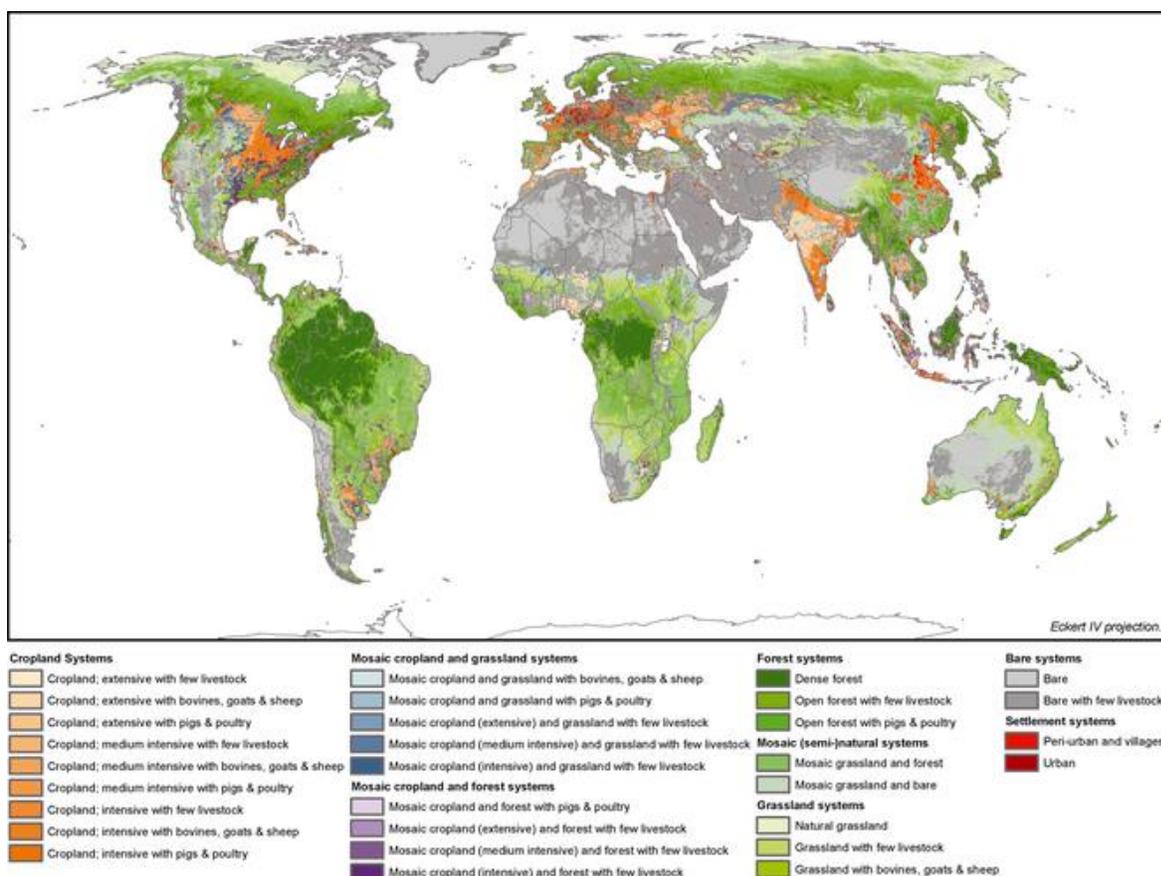


The CLUMondo land use change model

Manual and exercises



December 2015

CLUMondo is a dynamic, spatially explicit land use and land cover change model. The development of the user interface was funded by the Asian Development Bank's Greater Mekong Subregion Core Environment Program (CEP): www.gms-eoc.org. Improvements and updates of the model function were supported by funding from the CEP and the European Research Council under the European Union's Seventh Framework Programme ERC Grant Agreement nr. 311819 (GLOLAND)

- CLUMondo was developed by Peter Verburg.
- The user interface was developed by RIKS bv, The Netherlands
- The documentation was written by Jasper van Vliet and Ziga Malek.
- Sample data set developed by Christine Ornetsmüller.

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1. Introduction

This document acts a self-teaching manual for the CLUMondo land use change model. It is written for the CLUMondo version that is implemented in the Geonamica software environment. Hence all references to the user interface, refer to the user interface of this model implementation.

The first section provides a brief overview of the model structure and the different components. Subsequently, the case study application for Laos is introduced. Section 3 gives some background information about the usage of a GIDS to pre- and post-process model input and output. Sections 4 and further provide a number of exercises that guide you through the model and through the user interface step by step. As the exercises gradually increase the in difficulty, it is advised to follow all of them in order.

2. The CLUMondo model

2.1. Background

CLUMondo is a dynamic and spatially explicit land-use model. It is the latest addition in the series of models that started as the Conversion of Land Use and its Effects modelling framework (CLUE) (Verburg et al., 1999). Land-use models typically simulate changes in mutually exclusive classes that are related to their land cover, such as forests, cropland, and built-up land. However, many land-use changes do not directly affect the land cover on a location, but instead relate to the land use intensity, for instance changes from extensive cropland to intensive cropland, and changes from low density residential areas to high density apartment blocks. Moreover, many areas cannot be characterized by one single land use, but are multifunctional or mixed instead. For example, many rural villages combine residential use with crop production and livestock production, and classifying this area according to only one of these functions would be incomplete.

CLUMondo is specifically designed to simulate changes in land cover as well as changes in land use intensity. In addition, it can represent multifunctional land. At the core, the simulation of land use change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems. More information on the development of the CLUE and CLUMondo models can be found in (Eitelberg et al., 2015; van Asselen and Verburg, 2013; Verburg et al., 2002; Verburg and Veldkamp, 2004).

2.2. Model structure

The CLUMondo model is sub-divided into two distinct modules, namely a non-spatial demand module and a spatially explicit allocation module (Figure 1). The non-spatial module indicates the changes in demand at the level of the entire model region. Demands in this case can refer to demand for an area of a specific land use, but also to an amount of goods or services. An example of the former is an area of built-up land (which can be expressed in hectares), and an example of the latter is a demand for food (which can be expressed in tons of products). In the allocation module, these demands are subsequently translated into land-use changes at specific locations in the study area, using a raster-based system.

In CLUMondo, demands are external input to the system, while the allocation is determined by the model's allocation algorithm, which is supported by the user-interface. Land-use demands can be derived in different, ranging from simple trend extrapolations to complex economic models. Demands need to be specified on a yearly basis. The choice for a specific approach is very much dependent on the nature of the most important land use conversions taking place within the study area and the scenarios that need to be considered.

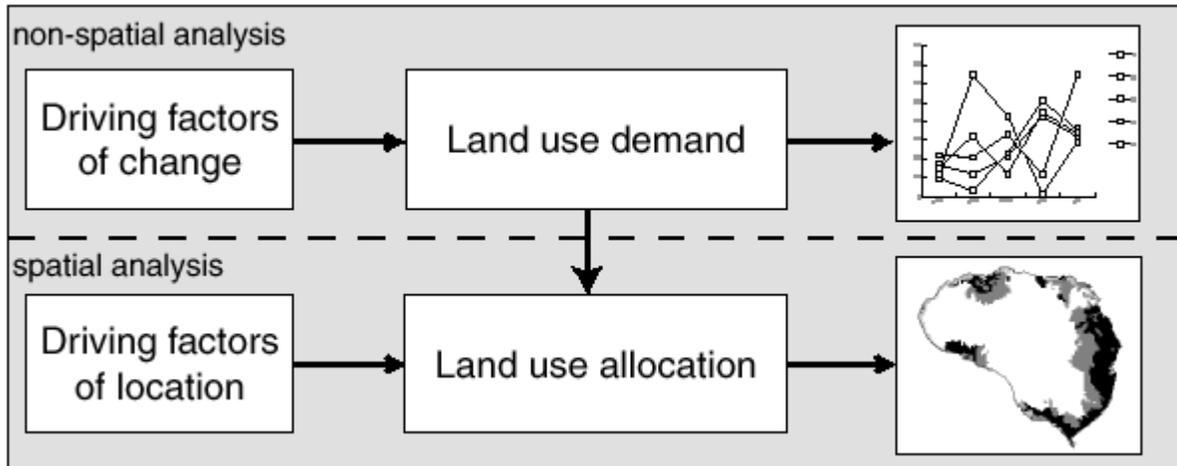


Figure 1. Overview of the modelling procedure.

Land-uses are allocated based on a combination of different drivers of land-use change, as shown in Figure 2. These drivers are subdivided into four categories: spatial policies and restrictions, land use type specific conversion settings, land use requirements (demand) and location characteristics. Together these drivers create land-use changes over time, using an iterative calculation procedure. The individual drivers are discussed one by one in the next sections.

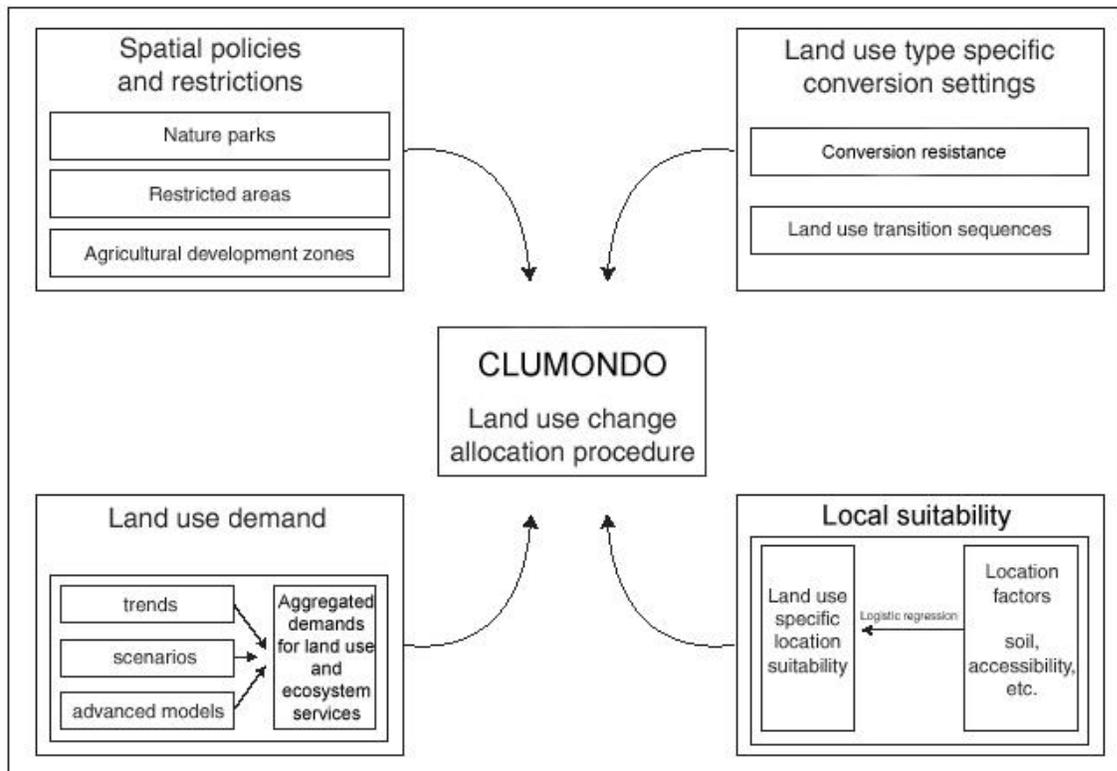


Figure 2. Overview of the information flow in the CLUMondo model.

1.2.1 Spatial policies and restrictions

Spatial policies and restrictions mostly indicate areas where specific land-use types or specific land-use changes are restricted, for example through zoning policies or tenure status. In CLUMondo, these areas are indicated in a number of maps that show the areas for which the policy or restriction is implemented. Some spatial policies restrict all land-use change in a certain area, e.g., a log-ban within a forest reserve. These type of general restrictions can be included in the model in a regions map. Other land-use policies only target a set of specific land-use conversions, e.g., residential construction in designated agricultural areas, or agricultural expansion in the buffer zone of a nature reserve. Conversions that are restricted by a certain spatial policy can be indicated in a land-use conversion matrix: for all possible land use conversions it is indicated if the spatial policy applies.

1.2.2. Land-use type specific conversion settings

Land-use type specific conversion settings represent the behavior of one specific land-use type. Two sets of parameters are needed to characterize each individual land-use types: conversion resistance, and land-use transition sequences. The conversion resistance is related to the reversibility of land-use change. Some land-use types will not easily be converted in other uses as long as there is sufficient demand, for example because of the capital investments in these areas. Examples are residential locations but also plantations with permanent crops (e.g., fruit trees). Other land-use types easily shift location when the location becomes more suitable for other land uses. For example, arable land often makes place for urban development while expansion of agricultural land occurs at the forest frontier. An extreme example is shifting cultivation: for this land-use system, a specific location is typically not used for periods exceeding two seasons, as a consequence of the nutrient depletion of the soil. These differences in behavior towards conversion can be approximated by conversion costs. For each land-use type a value needs to be specified that represents the relative conversion resistance, ranging from 0 (easy conversion) to 1 (irreversible change). The modeler decides on this factor based on expert knowledge or observed behavior in the recent past.

The second set of characteristics that needs to be specified are the land-use type conversion settings. These settings are specified in a conversion matrix. This matrix defines:

- To what other land-use types the present land use can convert, and to which types it cannot convert (see Figure 3).
- In which regions a specific land-use conversion is allowed and in which regions it is not.
- How many years (or time steps) the land-use type at a location should remain the same before it can change into another land use type. This can be relevant in case of the re-growth of forest. Open forest cannot change directly into closed forest. However, after a number of years it is possible that an

undisturbed open forest will change into closed forest because of re-growth.

- The maximum number of years that a land-use type can remain the same. This setting is particularly suitable for arable cropping within a shifting cultivation system. In these systems, the number of years a piece of land can be used is commonly limited due to soil nutrient depletion and weed infestation.

It is important to note that only the minimum and maximum number of years before a conversion can or should happen can be indicated in the conversion matrix. The exact number of years depends also on the pressure from land-use competition and location specific conditions. The simulation of these interactions combined with the constraints set in the conversion matrix will determine the length of the period before a conversion occurs. Figure 3 provides an example of the use of a conversion matrix for a simplified situation with only three land-use types.

