Simulating Europe in the 21 century

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This report describes a project carried out in the framework of the National Remote Sensing Programme (NRSP2) under responsibility of the Netherlands Remote Sensing Board (BCRS)

ABSTRACT

The project Simulation of Land Cover Dynamics (SIMILOR) aims at the understanding of the future of Europe’s urban and rural landscapes with special attention for the interaction processes in the urban-rural fringe. The project focuses on land use, land use change and the development of a spatial information system prototype that has the ability to translate current trends and alternative spatial planning scenarios into spatial images.

The prototype simulation model is applied to three test sites: Lisbon, Randstad Holland and Paris. For each test site a simulation of the period between 1984/86 and 1995/98 has been carried out and the results are compared with the actual found expansion and densification (derived from landsat-TM images). The major driving forces are then used to extrapolate the historic land use trends into the future. Finally alternative driving forces are used as input for simulation in order to assess the effects of different spatial policies on future land use.

With the development of this prototype spatial information one is able to assess the impacts different driving forces and alternative spatial planning policies on the development of land use in Europe.

EXECUTIVE SUMMARY

This report describes the results derived in the framework of the BCRS project "Simulation of Land Cover Dynamics" (4.2/DE-06). The aim of this project was to develop the understanding of the future of Europe’s urban and rural landscapes with special attention for the interaction processes in the urban-rural fringe. The project focuses on land use, land use change and the development of a spatial information system prototype that has the ability to translate current trends and alternative spatial planning scenarios into spatial images. In this report the role of remote sensing in the field of land use simulation or scenario planning is a major consideration.

The report starts with discussing the general concepts behind land use simulation. Attention is given to a wide range of topics relevant for land use simulation: information sources and their availability, data extraction, manipulation and integration, modelling, analysis and evaluation methodologies, forecasting and scenario planning.

With the knowledge obtained a prototype spatial simulation model is constructed. In this report the specifications and theoretical background of the information system are described. Moreover, an extensive coverage of the data-component is given focussing on the availability of European databases that describe land use and other additional data needed to perform land use simulations.

The prototype simulation model is applied to three test sites: Lisbon, Randstad Holland and Paris. For these test sites the locational pattern of the urban expansion and densification in the three test sites between 1984/86 and 1995/98 are derived from historical and recent satellite imagery. After deriving the historic land change and identification of the major driving forces in the urban rural fringe for each test site a correlation analyses is carried out to determine the contribution of the different driving forces. Next a regression analyses is performed to derive a regression equation that describes the processes of urban expansion and urban densification in the three test sites

The regression equations obtained with the statistical analysis are used as input for the simulation of land use. For each test site first a simulation of the period between 1984/86 and 1995/98 has been carried out and the results are compared with the actual found expansion and densification. These equations are then used to extrapolate the historic land use trends to the future in the three test sites and to assess the effects of alternative planning scenarios on future land use.

The report concludes with recommendations and conclusions with a special focus on the role of remote sensing in the simulation land use in Europe.

The main conclusion of the report is that remote sensing plays an important role in establishment of European land use databases. The advantages of the use of remote sensing is that the derived land use databases can be characterised as consistent, detailed, fixed in time and can be updated frequently. For the detection of land use changes in Europe, needed for instance to determine a trend that can be used for the simulation of future land use, remote sensing is also preferred above e.g. statistical databases. The use of satellite data on regional scale makes it possible to determine the land use changes on an objective manner throughout Europe, whereas most of the available statistical databases differ in nomenclature and detail.

This report shows that the chosen approach is appropriate to extrapolate historic land use trends in the urban-rural fringe to the future and defining alternative spatial planning scenarios. This makes it interesting to apply the methodology to other land use types and different scale levels.

PREFACE

Land use in Europe's urban and rural areas is subject to changes due to demographic, economic and socio-cultural developments. This is shown by the change in urban structures (e.g. urban sprawl) and the changing role and functions of rural areas (e.g. intensification / marginalization). In order to interpret these changes and their impact on man and environment, information on the location of land use and trends in land use change are needed. In recent years a number of European databases have been established and initiatives regarding monitoring land use change in Europe have been developed. Moreover, with the adoption of the European Spatial Development Perspective (ESDP) at the European ministerial conference in Tampere the subject has also returned to the forefront of politic and public attention.

In order to understand future developments in land use and their effects, just mapping and monitoring are not sufficient. Extrapolation of currently found trends and the development of long term alternative planning scenarios and translation of these scenarios in spatial images that show the effects of these alternative spatial developments on land use is also essential to gain insight in the driving forces behind land use change in urban and rural areas and the effects of these changes on man and environment

With the development of a prototype spatial information system that has the ability to simulate future land use one is able to assess the impacts of different driving forces on the development of land use in a certain area.

It was decided to focus on land use changes in the rural-urban fringe for the test sites of Lisbon, Randstad Holland and Paris. The historical urban expansion and densification in the period 1984/86 - 1995/98 in terms of amount and pattern are derived from satellite images.

Future urban expansion and densification is simulated showing future urban developments in the test sites assuming that current trends in land use change are, to a certain extend, still valid in the future. This approach makes it also possible to assess the effects of alternative land use scenarios, for instance the establishment of an airport and a double land use claim.

Land use simulations can be of great importance for planning, its quantitative outcome can support the planning process which is nowadays mainly qualitative orientated.

The authors of the report like to thank Rui Julião of the Universidade Nove de Lisboa, Portugal for his help obtaining data for the Lisbon test site, help with the regression analysis and sharing his knowlegde about the driving forces behind land use change in the Lisbon area with us.

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1.1 Context

Land use in Europe's urban and rural areas is subject to changes due to demographic, economic and socio-cultural developments. This is shown by the change in urban structures (e.g. urban sprawl) and the changing role and functions of rural areas (e.g. intensification / marginalization). In order to interpret these changes and their impact on man and environment, information on the location of land uses and trends in land use change are needed. In recent years a number of European databases have been established (e.g. Mücher, 2000, Loveland et al., 1999; van de Velde et al., 1994 and CEC, 1993). Initiatives regarding monitoring land use change in Europe have been developed over the years (e.g. the MARS program, the CORINE program and the MURBANDY project). Moreover, with the adoption of the European Spatial Development Perspective (ESDP) at the European ministerial conference in Tampere it is illustrated that the subject has also returned to the forefront of politic and public attention.

In order to understand future developments in land use and their effects, just mapping and monitoring are not sufficient. Extrapolation of currently found trends and the development of long term alternative planning scenarios and translation of these scenarios in spatial images that show the effects of these alternative spatial developments on land use is also essential to gain insight in the driving forces behind land use change in urban and rural areas and the effects of these changes on man and environment

1.2 Objectives of the study

The aim of this project, funded by the BCRS, is to show possible (historical and future) spatial developments of Europe's urban and rural landscapes with special attention for the interaction process in the urban-rural fringe. The project focuses on land use, land use change and the development of a spatial information system prototype that has the ability to simulate and predict changes in land use or land cover. Information sources and their availability, data extraction, manipulation and integration, modelling, analysis and evaluation methodologies, forecasting and scenario planning are all major considerations. One of the main strating points of the project was not to develop a totally new spatial information system but to use existing databases and models and to adjust them to the specific requirements for simulation of urban dynamics in Europe.

1.3 Activities during the project

During the project a number of activities have been carried out. These activities can be divided in two main parts. Firstly, gaining insight in the processes behind land use, land use change and current developments in land use simulation. In this scope an extensive literature review has been made and a workshop has been organised. Originally the workshop was scheduled after complementation of the project but in order to make use of the existing knowledge on the subject and to inform potential users of the project it was decided to organise the workshop in an earlier stage. Secondly, the prototype spatial information system has been developed. The following activities were carried out:

Selection of remotely sensed derived databases with a land-use map of Europe.

- Gathering of spatial data concerning physical suitability, spatial relations between land-use types and (intra) governmental policies that influence the land-use distribution in Europe.
- Classification of historical high-resolution spaceborne satellite data of three sites throughout Europe (Rotterdam, Paris and Lisbon) that are characterised by a specific urban morphology and developments in land-use dynamics.
- Establishment of a prototype of a spatial information system that simulates future land-use for the three test sites and on a European scale level.
- Testing of the prototype by simulation of future scenarios based on historic land-use dynamics in the three test sites.
- Demonstration of the prototype for the anticipated end users (RIVM, EEA and RPD) and a study aimed at investigating the incorporation of the project results in policy related reports of the RIVM, EEA and the RPD.
- Feasibility study of the added value of remote sensing derived data in this project in comparison with alternatives.

1.4 Contents of the report

The report starts with a discussion of the concepts behind land use simulation. Chapter 3 and 4 describe the spatial information system that is build to simulate future land use. The first chapter (3) focuses on the specifications and theoretical background of the information system. An extensive coverage of the data-component is given in chapter 4. The role of remote sensing in the project is described in chapter 5, with a special focus on the use of satellite imagery to derive different scenarios for land use changes. Chapter 6 discusses the underlying forces that cause change in the urban-rural fringe. The statistical analyses carried out to explain the locational pattern of the urban expansion and densification in the three test sites between 1984/86 and 1998 is described in chapter 7. The simulation results obtained by applying the historical statistical relations (derived in chapter 7) in the spatial information system are described in chapter 8. In the last chapter the derived conclusions and recommendations are given.

2 CONCEPTS

2.1 Land use and land cover

Before we can start discussing land use change and land use simulation, we should clearly define land use. In general land use refers to 'man's activities which are directly related to the land '. Examples of land use classes are: housing, forestry, industrial areas, grazing land, recreation area, etc. It is the purpose for which the land is used that determines the land use class. As a result of land use at a certain moment in time we distinguish land cover (Mücher et al., 1993). Examples of land cover are: forest, grassland, artificial land, etc. Land cover is very much related to land use and definitions of land use and land cover are therefore often confusing. In respect to this study we will focus on land use and we will distinguish land use and land cover according to the above definitions.

2.2 Land use change & land use simulation

Land use at a particular location at one point in time may be explained very simply by a small number of physical or climatic factors, such as altitude or temperature. However, in the densely populated Europe land use is often the result of the combination of a range of interdependent factors and land use change is the result of the complex dynamic interaction between physical and socio-economic trends. In Europe market forces often determine land use change with certain more accessible or advantaged areas commanding higher bid rents than other areas with different relationships between demand and supply. Von Thunen's classic theories are well known in this context. But Europe also has a long tradition of socio-political influenced planning control ensuring that certain areas are not necessarily sold to the highest bidder or that land use does not reflect the use prepared to pay the highest rent.

When trying to forecast future land use and land use change it is important to understand the interaction between physical environment, socio-economic and socio-political trends and to identify driving forces that describe these trends. In some cases these drivers will be extrapolations of historical trends in key variables, such as temperature and rainfall in existing climate models. In other cases, they may be particular developments in technology that will change the way people behave (e.g. the role of ICT development on the location on offices) or the goods and services that people require that indirectly lead to the rise and fall of certain industrial land use types. On the other hand, driving forces may be identified as part of the policy-making process. Regional planners, for example, may wish to maintain green belt areas at all costs or concentrate new industrial developments on wasteland. In all of these cases, scenarios are required that describe our visions of the future in a consistent way.

Scenario planning has the great benefit of providing policy-makers with the opportunity to make some evaluation of the implications of alternative investments, decisions or policies on future land use. An increasing number of computational modelling techniques are being adopted and developed by different groups of researchers in Europe and elsewhere for applications in the context of land use change. Grothe (1998) distinguishes four different model approaches on basis of the basic principles and methodological backgrounds:

1. Location models that take the locations as starting point to determine locational preferences of certain functions or land uses types (e.g. Kidner et al., 1999, Chuvieco, 1993).
2. Choice models that describe the allocation preferences of individual actors on basis of individual decision process (Timmermans, 1984)

3. AI-models derived from the field of Artificial Intelligence. Examples of these allocation algorithms are Neural Networks (NN), Genetic Algorithms and Cellular Automata (CA). Applications of AI-models in the field of allocation planning are e.g. described by Raju et al. (1998), Pereira et al. (1994), Wu, (1996) and White et al. (1997).
4. Spatial interaction models are those models that are derived from the classical location theories of which those of von Thünen, Webber and Christaller are the most known. An early example is the Lowry model (e.g. Webber, 1984). The Euroscanner used in this study is an example of a more recent application of this type of spatial interaction model in which the locational preferences of all land use types are considered.

Whatever the methodology, it is necessary to calibrate land use simulations on the basis of historical information and to ensure that the prediction for the observed point in time is within certain limits of acceptability. Once the model parameters have been estimated, they are assumed to stay fixed or to change according to some trend over time, and future simulations can be prepared.

2.3 Scenario Planning

Spatial planning has returned to the forefront of public attention. In Europe this is illustrated by the recent (1999) adoption of the European Spatial Development Perspective (ESDP) at the Ministerial conference in Tampere. On a national and regional level this is e.g. represented by the, for the year 2000, scheduled release of both the first Regional Plan for the Lisbon Metropolitan Area (Protalm) in Portugal and the Fifth National Physical Planning Report in the Netherlands.

