for land use in each step
'        Unskilled              = Unskilled labour-days required for land use in each step
'        Balance                = Potential labour-days minus required labour-days in each step
'        (In balance:           Negative value = shortage     Positive value = surplus)
'*****************************************************************************************
' Sub WMU  Village    Popu  LU labour  Available  Required  Annual   Labour    Step 1    2  ...
'                  (persons)           (1,000 labour-days)     balance   type
'-----------------------------------------------------------------------------------------
  1, 28, Long Hung, 4166   1469        448.0       327.8    120.3, Skilled,     4.1    3.7 ...
                                                                   Unskilled,  11.6   12.9 ...
                                                                   Balance,     6.4    5.4 ...
  2, 28, Hung Phu, 10387   3661       1116.6       732.1    384.5, Skilled,    10.6    9.1 ...
                                                                   Unskilled,  24.4   23.9 ...
                                                                   Balance,    19.9   21.9 ...
...
```

Appendix S13: Examples of input and output data of the Environmental Impact Sub-model [13]

File: ENVIRULE.S13 (Example of input data for analysis of environmental impacts)

```
' ==========================================================================================
' INPUT DATA TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Environmental Impact Sub-model [13]
' RULES IN ENVIRONMENTAL IMPACTS
' Last updated:  06 December 1994    by:  Chu Thai Hoanh
' ==========================================================================================
' Standard of water quality for domestic use
' ---------------------------------------------------------------------
  Maximum salinity (‰),        1
  pH range,                 6      7.5
' ---------------------------------------------------------------------
' Water salinity in relation to levels of malaria incidence
' Level of malaria incidence:      High       Medium        Low
'
' ------------------------------------------------------------------------------------------
  Water salinity (‰),                    0.6           4
...
```

File: MARI11.S13 (Example of output data on environmental impact indicators)

```
'*****************************************************************************************
' OUTPUT DATA FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Environmental Impact Sub-model [13]
' ENVIRONMENTAL IMPACT INDICATORS                         Generated at 13:13:35 on 12-07-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes          Water pH change: No        Year: 2
' Notes:    Pestic. use   = Total pesticide use from year 1
'           Fertic. use   = Total fertilizer use from year 1
'           Water supply  = Surface water for domestic use  (1 = possible, 0 = impossible)
'           Malaria       = Malaria incidence  (0 = low, 1 = medium, 2 = high)
'           Land cover    = Percentage of land cover over total area
'*****************************************************************************************
' Sub WMU    Village  Pestic.use Fertic.use  Item   Step: 1   2   3   4   5   6   7   8 ...
'-----------------------------------------------------------------------------------------
  1, 28,   Long Hung,     2         122, Water supply,   1   1   1   0   0   0   0   0 ...
                                         Malaria,        1   1   1   1   1   1   1   1 ...
                                         Land cover,    58  44  44  44  44  31  31  31 ...
  2, 28,   Hung Phu,      3         295, Water supply,   0   0   0   0   0   0   0   0 ...
                                         Malaria,        2   2   1   1   1   1   1   1 ...
                                         Land cover,    69  46  46  46  40  40  40  40 ...
...
```

Appendix S14: Examples of input and output data of the Goal and Impact Analysis Sub-model [14]

File: GOALRULE.S14 (Example of input data in goal and impact analysis)

```
'=========================================================================================
' INPUT TO CAILUP FOR QUAN LO PHUNG HIEP REGION - Goal and Impact Analysis Sub-model  [14]
' RULES IN GOAL & IMPACT ASSESSMENT
' Last updated:   08 December 1994       by:   Chu Thai Hoanh
'=========================================================================================
' DATA FOR THE ENTIRE REGION
'=========================================================================================
' Percentage of average in the Region used for assessment of food distribution
'-----------------------------------------------------------------------------------------
  60
'-----------------------------------------------------------------------------------------
' Percentage of average in the Region used for assessment of income distribution
'-----------------------------------------------------------------------------------------
  80
'-----------------------------------------------------------------------------------------
' Selected discount rate (%).
'-----------------------------------------------------------------------------------------
  12
'-----------------------------------------------------------------------------------------
' Goal priority in the entire Region:
'    Rice        Rice     %      Income     %     Income     %   Employment   %    Surface ...
' production  /capita  below   /capita  below  /capita    below              labour  water
'                      limit   no proc. limit with proc. limit              force   quality
'-----------------------------------------------------------------------------------------
      1          1     -1        1       -1       1        -1        1        0       1   ...
'-----------------------------------------------------------------------------------------
' Goal priority in the entire Region
' NPV    B/C Ratio   N/K Ratio    IRR    Payback period
'-----------------------------------------------------------------------------------------
   1       1          0.8         1        -0.5
'-----------------------------------------------------------------------------------------
' Non-fixed discount factor (%) used in goal & impact assessment
'-----------------------------------------------------------------------------------------
' Year Rice       Rice     %      Income     %     Income     %   Employment    %  Surface ...
'    production /capita  below   /capita  below  /capita    below             labour  water
'                        limit   no proc. limit with proc. limit  (1000      force quality
'      (tonne)    (kg)            (US$)            (US$)         labour-days)
'-----------------------------------------------------------------------------------------
  1     95        95      98       98       98      98       98      98       98       98
  2     91        91      96       96       96      96       96      96       96       96
;...