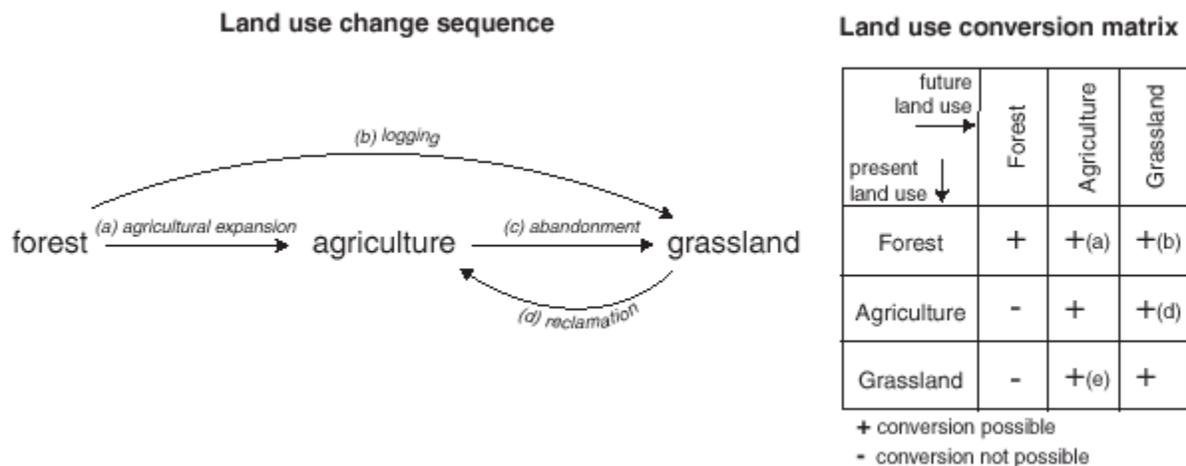


Figure 3. Illustration of the translation of a hypothetical land-use change sequence into a land-use conversion matrix.

1.2.3. Land-use demands

Land use demand are defined at the aggregate level (the level of the case-study region as a whole) as part of a specific scenario. Land-use demands in CLUMondo can be expressed in different units, for example areas expressed in a number of cells, hectares, of square kilometers, but also tons of food, heads of livestock, or number of houses. The land-use demands constrain the simulation by defining the totally required demand that need to be fulfilled by al land uses combined. Land-use demands are calculated independently from the CLUMondo model itself. This calculation can be based on a range of methods, depending on the case study and the scenario. The extrapolation of historic trends into the near future is a common technique to calculate land-use demands. When possible, these trends can be corrected for projected population growth and/or diminishing

land resources. For policy analysis it is also possible to base land-use demands on advanced macro-economic models, which can for example provide scenarios related to policy targets.

1.2.4. Location characteristics

Land-use conversions are expected to take place at locations with the highest 'preference' for the specific type of land use at that moment in time. Preference of a location is empirically estimated from a set of factors that are based on the different, disciplinary, understandings of the spatial determinants of land-use change. It can be calculated as follows:

$$R_{ki} = C + a_k X_{1i} + b_k X_{2i} + \dots$$

where R_{ki} is the preference to devote location i to land-use type k , C is a constant, $X_{1,2,\dots}$ are biophysical or socio-economical characteristics of location i , and a_k and b_k the relative impact of these characteristics on the preference for land-use type k . The exact specification of the model should be based on a thorough review of the processes important to the spatial allocation of land use in the study region.

A statistical model can be developed as a binomial logit model of two choices: convert location i into land use type k or not. The preference R_{ki} is assumed to be the underlying response of this choice. However, the preference R_{ki} cannot be observed or measured directly. Therefore it has to be calculated as a probability. The function that relates these probabilities with the biophysical and socio-economic location characteristics is defined in a logit model following:

$$\text{Log} \left(\frac{P_i}{1 - P_i} \right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \dots + \beta_n X_{n,i}$$

where P_i is the probability of a grid cell i for the occurrence of the considered land-use type, and the X 's are the location factors. The coefficients (β) are estimated through logistic regression using the actual land use pattern as dependent variable. This method is similar to econometric analysis of land-use change, which is very common in deforestation studies. In econometric studies the assumed behavior is profit maximization, which limits the location characteristics to (agricultural) economic factors.

In a study area it is assumed that locations are devoted to the land-use type with the highest 'suitability'. 'Suitability' includes the monetary profit, but can also include cultural and other factors that lead to deviations from (economic) rational behaviour in land allocation. This assumption makes it possible to include a wide variety of location characteristics, or their proxies, to estimate the logit function that defines the relative probabilities for the different land-use types.

Many location characteristics relate to a specific location directly, such as soil characteristics and altitude. However, land management decisions for a certain

location are not always based on location specific characteristics alone: Conditions at other levels, e.g., the household, community or administrative level can influence the decisions as well. These factors are represented by accessibility measures, indicating the position of the location relative to important regional facilities, such as the market, and by the use of spatially lagged variables. A spatially lagged measure of the population density approximates the regional population pressure instead of only representing the population living at the location itself.

1.2.5. Allocation procedure

When all input is provided, the CLUMondo model calculates the most likely land-use changes using discrete time steps. The allocation procedure is summarized in Figure 4. The following steps are taken to allocate the changes in land use:

- The first step includes the determination of all grid cells that are allowed to change. Grid cells that are either part of a protected area or presently under a land-use type that is not allowed to change are excluded from further calculation. Also the locations where certain conversions are not allowed due to the specification of the conversion matrix are identified.
- For each grid cell (i) at the time (t) the transition potential ($P_{tran\ t,i,LU}$) is calculated for each of the land use types (LU) u according to:

$$P_{tran\ t,i,LU} = P_{loc\ t,i,LU} + Pres_{LU} + P_{comp\ t,LU}$$

where $P_{loc\ t,i,LU}$ is the suitability of location i for land use type LU (based on the logit model), $Pres_{LU}$ is the conversion resistance for land use LU and $P_{comp\ t,LU}$ is an iteration variable that is specific to the land use type and indicative for the relative competitive strength of a land-use type. $Pres_{LU}$, the land-use type specific conversion resistance factor, is only added if grid-cell i is already under land-use type LU in the year considered.

- A preliminary allocation is made with an equal value of the iteration variable ($P_{comp\ t,LU}$) for all land-use types by allocating the land use type with the highest total probability for the considered grid cell. Conversions that are not allowed according to the conversion matrix are not allocated. This allocation process will cause a certain number of grid cells to change land use.
- The total allocated area and produced goods and services of all land uses combined is now compared to the land-use demand. For land uses related to demands that have not yet been met, the value of the iteration variable is increased. For land use demands that are more than satisfied by the land-use allocation, the value is decreased. Through this procedure it is possible that the local suitability based on the location factors is overruled by the iteration variable due to the differences in regional demand. The procedure followed balances the bottom-up allocation based on location suitability and the top-down allocation based on regional demand.

Steps 2 to 4 are repeated as long as the not all demands are correctly allocated.

When land use pattern satisfies all demand for areas, goods and services, this final map is saved and the calculations can continue for the next time step. Some of the allocated changes are irreversible while others are dependent on the changes in earlier time steps. Therefore, the simulations tend to result in complex, non-linear changes in land use pattern, characteristic for complex systems.

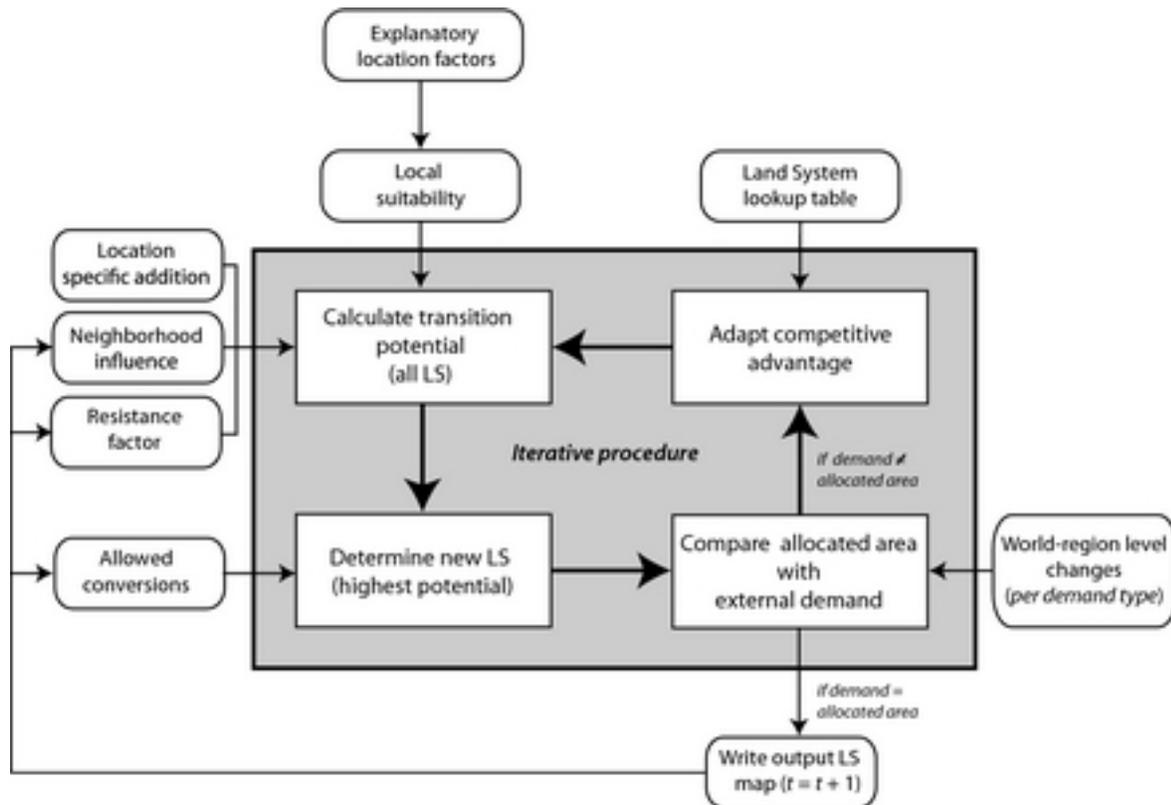


Figure 4. Flow chart of the allocation module of the CLUMondo model.

3. The case-study application

3.1. Land-use map

In these exercises the CLUMondo model will be used for the simulation of land-use change in Laos (Figure 5). The initial map represents the land use in Laos in the year 2010, using ten different classes.

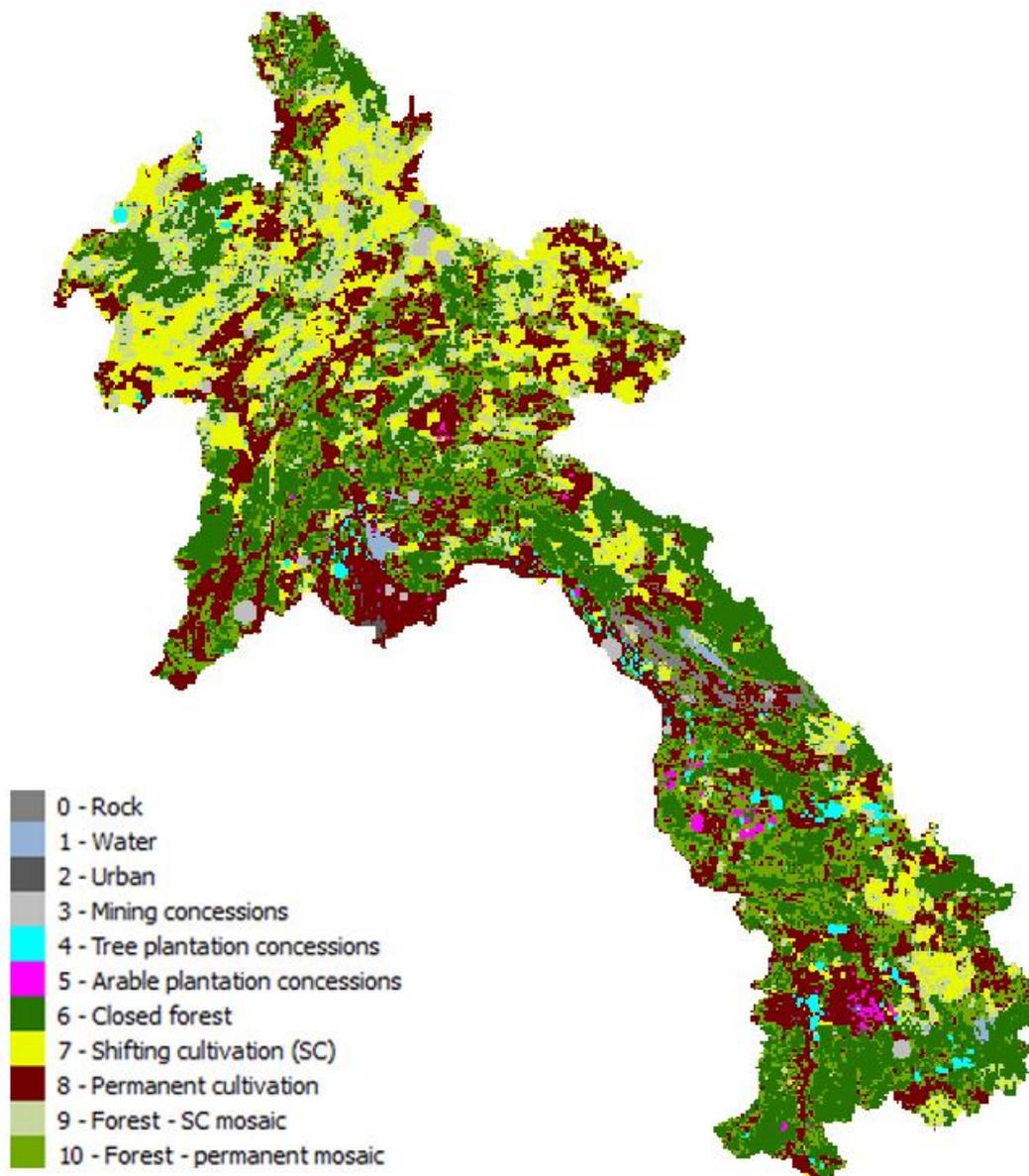


Figure 5. Land use map for the Laos case study

3.2. Location factors

In addition to the land use map, a number of maps representing location factors are included. These maps are used as determinants for the allocation of the different land use types (Table 1). All maps can be found as sc1gr*.fil files in the simulation directory, where * stands for the file number of the location factor.

Table 1. Location factors used in the new application. Cat indicates categorical variables (i.e. presence or absence of a category), and Num indicates numerical variables.