The use of geographic information for spatial planning has a long tradition and is almost common place. However, little attention has been given to the use of scenario planning tools or land use simulation models. The application of these techniques provides policy-makers the opportunity to make an evaluation of the implications of alternative investments, decisions or policies on future land use. An example includes the regional land use effects triggered by the formulation of specific development projects as the construction of a new airport (Scholten et al., 1999). A step further is the assessment of the impact of simulated land use change on different aspects of space and the environment in order to facilitate the (political) discussions, that are an essential part of strategic planning (e.g. Schotten, 1999; Young and Bowyer, 1996).

2.4 Remote sensing

One of the key requirements in our understanding of land use patterns and land cover is the availability of comprehensive, consistent and reliable data. Information is obtainable from various sources, but satellite remote sensing images of the earth’s surface are one source from which it is possible to produce land cover maps for Europe at increasingly refined levels of spatial resolution (e.g. Mücher., 2000, Loveland et al., 1999 and CEC, 1993). One of the major advantages of the use of remote sensing is the consistency of data across regions and nations. These benefits accrue even more distinct if remotely sensed derived data can be integrated with other types of geographical data to provide ‘improved products’ containing additional information (Wilkinson, 1996).

Remote sensing can also play an important role in the management of urban growth by detecting land use changes. According to Deursen et al. (1999) three types of urban land use changes occur: morphological, functional and socio-economic changes. Morphological changes are related to conversion of land use like the replacement of fields by houses. Functional changes are related to the function of urban areas: for instance the conversion of industrial in residential areas. Socio-economic changes are related to characteristics as income and employment situation. With remote sensing morphological changes can be detected, whereas additional GIS data is needed to gain information on functional and socio-economic changes.

In literature several studies are described that show the use of remote sensing in urban growth management and urban growth modelling. Yeh and Li have performed different studies that describe the use of satellite data for land use change detection and impact analyses on land resources (e.g. Yeh and Li, 1997; Yeh and Li, 1998; Li and Yeh, 2000). In their 1997 study they describe the general aspects of use of satellite data for land use change detection and impact analyses. In their two recent studies they describe different uses of satellite data. In their 2000 study they derive the initial state of land before simulation from satellite data, whereas in their 1998 publication they derive the type, amount and location of land use changes that form the input for a simulation of alternative land use scenarios.

Within this project remotely sensed derived data is used to determine current land use and recent changes for both Europe and the selected test sites before simulation. For the three selected test sites satellite images are used to derive amount and location of urban expansion and densification that has occurred over the last 12-14 years. These representations of urban dynamics form input for historical regression analyses. The derived regression equation is used to calibrate the simulation model and, together with from satellite data derived urban land use demands, to simulate future land use trends in the urban rural fringe.

2.5 Integration framework

The development of a framework for data manipulation and integration is a key dimension in land use simulation. This implies that there is an IT infrastructure with adequate storage facilities for very large European data sets, rapid query, retrieval and display plus facilities to allow data analysis, modelling and projection of model inputs and results.

The present generation of Geographical Information Systems (GIS) provides suitable environments for data management, storage, query and display which facilitate the important task of monitoring land use and land use change. Also the use of the in GIS incorporated spatial analytical functions to assess relevant spatial patterns is widely used to define performance indicators that quantify the changes taking place and making judgements about the necessity for and type of intervention steering these changes. The possibility to simulate land use changes however is still not found in conventional GIS packages. Therefore, it is decided to develop a spatial information system for Europe making use of existing databases and models and to adjust them to the specific requirements for simulation urban dynamics in Europe.

Main issue in the construction of a framework for the whole of Europe is the question of spatial resolution that is required to provide sufficient detail to describe the driving forces and the process of urban - rural land use change. For Europe a 2 by 2 kilometer grid is defined covering almost the whole EU (twelve countries). For this grid the current land use is stored together with additional GIS data that can be used for simulation on a European scale. In order to gain insight in the driving forces at the urban - rural fringe, grids with a more detailed resolution (500m) were used for three test sites throughout Europe (Paris, Lisbon and Rotterdam). The mixed approach enables to detect and interpret urban dynamics occurring in different parts of Europe and to incorporate additional data not available on a European scale. Moreover, it gives the opportunity to simulate land use making use of historical trends found in each of the test sites. So is it possible to apply the found relations between urban change and driving forces in for example Lisbon to the test site of The Netherlands or to see how the urban structures in Europe will change as both the demands and locational preferences of Paris are used.

By providing a simulation model that is able to display, query, allow analysis on data on current land use and driving forces and that is running rapidly under different scenario assumptions it becomes the spatial decision support system that can be used for planners on a regional, national and European scale.

3 THE EUROSCANNER: MODELSPECIFICATIONS

3.1 Introduction

Part of the project consist of the development of a prototype spatial information system that has the ability to simulate changes in land use or cover; the so-called Euroscanner.

Aim of the Euroscanner model is to make the implications of (autonomous) sectoral demands for space and the spatial policies that determine the location for these demands explicit on a high resolution level for the whole of Europe and the three selected test sites. The model is grid based and simulates land use in relative proportions at a spatial resolution of 2 by 2 kilometers for Europe and 500 by 500 meters for the test sites. The outcome of the model can be interpreted as expected proportions of land use in each grid cell. In figure 3.1 the overall conceptual structure of the model is presented.

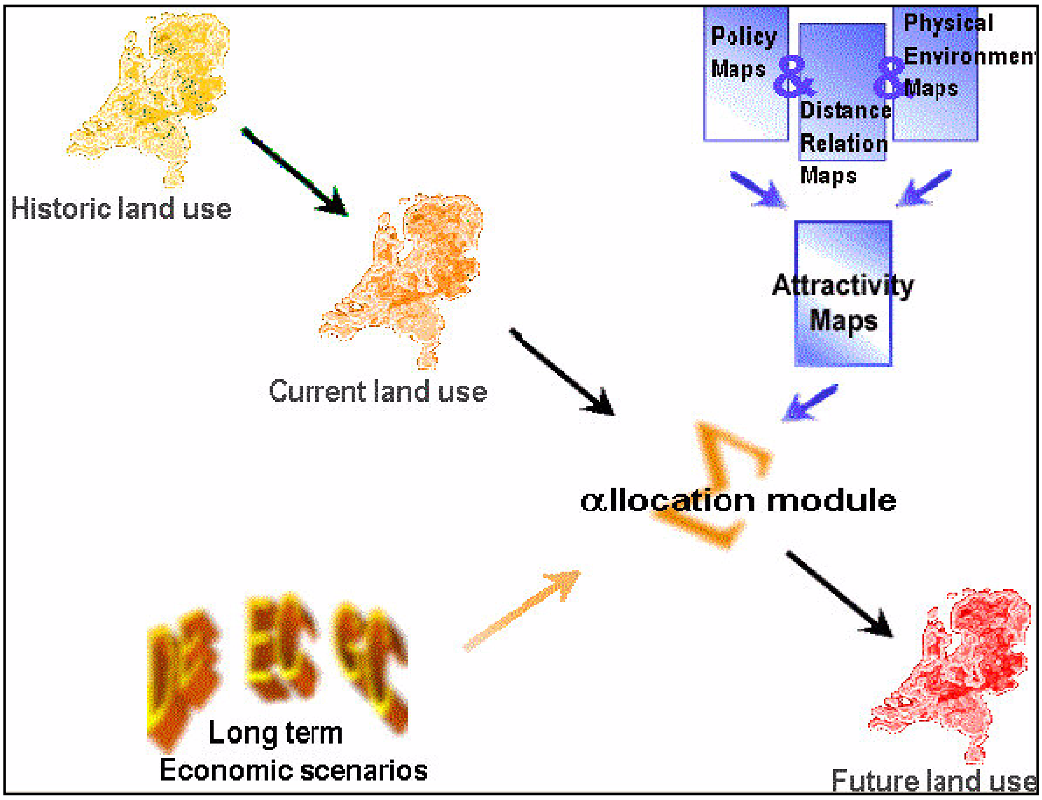

Figure 3.1: Overall structure of the EuroScanner

Starting point for each simulation is information on the current land uses.

A database contains future demands of space for the distinguished land use types. This database can be filled with the outcomes of sectoral models, which forecast land use claims at a much lower level of spatial resolution (e.g. the whole country or regions). Another possibility, used for the three test sites, is to extrapolate the future demands from historical trends derived from satellite images. Because we are not only interested in the quantity of land use change but also at the specific location land use changes occur it is necessary to identify the driving forces that determine the conversion of one land use type to another. For each land use type a so-called suitability map is constructed in which all the driving forces for that kind of land use are made spatially explicit. This suitability map is a combination of maps that show relevant politic regulations (e.g. housing planning regulations and nature conservation plans), physical properties (e.g. seismic hazard, yield reduction) and characteristics in relation to neighbouring cells (e.g. the presence of infrastructure and the deduced accessibility). In principle there are 2 different approaches in deriving the suitability maps, both applied in this study. A quantitative approach is to map historic land use change and to find mathematical relations with the selected driving forces by means of regression analyses. A more qualitative way is to use expert knowledge to select, combine and attoch weights to the maps that represent the driving forces. The quantitative approach can be applied to extrapolate historic trends to the future. The qualitative approach can be used to map the effects of new, or changed, driving forces on resulting land use patterns (e.g. the role of ICT development on the location on offices) or to determine the beneficial effects caused by alternative investments, decisions or policies.

To simulate future land use, maps of current land use, demands and suitability maps are all fed into the model engine. As mentioned at the beginning of this paragraph, the outcome exists of relative proportions per land use type in each grid cell that can be interpreted as the expected proportions.

3.2 European coverage and site selection

For the simulation of land use in Europe a grid is defined with a resolution of 2 x 2 kilometers. The grid covers the whole western part of Europe. In the west it is delimited by the Irish Sea west of Great Britain, in the east by the eastern boundary of Austria, In the north the boundary of the grid runs half way through Norway and Sweden and is delimited by the Mediterranean sea in the South. In Appendix I a list of countries included in the grid is given.

Apart from the European level, land use can be simulated on a regional scale (500m cell size) for the three test sites. The size of the grids for the individual sites is determined by the size of the Landsat TM-scenes used.

The test sites of Rotterdam / The Hague, Paris and Lisbon were selected on the criteria listed in table 3.1.

Table 3.1. Selection criteria for the test sites.

Criteria	**Rotterdam**	**Paris**	**Lisbon**
City structure	Multi nuclear agglomeration	Mono nuclear agglomeration	Mono nuclear agglomeration
Planning policy	Strong national planning	Strong national planning	Only recent municipal planning policy
Land use dynamics	Moderate	Moderate	High
Data availability	High	Low	High

Paris can be characterised as a mononuclear metropolis with moderate land use dynamics and a strong national planning policy. Lisbon has also a mono nuclear city structure, however the city is not as extended as Paris. The land use in Lisbon and its surroundings is highly dynamic and only recently there is a municipal spatial planning policy[1]. Rotterdam, as a part of Randstad Holland, is a multi nuclear agglomeration with moderate land use dynamics and a strong national planning policy that dates back some fifty years.

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[1] The first municipality plans were started in the eighties but not finished and approved before the nineties

For the selection of the three test sites also more practical aspects, like the availability of data, have been selection criteria. For Lisbon an extensive set of data was obtained from the Universidade Novo de Lisboa describing nearly all aspects that are relevant to describe the driving forces in Lisbon and surroundings. Also for the Netherlands this additional information was available from previous applications of the Ruimtescanner (e.g. Van de Velde et al., 1999 etc), the Dutch equivalent of the Euroscanner. For Paris no additional data was available, only data from European data sources was used.

3.3 Model architecture

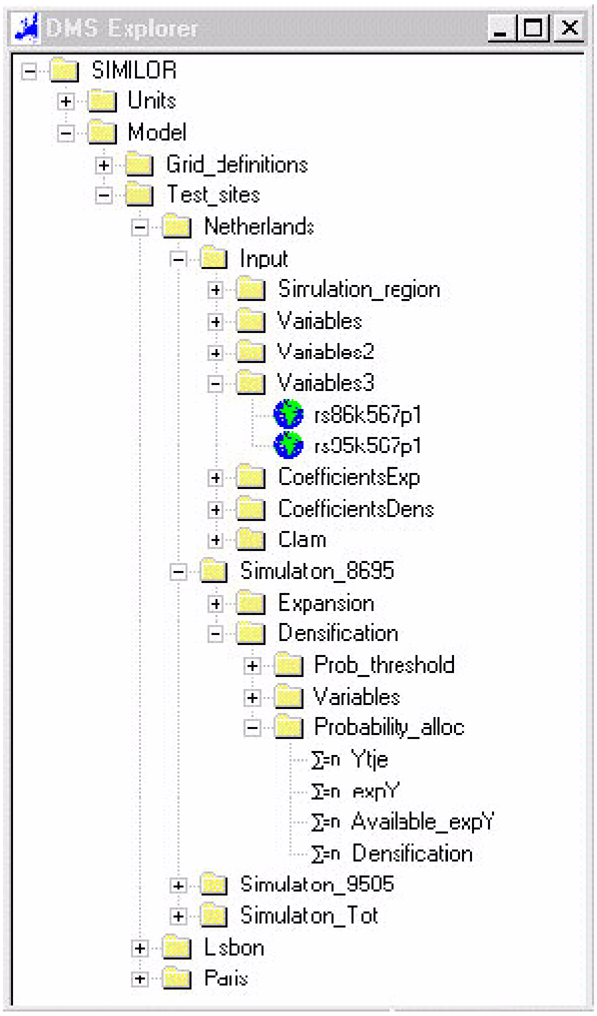
The Euroscanner model has a so-called three tiered architecture in which a fundamental distinction is made between the:

- Graphical user interface
- Model and computing subsystems
- Database or data warehouse subsystem

Advantage of this three tiered architecture is that the individual parts of the model can be developed or altered independently.