'-----------------------------------------------------------------------------------------
' Goals in the entire Region
'-----------------------------------------------------------------------------------------
' Year  Rice      Rice     %      Income     %     Income     %   Employment    %   Surface ...
'    production /capita  below   /capita  below  /capita    below             labour  water
'                        limit   no proc. limit with proc. limit  (1,000     force quality
'      (tonne)    (kg)            (US$)            (US$)        labour-days)   (%population)
'-----------------------------------------------------------------------------------------
  1  1000000     800      30        40      30       50      30    60000      70      50
  2  1100000     850      30        45      30       55      30    60000      70      50
...
' Without processing
'    NPV        B/C Ratio  N/K Ratio    IRR    Payback period
' 1000 US$                               %          years
'-----------------------------------------------------------------------------------------
  50000        1.2          1.2        15          10
' With processing
'    NPV        B/C Ratio  N/K Ratio    IRR    Payback period
' 1000 US$                               %          years
'-----------------------------------------------------------------------------------------
  120000       1.2          1.2        18          10

'=========================================================================================
' DATA FOR THE INSIDE
'-----------------------------------------------------------------------------------------
....
```

File: MARI1.I14 (Example of output data on achievements in water management units)

```
' ****************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP AREA - Goal and Impact Analysis Sub-model [14]
' ACHIEVEMENTS AT WATER MANAGEMENT UNIT LEVEL          Generated at 13:56:42 on 12-13-1994
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: MARI1.SCE)
' Extract water: Yes        Water pH change: No
' ****************************************************************************************
'  WMU   Year Population     Rice      Income     Income    Employment      %     Surface ...
'                          /capita    /capita    /capita                 labour    water  ...
'                                     no proc.  with proc.   (1,000       force    supply
'                (persons)   (kg)      (US$)      (US$)   labour-days)          (% population)
'_________________________________________________________________________________________
    28,    1,    39721       736        25         53        2237        58.5        0.0 ...
    29,    1,    92879       712        42         65        4148        45.1        0.0 ...
...
```

File: MARI1.P14 (Example of output data on production, area and yield)

```
' ****************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP AREA - Goal and Impact Analysis Sub-model [14]
' PRODUCTION, AREA & YIELD IN WATER MANAGEMENT UNITS   Generated at 13:56:40 on 12-13-1994
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1    (File: MARI1.SCE)
' Extract water: Yes  Water pH change: No   Abbreviations: see EXISTING.S03 in Appendix S3
' ****************************************************************************************
' WMU Year Items        OneTra  OneHY    SA     2ndTra   2ndHY    WS    Sugar  Pine  BeanSA...
' (Unit of production   tonne   tonne   tonne   tonne    tonne   tonne  tonne  tonne tonne
'_________________________________________________________________________________________
   28 , 1, Prod.,        8451  10903    8544    3776     296    2424  15001   934     56 ...
           Area (ha),    2722   2592    2030    1424     144     462    312    54     43 ...
           Yield,         3.1    4.2     4.2     2.7     2.1     5.2   48.1  17.3    1.3 ...
...
```

File: MARI1.S14 (Example of output data on goals and impact analysis)

```
'*****************************************************************************************
' OUTPUT FROM CAILUP FOR QUAN LO PHUNG HIEP REGION - Goal and Impact Analysis Sub-model [14]
' GOAL & IMPACT ANALYSIS                               Generated at 18:07:04 on 12-14-1995
' Scenario: RICE-ORIENTED + CONSTRUCTION SCHEDULE 1 (File: maril.SCE)
' Extract water: Yes        Water pH change: No
' Notes:  % below limit = % below 0.60 average of rice production per capita in the Region
'                     or % below 0.80 average of income per capita in the Region
'*****************************************************************************************
' Year  Rice       Rice      %      Income     %      Income     %  Employment    %     Surface...
'     production /capita   below   /capita   below   /capita   below            labour    water
'                          limit   no proc.  limit with proc.  limit   (1,000    force    supply
'      (tonne)    (kg)             (US$)             (US$)          labour-days)      (%population)
'=========================================================================================
' THE ENTIRE REGION
  1   942972       718    18.9        31     39.4       56      35.9   66183      57.4      0.0
  2  1011453       749    19.7        43     30.7       68      28.5   56028      47.4      0.0
...
'_________________________________________________________________________________________
' Relative deviation of realized value from goal (%)
  1     -5.7        -10.2  37.1     -38.8    -31.5     -20.7  -19.8     10.3     -18.0    -100.0
  2      1.1         -6.4  34.2     -13.1     -2.3      -2.6    4.9     -6.6     -32.3    -100.0
...
'_________________________________________________________________________________________
' Economic indicators:    Without processing                      With processing
'                          NPV    B/C   N/K  IRR  Payback       NPV     B/C   N/K  IRR  Payback
'                    (1,000 US$)              (%)  (years)   (1,000 US$)              (%)  (years)
'_________________________________________________________________________________________
'                        54607  1.14  0.59  16.8    11         127291  1.23  1.27  22.9     9
' Relative deviation:      9.2  -5.2 -50.9  11.7  -10.0           6.1   2.9 43.22  27.1   10.0
'_________________________________________________________________________________________
' Score of single goal:
'   Rice      Rice      %      Income      %     Income       %  Employment  NPV  B/C  N/K ...
