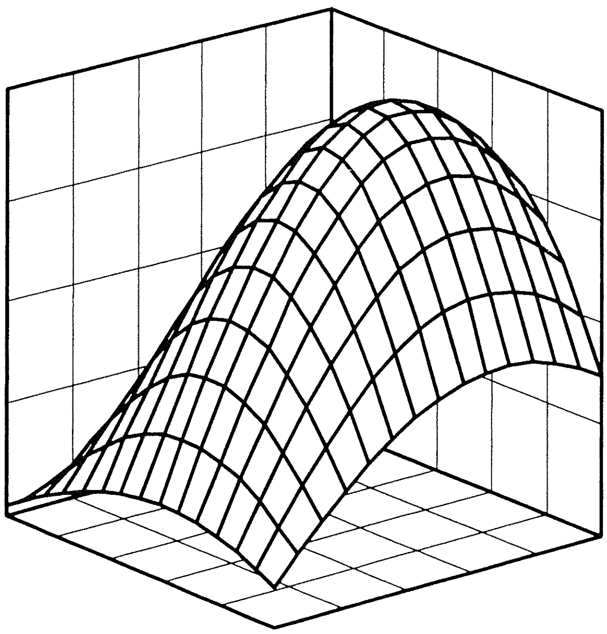
The Conversion of Land Use and its Effects (CLUE-CR):

a regression based model applied to Costa Rica (Pascal version 1.2)



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The Conversion of Land Use and its Effects (CLUE-CR):

a regression based model applied to Costa Rica (Pascal version 1.2)

J.M. Schoorl, A. Veldkamp & L.O. Fresco

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Samenvatting

In dit document wordt een modelbeschrijving en een gebruikershandleiding gegeven van een toepassing van CLUE, een dynamisch simulatiemodel op meerdere schalen voor de conversie van het landgebruik en de gevolgen daarvan. CLUE-CR simuleert de ruimtelijke en temporele veranderingen van het landgebruik in Costa Rica als een gevolg van de interactie tussen biofysische en menselijke factoren. Het regionale landgebruik zal in het CLUE-CR-model alleen dan veranderen wanneer het huidige landgebruik niet meer kan voorzien in de biofysische en menselijke behoeftes. Na een regionale evaluatie van het type landgebruik waar behoefte aan is, zal de uiteindelijke verandering plaatsvinden op het lokale niveau. De eerder genoemde biofysische en menselijke factoren die het landgebruik sturen komen voort uit de toepassing van multi-variate statistische technieken in een geneste schaalanalyse. De belangrijkste biofysische factoren in het model verantwoordelijk voor de ruimtelijke verdeling van de verschillende typen landgebruik zijn de biofysische geschiktheid (reliëf, bodem en klimaat) en de duur van het landgebruik. De belangrijkste menselijke factoren in CLUE-CR zijn de rurale en urbane bevolkingsdichtheid en het gevolg daarvan voor de toegepaste landbouwtechnieken en het beheer van het landgebruik. Deze documentatie is op de eerste plaats bedoeld ter ondersteuning van de reeds gepubliceerde artikelen met betrekking tot de ontwikkeling en toepassing van het CLUE-CR-model. We hopen daarom ook dat de voorgestelde methode in dit document een bijdrage zal leveren op het gebied van de kennis en de ontwikkeling van het dynamisch modelleren van landgebruik en de resulterende bedekking.

Summary

In this document a multi-scale dynamic model to simulate Conversion of Land Use and its Effects (CLUE) is described and documented, including a user's guide, for its application in Costa Rica. CLUE-CR simulates land use conversion and change in space and time as a result of interacting biophysical and human drivers. The basic principle of the model is that changes in land use/cover result from the combination of biophysical suitability and changes in driving forces at various scales. Land use/cover will be changed only when the biophysical and human demands can not be fulfilled by the existing land use. After a regional evaluation of the land use needs, the final land use decisions are made on a local level. This evaluation of needs and drivers on both regional and local levels are done with the aid of regression models. The biophysical and human land use drivers result from an evaluation using multivariate statistical methods in a nested scale analysis. The most important biophysical drivers of the model in the spatial distribution of the different land uses are biophysical suitability and their fluctuations, and the history of the present land use. Important human land use drivers in CLUE-CR are both rural and urban population size and density and their resulting management and technology levels. This extensive documentation provides a tool for further development and understanding of the presented methodology in handling this type of dynamic land use/cover modelling. Applications of CLUE in other countries (Ecuador and Colombia) and other continents (SE Asia) are currently undertaken. Last but not least, this documentation is also meant to be supplementary to publications made on development and applications of the CLUE-CR model and CLUE modelling framework.

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The authors would like to thank both the department of Agronomy of Wageningen Agricultural University and the National Research Programs on Global Air Pollution and Climate Change (NRP I and NRP II) who have partially supported the development and ongoing research on the Conversion of Land Use and its Effects (CLUE) in the projects under number 853128 *"Elaborating of land use and related factors"* and 954220 *"Multi-scale Land Use Modelling"*.

1 Introduction

Recent research indicates that human-induced conversions and modifications of land cover have significance for the functioning of the earth system (Bouwman, 1990; AMBIO, 1992; Turner *et al.*, 1993, 1994). Most land cover modification and conversion is now driven by human use, rather than natural change (Houghton *et al.*, 1991). In general, land use is viewed to be constrained by biophysical factors such as soil, climate, relief and vegetation. The human activities that make use of or change land attributes are considered as the proximate sources of land use/cover change. Interpretations of how such land use/cover driving forces act and interact is still controversial, especially in respect to the assessment of the relative importance of the different forces and factors underlying land use decisions in specific cases (Turner *et al.*, 1994). Relatively few regional comparative studies have explicitly addressed the role of these proposed driving forces, either separately or in combination. Even fewer studies have investigated the statistical relationships between them (Turner *et al.*, 1993), leaving the presented study here as one of the few attempts to explore multi-scale relations in land use/cover dynamics.

This report is based on the former work done on the CLUE conceptual model framework (Veldkamp & Fresco, 1996a) and will be focused on the application of the framework in the CLUE-CR model for Costa Rica (Veldkamp & Fresco, 1995, 1996b). This detailed documentation of the framework aims to provide a tool for further land use/cover conversion modelling and to support the published papers. The framework hopefully contributes to understand more of the processes involved in land use and cover changes. Furthermore, the CLUE-CR case study proves the value of well documented census data and shows an important and relevant way of using these valuable sources of data in modelling land use changes. In addition there are many efforts made by different institutions and organisations in building accurate and up to date regional and global biophysical and socio-economic databases which are likely to become available through the Internet and the World Wide Web in the near future.

Within the text the **`COURIER FONT`** will refer to expressions or variables used in the source code listings of the model. In order to avoid repetitive typing of similar expression or variable names, the acronym **`LUC`** (Land Use Cover) will be used to indicate the combination of the specific land use/cover types of permanent crops (`PER`), pastures (`PAS`), arable land (`ARA`), nature (`NAT`) and the rest covers (`RES`). In other words `LUC` appears where an expression name is applicable for all of them. For example in the land use/cover specific regression (`REG`) variable name `LUCREG` the letters `LUC` refer to all 5 cover types and so `LUCREG` means: `PERREG` and `PASREG` and `ARAREG` etc. (see list of variables in Appendix I).

In the second chapter the principles of land use modelling, including the theoretical and statistical backgrounds, will be discussed. The objectives and construction of the CLUE-CR model are described in chapter 3. Both model behaviour and results will be dealt with in chapter 4. The technical programming details and structures will be discussed in chapters 5 and 6 including a complete description of the main procedures and variables. Chapter 7 will be dedicated to guide the users of the CLUE-CR model in how to run the programme and how to control the inputs and outputs. Also more details are given about how to relate to the actual modelling results.

The modelling of actual land use changes and its drivers ought to be seen as complementary to other approaches such as the modelling of crop production potentials (Goudriaan & van Laar, 1994, Lanen *et al.*, 1992) and exploratory modelling efforts with the use of Interactive Multiple Goal Linear Programming (de Wit *et al.*, 1988, Rabbinge *et al.*, 1994). This is because the multi-scale modelling of land use drivers (both biophysical and demographic) deals with actual land use/cover as well as its land use potentials. The CLUE approach uses actual, georeferenced land use as a starting point. This is important since it has been shown (Veldkamp & Fresco, 1995) that the distribution of potential production often bears no relation to actual patterns, i.e. farmers nor agricultural policies are rarely guided by where what crop can best be grown from a biological point of view. In combination, these different modelling approaches will yield insight into future patterns of change as well as possible scenarios of land use and potential production.

The present CLUE-CR version 1.2 (as discussed in this document) can be seen as a standard version but is by no means the definitive version. This model is solely designed for the testing of the Costa Rica case study. Currently and in the near future other case studies for different countries will become available. Studies of applications of CLUE in countries as Ecuador and Colombia and other continents (SE Asia) are currently undertaken. The basic approach and methodology will be used in these countries for other scales or aggregation levels. The development of the model will continue in order to obtain better results and to be able to use the model in a wider range of applications and countries. It is felt that this approach, based on actual land use and actual driving forces, provides a powerful tool complementary to already established methods of exploring future land use/cover distributions.

The CLUE-CR model version 1.2 will be made available on a demonstration floppy disk with the necessary files to run the programme (see chapter 7). For ordering and registration to obtain the CLUE-CR version 1.2 demonstration model please contact the authors:

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2 Principles of land use modelling

The development of the CLUE-CR model has been based on the results and findings of the development of the conceptual CLUE model framework (Veldkamp & Fresco, 1996a). The main principles are based on the analysis of spatial and temporal data processed on different scale levels (Veldkamp & Fresco, 1997). In this chapter the theoretical and statistical background of the model will be discussed. After introducing some general effects and comments on scales an outline will be given of possible drivers and constraints in the modelling of land use/cover change. In the last paragraph some statistical procedures and solutions will be proposed and discussed.

2.1 Land use drivers and constraints

As already stated in the introduction, the modification and the conversion of the global land covers is nowadays much more driven by human land use then by natural change. The term land use can be defined, according to Mücher *et al.* (1993), as the human activities that are directly related to the land, making use of its resources or having an impact on it through interference in ecological processes that determine the function of the land cover. The effect of land use on the cover structure, phenology and composition is more relevant in the context of global change compared with the real purpose or function of the land use.

This human interference in the land cover structure depends mainly on the land- and region-related biophysical constraints and the human perception of these. From now on in this document these constraints will be referred to as the biophysical drivers of land use. So in general we state that land use is determined by the interaction in space and time of biophysical drivers (constraints) such as soil types, soil properties, (micro)climate, topography etc. and human factors like population size, population density, distribution, technology, economic conditions and structure etc.

2.2 Land use and scales

An illustrative case study of investigating land cover changes (Skole & Tucker, 1993) demonstrated that the land use changes which drive land cover changes are tied to numerous human factors. It is generally known that sometimes these factors operate at great spatial distance from the area affected. This leads to the conclusion that the main processes involved in land cover and land use changes operate across many different spatial and temporal scales.

In every case study of land use/cover changes, units and processes have scale-related properties with dimensions defined in space and time. As in the case of other living systems, scale dimensions do not evolve necessarily in a gradual manner, but may display clear threshold effects. The step from, say, a grassy vegetation on a given pasture field to vegetation in a savannah landscape is not just cumulative, which means that the landscape and the way it is managed cannot be understood entirely by taking only the sum of all individual pasture fields and the applied management actions on these fields. Although they are sometimes hard to visualise, other processes and units must be distinguished at higher levels.

The scale at which the analysis is conducted will affect the type of explanation given to the phenomena. At coarse (aggregated) scales, the high level of aggregation of data may obscure the variability of units and processes, and may therefore produce meaningless averages. Predictions based upon coarse scale data and models are therefore considered inaccurate for regional and local assessments, because at the aggregate level local key processes may be obscured. On the other hand, it would be both impractical and inadequate to obtain detailed scale models for every local situation if there is no possibility of generalising these models. We are thus confronted with two different scale properties that need to be taken into account:

1) each scale has its own specific units and variables;
2) the interrelationships between sets of variables and units can change with scale.

How can we then develop valid models at regional scales and deal with these two types of scale problems? The solution lies in the development of a truly hierarchical approach in both the observation and explanation of land use/cover change processes (Kolasa & Rollo, 1991). Once scale effects are known and quantified, models can be made for each measured scale level. The scale hierarchy may then function as a key to scale up and down relationships in space and time.

2.3 Nested scale analysis

A first step to unravel scale effects is to make certain that the necessary or collected data can be aggregated and processed for at least three different spatial scales (Odum, 1983). A way to do this, is to organise both the biophysical and socio-economic data in their respective hierarchies as proposed in a conceptual land use classification system of Stomph *et al.* (1994). Subsequently, these hierarchies must be compared and linked (matched) spatially. Socio-economic units only rarely coincide with biophysical units, and therefore processes and drivers do not overlap in space (the exception may be small islands as ecological and social communities).

To avoid this discrepancy, matching may require the 'construction' of artificial scales based on grid aggregations. A major disadvantage of this grid approach is that one may loose information, firstly because the minimum grid size becomes the most detailed level of analysis possible and secondly because of the borders of units which normally do not fit into one grid cell. A third disadvantage is the artificial nature of the units of analysis. However, once data are converted into grid units, similar and equally sized units can be compared without any spatial aggregation problem. Another advantage is that artificially gridded data can be aggregated into many different scales while for example data grouped in administrative boundaries can only be aggregated into a few predetermined scales. For example in Costa Rica these administrative boundaries allow only aggregation from districts (n = 419) into cantons (n = 80), provinces (n = 7) and Costa Rica (n = 1). However, for statistical analysis a sufficient number of cases is available only at two levels (district and canton), too few for a nested scale analysis.

Therefore the CLUE model framework proposes to use artificial grid based spatial data sets to test the central hypothesis that relationships between driving forces will change with scale. This has been elaborated in the next chapters for the CLUE-CR model. Nested aggregation may also apply to temporal scales. But such an analysis would require data covering considerable time spans, possibly up to 10^5 years to capture ecological evolutionary processes (see also Fresco & Kroonenberg, 1992).

2.4 Proposed CLUE regression analysis

Before the scale-related explanation of land use/cover variance can be made, the inter-relationships of the land cover and their potential drivers will have to be recognised and studied. One of the procedures to achieve this is to perform a principal component or a factor analysis. Both analyses make an effort to reveal the underlying structure which is presumed to exist within a set of multivariate observations (Davis, 1986; Johnston, 1978). This type of analysis has been performed for the case study of Costa Rica (Veldkamp & Fresco, 1997). Of course there are also other ways to reveal the most significant human and biophysical land use drivers within the system. For example, by taking already a good look a the correlation matrix of your data.

Once we have recognised the significant drivers, it is proposed to investigate the scale-dependent relationships of the studied land use/cover by multiple regression analysis (Davis, 1986; Johnston, 1978). First of all, each analysis considers only one land use/cover type as observational unit characterised by several variables. Then for each of the land use/cover types a separate series of multiple regression analysis are made on different aggregation levels. This means that the observational unit and the necessary characterising variables will have to be sampled or processed for different surface areas or grid sizes (see Section 2.4).

It is found beyond the scope of this documentation to give a complete course on statistical analysis of the data. This section was merely given as an introduction. The followed procedures and analysis underlying the CLUE-CR model are described in Veldkamp & Fresco (1997). In the next chapters an outline is given of the implementation of these statistical analysis into the model structure.

3 The objectives and structure of CLUE-CR

As described in the previous chapter the main idea behind the CLUE model framework is the handling of land use/cover related spatial data at various specific scales or aggregation levels. The main goal is to model the conversion of the land use/cover in space and time controlled by the most important driving forces, each at their own relevant aggregation levels. In this chapter the objectives are discussed how the basic principles of the CLUE model framework have been applied in the construction and development of CLUE-CR for the case study of Costa Rica. The next sections will discuss the data input and handling in the construction of the model in more details.

3.1 Costa Rica as a case study

The CLUE-CR model has been developed in the context of to what extent and how the distribution of Costa Rican land use/cover and its changes between 1973 and 1984 are related to biophysical and human factors at different spatial scales (Veldkamp & Fresco, 1995, 1996b, 1997). Costa Rica was chosen as a case study because this country is well known for its great biophysical diversity (Holdridge, 1967; Gómez, 1986), has a rapidly expanding population and had available well-documented census data for the years 1973 and 1984. Moreover, Costa Rica is characterised by rapid changes in its land use/cover, especially deforestation (Keogh, 1984; Sader & Joyce, 1988; Harrison, 1991; Veldkamp *et al.*, 1992).

As a result, the basic data used in this study were derived from the population and agronomic census of Costa Rica (DGEC, 1976a, 1976b, 1987a, 1987b) and from the preliminary atlas of Costa Rica (Nuhn, 1978). The census data on agriculture and demography of 1973 and 1984 were available at district level (n = 419). The demographic data consisted of totals and densities of rural population, agricultural labour force and urban population. The agricultural census data included various data from permanent crops like coffee and bananas to annual crop data on potato and maize production and so on. Previous research demonstrated that altitude (m), relief (classes) and soils (classes) give a good representation of the biophysical conditions including climate variability (Herrera, 1985; Brenes & Saborio Trejos, 1994).

3.2 Data preparation

As described in Section 2.3, the census data had to be converted into artificial grid cells. The selected minimum grid size has been based on the estimated average district size (the most detailed spatial scale for the census data) and was set at 0.04° on the geographical grid 7.5 * 7.5 = 56.25 km^2 at the equator (see level 1 in Fig. 3.1). The census data were digitised and as such georeferenced into the proposed grid map of Costa Rica. Some of the larger districts had to be allocated in two or more grid cells. In these cases the data has been equally distributed as a function of the surface of the grid cells and the original district. The same procedure has been followed with the biophysical map data (Nuhn, 1978) and the climate maps (Herrera, 1985) which were georeferenced into the same size of grids.

In order to allow a systematic analysis of spatial scale effects, the 0.04° grid data were aggregated into larger grids. These larger grids are aggregations of 4 (225 km^2), 9 (506 km^2), 16 (900 km^2), 25 (1406 km^2), 36 (2025 km^2) 0.04° grid units, making a total of six spatial aggregation levels (Fig. 3.1). The new, aggregated grid values were weighted averages of the included 0.04° grids, under the condition that at least 50% of the aggregated grids contributes a valid value. Values are valid when they are contributed by a grid with no missing value. This aggregating procedure was followed for all selected 1973 and 1984 data. The geographical specified data were managed and processed with the GIS software of IDRISI (Eastman, 1992). A description of the statistical analysis and an interpretation of the results can be found in Veldkamp & Fresco (1995, 1996b, 1997).

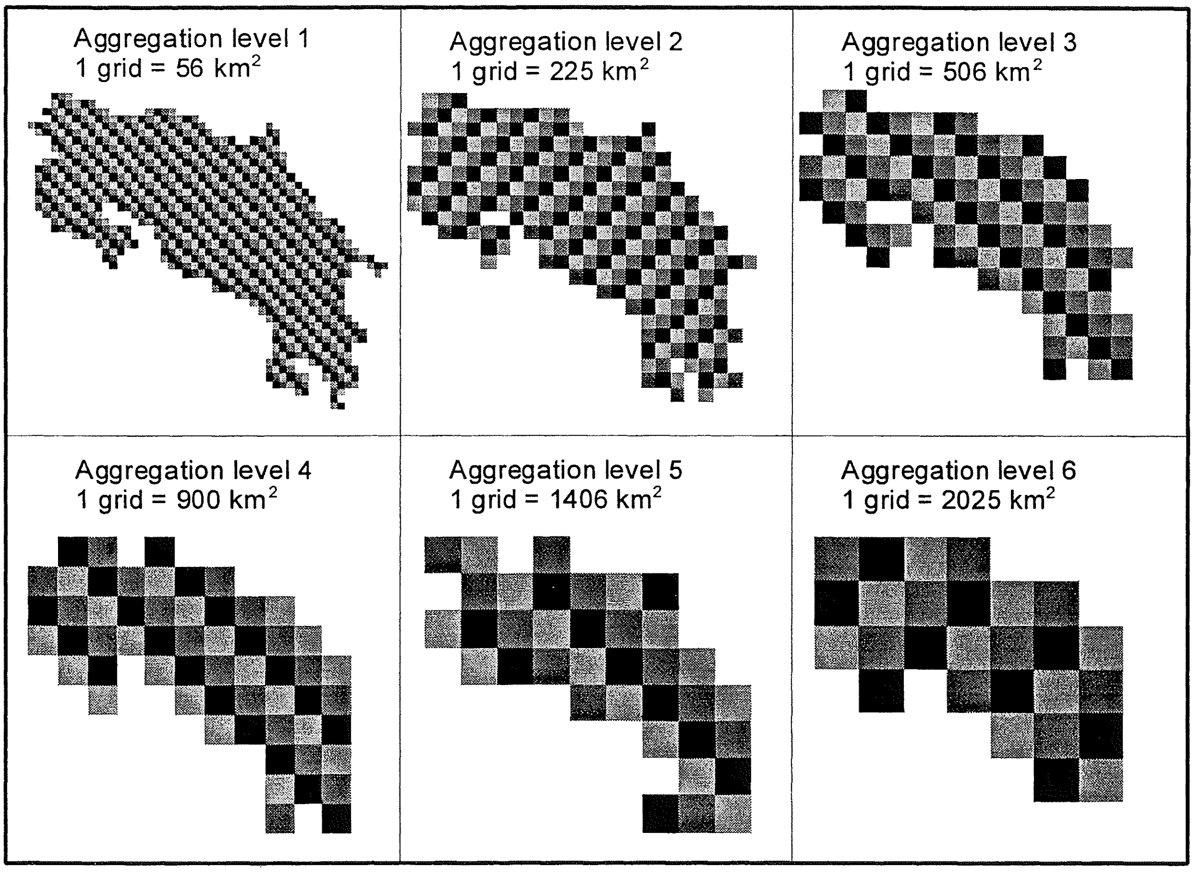

Figure 3.1 The six levels of aggregation processed from the nested scale analysis, in this case for the country of Costa Rica. These same levels have been used within the CLUE-CR model structure.

3.3 Data input requirements

The data required to run the CLUE-CR 1.2 model are directly related to the results of the nested scale analysis (Veldkamp & Fresco, 1997). The main calculations are done on a matrix of 50 by 44 grid cells. This means a total of 2200 grid cells for Costa Rica were each grid cell is 0.04° on the geographical grid or 7.5 * 7.5 = 56.25 km^2 at the equator. From now on in the text this will also be referred to as the local minimum grid level.

All data on the local minimum grid level (50 x 44 grids) are stored in the main data input file `COSTGISI.DAT` (see Appendix IX for its structure). This input file is structured as a giant spreadsheet or matrix with 2200 rows and 14 columns. In other words each row is filled with 14 different data values valid for one grid cell with co-ordinate [X,Y]. in which row number 1 is grid cell [1,1] and row number 2200 is grid cell [50,44].

In total we can distinguish two main groups, operating on several aggregation levels. First of all there is a group of grid specific data, georeferenced data on the minimal grid level, which are ordered in the Costa Rica GIS input file `COSTGISI.DAT` (Appendix IX). Secondly there is a group of general data on higher levels of regional and national scale as well as steering factors and mathematical parameters. This last group of data is included in the variable and constant declaration within the model source codes. These main input data types are:

Human land use/cover change driving factors
The human drivers are divided into two groups. First the *rural population density* and its annual growth rates (RUR and RURGR) in no. of people/ km^2 and secondly the *urban population density* and its growth rates (URB and URBGR) in no. of people/ km^2. For example the relative spatial distribution of the population density for 1973 in Costa Rica is given in Fig. 3.2.

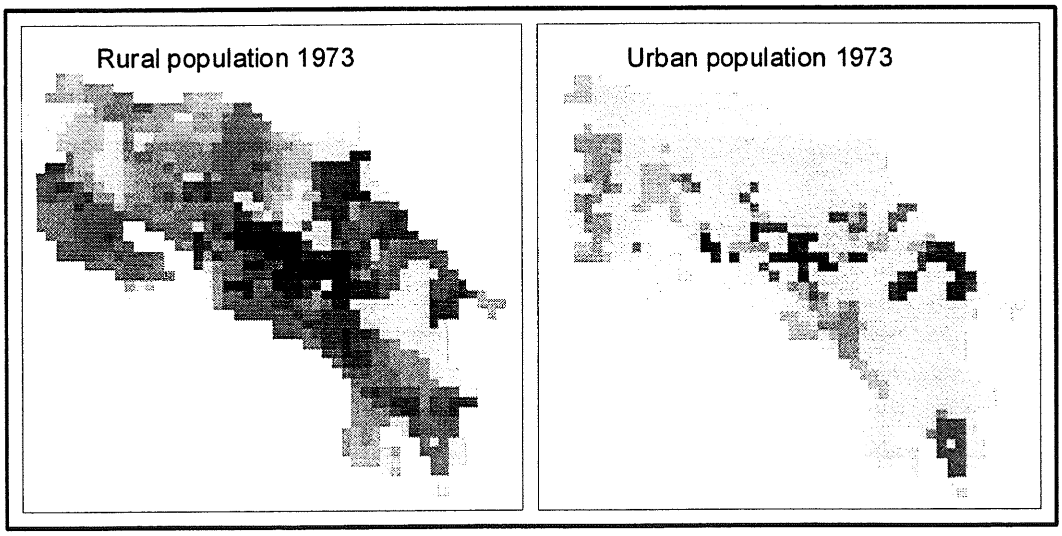

Figure 3.2 The spatial distribution of the Costa Rican rural and urban population density. The data is represented in relative classes with high density dark and low density light shaded.