The two main tasks of the Graphical User Interface or GUI are visualisation of data and model results and the communication between user, model and database subsystem, also known as the Data Model Server (DMS). The communication between the user and the DMS is established with a tree-structure that represents a graphical reproduction of the DMS and has more or less the same look and feel as the explorer of Windows (see figure 3.2).

The DMS manages input data, the computing subsystem (in our case a land use allocation algorithm) and the results. The tree structure gives the user the opportunity to reduce complex scenarios into small elementary steps and gives insight in relations between data, scenarios and results. With the Euroscanner one is able to view input data regarding current land use, driving forces and land use demands.



- SIMILOR
  - Units
  - Model
    - Grid_definitions
    - Test_sites
      - Netherlands
        - Input
          - Simulation_region
          - Variables
          - Variables2
          - Variables3
            - rs86k567p1
            - rs05k567p1
          - CoefficientsExp
          - CoefficientsDens
          - Clam
        - Simulation_8695
          - Expansion
          - Densification
            - Prob_threshold
            - Variables
            - Probability_alloc
              - Ytje
              - expY
              - Available_expY
              - Densification
        - Simulation_9505
        - Simulation_Tot
      - Lisbon
      - Paris

Figure 3.2: The DMS-tree of the Euroscanner

One can define its own scenarios by (1) selecting land use demands and by (2) using incorporated analytical functions to perform map operations in order to define its own suitability maps (out of the database with driving forces). After defining a scenario the allocation algorithm can be run and the results can be stored.

3.4 Mathematical formulation of the allocation algorithm.

The Euroscanner model makes use of a land use allocation algorithm developed by the Vrije Universiteit Amsterdam. In this paragraph the mathematical formulation of the allocation algorithm is given as described in the publications of Hilferink and Rietveld (1999) and Scholten et al. (1999). For a more comprehensive coverage of the model concepts, architecture and mathematical description of the model engine is referred to the above mentioned publications.

A core variable of the model is the suitability *scj* for land use of type *j* in grid cell *c*. This suitability represents the net benefits (benefits minus costs) of land use type *j* in cell *c.* The higher the suitability for land use type *j*, the higher the probability *xcj* that the cell will be used for this type. In the simplest version of our model we use a logit type approach to determine this probability:

$$x_{cj} = \frac{\exp\left(\beta \cdot s_{cj}\right)}{\sum_{j'} \exp\left(\beta \cdot s_{cj'}\right)} \qquad \text{for all } c \text{ and } j \qquad (1)$$

Thus, when β is zero, all types of land use have the same probability; i.e. the suitability factors *scj* do not play any role in determining these shares. On the other hand, when β goes to infinite, the limit of probability that the category with the highest suitability gets the cell is equal to 1.

In terms of expected values, the expected volume of land use *Lcj* for category *j* in cell *c* equals:

$$L_{cj} = x_{cj} \cdot L_c \qquad \text{for all } c \text{ and } j \qquad (2)$$

where *Lc* denotes the total volume of land in cell *c*. With equally sized cells *Lc* would of course be equal for all *c*. Unequally sized cells may occur in the case of cells located near the national border, or cells being partly water (if a transfer from water to non-water land use is not allowed), or contain preset land use based on exogenous data, such as infrastructure developments.

The model as formulated here does not guarantee that the allocation of space across possible land uses is in accordance with overall demand conditions. Therefore, side constraints have to be imposed in order to ensure that at the relevant levels of aggregation total demand is met.

This leads to a reformulation of the model. Let *Dj* be a restriction on total demand for land use category *j*. In addition, let *Mcj* denote the expected amount of land in cell *c* that will be used for category *j* taking into account the side constraints. We then arrive at a doubly constrained model:

$$M_{cj} = a_j \cdot b_c \cdot \exp \beta \cdot s_{cj} \qquad \text{for the constrained } j \text{ and all } c \qquad (3)$$

where *aj* and *bc* are balancing factors such that the following constraints are satisfied:

$$\sum_c M_{cj} = D_j \qquad \text{for the constrained } j \qquad (4)$$

$$\sum_j M_{cj} = L_c \qquad \text{for all } c \qquad (5)$$

Equation 4 guarantees that the expected amount of land allocated for land use type *j* equals the imposed amount *Dj*. In addition, equation 5 implies that the sum of the expected volumes of the various land use types per cell is equal to the total area of each cell. We use the expression "for the constrained *j*" when an aggregate constraint has been formulated for the particular land use type j. It is clear that the constraints may imply that no feasible solution exists. This can be checked by seeking for a starting solution of the system in a linear programming context. When no feasible solution is found, the aggregate constraints have to be reconsidered before the model can be used. For those land use types j for which no *aggregate constraint* applies we arrive at:

$$M_{cj} = b_c \cdot \exp \beta \cdot s_{cj} \qquad \text{for unconstrained } j \text{ and all } c \qquad (3')$$

under constraint (5) so that we may conclude that in this case a_j has been set equal to 1. Note that in the extreme case that none of the land use types has any aggregate constraints, we have $M_{cj} = L_{cj}$ for all *c* and *j*, and $b_c = \dfrac{L_c}{\sum_{j'} \exp\left(\beta \cdot s_{cj'}\right)}$ for all *c*.

The above reformulation as a doubly constrained land use model is helpful for an understanding of the structure of the model. The structure of the model is quite similar to doubly constrained spatial interaction models used in transportation research (see for example Fotheringham and O'Kelly (1989)). We now turn to the interpretation of the balancing factors. From equations (3)-(5) it follows that:

$$b_c = \frac{L_c}{\sum_j a_j \cdot \exp\left(\beta \cdot s_{cj}\right)} \qquad \text{for all } c \qquad (6a)$$

$$a_j = \frac{D_j}{\sum_c b_c \cdot \exp\left(\beta \cdot s_{cj}\right)} \qquad \text{for the constrained } j \qquad (6b)$$

$$a_j = 1 \qquad \text{for the other } j \qquad (6c)$$

$\sum_c b_c \cdot \exp\left(\beta \cdot s_{cj}\right)$ can be interpreted as the aggregate suitability of land for land use type *j*; when the suitability of land use type *j* would be low in terms of *scj*, the value of the denominator in (6b) is low as well. The balancing factor a_j is high when a high constraint *Dj* is combined with a low aggregate suitability.

In a similar way $\sum_j a_j \cdot \exp\left(\beta \cdot s_{cj}\right)$ in (6a) can be interpreted as a measure of demand for land use in cell *c*. A high value of this expression means that the demand for the land in cell *c* for the various land use types (taking into account the urgency of the land use types as represented by a_j) is relatively high. It leads to a low value of the balancing factor *bc*, and thus ensures that in equation (5) the total amount of land finally allocated in cell *c* does not exceed the supply of available land *Lc*. Thus, the solution of the doubly constrained model yields as a side-product the shadow prices of land in the cells.

Another way to interpret the balancing factors is to rewrite equation (3) as:

$$M_{cj} = \exp\left(\beta \cdot \left[s_{cj} + \beta^{-1} \cdot \log(a_j) + \beta^{-1} \cdot \log(b_c)\right]\right)$$

for the constrained *j* and all *c* (3'')

A large value of a_j implies a strong pressure on land use type *j*. It can be interpreted as a subsidy to this type of land use; the subsidy is given to ensure that the aggregate target for land use type *j* is achieved. The reverse case is a small value for a_j; this can be interpreted as a tax on this land use type to prevent that excess of the related target. Note that the case in between occurs when a_j equals 1, implying log(a_j)=0.

In order to clarify the role of the balancing factors, we perform the following transformation on (3''). Define land use price *pc* in cell *c* as - (1/β).log(*bc*) and price λ*j* for constraint *j* as +(1/β).log(a_j), now *Mcj* can be considered as a demand function of land use price *pc*.

$$Mcj(pc) = \exp(\beta \,.\, scj + \lambda j - pc) \qquad (3''')$$

This formulation also sheds light on the *bc* factor. A high value of *bc* means that use of cell *c* is discouraged. It can therefore be interpreted as an indicator of demand/supply conditions in each cell.

An increase in the aggregate demand of category *j* will lead to a shift in land use in the following way. The higher value of *Dj* will lead to a higher balancing factor a_j, which will lead to a corresponding increase in the expected land use in the various grids depending on the relative suitability of the grids for the various types of land use.

In reality the model is more complex than presented here. One complication is that the constraints are not always in terms of equalities, but in terms of inequalities. Consider the constraint that:

$$\sum_c M_{cj} \geq D_j \qquad (4')$$

Then in the case when the constraint is not binding, we have a_j =1, and when the constraint is binding we have a_j as defined in (6b). Thus, in this case we arrive at:

$$a_j = \max\left\{1, \frac{D_j}{\sum_c b_c \cdot \exp\left(\beta \cdot s_{cj}\right)}\right\} \quad \text{for all lower bounded } j \qquad (7)$$

In the case of an ≤ constraint we arrive at:

$$a_j = \min\left\{1, \frac{D_j}{\sum_c b_c \cdot \exp\left(\beta \cdot s_{cj}\right)}\right\} \quad \text{for all upper bounded } j \qquad (8)$$

Another complication is that the aggregate constraints not only function at the level of the country, but also at various regional levels. This means for example that population predictions have been made for labour market regions, or that agricultural production has been predicted at the level of agricultural areas. This leads to an extended version of the model where the balancing factor a_j becomes specific for each region for which a constraint has been formulated.

Solution of the model is done in an iterative way. In the case of equality constraints, it only boils down to finding the values of a_j and *bc* in equations (6a-c).

Beginning with arbitrary values for the a_j, one can compute the resulting values for *bc* by means of (6a). Then these *bc* values are fed into equation (6b) leading to revised values for a_j.

In the case where some of the constraints are in terms of inequalities, one should use equations (7) and (8) instead of (6b). Once these factors have been determined, the implied land use pattern can easily be found by means of equation (3).

4 THE EUROSCANNER: THE DATA COMPONENT

4.1 Current European land use databases

4.1.1 Introduction

Starting point for a simulation is information on the current location of land uses. Only a limited number of databases are available that cover the entire European continent. In this chapter these land use databases are described briefly. For each database a reference to the World Wide Web is given so additional information can be obtained. After description of the individual databases a comparison is made taking into account the scope of the project.

4.1.2 The Corine land cover database

(http://etc.satellus.se/index.htm)

From 1985 to 1990, the European Commission has realised the CORINE program (Coordination of Information on the Environment), while in 1991 it was decided to extend the CORINE inventories to the Central and Eastern European Countries.

One of the major tasks undertaken in the framework of the CORINE program has been the establishment of a computerised inventory on the land cover resulting in a land cover database for the twelve EC countries (2,36 million Km^2), at an original scale of 1:1,000,000 (CEC, 1993).

The methodology used consists of computer-assisted photointerpretation of high-resolution satellite images (e.g. Landsat-TM and SPOT-XS), with the simultaneous consultation of ancillary data (e.g. maps, air photos, statistics, and local knowledge). The final Corine land cover database consist of a geographical database that distinguishes 44 classes grouped in a hierarchical three level nomenclature (Appendix II) that covers the entire land cover spectrum of Europe

For the project the Corine database (version of spring 1998) was obtained in grid format with a resolution of 250 by 250 meters covering the whole European study area except for the United Kingdom and Scandinavia. The original database was resampled to a 2 by 2-kilometer grid, containing the percentage of land cover per gridcell. For the three test sites the Corine database was projected into the national projection systems and converted to a 500m by 500m grid, containing also the percentage land cover per gridcell. The original three level nomenclature was kept unimpaired during the conversion.

4.1.3 The PELCOM Database

*(*http://www.geodan.nl/ec_lu/index.htm*)*

The second database used in the project is the land cover database established in the Pan-European Land Cover Monitoring (PELCOM) project (Mücher, 2000). This 1-km pan-European land cover database is based on the integrative use of multispectral and multitemporal 1-km resolution 1995, 1996 and 1997 NOAA-AVHRR satellite data and ancillary data. The PELCOM classification scheme consists of ten major land cover classes at the first level and of 11 subclasses at the second level (Appendix III). The classes chosen are related to the use of the database in environmental impact studies and climate research. In the

PELCOM project attention was given to the development of consistent methodology development enabling regular update of the database and detection of land cover changes.