Code	Type	Variable name	Description
0	Cat	w_3_ab2k	distance to water above (more than) 2 km
1	Num	access	accessibility to villages
2	Num	access_dom	domestic market accessibility (to province and district capitals)
3	Num	access_int	international market accessibility (to capitals, airports and border checkpoints)
4	Cat	contractp	villages where contract farming is prevalent
5	Num	popdensity	population density
6	Num	slope	slope (mean of 2x2 km)
7	Num	elevation	elevation (mean of 2x2 km)
8	Num	precipitation	annual mean precipitation
9	Num	temperature	annual mean temperature
10	Cat	awc_1	available water storage capacity FAO class 1: 150 mm/m
11	Cat	awc_4	available water storage capacity FAO class 4: 75 mm/m
12	Cat	awc_5	available water storage capacity FAO class 5: 50 mm/m
13	Cat	drain4	soil drainage FAO class 4: moderately well
14	Num	t_clay	topsoil clay content in %
15	Num	s_clay	subsoil clay content in %
16	Num	t_gravel	topsoil gravel content in %
17	Num	toc_4	topsoil organic carbon content FAO class 4: 1.2 – 2.0 %
18	Cat	w_2_un2k	distance to water under (less than) 2 km

3.3. Scenario data

The example case study includes a scenario for future land-use changes in Laos. This scenario is represented by the demand for the different land-use services. 4 different demands are defined in the scenario: built-up area, staple crop production, arable cash crops production, and tree cash crops production. The scenario assumes a moderate increase in urbanization, and an associated increase in staple crop production. The increase in arable cash crops and tree cash crops relate to the production in land concessions, which is driven by a foreign demand.

Two restriction files are included in the application, representing areas where land-use changes are not allowed in the simulation. The first one represents the national park network in Laos, and is defined by the file 'region_park.fil'. The second one, named 'region_1000' defines areas above the elevation of 1000 m and serves as an example of how to include exclusion layers. The exercise on spatial policies (section0) provides some more information about the use of exclusion layers.

It should be noted that the scenarios in this case study application are included solely for training purposes, and thus modified on purpose to illustrate how the model works. Therefore they do not reflect any realistic scenarios for Laos, and should not be interpreted as such either.

4. Preparing your computer and using a Geographic Information System

4.1. Preparing your computer

In order to be able to use the CLUMondo model, and to set-up an application with your own data, you need to check and adjust the location settings of your computer. Specifically, you need to make sure the computer a period (.) for a decimal separator, instead of a comma (,). The data in the tutorial is already adequately prepared, however in order to avoid any issues with running the model with your own data, you should change this setting in your computer.

- In Windows, go to Control Panel / Clock, Language, and Region. There, select 'Region and Language'.
- Under 'Format', select 'English (United States)' (Figure 6). Click on 'Additional settings' to check whether the dot is used for the decimal symbol.

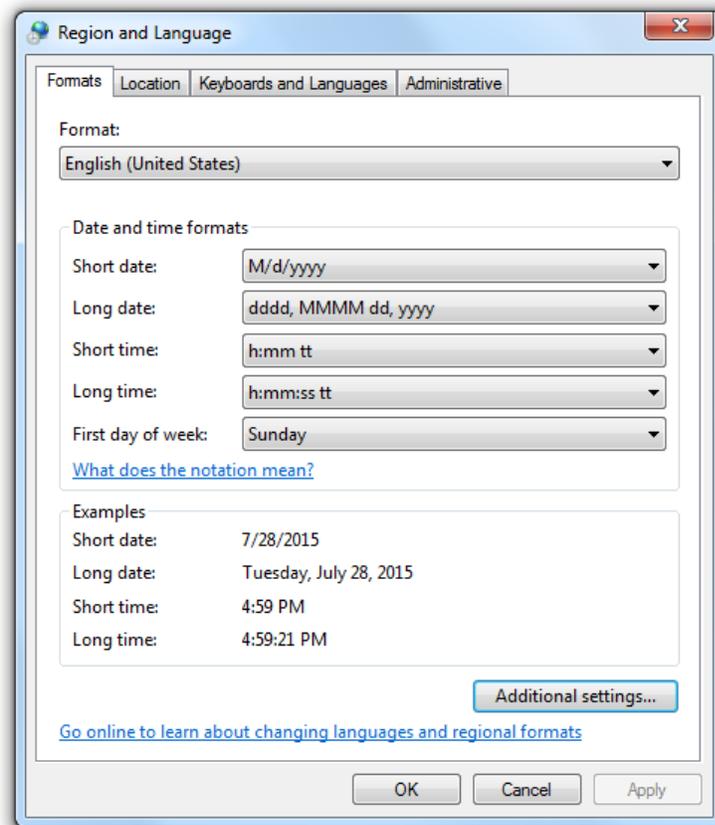


Figure 6. Adjusting the Region and Language settings on your computer.

4.2. GIS software

In order to setup a new application, you probably need to process some spatial data, such as your land use map or the suitability maps. This pre-processing cannot be done within the CLUMondo software and therefore your computer needs to be equipped with a Geographic Information System (GIS). A GIS is needed in order to:

- Prepare and edit data needed for a CLUMondo application (e.g. digitize and rasterize spatial data such as land-use maps, spatial restrictions, location factors).
- Perform additional spatial analysis of the results if needed.
- Prepare maps with legends and text for documentation, and publication.

Common proprietary GIS packages are ArcGIS from ESRI (www.esri.com/software/arcgis) and IDRISI from Clark Labs (www.clarklabs.org/products/idrisi-gis.cfm). However, there are also a number of open source GIS packages. In this section we will focus on free and open source GIS software only. The the most widespread free GIS software packages listed below:

- QGIS <http://www.qgis.org>
- GRASS GIS <http://grass.osgeo.org>
- SAGA GIS <http://www.saga-gis.org>
- ILWIS <http://52north.org/downloads/category/10-ilwis>

Most of them are fully functional and can successfully replace proprietary GIS software. They are efficient in either displaying data or preparing maps, or performing more detailed spatial analysis with geoprocessing.

4.3. Installing the Map Comparison Kit

In the exercises we will also use the Map Comparison Kit (MCK).. MCK includes numerous algorithms for comparing raster maps, which are particularly useful for land use change simulation models. It has a user friendly interface, is easy to learn and is especially suitable for comparing raster maps. With MCK, we can compare:

- the overall extent of the differences
- the spatial distribution of the differences
- the nature of the differences
- the measurement scale of the maps (nominal, ordinal, interval or ratio scale)

MCK is freely available from its website. You can find the most recent version on <http://mck.riks.nl/>. After the installation, run MCK. The main window with the user

interface appears (Figure 7). The software asks you to open a log file, which we have not generated yet, so press cancel.

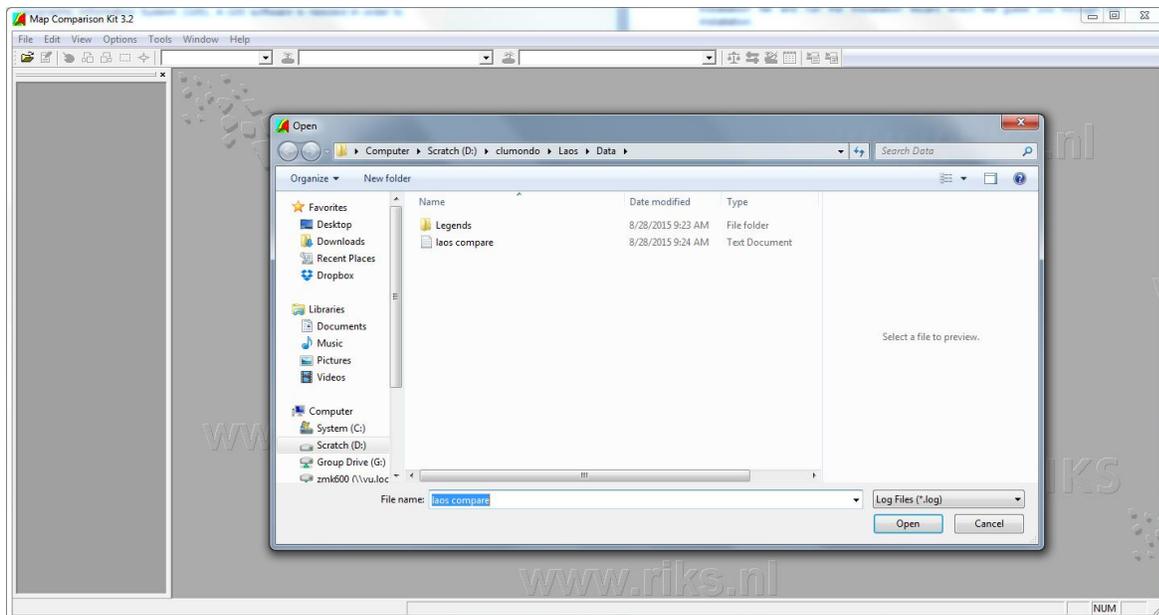


Figure 7. MCK user interface

You can exit the MCK software. In the section 'Displaying simulation results' of Exercise 1, we will guide you through setting up a new map comparison.

5. Introduction to the CLUMondo user-interface (exercise)

The objective of this exercise is to become familiar with the CLUMondo user-interface. You will already see some model parameters, but more specific information about the different parameters and input files is given in other exercises as well as in the user manual.

5.1. Start CLUMondo

In CLUMondo, the the model itself is separated from the model application. In this sense CLUMondo works similar to, for example, Microsoft word, where documents are also separated from the software itself. Consequently, upon installation, both are installed in different locations.

After installing CLUMondo, the software is available in Start/All Programs/CLUMondo. Alternatively, open the directory where CLUMondo is installed with windows explorer and double-click the file 'Geonamica.exe'.

After opening the software, CLUMondo prompts for a project file. A project file is the file that contains the model application. One model application (Laos), is provided with the model. Go to the project folder defined during the installation (usually Documents\CLUMondo\Laos), and select Laos. The user-interface should appear on the screen.

5.2. User interface and main functions

The user-interface enables you to edit and view the main input files and parameters, and allows the user to choose the scenario conditions. In the Laos application, all model parameters are already set, so you can already run a simulation by clicking the 'Run' button, or go to Simulation/Run.

When the model is running, buttons are disabled (i.e. they appear grey, so you cannot start a new run in the meanwhile), and you see a green progress bar in the bottom right corner. As long as you see this progress bar (even when it says 100%), the model is running.

Simulation results will be saved to output files (maps in ASCII format) that can be imported by a GIS for display and analysis. All maps of a single run are stored in one folder, and new runs are subsequently stored in a new folder, so you never lose track. These folders are located in the CLUMondo/Laos/ClumondoWorkingDir, and are identified by the date and time you pressed start. This way you can always recognize your latest run.

5.2.1. Application characteristics

In the first tab of the CLUMondo user-interface 'Application characteristics', the user can add, remove and display suitability layers, land use types and exclusion

layers (Figure 8). The suitability layers – location factors represented by e.g. accessibility, population density, elevation and precipitation maps – can be added by clicking the ‘Add suitability layer’. In the section ‘Land use services’ the land use classes can be viewed and edited. The section ‘Exclusion layers’ define the areas which are excluded from simulation and can be added with the ‘Add exclusion layer’ function. All input maps (suitability and exclusion layers), can be viewed by clicking the ‘Show’ button next to the file description.

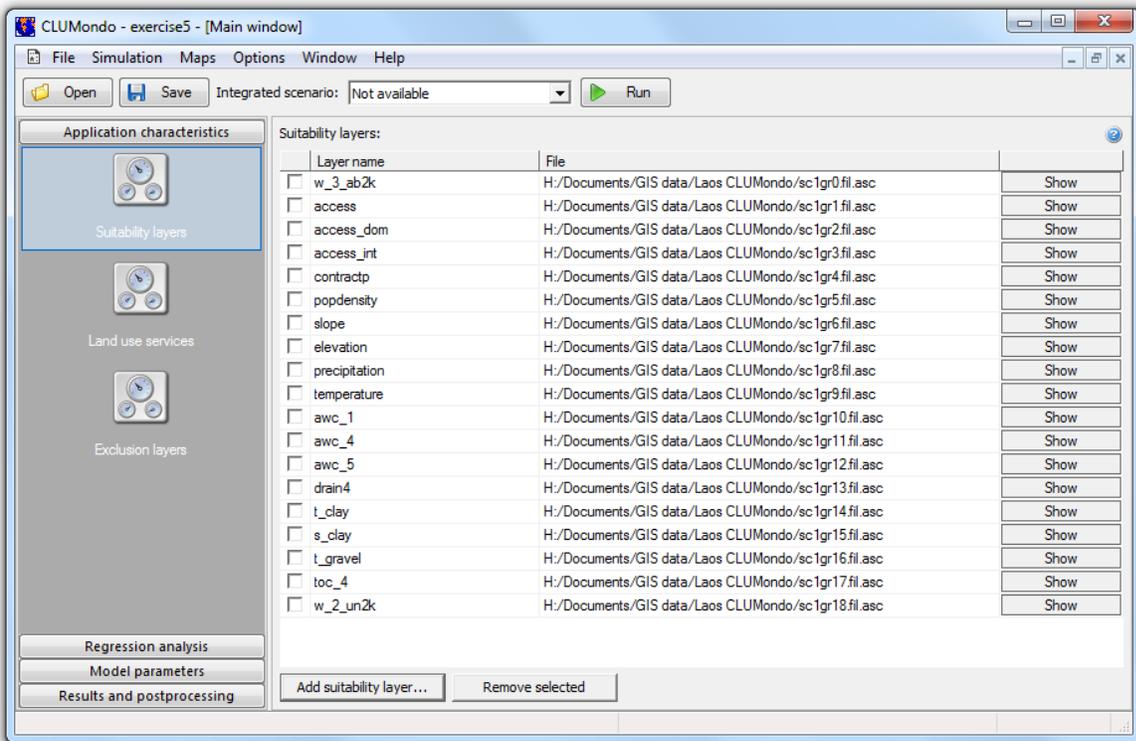


Figure 8. Application characteristics of the CLUMondo model user-interface.

5.2.2. Regression analysis

In the second tab, named ‘Regression analysis’, the user can perform the statistical analysis that is required to setup a new application (Figure 9). For existing applications, it is not needed to redo this regression analysis.