Biophysical land use/cover driving factors

The input file starts with the parameters LAND and RESER which only give a value of 1 if the grid is within the land of Costa Rica or if it is a protected nature reserve respectively (if not then 0). The main biophysical drivers (Fig. 3.3) which appeared significant for the model are the temperature effect of *altitude* (ALT in meters), the slope angle or the *relief* (REL in classes) and suitability or drainage characteristics of the *soil* (SOIL in classes).

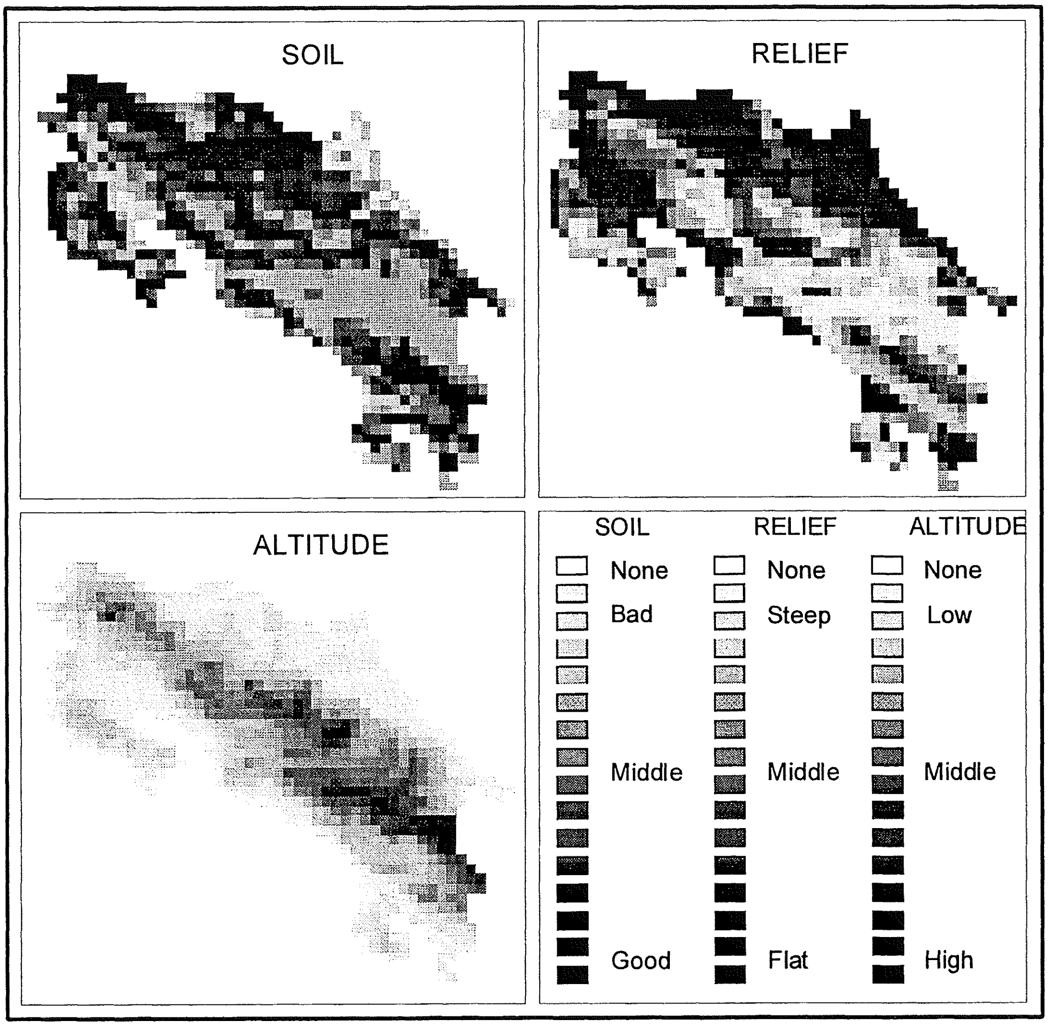

Figure 3.3 Overview of the georeferenced maps for the biophysical drivers. The drivers are presented in 15 classes. For altitude the highest values are dark and the lowest values are light. The relief and soil characteristics are shown with the high (dark) value for a low slope angle and a good drainage respectively.

Simulated land use/cover types

The CLUE-CR model simulates five different land use/cover classes (in % of total grid cell cover). Based on the agricultural census the following aggregated land use/cover classes are used:

- *Permanent crops* (% PER), comprising perennial crops like coffee, bananas, palms etc.
- *Pastures and range lands* (% PAS), which includes all grassland types (with and without trees) used for grazing cattle.

- *Arable land* (% ARA), including for example annual crops like maize, beans and rice.
- *Natural Vegetation* (% NAT), comprising tropical rain-forest, savannah and paramo (alpine vegetation).
- *Residual Group* (% RES) comprising the remaining land uses and covers like secondary vegetation, swamps, towns, roads and bare rock.

Model parameters
Parameters and constants used during the modelling concerning the mathematical functions and expressions.

Regression coefficients used in the model statements
The regression constant and coefficients (LUCCONST, LUCURB, LUCRUR, LUCALT, LUCREL and LUCSOIL) are to be implemented in algorithms, where the land use/cover is calculated or modelled as a function of the five principal biophysical and human driving factors. All regression parameters are available for both the local minimum grid level and the optimal aggregated grid levels (artificial regions) to simulate the specific and related regional scale effects.

3.4 Overall assumptions in CLUE-CR

The following overall assumptions were used in the construction of the CLUE-CR model version 1.2:
-1- We assume a dynamic equilibrium between the total urban and rural population and the agricultural production.
-2- In the rural areas of Costa Rica, agriculture is the main employment and generator of income.
-3- The resolution of the local minimum level or grid cell is the smallest unit of analysis. Despite its assumed biophysical and demographical uniformity, each grid cell may contain five different land use/covers.
-4- The total land cover consists only of these five different land use/covers (PER, PAS , ARA, NAT and RES) and the sum of the totals in each grid cell is always 100%.
-5- Changes in land use/cover only occur when biophysical and human demands can not longer be met by the existing land uses.
-6- By incorporating reserves (food and/or money) for two years, seasonal and annual yield fluctuations have no direct effect on the land use changes.
-7- As a result from the statistical analysis in the nested scale analysis, the Costa Rican land use/covers (PER, PAS , ARA, NAT and RES) can be modelled as a function of the grid-dependent biophysical and human drivers (URB, RUR, ALT, RELIEF and SOIL), both on the minimum local grid level as on the cover specific optimal aggregated grid level according to the following equation:

$$LUC^{t}(X,Y) = LUCCONST^{t} + LUCURB*URB^{t}(X,Y) + LUCRUR*RUR^{t}(X,Y) + LUCALT*ALT(X,Y) + LUCREL*RELIEF(X,Y) + LUCSOIL*SOIL(X,Y)$$

In which $LUC^{t}(X,Y)$ stands for the modelled cover at time t (1973 or higher), in the selected local grid or selected artificial region with co-ordinates X and Y. $LUCCONST^{t}$ is the regression constant valid only for the selected cover and on the selected aggregation level at time t. The five human and biophysical drivers are multiplied by their coefficient values from the multiple regression analysis.

Note that only the grid-depended URB and RUR are changing in time, the temporal change in ALT, RELIEF and SOIL is kept at zero as a result of our limited time scale of years.

3.5 The central CLUE-CR framework

The CLUE-CR model has been constructed on the basis of the results from the previous investigations on the CLUE model framework and the nested scale analysis for Costa Rica (Veldkamp & Fresco, 1996a, 1997). In this paragraph the basic structure will be summarised; for more details and flow diagrams see next chapters.

The objective of CLUE-CR is to model on a year to year basis plausible total coverages and realistic spatial distributions of the five land use/cover classes for Costa Rica. The model is currently tuned with the results from the nested scale analysis of the 1973 and 1984 data. During each yearly update the spatial land use/cover distributions are evaluated and modelled using different aggregation levels. The result for each year has to be a realistic distribution of the five different covers inside each grid cell. Apart from the regression parameters for each cover separately, the CLUE-CR model takes into account the competition with and preferences of the covers over each other.

The model starts with the land use/cover percentages and distributions of 1973 (given as input in COSTGISI.DAT) and evaluates in steps of one year the total population growth and food/money production and the resulting conversion of land use. For any given year starting from 1973, it is possible to process a georeferenced land use/cover map, ready for display and processing in a GIS programme.

The basic structure of the model (see for example already Fig. 5.3) is built to calculate in steps of one year, the growth of urban and rural population (POPGROWTH section 6.1) in each grid cell. Subsequently this information is used to calculate a new total national demand for needed production of food/money for that year. At the same moment the yield of food/money is determined of the different land use types, taking into account biophysical feedbacks and annual yield fluctuations. Comparing the demand and yield results in a certain amount of increasing or decreasing need for each land use (CRNEED section 6.2).

The next step is to allocate new land use to satisfy the national demand or need and feed the population. This allocation (CHANGE section 6.3) is done by selecting the optimal aggregation level (artificial region) for each land use/cover, as a result of the nested scale analysis (Veldkamp & Fresco, 1997). The most suitable regions for allocating new areas of a certain land use/cover are selected by calculating the land use/cover as a function of the region-dependent drivers and regression coefficients and to compare this with the present percentage of land use/cover. If these two figures do not match sufficiently, the selected region is approved for change. The actual quantity of allocation and change of land cover is done at the local grid level. Within the selected region, for all of the local grids, the requested cover is modelled again as a function of its local drivers and compared with the existing cover. When these two amounts do not sufficiently match the local cover extension is altered.

For those grids that are not selected within the CHANGE procedure and in case there is no national demand for change, the next step in the model is to simulate the autonomous land use/cover development at the local 0.04° grid level (AUTODEV section 6.4). This means an evaluation and change exclusively based on seriously changed local biophysical and demographic conditions. In other words, a change which is determined per grid cell and as such independent of the regional and national demands and surpluses. For example, an area of agricultural lands on very steep slopes can suffer from severe degradation effects after some years of cultivation and as a consequence the area will be forced to change.

Finally, the CLUE-CR model version 1.2 is constructed to implement different land use/cover change scenarios. The impact of these scenarios is translated into separate parameters and special variables which are programmed into the basic structure. Apart from the business as usual modelling, two scenario specific modules can be selected. Implementing these scenarios both at the same time makes a total of four different scenarios (see Chapter 7). The first scenario is simulating the effects of overuse and degradation (BIOPHEED section 6.5) on the land use/cover of permanent crops and arable land. The second scenario simulates the effects of a disease in the permanent crops spreading through the country (DISPEST section 6.6).

4 The CLUE-CR output and results

Before going into more detail about the practical and technical programming (see Chapter 5 and 6), the output and results of the CLUE-CR model version 1.2 will be discussed. In this chapter an effort will be made to summarise the CLUE-CR model framework in terms of validation and applicability. It goes without saying that the version 1.2 discussed in this document is only applicable for the country of Costa Rica. Simply because the main constraints, variables and scenario parameters in the programmed model are the results from the nested scale analysis of the Costa Rica data set. Nevertheless, the general framework shows a new and interesting approach in handling land use/cover modelling at different scales or aggregation levels.

4.1 Output of data

During one simulation the programme will run its main loop several times, processing and calculating all variables, statements and procedures. The number of these loops is dependent on the number of simulation years given as input by the user. Each of these simulation years, the variable data on total cover and distribution is updated and evaluated to asses and allocate the needed land use/cover.

Since the main variables in the programme are the five simulated land use/cover types, they are also the main subject of the data output. For each update loop or, in other words, each simulation year, the total cover percentages of the main land use/cover types are stored in a data file called `CRCOVERS.TAB`. This ASCII table is readable in all sorts of text processing software or spreadsheets. The file `CRCOVERS.TAB` contains the total cover percentages for `PER`, `PAS` , `ARA`, `NAT` and `RES` aggregated for three different agro-ecological regions and for the total of Costa Rica (see Appendix IX). These three agro-ecological regions or zones are introduced to illustrate their differing behaviour during the simulations. These regions are: (1) a hot and humid region, (2) a hot and dry region, and (3) a cool and humid region (see Fig 4.1). They provide a convenient additional level of aggregation for inputs and outputs.

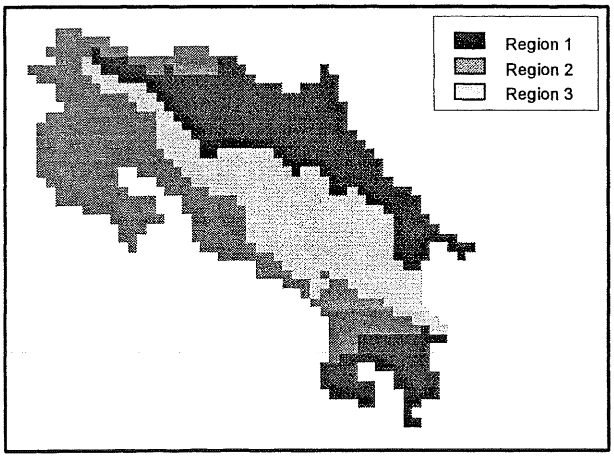

Figure 4.1 The 3 agro ecological regions for Costa Rica used to show the different behaviour in relation to land use/cover changes.

The second output of the programme is a GIS of 0.04° grids with the georeferenced cover percentages of the Costa Rican land use/covers for PER, PAS , ARA, NAT and the distribution of the population densities URB and RUR. The time or year of output is determined by the user during the initialisation phase of the programme. Land use/cover data is stored (in percentage) for each cover separately in the files PERUIT.IMG, PASUIT.IMG , ARAUIT.IMG and NATUIT.IMG, while population is stored in grid density for the rural and urban population in RURUIT.IMG and URBUIT.IMG.

In this model version the files are processed in IDRISI (.IMG) format what means a single column of 2200 values storing the grid map from the top left corner, reading left to right until the bottom right corner. The actual co-ordinate information about the number of rows and columns of the grid map is found in the accompanying IDRISI documentation file (.DOC). Other output formats are not supported at this moment, although one can edit or add co-ordinate values in any editor or spreadsheet.

4.2 Input and output data resolution

One of the main problems in validating these types of models is the resolution or accuracy of the original data sets. Since this information is often not or only partly available from the original data sets, it will become very difficult to estimate the amount of uncertainty in the final results of a model. The CLUE-CR 1.2 model framework has three main sources of data which show more or less degrees of uncertainties:

Demographic, economic and land use (Census) data
For example, census data for any country are normally the result of a very long process of data sampling going from interviewing local farmers and communities to difficult data processing at the different administrative levels and organs. The uncertainty of the census data is produced by different factors:
- What is the purpose of the census, in whose interest are they made (to locate forests area or to count cattle).
- What are the types of questions asked, how are they phrased (communication with the local farmer or with the owner of a large multinational plantation).
- Which institution or institutions are executing the investigation (level of communication and co-operation between the institutions).
- The geographical matching of data. For example the administrative boundaries can shift and change quite frequently, especially with multiple years of data.

Normally, this type of data becomes available some years after sampling and the statistics about the uncertainty of data are usually completely unknown. Nevertheless, this case study proves the value of well-documented census data and shows an important and relevant way of using these valuable sources of data which normally are available for many countries in the world.

The biophysical (maps) data
The input of the biophysical data is normally obtained from digitising maps and atlases. Nowadays, climatological and elevation data are relatively easy to obtain and show improving quality. However, we have to bear in mind that originally we deal here with point data extrapolated to a surface. For

example, the mapping units of soils are normally associations of different soils and sub-types with different characteristics. The uncertainty or variability of the mapping units is rarely given by the authors.

The CLUE-CR model technical structure
Moreover, several problems within the CLUE-CR model framework are limiting its validation. As discussed in previous sections, the model uses artificial grids which makes the minimum grid size the most detailed level of observation. This means that the original data sampling was done for different units and surfaces. The problems with converting this data into these artificial grids, arise in matching of administrative and biophysical units; especially the boundaries and borders may create errors. Another possible source of uncertainties in the CLUE-CR model can be found in the followed statistical analysis. For example, the multiple regression analysis never shows a perfect fit, the goodness of fit is always lower than 100 %. This will also be expressed by the amount of unexplained variance in the processed regression models during the nested scale analysis. And last but not least, there are possible sources of errors in the way in which formulas and calculations are programmed. Although we must state that the consistent and consequent model behaviour indicates a stable and balanced way of processing the land use/cover changes.

4.3 CLUE-CR model framework calibration

The CLUE-CR model version 1.2 has been developed using two different ways of calibration, namely spatial and temporal. The complexity of these types of models requires a thorough investigation of the possible effect of each change that is made in controlling parameters or in calculation statements. This is a very time-consuming and never-ending process and finally some decisions have to be made to continue with the next step.

Spatial calibration
The first spatial calibration was made purely on the spatial distribution of the land use/cover, basically following the main trends from the regression analysis, without external influences. The CLUE-CR model starts with the 1973 land use/cover distribution (Table 4.1) and simulates the spatial development of the land use/cover for a maximum period of 22 years using the regression parameters from 1973 to 1984. Afterwards, both the actual 1984 data and the CLUE-CR modelled 1984 data were compared and checked for their spatial distribution of the main land use/covers. The second spatial calibration process focused stronger on the quantities of the total land use allocation in the different agro-ecological regions and for the whole country of Costa Rica, again comparing the amounts of total cover in the real 1984 data and the modelled 1984 data. For both calibrations the preference and competition parameters were adjusted until an optimal result had been obtained

Temporal calibration
The temporal calibration of the model framework focused on modelling the allocation of the amounts of land use/cover changes at the right time intervals, taking into account the changes in the regression modelling for the 1973 and 1984 data. For the best tuning of the results, the Δ Time factor was introduced. This factor determines the minimum value of the regression constants, and thus the start amount of necessary cover, to simulate the differences inside the valid time domain and data interval.

4.4 Model behaviour

The behaviour of the CLUE-CR model version 1.2 under standard conditions is given in this section. This means that no degradation or pest scenarios are implemented or simulated. Table 4.1 gives the initial 1973 values for the land use/cover distribution, as percentages of the total land use/cover (Costa Rica is 100 %). The amounts in brackets in the last row of Table 4.1 show the total amount of coverage of the 913 (Costa Rica grids) times 100 % for each land use/cover. Adding up these five values will give a total of 91300 %. Mind that also the axes of Fig. 4.2 are expressed in this way.

Table 4.1 The initial amounts of the 1973 land use/covers , as a percentage of the total Costa Rica surface. Between brackets is shown the total amount of percentages, taking into account that each of the 913 grids contains 100 % of possible land use/covers.

1973 data	PER (%)	PAS (%)	ARA (%)	NAT (%)	RES (%)
Region 1	2.97	10.11	2.95	15.36	4.53
Region 2	0.88	19.80	3.89	6.54	4.72
Region 3	2.49	8.66	1.34	13.34	2.42
Costa Rica	6.34 (5792)	38.57 (35215)	8.18 (7475)	35.24 (32162)	11.67 (10656)

Figure 4.2 shows the trends in the total amounts of land use/cover allocation by the CLUE-CR model version 1.2. The simulation period is 22 years, which means that simulation year 11 is equal to 1984. In this example no scenarios for diseases or degradation were allowed. The straight line representing the 1984 data is merely an indication of a possible development of the land use/cover, if the trends remain unchanged.

The results in Fig. 4.2 show clearly that until 1984 the results are quite consistent, as a result of the intensive calibration. We have to bear in mind that these trends are not only the result of individual regressions, but also of a dynamic multi-cover and multi-scale model. The simulated trends seam plausible and quite reasonable explanations can be given. However, to evaluate these results outside the 1973 to 1984 data range, we need data of at least one but preferably more years. In that case we would be able to replace the linear interpolated curves by more sophisticated curves in order to improve the simulation results.

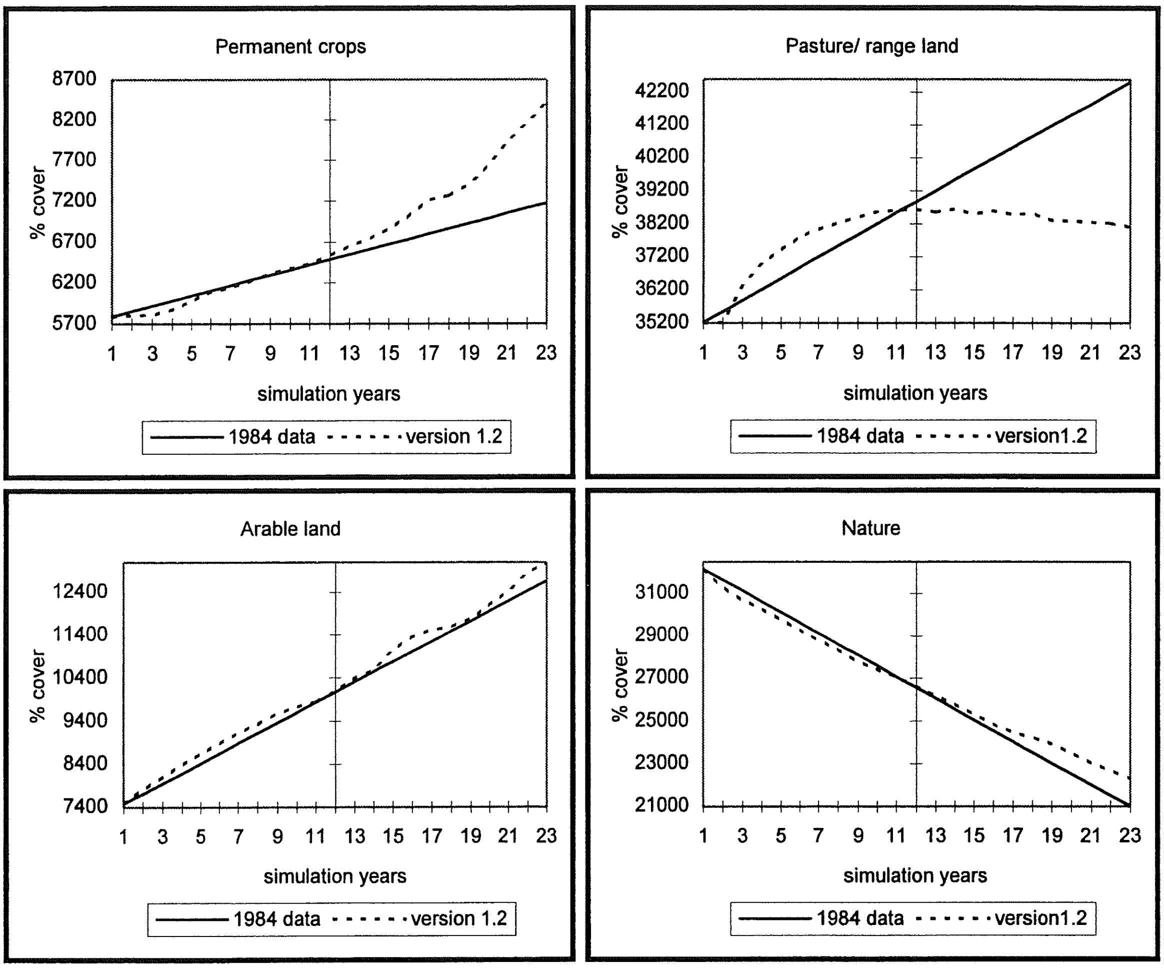

Figure 4.2 The results of a simulation for the four main land use/cover types. The results are shown as dotted lines compared with the linear extrapolation of the 1984 data set.

5 THE CLUE-CR PROGRAMME STRUCTURE

The CLUE-CR model will be presented in a more technical sense in this chapter and in Chapter 6. The original source code listing was programmed in the Pascal language (Koffman, 1995) and afterwards revised, adapted and extended towards Turbo Pascal (Zandvoort, 1994). As a consequence, in these chapters many words and expressions will be used in their reserved Pascal definition context (explained where necessary). The most important components of the model are summarised in several flow charts, to enhance the comprehension of the programmed structures. Fig. 5.1 shows the generally accepted symbols for the flow charts used in this document.