For this study the PELCOM database was projected into the Lambert Azimuthal projection used by the Corine database. Of each 2 x 2-Km cell the distribution of the various land use classes, stored as a percentage of the area of the entire cell, was derived from the 1-Km PELCOM database.

4.1.4 Ten-Minutes pan European land use database

*(*http://www.geodan.nl/lu10/general.htm*)*

The '10 Minutes' pan-European land use database, established in 1994, consists of three parts: LuStat, LuVec and LuGrid (Van de Velde et al., 1994 and Veldkamp et al. 1995). The database LuStat is a tabular database, containing land use statistics on NUTS-2 or -1 (regional, if available) or NUTS-0 (national) level. LuStat is a compilation from various sources of land use statistics. LuVec is a land use map in vector format, which is compiled from various map sources. LuGrid is derived from LuVec and LuStat using a calibration routine, which combines the locational accuracy of LuVec with the correct area totals of LuStat. LuGrid consists of two parts: a vector-format fishnet grid used for geographical reference, consisting of cells measuring 10 geographical minutes (which equals about 10 x 15 km on average for the area covered), covering pan-Europe and an attribute table in which for all fishnet cells the distribution of the various land use classes stored, as a percentage of the area of the entire cell. In total 8 different classes are included. The database developed for use in environmental models on a European scale distinguishes eight classes: grass, arable land, permanent crops, inland water, urban areas, extensive agriculture and natural areas, coniferous/mixed forest and deciduous forest.

For this study the LUGrid database was projected into the Lambert Azumenthal projection used by the Corine database. Of each 2 x 2-Km cell the distribution of the various land use classes stored as a percentage of the area of the entire cell was derived directly from the LUGrid database.

4.1.5 IGBP-DIS global 1-km land cover dataset DISCover.

(http://edcwww.cr.usgs.gov/landdaac//glcc/glcc.html)

Although not used in the project the International Geosphere Biosphere Programme's Data and Information System (IGBP-DIS) has developed a global 1-Km land cover data set that needs to be mentioned here. This global land characteristics database is developed on a continent-by-continent 1 Km normalised difference vegetation index (NDVI) composites derived from NOAA AVHRR imagery obtained in 1992 and 1993. The classification process was based on the unsupervised classification of the (monthly) NDVI composites, followed by extensive postclassification refinement using other environmental data (Loveland et al., 1999).

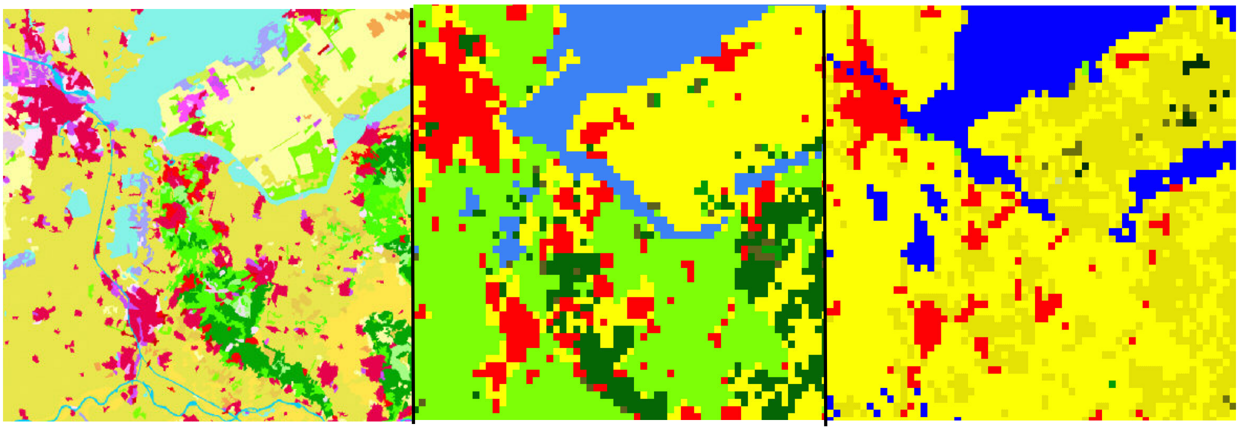
In total 17 classes are identified that are related to the needs of a wide range of studies like gas exchange studies, modelling Net Primary production (NPP), burn emission, wetlands cover and wetland water regimes, changes in vegetation / land cover over time, biological attributes, physical attributes and landscape characteristics (Belward et al., 1999).

4.2 Comparison of the land cover databases covering Europe

The four previously described land cover databases can be compared on several criteria that are important in the scope of this project. These criteria include the geographical coverage of the European continent, the nomenclature (the number of classes distinguished and the availability of classes that give insight in the land use change processes that occur in the urban - rural fringe), the resolution but also the year(s) of acquisition of the underlying data and the possibility to update the databases in order to use this for monitoring purposes. In table 4.1 the characteristics of the four described databases are given. While in figure 4.1 a detail of the Corine, PELCOM and IGBP-DIS is shown.

Table 4.1 Characteristics of the land cover databases covering Europe

	CORINE	PELCOM	10 Minutes	IGBP-DIS
Coverage	Europe except for United Kingdom and Scandinavia	Pan Europe	Pan Europe	The World
Methodology	Visual interpretation of Landsat-TM and SPOT-XS images	Stratified supervised classification, post refinement with ancillary data	Compilation from various land use statistics and various map sources	Unsupervised classification of multi-temporal NDVI images, post refinement with ancillary data
Resolution	250m	1 Km	Approx. 10x15 Km	1 Km
Distinguished classes	44	21	8	17
Year	1986 until 1997 (country dependent)	1997		April 1992 - March 1993
Update	Announced	Possible	Not foreseen	Possible



Corine PELCOM IGBP-DIS

Figure 4.1 Detail of the Corine, PELCOM and IGBP-DIS land cover databases

Looking at the methodology it is striking that the 3 most up-to-data databases with a high resolution (Corine, PELCOM and IGBP-DIS) are based on remotely sensed imagery. For the establishment of a georeferenced continental land cover database that can be characterised as consistent across regions and nations, detailed, fixed in time and that can be updated frequently the use of remote sensing data is essential.

The oldest, and not directly from remote sensing images derived, land cover database is the "10 Minutes" database of the RIVM. Major drawback, observed by Veldkamp et al. (1998), of the database is that it is based on statistical and spatial data from different sources that differ in spatial accuracy, reliability, age and nomenclature. Also the limited number of classes and low resolution make that this database is not optimal suited as input to simulate land cover change on a 2 x 2 kilometer resolution or to identify the location of driving forces behind land cover / land use change. However, due to the availability and little effort needed chosen is to incorporate this database in the final system.

The Corine database has the highest spatial resolution and the most extensive nomenclature with a focus on both urban and rural land cover classes. The spatial resolution of 250 meters makes it a good description of the land cover possible not only on the European level (2 km cells) but also for the three test sites (500 m. cells). Moreover, after determination of the driving forces behind land use change in the urban - rural fringe the location of relevant land cover can be determined and used as input for land use change modelling. Three limitations related to the Corine database can be mentioned here. First of all the used Corine version (spring 1998) does not include the United Kingdom, Scandinavia and Switzerland (the former Yugoslavia and Albania also, but these countries are not included in the defined European grid). Secondly, the database is developed over a long period of time (1986 until 1997, country dependant) resulting in an inconsistency in age. Finally, the visual interpretation makes it possible that the classes are not as uniform as when the classes would be derived by automated classification.

The PELCOM and the IGBP-DIS databases are comparable in terms of spatial resolution, coverage of Europe and possibilities for frequent updates. Also both databases are based on 1 Km normalised difference vegetation index (NDVI) composites derived from NOAA AVHRR imagery, although the classification methodology is different. Because PELCOM is based on more resent satellite data then IGBP-DIS (respectively 1997 - 1992 and 1993) and the nomenclature of IGBP focuses mainly on vegetation, chosen is only to incorporate the PELCOM land cover database.

4.3 Historical land use data

When land use changes are based on trend analyses historical and recent data is needed to determine the land use change that has occurred. On a European scale no databases are available that include information regarding historical and recent land use on the scale level that is in line with the scale most driving forces occur that cause the change of land use. With the proposed update of the Corine database a datasource will become available that covers the whole of Europe and makes the detection of land use changes possible on a scale level that is required for applications in spatial planning. The comprehensive nomenclature and detail resolution makes it possible to determine the amount and location of land use changes and gain insight in the factors behind change. However, to determine land use change it is important that the nomenclature is identical to the current version. The same accounts for the guidelines and methods used for the interpretation of the satellite images.

4.4 Auxiliary data representing driving forces

4.4.1 Introduction

In order to be able to simulate future land use for Europe and the three test sites the driving forces that determine land use change have to be known. A selection of available ancillary data is made that represent the driving forces. The used ancillary data can be grouped together in four types of data that will be described below.

4.4.2 Data describing administrative regions and political regulations

The European NUTS regions have been used to subdivide Europe and the respective test sites into separate units of interest. Whereas, for the complete European test site the NUTS-0 level has been used, NUTS-3 levels have been used for the test sites (Lisbon, Paris and the Randstad).

For the test sites randstad Holland and Lisbon data regarding spatial policy have been used. For Randstad Holland the data comprises future building locations as delimited in the Fourth National Physical Planning Report Extra (VINEX). For Lisbon a digital version of the (first) Regional Plan for the Lisbon Metropolitan Area (PROTALM) has been used.

Finally an attempt was made to take ecological networks into account. Therefore, for Europe, natural land cover was selected for connectivity analysis from the actual land cover database (Corine). According to Veldkamp et al. (1998) a successive map-filtering methodology was used to identify locations which are threatened by fragmentation (using a shrink-dilate succession). For the Netherlands test-site data showing the Ecological Framework (EHS) has been used. Wereas for Lisbon available data showing protected areas and the Corine Biotopes has been used.

4.4.3 Data describing physical properties

In a European scale the digital elevation map (GTOPO30) has been used. GTOPO30 is a global digital elevation model (DEM) resulting from a collaborative effort led by the USGS EROS Data Center. The DEM is based on data from 8 different sources of elevation information, including vector and raster data sets. The data of the European continent originates almost completely from the Digital Chart of the World; a vector data set based on the 1:1,000,000 scale Operational Navigation Chart. Elevations are regularly spaced at 30-arc seconds (approximately 1 kilometer). Data have been resampled to 500 meter gridcells.

Next the soil conditions have been used to explain rural land use changes. Therefore, the FAO-UNESCO Soil Map of the world, published between 1974 and 1978 at 1:5,000,000 scale (FAO, 1992) has been selected. The legend comprises an estimated 1650 different map units, which consist of soil units or associations of soil units. The soil units (106 from Af to Zt) are grouped in 26 major soil groupings. For the Netherlands agricultural soil reduction coefficients (available for cropping type) were used to explain land use change in the rural areas.

4.4.4 Data describing infrastructure

Infrastructure has been derived either from the existing data for the test sites (Lisbon and the Randstad) or from the Digital Chart of the World (DCW) (for Paris). The DCW is a comprehensive 1:1,000,000 scale vector base map of the world. It consists of 17 thematic and topographic layers with 31 feature classes of cartographic, attribute and textual data stored on compact discs. The DCW was digitized under contract of the US Defense Mapping Agency (DMA) from their Operational Navigation Chart series in the Vector Product Format.

4.5 Conclusions

For the establishment of a georeferenced continental land cover database that can be characterised as consistent, detailed, fixed in time and that can be updated frequently the use of remote sensing data is essential.

5 LAND USE CHANGE DETECTION

5.1 Introduction

The use of satellite imagery for detecting land use changes

The use of satellite imagery for detecting land use changes has been applied in a variety of studies (e.g. Berg *et al.*, 1996; Stormvogel, 1995). The main advantage of using satellite imagery is the possibility to make uniform comparisons in different time-spans and between different regional zones. Especially in Europe were land use classifications tend to differ enormously between the different countries, a uniform classification method proves to be extremely useful. But also in the US satellite imagery are used for detecting and forecasting land use changes. A recent example of the use of satellite imagery for the definition of growth patterns of urban sprawl is the research by Masek and Lindsey (1999) from the University of Maryland. They studied expansion of the Washington D.C. metropolitan area between 1973 and 1996 by multi-temporal (every two years) Landsat images. Methodological research on the use of geo-information for monitoring purposes has shown that simple overlay techniques applied to multi-temporal data sets give unsatisfactory results (de Zeeuw et al., 1999). More sophisticated object oriented techniques and modified data structures of multi-temporal databases are required to reflect the land use changes in the real world situation sufficiently.