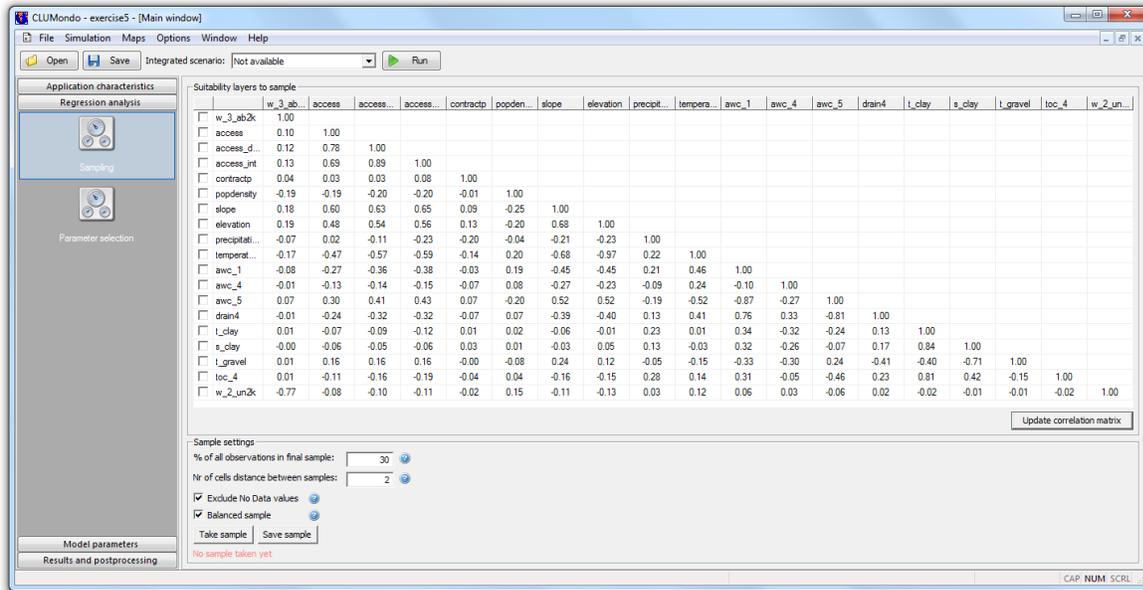


Figure 9. Regression analysis in the CLUMondo user-interface.

5.2.3. Model parameters

In this tab, the user can define all model parameters, such as the regression parameters, conversion order and resistance, adjust the conversion matrix and neighbourhood characteristics, as well as define the scenarios (Figure 10). These parameters are important when defining new scenarios, and are described in more detail in Exercise 2: Land use change scenarios.

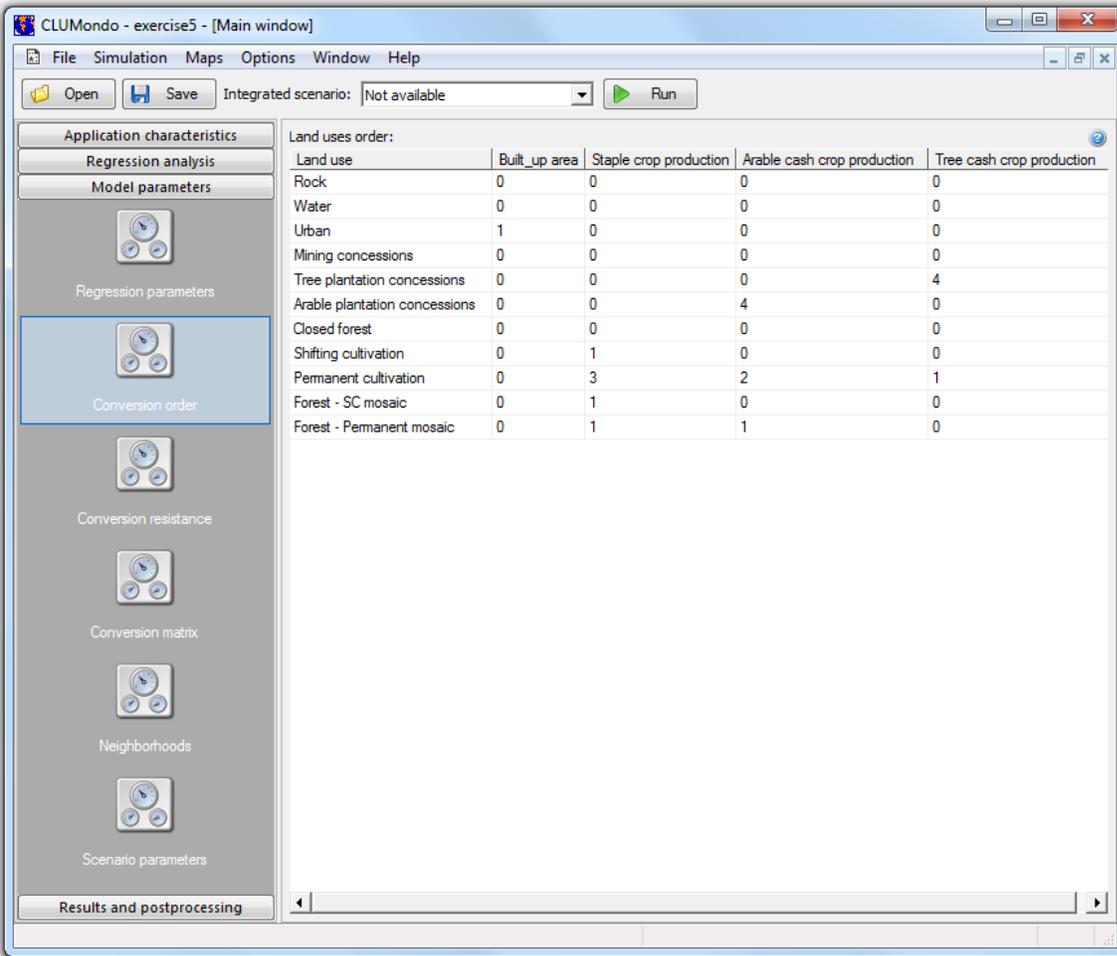


Figure 10. Editing model parameters in the CLUMondo user-interface.

5.3. Start of a simulation

The model can be run when the project is provided with the necessary input files. In this case, all input files are supplied in the working directory.

- Press 'Run' and the model will start with the simulation.

After the model has finished its run, output files are available in the resulting folder (in this example \CLUMondo\Laos\CLUMondoWorking\ and a subfolder showing the date and time of the model execution). The model can be run again by adding new spatial layers, defining new exclusion layers, or by changing any of the parameters in the user interface (e.g. conversion order, conversion resistance, neighbourhood characteristics...).

5.4. End of the simulation

When the simulation is successfully finished CLUMondo will inform you with a message (Figure 11) and the progress bar will show no activities. Numerous output files will be available in the project directory. First, the log file contains information on the input files and run-time information on the iterations and may be consulted when errors occur or unexpected results are found. Second, for each year a file cov_all.* is created, where * stands for the year of the simulation. It contains the resulting land use type distribution after the simulation for that year. This is an ASCII file that can be imported by a GIS package (ArcGis, Idrisi, QGIS) and in the Map Comparison Kit. Third, the age.* files, where * stands for the year of the simulation are created. This file indicates for each grid cell the number of time-steps after the last land use change at that location. Moreover, the model will produce a file called landarea.txt. The file contains the information on areas allocated in each year (except for year 0) of the different land use systems (in terms of number of cells * cellsize). Other output files are described in the Manual that is include in the software (help).

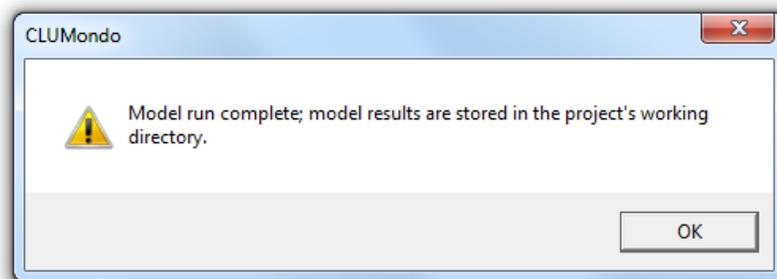


Figure 11. End of the model run.

5.5. Display and compare simulation results

All results of a CLUMondo simulation are saved in the CLUMondo installation directory CLUMondo\Laos\CLUMondoWorking. The simulation results can be displayed in the CLUMondo user interface by showing the initial and modelled land use map in the 'Results and postprocessing' tab. For a more detailed visualisation and analysis of the simulation results it is necessary to use a GIS package. This section presents how to display and compare simulation results using the Map Comparison Kit (MCK).

- Start the MCK (instructions how to install it are described in section 3 'Using a geographic information system').
- When the software opens and asks for opening a .log file, press cancel. We have not made a .log file yet.
- Select 'File/New'. An 'Edit log file' window appears (Figure 12)

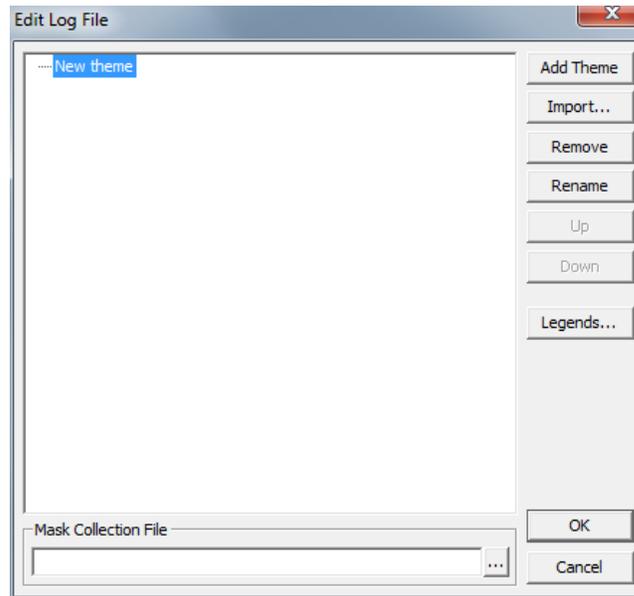


Figure 12. Editing a log file in MCK.

- Select 'Import' and browse to the Simulation results folder (CLUMondo\Laos\CLUMondoWorking, subfolder defined by the date and time of the simulation), set 'List Files of Type:' at 'All Files (*)'. The simulation results (land use maps) are stored in files called: cov_all.* where * indicates the year after the start of the simulation.
- Select the files we will compare, i.e. the file presenting the starting (year 0) and final year (e.g. year 10). Select files cov_all.0 and cov_all.10 and click 'OK'.
- The files will be added to the 'Edit log file' list. Press 'Ok', and the software will ask you to name and save the .log file. Save it using an appropriate name and you can start with comparing maps.
- Maps are displayed in the main window of the MCK, however in a default color style. In order to compare the maps more easily, it is advised to change the color map. To do so, double-click on the legend of the map in the left of the windows, the 'Legends editor' will open (Figure 13). There you can modify the colors for the land use classes, as well as rename them into proper land use class names (e.g. urban, closed forest...). Renaming the classes will enable easier comparison later.
- Choose the colors easily associated with different land use types to ensure a more effective graphical representation. Results of the simulation can now be seen on the screen and further analyzed using MCK (Figure 14).
- You can switch between the initial and simulated land use map anytime by clicking the  or  buttons.

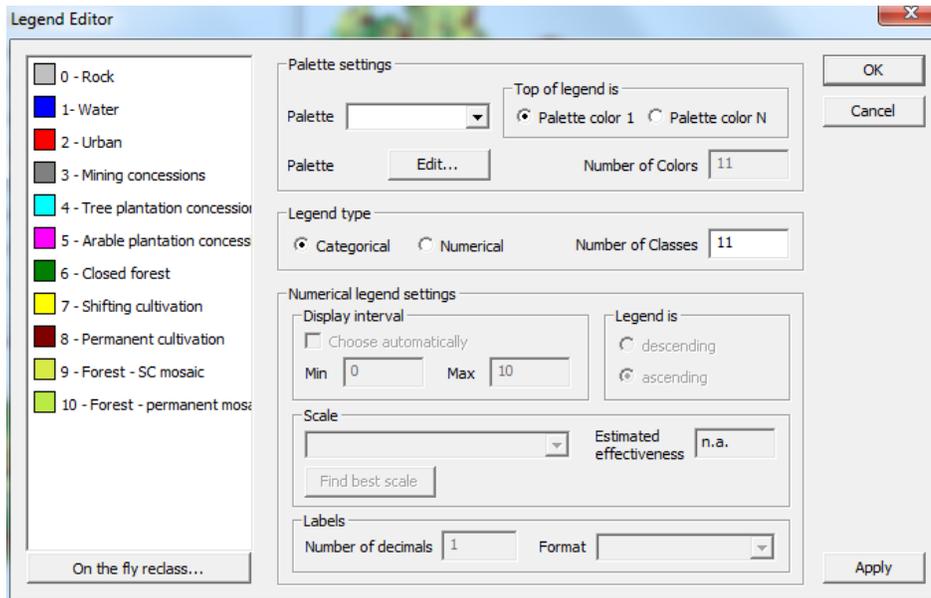


Figure 13. Editing the graphical representation of a land use map in MCK.

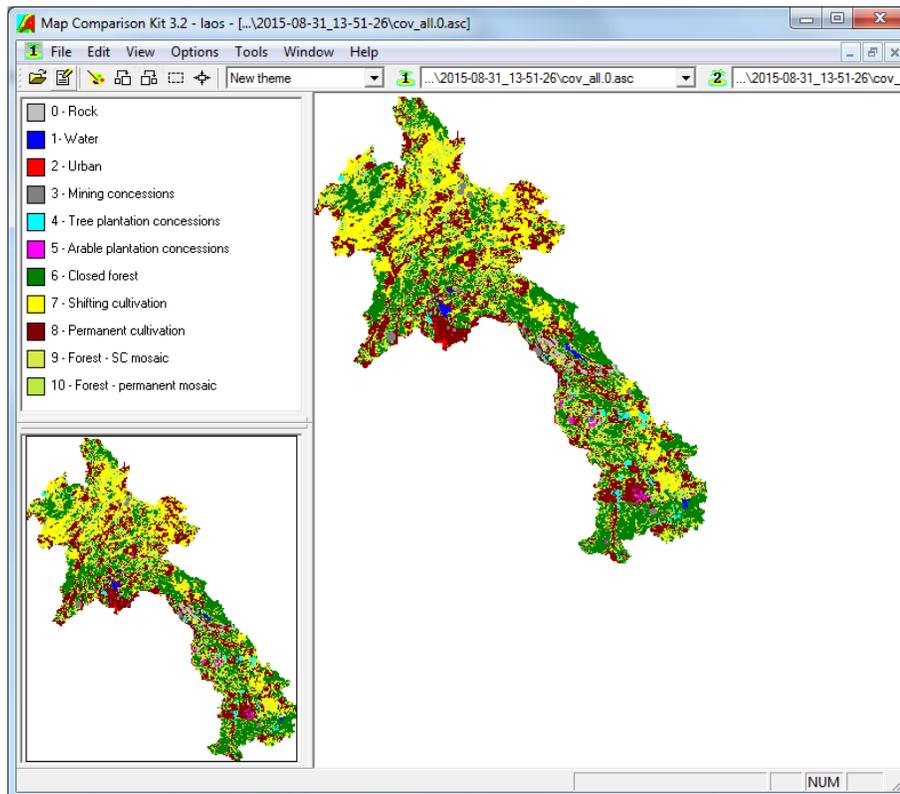


Figure 14. Display of a land use map in MCK.