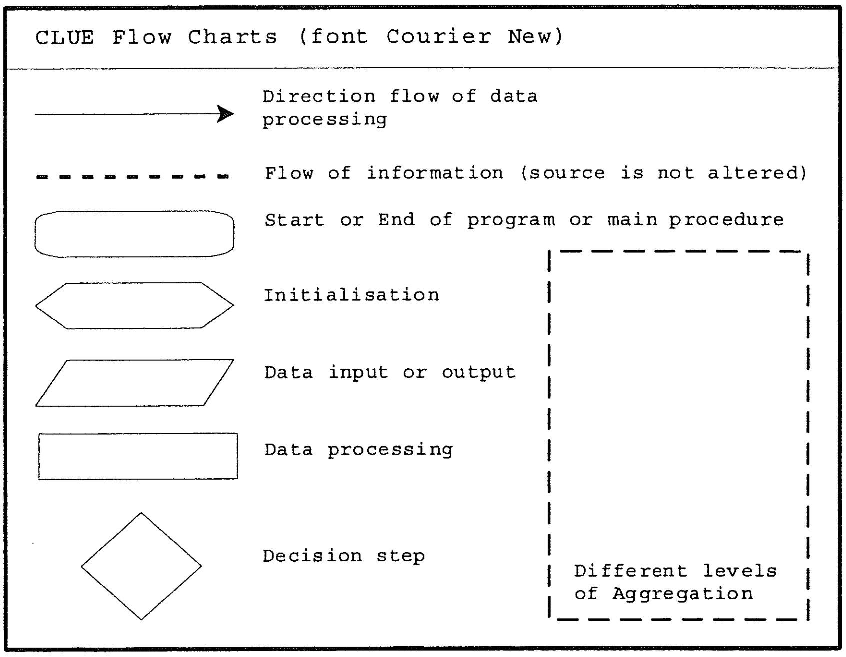

Figure 5.1 Summary of the symbols used for the CLUE-CR model flow charts and the procedure flow charts as they are presented in this document.

With the aid of these flow charts the most important source code statements will be discussed in their programmed order. The source code listings in the appendices contain explanatory information as well, with the explanations given inside a pair of brackets and stars `(* remark *)`. The entire source code listings are given in the indicated appendices. As in the previous chapters, the acronym `LUC` will be used as a substitute for the specific land use/cover types of permanent crops, pastures, arable land, nature and the rest group (`PER`, `PAS`, `ARA`, `NAT` and `RES`) in case an expression name is applicable for all of them.

In Fig. 5.2 the flow diagram is given of the CLUE-CR programme structure, divided into its most important components. The declarations of variables are described in Section 5.1 while the main PROCEDURES are subject of Chapter 5. Section 5.2 is focused on the initialisation phase of the programme. The main CLUE-CR simulation loop will be discussed in Section 4.3.

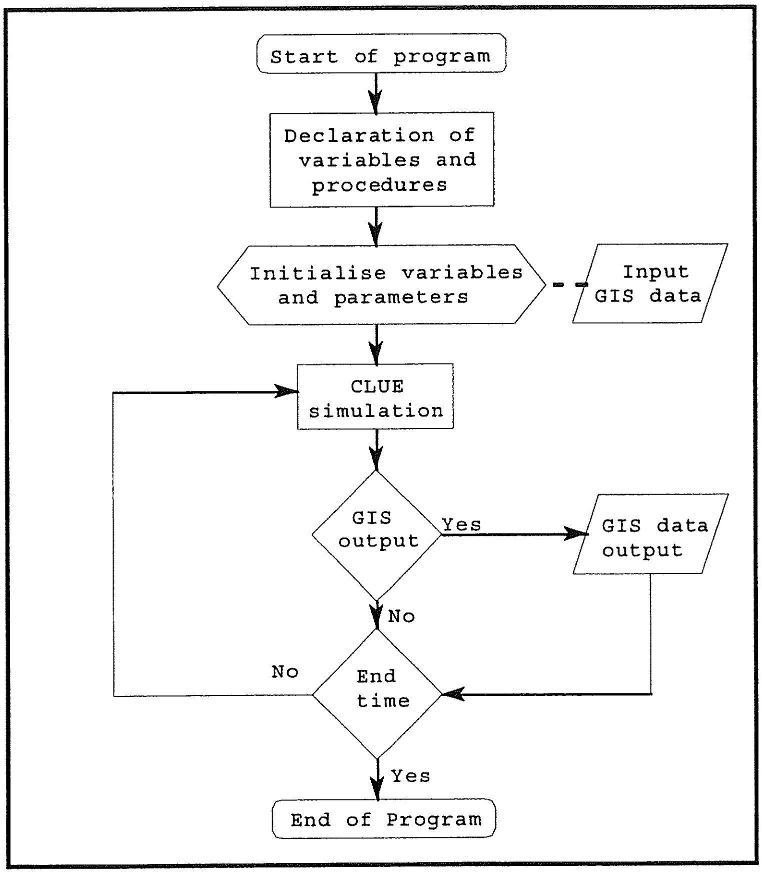

Figure 5.2 The flow diagram of the CLUE-CR programme The boxes show the most important components in their programmed order. These components are described in the paragraphs below.

5.1 Variable declarations

One of the general characteristics of the Pascal language is the intensive declaration of all the different classes and types of variables and constants which will be used later by the programme. In this declaration every piece of information in any form is assigned to a unique name and memory location. In the CLUE-CR programme an effort is made to keep these names as clear and uniform as possible. The exact source code listing of all these declarations is given in Appendix I. In this section the most important constants and variables will be discussed, divided into their main Pascal data type.

USES

In this section the external libraries used by the programme are declared. Such a library contains standard functions and parameters which can be used by several programs so that the same routines do not have to be reprogrammed again and again. `Dos` and `Crt` are standard Turbo Pascal libraries containing mathematical functions like for example dividing, subtracting, rounding off to whole numbers etc. and also command functions like for example clear the screen and so on. The

`CLUE_SCR` library contains graphical functions to build up the screen and to ask for the parameters in the user framework around the programme.

CONST

The values of the parameters which remain constant during the programme can be divided into four groups:

1) General settings like for example the co-ordinate values `XMIN` and `XMAX` .
2) The regression coefficients from the nested scale analysis valid for the minimum grid level:
   - `(LUC)CONST` Regression constant for the valid model.
   - `D(LUC)` Change of the regression constant for each time step.
   - `(LUC)URB` (or `RUR`, `ALT`, `RELIEF`, `SOIL`) regression coefficients for the five main driving factors in the regression models.
3) The regression coefficients valid for the optimal aggregated grid scale:
   - `(LUC)AG` Optimal aggregation level for that land use/cover.
   - `(LUC)AGCONST` Regression constant for the valid model.
   - `D(LUC)AG` Change of the regression constant for each time step.
   - `(LUC)AGURB` (or `RUR`, `ALT`, `RELIEF`, `SOIL`) regression coefficients for the five main driving factors in the regression models.
4) Scenario-specific constants, only used by the programme whenever one or more scenario options are activated. This will be explained in more detail in the Chapter 6.

The results of the nested scale analysis are shown in Table 5.1 and have been used to formulate the equations for the procedures and constraints within the model structure. The resulting regression models will be used at different scale levels within the model and they will include the biophysical drivers relief, altitude and soil as well as the human drivers rural and urban population density.

To simulate the temporal dynamics of the land use/cover changes, the Δ Time factor is introduced. Δ Time is the rate of change of the regression constants after each time-step. In this way the changes in the regression constants from 1973 to 1984 are simulated.

Table 5.1 The parameters used in the CLUE-CR model framework resulting from the nested scale analysis.

	CONST	β RUR	β URB	β ALT	β REL	β SOIL	Δ Time	Scale
PER	9.37	0.905	-0.0026	0	0.022	0	0.1061	level 1
PAS	25.81	0.26	-0.0025	-0.01	0	0.025	-0.0182	level 1
ARA	11.34	0.27	-0.0015	-0.0075	-0.018	-0.0003	0.013	level 1
NAT	51.6	-1.59	0.035	0.02	0	-0.0025	-0.0174	level 1
PER	15.8	0.469	-0.0045	0	0.005	0	-0.0008	level 4
PAS	13.12	0.7	0.02	0.026	0	0.0043	0.0129	level 5
ARA	9.2	0.57	0.048	0.004	-0.0003	-0.0003	0.022	level 5
NAT	97.1	-0.85	-0.7	0.017	0	-0.0034	-0.154	level 6

TYPE

The multi dimensional ARRAYS are declared in this section. Each of them contains the total number of 2200 values going from the minimum X and Y to the maximum X and Y co-ordinates (from [1,1] to [50,44]). In fact each ARRAY is a minimal grid level map containing georeferenced data values of one specific attribute for Costa Rica. This version 1.2 of the CLUE-CR model framework contains 25 of these ARRAY maps, divided into five main groups and subdivided into specific cover or driver classes etc. The name of the main group forms the beginning of the array code followed by the [X,Y] parameter and the subdivisions as follows:

```
MAINgroup = ARRAY [XMIN..XMAX,YMIN..YMAX] OF
            RECORD
                SUB1: datatype;
                SUB2: datatype;
                SUB3: datatype; etc.
            END.
```

In the programme statements each array variables will be called with the following construction: for example CRLU^[XY].PER which stands for the permanent crop percentage of coverage in grid co-ordinate (X,Y). The following names and codes are used for the arrays and the subdivisions in the CLUE-CR model source code:

- CRLU the Land Use of Costa Rica divided into PER, PAS, ARA, NAT, RES and LU.
- CRLUAGE the duration or AGE of Land Use in number of months also divided into PER, PAS, ARA, NAT, RES and LU.
- CRBP the BioPhysical characteristics divided into LAND (land or sea), REGIO (in which region), RESER (is this grid a protected nature reserve), ALT; RELIEF and SOIL.
- CRBPDE Impact factor (BioPhysical Degradation Effect) divided into DEPER, DEARA (degradation of PER and ARA) and PERDI and DIPES (disease).
- CRPOP The POPulation of Costa Rica divided into RUR (rural population density), URB (urban population density), RURGR and URBGR (growth rates).

VAR

In the VAR section all the codes and names have to be declared according to their data type. Again the exact code names and their meaning are given in Appendix I and they will be explained if necessary in the statements and procedures were they are implemented in the following paragraphs and chapters. The main data types for the CLUE-CR model are:

TEXT a variable containing a series of letters mainly names of files.

INTEGER a variable containing a whole number between +32767 and -32767.

REAL a variable containing any number that can be expressed exponentially.

BOOLEAN a variable which can be set and switched to TRUE or FALSE.

5.2 Programme initiation

Before we can start the simulation in the central CLUE-CR loop, the programme has to be initiated with several parameters. In this present CLUE-CR version 1.2 only a few of these parameters are made user interactive but for future versions, with more scenario possibilities, this can be easily extended. In this section the most important actions are described by the name of the variable, function or procedure. The listing to follow the actual order and implementation is given in Appendix II.

BEGINSCREEN, TIMEINI, TIMER1

The programme starts with building the screen (BEGINSCREEN) by using general functions from the USES library CLUE_SCR. First of all the user of the programme needs to return some information to the model (TIMEINI) about the required duration of the simulation (TMAX = number of simulation years * 12 time steps), time of output (UITTIJD) and which scenarios have to implemented (PHEEDBIO and PESTDIS are set to FALSE or TRUE). The function TIMER1 is setting the timer to calculate the elapsed real time of simulation.

MEMDECLAR1, GetMem, MEMDECLAR2

These three functions are used to allocate the required space in the working memory of the computer. MEMDECLAR1 checks the available free space before the memory is filled, GetMem reserves the memory for the arrays and MEMDECLAR2 gives the free memory that is left.

ASSIGN

In this section the input and output files are assigned to a name so that the programme can refer to them whenever needed. The input files COSTGISI.DAT and CRREGIO.IMG are assigned and RESET to codes LANDIN and REGIO. The output files LUCUIT.IMG are new (REWRITE) and assigned the same name (LUC)UIT without their extension for internal use except for the table output file CRCOVERS.TAB which gets the internal name TUSSEN.

FOR TO DO

In this loop the programme will execute the included statements for every **X** and **Y** value from their minimum to their maximum value. This is a frequently used statement in the CLUE-CR model framework and will be referred to as XY-loop. Here it becomes clear why the ARRAY^[X,Y] structure is used because inside the XY-loop you can combine all the variables related to the same georeferenced Costa Rica grid cell with co-ordinate [X,Y] before the next co-ordinate is called. In this case all the data from the input file is loaded into the memory and assigned to their specific array name and subdivision by the statement:

```
READ(LANDIN,ARRAY^[X,Y].SUB
```

Each value is read before going to the next number on the same line with the next statement. The specific number and order of the statements with the arrays is related to the number and order of the columns in the data input file. The 7th statement reads the 7th column which contains the initial percentage of Pasture cover in 1973. The last READLN statement assures that the next [X,Y] co-ordinate is read from the next line in the file. Also in this same XY-loop some variables are assigned an initial value which can be changed during the course of the simulation.

Second XY-loop

Directly after the first one, another XY-loop is started to load the agro-ecological region number (see Section 4.1 and Fig. 4.1) for each grid cell. This data is loaded from a separate input file because it is only used to arrange the output in CRCOVERS.TAB.

Initial scenario specific values

First of all, both the counters of the time steps (TIJD) and the update steps (UPDATE) are set at the minimum value of TMIN. The initial need ((LUC)NEED) is set at 10 and the change driver is set at FALSE (LUC-CHANGE) because at that moment in the simulation the programme does not know any data from the year before. OUTPUT then shows the version number and the function PARAMETER returns to the screen the number of time steps and scenarios selected by the user. Last but not least the procedure `CRNEED` is processed for the first time to fill the year-dependent parameters and variables (see also Section 5.1).

5.3 The CLUE-CR simulation loop including UPDATE

The CLUE-CR simulation loop is the most important component of the model framework. The decisions and evaluations concerning the land use/cover change are made in a yearly update sequence running the different procedures in their fixed order. Fig. 5.3 shows the programmed structure in the order of the procedures. In the following paragraphs the main actions are described indicating their processing order by numbering the steps from 1 to 11.

`REPEAT UNTIL` (repeat action 1 to 4 and 11)
After the process of initiation the model is ready to start the actual simulation run by entering the central CLUE-CR loop (the `REPEAT UNTIL (TIJD = TMAX)` statement). The present model is running in time steps of one month and will continue until the time of `TMAX` is reached, which was entered by the user.

`TIME STEP` (action 1)
The counting of the time steps is done directly after the beginning of the loop to emphasise that a new time step has begun: `TIJD := TIJD + 1`

Age (action 2)
Each time step the ages of the different land use/covers are increased by 1 month in the age array `CRLUAGE^[XY].LUC`. The grids are selected one by one in an XY-loop (see Section 4.2). First of all the land grids are selected with the statement:

```
IF CRBP^[XY].LAND = 1 THEN.
```

Only the age of these land grids are altered for the covers of `PER`, `PAS` , `ARA` and `NAT`.

`LUC(AG)CONST` Regression constants (action 3)
In this part of the programme the regression coefficients for the local and aggregated regional `(AG)` grid scales are adapted for each of the covers by adding the cover and scale specific time step change `DLUC(AG)` multiplied by the actual model time step time `TIJD` resulting in the variables `LUC(AG)CONSTI`.

`IF UPDATE = UPDATETIME THEN` (action 4)
This is the statement that controls the moment of update after 12 months or 1 year of modelling, in other words when de variable `UPDATE` has reached the value of 12. The update is processing action 5 to 10. Directly after approval of this statement this variable is set to 0 to start the next 12 time steps.

`POPGROWTH and CRNEED` (action 5)
Every update cycle the programme starts with calculating the population growth over the last 12 months in the procedure `POPGROWTH` (see Section 5.1) and directly after that `CRNEED` (see Section 5.2) starts to evaluate the consequences of this population growth for the needs to change land use/covers.

IF (LUC)NEED > (LUC)CONSTI THEN CHANGE (action 6)
Actually this statement is repeated four times, so for each land use/cover type separately is checked whether the need to change is actually higher than the valid regression constant for that time step. If this constraint is approved the needed cover is passed into the CHANGE (see Section 5.3) procedure, after assigning the data and regression parameters of this cover to the local CHANGE variables.

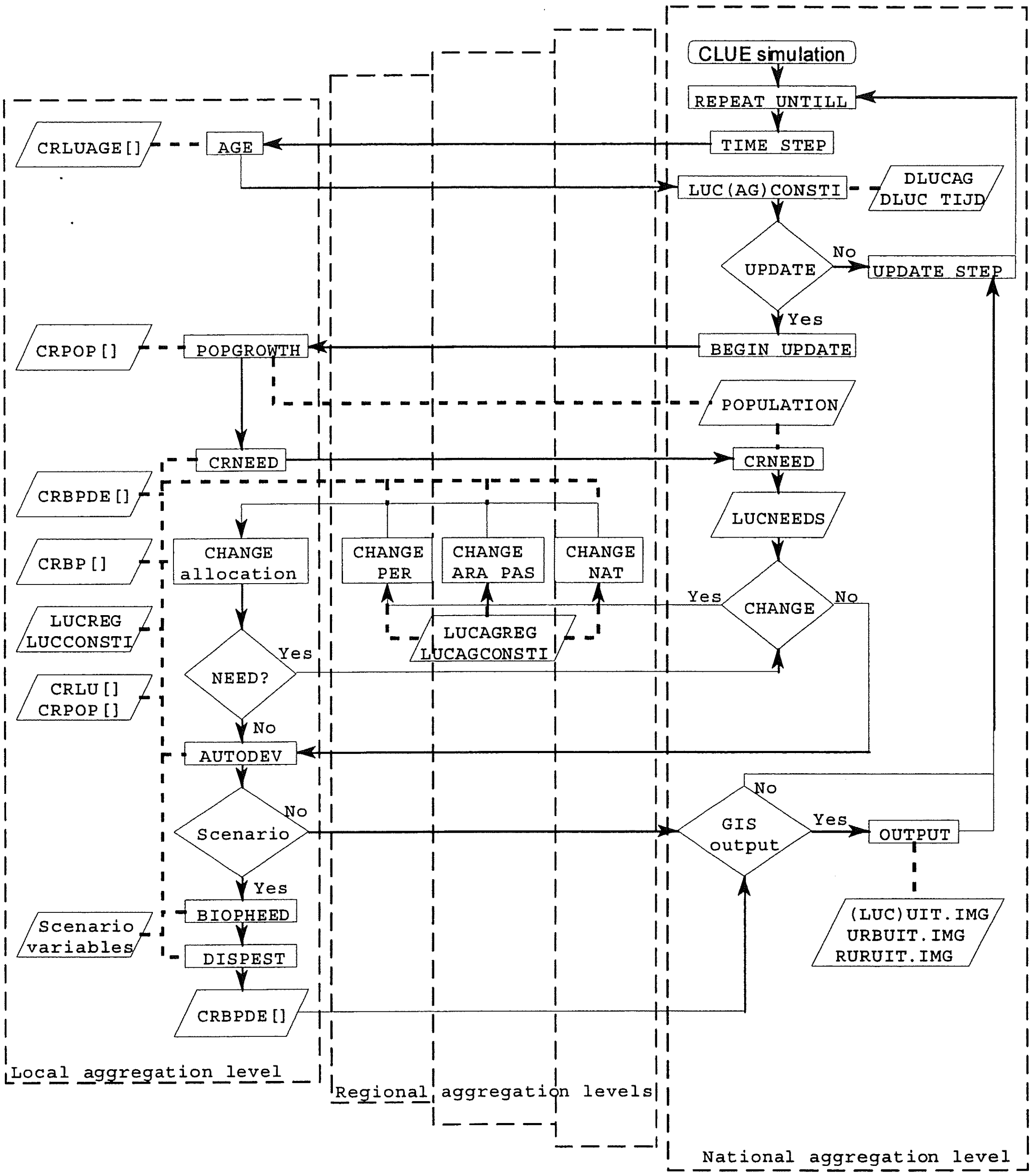

Figure 5.3 The flow chart of the UPDATE step showing the programmed order of the main procedures. The dotted boxes indicate at which aggregated scale level the procedures are calculating and processing their data.

AUTODEV (action 7)
This procedure is processed every update after the possible CHANGE developments and simulates the autonomous land use/cover change development evaluating also the effects of the CHANGE to get a valid total land cover distribution (see Section 5.4).

IF FEEDBIO or **PESTDIS = TRUE THEN** (action 8)
After the evaluation of the conversions of needs into changes, the update checks the implementation of scenario-specific consequences. If the user has entered to simulate the effects of degradation effects (FEEDBIO set TRUE) or the effects of a disease in the permanent crops (PESTDIS set TRUE) the procedures of BIOPHEED and DISPEST are executed (see Section 5.5. and 5.6).

TUSSENDOOR (action 9)
At the end of the update sequence, this function (from the CLUE_SCR library) sends some information to the user screen about the progress of the model.

IF TIJD = UITTIJD THEN (action 10)
The final step in the update sequence is to check if the time is reached to process the output GIS files. If the valid year is reached (given by the user) the programme processes the six IDRISI. IMG files in a XY-loop. The values of PER, PAS , ARA, NAT and the distribution of the population densities URB and RUR are stored in their output files (see Section 3.3). To avoid confusing the 0 values of the ocean and other grids outside Costa Rica with the 0 values of covers and densities, the value of 10 is added to those grids that are located on the main land of Costa Rica. As a consequence, the actual values in the output cover maps vary from 10 to 110 % which has to be taken into account with the further analysis of these output files.

UPDATE = UPDATE + 1 (action 11)
The UPDATE counter is set at 0 after each update sequence.

5.4 Closing down the programme

When the programme has reached the value of the user set TMAX (amount of simulation years) the programme is terminated. The special assigned memory is set free (FreeMem statements), the status of the memory is shown on the user screen (MEMDECLAR3) and the input and output files are closed and stored in the working directory. The programme is ended by giving some general information about the elapsed real time, the authors etc. The functions concerning the user interface and the DOS screen are not further discussed. They are just to demonstrate the progress during the modelling and can be easily improved, replaced or even totally removed to integrate the model into more advanced driving systems.

6 DESCRIPTION OF THE CLUE-CR MAIN PROCEDURES

This chapter will describe the main procedures or modules of the CLUE-CR model version 1.2, following the same structure as in the previous chapter. The detailed source code listing will be given in the appendices while in this chapter the structure and function of each procedure will be outlined and explained. An effort is made to visualise the procedure structure with flow charts or relation diagrams where some details were omitted for the sake of a clear and direct understanding.

6.1 The POPGROWTH procedure

One of the most important factors during each update sequence is the procedure for the actual growth of the population POPGROWTH (see source code listing in Appendix III) since this is one of the driving forces of the land use/cover change. The growth of the population is divided into the rural population growth (RUR, RURGR) and the urban population growth (URB, URBGR). The model processes the population changes in terms of densities for each local grid cell, in order to capture the spatial characteristics. Fig. 6.1 shows the flow chart of the POPGROWTH procedure. The present version 1.2 implements a linear growth curve for both rural and urban population. It is to be expected though that more complicated growth curves will become available in the future.

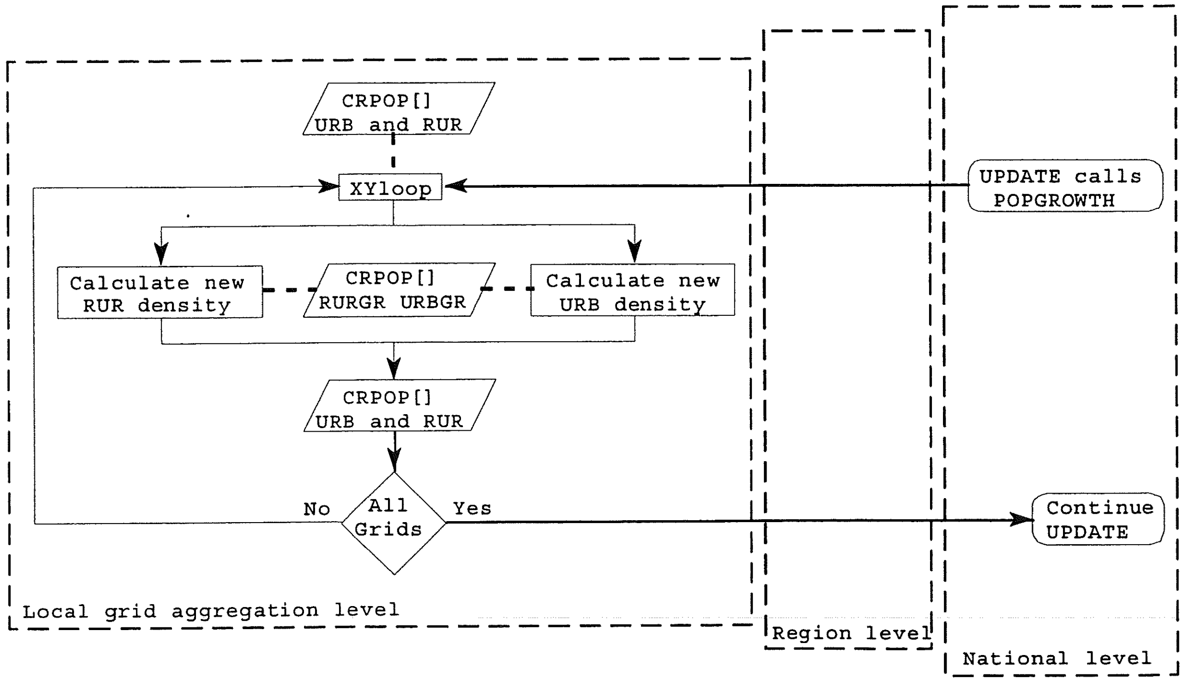

Figure 6.1 The flow chart of the POPGROWTH procedure, which is called as the first action within every update sequence.

XY-loop (see FOR TO DO in Section 4.2)
The population growth is implemented at the local grid aggregation level. Each grid cell is selected separately using its unique [X,Y] co-ordinate. This co-ordinate first of all calls the old both CRPOP^[XY].RUR and CRPOP^[XY].URB from the memory.