The use of satellite imagery for forecasting changes between rural and urban land use

The use of satellite imagery with the purpose of forecasting changes in land use is fairly new. By quantifying the trend in land use changes over a historic period in a certain region, a scenario for the future developments can be derived in order to predict land use changes in larger or other regions.

Nevertheless, there are some restrictions to the method. Only changes relevant on the longer term (e.g. longer than 10 years) can be qualified as a trend. Short-term cyclic changes (like crop rotations) are less relevant and hard to express as a trend. Therefore, the prediction/scenario technique is not applicable to all land use changes that can be monitored from satellite imagery, but must be restricted to the long-term non-cyclic changes like the process of urbanization.

Objective of the application of satellite imagery

Within the SIMILOR project satellite imagery has been used to derive different scenarios for land use changes, based on trends in urbanization as observed in different European metropolitan regions. Three large European urban areas were selected as test sites: Paris - France, Lisbon-Portugal and Randstad - the Netherlands. The urbanization processes in these regions were expected to differ significantly due to different political strategies and physical environments. Not only the scenario as such, but also the development of proper data handling techniques and classification procedures were to be explored in this project.

5.2 Data

Three European urban regions have been selected as test sites, representing different forms of urbanization as present in Western Europe. Landsat-TM images of Paris, Lisbon and the Dutch Randstad have been chosen as data source for change detection in the test sites. Two cloud free images within the period 1984 – 1998 were purchased for all three test-sites. Table 5.1 shows details on the used satellite images. In annex 1 hard copies of the images are given.

Table 5.1. Characteristics of Landsat-TM5 images as used.

	Paris	Lisbon	Randstad
Sensor	Landsat-TM	Landsat-TM	Landsat-TM
Date 1	20-10-1984	08-10-1984	03-08-1986
Date 2	10-08-1998	15-09-1998	12-08-1995
Path / Row	199/026	204/33	198/024

5.3 Methodology

Transitions and driving factors test-sites

As explained in the previous chapter we focus on the process of land conversion from rural to urban and the resulting spatial patterns in urban expansion. In the urban-rural fringe different types of conversions can be distinguished (Turkstra, 1998), i.e.:

- rural/nature - residential
- rural/nature - other urban (commercial, recreational, urban green, etc.)
- vacant - residential (vacant areas are without construction but with development indications)
- vacant - other urban
- residential - commercial
- commercial - residential
- residential-residential (from low to medium to high density)

With the applied classification method of the satellite images however, no distinction can be made between e.g. urban commercial or urban residential. Only land cover can be identified rather than land functions. With the uniform classification method for the satellite images within the period 1984 - 1998 of the three test-sites the following classes can be distinguished:

Table 2. Distinguished classes in the satellite image classification procedure.

Class number	Class
1	water
2	rural bare
3	rural vegetation low
4	rural vegetation high
5	urban bare
6	urban built-up open
7	urban built-up
8	urban vegetation low
9	urban vegetation high

On the basis of this classification the following transitions could be measured by overlaying and cross-tabulate the maps from 1984 and 1998 (1986 and 1995 for the Randstad):

1 - no change
2 - expansion
3 - densification

The following decision rules have been applied:

Expansion = 1984 (classes 2,3,4) -> 1998 (classes 5,6,7,8,9)
Densification = 1984 (class 9) -> 1998 (classes 5,6,7)

Transitions from urban bare/urban green/urban built-up open to urban built-up are also considered as densification. However, between 1994 and 1998 these changes appeared to be unreliable in the multi-temporal classification and were therefore neglected.

After defining the type and measure the amount of land use changes in the rural-urban fringe, our next aim is to find the driving factors behind these changes and to quantify the amount in which these factors explain the measured changes. Then, the derived rules can be used for the prediction of land use changes. But first we have to define clearly the type of change we want to study.

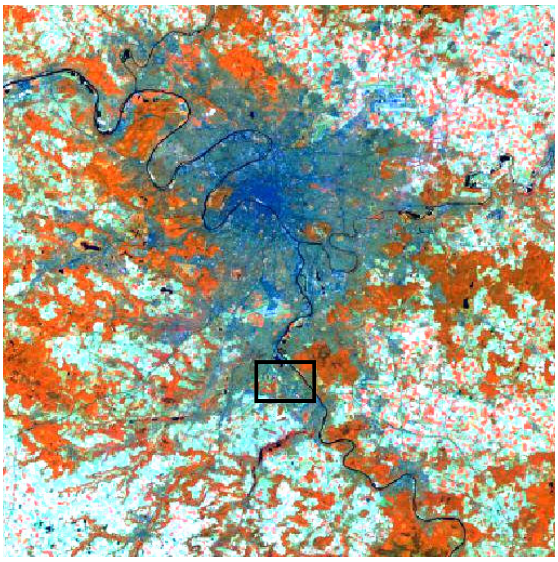
Land use changes to explain
The nine distinguished classes in the image classification cover all possible land uses. This implies that the first four classes of water and rural classes also include conservation areas, forests, wastelands etc. The five urban classes include, apart from built-up area with houses and commercial and industrial units, also the parks, sport fields, leisure areas, undeveloped bare ground, etc. With the chosen classification and stratification techniques of the satellite images we implicitly have chosen also the definitions for rural and urban. Our chosen definitions of rural and urban are fairly simple because they had to be based on the limited capability of class distinction in the image classification method. But we have of course to realise that this distinction is not straightforward at all, or like Tacoli (1998) states, '… populations and activities described as either "rural" or "urban" are more closely linked across space and sectors than is usually thought, and that the categorisations are often misleading'.

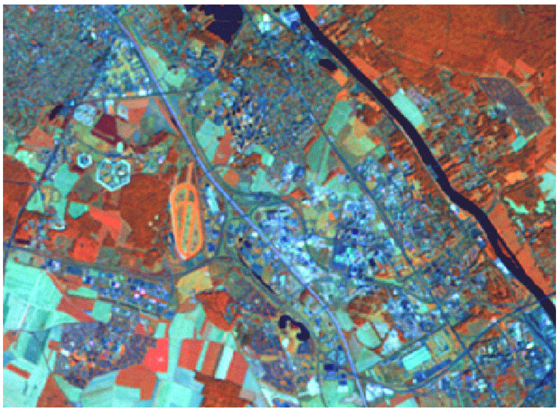
It is clear that the definition of 'urban' is in this case so general, that we will not find general driving factors that will explain the whole spectrum of changes into the different urban classes. Therefore we will concentrate on the most important classes of the urban area considering the amount of surface and importance, i.e. houses and commercial/industrial units. Another motivation for the focus on these two classes is that in case of densification the other urban classes are following or exchangable in regard to these two main classes. For example an undeveloped urban bare area is turned into a residential area or a business park with accompanying infrastructure, urban green, sport fields etc., but never, or seldom, the other way around. Another possibility in case of densification is the sacrifice of urban green, or sport fields into residential or commercial areas. Even land used by main infrastructure like highways and railways inside the city borders, can be transformed these days into commercial and residential area by layered multiple land use. In case of expansion outside the city or along the city edge however, the main infrastructure is often the determining factor in location and shape of the new commercial/residential areas.

Monitoring and simulation processes often require land use information with land use classes specific to the process. Sometimes these specific classes can be derived from available databases like the Corine database or created for this purpose from other sources like remote sensing images. The following paragraph describes the approach carried out for the SIMILOR project.

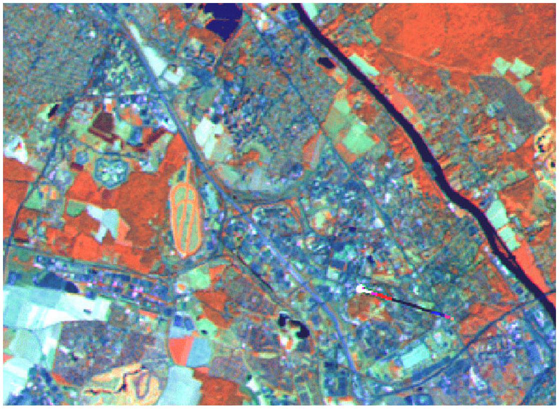
5.4 Approach

Using the test-site of Paris as example the followed approach is being explained. Historical and up-to-date information about the urban area of Paris is required to monitor the urban land use change. For the historical database a satellite image from 1984 is used, for the up-to-date database a satellite image from 1998 (figure 5.1). Additional information like topographic maps and knowledge about the area is used during the classification process.





Landsat TM, 20-10-19984



Landsat TM, 10-08-1998

Figure 5.1. Landsat TM image of Paris with enlarged two details from 1984 and 1998.

A small area from the southern part of Paris (see detail) is used to demonstrate the creation of the land use database. The classification process consists of three parts. First a visual interpretation of the satellite images to indicate the urban area. Secondly, the classification of the land cover is done. Finally, the land cover classes are assigned to land use classes. Figure 5.2 shows the visual interpretation results of both images.

1984 1998

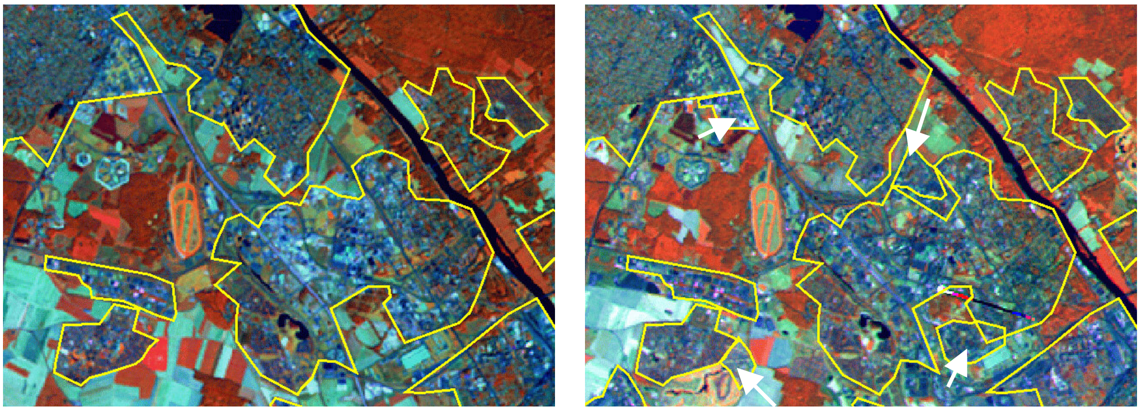


Figure5.2. Visual interpretation of Landsat TM images of Paris.

First the urban boundaries are digitized on the 1984 images, based on colors and patterns that identify the urban area. These boundaries then are superimposed on the 1998 image. Additional areas are digitized (indicated with an arrow on the 1998 image in figure 5.2).

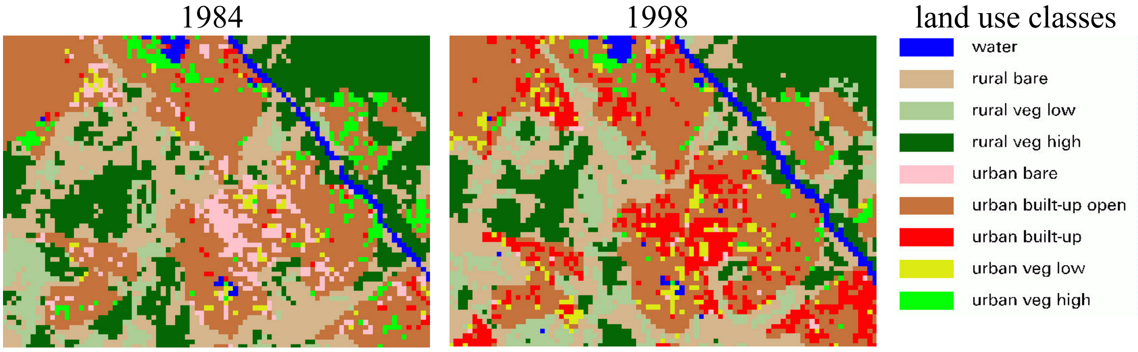


Figure 5.3. Land Use classification results.

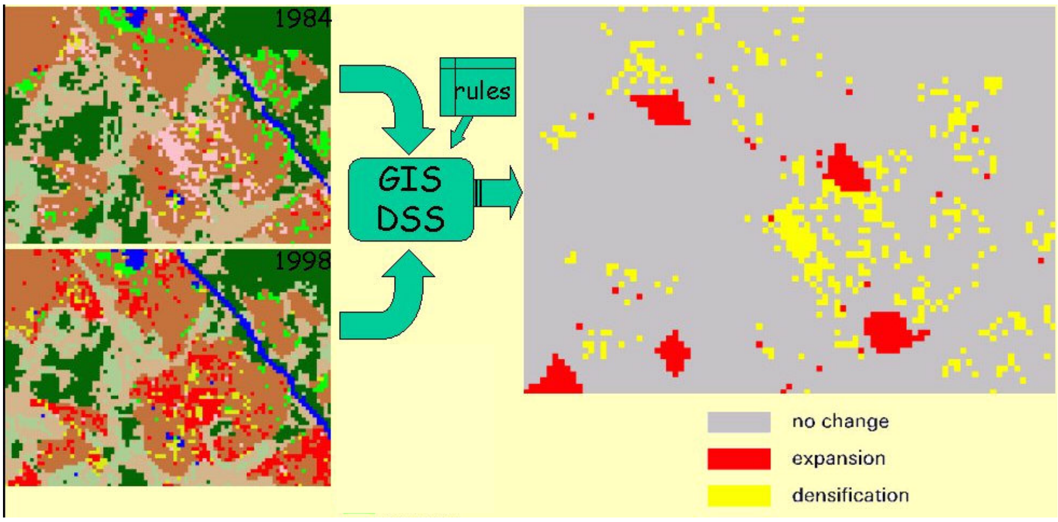


Figure 5.4. Performing change detection using a GIS.