Figure 15. Example legend for land use types for Laos.

Now we can start comparing the maps. First we will compare the initial and final simulation map using the 'Per comparison' function of MCK. This function performs a cell-by-cell comparison of the selected land use category.

- Select 'Options/Comparison algorithm' or click on the Comparison algorithm button . Select 'Per category'.
- Select 'Options/Algorithm settings' or click on the Algorithm settings button .
- Select a land-use class you first want to compare. Let us focus first on the class '6 – Closed forest'. We can observe the changes to the forest cover between the initial and final simulation year (Figure 16). This way we can see where the forest has remained stagnant, and where deforestation and forest expansion were simulated. In order to compare the changes better, double click on the legend on the left and set the color of 'in none of the maps' to grey.
- The result statistics ('Options/Result statistics, or by clicking the  button) describe the changes between the two maps focusing on one particular land use class in a quantitative way.
- Continue comparing the maps for all other land-use classes by selecting different classes in the 'Algorithm settings'.

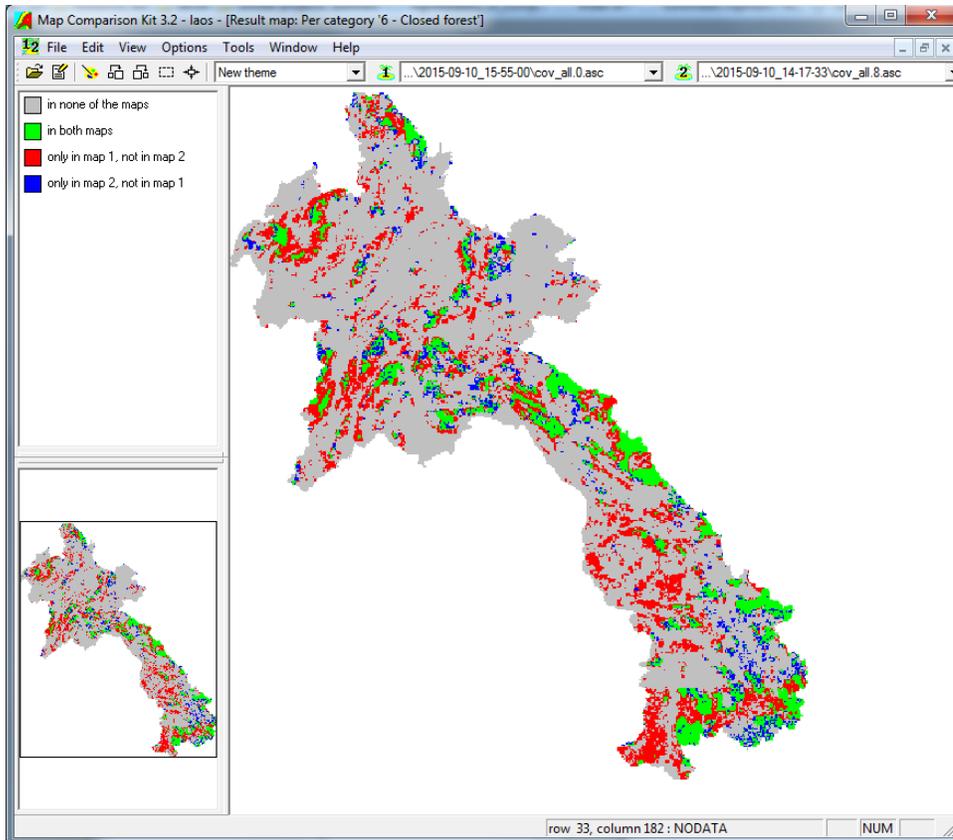


Figure 16. Per category comparison in MCK.

Next, we will compare the two maps using the Kappa algorithm. This algorithm compares both maps on a cell-by-cell comparison, and considers for each pair of cells on the two maps whether they are equal or not.

- Select Kappa in the 'Select comparison algorithm' window. In the results we can see the overall differences between the two maps (Figure 17).
- Select 'Options/Result statistics' or click on the Statistics button . We will examine the Per category and Contingency tables of the Kappa algorithm.

In the 'Per category' table, you can see the differences between the two maps in terms of how much a particular land use category has changed. The K_{Loc} values describe similarity between the two maps in terms of location, and the K_{Histo} values describe the similarity of quantity. Values closer or equal to 1, mean that the two maps are more similar either in terms of quantity or location. We can expect land use classes such as rocks and water, to remain stagnant and have values of 1. Land-use classes such as closed forest on the other hand, will have much lower values, meaning that the forest cover of the simulated year differs significantly compared to the initial year.

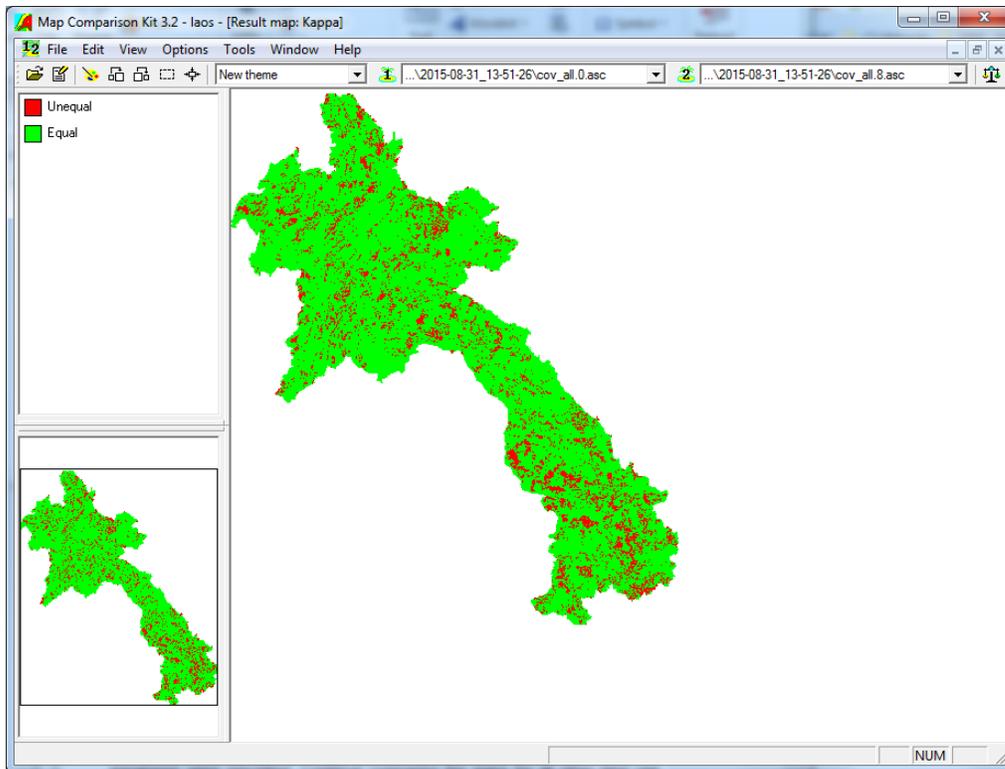


Figure 17. Comparing two maps in MCK using the Kappa algorithm.

The contingency table details the cross-distribution of categories on the two maps and is expressed in number of cells. In the Contingency table, we can see how much of each individual land use class, has changed into other land use classes. Take your time to study both tables and try to identify which classes witnessed most changes.

6. Simulating land use change scenarios (exercise)

In this exercise you will become familiar with CLUMondo's ability to model different scenarios. More precisely, you will deal with modifying and adjusting model parameters to define scenarios, and subsequently compare results from different scenarios.

6.1. Land use change scenario conditions

CLUMondo has a number of parameters that need to be specified before a simulation can be made. The setting of these parameters is dependent on the assumptions related to a particular scenario. You can define different scenarios by adjusting the following model parameters:

- Conversion resistance parameters
- Conversion matrix
- Scenario parameters

Scenarios allow the comparison of different possible developments and give insight in the functioning of the model also in terms of performing a sensitivity analysis of the model. Such analysis is most easily done by visual comparison or through the calculation of the difference between scenarios in a GIS or the Map Comparison Kit.

6.1.1. Conversion resistance parameters

The conversion resistance is one of the land-use type specific settings that determine the temporal dynamics of the simulation. The conversion resistance is related to the reversibility of land-use changes (Figure 18). Land-use types with high capital investment or irreversible impact on the environment will not easily be converted in other uses as long as there are land requirements for those land uses. Such land use types are therefore more 'static' than other land use types. Examples of relatively static land uses are residential areas, but also plantations with permanent crops (e.g., slow growing or expensive fruit trees). Other land-use types are more easily converted when the location becomes more suitable for other land use types or when more suitable locations become available that were previously unavailable. Arable land often makes place for urban development while expansion of agricultural land can occur at the same time at the forest frontier. An extreme example is shifting cultivation: for this land-use system the same location is mostly not used for periods exceeding two seasons as a consequence of nutrient depletion of the soil.

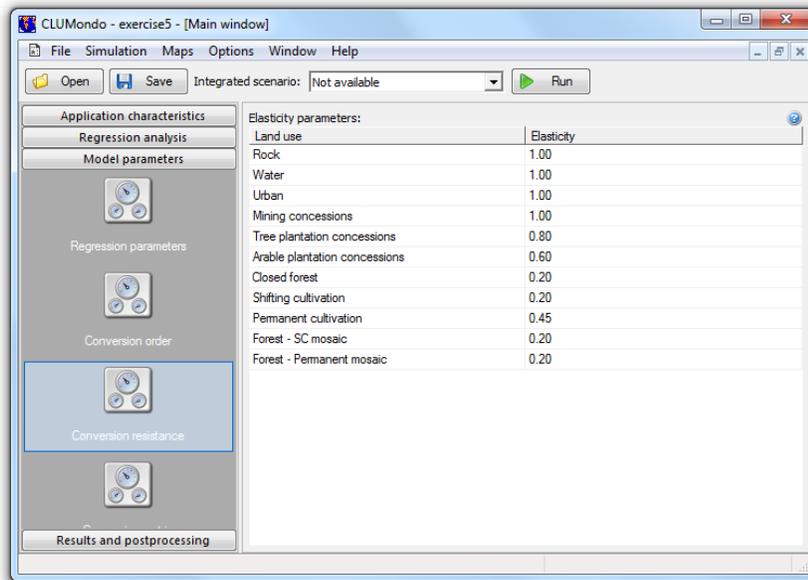


Figure 18. Conversion resistance parameters.

The differences in behavior towards conversion of the different land-use types can be approximated by the conversion costs. However, costs cannot represent all factors that influence the decisions towards conversion such as nutrient depletion, esthetical value etc. Therefore, in the model we have assigned each land-use type a dimensionless factor that represents the relative elasticity to conversion, ranging from 0 (easy conversion) to 1 (irreversible change). The user should specify this factor based on expert knowledge or observed behavior in the recent past. An extended explanation of the possible values of the conversion elasticity and how behavior changes when the land requirements increase or decrease in time is given below.

- 0: Means that this land use changes relatively easily and that all changes for that land use are allowed, independent from the current land use of a location. This means that a certain land-use type can be removed at one place and allocated at another place at the same time, e.g. shifting cultivation.
- >0...<1: Means that changes are allowed, however, the higher the value, the higher the preference that will be given to locations that are already under this land-use type and the less likely it is to move. This setting is relevant for land-use types with high conversion costs.
- 1: Means that grid cells with one land-use type can never be added and removed at the same time (i.e. in one simulation step). This is relevant for land uses that are difficult to convert, e.g., urban settlements and primary forests. A value of one stabilizes the system and prevents that in case of deforestation other areas are reforested at the same time.

For this exercise, we will increase the conversion resistance of the land-use class 'Closed forest'. This means that this particular land use is less likely to change in our scenario. Implementing numerous forest and agricultural policies will lead to less agricultural and urban expansion on the account of forests, and more on the account of other land use classes. Changes to the forest cover are still possible, but much less likely, and classes with lower conversion resistance will be preferred when simulating land-use changes.

- Before making any changes, run the model once, as described in the previous exercise. This run will serve as a reference against which we will compare our scenarios.
- In the user-interface of the CLUMondo model, select Model parameters/Conversion resistance and change the conversion resistance of the land use type 'Forest-SC Mosaic' to the value 0.8. Afterwards, click on the 'Run' button to start the simulation.
- When the model finishes its run, compare the results with the previous simulation results in the Map Comparison Kit. Add the final simulation map (year 10) to the MCK log file you generated in the previous exercise.
- Compare the simulation results with the initial year, for the land use type Forest-SC Mosaic (use the 'Per category'). What do you observe?
- Compare the simulation result of the reference scenario and the adjusted scenarios for the Forest-SC map (use the 'Per category').
- Finally, check the differences in other land-use types as well. Can you see how changing the conversion resistance of land-use also affects the allocation of other land uses? (use the 'Per category' or 'Kappa')

We can also simulate other scenarios modifying the conversion resistance parameter. For example, we could lower the conversion resistance of forest to 0, thus simulating a complete lack of forest protection.

6.1.2. Conversion matrix

The conversion matrix, which indicates what types of land-use conversions are allowed by the model (shown in Figure 19). The conversion matrix is actually text file that can be edited in a text editor as well as through the user interface. Rows of the matrix denote the present land-use type and columns the potential future land-use type. To define a conversion between two land uses, you can edit the matrix by defining values in the boxes with different options:

0: no conversion allowed

1: conversion is allowed

10x: Conversion is allowed after a specified number of years as the 'from' land use class. For example, 104 means a conversion is allowed after a cell has been 4 years in the 'from' land-use class, and 110 means a conversion is allowed after 10 years in this class only, etc. For instance, shifting cultivation can change to arable plantation only after 4 years. This option is only relevant for land-use changes, i.e.

those cells that are not on the diagonal of the conversion matrix.