Calculate new density
With the same co-ordinate value the growth rates are called from the memory array CRPOP^[XY].RURGR and CRPOP^[XY].URBGR. These rates represent the difference in density from 1973 to 1974 for each local grid cell. The general trend is an increase in population but there are some remote areas where the population decreases. To avoid negative population densities after several years of decrease, the procedure corrects these negative values to 0. When the new density has been calculated it is stored again in the array CRPOP^[XY].RUR and CRPOP^[XY].URB, respectively.

All grids
The XY-loop will continue until all 2200 grids have been processed. When the loop has finished the programme continues with the rest of the update sequence.

6.2 The CRNEED procedure

The purpose of the Costa Rican need procedure (CRNEED see source code listings in Appendix IV) is to evaluate the present (at the moment of update) land use/cover and the consequences of the population growth which has just been calculated. This procedure operates at three different aggregation levels (local, regional and national) of which the regional aggregated level is only used to produce the yearly updated regional specific land use/cover table CRCOVERS.TAB. The structured flow diagram of CRNEED is shown in Fig. 6.2, starting and ending the procedure in the upper right corner.

YIELDFLUCT
Directly after resetting some internal counting variables the programme determines the annual fluctuation in the biophysical conditions valid at the time of update. This YIELDFLUCT is determined with a triple sinus function using the variables PI (3.14159 etc.), TIJD (the elapsed time in months since the start of simulation) and FREQ 1-3 (fluctuations given in months). Depending on the elapsed time interval the value of YIELDFLUCT can vary between -0.10306 and 0.84359.

First XY-loop
The next step in the procedure is to go down to the local grid level. Inside the XY-loop (see FOR TO DO in Section 4.2) all the local drivers and attributes will be processed to determine the yield of each local grid cell separately (56.25 km^2). This yield or production level (VALUE) is calculated using four factors: BIOPHY, MANAGEMENT, TECHNOLEVEL and GRIDLU.

BIOPHY
The local grid dependent BIOPHY factor is calculated using the annual YIELDFLUCT and the proportion of the local CRBP^[XY].RELIEF and CRBP^[XY].SOIL conditions. The value of BIOPHY is also adapted for altitudes, CRBP^[XY].ALT, higher than 2500 metres.

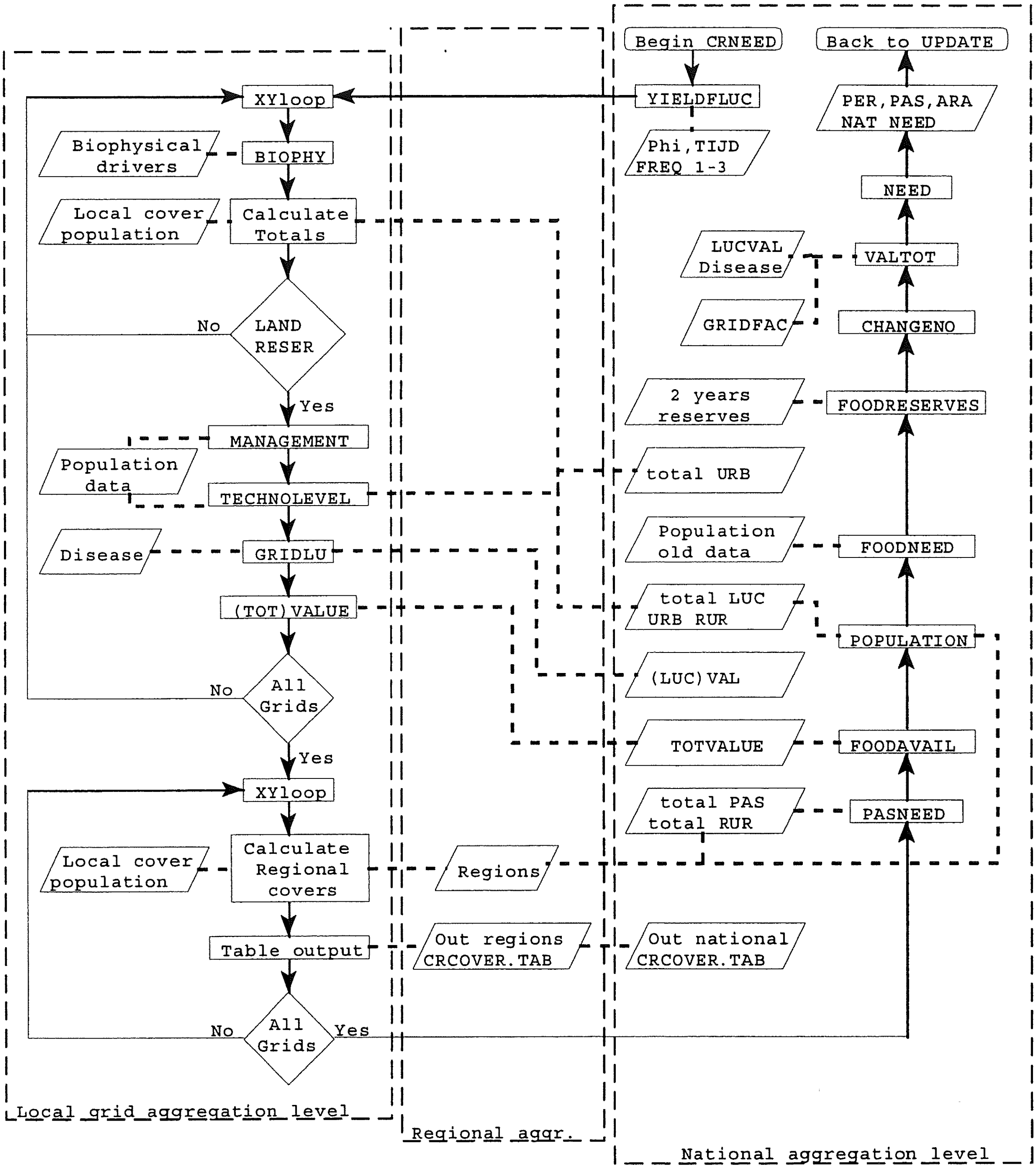

Figure 6.2 The flow chart for the CRNEED procedure showing the programmed order of the main components. The dotted boxes give an indication at which aggregated level the model is actually processing the data and variables.

Calculate totals

Still inside the XY-loop, the procedure continues with calculating the totals of the present land use/cover and population data. In the statements for each [X,Y] co-ordinate the local data is added to the total so far for the five different LUCTOT 's, URBTOT and RURTOT. When the loop has finished these totals are complete and they will be used later in the procedure by several components.

LAND or **RESER**

In order to increase the processing speed and to avoid unnecessary calculations the procedure checks the CRBP^[XY].LAND and CRBP^[XY].RESER value. Only the value of 1 for LAND is allowed to select only those grids that belong to the main land of Costa Rica (913 local grids). The values of 1 for RESER are not allowed because they represent the protected nature reserves with 100 % natural rain forest. In these areas land use/cover changes are not allowed and there is no yield production.

MANAGEMENT

After the previous selection (we are still inside the XY-loop) the local MANAGEMENT factor is calculated. This factor ranges from 1 for poor management to 2 for good management and is dependent on the amount and proportion of the RUR and URB population density within the selected local grid. With the presence of more population to work, the management improves.

TECHNOLEVEL

In a similar way the TECHNOLEVEL is determined by the proportion of URB population related to the average for Costa Rica of the URB population per local grid. In this the sense the bigger cities contribute positively to a higher level of technology.

GRIDLU

This factor represents the balanced value of the five local land use/cover types. The local percentages of land use/cover are multiplied by a cover-specific value which gives an indication of the different land-use/cover-specific contributions to the actual food and money production.

(TOT)VALUE

First of all, the local grid VALUE is calculated by multiplying the different yield-contributing factors of BIOPHY, MANAGEMENT, TECHNOLEVEL and GRIDLU. Before the next grid cell is processed the total yield value TOTVALUE is adapted by adding the VALUE. The TOTVALUE is used later in this procedure in the national evaluation of production and demand.

All grids, second XY-loop

The all grids decision is checking whether all the 2200 grids have been processed and when this is done, the procedure enters a second XY-loop to calculate the regional totals of the five different land use/covers. With the aid of the region array CRBP^[XY}.REGIO the three agro-ecological regions are separately processed to calculate their regional totals.

Table output and all grids

The regional totals are stored in the table output file CRCOVERS.TAB, together with the national totals calculated in the previous XY-loop. This output is processed every update and after the full simulation is finished as a result the CRCOVERS.TAB file will contain a yearly overview of the cover distribution. When all the grid cells have been processed and the XY-loop is finished, the procedure will start to operate at the highest aggregation level.

PASNEED

At this moment, after closing down the local aggregation level, the procedure has arrived at the national aggregation level and the first action that takes place comprises the evaluation of the proportion of total PAS and total RUR. Due to the fact that cattle is recognised as a status symbol in Costa Rica, there is a general relation between the total rural population and, as a consequence of the cattle, the total area of pasture and range lands.

FOODAVAIL

The absolute total of food production and yield for the country of Costa Rica (FOODAVAIL) at the time of update is given by the total of local grid yields (VALUE) TOTVALUE. Also in this section of the procedure the variables OLDPOP and OLDNEED are filled with the values of POPULATION and FOODNEED, respectively (their values of the previous update sequences one year ago).

POPULATION

The new increased total population of Costa Rica for the present update cycle is calculated as the product of the total rural (RURTOT) and the total urban (URBTOT) population densities. These total values were calculated in the first XY-loop of this procedure.

FOODNEED

The demand for food is directly related to the total population of the country. This population, however, expands every year, increasing the demand or FOODNEED proportional to the absolute growth of the population.

FOODRESERVES

The procedure continues with comparing the values of FOODAVAIL and the FOODNEED for this update step. If there is more food available then needed, the surplus is stored in FOODRESERVES and can be made available for two more years, in case of need. When more food is needed than actually available, the FOODRESERVES are first used and after three years of not fulfilled need the country is supposed to be in a state of famine. The difference between FOODAVAIL + FOODRESERVES and FOODNEED results in a need to change and adapt the land use/cover to improve and increase production and yields.

CHANGENO

When the available food and reserves cannot meet the demand, the procedure evaluates the maximal amount of change possible for the current update. This amount of CHANGENO is the product of the absolute national need divided by GRIDFAC, a dimensionless variable which can be tuned and made scenario-specific.

VALTOT and NEED

With this absolute number of change CHANGENO the procedure evaluates the consequences for the different LUC cover types by selecting the proportion of need for each cover. This proportion is dependent on the intrinsic cover value LUCTOT compared to the total of these values VALTOT, taking into account the feedback effects of possible diseases upon the capability of the cover to provide change to fulfil the need.

As a consequence the last step in this procedure is to calculate the national amount of need to change of coverage for each simulated land use/cover type. This LUCNEED value is the product of the LUCNEED left from the previous update (need not yet accomplished) and the present need (CHANGENO/ VALTOT) divided by the cover specific value of LUCVAL.

6.3 The CHANGE procedure

The CHANGE procedure is used for the allocation of the (national) cover-dependent demands. These demands or LUCNEED's were estimated during the previous procedure. This allocation is done by selecting the most suitable aggregated regions at the sub-national level before the actual change is allocated at the local grid level. The selection of the aggregated regions involves the processing and comparing of the mean regional cover extensions and the regional regression model cover extensions. When the calculated differences allow allocation of new cover inside the selected aggregated region, the CHANGE procedure goes down to the local grid level and evaluates the local regression models before new covers are allocated.

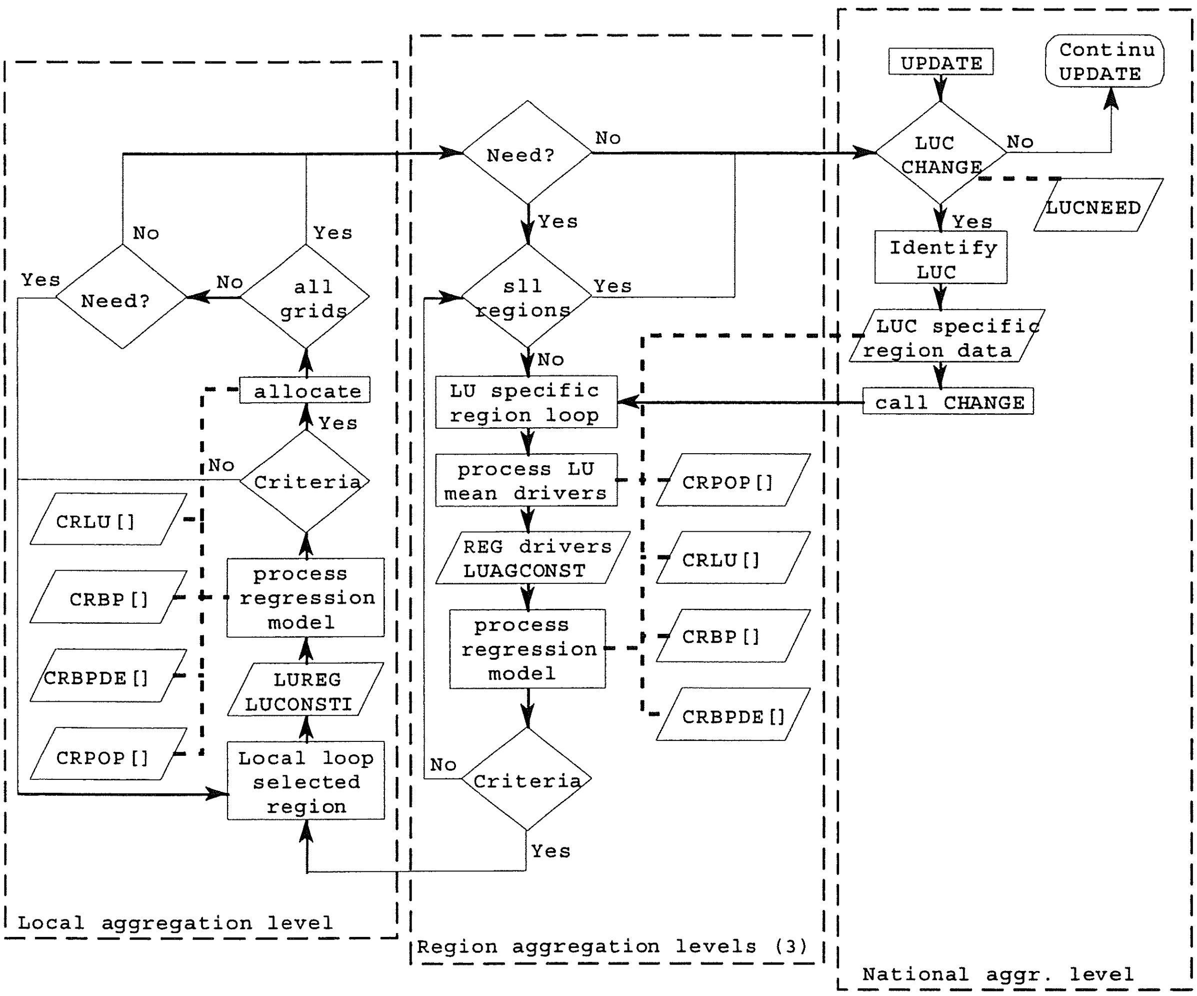

Figure 6.3 The flow chart for the CHANGE procedure. Note that the single dotted box of the regional aggregation level indicates only the level of the **selected** land use/cover for change (the land use/covers operate at three different regional aggregation levels).

Figure 6.3 shows the flow chart of the main structure of the CHANGE procedure while the source code listings are given in Appendix V. A major difference between CHANGE and the other procedures is the fact that the CHANGE procedure is processed for only one LUC cover type at the time. The main reason for this is that each LUC cover type has its own optimal artificial aggregated region size resulting from the nested scale analysis. Before calling the CHANGE procedure in the update sequence, the programme checks first for each cover type (PER, PAS, ARA or NAT) whether the cover possesses a high enough LUCNEED to induce change (see the upright section in the flow chart of Fig. 6.3).

LUC CHANGE/ identify LUC

Still at the level of the update sequence, the programme checks first whether there is enough need or demand (LUCNEED) for changes in coverage for each of the LUC cover types separately. In case the LUCNEED value is higher than the cover-dependent regression constant (LUCCONSTI), the programme will continue with initiating the local cover-specific CHANGE variables and constants. These LUC-specific parameters concern the national cover demand, the specific region size, the regional regression model parameters and the local regression model parameters. After initiating the specific cover parameters the procedure CHANGE is called to start processing.

LUC-specific region loop/ need/ all regions

The first part of the CHANGE procedure is operating at the cover-specific regional aggregation level. The loop is started in the region that was not called to change during the last update cycle (the region number after the last processed). The main regional loop is selecting one region after the other until there is no longer need to change (Need?) or until all the cover-specific regions have been selected and processed once (all regions). Note that a second loop is nested inside this loop (see Fig. 6.3) which is operating at the local grid level, selecting only those local grids which belong to the same selected region.

Process LUC mean drivers

The average or mean values of the land use/cover driving factors are calculated from the grid values situated inside the selected region. The following parameters are calculated from a local grid loop inside the selected region:

TELLAND -> the number of valid main land Costa Rica grids
URBTELR -> the average urban population density
RURTELR -> the average rural population density
ALTTELR -> the average altitude
RELTELR -> the average relief value
SOITELR -> the average soil value

Process regression model (regional)

The regional regression model LUAGREG value is calculated (see also Section 2.4) by multiplying each driver average (driverTELR) by its regional regression coefficient (LUAGdriver) and adding these driver values to the regression constant (LUAGCONST) with the following statement:

```
LUAGREG := LUAGCONST + LUAGURB*URBTELR + LUAGRUR*RURTELR +
    LUAGALT*ALTTELR + LUAGRELIEF*RELTELR + LUAGSOIL*SOITELR
```

Criteria

The decision whether or not the allocation of new land use/cover can take place in the selected region depends on the following criteria:

- Inside the selected region more than half of the grids have to belong to the Costa Rica main land (CRBP^[XY].LAND) before the regional regressions can be valid. This imposes problems mainly along the coast line and border line of the country.
- The difference (LUDIF) between the average coverage of the selected cover in the region (LUTELR) minus the cover amount of the regression model LUAGREG has to be more than the regional regression constant divided by 4 (LUAGCONST/4). In this way those regions are selected where enough potential for change exists.

When the procedure has approved these restrictive criteria, the allocation loop will start at the local grid level. If one of these criteria is not met, the procedure will continue with selecting the next region.

Local loop selected region
When a suitable region has been selected to allocate the new land use/cover, the procedure moves down to the local grid level. Only the local grids inside the region will be selected to process an individual evaluation of the possible change.

Process regression model (local)
To evaluate possible change, the cover is modelled (LUREG) at the local grid level with the local CRBP^[XY].drivers and their local regression coefficients (LUCdrivers) and constants (LUCONST). The statement is programmed in a similar way as shown for the regional regression model.

Local criteria
Before actual allocation of the new cover the procedure first checks the age CRLUAGE^[XY].LUC of the selected cover to allow new changes (not younger than LUAGE). Secondly, the LUNEED for change has to be higher than the regression constant (LUCONST). Thirdly, the regression LUREG has to be positive because CHANGE evaluates the possible allocation of new covers to satisfy the need. Decrease of covers is left for the AUTODEV procedure. When one of these criteria is not met the procedure selects the next local grid cell until all cells have been evaluated.

Allocate
When all the criteria are met the suitable grid cell has been found for the selected region and cover, to allocate the new land use/cover. The procedure first saves the old land use/cover value in OLD1LU. The selected land use/cover is allocated depending on the modelled cover (LUREG) and a factor for the valid time domain (CHLU) with the following statement:

```
CRLU^[XY].LU := CRLU^[XY].LU + ROUND(CHLU*LUREG)
```

After calculating the actual allocated amount of cover (COR1LU) the new decreased LUNEED is calculated.

All grids and need?
The local grid cell loop will continue until all the cells inside the selected region have been evaluated or when the LUNEED has been completely satisfied. When all grids have been processed the procedure moves up to the next region at the aggregated regional level. If the LUNEED has been finished the procedure stops directly and the programme continues with the rest of the update sequence.

6.4 The AUTODEV procedure

This procedure simulates the autonomous development of the land use/cover and also evaluates the impact of the newly allocated covers from the CHANGE procedure. The AUTODEV procedure (see Fig. 6.4 and source code listings in Appendix VI) operates only at the local grid level, processing the regression models independent of the existing LUCNEED's. In this way the local land use/cover is evaluated purely on the basis of its biophysical and demographic driving factors.

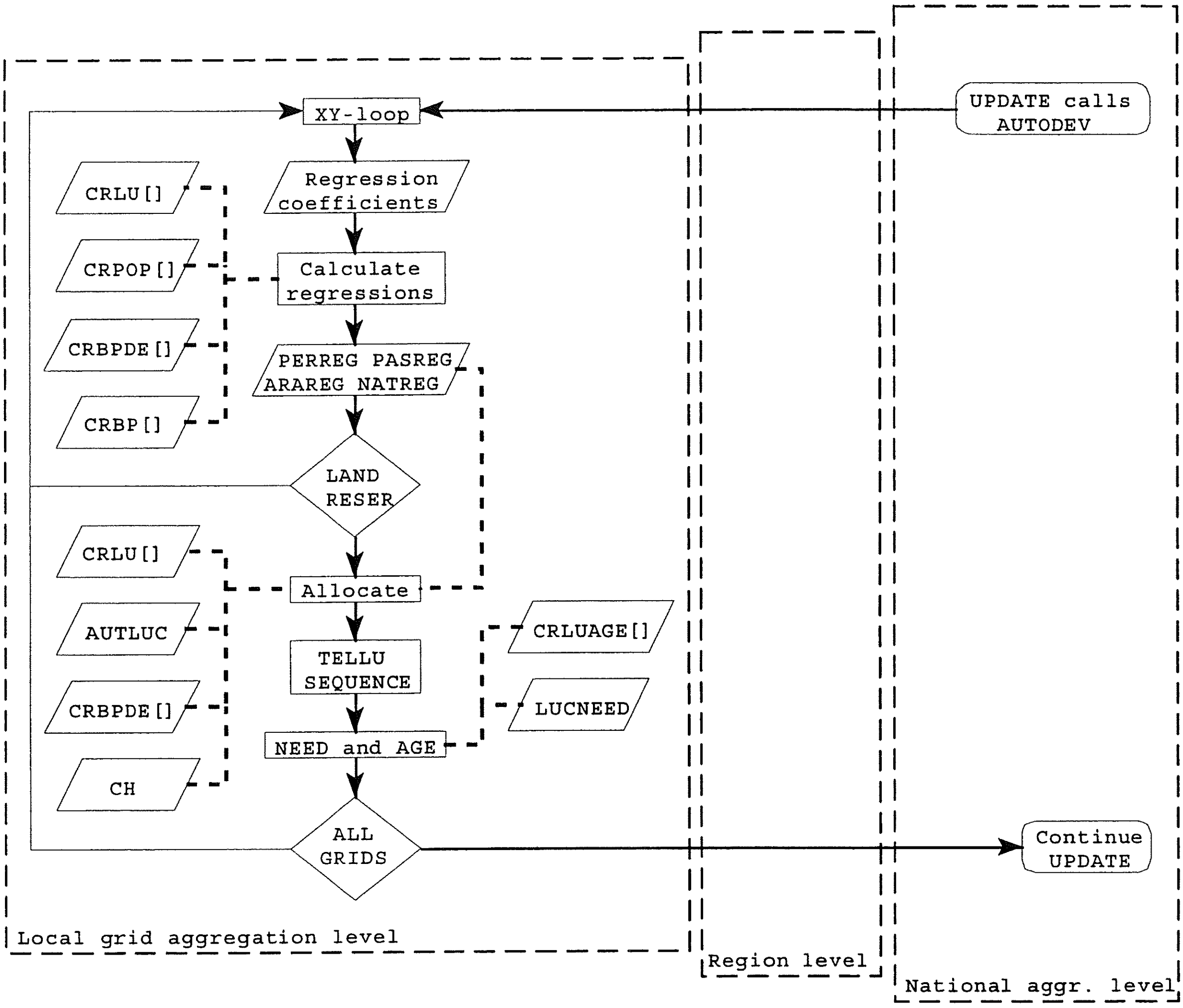

Figure 6.4 The flow chart of the AUTODEV procedure, showing the order of processing. This procedure is operating only at the local grid level.

XY-loop

The procedure directly starts to operate at the local grid level with selecting all grids one after the other. The first action that is undertaken inside this loop is resetting the local variables OLD1LUC and COR1LUC to 0. Next, the old land use/cover values (before AUTODEV processing) of CRLU^ [XY] . LUC are stored in the OLD1LUC variables (LUC stands for PER, PAS, ARA and NAT).

Regression coefficients

The local grid level regression coefficients are called from the memory (constant or CONST values) which comprises the following parameters: LUCCONSTI (regression constant), LUCRUR (rural population regression coefficient), LUCURB (urban population), LUCALT (altitude), LUCRELIEF, LUCSOIL.