Figure 5.3 on the previous page shows the results of steps 2 and 3. In step 2 the images are classified into 6 land cover classes; water, bare 1, bare 2, bare 3, vegetation low, vegetation high. Combined with the visual interpretation of the urban area the 6 land cover classes are assigned to 9 land use classes.

The classification results from 1984 and 1998 are used to monitor the land use change. Figure 5.4 shows an example of how change detection can be performed with a GIS. The available land use classes make it possible to detect expansion of urban area (rural area changed to urban area) and densification of urban area (bare, vegetated or open built-up urban area changed to built-up urban area). These two types of land use change are used in this project to simulate land use change in the future.

5.5 Results: Visual analysis map-series 1984-1998

First important observation in comparing the three test sites is that the urban classes in the satellite images differ significantly (appendix IV). The satellite image of the Paris region has been the standard for the classification, as the city is sharply divided in an urban built-up open part along the city edges and a purely built-up area in the city center. Further, urban bare areas and urban areas with low and high vegetation can be clearly distinguished. In the maps of the Randstad and Lisbon, the Paris classification is used to classify the urban classes, leading to different classes. This is a result of differences in city structures, materials and vegetation types, water content of soils and materials and different reflection characteristics between the regions due to climatic factors. In the Lisbon map the whole city-area consists only of three classes: ‘urban bare’, ‘urban vegetation low’ and ’urban vegetation high’. Especially the large area of urban vegetation compared to the other cities is remarkable. The classes ‘urban built-up’ and ‘urban built-up open' are non-existent in the classification of Lisbon. In the Randstad map the main urban class is the ‘urban built-up’ class, but also some urban bare areas can be found (e.g. around The Hague and near the coast). Next, but hardly present is the ‘urban vegetation high’ class. The classes ‘urban built-up open’ and ‘urban vegetation low’ are not present at all in the map map of Randstad Holland.

Comparing the expansion and densification patterns in the different maps some interesting differences can be found between the three regions:

Densification patterns

In the **Paris** map it can be seen that densification has taken place in some clear defined regions, mainly in the city-edges in the southern parts of the city and locally in the north of the city. From the summary statistics table 5.3 it can be derived that from the total urban area of the Paris-region of 119,982 ha in 1984, 3.4% (4,052 ha) has been densified between 1984 and 1998.

In the **Randstad** map we can see many large areas where densification has taken place, especially in the outskirts of the city. From the summary statistics table 5.3 it can be derived that from an urban area of 61,446 ha in 1984, 10.0% (6168 ha) has been densified between 1986 and 1995.

In the **Lisbon** map we can see densification all around the main city but also along the urbanised coastal zones. From the summary statistics table 5.3 it can be derived that from the total urban area of Lisbon of 34,606 ha in 1984, 6.5% (2,247 ha) has been densified between 1984 and 1998.

Expansion patterns

The expansion patterns in the three regions show again a quite different view. In the **Paris**-region it is remarkable that almost all expansion areas are located outside the main-city, in most cases attached to already existing satellite-cities. The total urban area of 119,982 ha has expanded with 3.9% (4,708) in the period 1984-1998.

In the **Randstad** map it can be clearly seen that expansions are directly attached to the borders of existing small and bigger cities, like Rotterdam, Zoetermeer, Gouda, Alphen aan de Rijn, Dordrecht, etc. Around some of the major cities like The Hague and Delft no expansion at all can be seen. The total urban area of 61,446 ha has expanded with 4.4% (2,676 ha) in the period 1986-1995.

Again another picture can be seen on the **Lisbon** map, were big expansion has taken place west of Lisbon and along the Tagus. Here the expansion is not necessarily attached to existing urban areas. The total urban area of 34,606 ha has expanded with 29.9% (10,351 ha) in the period 1984-1998.

Discussion

From the densification and expansion patterns we can already conclude that the process and speed of urbanisation in the three different regions is quite different.

Table 5.3 Growth rates urban expansion and urbanisation

	Urban area in hectare		*Yearly urban growth rate (%)*	*Expansion (ha)*	*Densification (ha)*	*Expansion / densification ratio*
	1984 / 1986	*1998*				
Randstad 86	61462	70307	1.13	2676	6169	0.43
Paris 84	119982	128742	0.50	4708	4052	1.16
Lisbon 84	34606	47204	2.24	10351	2247	4.61

In table 5.3 we see that the yearly urban growth rate is lowest in Paris (0.5 %) followed by the Randstad area (1.1 %) and the fast growing area of Lisbon (2.2 %). The column with the expansion-densification ratio shows that in Paris the urban growth is quite evenly divided between expansion and densification (ratio 1.2) while in the Randstad region most of the growth is the result of densification (ratio 0.4). Again a totally different picture is found in the Lisbon area where the urban growth is by far the result of urban expansion (ratio 4.6). The relative low densification in the Paris region is not very surprising when the already high density in this city is taken into account. Also possibilities for further expansion of the main city seem to be limited considering the fact that the expansions take place farther away from the main city. However, the reason for this could also be a more administrative one, related to the border of Paris and the surrounding municipalities.

The high figures for densification in the Randstad area along the city borders and the relative limited expansion confirm the Dutch spatial policies of the eighties and nineties of compact building and limited expansion in the open areas. In the Lisbon area we see completely the opposite, a big quite chaotic expansion in the open areas west and south of the main city and a relatively low densification. This pattern seems a clear expression of the lack of spatial planning in this area during the last two decades.

5.6 Conclusions

The monitoring of land use changes with the aid of satellite imagery has been applied in various projects. However, the establishment of map presentations of land use change scenarios from historic imagery is fairly new. In this study it is shown that satellite imagery can play a role in establishing urbanization patterns at a regional scale. Landsat-TM images of Paris. Lisbon and the Randstad have been used in this study. The degree of urbanization has been expressed in two components that could be observed from the satellite imagery: densification and expansion. In table 5.4 the results for three European urban areas are given, which can be used as three different scenarios for other European regions.

Table 5.4. Three possible scenarios for the densification and expansion of urban areas in Europe, based on the developments as derived from satellite imagery for Lisbon, Paris and the Randstad.

Scenario	Densification	Expansion
Lisbon (1984 – 1998)	6.5%	30%, anywhere
Paris (1984 – 1998)	3.4%	4.4%, designated
Randstad (1986 – 1995)	10.0%	3.9%, external

The applied approach consists to a large extent of a visual interpretation of satellite imagery and on screen digitizing, especially with regard to extension of urban areas. Full automatic procedures did not give acceptable results. Once a manual stratification has been applied, supervised classification procedures have been applied to derive the degree of urban densification.

6 DRIVING FACTORS BEHIND URBAN - RURAL CHANGE

6.1 Introduction

Underlying factors for the amount of rural – urban change are basically population growth and economic growth. We will however not consider these factors here because we take the amount of land use change as exogenous and concentrate only on the driving factors behind the distribution of this land use conversion.

From the two main urban land use types residential and commercial/industrial, the residential area seems to be the most important because of its size and in it's leading role in expansion and sub-urbanisation. The times that houses were constructed directly around industrial and commercial areas are long past. In contrary, we can see a reverse effect of development of commercial areas near new residential areas. Another known spatial development starting from approximately the eighties, is the replacement of old industrial land by residential or commercial areas, for example in some of the old harbour areas in Amsterdam and Rotterdam and the Docklands in London and Lisbon. The opposite, replacement of residential land use by other land use types is a phenomenon that is seen less often in Europe. The few exceptions that can be found are small parts of residential areas which are sacrificed for important infrastructural works like highways, high-speed railway connections like the HSL or new landing strips of airports (e.g. the new fifth runway of Schiphol).

As Bruckner (2000) argues the conversion from rural to urban land use depends solely on the land's productivity in urban use (which depends on the value of the houses built) relative to the land's productivity in agriculture (as reflected in the value of the farm output).

For these reasons it seems logical to focus on the social and economical forces behind the conversion to residential land use. Also Bibby (1997) mentions four reasons to justify the attention on housebuilding as the driving force behind the overall rate of land conversion. First the residential area occupies in general the largest share of the total built-up area. According to Bibby (1997) housing accounts for seven tenths of land in urban use in England. This ratio is however dependent on the way the residential area is measured in relation to the urban area. In the Netherlands for example this ratio is much lower: 36% of the total built-up area[2] in 1993 is residential. Secondly, like stated before, other forms of land uses, like retail, warehouses, schools and leisure follow the residential developments. Thirdly, it is generally argued that it is the decentralisation of population rather than the decentralisation of employment that is leading the evolution of the settlement pattern. And last but not least the spatial planning departments of the different European governments lay particular emphasis on housing allocations from which flow the assessment and allocation of land for other uses.

Although it might be a good starting point, it doesn't seem logical to focus solely on the driving factors behind residential development. We can add for example driving factors for the other main urban land use types, infrastructure and commercial and industrial areas. These urban land use types can usually be clearly distinguished spatially and have more or less independent driving factors compared to the driving factors of residential development. In the first place we think for instance of spatial policy plans for infrastructure and business

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[2] The urban area in the Netherlands was 17% of the total land use in 1993

parks, but also the proximity of existing commercial and industrial areas because of advantages in the economy of scale (e.g. Mills and Hamilton, 1994).

Last but not least we have to consider limiting factors to rural – urban change as well. This can be physical terrain factors like slope or soil-stability, as well as environmental factors like noise and pollution preventing urban development. Other limiting factors can be policy restrictions for building in or near certain areas like conservation areas, or urban growth boundaries to limit urban sprawl.

Resuming, we concentrate on the driving factors behind residential development and independent - from residential development- driving factors behind the development of main infrastructure and commercial/industrial areas.

6.2 Identification of driving factors behind residential development

Studying the driving factors behind residential development implies answering the question where are new houses built ? The answer is related to available space, spatial policy and personal preferences (of the real estate developer and his target market). A good example of a study in which the driving factors behind the growth of the residential area in the Netherlands was studied can be found in Wagtendonk and Rietveld (2000). In this study a geostatistical analysis was carried out showing the relation of the distribution of new build houses between 1980 and 1995 and a number of well documented driving forces. Although we can expect regional and cultural differences in the importance of certain driving forces, we assume that the location factors used in the study of Wagtendonk and Rietveld (2000) are also valid for other European regions. Therefore, we distinguish the following driving factors:

Proximity and concentration of existing residential areas
Although the search-radius of people is quite big (Goetgeluk, 1997), in the Netherlands the majority of people move inside their own neighbourhood or municipality. Accessibility to friends and family and already available services like schools, shops, hospitals, restaurants, but also cultural services like cinema’s and theatres and so on, form the basic advantages of living in existing residential areas. Nearby situated residential area should therefore be weighted as an important factor.

Proximity and concentration of employment
People attach value to the amount and the accessibility of work in their surroundings and in reverse they accept to a certain extent the disadvantage of commuting because of the better living environment and cheaper housing at the home end of the commute (Mills and Hamilton, 1994). This implies that the distance to work should be weighted according to a certain distance-decay function and depending on the concentration of available work. Different investigations point out that the mean maximal accepted commuting distance in the Netherlands is between 30 and 60 minutes (Gerritsen, 1997). This is also confirmed by Van Ham (1999) who shows that the majority of jobs are found on short distance from home.

Proximity, quality and size of nature conservation, forest and recreation areas (including surface water) and distance to coast.

Rest, open space, nature and recreational possibilities are important location factors which is shown by the considerable price increases of dwellings near this kind of areas. Especially the Lisbon region has a very attractive coastline for beach and water recreation, fishing and transport over sea. The distance to the coast is therefore regarded as an important driving factor for both residential as commercial development. The same accounts, but to a lesser extent for the attraction for recreational purposes (due to less favourable climatic conditions), to the Randstad.

Distances to railway stations and highway exits

A short travelling distance to work and recreation is except for local forms of transport (by foot, bicycle, tram) heavily dependent on good connections to the highway and the railway net. Therefore, we consider the distance to the closest connection point as an important factor. Further it should be considered to distinguish new from old infrastructure because new investments in freeways and other transportation infrastructure spurs sub-urbanisation because of reduced costs for commuting and transport in areas with low groundprices and cheap housing (see also Bruckner, 2000).