-10x values are only relevant in the diagonal, as it defines how long a particular land use can remain in one location: The class cannot stay the same location for more than x years. For example, -103 for the land use type shifting cultivation means that shifting cultivation can stay in a location (i.e. no change) for a maximum of 3 years, and needs to change into something else after that. In the case a land use cannot stay the same, you must allow a conversion into another land use in order to run a simulation.

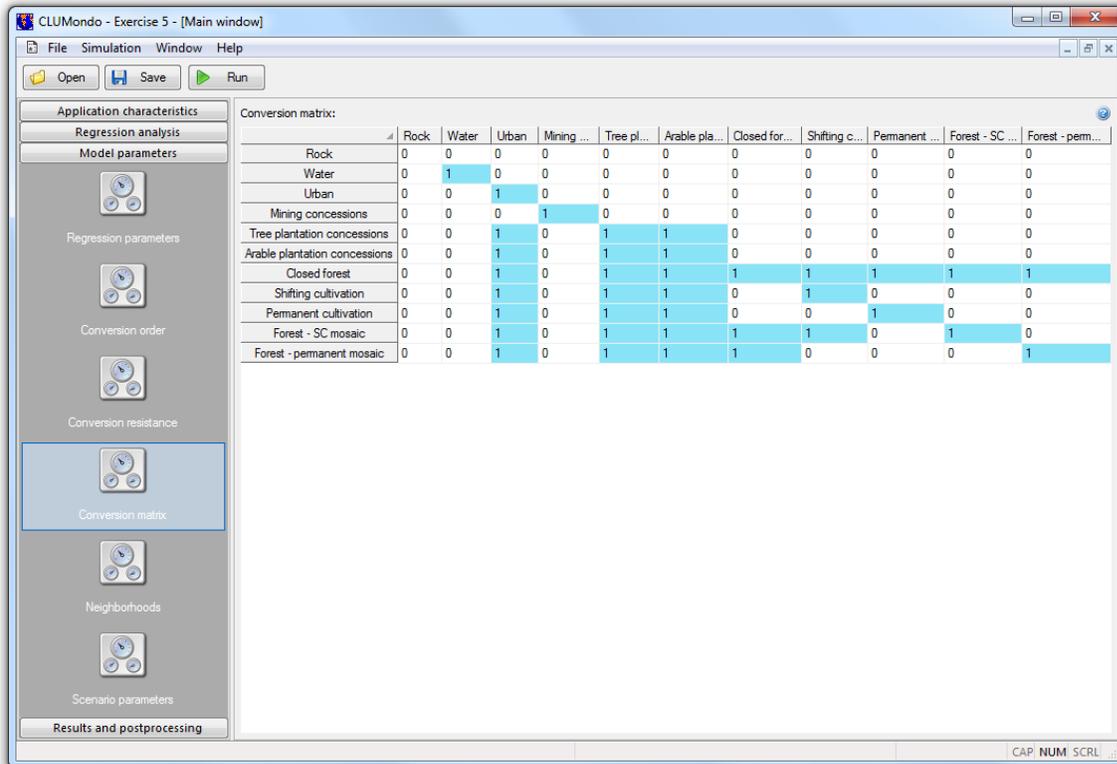


Figure 19. Conversion matrix.

Using the conversion matrix, we will now simulate a scenario where it is forbidden to clear forests in order to develop tree plantations. Tree plantations will still be possible, however, only at the expense of other (non-forest) land-use classes. This scenario can demonstrate how the demand for tree crops can be fulfilled by non-forest land use classes.

- Modify the conversion matrix in 'Model parameters/Conversion matrix'. Find the Row/column combination of 'Closed forest/Tree plantations' and enter the value 0.
- Run the model after modifying the conversion matrix. After the model finishes its run, display and compare the results in the Map Comparison Kit.

- In MCK, add the final simulated map to the existing .log file, developed in section 4.5. 'Display and compare simulation results'. Compare the results with the initial year, as well as with other simulation results.

In order to demonstrate the potential of the conversion matrix, we will try another scenario modifying this parameter. We will simulate a scenario, where all mining concessions will end after 5 years. This scenario can describe a set of different futures: the big mining operations are either closed due to environmental concerns.

- Modify the conversion matrix in 'Model parameters/Conversion matrix'. Find the Row/column combination of 'Mining concessions/Mining concessions' and enter the value -105. This way, we can be sure, that conversions are needed after 5 years.
- However, if mines are not allowed to remain mines after five years, it should be allowed (technically) to convert into at least one other land use, otherwise the model cannot find a solution. Therefore, allow the conversion from Mining into Closed forest in the conversion matrix by changing the 0 into a 1 as well.

Note: At the start of a CLUMondo simulation, each cell is assigned a random age. As some cells might already have the age 3 assigned, they might be subject to change after 2 years already.

- Run the model after modifying the conversion matrix. After the model finishes its run, display and compare the results in the Map Comparison Kit.
- In MCK, add the final simulated map to the existing .log file, developed in section 4.5. 'Display and compare simulation results'. Compare the results with the initial year, as well as with other simulation results.
- Instead of comparing the end years in the MCK, you can also introduce all year and compare with the initial situation. Using 'Per category' and selecting Mining, you can see that after each year,. A part of the mines disappear.

6.1.3. Scenario parameters

In the scenario parameters section (Figure 20), the user can state the duration of the simulation in years (e.g. 10 years after the initial land use situation), and also define the demands for each year of the simulation. The land use demands are model inputs and can also be edited in the file demand.in* in the CLUMondo\Laos\CLUMondoWorking folders. For each year of the simulation these requirements determine the total area of each land-use type that needs to be allocated by the model. The iterative procedure will ensure that the difference between allocated land uses and the land use demands is minimized.

Land use demands are calculated independently from the CLUMondo model itself, which calculates the allocation of land-use change only. Land use demands can be based on a range of methods, depending on the case study and the scenario.

The extrapolation of historic trends in the recent past into the near future is a common technique for example. When necessary, these trends can be corrected for changes in population growth and/or diminishing land resources. For policy analysis it is also possible to base the land-use demands on advanced models of macro-economic changes, which can serve to provide scenario conditions that relate policy targets for land-use change.

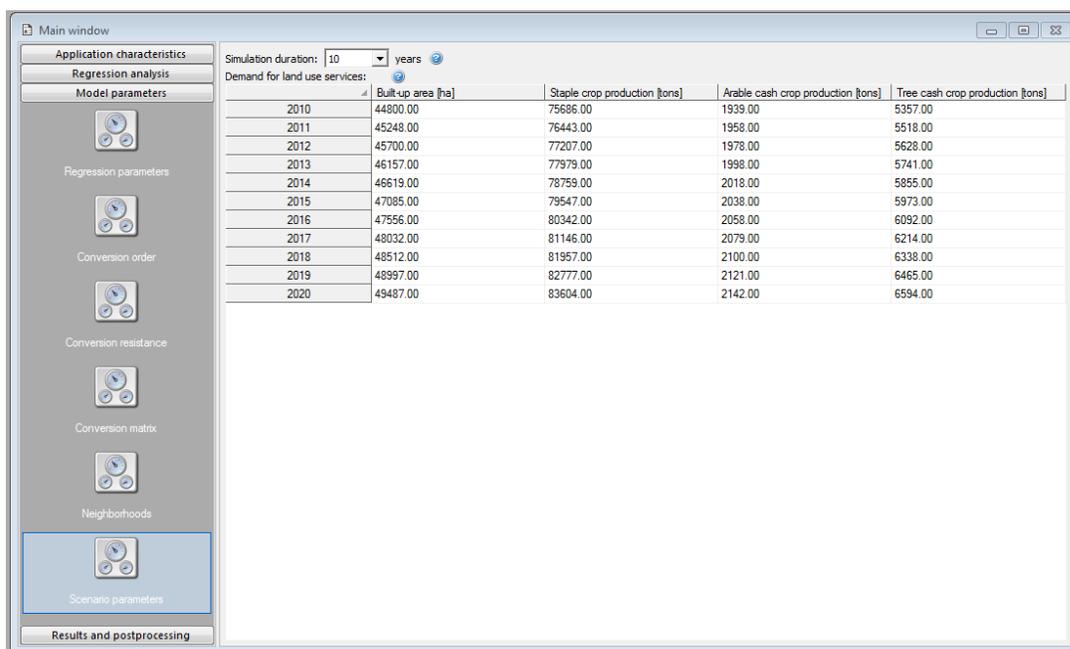


Figure 20. Scenario parameters.

We will adjust the demand scenario provided in the Laos application and create a more dramatic urban increase scenario. This scenario depicts a near future where the population in cities grows strikingly. This is accompanied by the increase of other built up areas such as infrastructure, industry, etc. More precisely, the urban areas will have a more than 10 % annual growth until between 2010 and 2020. Despite the fact that the scenario might seem extreme, we can use it to study the potential environmental effects of such development.

- Go to Model parameters / scenario parameters
- Here you can define your own scenario by changing the demand for land use services in Model parameters/Scenario parameters. In this case, we will change the demand for 'Built-up areas' for each year.
- Enter the following values for each year in the 'Scenario parameters' section (instead you can also copy a table from an excel file, using Ctrl + c and Ctrl + v):

year	Built-up areas [ha]
2010	44800
2011	53000
2012	57000
2013	64600
2014	73000
2015	80000
2016	87000
2017	93000
2018	100000
2019	110000
2020	120000

- Run the model after modifying the scenario demands. After the model finishes its run, introduce and compare the results in the Map Comparison Kit.
- In MCK, add the final simulated map to the existing .log file, developed in section 4.5. 'Display and compare simulation results'. Compare the results with the initial year, as well as with other simulation results.

7. Simulating spatial policies (exercise)

Several planning and policy instruments can be used to influence future land use change trajectories. In this exercise we will explore how you can include these measures in a CLUMondo scenario. For this, you need a map that indicates the areas for which the spatial policy is implemented. Some spatial policies restrict all land-use change in a certain area, e.g. when in a forest reserve all logging is banned. Other policies restrict a set of specific land-use conversions, e.g. residential construction in designated agricultural areas. In this exercise we will only address policies that restrict all land-use changes in designated areas.

7.1. Adding exclusion layers

Area restriction files can be used to indicate where land-use changes are not allowed. Example maps are supplied in the case study application and can be selected through the user-interface, in the 'Application characteristics' tab in the section 'Exclusion layers'.

The 'region_park.fil' file contains a protected areas map, designating the areas where land use change is restricted. The map is shown in Figure 21 but can also be imported in a GIS as an ASCII raster file similar to the procedure used to import the results of the simulations. The example spatial restriction file represents nature protection areas where land-use change is not allowed.

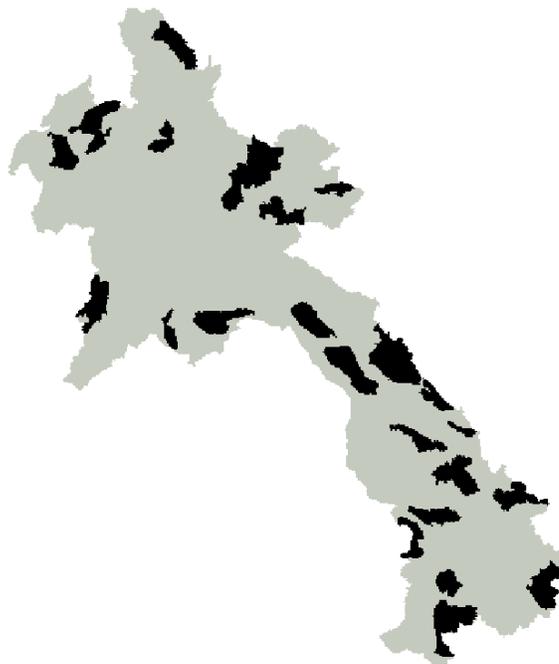


Figure 21. Example of spatial restrictions

- Start CLUMondo if it is not already open, and open the Laos application.
- Go to the 'Exclusion layers' section of the tab Application characteristics. Currently, the normal region map (no exclusion) is selected. Change this to the region_park exclusion layer, by clicking the radio button in front of it.
- Run the model again, without changing any other parameters. After the model finishes its run, display and compare the results in the Map Comparison Kit.
- In MCK, add the final simulated map to the existing .log file, developed in section 4.5. 'Display and compare simulation results'. Compare the results with the initial year, as well as with other simulation results.

7.2. Other exclusion areas

Next to national parks, other restrictions are possible, such as protecting areas near or adjacent to water bodies, areas on slopes on specific soils, or areas above a certain elevation. In this example we will use a map that excludes high elevation areas (areas above 1000 m). This spatial policy protects high elevation areas, that might be more vulnerable to environmental degradation as a consequence of land-use change. A few examples of such degradation are deforestation or drastic increase of urban areas in high elevation areas.

- Go to the 'Exclusion layers' section of the tab Application characteristics. Then, select 'region_1000.asc' as the exclusion layer..
- Run the model again, without changing any other parameters. Run the model again, without changing any other parameters. After the model finishes its run, display and compare the results in the Map Comparison Kit.
- In MCK, add the final simulated map to the existing .log file, developed in section 4.5. 'Display and compare simulation results'. Compare the results with the initial year, as well as with other simulation results.

Note: Using a GIS you can prepare your own exclusion layers. Examples can range from areas within a distance of a water body, areas above a particular slope, areas too far away from roads. You can introduce your own exclusion layer by clicking 'add exclusion layer'. Note also that these layers must have exactly the same dimension as your land-use map and regions map. More information about the data requirements can be found in the user manual.

8. Logistic regression analysis (exercise)

In this exercise you will analyze the significance of the suitability factors by performing a logistic regression analysis. A logistic regression analysis estimates the relation between one or more explanatory variables (such as soil type, elevation, and accessibility), and an explained variable (a specific land-use type).

- Start CLUMondo if it is not already open, and (re-)open the Laos application. Do not change any parameters.
- First, calculate the correlation values by clicking on the 'Update correlation matrix' button in the Regression analysis/Sampling section. CLUMondo will show that a calculation is being performed (Figure 22).
- When the calculation is finished, you will be able to see multicollinearity values in the lookup table. The values tell you, if any of the suitability layers are highly correlated with other suitability layers. For a proper analysis, suitability layers should be sufficiently different (i.e. not correlated)
- Select all relevant suitability layers. Layers can be selected for inclusion when their correlations are below 0.8. If one or more maps are significantly correlated (e.g. above 0.8), you can only select one of these maps, but not both. After you have selected the uncorrelated suitability maps, click on 'Take sample'.