Calculate regressions

The regression model is processed for each cover type, still at the local grid level, resulting in the modelled cover values of PERREG, PASREG, ARAREG and NATREG. The values of these LUCREG's are the product of the LUCCONSTI plus the five driving factors of CRPOP^[XY].RUR, CRPOP^[XY].URB, CRBP^[XY].ALT, CRBP^[XY].RELIEF and CRBP^[XY].SOIL multiplied by their regression coefficients of LUCRUR; LUCURB, LUCALT, LUCRELIEF and LUCSOIL. Taking also into account the disease and degradation effects on the covers of ARA and PER from the variables CRBPDE^[XY].DEPER, DEARA and PERDI

LAND or RESER

In order to increase the processing speed and to avoid unnecessary calculations the procedure checks the CRBP^[XY].LAND and CRBP^[XY].RESER value. Only the value of 1 for LAND is allowed to select only those grids that belong to the main land of Costa Rica (913 local grids). The values of 1 for RESER are not allowed because they represent the protected nature reserves with 100 % natural rain forest. In these areas land use/cover changes are not allowed and there is no yield production.

Allocate

The allocation of the new land use for the autonomous development is done at the local grid level by adding the modelled LUCREG to the cover value of CRLU^[XY}.LUC. The magnitude of LUCREG is evaluated taking into account the valid time domain CH (result of UPDATTIME/(2*TMEASURE)), the percentage of cover already present in the grid cell and a steering variable AUTLUC which is a cover specific scenario value. This last value can be set to increase or decrease the influence of the autonomous development on the final land use/cover changes results. Also during this allocation the impacts of CRBPDE^[XY].PERDI (disease) and CRBPDE^[XY].DEPER/ DEARA (degradation) are taken into account. If for example the variable of CRBPDE^[XY].PERDI is not equal to 1 the cover of CRLU^[XY}.PER is not allowed to have any increase for that update year.

TELLU sequence

Besides overestimation, the regression model can also produce negative values, meaning that such a specific cover is highly unsuitable and will decrease according to the driving forces. After multiple updates the possibly resulting negative covers values have to be set at 0 (no cover left). The next step in this section of the procedure is a sequence of TELLU operations. Due to too much or too little allocation, the main purpose of TELLU is to get the total percentage of cover inside the single grid cell back to 100 %.

The TELLU operations always start with filling the TELLU counter with the values of the CRLU^[XY].LUC types (for PER, PAS, ARA and NAT). Next the procedure checks whether the TELLU value is equal to 100-CRLU^[XY].RES. The RES group has not been altered, because this group is not participating in the regression models. As a consequence this value is kept as constant as possible and will only be adapted if necessary at the end of the procedure. If the total coverage of the five CRLU^[XY].LUC 's is 100 %, the procedure will continue with the XY-loop. When the total coverage does not equal 100 %, the TELLU sequence is repeated, until 100 % is reached, with the following procedure:

-1- Proportioning the cover back to 100 % by dividing each CRLU^ [XY] .LUC value (only PER, PAS, ARA and NAT) by the TELLU total multiplied by 100. Normally this results directly in a total of 100 % but there are some exceptions to that rule. For example, differences lost in the rounding can result in a few % deviation from the 100 %.

-2- The difference of a few % plus or minus in the total cover is allocated at the local grid level. The percentage more than 100 is subtracted from the LUC which already has shown a decrease during this update procedure. The percentage below 100 % is compensated by adding extra cover to the LUC which is already showing an increase in the present update cycle. When all these rules do not solve the problem, the final solution is found in adapting the RES cover group.

NEED and AGE

When in the end the total grid cover is again 100 %, the final step in this procedure includes the adaptation of the age and need values as a result of the changed covers. First, the correction factors COR1LUC's are calculated. COR1LUC is the difference between the OLD1LUC and CRLU^ [XY] .LUC (the past and the present land use/cover extension). If the LUC cover has been changed in extension during this update the age of the covers CRLUAGE^ [XY] .LUC together with LUCNEED's is adjusted to the new situation.

In this way all the [X,Y] co-ordinate values are processed and when all the grids have been evaluated the programme continues with the update sequence by checking if the scenario-specific procedures DISPEST and BIOPHEED are selected to be processed.

6.5 The DISPEST procedure

The scenario-specific DISPEST procedure (see Fig. 6.5 and the source codes in Appendix VII) simulates the impact of an unspecified disease within the permanent crops below 300 metres resulting in the grid specific factor variable CRBPDE^ [XY] .DIPES. With this factor both biophysical and demographic feedback mechanisms will be evaluated. The disease is set to start after 5 years of simulation, starting in the harbour of Limon in the Atlantic zone. The disease is following a contamination pattern common for banana or cacao diseases with insect vectors (Chan & Jeger, 1993). After 10 years of spreading through the country it is assumed that cure and controlling measurements are introduced (Anderson & Mistretta, 1982). The scenario-specific parameters that are explained in this section can be found in Appendix I. Fig. 6.5 shows the basic flow chart of the DISPEST procedure. The procedure (if selected) is called each update (each year of simulation) after the evaluation of the covers and population. In this way the impact of the disease will be noticed the next year or update when it is time to evaluate the production and yields of these infected permanent crops.

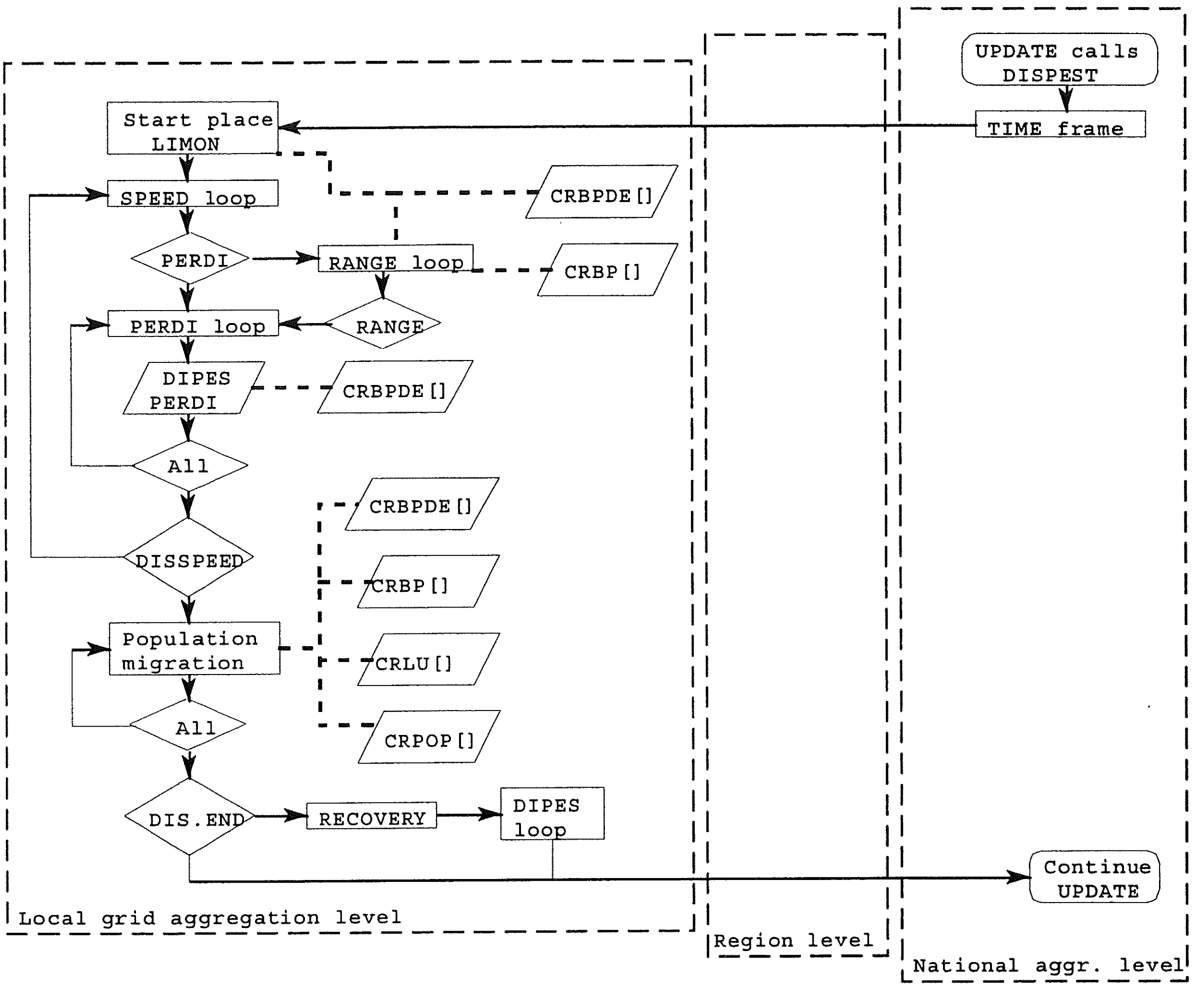

Figure 6.5 The flow chart for the scenario-specific **DISPEST** procedure. The procedure starts in the right upper corner, is operating at the local grid level and ends down in the right corner.

TIME frame

From the start time DISPERTIME until the end time DISPEREND of the uncontrolled disease the Boolean variable PESTDIS is set TRUE. This PESTDIS variable is used by the other procedures (mainly CRNEED) to verify the impact of the disease at the permanent crops.

Start place LIMON

The spreading of the disease is started at the Atlantic coast in the harbour of Limon. Geographically this place is situated in grid cell [21,10] and as a consequence this cell starts with setting the local variable CRBPDE^ [21.10] .DIPES to the value of DIPES which is set at 0.1.

SPEED loop

The pattern of spreading is dependent on both factors speed (DISSPEED) and distance (RANGE). In this first loop the DISPPEED factor is determining how fast the disease can spread through the country.

PERDI
If during the SPEED loop one of the grids is found to have a CRBPDE^ [XY] .PERDI value <1 (grid cell infected), the procedure starts the RANGE loop to simulate the spreading.

RANGE loop
In this second nested loop all the grid cells surrounding the infected cell are given a CRBPDE^ [XY] .DIPES value <1 when the grid cell is situated on the main land (CRBP^ [XY] .LAND > 0) and the altitude is not more than the critical height of 300 metres (CRBP^ [XY] .ALT < DISALTCRI).

RANGE
The surrounding cells are selected by plus distance and minus distance of the infected grid cell co-ordinate. In other words, all the grid cells with the X-co-ordinates between X-RANGE and X+RANGE and the Y-co-ordinate between Y+RANGE and Y-RANGE.

PERDI loop
This third nested loop will evaluate all local grid cells one by one. First, it is checked whether the value of CRBPDE^ [XY] .DIPES is still valid. Secondly, for each single grid cell the value of CRBPDE^ [XY] .DIPES (procedure local variable) is assigned to CRBPDE^ [XY] .PERDI (general disease impact variable).

All and DISSPEED
These are two decisions counters that control the PERDI loop (every single grid) and the RANGE loop (dependent on the value of RANGE), respectively. This last value controls how many times the two nested loops are executed.

Population migration
This section of the procedure evaluates the impact of the disease on the local food supply. If the food supply declines too strong, the local population will migrate to the cities. To estimate the local supply of food (GRIDTOT) the same BIOPHY factor is calculated as in the CRNEED procedure (see Section 6.2). The other variables in the GRIDTOT calculation concern the local land use CRLU^ [XY] .LUC and the impact factor of the disease CRBPDE^ [XY] .PERDI. The value of GRIDTOT is the result of adding all the land uses and impact factors together multiplied by the BIOPHY factor. If the GRIDTOT is less than the critical food value of GRIDCRI, the population will migrate to the cities.

DISPEREND
The last step in this procedure is checking if the end time of the disease is already reached. When TIJD (time steps counter) is equal to DISPEREND (the disease end time) the model will put the Boolean variable RECOVERY on TRUE and PESTDIS on FALSE. The variable RECOVERY makes sure that the effect of the disease is slowly eliminated once the cure or management measures are found.

DIPES loop
When the RECOVERY is set at TRUE the procedure will execute a XY-loop where all the values of CRBPDE^ [XY] .DIPES and CRBPDE^ [XY] .PERDI will be increased every update step by 2*DIPES, until these impact factors have again reached the neutral value of 1.

6.6 The BIOPHEED procedure

The second scenario-specific procedure BIOPHEED (see Fig. 6.6 and the source code listings in Appendix VIII) is firstly modelling the biophysical and demographical impacts or feedbacks of erosion on arable lands and on permanent crops in areas with steep slopes resulting in the factors CRBPDE^[XY].DEPER and CRBPDE^[XY].DEARA (Hall & Hall, 1993). Secondly, the impact is simulated of decreasing soil fertility (for the drainage factor) in remote areas with prolonged use as arable land using also the factor CRBPDE^[XY].DEARA (Reiners *et al.*, 1994). The impact and calculation of these factors are decision rule based and both factors will cause a biophysical reduction of yield or production value in the CRNEED procedure and will also have limiting effects on the allocation in CHANGE and AUTODEV. The scenario specific-parameters that are used by this procedure can be found in Appendix I. Fig. 6.6 shows the flow chart for the basic structure of the procedure, the main steps are outlined in the rest of this section.

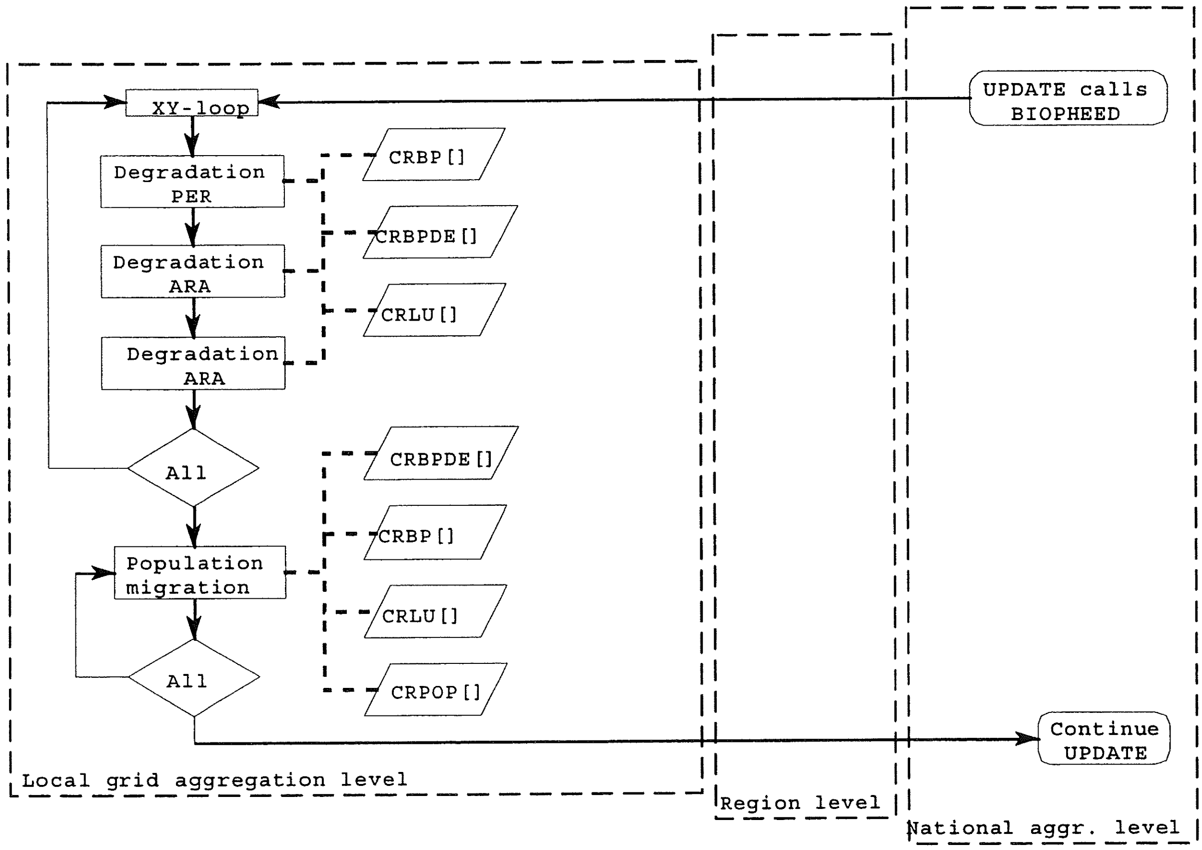

Figure 6.6 The flow chart of the **BIOPHEED** procedure. The procedure is called (if selected) during the end of the update sequence. **BIOPHEED** starts in the upper right corner, is processing at the local grid level and ends in the lower right corner.

XY-loop

The BIOPHEED procedure is operating entirely at the local grid level. In this first XY-loop all local grid cells are processed one after the other. Like in the DISPEST procedure, the model is calculating a separate degradation factor which is used as a limiting or steering parameter in the other procedures.

Degradation PER

This section calculates the limiting effect of soil degradation on steep slopes under permanent crops resulting in the factor CRBPDE^[XY].DEPER. This factor is calculated as a function of the permanent crop cover extension in the grid cell (more than 5 %) and the slope steepness (CRBP^[XY].RELIEF), which has to be more than the critical value of PERRELCRI (scenario specific) and the prolonged time of use.

Degradation of ARA (slope)

As for PER, the limiting effect of soil degradation on steep slopes is calculated for the arable lands (CRBPDE^[XY].DEARA) using a different critical slope value of ARARELCRI.

Degradation of ARA (drainage)

The last simulated biophysical feedback concerns the effect of poorly drained soils in remote arable lands (away from urban centres). The same factor for arable land CRBPDE^[XY].DEARA (so both slope and drainage effects) is used as a function of CRBP^[XY].SOIL (drainage below ARASOICRI) and CRPOP^[XY].URB.

All

After processing all the local grid cells the model continues.

Population migration

This section of the procedure evaluates the impact of the degradation on the local food supply (the same as in the DISPEST procedure). If the food supply declines too strongly the local population will migrate to the cities. To estimate the local supply of food (GRIDTOT) the same BIOPHY factor is calculated as in the CRNEED procedure (see Section 6.2). The other variables in the GRIDTOT calculation concern the local land use CRLU^[XY].LUC and the impact factors of the degradation CRBPDE^[XY].DEPER/ DEARA. The value of GRIDTOT is the result of adding all the land uses and impact factors together multiplied by the BIOPHY factor. If the GRIDTOT is less than the critical food value of GRIDCRI, the population will migrate to the cities.

7 USER'S GUIDE

This section gives an example how the programme software can be used and how the results can be processed in the GIS software of IDRISI (Eastman, 1992). The explanation is done step by step and should be sufficient for users familiar with the DOS operating system on the IBM-compatible Personal Computers. The authors have tried to keep this basic version as simple as possible to make it accessible for a wide range of users. If the user does not have the IDRISI software, it hopefully will be clear from this section and the rest of this document, in which format the simulation input and output data is available. For the more experienced computer user it will be no problem to evaluate the data in any other GIS programme. The introduction (Chapter 1) gives more information about the way to obtain a copy of the CLUE-CR demonstration version.

7.1 Contents of the CLUE-CR demo

The CLUE-CR demo version 1.2 is available on a 3.5 inch 1.44 megabyte floppy disk (see the Introduction for ordering). Make sure that you first have the file `README.TXT` included with the CLUE-CR demo version 1.2 (a text or TXT file can be read by any word-processor or ASCII editor). The data files are also discussed in other sections and in Appendix IX. On the floppy disk, the directory `A:\CLUEFILE\` should contain the files of Table 7.1 in alphabetical order.

Table 7.1 Contents of the CLUE-CR demonstration floppy disk

Filename	Size (bytes)	Date
ARAUIT.DOC	493	11/01/1996
CLUE_SCR.TPU	10272	11/01/1996
CLUEQASA.EXE	65696	11/01/1996
CLUEQASA.MAP	21425	11/01/1996
COSTGISI.DAT	250800	06/12/1996
CRREGIO.DAT	30801	12/14/1994
NATUIT.DOC	493	11/01/1996
PASUIT.DOC	494	11/01/1996
PERUIT.DOC	496	11/01/1996
README.TXT	2730	01/21/1997
RURUIT.DOC	501	11/01/1996
URBUIT.DOC	503	11/01/1996

The `NAME.DOC` files are IDRISI documentation files, necessary to process and display the named files in the IDRISI programme. The `CLUE_SCR.TPU` file contains the source codes for the library of graphical functions to build up the screen and to ask for the parameters in the user framework around the programme. Both `CLUEQASA` files contain the executable machine codes for running the CLUE-CR model. `COSTGISI.DAT` contains the georeferenced GIS data base with all the grid-specific parameters and `CRREGIO.DAT` contains the Costa Rican agro-ecological regions (Appendix IX).

7.2 Installing the programme

The CLUE-CR demo model can be installed on all IBM-compatible computers (configuration 386 or higher) running under the DOS operating system. Table 7.2 shows the average computing time (in seconds) for some widely used computer configurations, For each configuration the CLUE-CR demo model has been run for a time span of 22 years with the output on the 21st year. Each run has also been performed for scenario 1 and 4 (see Section 7.4) from floppy disk as well as from the hard disk of the computer.

Table 7.2 Processing time in seconds for two different scenarios running the programme from floppy disk and from hard disk.

Configuration Type	Speed (MHz)	Floppy disk Scenario 1 (s)	Floppy disk Scenario 4 (s)	Hard disk Scenario 1 (s)	Hard disk Scenario 4 (s)
Pentium	133	51	53	10	13
Pentium	90	58	62	13	19
80486	66	80	113	39	52
80386	25	370	449	207	285

7.3 Running the programme

The CLUE-CR version 1.2 demo model will start operating after typing the name of the executable file `CLUEQASA`:
-1- for running from floppy disk `A:\CLUEFILE\CLUEQASA`.
-2- for running from the hard disk `C:\CLUEFILE\CLUEQASA`.
The model will then start with a simple DOS menu screen divided into three small screens and two larger screens with the following headings:

MEMORY USED
The screen will show the available work space in the computers ROM memory and the work space used during processing of the programme. After a successful simulation the memory space is returned free.

CLUE-CR
This part will show the computer real start time after initialising the specified model run as well as the version number of the executable CLUE-CR model.

PROGRESS

The progress screen shows the month and year steps of the progressing model and gives the elapsed computing time after a successful simulation.

PARAMETERS

In the parameters screen the user defines the scenario before each start of the run. This screen will show the choices made during the modelling.

INFORMATION

The information screen will show, after a successful simulation run , the authors of the CLUE-CR demo model with their names and addresses.

Before the model will start the simulation, the user is requested to give the number of years or duration of the simulation run. Here the user can give a number between 1 and 22, any other number can and will probably give runtime errors. Once the computer has started processing the programme will display the given number of years in the PARAMETERS screen in months. In this way they can be compared with the months given in the PROGRESS screen.

The second question of the programme is to give the moment of producing the output files. This also has to be a number between 1 and 22. Keep in mind that the duration from the first question has to be longer than the moment of output. The CLUE-CR demo model takes 1973 as the base year. If the duration from the first question is set at 10 the model will simulate until 1983, if the second question is returned with 11 then the programme will never arrive to writing the output files in 1984 because it already stopped in 1983.

The last two questions are related to the implementation of the two available scenarios. The user will have to answer yes or no. After the start of the simulation the PARAMETERS screen displays which scenario is set at TRUE for operating or FALSE for not operating. More details about the scenarios are given in Sections 6.5 and 6.6, as well as in the following section.

7.4 Scenario options

The different scenario options that are available in the CLUE-CR demo version are already programmed in the model source code (see Sections 6.5 and 6.6). Therefore it is not possible (in this version) to define your own scenario parameters. On the one hand this is because the current expansion and development in the CLUE model is still directed in that area and at the other hand to avoid a very long and complicated user instruction and interface. The scenarios that we do offer are called BIOPHEED (see Section 6.5) and DISPEST (see Section 6.6).

As explained in the Section 7.3, the user can indicate whether or not to implement one or both of the scenario procedures. This leaves us with four possible combinations (Table 7.3):

Table 7.3 The four possible scenarios of the CLUE-CR demo version 1.2. The status is also returned on the PARAMETERS screen after starting the model run.

	BIOPHEED	Status	(DIS)PEST	Status
Scenario 1	no	FALSE	no	FALSE
Scenario 2	yes	TRUE	no	FALSE
Scenario 3	no	FALSE	yes	TRUE
Scenario 4	yes	TRUE	yes	TRUE

7.5 Output and data management

After a successful run the programme will have produced seven different output files (see for formats Appendix IX). These files will have been created in the directory of the CLUE-CR programme and executable files on the floppy disk or hard disk.

GIS map data files: ARAUIT.IMG, NATUIT.IMG, PASUIT.IMG, PERUIT.IMG, RURUIT.IMG, URBUIT.IMG

These files will contain the percentage of cover for each grid cell (% of 56.25 km^2) of arable land (ARA), nature (NAT), pastures (PAS) permanent crops (PER) and the rural and urban population density (pop/km^2) for each grid cell (RUR and URB). These output numbers are ordered in the IDRISI compatible IMG-format (Eastman, 1992) and accompanied by a documentation or DOC-file. For example, by selecting the CLUE-CR directory \CLUEFILE\ as data source area in the environment menu in IDRISI, the data will be easily displayed in IDRISI by simply typing the filename without extension in one of the display modules.

Update table: CRCOVERS.TAB
This file contains a yearly update of accumulative covers for the three agro-ecological zones and for the whole country of Costa Rica (see also Section 6.2). This ASCII file is readable in any text editor or word processor.