The proximity of railways (except stations), highways (except exits), airports, industries can be a negative factor in the case of noise, air or visual pollution.

Location in new (planned) towns or expanded towns

In countries or regions with a long planning history a large part of the spatial distribution of dwellings is explained by the stock created or co-ordinated by the government. For example in the Netherlands the larger part of the building program, in the period from 1980 till 1995, was concentrated in new towns and expanded towns. In countries or regions that lack a spatial policy, like Greece and until recent Portugal, the location of new residential areas is solely determined by the autonomous driving forces mentioned above.

Distance to existing urban area

In countries like the Netherlands spatial policy since the sixties has promoted the concept of compact cities and the prevention of uncontrolled urban sprawl. It is therefore expected that the main part of urban expansion takes place along the border or near existing cities. Secondly the combination of the availability of land with relatively cheap groundprices, the proximity of the city with social and cultural facilities and possibilities for work makes people in an autonomous way decide to live as nearby the city as possible. This trend is visually confirmed by the expansion patterns later shown in chapter 8. More or less the same accounts for the Paris region. For the Lisbon area with its less clearly defined urban expansion probably only the second (autonomous) motivation is true. For these reasons it was decided to add a location factor which expresses the distance to the edge of the existing urban area (the city edge).

Physical terrain factors

Although in the test sites Randstad and Paris there are hardly any physical restrictions for residential development, factors like slope, soil stability and zones with natural risks (e.g. riskzones for flooding, land slides, avalanges, etc.) can be serious limiting factors for urban development in other areas, like some parts of Lisbon. In the historical analysis these factors are however not considered. For the test site Lisbon for example these factors can easily be integrated in the future simulations by adding them as restrictive zones on the map.

6.3 Identification of driving factors behind industrial/ commercial development

Also for the study of the driving factors behind the development of industrial and commercial areas we can ask the question where exactly the commercial and industrial areas are developed. Again the answer is related to available space, spatial policy and personal preferences of the real estate developer and his target market. Different from the residential development the spatial development of commercial and industrial areas is however a more dynamic one in the sense that the locations of these areas are more shifting as a result of pull and push factors. At the level of individual cities for example in the last 25 years in the Netherlands a process has taken place of sub-urbanisation of employment from the centre to the edge of the cities (Van Ham, 1999). Push factors are the high groundprices, the congestion and the decreased accessibility, environmental restrictions and the limited possibilities for expansion in the inner-city, while the main pull factors of the city-edge are exactly the opposite. These deconcentration processes can be found in almost all-major European cities and also in Lisbon (Soares, 1998). Also on a regional scale changes are taken place. For instance in the Netherlands a relative employment shift has taken place from the Randstad to adjacent areas (Louter en de Ruijter, 1994; Van der Vegt and Manshanden, 1996). Also in Portugal it seems that the core area of Lisbon is starting to become (relatively) less important as an economic centre compared to the adjacent new developing urban areas. This is however a quite recent trend for which less physical evidence is available.

Proximity and concentration of existing commercial/industrial areas
Regarding the importance of the above described concentration processes in the city-edges one of the most important driving factors for the spatial distribution of commercial and industrial development is the proximity and the extension of existing commercial/industrial areas. For many companies it is important to be in a concentrated commercial area to be at short distance of suppliers and the customers of goods and services. Especially bigger companies tend therefore to concentrate at regional economic centres located in mixed or sector specific business parks mainly in the edge of the cities. Also new offices tend to concentrate mainly in the city edges as development possibilities in the inner cities are usually quite limited. Industries also tend to cluster, but are more often located farther away from the cities close to water, road or railinfrastructure for the supply of groundmaterials. Nearby situated commercial/industrial area should therefore be weighted as an important factor.

Distance to employees and customers (existing urban area)
For labour intensive companies and companies delivering goods and services directly at their customers it is important to be at short distance of densely populated areas where their consumers live and where the commuting distances of their employees are short. The best locations for this type of companies are usually near the city edges of moderate to large cities.

Distances to ports, airports, railway stations and highway exits

Many companies and industries are heavily dependent on good and quick transport facilities. Therefore the distances to the access points for the main road, water and air infrastructure are considered very important factors. The distances to highway-exits and railway-stations are especially important for the accessibility of the commuting employees of companies, offices and industries. Companies and offices tend therefore to be even more concentrated around highway exits and railway stations than residential areas. Another reason that locations along highways are often popular among companies and offices is their great visibility from the highway (Wagtendonk and Schotten, 2000).

Location in economic development zones and planned commercial areas

Also the location of economic development zones and business parks is often planned in countries or regions with a long planning history. This can be done in an allowing or commanding planning fashion (Rietveld and Wagtendonk, 2000). Where available physical planning maps should therefore be included in the dataset.

Physical terrain factors

Like for residential development in some areas the development of commercial/industrial areas can be hampered by factors like slope, soil stability and zones with natural risks. Like mentioned before in the historical analysis these factors are however not considered. For the test site Lisbon for example these factors can easily be integrated in the future simulations by adding them as restrictive zones on the map.

6.4 Identification of driving factors behind infrastructure development

As the development of infrastructure is mainly following the residential and commercial development we don’t consider them as separate driving factors in this study. However, infrastructure can also be planned for example to develop or access underdeveloped areas. Also other reasons can be possible. For example the new bridge in Lisbon (Vasco de Gama) of 1998 was build to create a regional connection of Lisbon with the south riverbank of the Tagus river and to divert the traffic to Lisbon coming from the South. Another example is the planned shift in northerly direction of the national airport of Lisbon to make growth of the airport possible. A major example in the Netherlands is the Deltaworks that were completed in the eighties to protect the mainland of the province of Zeeland from possible floods. It may be clear that the driving forces behind these infrastructure developments are much too specific and unique to integrate in this analysis. If the plans themselves are available however they can be integrated in the future simulations.

6.5 Operationalisation of the driving forces

In order to be able to explain the historic urban developments in the test sites the driving forces must be mapped. The available auxiliary data mentioned in paragraph 4.3 is processed in such a way that they represent the driving forces in the study areas. Because of the driving forces different nature the following three type of maps are used to derive the driving forces from the auxiliary data:

- Gravity maps
- Euclidean distance maps
- Boolean maps

Gravity maps

It is clear that the spatial factors distance to and the extension of work areas, natural areas and social facilities are important driving forces. The effects of distance and area are incorporated in the spatial variable by means of a distance-decay function. With this function we calculate (by summation) a gravity value for each grid cell, which depends on the distance, concentration, and area (surface) of the driving force. Only cells around the destination cell within a specified circular radius (minimum and maximum distance) are included in this calculation. The type of distance decay function differs for all the factors described above. We have used an empirically based log-logistic distance decay function from the research of Hilbers & Verroen (1993):

$$W(x)=1/(1+e(-a+b*\ln x))$$

Where W (x) is the weight to be applied in the accessibility index. The factor x presents distance, so that the weights are proportional to the potential interaction between two grid cells at a distance x. To produce the different gravity maps, this function was used in a ‘focal-sum’ operation in the GIS Arc Info with the following maximum influence distances:

- Gravity maps: work factors (max 60 kilometer)
  - industrial/commercial areas, ports, airports
- Gravity maps: recreation factors (max. 15 kilometer)
  - green urban areas and *high urban vegetation*[3], areas with sport and leisure facilities, forest areas, natural areas, water and wetland areas
- Gravity maps: social and commercial concentration factors (max. 500 meter)
  - urban continuous and discontinuous area, *urban built-up and urban bare/urban green area*, industrial/commercial area.

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[3] The gravity maps in the list above written in Italic are maps derived from the Landsat classification, the maps in normal text are derived from the Corine classification.

Euclidean distance maps

Euclidean distance maps[4] were made for driving forces that are related to the distance to a certain feature and not the occupied area of the feature itself. Distance to infrastructure is an example. The following euclidean distance maps were calculated.

- Distance to railways and railway stations[5]
- Distance to highways and highway exits[6]
- Distance to city edges (based on urban areas Landsat 1984/1986 > 100 ha)
- Distance to coasts (only for Lisbon area)
- Distance to municipality centres (only for Lisbon area)
- Distance to Lisbon centre (only for Lisbon area)

For the accessibility to the infrastructure network it would of course have been better if we could have used real distance or time distance maps, that can represent the ground truth in a more appropriated way. These maps were however only available for the Lisbon area and have been added as an extra to the standard dataset. For the distance to existing cities the urban areas in the Landsat images of 1984 (Lisbon and Paris) and 1986 (Randstad) have been used to calculate Euclidean distances. Because a significant influence is only expected from reasonable large urban areas, only connected urban areas larger than 100 ha were selected. The distance to coasts in the Lisbon area have been added as an extra map, because the Lisbon coast with its many beaches are expected to attract urban development, both commercial and residential.

Boolean maps

Boolean maps were composed in which information regarding spatial planning is incorporated. The following boolean maps were generated:

- the location of new towns or expanded towns
- the presence of railways or highways in a grid cell.

All the above described maps that are the result of the operalisation of mapping the driving factors in the three selected sites were used as the basic input variables for the correlation and regression analysis that is described in the following chapter

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[4] All maps were calculated on the basis of Euclidean distance between the cellcenters of rasterised vectormaps (500 meter cells). All distances are expressed in kilometers.

[5] If datasets with railway stations were not available like for the Paris region, the distances were calculated to the intersections in the railway network instead. This implies that some intersections were assumed to be railwaystations while in reality they are not, also railwaystations not located on intersections were missed

[6] If datasets with highway exits were not available like in the Paris and Lisbon region, the distances were calculated to the nodes in the highway network instead. This implies that some intersections were assumed to be highwayexits while in reality they are not and that highway-exits not located on intersections were missed.

7 TRENDANALYSIS

7.1 Introduction

This section presents the statistical analysis carried out to explain the locational pattern of the urban expansion and urban densification in the different test-sites between 1984/86 and 1998. The statistical relations are analysed with the help of a logistic regression model, which has been discussed in section 3.4. The application of such a model is possible because it is plausible to consider the observed increase of new urban area in each map square (500 x 500 meters) as the result of a bi-nominal chance process in which the chance is estimated of transition from respectively rural to urban area or from urban green to urban bare/built-up area, or that no transition occurs at all. The statistical analysis is divided in two sections the correlation analysis and the regression analysis. First correlation analysis is used to get a first impression of the statistical relations between the different variables that represent the driving factors behind land use change (see the previous chapter) and to make a first selection of independent variables for the regression analysis. Secondly, in the process of the regression analysis different sets of variables are tested to end with a regression equation with a small set of variables of relative high explanatory value. Next, the regression equation can be used to simulate the trends in land use change in the urban - rural fringe as will be described in chapter 8.

7.2 Correlation analysis

With correlation analysis it is possible to measure the magnitude of the spatial relation between different variables. This relation is expressed in the correlation-coefficient r, which can take values between –1 and +1. The r-coefficient gives the amount of dispersion around the linear least square equation. If all x, and y co-ordinates of two variables in a graph, are positioned exactly on one line, than the r-coefficient is 1 or –1, depending on the sign of the relation. An r-coefficient of zero however, doesn’t necessarily mean that there is no relation between two variables. It is possible that a non-linear relation exists between the two variables. This can be tested by making a scatter-diagram of the variables, in which also outliers can be identified well. For the rest it should be noted that the r-coefficients between different variables could only be compared in a relative way, because the correlation of variables with few observations is usually low.

7.3 Correlation analysis results

The main purpose of our correlation analysis is to find the relation between the *independent* variables (the location factors) and the *dependent* change variables expansion[7] and densification[8]. Secondly we use the correlation-analysis to investigate the mutual relationships of the ‘independent’ variables, or in other words to filter out only real independent variables.
In the following paragraphs the results of the correlation analysis for the three test-sites are given.

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[7] Because the used definition of urban expansion implies that only cells partly or fully filled with rural land use can transform into urban land use we select only those gridcells from the dataset, where change from rural to urban land use is possible, i.e. where the rural class from the Landsat classification is larger than zero.

[8] Because of the used definition of urban densification we select only those gridcells where change from urban green to urban built-up is possible.