' production /capita  below   /capita   below   /capita     below
'                     limit   no proc.  limit   with proc.  limit
 _________________________________________________________________________________________
    13.4      2.4    -2.1       6.0   -10.9      6.8        -9.5      5.0     10.0 -6.5  0.1 ...
'_________________________________________________________________________________________
  Total score without processing,    1.1,        Total score with processing,     4.3
'=========================================================================================
' FOR THE INSIDE
'_________________________________________________________________________________________
...
```

SAMENVATTING

SUMMARY IN VIETNAMESE

LIST OF REFERENCES

BIOGRAPHY

SAMENVATTING

Het probleem - Doel van de studie

Landgebruiksplanning is een essentiële activiteit voor ieder land, omdat de vraag naar produkten van verschillende vormen van landgebruik gewoonlijk groter is dan wat de beschikbare natuurlijke hulpbronnen kunnen leveren. Landgebruiksplanning houdt in dat doelstellingen, die met elkaar in conflict zijn vanwege verschillende belangen in de maatschappij, tegen elkaar moeten worden afgewogen. Ook de vraag naar water is vaak groter dan de hoeveelheid die beschikbaar is.

Het doel van deze studie is het ontwikkelen en implementeren van een methode en software systeem voor geïntegreerde landgebruiksplanning op regionaal niveau in geïrrigeerde gebieden en de methode en het systeem te testen in het Quan Lo Phung Hiep gebied in de Mekong Delta in Vietnam. In de studie is gebruik gemaakt van een methodologie voor systeemontwikkeling - System Development Methodology (SDM) - die bestaat uit zeven specifieke stappen. Daarmee is een computermodel voor geïntegreerde landgebruiksplanning - Computerized Aid to Integrated Land Use Planning (CAILUP) - ontwikkeld.

De onderzoeksfilosofie

De grootste uitdaging in landgebruiksplanning is de diversiteit in landgebruik, zoals die tot uiting komt in verschillen in landgebruikers, doelstellingen, management en gebruikte technologieën, te integreren in het planningsproces. De benadering als gebruikt in CAILUP houdt rekening met die diversiteit in landgebruik door veelbelovende vormen van landgebruik voor landbouwkundige, visserij- en bosbouwdoeleinden te integreren met het gebruik van land voor andere doeleinden.

Integratie is een belangrijk aandachtspunt in landgebruiksplanning. Binnen CAILUP is gestreefd naar integratie van keuzen voor landgebruik op verschillende hiërarchische niveaus, van biofysische en sociaal-economische factoren, van lokale en internationale kennis, en van computertechnologie en landgebruiksplanning.

In CAILUP wordt integratie van verschillende hiërarchische niveaus bereikt door top-down en bottom-up benaderingen te combineren. Interventies worden afgeleid van doelstellingen voor regionale ontwikkeling, binnen de nationale context. De uitvoerbaarheid van deze interventies wordt beoordeeld door rekening te houden met voorkeuren en prioriteiten van de lokale landgebruikers, en vervolgens de resultaten en effecten van de interventies te evalueren. Beslissingen met betrekking tot landgebruik worden daardoor beslissingen van de gemeenschap met bijdragen van wetenschappers, planners, gespecialiseerde regeringsinstellingen en landgebruikers. Integratie in de publieke besluitvorming wordt bereikt door het beslissingsproces te simuleren.

Een geïntegreerde biofysische en sociaal-economische benadering - Integrated Bio-physical and Socio-economic approach (IBS) - wordt gebruikt om de effecten van alternatieve vormen van waterbeheer vast te stellen. Deze integratie vraagt om een gelijke resolutie (in ruimte en tijd) van zowel biofysische als sociaal-economische gegevens. Landeenheden worden daarom ruimtelijk bepaald door zowel administratieve grenzen, als door grenzen gebaseerd op eigenschappen met betrekking tot de invloed van belangrijke fysische interventies.

Landgebruiksplanning houdt ook in integratie van verschillende sectoren. De belangrijkste interventie wordt in eerste instantie vastgesteld, bijvoorbeeld de constructie van een waterbeheerssysteem voor een geïrrigeerd gebied. Andere interventies zijn aanvullend en dienen de efficiëntie van het waterbeheer te verbeteren. Het team, dat verantwoordelijk is voor landgebruiksplanning, moet kunnen beschikken over een groot aantal kennisvelden. CAILUP bevat een "knowledge base", die specialistische kennis van zowel lokaal (regionaal en nationaal) als internationaal niveau integreert.

Simulatietechnieken zijn veelbelovende hulpmiddelen om integratie te bereiken in landgebruiksplanning. Bij de ontwikkeling van CAILUP is gekozen voor integratie van eenvoudige sub-modellen van alle relevante componenten, en niet voor een beperkter aantal complexe sub-modellen die zijn ontwikkeld binnen disciplinair onderzoek. CAILUP bevat functies om de effecten van verschillende, door planners geformuleerde, hypotheses en scenario's te analyseren. Een scenario bestaat uit een aantal acties en effecten, waarmee doelstellingen in meerdere of mindere mate worden gerealiseerd. De effecten van waterbeheer op de fysische omstandigheden worden eerst geëvalueerd. Veranderde fysische omstandigheden leiden tot gewijzigde biofysische produktieniveau's die, na toetsing aan sociaal-economische criteria op bedrijfsniveau, worden gebruikt om een geïntegreerde haalbaarheid ("feasibility") voor elk landgebruikstype vast te stellen. Deze feasibility wordt, in combinatie met beleidsdoelstellingen op nationaal niveau, gebruikt om een landgebruiksplan te formuleren. Uiteindelijk wordt nagegaan wat de gevolgen zijn van uitvoering van het plan en wat de effecten zijn op de biofysische en sociaal-economische omstandigheden.