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Appendix I: The CLUE-CR variables and constants

```
(*************************************************************************)
(*                              CLUECR                                   *)
(*                              PC 1.2                                   *)
(*                                                                       *)
(*   CLUE-CR:      Conversion of Land Use and its Effects in Costa Rica  *)
(*   AUTHOR:       A. Veldkamp                                           *)
(*   ADAPTED BY:   J.M. Schoorl                                          *)
(*   DEVELOPEMENT PROTOTYPE (VERSION 1.0)    29/11/1993 to 02/02/1994    *)
(*   DEVELOPEMENT VERSION 1.1 COSTA RICA     07/10/1994 to 28/11/1994    *)
(*   PC VERSION 1.2 COSTA RICA               15/01/1996 to 01/06/1996    *)
(*   INPUTS: COSTGISI.DAT   &  CRREGIO.DAT                               *)
(*   OUTPUT: PERUIT.IMG, PASUIT.IMG, ARAUIT.IMG, NATUIT.IMG              *)
(*           RURUIT.IMG, URBUIT.IMG, CRCOVERS.TAB                        *)
(*************************************************************************)

PROGRAM CLUECR(LANDIN,REGIO,PERUIT,PASUIT,ARAUIT,NATUIT,RURUIT,URBUIT,
                                                                  TUSSEN);

USES Dos,Crt,CLUE_SCR;          (* Modification PC version 03/96          *)

CONST                      (* general settings and conditions CLUECR      *)
      TMIN=1;              (* starting time of simulation                 *)
                           (* TMIN <= TIJD <= TMAX                        *)
      UPDATETIME=12;       (* Update time of land use needs               *)
      XMIN=1;              (* XMIN <= X <= XMAX                           *)
      XMAX=50;             (* size region X-axis, effective               *)
                           (* regionsize is XMAX=7.5*50 km                *)
      YMIN=1;              (* YMIN <= Y <= YMAX                           *)
      YMAX=44;             (* size region Y-axis, effective               *)
                           (* regionsize is YMAX=7.5*44 km                *)
                           (* simulated is area of approx                 *)
                           (* 123750 sq-km (CR=913 cells)                 *)
(* "CONSTANTS" FROM NESTED SCALE ANALYSIS, SEE VELDKAMP & FRESCO(SUBM)    *)
(* THESE VALUES ARE ONLY VALID FOR COSTA RICA 0.04o GRIDS DURING '73-'84  *)
      (* regression Beta's from the nested scale analysis                 *)
      (* at 0.04 degree grid level                                        *)
      TMEASURE= 132;       (* Valid time domain regression                *)
                           (* max sim.time=2*TMEASURE=22yr                *)
      PERCONST= 9.37;      (* Permanent Crops                             *)
      DPER= 0.1061:        (* Change in constant/timestep                 *)
      PERURB= -0.0026;
      PERRUR= 0.905;
      PERALT= 0;
      PERRELIEF= 0.022;
      PERSOIL= 0;
      PASCONST= 25.81;     (* Pastures                                    *)
      DPAS= -0.0182;       (* Change in const/timestep                    *)
      PASURB= -0.0025;
      PASRUR= 0.26;
      PASALT= -0.01;
      PASRELIEF= 0;
      PASSOIL= 0.025;
      ARACONST= 11.34;     (* Arable lands                                *)
      DARA= 0.013;         (* Change in const/timestep                    *)
      ARAURB= -0.0015;
      ARARUR= 0.27;
      ARAALT= -0.0075;
      ARARELIEF= -0.018;
      ARASOIL= -0.0003;
      NATCONST= 51.6;      (* Natural vegetation                          *)
      DNAT= -0.0174;       (* Change in const/timestep                    *)
      NATURB= 0.035;
      NATRUR= -1.59;
      NATALT= 0.02;
      NATRELIEF= 0;
      NATSOIL= -0.0025;
(* regression Beta's from the nested scale analysis                       *)
(* at optimal aggregated grid scale                                       *)
      PERAG=4;             (* Permanent Crops: 4*4  grids                 *)
      PERAGCONST= 15.8;
      DPERAG= -0.0008;     (* Change in const/timestep                    *)
      PERAGURB= -0.0045;
      PERAGRUR= 0.469;
      PERAGALT= 0;
      PERAGRELIEF= 0.005;
      PERAGSOIL= 0;
      PASAG=5;             (* Pastures:    5*5 grids                      *)
      PASAGCONST= 13.12;
      DPASAG= 0.0129;      (* Change in const/timestep                    *)
      PASAGURB= 0.02;
      PASAGRUR= 0.7;
      PASAGALT= 0.026;
      PASAGRELIEF= 0;
      PASAGSOIL= 0.0043;
      ARAAG=5;             (* Arable lands:  5*5 grids                    *)
      ARAAGCONST= 9.2;
      DARAAG= 0.022;       (* Change in const/timestep                    *)
      ARAAGURB= 0.048;
      ARAAGRUR= 0.57;
      ARAAGALT= 0.004;
      ARAAGRELIEF= -0.0003;
      ARAAGSOIL= -0.0003;
      NATAG=6;             (* Natural vegetation: 6*6 grids               *)
      NATAGCONST= 97.1
      DNATAG= -0.154;      (* Change in const/timestep                    *)
      NATAGURB= -0.7;
      NATAGRUR= -0.85;
      NATAGALT= 0.017;
      NATAGRELIEF= 0;
      NATAGSOIL= -0.0034;
(* END "CONSTANTS" FROM NESTED SCALE ANALYSIS                             *)

(* RELATIVE VALUES/YIELDS OF LAND USE COVER TYPES                         *)
(* THESE VALUES MAY BE CHANGED AND ARE SCENARIO DEPENDENT, GRIDFAC IS     *)
(* TUNING VARIABLE OF THE LU USE NEED, POPULATION DEPENDENT               *)
      PERVAL=10;           (* relative value permanent crops              *)
      PASVAL=40;           (* relative value pastures                     *)
      ARAVAL=35;           (* relative value arable lands                 *)
      NATVAL=1;            (* relative value natural vegetation           *)
      RESVAL=0;            (* relative value rest group                   *)
      GRIDFAC=99;          (* tuning factor population/FOODNEED           *)
                           (* requires elasticity component               *)
      AUTPER=1.4;          (* Autodevelopment constant to steer           *)
      AUTPAS=99;           (* REGRESSION effects  V180 05-96              *)
      AUTARA=16;
      AUTNAT=13;
(* OTHER SIMULATION CONSTANTS USUALLY SCENARIO SPECIFIC                   *)
      FREQ1=24;            (* Monthly Frequency yield fluctuation         *)
      FREQ2=60;            (* Monthly Frequency yield fluctuation         *)
      FREQ3=132;           (* Monthly Frequency yield fluctuation         *)
      PERAGE=37;           (* Min. no months before decrease is OK        *)
      PASAGE=1;            (* Min. no months before decrease is OK        *)
      ARAAGE=24;           (* Min. no months before decrease is OK        *)
      NATAGE=1;            (* Min. no months before decrease is OK        *)
      ARASOICRI=40;        (* LU specific biophy feedback criteria        *)
      ARARELCRI=30;        (* LU specific biophy feedback criteria        *)
      PERRELCRI=40;        (* LU specific biophy feedback criteria        *)
      GRIDCRI=50;          (* Value criteria for urbanisation eff.        *)
```

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```
      CITYCRI=600;             (* Criteria for urbanisation centres      *)
      DISALTCRI=300;           (* Per < Alt. criteria will turn sick     *)
                               (* bananas below 300 m JB                 *)
      DISPERTIME=60;           (* Start of disease or pest of PER        *)
      DISPEREND=180;           (* End of disease or pest of PER          *)
      RANGE=2;                 (* Amount of grids disease spreads /yr    *)
      DISSPEED=2;              (* Range * speeds is disspeed/yr          *)
      DIPES=0.1;               (* Yield reduction due to disease/pest    *)

(*   END OF SCENARIO AND TUNING CONSTANTS                                *)
(************************************************************************)
(******************BEGIN HEAP MEMORY DECLARATION*************************)

TYPE  LUarray = ^Luheme;              (* Declaration of arrays in the heap *)
      LUAGEarray = ^LUAGEheme;        (* Modification PC version 03/96     *)
      BParray = ^BPheme;
      BPDEarray = ^BPDEheme;
      POParray = ^POPheme;

      LUheme = ARRAY[XMIN..XMAX,YMIN..YMAX] OF
        RECORD
          PER: INTEGER;               (* Permanent crops                   *)
          PAS: INTEGER;               (* Pastures                          *)
          ARA: INTEGER;               (* Arable lands                      *)
          NAT: INTEGER;               (* natural vegetation                *)
          RES: INTEGER;               (* rest group                        *)
          LU:  INTEGER;               (* Local land use vars in CHANGE     *)
        END;

      LUAGEheme = ARRAY[XMIN..XMAX,YMIN..YMAX] OF
        RECORD
          PER: INTEGER;               (* Age Permanent crops               *)
          PAS: INTEGER;               (* Age Pastures                      *)
          ARA: INTEGER;               (* Age Arable lands                  *)
          NAT: INTEGER;               (* Age natural vegetation            *)
          LU:  INTEGER;               (* Local Age in CHANGE               *)
        END;

      BPheme = ARRAY[XMIN..XMAX,YMIN..YMAX] OF
        RECORD
          LAND: INTEGER;              (* land grids                        *)
          REGIO: INTEGER;             (* Three regions in CR               *)
          RESER: INTEGER;             (* Reserve grids                     *)
          ALT: INTEGER;               (* Altitude                          *)
          RELIEF: INTEGER;            (* Relief                            *)
          SOIL: INTEGER;              (* Soil drainage                     *)
        END;

      BPDEheme = ARRAY[XMIN..XMAX,YMIN..YMAX] OF
        RECOR
          DEPER: REAL;                (* biophy degradation PER            *)
          DEARA: REAL;                (* biophy degradation ARA            *)
          PERDI: REAL;                (* Disease or pest PER               *)
          DIPES: REAL;                (* Disease or pest general           *)
        END;

      POPheme = ARRAY[XMIN..XMAX,YMIN..YMAX] OF
        RECORD
          RUR: REAL;                  (* rural population                  *)
          URB: REAL;                  (* urban population                  *)
          RURGR: REAL;                (* growth rural pop                  *)
          URBGR: REAL;                (* growth urban pop                  *)
        END;
(************************************************************************)
(******************BEGIN VARIABLE DECLARATIONS***************************)
VAR
      LANDIN,                         (* Input file GIS                    *)
      TUSSEN,                         (* Table of total covers for year    *)
      REGIO,                          (* Regions in CR                     *)
```

```
        PERUIT,                       (* Permanent crop outputs            *)
        PASUIT,                       (* Pastures outputs                  *)
        NATUIT,                       (* Natural vegetation outputs        *)
        ARAUIT,                       (* Arable land outputs               *)
        RURUIT,                       (* Rural population output           *)
        URBUIT: TEXT;                 (* Urban population output           *)


      A,B,AMAX,BMAX,ATEL,BTEL,C,D,E,    (* loop counters                   *)
      AMIN,BMIN,                        (* Window counters to store the    *)
      PERAOLD,PERBOLD,PASAOLD,PASBOLD,  (*the last artificial region       *)
      ARAAOLD,ARABOLD,NATAOLD,NATBOLD,  (*used to allocate in CHANGE       *)
      TELLAND,LUTEL,VENSTER,            (* COUNTERS/VARS CHANGE PROCEDURES *)
      LUNEED,LUAG,TELLU,                (* COUNTERS/VARS CHANGE PROCEDURES *)
      PERTEL,PASTEL,ARATEL,NATTEL,
      OLD1PER,OLD1PAS,OLD1ARA,          (*Cover before 1st change ADEV/CHA *)
      OLD1NAT,COR1PER,COR1PAS,          (*Correction factors 1 in ADEV/CHA *)
      COR1ARA,COR1NAT,
      COR1LU,OLD1LU,
      PERNEED,PASNEED,ARANEED,
      NATNEED,                          (* LAND USE NEED IN % (0.04 GRIDS) *)
        INPER,UITPER,                   (* In- outputs permanent crops     *)
        INPAS,UITPAS,                   (* In- and output pastures         *)
        INARA,UITARA,                   (* In- and output arable land      *)
        INNAT,UITNAT,                   (* In- and output natural vegetation *)
        FAMTEL,CHANGENO,                (* dummy PROCEDURE CRNEED          *)
        UPDATE,                         (* output variable                 *)
        MINTIME,                        (* land use history counter        *)
        RURAF,URBBIJ,URBTELL,           (* Population changes due to feedb *)
        GRIDTOT,
        X,                              (* X-axis in grid units            *)
        Y:INTEGER;                      (* Y-axis in grid units            *)

    ARACONSTI,ARAAGCONSTI,              (* Local regression const. in CLUE *)
    PASCONSTI,PASAGCONSTI,              (* Local regression const. in CLUE *)
    PERCONSTI,PERAGCONSTI,              (* Local regression const. in CLUE *)
    NATCONSTI,NATAGCONSTI,              (* Local regression const. in CLUE *)
    LUAGREG,LUDIF,LUTELR,               (* COUNTERS/VARS CHANGE procedures *)
    URBTELR,RURTELR,RELTELR,            (* COUNTERS/VARS CHANGE procedures *)
    SOITELR,ALTTELR,                    (* COUNTERS/VARS CHANGE procedures *)
    URBTEL,RURTEL,RELTEL,ALTTEL,        (* COUNTERS/VARS CHANGE PROCEDURES *)
    SOITEL,SUMLU,
    LUREG,CHLU,LUAGE,                   (* change age variables CHANGE     *)
    PERREG,PASREG,ARAREG,NATREG,        (* Regression values lu at 0.04 grd *)
    LUCONST,LUURB,LURUR,LUALT,          (* Regression Beta's at 0.04 grd   *)
    LURELIEF,LUSOIL,                    (* Regression Beta's at 0.04 grd   *)
    LUAGCONST,LUAGURB,LUAGRUR,          (* Regression Beta's aggreg. grids *)
    LUAGALT,LUAGRELIEF,LUAGSOIL,        (* Regression Beta's aggreg. grids *)
    URBTOT,RURTOT,PERTOT,PASTOT,        (* Total amount of population and  *)
    URBTOTOLD,ARATOT,NATTOT,RESTOT,     (* land use/cover for Costa Rica   *)
    PERTOTDP,ARATOTD,                   (* Total amounts with deper and perdi*)
    PERTOT1,PASTOT1,ARATOT1,REST1,      (* In- and output VARS subregions  *)
    NATTOT1,PERTOT2,REST2,PASTOT2,
    ARATOT2,NATTOT2,PERTOT3,PASTOT3,
    ARATOT3,REST3, NATTOT3,           (* In- and output VARS subregions    *)
    OLDPOP,POPULATION,VALTOT,         (* Total population, yield factor CRNEED *)
    CH,BIOPHY,TOTVALUE,VALUE,         (* biophysical fluctuation, yield factors*)
    OLDNEED,FOODNEED,                 (* The demand past and present for food *)
    FOODRESERVE,                      (* Reserves of over production in CRNEED *)
    TECHNOLEVEL,FOODAVAIL,            (* The population dependent technology *)
    RESERVENIL,                       (* Food reserves counters stored for two *)
    RESERVEONE, RESERVETWO,           (* years in CRNEED                   *)
    MANAGEMENT,FOODVALOLD,            (* Population related management improved*)
    GRIDLU,                           (* Total weight factor dummy CRNEED  *)
    YIELDFLUCT,                       (* biophysical yield fluctuations    *)
    UITRUR,UITURB,                    (* Output of POPULATION              *)
    RUIT1,RUIT2,RUIT3,RUIT4,RUIT5,
    RUIT6,RUIT7,RUIT8,                (* Output/test variables 03/96       *)
    PI :REAL;                         (* phi 3.14...                       *)
```

```
 PERCHANGE,PASCHANGE,          (* indicator vars of which lu is changed     *)
 ARACHANGE,NATCHANGE,          (* indicator vars of which lu is changed     *)
 FAMINE:BOOLEAN;               (* true if the available food is insufficient*)


CRLU : Luarray;                (* To assign the array records to the heap   *)
CRLUAGE : LUAGEarray;          (* Modification PC version 03/96             *)
CRBP : BParray;
CRBPDE : BPDEarray;
CRPOP : POParray;

(***********END VARIABLE DECLARATIONS*************************************)
(************************************************************************)
```

Appendix I-4

Appendix II: Listing of the MAIN programme

```
(*************BEGIN MAIN PROGRAMME*****************************************)
(*  CLUECR (Costa Rica)                                                    *)
(*  Begin main programme                                                   *)
(**************************************************************************)
(*************BEGIN INITIALIZATION****************************************)
(*  Old and new files are opened. COSTGISI.DAT data are loaded             *)
(*  into the memory as array of records                                    *)
(*                                                                         *)
(*  several local and global variables are given initial values.           *)
(**************************************************************************)
(*                               MAIN PROGRAM                              *)
BEGIN  (* CLUECR *)

  VERSION := 12;
  BEGINSCREEN;
  MEMDECLAR1;
  TIMEINI;
  TIMER1;
  GetMem(CRLU,SizeOf(LUheme));
  GetMem(CRLUAGE,SizeOf(LUAGEheme));
  GetMem(CRBP,SizeOf(BPheme));
  GetMem(CRBPDE,SizeOf(BPDEheme));
  GetMem(CRPOP,SizeOf(POPheme));
  MEMDECLAR2;

  ASSIGN(LANDIN,'COSTGISIN.DAT');
  RESET(LANDIN);
  ASSIGN(REGIO,'CRREGIO.DAT');
  RESET(REGIO);
  ASSIGN(PERUIT,'PERUIT.IMG');
  REWRITE(PERUIT);
  ASSIGN(PASUIT,'PASUIT.IMG');
  REWRITE(PASUIT);
  ASSIGN(ARAUIT,'ARAUIT.IMG');
  REWRITE(ARAUIT);
  ASSIGN(NATUIT,'NATUIT.IMG');
  REWRITE(NATUIT);
  ASSIGN(RURUIT,'RURUIT.IMG');
  REWRITE(RURUIT);
  ASSIGN(URBUIT,'URBUIT.IMG');
  REWRITE(URBUIT);
  ASSIGN(TUSSEN,'CRCOVERS.TAB');
  REWRITE(TUSSEN);
  FOR Y := YMIN TO YMAX DO
  BEGIN
    FOR X := XMIN TO XMAX DO
    BEGIN
       READ(LANDIN,CRBP^[X,Y].LAND);
       READ(LANDIN,CRBP^[X,Y].RESER);
       READ(LANDIN,CRBP^[X,Y].RELIEF);
       READ(LANDIN,CRBP^[X,Y].SOIL);
       READ(LANDIN,CRBP^[X,Y].ALT);
       READ(LANDIN,CRLU^[X,Y].PER);
       READ(LANDIN,CRLU^[X,Y].PAS);
       READ(LANDIN,CRLU^[X,Y].ARA);
       READ(LANDIN,CRLU^[X,Y].NAT);
       READ(LANDIN,CRLU^[X,Y].RES);
       READ(LANDIN,CRPOP^[X,Y].RUR);
       READ(LANDIN,CRPOP^[X,Y].URB);
       READ(LANDIN,CRPOP^[X,Y].RURGR);
       READ(LANDIN,CRPOP^[X,Y].URBGR);
       READLN(LANDIN);
       CRLU^[X,Y].LU := 0;
       CRLUAGE^[X,Y].PER := 50;
       CRLUAGE^[X,Y].PAS := 50;
       CRLUAGE^[X,Y].ARA := 50;
       CRLUAGE^[X,Y].NAT := 50;
       CRLUAGE^[X,Y].LU := 0;
       CRBPDE^[X,Y].DEPER := 1;
       CRBPDE^[X,Y].DEARA := 1;
       CRBPDE^[X,Y].PERDI := 1;
       CRBPDE^[X,Y].DIPES := 1;
    END;
  END;
  FOR Y := YMIN TO YMAX DO
  BEGIN
    FOR X := XMIN TO XMAX DO
    BEGIN
       READLN(REGIO,CRBP^[X,Y].REGIO);
    END;
  END;

TIJD := TMIN;
  UPDATE := TMIN;
  OLDPOP := 0; POPULATION := 0;
  PERNEED := 10;
  PASNEED := 10;
  ARANEED := 10;
  NATNEED := 10;
  NATCHANGE := FALSE;
  ARACHANGE := FALSE;
  PASCHANGE := FALSE;
  PERCHANGE := FALSE;
  OUTPUT;
  WRITELN(TUSSEN,'CLUECR PCversie ',VERSION:3);
  WRITELN(TUSSEN);
  PARAMETERS;
  CRNEED;
(****************END INITIALIZATION****************************************)

(****************BEGIN CLUE************************************************)
(*  The REPEAT ....  UNTILL loop is the actual time loop of CLUE 1.0       *)
(*  during this loop all procedures are called and used. After each        *)
(*  update interval the land use and land use ages are stored in output    *)
(*  files.                                                                 *)
(**************************************************************************)
  REPEAT
(* update step within the repeat untill loop of CLUE                       *)
    TIJD:= TIJD +1;
    FOR Y := YMIN TO YMAX DO
    BEGIN
      FOR X := XMIN TO XMAX DO
       BEGIN
        IF (CRBP^[X,Y].LAND=1) THEN
        BEGIN                                   (* Land use ages each step  *)
          CRLUAGE^[X,Y].PER := CRLUAGE^[X,Y].PER + 1;
          CRLUAGE^[X,Y].PAS := CRLUAGE^[X,Y].PAS + 1;
          CRLUAGE^[X,Y].ARA := CRLUAGE^[X,Y].ARA + 1;
          CRLUAGE^[X,Y].NAT := CRLUAGE^[X,Y].NAT + 1;
        END;
       END;
    END;

    ARACONSTI := ARACONST + (DARA*TIJD);
    ARAAGCONSTI := ARAAGCONST + (DARAAG* TIJD);
    PASCONSTI := PASCONST + (DPAS*TIJD);
    PASAGCONSTI := PASAGCONST + (DPASAG* TIJD);
    PERCONSTI := PERCONST + (DPER*TIJD);
```

Appendix II-2

```
PERAGCONSTI := PERAGCONST + (DPERAG* TIJD);
NATCONSTI := NATCONST + (DNAT*TIJD);
NATAGCONSTI := NATAGCONST + (DNATAG* TIJD);
IF UPDATE = UPDATETIME THEN
BEGIN
   UPDATE := 0;
   POPGROWTH;
   CRNEED;
   IF ARANEED > ARACONSTI THEN
   BEGIN
     ARACHANGE := TRUE;
     LUNEED := ARANEED; LUCONST := ARACONSTI; LUURB := ARAURB;
     LURUR := ARARUR; LUALT := ARAALT; LURELIEF := ARARELIEF;
     LUSOIL := ARASOIL; LUAG := ARAAG; LUAGCONST := ARAAGCONSTI;
     LUAGURB := ARAAGURB; LUAGRUR := ARAAGRUR; LUAGALT := ARAAGALT;
     LUAGRELIEF := ARAAGRELIEF; LUAGSOIL := ARAAGSOIL; LUAGE := ARAAGE;
     CHANGE;
     ARACHANGE := FALSE;
   END;
   IF PASNEED > PASCONSTI THEN
   BEGIN
     PASCHANGE := TRUE;
     LUNEED := PASNEED; LUCONST := PASCONSTI; LUURB := PASURB;
     LURUR := PASRUR; LUALT := PASALT; LURELIEF := PASRELIEF;
     LUSOIL := PASSOIL; LUAG := PASAG; LUAGCONST := PASAGCONSTI;
     LUAGURB := PASAGURB; LUAGRUR := PASAGRUR; LUAGALT := PASAGALT;
     LUAGRELIEF := PASAGRELIEF; LUAGSOIL := PASAGSOIL; LUAGE := PASAGE;
     CHANGE;
     PASCHANGE := FALSE;
   END;
   IF PERNEED > PERCONSTI THEN
   BEGIN
     PERCHANGE := TRUE;
     LUNEED := PERNEED; LUCONST := PERCONSTI; LUURB := PERURB;
     LURUR := PERRUR; LUALT := PERALT; LURELIEF := PERRELIEF;
     LUSOIL := PERSOIL; LUAG := PERAG; LUAGCONST := PERAGCONSTI;
     LUAGURB := PERAGURB; LUAGRUR := PERAGRUR; LUAGALT := PERAGALT;
     LUAGRELIEF := PERAGRELIEF; LUAGSOIL := PERAGSOIL; LUAGE := PERAGE;
     CHANGE;
     PERCHANGE := FALSE;
   END;
   IF NATNEED > NATCONSTI THEN
   BEGIN
     NATCHANGE := TRUE;
     LUNEED := NATNEED; LUCONST := NATCONSTI; LUURB := NATURB;
     LURUR := NATRUR; LUALT := NATALT; LURELIEF := NATRELIEF;
     LUSOIL := NATSOIL; LUAG := NATAG; LUAGCONST := NATAGCONSTI;
     LUAGURB := NATAGURB; LUAGRUR := NATAGRUR; LUAGALT := NATAGALT;
     LUAGRELIEF := NATAGRELIEF; LUAGSOIL := NATAGSOIL; LUAGE := NATAGE;
     CHANGE;
     NATCHANGE := FALSE;
   END;
   AUTODEV;
   IF PHEEDBIO = TRUE THEN
   BEGIN
     BIOPHEED;
   END;