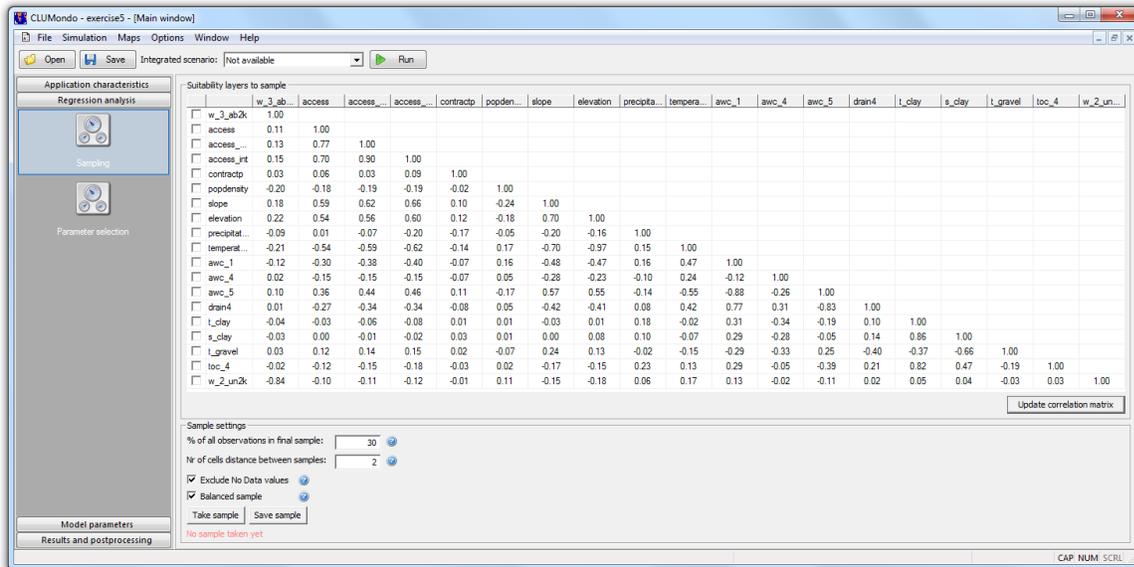


Figure 22. Calculating the correlation matrix

- Now you can calculate coefficients in the 'Parameter selection' section (Figure 23). Select a land-use type and calculate the coefficients, by selecting the (all) suitability layers and clicking 'Calculate coefficients'.

To qualify for inclusion, a suitability layer must be significantly related with the selected land-use type. This means that the value for significance should be below

0.05, and preferably below 0.01. As the parameter and significance values depend on the number of suitability layers, it requires some iteration to find the right set of suitability maps.

- Unselect the least significant suitability layer, as long as it is > 0.05 , and recalculate all values by clicking 'Calculate coefficients'. Repeat this until all suitability layers left are significant, and there are less than 7 suitability layers.
- In some cases CLUMondo will inform you with a message 'Could not find a stable solution. Check parameters'. In that case, unselect one or a few suitability layers and try again.
- After you have selected maximum 7 most appropriate suitability layers, calculate coefficients again, and click on 'Use this coefficients'. This way, you will update the 'Regression parameters' matrix in the 'Model parameters' tab.
- Perform the same step of parameter selection for each land use type, and use their parameter values.

Note: In the bottom of the 'Parameter selection' window, there is an information on the Area under the curve, the 'AUC' value. This value presents the accuracy of the calculated regression, and is described as a value between 0 and 1. Values over 0.9 present excellent accuracy, values between 0.8 and 0.9 good, and values between 0.7 and 0.8 present a fair accuracy. Values below 0.7 present a poor accuracy, and values below 0.6 can be considered as not good. This way, you can assess the selection of suitability layers and their regression coefficients in CLUMondo in real time.

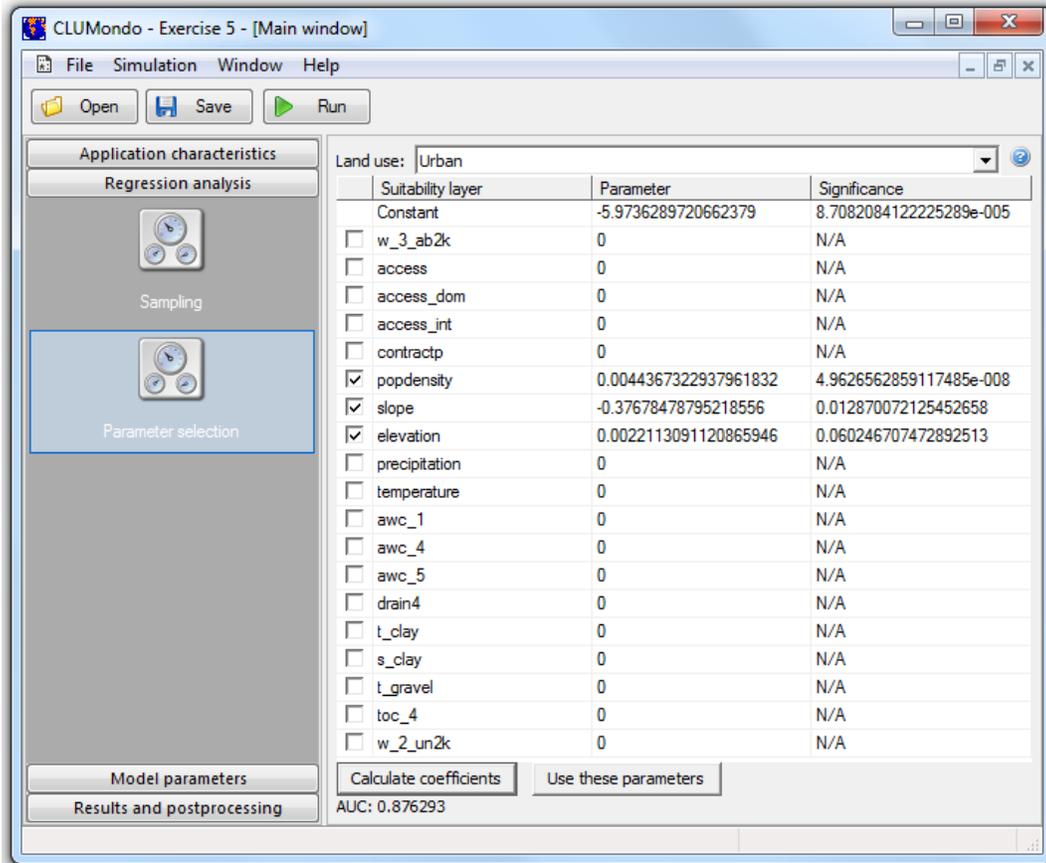


Figure 23. Calculating regression coefficients

9. Creating a new application (exercise)

In the previous exercises you explored the CLUMondo model and learned how to adapt the different input files and scenarios. In this exercise we will guide you step by step to create a new application for the Laos case study by yourself. More precisely, we will set up a land-use change simulation for the period 2010 to 2020 using exactly the same data that was used to develop the existing application for Laos.

Step 1: Starting a new CLUMondo simulation project

- Start CLUMondo, but do not open an existing application. Instead, start a new project through File/New project. Give it an appropriate name, such as 'New Laos application' and define the output directory (Figure 24). Click 'Next'.

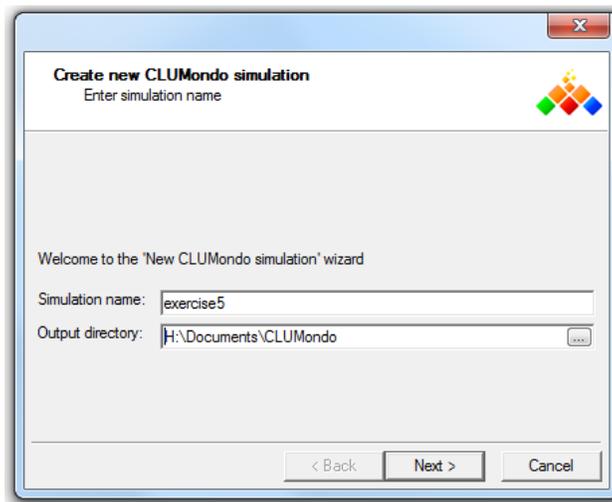


Figure 24. Creating a new simulation

- Indicate an initial land-use map and region map. You can find this data in the folder Laos/Data. Use the map 'cov_all.0.asc' for the initial land-use map, and 'region1.asc.' for the region map (Figure 25).
- The software automatically recognizes the number of land-use classes, but it doesn't know the name or legend associated with it, so you need to provide this. Edit the names of land-use classes and edit the legend colors following the example provided in Figure 26.

Note: After you have created your model application completely, it is not possible to change the names of the land-uses. Therefore, it is a good habit to provide complete names here, at once, rather than go over this step quickly.

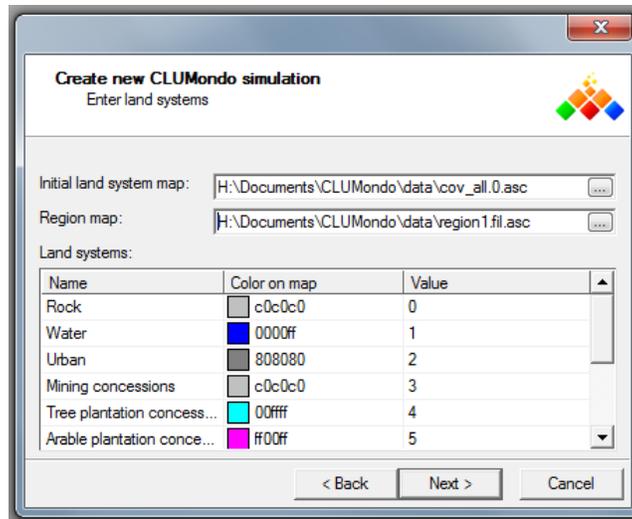


Figure 25. Define the initial land-use map and region map



Figure 26. Land-use classes and color legend example

- Click next when all land-uses have a name and a color.
- Define the start year of the simulation. This year should correspond with the year for which you have provided the initial land-use map. For the Laos application this is 2010.
- Define the land use services (i.e. goods or services for which you will define a demand later on in the model). To illustrate that these the relation between land uses and services is flexible, we will use two demands here: Built-up area [km²], and Staple crops [tons]. To facilitate the interpretation, it is a good habit to include the units here already (Figure 27). Note that these units are different from the ones in the example application.

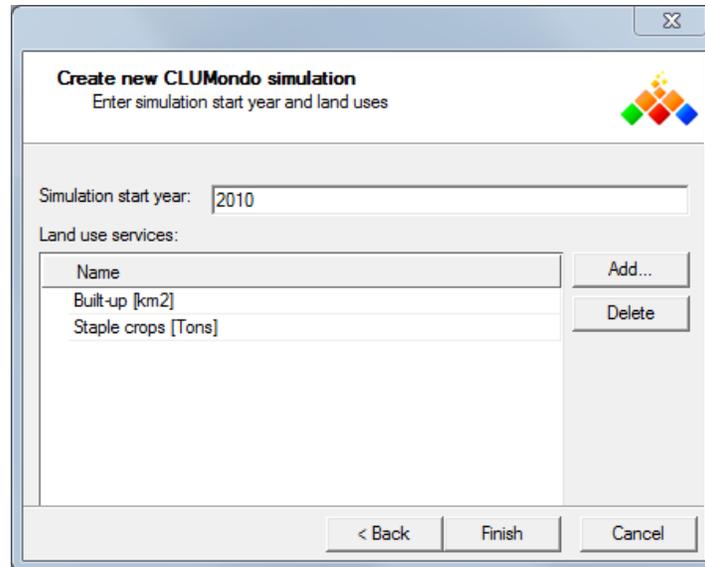


Figure 27. Defining the initial simulation year and adding land use demands

- Click on 'Finish' to complete setting up the application
- The project is now created, but you cannot run it, as there are no parameters in there yet, nor is there much data based on which you can simulate changes. In the next steps we will modify the application characteristics.
- You can save your progress anytime by clicking the 'Save' button, or by File/Save project. Remember saving your application every time you made changes to it.

Step 2: Modifying application characteristics

The next step is to fill the, yet almost empty, application with the necessary data. To start with, we will need to add suitability layers.

- In application characteristics/suitability layers, click 'Add suitability layer' and select sc1gr0.fil. Name it 'w_3_ab2k'. Select 'Create a new legend', and click on 'Edit legend'. This is a categorical map, and you can derive the legend automatically by selecting the 'Categoric' legend type, and clicking on 'Derive from map' (Figure 29). You can change the colors if you want. Click on 'Ok' and save the legend by type the name of the layer in the 'Create new legend' space.
- A detailed description of each layer is provided in 'Section 2. Case study'.