Integratie van computertechnologie en landgebruiksplanning is bereikt binnen een systeem dat bestaat uit kwantitatieve modellen, databanken en een geografisch informatiesysteem (GIS) gebaseerd op de concepten van beslissingsondersteunende systemen ("decision support systems") en specialistensystemen ("expert systems").

Een computermodel voor beslissingsondersteuning bij geïntegreerde landgebruiksplanning (A Computerized Aid to Integrated Land Use Planning - CAILUP)

CAILUP bestaat uit vier componenten: een "core expert" component, een databank component, een GIS component en een modelcomponent. De modelcomponent die de essentiële functies van het systeem uitvoert, bestaat uit een mathematisch model dat ontwikkeld is op basis van een conceptueel model.

Het conceptuele model werd ontwikkeld door het identificeren van achtereenvolgens problemen bij het huidige landgebruik, doelstellingen en indicatoren, relevante landgebruikstypen, relevante componenten, factoren, ruimtelijke omvang en resolutie, tijdshorizon en tijdsstappen, en opties "met" en "zonder" interventies.

Het mathematische model bestaat uit 14 sub-modellen:

[1] Een *Interventie-Genererend Sub-model*, dat gegevens genereert voor de opties "met" en "zonder" interventie.

[2] Een *Fysisch Impact Sub-model*, dat een dataset van de gewijzigde fysische omstandigheden genereert.

[3] Een *Biofysisch Sub-model (landbouw, visserij, bosbouw)*, waarin gewasgroeikalenders worden geselecteerd en opbrengsten geschat onder de gewijzigde fysische omstandigheden.

[4] Een *Economisch Sub-model op bedrijfsniveau*, dat de gecombineerde biofysische/economische "feasibility" genereert, op basis van financiële criteria op bedrijfsniveau.

[5] Een *Sociaal Sub-model op bedrijfsniveau*, dat een geïntegreerde "feasibility" genereert op basis van sociale voorkeuren en de biofysische/economische "feasibility" van [4].

[6] Een *Demografisch Sub-model*, dat gegevens over bevolking en arbeidspotentieel genereert.

[7] Een *Sub-model voor weging van landgebruiksvormen*, dat wegingsfactoren bepaalt op basis van de geïntegreerde feasibility [5] en het vigerend regeringsbeleid.

[8] Een *Sub-model voor allocatie van landgebruik*, dat verschillende vormen van landgebruik toewijst aan landeenheden op basis van de wegingsfactoren [7] en regels voor landgebruiksconversie.

[9] Een *Produktie Sub-model*, dat de totale produktie berekent door oppervlakten met opbrengsten te vermenigvuldigen.

[10] Een *Aanvullende Interventies Sub-model*, dat aanvullende interventies genereert ter ondersteuning van de landgebruiksscenario's.

[11] Een *Economisch Sub-model op Regionaal Niveau*, dat de economische baten berekent op het niveau van landeenheid en regio.

[12] Een *Sociaal Sub-model op Regionaal Niveau*, dat sociaal-economische indicatoren berekent op het niveau van landeenheid en regio.

[13] Een *Milieueffect Sub-model*, dat indicatoren berekent met betrekking tot de milieueffecten.

[14] Een *Sub-model voor analyse van de Ontwikkelingsdoelstellingen en de Effecten*, dat een rangorde toekent aan de geselecteerde scenario's.

Een voorbeeld uit de werkelijkheid

De Quan Lo Phung Hiep regio met een totale oppervlakte van ongeveer 450.000 hectare, gelegen in de Mekong Delta in Vietnam, is gekozen voor de case studie. De landbouwproduktie in deze regio wordt beperkt door ongunstige bodem- en watercondities. Lage regenval gedurende de droge tijd maakt landbouw zonder irrigatie onmogelijk. Intrusie van zout water uit de zee maakt het water in rivieren en kanalen in grote delen van de regio ongeschikt voor irrigatie. Aan het begin van de regentijd wordt de kwaliteit van het oppervlaktewater beïnvloed door draïnagewater uit kattekleigebieden waardoor de pH plaatselijk daalt tot beneden 4, wat uiterst schadelijk is voor de produktie van gewassen, vis en garnalen.

In het gebied werkt 85 procent van de bevolking in de landbouw, visserij en bosbouw. Relevante landgebruikstypen zijn de verbouw van één gewas per jaar (rijst, suikerriet, enz..), combinaties van verschillende gewassen (rijst+rijst, rijst+bonen) en combinaties van gewassen met andere activiteiten (bv. rijst+garnalen), met verschillende produktietechnieken. Rijst is het belangrijkste gewas. De levensstandaard in gebieden met zout en brak water zou lager zijn dan in gebieden met zoet water.