   IF PESTDIS = TRUE THEN
   BEGIN
     DISPEST;
   END;
   TUSSENDOOR;           (* Give update information on the user screen *)
   IF TIJD = UITTIJD THEN  (* Process GIS outpute files               *)
   BEGIN
     FOR Y := YMIN TO YMAX DO
     BEGIN
       FOR X := XMIN TO XMAX DO
         BEGIN       (* The sea is 0 the land grids at least 10          *)
                     (* maximum 110 except for the population which      *)
                     (* are given in real densities from 10 to           *)
                     (* maximum density                                  *)
           UITPER := CRLU^[X,Y].PER+CRBP^[X,Y].LAND*10;
           WRITELN(PERUIT,UITPER:5);
           UITPAS := CRLU^[X,Y].PAS+CRBP^[X,Y].LAND*10;
           WRITELN(PASUIT,UITPAS:5);
           UITARA := CRLU^[X,Y].ARA+CRBP^[X,Y].LAND*10;
           WRITELN(ARAUIT,UITARA:5);
           UITNAT := CRLU^[X,Y].NAT+CRBP^[X,Y].LAND*10;
           WRITELN(NATUIT,UITNAT:5);
           UITRUR := ROUND(CRPOP^[X,Y].RUR+CRBP^[X,Y].LAND*10);
           WRITELN(RURUIT,UITRUR:7);
           UITURB := ROUND(CRPOP^[X,Y].URB+CRBP^[X,Y].LAND*10);
           WRITELN(URBUIT,UITURB:7);
         END;
       END;
     END;
   END;
   UPDATE:= UPDATE+1;
 UNTIL (TIJD = TMAX);
(*****************END TIME LOOP CLUE**************************************)

 FreeMem(CRLU,SizeOf(LUheme));
 FreeMem(CRLUAGE,SizeOf(LUAGEheme));
 FreeMem(CRBP,SizeOf(BPheme));
 FreeMem(CRBPDE,SizeOf(BPDEheme));
 FreeMem(CRPOP,SizeOf(POPheme));
 MEMDECLAR3;
 INFORMATION;
 CLOSE(LANDIN);
 CLOSE(REGIO);
 CLOSE(TUSSEN);
 CLOSE(PERUIT);
 CLOSE(PASUIT);
 CLOSE(ARAUIT);
 CLOSE(NATUIT);
 CLOSE(RURUIT);
 CLOSE(URBUIT);
 TIMER2;
 FINISHED;
 BEDANK;
END. (* CLUECR *)
(*************************************************************************)
```

Appendix III: Listing of the POPGROWTH procedure

```
(****************************************************************************)
(* Procedure POPGROWTH                                                     *)
(* Calculating the growth in both urban and rural population densities     *)
(* with the growth rates from 1973 to 1984, liniair interpolation          *)
(****************************************************************************)
PROCEDURE POPGROWTH;
BEGIN (* PROCEDURE POPGROWTH v1.2*)
URBBIJ := 0; URBTELL := 0;
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN
       CRPOP^[X,Y].RUR := (CRPOP^[X,Y].RUR + (CRPOP^[X,Y].RURGR/11));
       CRPOP^[X,Y].URB := (CRPOP^[X,Y].URB + (CRPOP^[X,Y].URBGR/11));
                                (* to stop negative growth for empty areas  *)
       IF CRPOP^[X,Y].RUR < 0 THEN CRPOP^[X,Y].RUR := 0;
       IF CRPOP^[X,Y].URB < 0 THEN CRPOP^[X,Y].URB := 0;
    END;
  END;
END;                                            (* PROCEDURE POPGROWTH v170*)
(****************************************************************************)
```

Appendix III-2

Appendix IV: Listing of the CRNEED procedure

```
(***********************************************************************)
(* Procedure CRNEED                                                    *)
(* CRNEED calculates the total land use/cover need within Costa Rica.  *)
(* All extensions and their relative values are counted and compared   *)
(* with changes in population composition and densities. It is assumed *)
(* that there is a king of equilibrium between population and land use *)
(* Furthermore a fluctuation in land use values in included to simulate *)
(* good and bad years due to biophysical conditions                    *)
(* Social requirements such as the extra need for pasture due to the   *)
(* status symbol function of cattle in rural areas are included as well *)
(****************************************************************** *****)
PROCEDURE CRNEED;
BEGIN                                    (* PROCEDURE CRNEED          *)
URBTOTOLD := URBTOT;                     (* The total urban population *)
IF URBTOTOLD <= 0 THEN URBTOTOLD := 30275;  (* is stored from last year  *)
URBTOT := 0;                             (* TOT to count the totals   *)
RURTOT := 0;
PERTOT := 0;
PASTOT := 0;
ARATOT := 0;
NATTOT := 0;
RESTOT := 0;
BIOPHY := 0;
TOTVALUE := 0;
                        (* annual fluctuations in biophysical conditions *)
PI := 4*ARCTAN(1);      (* FREQuencies are scenario inputs             *)
YIELDFLUCT := 0.05 * ((SIN(2*PI*TIJD/FREQ1)) + (SIN(2*PI*TIJD/FREQ2)) +
                      (SIN(2*PI*TIJD/FREQ3)));
  FOR X := XMIN TO XMAX DO
  BEGIN                                  (* XY-loop to select all  *)
    FOR Y := YMIN TO YMAX DO             (* grid cells separately  *)
    BEGIN                           (* Biophysical feedback calculated *)
      BIOPHY := YIELDFLUCT +((CRBP^[X,Y].RELIEF+CRBP^[X,Y].SOIL)/150);
      IF (CRBP^[X,Y].ALT > 2500) THEN BIOPHY := BIOPHY/2;
      RURTOT := RURTOT + CRPOP^[X,Y].RUR;   (* Counting totals covers and *)
      URBTOT := URBTOT + CRPOP^[X,Y].URB;   (* population                 *)
      PERTOT := PERTOT + CRLU^[X,Y].PER;
      PASTOT := PASTOT + CRLU^[X,Y].PAS;
      ARATOT := ARATOT + CRLU^[X,Y].ARA;
      NATTOT := NATTOT + CRLU^[X,Y].NAT;
      RESTOT := RESTOT + CRLU^[X,Y].RES;
                                        (* select only valid grids    *)
      IF ((CRBP^[X,Y].LAND > 0) AND (CRBP^[X,Y].RESER < 1)) THEN
      BEGIN                          (* Modification PC version 03/96 *)
            (* Management factor is a function of rur/urb population  *)
        IF (CRPOP^[X,Y].RUR + CRPOP^[X,Y].URB <=0) THEN
        BEGIN
          MANAGEMENT := 1
        END
        ELSE
        BEGIN
         MANAGEMENT := 2*CRPOP^[X,Y].RUR/(CRPOP^[X,Y].RUR + CRPOP^[X,Y].URB)
        END;
        IF MANAGEMENT < 1 THEN MANAGEMENT := 1;
        IF MANAGEMENT > 2 THEN MANAGEMENT := 2;
           (* Regional technology level grows in time with population *)
        TECHNOLEVEL := CRPOP^[X,Y].URB/(URBTOTOLD/913);
                                     (* Modification PC version 03/96 *)
        IF TECHNOLEVEL < 1 THEN TECHNOLEVEL := 1;
        IF TECHNOLEVEL > 2 THEN TECHNOLEVEL := 2;
        IF PESTDIS = TRUE THEN GRIDLU := (CRLU^[X,Y].PER*CRBPDE^[X,Y].DIPES*
             PERVAL + CRLU^[X,Y].PAS*PASVAL + CRLU^[X,Y].ARA*ARAVAL +
             CRLU^[X,Y].NAT*NATVAL + CRLU^[X,Y].RES*RESVAL);
        IF RECOVERY = TRUE THEN GRIDLU := (CRLU^[X,Y].PER*PERVAL +
             CRLU^[X,Y].PAS*PASVAL + CRLU^[X,Y].ARA*ARAVAL +
             CRLU^[X,Y].NAT*NATVAL + CRLU^[X,Y].RES*RESVAL);
           (* The yield for all covers together for one single grid cell *)
        VALUE := BIOPHY*MANAGEMENT*TECHNOLEVEL*GRIDLU;
           (* The yield counter to calculate the total for all grids     *)
        TOTVALUE := TOTVALUE + VALUE;
      END;
    END;
  END;
           (* Loop to file the cover data in the table file CRCOVERS.TAB *)
                                  (* Reset the regional totals counters *)
PERTOT1:=0; PASTOT1:=0; ARATOT1:=0; NATTOT1:=0; REST1:=0;    (* HUMID HOT  *)
PERTOT2:=0; PASTOT2:=0; ARATOT2:=0; NATTOT2:=0; REST2:=0;    (* DRY HOT    *)
PERTOT3:=0; PASTOT3:=0; ARATOT3:=0; NATTOT3:=0; REST3:=0;    (* HUMID COOL *)
RUIT1:=0; RUIT2:=0; RUIT3:=0; RUIT4:=0; RUIT5:=0; RUIT6:=0;  (* counters   *)
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN
      IF (CRBP^[X,Y].REGIO = 1) THEN
      BEGIN
        PERTOT1 := PERTOT1 + CRLU^[X,Y].PER;
        PASTOT1 := PASTOT1 + CRLU^[X,Y].PAS;
        ARATOT1 := ARATOT1 + CRLU^[X,Y].ARA;
        NATTOT1 := NATTOT1 + CRLU^[X,Y].NAT;
        REST1 := REST1 + CRLU^[X,Y].RES;
      END;
      IF (CRBP^[X,Y].REGIO = 2) THEN
      BEGIN
        PERTOT2 := PERTOT2 + CRLU^[X,Y].PER;
        PASTOT2 := PASTOT2 + CRLU^[X,Y].PAS;
        ARATOT2 := ARATOT2 + CRLU^[X,Y].ARA;
        NATTOT2 := NATTOT2 + CRLU^[X,Y].NAT;
        REST2 := REST2 + CRLU^[X,Y].RES;
      END;
      IF (CRBP^[X,Y].REGIO = 3) THEN
      BEGIN
        PERTOT3 := PERTOT3 + CRLU^[X,Y].PER;
        PASTOT3 := PASTOT3 + CRLU^[X,Y].PAS;
        ARATOT3 := ARATOT3 + CRLU^[X,Y].ARA;
        NATTOT3 := NATTOT3 + CRLU^[X,Y].NAT;
        REST3 := REST3 + CRLU^[X,Y].RES;
      END;
    END;
  END;
RUIT1 := PERTOT1 + PASTOT1 + ARATOT1 + NATTOT1 + REST1;    (* Totals of all*)
RUIT2 := PERTOT2 + PASTOT2 + ARATOT2 + NATTOT2 + REST2;
RUIT3 := PERTOT3 + PASTOT3 + ARATOT3 + NATTOT3 + REST3;
RUIT4 := PERTOT + PASTOT + ARATOT + NATTOT + RESTOT;
YEAR := TRUNC(((TIJD-1)/12)+1973);
WRITELN(TUSSEN);
WRITELN(TUSSEN,'TIME:',TIJD:7,' YEAR: ',YEAR:7);
WRITELN(TUSSEN,'PERTOT1-3  ','PASTOT1-3  ','ARATOT1-3  ','NATTOT1-3  ',
              'RESTTOT1-3  ','TOTALS      ');
WRITELN(TUSSEN,PERTOT1:6:2,'     ',PASTOT1:6:2,'     ',ARATOT1:6:2,'     ',
              NATTOT1:6:2,'     ',REST1:6:2,'     ',RUIT1:6:2);
WRITELN(TUSSEN,PERTOT2:6:2,'     ',PASTOT2:6:2,'     ',ARATOT2:6:2,'     ',
              NATTOT2:6:2,'     ',REST2:6:2,'     ',RUIT2:6:2);
WRITELN(TUSSEN,PERTOT3:6:2,'     ',PASTOT3:6:2,'     ',ARATOT3:6:2,'     ',
              NATTOT3:6:2,'     ',REST3:6:2,'     ',RUIT3:6:2);
WRITELN(TUSSEN,PERTOT:6:2,' T  ',PASTOT:6:2,' T  ',ARATOT:6:2,' T  ',
              NATTOT:6:2,' T  ',RESTOT:6:2,' T  ',RUIT4:6:2);
      (* Pasture is function rural population due to status symbol cattle *)
  IF PASTOT/RURTOT < 1 THEN PASNEED := PASNEED + TRUNC(RURTOT/PASTOT);
```

Appendix IV-2

```
                  (* Food requirements of the population are determined *)
OLDPOP := POPULATION;
OLDNEED := FOODNEED;
FOODAVAIL := TOTVALUE;
POPULATION := TRUNC(RURTOT + URBTOT);
IF (OLDNEED > 0) THEN FOODNEED := OLDNEED+((OLDPOP/OLDNEED)*(POPULATION-
                                                                OLDPOP));
IF (OLDNEED = 0) THEN FOODNEED := FOODAVAIL;
                 (* Food surpluses are stored as reserves for two years  *)
IF (FOODNEED - FOODAVAIL) <= 0 THEN
BEGIN
  FAMTEL := 0;
  RESERVETWO := RESERVEONE;
  RESERVEONE := RESERVENIL;
  RESERVENIL := FOODNEED - FOODAVAIL;
  FOODRESERVE := RESERVENIL + RESERVEONE + RESERVETWO;
END;
               (* If food production of simulated year are insufficient  *)
               (* food reserves are used                                 *)
IF (FOODNEED - FOODAVAIL) > 0 THEN
BEGIN
  RESERVETWO := RESERVEONE;
  RESERVEONE := RESERVENIL;
  RESERVENIL := 0;
  FOODRESERVE := RESERVENIL + RESERVEONE + RESERVETWO;
END;
        (* After three poor years, when the yields could not feed the    *)
        (* regional population a famine condition/state exists           *)
IF FAMTEL > 3 THEN FAMINE := TRUE;
IF (FOODNEED - (FOODAVAIL + FOODRESERVE)) > 0 THEN
BEGIN
  FAMTEL := FAMTEL + 1;
  RESERVENIL := 0;
  RESERVEONE := 0;
  RESERVETWO := 0;
  CHANGENO := TRUNC((FOODNEED - (FOODAVAIL + FOODRESERVE))/GRIDFAC);
  IF RECOVERY = TRUE THEN VALTOT := PERVAL+PASVAL+ARAVAL+NATVAL;
  IF PESTDIS = TRUE THEN VALTOT := TRUNC(0.1*PERVAL)+PASVAL+ARAVAL+NATVAL;
  PERNEED := PERNEED + TRUNC((CHANGENO/VALTOT)*PERVAL);
  PASNEED := PASNEED + TRUNC((CHANGENO/VALTOT)*PASVAL);
  ARANEED := ARANEED + TRUNC((CHANGENO/VALTOT)*ARAVAL);
  NATNEED := NATNEED + TRUNC((CHANGENO/VALTOT)*NATVAL);
END;
WRITELN(TUSSEN,'CRNEED PER PAS ARA NAT NEED:', PERNEED:7, PASNEED:7,
                                                  ARANEED:7,NATNEED:7);

END;                                               (* PROCEDURE CRNEED*)
(****************************************************************************)
```

Appendix V: Listing of the CHANGE procedure

```
(***********************************************************************)
(* Procedure CHANGE                                                   *)
(* CHANGE changes land use/covers as a function of national demands   *)
(* these land use needs (LUNEED) are fullfilled in those regions (aggre *)
(* gated 0.04o grids) where most changes are required. The region size is *)
(* land use/cover dependent and is determined bij regression models.  *)
(* The actual changes and their evaluations are done within the selec  *)
(* ted regions at the 0.04o grid level.                               *)
(***********************************************************************)
PROCEDURE CHANGE;
LABEL 999;
BEGIN (* PROCEDURE CHANGE v 1.2*)
  VENSTER := LUAG;          (* The cover specific artificial region size *)
  CHLU := UPDATETIME/(2*TMEASURE);
  IF (LUNEED <= LUCONST+1) THEN GOTO 999; (* Not enough need exit directly *)
      (* To get the selected windows more used through the whole country  *)
      (* After CHANGE is stopped the artificial region for each cover is  *)
      (* saved to use it the next update step                              *)
  AMAX := TRUNC(XMAX/VENSTER); AMIN := XMIN;
  BMAX := TRUNC(YMAX/VENSTER); BMIN := YMIN;
  IF PERCHANGE THEN BEGIN A:=PERAOLD-1; B:=PERBOLD-1; END;
  IF PASCHANGE THEN BEGIN A:=PASAOLD-1; B:=PASBOLD-1; END;
  IF ARACHANGE THEN BEGIN A:=ARAAOLD-1; B:=ARABOLD-1; END;
  IF NATCHANGE THEN BEGIN A:=NATAOLD-1; B:=NATBOLD-1; END;
  IF (A<1) OR (A>AMAX) THEN A := AMAX;
  IF (B<1) OR (B>BMAX) THEN B := BMAX;
  ATEL := 0; BTEL := 0;
  REPEAT           (* Repeat for all regions untill the NEED is finished *)
                   (* Set the moving windows                           *)
    IF ((BTEL = BMAX) AND (ATEL < AMAX)) THEN ATEL := ATEL + 1;
    IF (BTEL < BMAX) THEN BTEL := BTEL + 1;
                    (* Set the regional mmean drivers counters          *)
    TELLAND := 0; URBTEL:=0; RURTEL:=0; RELTEL:=0; ALTTEL:=0; SOITEL:=0;
    LUTEL := 0;
             (* Regions loop untill all regions done or NEED is finished *)
    FOR X := (A*VENSTER) DOWNTO ((A*VENSTER-VENSTER+1)) DO
    BEGIN
       FOR Y :=(B*VENSTER) DOWNTO ((B*VENSTER-VENSTER+1)) DO
       BEGIN
         IF PERCHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].PER;
         IF PASCHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].PAS;
         IF ARACHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].ARA;
         IF NATCHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].NAT;
         IF CRBP^[X,Y].LAND = 1 THEN
         BEGIN
           TELLAND := TELLAND + 1;  (* counting number of valid land grids *)
           LUTEL := LUTEL + CRLU^[X,Y].LU;          (* couting the drivers *)
           URBTEL := URBTEL + CRPOP^[X,Y].URB;
           RURTEL := RURTEL + CRPOP^[X,Y].RUR;
           ALTTEL := ALTTEL + CRBP^[X,Y].ALT;
           RELTEL := RELTEL + CRBP^[X,Y].RELIEF;
           SOITEL := SOITEL + CRBP^[X,Y].SOIL;
         END;
         IF CRBP^[X,Y].LAND = 0 THEN
         BEGIN
           TELLAND := TELLAND + 0;
           LUTEL := LUTEL + 0;
           URBTEL := URBTEL + 0;
           RURTEL := RURTEL + 0;
           ALTTEL := ALTTEL + 0;
           RELTEL := RELTEL + 0;
           SOITEL := SOITEL + 0;
         END;
       END;
    END;
    IF TELLAND < TRUNC(VENSTER*VENSTER/2) THEN
    BEGIN
      TELLAND:=0; URBTEL:=0; RURTEL:=0; RELTEL:=0; ALTTEL:=0;
      SOITEL:=0; LUTEL:=0;
    END;
         (* When the region is valid the regression model is processed  *)
    IF TELLAND >= TRUNC(VENSTER*VENSTER/2) THEN
    BEGIN
      LUTELR := LUTEL/TELLAND;
      URBTELR := URBTEL/TELLAND;
      RURTELR := RURTEL/TELLAND;
      ALTTELR := ALTTEL/TELLAND;
      RELTELR := RELTEL/TELLAND;
      SOITELR := SOITEL/TELLAND;
      TELLAND:=0; URBTEL:=0; RURTEL:=0; RELTEL:=0; ALTTEL:=0;
      SOITEL:=0; LUTEL:=0;                          (* Regression model *)
      LUAGREG := (LUAGCONST + LUAGURB*URBTELR + LUAGRUR*RURTELR +
             LUAGALT*ALTTELR + LUAGRELIEF*RELTELR + LUAGSOIL*SOITELR);
      LUDIF := ABS(ABS(TRUNC(LUTELR)) - ABS(TRUNC(LUAGREG)));
      IF LUDIF > TRUNC(LUAGCONST/4) THEN
      BEGIN
(* If the regresssion model is valid the change for new cover is made     *)
(* on the local grid level                                                 *)
        FOR X := (A*VENSTER) DOWNTO ((A*VENSTER-VENSTER+1)) DO
        BEGIN
          FOR Y :=(B*VENSTER) DOWNTO ((B*VENSTER-VENSTER+1)) DO
          BEGIN
            IF PERCHANGE AND (CRBPDE^[X,Y].PERDI=1) THEN
                                        CRLU^[X,Y].LU := CRLU^[X,Y].PER;
            IF PASCHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].PAS;
            IF ARACHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].ARA;
            IF NATCHANGE THEN CRLU^[X,Y].LU := CRLU^[X,Y].NAT;
            IF PERCHANGE AND (CRBPDE^[X,Y].PERDI=1) THEN
                                  CRLUAGE^[X,Y].LU := CRLUAGE^[X,Y].PER;
            IF PASCHANGE THEN CRLUAGE^[X,Y].LU := CRLUAGE^[X,Y].PAS;
            IF ARACHANGE THEN CRLUAGE^[X,Y].LU := CRLUAGE^[X,Y].ARA;
            IF NATCHANGE THEN CRLUAGE^[X,Y].LU := CRLUAGE^[X,Y].NAT;
            IF ((CRBP^[X,Y].LAND=1) AND (CRBP^[X,Y].RESER <1))THEN
            BEGIN                  (* The IF statement selects the cover *)
             IF PERCHANGE AND (CRBPDE^[X,Y].PERDI=1) THEN LUREG :=
                 (((PERCONSTI + PERURB*CRPOP^[X,Y].URB +
                 PERRUR*CRPOP^[X,Y].RUR + PERALT*CRBP^[X,Y].ALT +
                 PERRELIEF*CRBP^[X,Y].RELIEF + PERSOIL*CRBP^[X,Y].SOIL)*
                 CRBPDE^[X,Y].DEPER) * CRBPDE^[X,Y].DIPES);
             IF PASCHANGE THEN LUREG := (PASCONSTI + PASURB*CRPOP^[X,Y].URB
                 + PASRUR*CRPOP^[X,Y].RUR + PASALT*CRBP^[X,Y].ALT +
                 PASRELIEF*CRBP^[X,Y].RELIEF + PASSOIL*CRBP^[X,Y].SOIL);
             IF ARACHANGE THEN LUREG := ((ARACONSTI +
                 ARAURB*CRPOP^[X,Y].URB + ARARUR*CRPOP^[X,Y].RUR +
                 ARAALT*CRBP^[X,Y].ALT + ARARELIEF*CRBP^[X,Y].RELIEF +
                 ARASOIL*CRBP^[X,Y].SOIL)*CRBPDE^[X,Y].DEARA);
             IF NATCHANGE THEN LUREG := (NATCONSTI + NATURB*CRPOP^[X,Y].URB
                 + NATRUR*CRPOP^[X,Y].RUR + NATALT*CRBP^[X,Y].ALT +
                 NATRELIEF*CRBP^[X,Y].RELIEF + NATSOIL*CRBP^[X,Y].SOIL);
             IF (CRLUAGE^[X,Y].LU < LUAGE) AND (LUREG < 0) THEN LUREG := 0;
             IF (LUNEED > LUCONST) THEN


(* Final allocation when all the criteria are met, the cover is adapted   *)
(* using the regression model cover, NEED is directly adapted.            *)
(* The procedure conitues untill the NEED is finished                     *)
                BEGIN
                  OLD1LU := CRLU^[X,Y].LU; COR1LU := 0;
```

```
                CRLU^[X,Y].LU := CRLU^[X,Y].LU + ROUND(CHLU*LUREG);
                IF CRLU^[X,Y].LU < 0 THEN CRLU^[X,Y].LU := 0;
                COR1LU := OLD1LU - CRLU^[X,Y].LU;
                LUNEED := LUNEED + COR1LU;
                IF PERCHANGE AND (CRBPDE^[X,Y].PERDI=1) THEN
                   CRLU^[X,Y].PER := CRLU^[X,Y].LU;
                IF PASCHANGE THEN CRLU^[X,Y].PAS := CRLU^[X,Y].LU;
                IF ARACHANGE THEN CRLU^[X,Y].ARA := CRLU^[X,Y].LU;
                IF NATCHANGE THEN CRLU^[X,Y].NAT := CRLU^[X,Y].LU;
                IF (LUNEED <= LUCONST + 1) THEN GOTO 999;
              END;
            END;
          END;
        END;
      END;
    END;
(* To change the window of the artificial aggregated region, the window    *)
(* moves from south east to north west, untill all windows are done        *)
    IF (BTEL < BMAX) THEN
    BEGIN
       IF (B = BMIN) THEN B := BMAX + 1;
       B:= B - 1;
    END;
    IF ((BTEL = BMAX) AND (ATEL < AMAX)) THEN
    BEGIN
       IF (A = AMIN) THEN A := AMAX + 1;
       A := A - 1;
    END;
  UNTIL (ATEL = AMAX);