Suitability layers:

<input type="checkbox"/>	Layer name	File	
<input type="checkbox"/>	w_3_ab2k	H:/Documents/CLUMondo/data/sc1gr0.fil.asc	Show
<input type="checkbox"/>	access	H:/Documents/CLUMondo/data/sc1gr1.fil.asc	Show
<input type="checkbox"/>	access_dom	H:/Documents/CLUMondo/data/sc1gr2.fil.asc	Show
<input type="checkbox"/>	access_int	H:/Documents/CLUMondo/data/sc1gr3.fil.asc	Show
<input type="checkbox"/>	contractp	H:/Documents/CLUMondo/data/sc1gr4.fil.asc	Show
<input type="checkbox"/>	popdensity	H:/Documents/CLUMondo/data/sc1gr5.fil.asc	Show
<input type="checkbox"/>	slope	H:/Documents/CLUMondo/data/sc1gr6.fil.asc	Show
<input type="checkbox"/>	elevation	H:/Documents/CLUMondo/data/sc1gr7.fil.asc	Show
<input type="checkbox"/>	precipitation	H:/Documents/CLUMondo/data/sc1gr8.fil.asc	Show
<input type="checkbox"/>	temperature	H:/Documents/CLUMondo/data/sc1gr9.fil.asc	Show
<input type="checkbox"/>	awc_1	H:/Documents/CLUMondo/data/sc1gr10.fil.asc	Show
<input type="checkbox"/>	awc_4	H:/Documents/CLUMondo/data/sc1gr11.fil.asc	Show
<input type="checkbox"/>	awc_5	H:/Documents/CLUMondo/data/sc1gr12.fil.asc	Show
<input type="checkbox"/>	drain4	H:/Documents/CLUMondo/data/sc1gr13.fil.asc	Show
<input type="checkbox"/>	t_clay	H:/Documents/CLUMondo/data/sc1gr14.fil.asc	Show
<input type="checkbox"/>	s_clay	H:/Documents/CLUMondo/data/sc1gr15.fil.asc	Show
<input type="checkbox"/>	t_gravel	H:/Documents/CLUMondo/data/sc1gr16.fil.asc	Show
<input type="checkbox"/>	toc_4	H:/Documents/CLUMondo/data/sc1gr17.fil.asc	Show
<input type="checkbox"/>	w_2_un2k	H:/Documents/CLUMondo/data/sc1gr18.fil.asc	Show

Figure 28. Suitability layers example

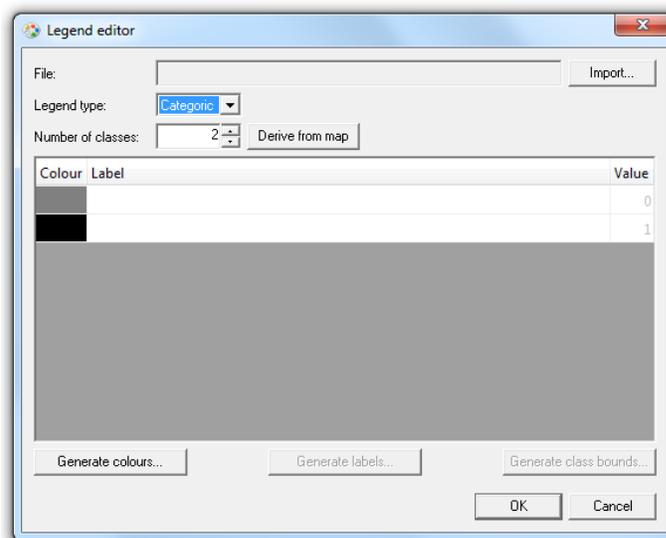


Figure 29. Legend editor for a categorical map

- Then, add 'sc1gr1.fil', and name it 'access'. This is a numeric map, so the legend will need to be derived differently here. Again, create a new legend. Select the 'numeric' legend type, and select 10 classes in the 'Number of classes' section. Afterwards, click on 'Generate class bounds', select

'Choose automatically', and click on the 'Find best scale' button (Figure 30). Close the window by clicking 'Ok' and click on 'Generate labels'. Finally, click on 'Generate colors' and select a color gradient by choice. After doing this, you close the window and define the name in the 'Create new legend' space. Do the same for every numerical map.

Note: You can also import existing legends in your future applications, so you do not need to edit the legends every time. After defining the name of a suitability layer and loading a map, select 'Create new legend'. Then load a legend file by clicking 'Edit legend/Import'. Type in the corresponding name for the legend.

- After you are done with adding the suitability layers, your 'Suitability layers' tab should look like the example on Figure 28. You can display any suitability layer by clicking on the 'Show' button.

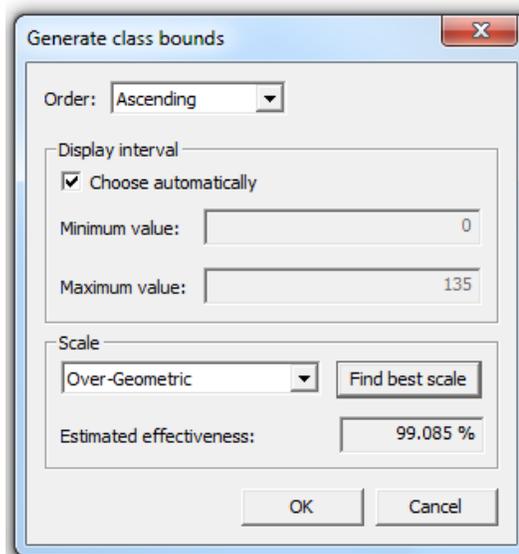


Figure 30. Generate class bounds of a numeric map.

In the next step, you need to define the 'Land-use services'. The land-use services matrix defines the productive capacity of one cell of a land use type for a specific land use service, e.g. for urban land per km, or yield for crops. These estimates are typically based on data, and depend on the unit you use.

For example, the demand for built-up area you introduced can be expressed in square kilometers. The resolution of one cell in the land-use map is 2 km, so one cells equals 4 km². However, in addition to urban land, you can also argue that there is a bit of built-up area in each cell with permanent agriculture, as there are the villages.

Similarly, Staple crops can be produced by multiple different land system, and in different quantities. One hectare of rice can produce about 4000 kg each year in Laos. But not all land in a cell with permanent agriculture is used for rice production, so we estimate the rice production of one cell as: $75\% * 4 \text{ [Ton/ha]} * 400 \text{ [ha/cell]} = 1200 \text{ Tons}$.

- Fill in the land use services matrix as provided by the example on Figure 31

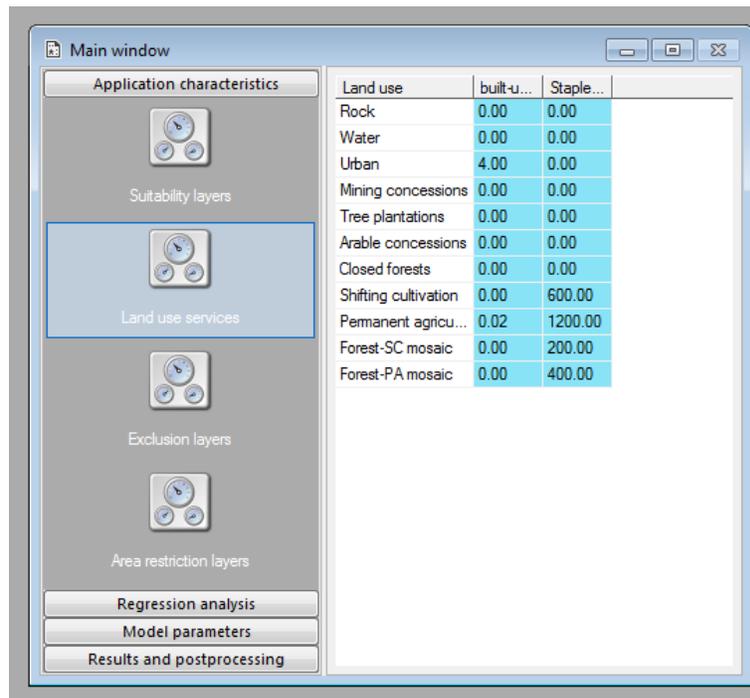


Figure 31. Land-use services matrix.

Note: when using your own data, you have define these values based on an analysis of the land-use system in your own study area. The values are based on average values of a specific land-use type to provide a land use service in a study area. Data used for such an analysis ranges from land cover maps, agricultural censuses, concessions, and expert opinion.

- The final step of the 'Application characteristics' section, is to define exclusion layers. In our example, we will use the provided map of the national parks network in Laos.
- Click on 'Add exclusion layer' and add the map region_park.fil, define the legend for a numeric map, as described in the Spatial policies section.

Step 3: Performing a regression analysis

The next step in creating your application is to conduct a regression analysis. For this we refer to the previous exercise on regression analysis. Note that the results of the regression analysis are required of each land use separately.

Step 4: Define the model and scenario parameters

After you have done a regression analysis, we need to fill all model parameters in the section model parameters. In some cases this means you can keep the default values assigned when creating the application, and in other cases this means you need to provide other values before you can run. A detailed description of the individual parts of 'Model parameters' is available in 'Land use change scenario modeling (Exercise)'.

First, you need to define the conversion order. The conversion order is a technical parameter that tells the model how to change land use to fulfill demand. Basically, cells get a integer value from low to high, where higher values indicate a larger supply. This means that all values that do not supply a good or service get a 0, and all land-uses that do supply a good or service get a value from 1 onwards.

- Land use order values for our example are provided in Figure 32.

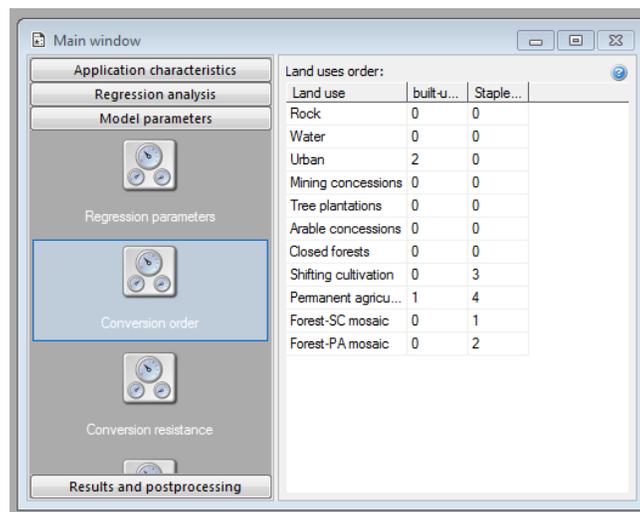


Figure 32. Land use order values

- Secondly, the conversion resistance factors need to be defined. As described in Exercise 2, these can range between 0 and 1. Example conversion resistance values for this application are provided in Figure 33.

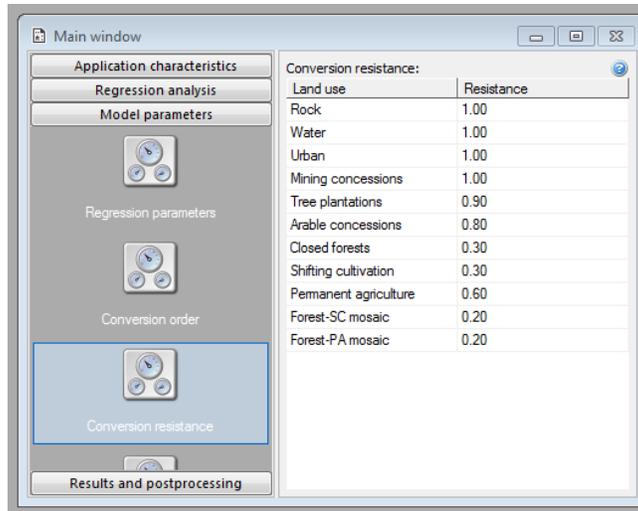


Figure 33. Conversion resistance values

- The next stage in preparing the model parameters is to define the conversion matrix. Here, you define which conversions are allowed, and the nature of these conversions in terms of temporal or spatial constraints. Please refer to the Conversion matrix section of Exercise 2 for a more detailed explanation on how to fill in the conversion matrix.
- The example conversion matrix values for the Laos study area are provided in Figure 34.

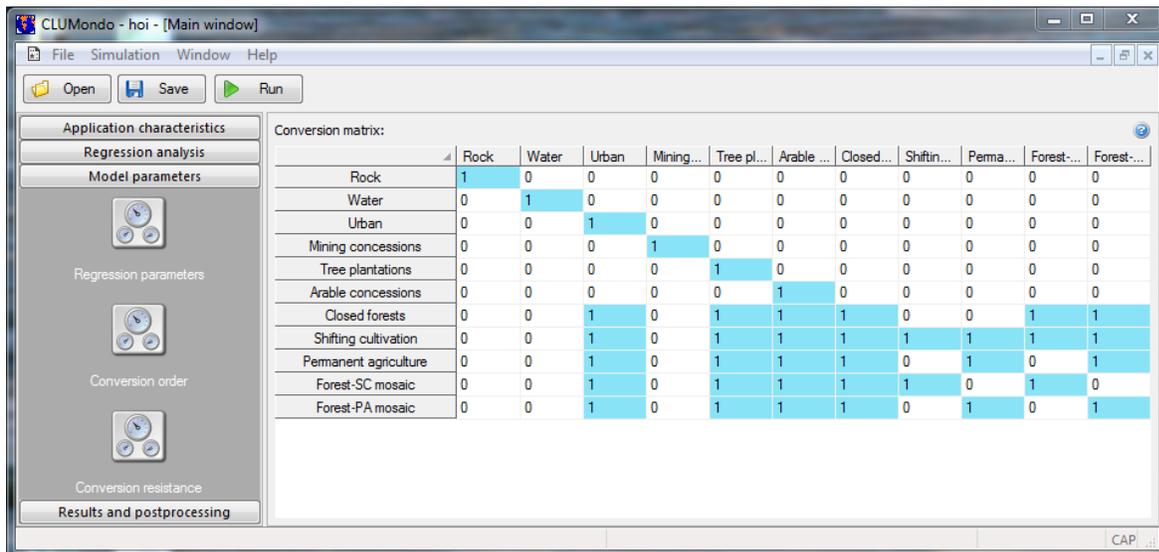


Figure 34. Conversion matrix example

Note: You can also copy the transition matrix from a spreadsheet software (e.g. Excel, Open office Calc).

The final stage of the model parameter preparation are the scenario parameters. The first step is to calculate the services that are provided in the initial land-use map. This depends on the values that you have identified for the 'Land-use Services', and the number of cells in each class in the initial map.

For example, in this document we suggested 4km² of built-up land per cell of urban, and 0.02 km² of built-up land per cell of Permanent agriculture. In the initial land use map, there are 112 cells with urban land, and 15655 cells of permanent agriculture. Hence in total there are $(4*112) + (0.02*14290) = 448 + 285.8 = 733.8$ km² of built-up land.

Similarly, you can calculate the Staple food production in 2010, which is 27 565 600 ton if you use the numbers that are suggested. Note that the number of cells in the initial land-use map can be derived relatively easily in the Map Comparison Kit.

Future land use demands are up to you to define, for example by using a yearly percentage of increase.

- Define the number of years you want to simulate, and enter the demands for specific land use services for each year of the simulation. To define the future land use change scenario, select 15 years in 'Simulation duration'.
- Then enter the example values for the demand for land use services for the year 2010 as provided by Table 2, which represent a 2% annual increase scenario.

Table 2. Demand for land use services.

	built-up [ha]	staple crops [tons]
2010	734	27565600
2011	748	28116912
2012	763	28679250
2013	779	29252835
2014	794	29837892
2015	810	30434650
2016	826	31043343
2017	843	31664210
2018	860	32297494
2019	877	32943444
2020	894	33602313
2021	912	34274359
2022	931	34959846
2023	949	35659043
2024	968	36372224
2025	988	37099668

Step 5: Running the simulation and displaying the results

After all the input files have been prepared, the statistical analysis has been performed and the model and scenario parameters were defined, you can run the model, by pressing the 'Run' button.

- After the model finishes its run, display and compare the results in the Map Comparison Kit.
- In MCK, add the final simulated map to the existing .log file, developed in section 4.5. 'Display and compare simulation results'. Compare the results with the initial year, as well as with other simulation results.

Congratulations! You have successfully set up and run a CLUMondo application from scratch. Feel free to explore the model by adjusting the model and scenario parameters, either by constructing new scenarios, or exploring the effects of extreme parameter/scenario values.

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