Een waterbeheerssysteem, dat de intrusie van zout water tegengaat en de toevoer van zoet water uit de Mekong rivier vergroot, wordt beschouwd als de belangrijkste interventie voor de ontwikkeling van de regio. De voornaamste doelstellingen van verbeterd waterbeheer zijn het verhogen van voedselproduktie en inkomens en het verbeteren van de levensomstandigheden. Een partiële waterbeheersoptie, bestaande uit bescherming tegen zout water van en creëren van mogelijkheden voor irrigatie voor het centrale deel van de regio door middel van 11 middelgrote sluizen, werd geselecteerd. Zeven alternatieve constructieschema's zijn geformuleerd, die verschillen in benodigde investeringen en strategieën met betrekking tot het terugdringen van de effecten van zuur drainagewater. Vier doelstellingen met betrekking tot landgebruik zijn geformuleerd: maximaliseren van rijstproduktie, maximaliseren van inkomen uit rijstproduktie, gewasdiversificatie en minimaliseren van de effecten van zuur water.

CAILUP als ontwikkeld voor de Quan Lo Phung Hiep regio is gebruikt voor het analyseren van de effecten van verschillende constructieschema's en landgebruiksstrategieën.

Voor de calibratie werden watergegevens van 1989-1990, opbrengstgegevens van 1986-1990, produktiegegevens van 1985-1990, en gegevens over bevolking en landgebruiksarealen van 1985 en 1990 gebruikt. Na calibratie van individuele sub-modellen werden combinaties van opeenvolgende sub-modellen gecalibreerd. Het model werd gevalideerd met gegevens van 1991 en 1994.

Achtentwintig ontwikkelingsscenario's, gevormd door combinatie van de 7 constructieschema's van het waterbeheerssysteem en de 4 landgebruiksstrategieën, zijn vergeleken met een optie zonder waterbeheersmaatregelen ("without case"). Voor evaluatie van de ontwikkelingsscenario's zijn "scores" voor afzonderlijke doelstellingen en totale "scores" gebruikt. Een gevoeligheidsanalyse is uitgevoerd om de gevoeligheid vast te stellen van outputs voor variaties in veranderingen in verschillende parameters, functies en sub-modellen, en de effecten van veranderingen van inputwaarden op scenario scores.

Een constructieschema werd gekozen op basis van ontwikkelingsdoelstellingen en mogelijke effecten, als weerspiegeld in de scores van verschillende scenario's, rekening houdend met de institutionele omstandigheden in de regio. Het kiezen van een landgebruiksstrategie was moeilijker, omdat voor de geanalyseerde situaties, elke strategie leidt tot een hoogste score voor op zijn minst één ontwikkelingsdoelstelling. Er is gekozen voor een op rijst georiënteerde strategie met meer gewasdiversificatie buiten het tegen zout water beschermde gebied.

Conclusies en aanbevelingen

De doelstellingen van de studie zijn gerealiseerd. CAILUP is ontwikkeld om integratie in landgebruiksplanning gemakkelijker te maken, waarbij rekening is gehouden met de belangrijkste aandachtspunten in de methodologie voor landgebruiksplanning. Een software systeem is ontwikkeld en met succes getest in de Quan Lo Phung Hiep regio. Het ontwikkelen en met succes toepassen van CAILUP is alleen mogelijk onder omstandigheden waarbij kundige staf, gegevens, hardware en software beschikbaar zijn.

Hoewel de bovengenoemde omstandigheden gunstig waren bij de ontwikkeling van CAILUP, moet er bij verdere ontwikkeling en toepassing toch rekening gehouden worden met vele uitdagingen, die voortkomen uit telkens twee alternatieven (zie Hoofdstuk V.2). Deze ontwikkeling vertoont een cyclisch gedrag, waarbij gedurende een aantal jaren één uitdaging dominant is, en het hoofddoel van vele studies, waarna het wordt afgelost door een andere uitdaging. Bij de ontwikkeling en toepassing van CAILUP in verdere studies moeten pogingen worden ondernomen om het CAILUP systeem aan te passen aan deze cycli.

SUMMARY IN VIETNAMESE - TÓM TẮT

Vấn đề - Mục tiêu nghiên cứu

Quy hoạch sử dụng tài nguyên đất đai là công tác thiết yếu tại bất cứ quốc gia nào, vì nhu cầu đất đai cần cho các loại sử dụng đất khác nhau thường vượt quá tài nguyên đất đai hiện có. Quy hoạch sử dụng tài nguyên đất đai bao hàm sự cân nhắc giữa các mục tiêu mâu thuẫn nhau, vì trong xã hội luôn có các mối quan tâm khác nhau. Nhu cầu nước cũng thường cao hơn tài nguyên nước hiện có.

Mục tiêu của nghiên cứu này là xây dựng và thực hiện một phương pháp và phần mềm máy tính tương ứng dùng cho việc quy hoạch tổng hợp sử dụng tài nguyên đất đai cấp vùng cho công tác phát triển thủy lợi, và thử nghiệm phương pháp này trong vùng Quản Lộ Phụng Hiệp, đồng bằng sông Cửu Long, Việt Nam. Phương pháp Xây dựng Hệ thống (System Development Methodology, SDM) bao gồm 7 giai đoạn được áp dụng trong nghiên cứu này. Một Phần mềm Quy hoạch Tổng hợp Sử dụng Đất (Computerized Aid to Integrated Land Use Planning, CAILUP) đã được xây dựng.