  999:
  IF PERCHANGE AND (CRBPDE^[X,Y].PERDI=1) THEN PERNEED := LUNEED;
  IF PASCHANGE THEN PASNEED := LUNEED;
  IF ARACHANGE THEN ARANEED := LUNEED;
  IF NATCHANGE THEN NATNEED := LUNEED;
  IF PERCHANGE AND (CRBPDE^[X,Y].PERDI=1) THEN
                    BEGIN PERAOLD := A; PERBOLD := B; END;
  IF PASCHANGE THEN BEGIN PASAOLD := A; PASBOLD := B; END;
  IF ARACHANGE THEN BEGIN ARAAOLD := A; ARABOLD := B; END;
  IF NATCHANGE THEN BEGIN NATAOLD := A; NATBOLD := B; END;
END;                                              (* PROCEDURE CHANGE v 1.2*)
(****************************************************************************)
```

Appendix VI: Listing of the AUTODEV procedure

```
(***********************************************************************)
(* Procedure AUTODEV                                                   *)
(* AUTODEV simulates the autonomous land use development at the 0.04o  *)
(* grid level. It is thus the local land use/cover development without *)
(* direct effects of regional or national demands and wishes          *)
(***********************************************************************)
PROCEDURE AUTODEV;
BEGIN (* PROCEDURE AUTODEV v 1.2   *)
  PERTEL:=0; PASTEL:=0; ARATEL:=0; NATTEL:=0;
  CH := UPDATETIME/(2*TMEASURE);          (* Valid time domain regressions *)
  FOR Y := YMIN TO YMAX DO
  BEGIN                                   (* Directly operating on local level *)
    FOR X := XMIN TO XMAX DO
    BEGIN
      OLD1PER:=0; OLD1PAS:=0; OLD1ARA:=0; OLD1NAT:=0;
      OLD1PER := CRLU^[X,Y].PER; COR1PER := 0;     (* correction factors  *)
      OLD1PAS := CRLU^[X,Y].PAS; COR1PAS := 0;
      OLD1ARA := CRLU^[X,Y].ARA; COR1ARA := 0;
      OLD1NAT := CRLU^[X,Y].NAT; COR1NAT := 0;
(* Processing the local regression models for all covers taking into     *)
(* account the valid contraints and driving parameters                   *)
      PERREG := (PERCONSTI+PERURB*CRPOP^[X,Y].URB+PERRUR*CRPOP^[X,Y].RUR +
             PERALT*CRBP^[X,Y].ALT + PERRELIEF*CRBP^[X,Y].RELIEF +
             PERSOIL*CRBP^[X,Y].SOIL);
      PERREG := PERREG*CRBPDE^[X,Y].DEPER*CRBPDE^[X,Y].PERDI *
             CRBPDE^[X,Y].DIPES;
      PASREG := (PASCONSTI+PASURB*CRPOP^[X,Y].URB+PASRUR*CRPOP^[X,Y].RUR +
             PASALT*CRBP^[X,Y].ALT + PASRELIEF*CRBP^[X,Y].RELIEF +
             PASSOIL*CRBP^[X,Y].SOIL);
      ARAREG := (ARACONSTI+ARAURB*CRPOP^[X,Y].URB+ARARUR*CRPOP^[X,Y].RUR +
             ARAALT*CRBP^[X,Y].ALT + ARARELIEF*CRBP^[X,Y].RELIEF +
             ARASOIL*CRBP^[X,Y].SOIL);
      ARAREG := ARAREG * CRBPDE^[X,Y].DEARA;
      NATREG := (NATCONSTI+NATURB*CRPOP^[X,Y].URB+NATRUR*CRPOP^[X,Y].RUR +
             NATALT*CRBP^[X,Y].ALT + NATRELIEF*CRBP^[X,Y].RELIEF +
             NATSOIL*CRBP^[X,Y].SOIL);
(* The autonomous regresion modelled covers are evaluated taking into    *)
(* account the new covers resulting from the CHANGE procedure            *)
(* Only grids are processed outside Reserved parks and inside the        *)
(* Rican borders                                                         *)
      IF (CRBP^[X,Y].RESER <1) AND (CRBP^[X,Y].LAND=1) THEN
      BEGIN
        IF (CRBPDE^[X,Y].PERDI=1) THEN
        BEGIN
          CRLU^[X,Y].PER := CRLU^[X,Y].PER + ROUND(CRBPDE^[X,Y].DEPER *
             (CH*PERREG*CRBPDE^[X,Y].DEPER* (AUTPER * CRBPDE^[X,Y].DEPER /
               (1+CRLU^[X,Y].PER))));
        END;
        CRLU^[X,Y].PAS:=CRLU^[X,Y].PAS +
          ROUND(CH*PASREG*(AUTPAS/(1+CRLU^[X,Y].PAS)));
        CRLU^[X,Y].ARA:=CRLU^[X,Y].ARA +
          ROUND(CRBPDE^[X,Y].DEARA * (CH*CRBPDE^[X,Y].DEARA*ARAREG *
             (AUTARA*CRBPDE^[X,Y].DEARA/(5+CRLU^[X,Y].ARA))));
        CRLU^[X,Y].NAT := CRLU^[X,Y].NAT +
          ROUND(CH*NATREG*(AUTNAT/(5+CRLU^[X,Y].NAT)));
        (* To avoid too negative decline of land use*)
        IF CRLU^[X,Y].PER < 0 THEN CRLU^[X,Y].PER := 0;
        IF CRLU^[X,Y].PAS < 0 THEN CRLU^[X,Y].PAS := 0;
        IF CRLU^[X,Y].ARA < 0 THEN CRLU^[X,Y].ARA := 0;
        IF CRLU^[X,Y].NAT < 0 THEN CRLU^[X,Y].NAT := 0;
(* After the allocation of the new land uses the total cover for the     *)
(* grid cells have to be 100 percent again. To evaluate the change       *)
(* some decision reules are included                                     *)
        TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
        IF (TELLU <> (100-CRLU^[X,Y].RES)) THEN
        BEGIN
          CRLU^[X,Y].PER := ROUND((CRLU^[X,Y].PER/TELLU)*
             (100-CRLU^[X,Y].RES));
          CRLU^[X,Y].PAS := ROUND((CRLU^[X,Y].PAS/TELLU)*
             (100-CRLU^[X,Y].RES));
          CRLU^[X,Y].ARA := ROUND((CRLU^[X,Y].ARA/TELLU)*
             (100-CRLU^[X,Y].RES));
          CRLU^[X,Y].NAT := ROUND((CRLU^[X,Y].NAT/TELLU)*
             (100-CRLU^[X,Y].RES));
        END;
(* The result of the above means evaluation gives normaly rest covers         *)
(* evaluation and Correction for land use more then 100 percent               *)
        TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
        IF (TELLU > (100-CRLU^[X,Y].RES)) THEN
        BEGIN
          IF (CRLU^[X,Y].NAT > 0) THEN
          BEGIN
            CRLU^[X,Y].NAT := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].ARA +
              CRLU^[X,Y].PAS + CRLU^[X,Y].RES);
            IF (CRLU^[X,Y].NAT < 0) THEN CRLU^[X,Y].NAT := 0;
          END;
        END;
        TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
        IF (TELLU > (100-CRLU^[X,Y].RES)) THEN
        BEGIN
          IF (OLD1PER > CRLU^[X,Y].PER) AND (CRLU^[X,Y].PER>0) THEN
          BEGIN
            CRLU^[X,Y].PER := 100 - (CRLU^[X,Y].ARA + CRLU^[X,Y].PAS  +
              CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
          END;
        END;
        TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
        IF (TELLU > (100-CRLU^[X,Y].RES)) THEN
        BEGIN
          IF (OLD1ARA > CRLU^[X,Y].ARA) AND (CRLU^[X,Y].ARA>0) THEN
          BEGIN
            CRLU^[X,Y].ARA := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].PAS  +
              CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
          END;
        END;
        TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
        IF (TELLU > (100-CRLU^[X,Y].RES)) THEN
        BEGIN
          IF (OLD1PAS > CRLU^[X,Y].PAS) AND (CRLU^[X,Y].PAS>0) THEN
          BEGIN
            CRLU^[X,Y].PAS := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].ARA +
              CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
          END;
        END;
        TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
        IF (TELLU > (100-CRLU^[X,Y].RES)) THEN

        BEGIN
          CRLU^[X,Y].RES := 100 - TELLU;
        END;
(* Correction for total cover less then 100 percent                           *)
        TELLU := 0;
```

```
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
         IF (TELLU < (100-CRLU^[X,Y].RES)) THEN
         BEGIN
           IF OLD1ARA < CRLU^[X,Y].ARA THEN
           BEGIN
              CRLU^[X,Y].ARA := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].PAS +
                CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
           END;
         END;
         TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
         IF (TELLU < (100-CRLU^[X,Y].RES)) THEN
         BEGIN
           IF OLD1PAS < CRLU^[X,Y].PAS THEN
           BEGIN
              CRLU^[X,Y].PAS := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].ARA +
                CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
           END;
         END;
         TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
         IF (TELLU < (100-CRLU^[X,Y].RES)) THEN
         BEGIN
           IF OLD1PER < CRLU^[X,Y].PER THEN
           BEGIN
              CRLU^[X,Y].PER := 100 - (CRLU^[X,Y].ARA + CRLU^[X,Y].PAS +
                CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
           END;
         END;
         TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
         IF (TELLU < (100-CRLU^[X,Y].RES)) THEN
         BEGIN
           IF OLD1NAT < CRLU^[X,Y].NAT THEN
           BEGIN
              CRLU^[X,Y].NAT := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].ARA +
                CRLU^[X,Y].PAS + CRLU^[X,Y].RES);
           END;
         END;
         TELLU := 0;
        TELLU:=(CRLU^[X,Y].PER+CRLU^[X,Y].PAS+CRLU^[X,Y].ARA+CRLU^[X,Y].NAT);
         IF (TELLU < (100-CRLU^[X,Y].RES)) THEN
         BEGIN
           CRLU^[X,Y].ARA := 100 - (CRLU^[X,Y].PER + CRLU^[X,Y].PAS +
              CRLU^[X,Y].NAT + CRLU^[X,Y].RES);
         END;
(* If the evaluation is finished the final total cover change is :          *)
         COR1PER := OLD1PER - CRLU^[X,Y].PER;
         COR1PAS := OLD1PAS - CRLU^[X,Y].PAS;
         COR1ARA := OLD1ARA - CRLU^[X,Y].ARA;
         COR1NAT := OLD1NAT - CRLU^[X,Y].NAT;
(* The age of the changed cover is set back to 0 months                     *)
         IF OLD1PER <> CRLU^[X,Y].PER THEN CRLUAGE^[X,Y].PER := 0;
         IF OLD1PAS <> CRLU^[X,Y].PAS THEN CRLUAGE^[X,Y].PAS := 0;
         IF OLD1ARA <> CRLU^[X,Y].ARA THEN CRLUAGE^[X,Y].ARA := 0;
         IF OLD1NAT <> CRLU^[X,Y].NAT THEN CRLUAGE^[X,Y].NAT := 0;



(* The national NEEDS are adapted to evaluate the changes made              *)
         PERNEED := PERNEED + COR1PER;
         PASNEED := PASNEED + COR1PAS;
         ARANEED := ARANEED + COR1ARA;
         NATNEED := NATNEED + COR1NAT;
       END;
    END;
  END;
END;                                         (* PROCEDURE AUTODEV v 1.2  *)
(**************************************************************************)
```

Appendix VII: Listing of the DISPEST procedure

```
(*************************************************************************)
(* Procedure DISPEST                                                     *)
(* DISPEST simulates possible spatial effects of pests and diseases in   *)
(* certain land covers/crops. These deseases are all scenario options    *)
(*************************************************************************)
PROCEDURE DISPEST;
BEGIN (* PROCEDURE DISPEST *)
  X:=0; Y:=0; C:=0; D:=0;
  IF (TIJD >= DISPERTIME) AND (TIJD <= DISPEREND) THEN PESTDIS := TRUE;
  FOR X:= XMIN TO XMAX DO                    (* START PLACE DISPEST IS LIMON *)
  BEGIN
    FOR Y:= YMIN TO YMAX DO
    BEGIN
      IF (X = 21) AND (Y = 10) THEN
      BEGIN
        CRBPDE^[X,Y].DIPES := DIPES;
      END;
    END;
  END;
  FOR E := 1 TO DISSPEED DO
  BEGIN
    FOR X := (XMIN+RANGE) TO (XMAX-RANGE) DO
    BEGIN
      FOR Y := (YMIN+RANGE) TO (YMAX-RANGE) DO
      BEGIN
        IF CRBPDE^[X,Y].PERDI < 1 THEN
        BEGIN
          FOR C := (X-RANGE) TO (X+RANGE) DO
          BEGIN
            FOR D := (Y-RANGE) TO (Y+RANGE) DO
            BEGIN
              IF (CRBP^[C,D].LAND > 0) AND (CRBP^[C,D].ALT < DISALTCRI)
THEN
              BEGIN
                CRBPDE^[C,D].DIPES := CRBPDE^[C,D].DIPES - DIPES;
              END;
            END;
          END;
        END;
      END;
    END;
    FOR X := XMIN TO XMAX DO
    BEGIN
      FOR Y := YMIN TO YMAX DO
      BEGIN
        IF (CRBPDE^[X,Y].DIPES < DIPES) THEN CRBPDE^[X,Y].DIPES := DIPES;
             CRBPDE^[X,Y].PERDI := CRBPDE^[X,Y].DIPES;
      END;
    END;
  END;
  URBBIJ := 0; URBTELL := 0;
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN          (* IF LOCAL FOOD SUPPLY DECLINES DUE TO PESTS DISEASES  *)
                   (* POPULATION EMIGRATES TO CITIES                       *)
      BIOPHY := YIELDFLUCT +((CRBP^[X,Y].RELIEF+CRBP^[X,Y].SOIL)/150);
      IF (CRBP^[X,Y].ALT > 2500) THEN BIOPHY := BIOPHY/2;
      IF (CRBP^[X,Y].LAND > 0) THEN

      BEGIN
        GRIDTOT := TRUNC(((CRLU^[X,Y].PER*CRBPDE^[X,Y].DEPER*
        CRBPDE^[X,Y].PERDI) + CRLU^[X,Y].PAS + TRUNC(CRLU^[X,Y].ARA*
        CRBPDE^[X,Y].DEARA) + CRLU^[X,Y].NAT) * BIOPHY);
        IF GRIDTOT <= 5 THEN GRIDTOT := 5;
        IF GRIDTOT < GRIDCRI THEN
        BEGIN
          RURAF := ABS(TRUNC(100*CRPOP^[X,Y].RUR/GRIDTOT));
          IF RURAF<(CRPOP^[X,Y].RUR/2) THEN RURAF:=TRUNC(CRPOP^[X,Y].RUR/2);
          URBBIJ := URBBIJ + RURAF;
          CRPOP^[X,Y].RUR := CRPOP^[X,Y].RUR -
             TRUNC(100*CRPOP^[X,Y].RUR/GRIDTOT);
          IF CRPOP^[X,Y].RUR < 0 THEN CRPOP^[X,Y].RUR := 0;
        END;
        IF  CRPOP^[X,Y].URB > CITYCRI THEN URBTELL := URBTELL + 1;
      END;
    END;
  END;
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN
      IF (URBBIJ > 0) AND (URBBIJ > URBTELL) THEN
      BEGIN
        IF CRPOP^[X,Y].URB > CITYCRI THEN
          CRPOP^[X,Y].URB := CRPOP^[X,Y].URB + TRUNC(URBBIJ/URBTELL);
      END;
    END;
  END;
  IF (TIJD = DISPEREND) THEN
  BEGIN
    PESTDIS := FALSE;
    RECOVERY := TRUE;
  END;
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN
      CRBPDE^[X,Y].DIPES := CRBPDE^[X,Y].DIPES + 2*DIPES;
      IF CRBPDE^[X,Y].DIPES > 1 THEN CRBPDE^[X,Y].DIPES := 1;
      CRBPDE^[X,Y].PERDI := CRBPDE^[X,Y].DIPES;
    END;
  END;
END;                                                 (* PROCEDURE DISPEST *)
(*************************************************************************)
```

Appendix VII-2

Appendix VIII: Listings of the BIOPHEED procedure

```
(*************************************************************************)
(* Procedure BIOPHEED                                                    *)
(* BIOPHEED simulates possible biophysical feedback effects of land use  *)
(* such as erosion and nutrient depletion. Certain 'rules' are used to   *)
(* simulate such feedbacks. Again certian specific scenarios can be      *)
(* formulated and simulated. The effect of steep relief on PER and ARA   *)
(* erosion causing a biophysical reduction of yield/value                *)
(*************************************************************************)
PROCEDURE BIOPHEED;
BEGIN (* PROCEDURE BIOPHEED *)
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN
   (* For steep grids erosion [biophy. degradation] under permanent crops *)
      IF (CRLU^[X,Y].PER > 5) AND (CRBP^[X,Y].RELIEF <= PERRELCRI) THEN
      BEGIN
        IF (CRBPDE^[X,Y].DEPER > CRBP^[X,Y].RELIEF/100) THEN
        BEGIN
          CRBPDE^[X,Y].DEPER := CRBPDE^[X,Y].DEPER -
             ((TIJD/TMAX)*(CRBP^[X,Y].RELIEF/100));
        END;
      END;
             (* on poorly drained soils [biophy. degradation] away from *)
             (* urban centers and used as arable lands                  *)
      IF (CRLU^[X,Y].ARA > 5) AND (CRBP^[X,Y].RELIEF <= ARARELCRI) THEN
      BEGIN
        IF (CRBPDE^[X,Y].DEARA > CRBP^[X,Y].RELIEF/100) THEN
        BEGIN
          CRBPDE^[X,Y].DEARA := CRBPDE^[X,Y].DEARA -
             ((TIJD/TMAX)*(CRBP^[X,Y].RELIEF/100));
        END;
      END;
      IF (CRLU^[X,Y].ARA > 2) AND (CRBP^[X,Y].SOIL <= ARASOICRI) THEN
      BEGIN
        IF ((CRPOP^[X,Y].URB) < 100) THEN
        BEGIN
          IF (CRBPDE^[X,Y].DEARA > CRBP^[X,Y].SOIL/100) THEN
          BEGIN
             CRBPDE^[X,Y].DEARA := CRBPDE^[X,Y].DEARA -
               ((TIJD/TMAX)*(CRBP^[X,Y].SOIL/100));
          END;
        END;
      END;
      IF (CRBPDE^[X,Y].DEPER < CRBP^[X,Y].RELIEF/100) THEN
             CRBPDE^[X,Y].DEPER := (CRBP^[X,Y].RELIEF/100);
      IF (CRBPDE^[X,Y].DEARA < CRBP^[X,Y].RELIEF/100) THEN
             CRBPDE^[X,Y].DEARA := (CRBP^[X,Y].RELIEF/100);
      IF (CRBPDE^[X,Y].DEARA < CRBP^[X,Y].SOIL/100) THEN
             CRBPDE^[X,Y].DEARA := (CRBP^[X,Y].RELIEF/100);
    END;
  END;
  URBBIJ := 0; URBTELL := 0;
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN          (* IF LOCAL FOOD SUPPLY DECLINES DUE TO PESTS DISEASES *)
                   (* POPULATION EMIGRATES TO CITIES                      *)
      BIOPHY := YIELDFLUCT +((CRBP^[X,Y].RELIEF+CRBP^[X,Y].SOIL)/150);
      IF (CRBP^[X,Y].ALT > 2500) THEN BIOPHY := BIOPHY/2;
      IF (CRBP^[X,Y].LAND > 0) THEN
      BEGIN
        GRIDTOT := TRUNC(((CRLU^[X,Y].PER * CRBPDE^[X,Y].DEPER *
        CRBPDE^[X,Y].PERDI) + CRLU^[X,Y].PAS + TRUNC(CRLU^[X,Y].ARA *
        CRBPDE^[X,Y].DEARA) + CRLU^[X,Y].NAT) * BIOPHY);
        IF GRIDTOT <= 5 THEN GRIDTOT := 5;
        IF GRIDTOT < GRIDCRI THEN
        BEGIN
          RURAF := ABS(TRUNC(100*CRPOP^[X,Y].RUR/GRIDTOT));
          IF RURAF < (CRPOP^[X,Y].RUR/2) THEN
               RURAF := TRUNC(CRPOP^[X,Y].RUR/2);
          URBBIJ := URBBIJ + RURAF;
          CRPOP^[X,Y].RUR :=CRPOP^[X,Y].RUR-
               TRUNC(100*CRPOP^[X,Y].RUR/GRIDTOT);
          IF CRPOP^[X,Y].RUR < 0 THEN CRPOP^[X,Y].RUR := 0;
        END;
        IF  CRPOP^[X,Y].URB > CITYCRI THEN URBTELL := URBTELL + 1;
      END;
    END;
  END;
  FOR X := XMIN TO XMAX DO
  BEGIN
    FOR Y := YMIN TO YMAX DO
    BEGIN
      IF (URBBIJ > 0) AND (URBBIJ > URBTELL) THEN
      BEGIN
        IF  CRPOP^[X,Y].URB > CITYCRI THEN
        CRPOP^[X,Y].URB := CRPOP^[X,Y].URB + TRUNC(URBBIJ/URBTELL);
      END;
    END;
  END;
END;                                              (* PROCEDURE BIOPHEED  *)
(*************************************************************************)
```

Appendix VIII-2

Appendix IX: list of data files

COSTGISI.DAT

The complete GIS database as it is used by the CLUE-CR model framework. The file is created in ASCII format and contains 2200 rows (50 times 44, for each grid cell one value) and 14 columns. The first row represents all the data for grid [1.1] continuing with [2.1], [3.1] etc. and the last row contains all the data for grid [50,44] Each row contains the following information (14 columns):

LAND	Costa Rica main land grids (913 grids), a value of 0 (sea, border) or 1 (Costa Rica)
RESER	The protected nature reserves (total 143 reserves value 1) or not 0
RELIEF	The relief with 100 no relief to 0 steep slopes
SOIL	Soil characteristics from 100 well drained to 0 poor drained
ALT	Altitude in meters from sea level from 0 to 3200 meters
PER	Land use/cover of permanent crops in 1973 from 0- 100%
PAS	Land use/cover of pastures and range lands in 1973 from 0- 100%
ARA	Land use/cover of arable land in 1973 from 0- 100%
NAT	Land use/cover of nature in 1973 from 0- 100%
RES	Land use/cover of the rest group in 1973 from 0- 100%
RUR	Rural population density in 1973
URB	Urban population density in 1973
RURGR	Rural population growth from 1973 to 1984
URBGR	Urban population growth from 1973 to 1984

CRREGIO.IMG

This file contains the data about the agro-ecological regions used in the model framework. This is an ASCII file containing only one column of a total of 2200 values from 0 to 4 starting with grid value [1,1] to [50,1] then [1,2] to [50,2] etc. and ending with grid value [50,44]. The file can be displayed in IDRISI with the accompanying CRREGIO.DOC documentation file. The following values have been used

0 for the ocean or outside Costa Rica main land
1 Region 1, hot and humid mainly west part of Costa Rica (328 grid cells)
2 Region 2 hot and dry mainly east side of Costa Rica (327 grid cells)
3 Region 3 cool and humid mainly the central valley in Costa Rica (258 grid cells)

CRCOVERS.TAB

During the simulation the program automatically processes a table in ASCII format, containing the yearly update results from the cover distributions in the 3 agro-ecological regions and for the whole country of Costa Rica. The table is processed in the following way:

TIME of update and YEAR of update

PERTOT1-3	PASTOT1-3	ARATOT1-3	NATTOT1-3	RESTOT1-3	TOTALS
region 1 PER	region 1 PAS	region 1 ARA	region 1 NAT	region 1 RES	region 1 total
region 2 PER	region 2 PAS	region 2 ARA	region 2 NAT	region 2 RES	region 2 totals
region 3 PER	region 2 PAS	region 3 ARA	region 3 NAT	region 3 RES	region 3 totals
Costa Rica PER	Costa Rica PAS	CostaRica ARA	CostaRica NAT	Costa Rica RES	Costa Rica totals

CRNEEDS results for PER, PAS ARA and NAT

PERUIT.IMG and PERUIT.DOC
PASUIT.IMG and PASUIT.DOC
ARAUIT.IMG and ARAUIT.DOC
NATUIT.IMG and NATUIT.DOC
URBUIT.IMG and URBUIT.DOC
RURUIT.IMG and RURUIT.DOC

At the chosen time of output the model will process the output cover files of the land use/cover distribution on that moment and the population densities of the rural and urban population. Again like for CRREGIO.IMG

the files are processed in one large column of numbers directly ready for display in IDRISI together with the documentation file which has the same filename with extension .DOC. During the output process the file is written in the column from [1,1] to [50,44] reading the map from the upper right corner to the lower left corner. To distinguish between the 0 values of the oceans and other not Costa Rica grids and the real 0 values of empty grids, the program has saved the valid Costa Rica values starting from 10 instead of 0. This means for example for PERUIT.IMG that the cover percentages can be between 10 and 110 percent.