Quan điểm nghiên cứu

Thử thách lớn nhất trong quy hoạch sử dụng tài nguyên đất đai là làm thế nào kết hợp tính đa dạng, bao gồm nhiều đối tượng sử dụng, nhiều mục tiêu, nhiều phương thức quản lý và canh tác, vào tiến trình quy hoạch. Tính đa dạng này được đưa vào CAILUP bằng cách tổng hợp các loại sử dụng đất có triển vọng cho sản xuất nông nghiệp, thủy sản và lâm nghiệp với các loại sử dụng đất cho các mục tiêu khác.

Tổng hợp là một công tác quan trọng trong quy hoạch sử dụng đất. CAILUP đặt trọng tâm vào việc tổng hợp sự chọn lựa loại sử dụng đất ở các cấp quản lý khác nhau, tổng hợp các yếu tố sinh học tự nhiên với các yếu tố kinh tế xã hội, tổng hợp kiến thức chuyên gia trong nước với kiến thức chuyên gia quốc tế, và tổng hợp kỹ thuật máy tính với quy hoạch sử dụng đất.

Sự tổng hợp giữa các cấp quản lý được thực hiện trong CAILUP bằng cách kết hợp phương pháp quy hoạch từ trên xuống và từ dưới lên. Các công tác cần thực hiện được dựa trên mục tiêu phát triển của vùng trong bối cảnh phát triển chung của quốc gia. Tính hiện thực của các công tác này được đánh giá bằng cách xem xét thị hiếu và mức độ ưu tiên của những người sử dụng đất tại địa phương, và sau đó tất cả các thành quả và tác động của các công tác này được đánh giá chung. Việc chọn lựa loại sử dụng đất được coi như một quyết định chung của xã hội bao gồm sự đóng góp của các nhà khoa học, quy hoạch, lãnh đạo, các cơ quan chuyên ngành và người sử dụng đất. Việc chọn lựa này được tổng hợp bằng cách mô phỏng tiến trình chọn lựa loại sử dụng đất thích hợp đang diễn ra trong thực tế.

Một phương pháp tổng hợp các yếu tố sinh học tự nhiên và kinh tế xã hội (Integrated Bio-physical and Socio-economic, IBS) được đề nghị để đánh giá kết quả của công tác thủy lợi. Việc tổng hợp đòi hỏi số liệu về sinh học tự nhiên và kinh tế xã hội phải có cùng một độ phân giải (không gian và thời gian). Các đơn vị đất đai được xác định bằng ranh giới hành chánh kết hợp với ranh giới của công trình thủy lợi chính.

Quy hoạch sử dụng tài nguyên đất đai cũng có thể coi như một tiến trình tổng hợp đa ngành. Một công tác chủ chốt được xác định, đó là xây dựng một hệ thống công trình thủy lợi. Các công tác khác được coi là công tác hỗ trợ để nâng cao hiệu quả của phát triển thủy lợi. Nhóm công tác quy hoạch sử dụng tài nguyên đất đai phải bao gồm chuyên gia nhiều lãnh vực. CAILUP bao gồm một hệ thống kiến thức chuyên gia tổng hợp từ kiến thức của chuyên gia trong nước (vùng và quốc gia) với kiến thức chuyên gia quốc tế.

Xây dựng mô hình mô phỏng là kỹ thuật thích hợp cho việc tổng hợp trong quy hoạch sử dụng đất. Chiến lược xây dựng mô hình của CAILUP là tổng hợp các mô hình đơn ngành đơn giản của tất cả các thành phần, thay vì chỉ bao gồm một số mô hình phức tạp xây dựng cho nghiên cứu chuyên ngành. CAILUP có các chức năng để phân tích tác động của các công tác phát triển với các giả thiết hoặc tình huống khác nhau do các nhà quy hoạch đề ra. Một tình huống phát triển bao gồm một loạt các công tác và kết quả trong đó các mục tiêu được đánh giá đạt ở mức độ nào. Trước hết , tác động của công tác thủy lợi trên các yếu tố tự nhiên được phân tích. Điều kiện tự nhiên mới sẽ đem lại năng suất sinh học mới, được dùng để xác định hệ số khả thi của từng loại sử dụng đất bằng cách so sánh với các tiêu chuẩn kinh tế xã hội cấp nông hộ. Hệ số khả thi này được sử dụng, cùng với các mục tiêu và chiến lược của Chính phủ, để xây dựng một quy hoạch sử dụng tài nguyên đất đai. Cuối cùng, thành quả của quy hoạch này và các tác động kèm theo về sinh học tự nhiên và kinh tế xã hội sẽ được xem xét.

Việc tổng hợp kỹ thuật máy tính và quy hoạch sử dụng tài nguyên đất đai sẽ đạt được bằng cách xây dựng một hệ phần mềm bao gồm mô hình định lượng, cơ sở dữ liệu và hệ thống thông tin địa lý (GIS) trên quan điểm của hệ thống hỗ trợ quyết định và hệ chuyên gia.

Phần mềm Quy hoạch Tổng hợp Sử dụng đất

CAILUP bao gồm 4 bộ phận: bộ phận chuyên gia hạt nhân, cơ sở dữ liệu, bộ phận GIS và hệ thống mô hình. Hệ thống mô hình, bộ phận chính thực hiện nhiệm vụ của CAILUP, bao gồm một mô hình toán phát triển từ một mô hình nhận thức.

Mô hình nhận thức được xây dựng theo trình tự: xác định các vấn đề, các mục tiêu và chỉ số để đánh giá, những loại sử dụng đất thích hợp, các thành phần, các thông số cần phân tích, phạm vi và độ phân giải không gian, thời gian quy hoạch và các bước tính toán, và các tình huống "có" và "không" thực hiện công tác thủy lợi.

Mô hình toán bao gồm 14 mô hình con:

[1] *Mô hình Xây dựng Công tác* cung cấp một bộ số liệu cho tình huống "có" hoặc "không" thực hiện công tác thủy lợi.

[2] *Mô hình Tác động Vật lý* tính toán số liệu về điều kiện tự nhiên mới.

[3] *Mô hình Sinh học Tự nhiên (Nông nghiệp, Thủy sản, Lâm nghiệp)* ước tính năng suất và thời vụ chọn lựa theo điều kiện tự nhiên mới.

[4] *Mô hình Kinh tế Cấp Nông hộ* tính toán hệ số khả thi sinh học tự nhiên/kinh tế trên cơ sở các tiêu chuẩn tài chính ở cấp nông hộ.

[5] *Mô hình Xã hội Cấp Nông hộ* tổng hợp thị hiếu xã hội với hệ số khả thi sinh học tự nhiên/kinh tế để tính ra một hệ số khả thi tổng hợp.

[6] *Mô hình Dân sinh* tính toán số liệu về dân số và lao động.

[7] *Mô hình Trọng số Sử dụng đất* xác định các trọng số trên cơ sở hệ số khả thi tổng hợp và chiến lược của Chính phủ.

[8] *Mô hình Phân phối Sử dụng Đất* tính toán phân phối tài nguyên đất đai trên cơ sở trọng số và các quy luật về chuyển đổi sử dụng đất.

[9] *Mô hình Sản lượng* tính toán tổng sản lượng bằng cách nhân diện tích với năng suất.

[10] *Mô hình Công tác Hỗ trợ* tính toán khối lượng các công tác khác cần thực hiện để hỗ trợ cho phương án sử dụng tài nguyên đất đai.

[11] *Mô hình Kinh tế Cấp Vùng* tính hiệu quả kinh tế cho các đơn vị đất đai và toàn vùng.

[12] *Mô hình Xã hội Cấp Vùng* tính toán các chỉ số kinh tế xã hội cho các đơn vị đất đai và toàn vùng.

[13] *Mô hình Tác động Môi trường* tính toán các chỉ số diễn tả các tác động về môi trường.

[14] *Mô hình Phân tích Mục tiêu và Tác động* tính toán một trị số để xếp hạng tình huống phát triển cần xem xét.

Một thí dụ trong thực tế

<u>Vùng Quản Lộ Phụng Hiệp</u> tại đồng bằng sông Cửu Long, Việt Nam, với tổng diện tích khoảng 450.000 ha, đã được chọn làm vùng nghiên cứu điển hình. Sản xuất nông nghiệp tại đây bị hạn chế vì điều kiện đất và nước. Nếu không có nguồn nước mặt, sản xuất nông nghiệp bị giới hạn bởi lượng mưa thấp trong mùa khô. Tuy nhiên, nước mặn xâm nhập từ biển vào làm cho chất lượng nước tại phần lớn diện tích trong vùng không dùng được cho nông nghiệp. Vào đầu mùa mưa, các chất độc rửa trôi từ đất phèn làm ô nhiễm nguồn nước mặt và hạ thấp độ pH xuống dưới 4, không thể sử dụng cho nông nghiệp và thủy sản.

85% dân số trong vùng sống nhờ nông nghiệp, thủy sản và lâm nghiệp. <u>Các loại sử dụng đất thích hợp</u> là đơn canh (lúa, mía, v.v.) hoặc kết hợp nhiều loại canh tác (lúa hai vụ, lúa + đậu, lúa + tôm, v.v.) với các biện pháp canh tác khác nhau. Lúa là loại cây trồng chính. Mức sống ở vùng nước mặn và nước lợ được ghi nhận là thấp hơn ở vùng có nước ngọt.

<u>Phát triển thủy lợi</u> để ngăn mặn và gia tăng lượng nước ngọt dẫn tưới từ sông Cửu Long được coi là công tác hàng đầu cho việc phát triển trong vùng. Các mục tiêu chính của công tác thủy lợi là nâng cao sản lượng lương thực và thu nhập cho nông dân, và cải thiện điều kiện sống. Một phương án ngăn mặn quy mô vừa đã được chọn lựa, trong đó vùng trung tâm được ngăn mặn và tiếp nước ngọt từ sông Cửu Long bằng 11 cống ngăn mặn quy mô trung bình. Bảy tiến độ xây dựng công trình khác nhau đã được soạn thảo dựa trên nguồn vốn và chiến lược hạn chế ảnh hưởng của nước chua phèn. Bốn chiến lược sử dụng đất đã được xây dựng: Tối đa hoá sản lượng lúa, Tối đa hoá thu nhập từ canh tác lúa, Đa dạng hoá cây trồng và Tối thiểu hoá ảnh hưởng của nước chua phèn.

CAILUP cho vùng Quản Lộ Phụng Hiệp đã được xây dựng và sử dụng để phân tích ảnh hưởng củaccác tiến độ xây dựng và chiến lược sử dụng đất khác nhau.

Số liệu dùng để điều chỉnh mô hình là số liệu về điều kiện nước năm 1989 và 1990, năng suất từ năm 1986 đến 1990, dân số và diện tích sử dụng đất năm 1985 và 1990, và số liệu sản lượng từ năm 1985 đến 1990. Việc điều chỉnh từng mô hình riêng lẻ được kèm theo bằng việc điều chỉnh một loạt mô hình liên hệ. Sau đó, các mô hình được đánh giá lại với số liệu từ năm 1991 đến 1994.

Hai mươi tám tình huống phát triển, tổng hợp từ 7 tiến độ xây dựng công trình thủy lợi và 4 chiến lược sử dụng đất, đã được so sánh với trường hợp "không" xây dựng trong đó giả sử không có công trình thủy lợi mới. Điểm xếp hạng cho từng mục tiêu riêng lẻ và điểm tổng cộng là các trị số tính toán chính dùng để đánh giá các tình huống phát triển. Việc phân tích độ nhạy đã được thực hiện để tính toán độ nhạy của kết quả tính từ mô hình đối với các thông số, các công thức tính toán hay mô hình con, và để phân tích ảnh hưởng của việc thay đổi trị số nhập vào mô hình đối với điểm xếp hạng của tình huống.

Một tiến độ xây dựng công trình đã được chọn lựa trên cơ sở các mục tiêu phát triển và các tác động có thể xảy ra phản ánh qua điểm xếp hạng của các tình huống phát triển, có xét tới cơ cấu tổ chức quản lý trong vùng. Việc chọn lựa một chiến lược sử dụng đất khó khăn hơn vì trong các tình huống đã tính toán, mỗi chiến lược đều có ít nhất điểm xếp hạng cao nhất cho một mục tiêu. Chiến lược đã được chọn lựa có trọng tâm là sản xuất lúa, với gia tăng đa dạng hoá hệ thống canh tác ngoài vùng được ngăn mặn.

Kết luận và kiến nghị

Các mục tiêu nghiên cứu đề ra đã đạt được. Từ việc phân tích các vấn đề chủ chốt trong phương pháp luận quy hoạch sử dụng tài nguyên đất đai, CAILUP đã được xây dựng để thực hiện việc tổng hợp trong quy hoạch này. Một hệ phần mềm tương ứng đã được xây dựng và thử nghiệm thành công cho vùng Quản Lộ Phụng Hiệp. Để có thể xây dựng và áp dụng thành công, CAILUP đòi hỏi các điều kiện thích hợp về nhân lực, thông tin và số liệu, và phương tiện phần cứng và phần mềm.

Mặc dù các điều kiện trên có thể thoả mãn, việc xây dựng và áp dụng CAILUP cũng còn nhiều thử thách, mà mỗi thử thách phát sinh do luôn luôn có hai giải pháp khác nhau. Một chu kỳ nghiên cứu đã được ghi nhận trong đó một thử thách trở nên nổi bật và trở thành đối tượng của nhiều công tác nghiên cứu trong nhiều năm, và cũng có một chu kỳ tương tự trong việc chọn lựa một trong hai giải pháp của mỗi thử thách. Nỗ lực của các nghiên cứu tiếp theo sẽ là xây dựng và áp dụng CAILUP phù hợp với các chu kỳ này.

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Chu Thai Hoanh was born in Thanh Hoa, Vietnam on 24 June 1949. He obtained his Civil Engineer degree in 1972 at the Polytechnical School in Saigon (presently, Ho Chi Minh City), Vietnam. He took the position of Head of the Technical Division in the National Water Resources Committee in 1973 and was a national counterpart in a project of The Netherlands Delta Development Team, in 1973-1974.

Since the unification of Vietnam in 1975, Mr. Hoanh has worked with the Sub-Institute of Water Resources Planning and Management, Ministry of Water Resources, and at present, he is Deputy Head of the Technical and Integration Office.

He participated in training courses on Remote Sensing and on Remote Sensing for Integrated Survey in a UNDP/FAO Project, on GIS in a Mekong Project, on Adaptive Environmental Assessment & Management in a Canadian CIDA Project, and on Water Development Economics in a Mekong Training Program supported by the Australian Government.

From 1983 to 1990, he participated in a State Programme for Integrated Surveys in the Mekong Delta, Vietnam. From 1989 to 1992, he was the National Coordinator and worked on integrated modelling in the "Water Control Project for the Quan Lo Phung Hiep area, Pre-Feasibility Study" assisted by CIDA. Finally, he was a counterpart in the "Mekong Delta Master Plan Project" financially supported by UNDP and carried out by NEDECO, The Netherlands, from 1991 to 1993.