7.3.1.1 Correlations Lisbon

Expansion

Compared to the other two test-sites relatively high correlations are found for the gravity maps that show proximity and extension of urban continuous area (r = 0,20) and even higher for gravity maps of urban discontinuous areas (r = 0,40). Also the gravity maps of urban classes of Landsat correlate well, the r-value is respectively 0.41 for urban bare and 0.35 for the urban open class (urban vegetation low). Also different is the remarkable absence of correlation with the proximity and extension of industrial and commercial areas. Only a low positive correlation is found with the 60 km gravity map of these areas (r = 0,06). This result can be explained by looking at the Corine map which shows that only very small areas of commercial/industrial areas were classified, which automatically results in low correlations. Strong positive correlations however are found for the (60 km) proximity and extension of ports (r = 0,32) and airports (r = 0,23). Also the 15 km gravity map of green urban areas and areas with leisure facilities correlate strongly (r-values of respectively 0,31 and 0,32). A less strong but significant positive correlation (r = 0.17) is also found with the (15 km) proximity and extension of water areas. From these strong correlations we can assume that the location choice of new expanding areas is strongly influenced by the accessibility to green and natural areas and areas with leisure facilities. Finally quite strong correlations are also found for the traveltime and distance to highway exits (r = -0,22 / -0,20) and distance to railway stations (r = -0,18), the traveltime and distance to Lisbon (r = -0,29 / -0,25) and the traveltime and distance to the centers of municipalities (r = -0,16 / -0,13). Also a high correlation is found for the distance to town edges (r = -0,25) and to coast-recreation (-0.15). Significantly negative correlations were only found for proximity and extension of forest areas. On the basis of this correlation we conclude that autonomous forces mainly drive the urban expansion in Lisbon, where living close to existing towns, green urban areas, coast, leisure facilities and access to car infrastructure is more important than the proximity and extension of work areas.

Densification

Relatively high correlation is found for the gravity map showing proximity and extension of urban discontinuous areas (r = 0,12). This is less clearly expressed in the open urban class of Landsat (r= 0.03). Densification is also only weakly related to the gravity map industrial and commercial areas and proximity to ports and airports. The 15 km gravity maps of wetlands (r = 0,17) and water areas (r = 0,12) correlate reasonably with densification. Also the correlation with distance to the nearest railway stations is quite high (r = 0,13), which is confirmed by physical evidence of large concentrated building (high apartment blocks) directly around railway stations nearby Lisbon, for instance in the municipalities of Barcarena, Cacem, etc. Negative correlations are especially found for the location in forest (r = -0,12), green urban areas (r = -0,12) and proximity and extension of areas with leisure facilities (r = -0,13). This seems to be coincidence related to the central location from for example the large Forest Park 'De Monsanto’. The correlations found for the traveltime and distance to highway exits (-0,1 -0,02) and municipality centers are rather weak and in the case of distance to Lisbon even negative. It is clear that the relative differences in the correlations of traveltimes and Euclidean differences are bigger here in the central part of town.

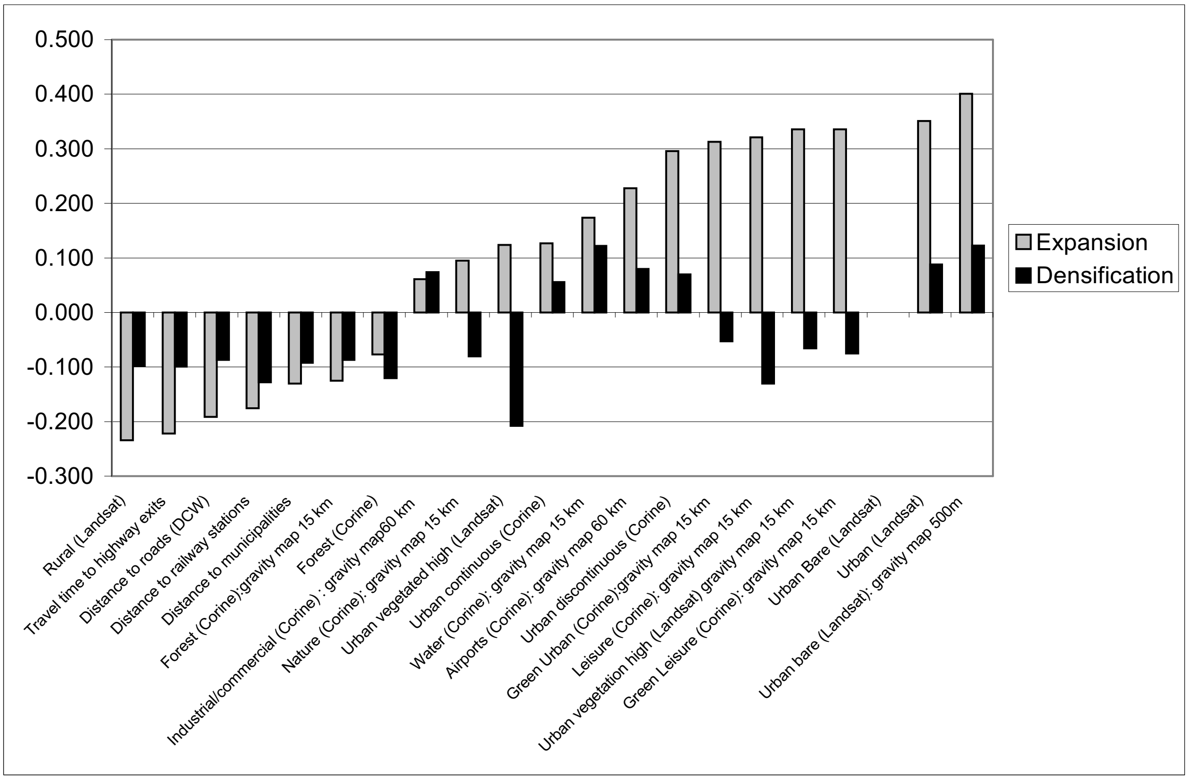

Figure 7.1 Correlations Lisbon (only r values less then -0.05 and more then 0.05 are shown)

7.3.1.2 Correlations Randstad

<u>Expansion</u>

In figure 7.2 the results of the correlation analyses for expansion in Randstad Holland are given. The highest correlation values are found for by policy regulations appointed new towns, accessibility of work and the distance variables to infrastructure and borders of towns. A clear positive correlation is found for the proximity and the extension of the existing urban continuous area according to Corine (r = 0.11). A considerably higher correlation is shown by the gravitymap of the combined urban bare and urban built-up area from the Landsat classification (r = 0.21). This is an expected result as the expansion is directly derived from the Landsat classification. Also a high correlation (r = -0.17) is found for expansion for the distance to the town borders (towns > 100 ha) of 1986. This observation is confirmed visually by the distribution of expansion areas and relates also well to the spatial policy of compact cities of the last decades of the Dutch government. Also relatively high correlations are found in the new town areas (r = 0.15). Also this is an expected outcome because in the period from 1980 till 1995 the larger part of the house building program was concentrated in new towns and expanded towns chosen by the government. The next clearly correlated location factor found is that of proximity and size of industrial and commercial areas (r = 0,15), which seems to be a clear driving factor for urban expansion. Possibly this effect relates mainly to the growth of existing industrial commercial areas and has little to do with residential expansion. Also construction sites correlate quite well (r=0.14), which is a logical outcome whereas areas in construction are often in preparation to be converted into build up area. This factor can however not be considered a driving factor, because the land use change to a construction site is already the first stage of urban expansion and the result of a driving factor.

Correlations with infrastructure[9] are especially high for both the distance to railways and railway stations (r = -0.14). Also the correlation with the distance to highway exits (r = -0.086) and the distance to highways (r=-0.061) are considerably lower. The values for distance to infrastructure are comparable with the values found in the correlation analysis of Wagtendonk and Rietveld (2000)[10]. All these infrastructure variables are considered independent, because they have different geographic locations or a different relation with urbanization[11]. It can however be discussed if the railways and highways can be considered as driving forces or should be considered as limiting forces for expansion due to their impact on the living environment of man.

Small but positive correlations are found for proximity and concentration of green urban and leisure areas. Again a higher correlation is found for the gravity map of the Landsite image for high urban vegetation (r= 0.1). Negative correlations are found however for locations near to the airport, nature and water. The first factor is probably related to noise nuisance and the latter factors to building limitations near natural areas. On the basis of these correlations we conclude that recent urban expansion is related highly to the spatial planning activities of the Dutch government close to the existing towns, work-areas and railway-stations. Urban expansion in the Randstad seems therefore to be especially residential expansion.

Densification

The correlation values for densification are comparable with correlation values for residential growth in number of dwellings in the Netherlands between 1980 and 1995 in the Dutch study of Wagtendonk and Rietveld (2000).

Highest positive correlation values are found for the distances to highway exits (r = -0.15) and freeways (r = -0.16), which indicates a high dependency of densification areas for accessibility by car. A quite low correlation is found with the 500 meter and 60 kilometer gravity maps to industrial/commercial areas (r = respectively 0.09 and 0.06). Remarkable negative correlations are however found for proximity and extension of forest (r = -0.15) and nature (r = -0.16) areas. Finally it is remarkable that correlations are higher for the urban continuous area than for the urban discontinuous areas. This could however be related to the differences between the Corine and Landsat classifications of urban area. The gravity-map of the combined urban Landsat classes urban bare and urban built-up shows however better correlations (r= 0.14). On the basis of these correlations we conclude that the recent urban densification in the Randstad area is highly related to the accessibility by car of the infrastructure network.

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[9] Correlation values related to the distance to towns and infrastructure are negative because in these correlations the shortest distances are represented by the lowest figures. These negative correlations should therefore be interpreted as positive.

[10] In this study however, not the distance to railways was used, but a boolean map indicating the presence of railways in each cell.

[11] Railway stations and highway exits are located on respectively railways and highways, but are considered separately because they form the entrance to these railway and highway networks and have therefore another type of relation (a radial-shaped access relation) with urbanisation, than railways and highways (a rectangular influence-zone related to physical bordering of urbanisation).

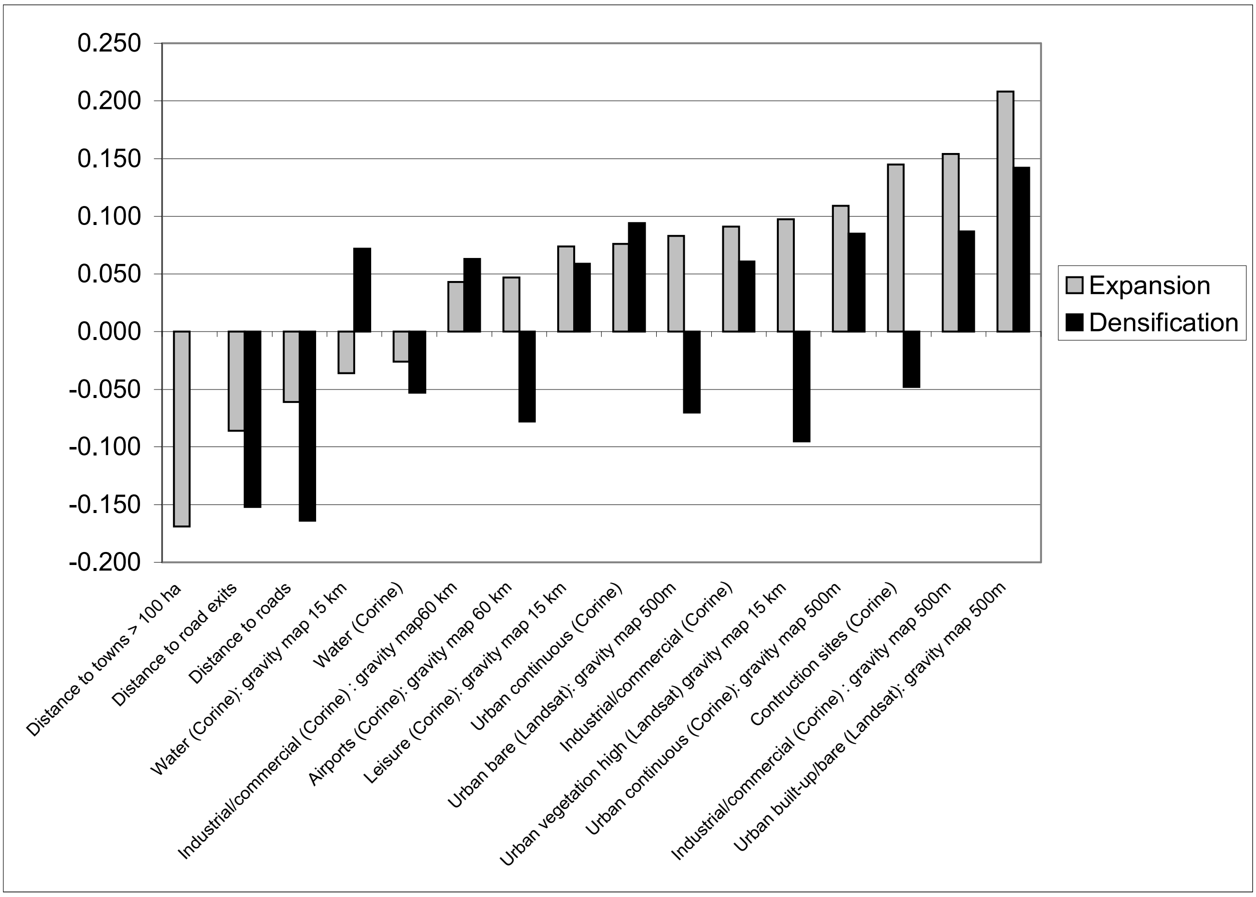

Figure 7.2 Correlations Randstad (only r values less then -0.025 and more then 0.025 are shown)

7.3.1.3 Correlations Paris

<u>Expansion</u>

In contrary to expansion in the Dutch dataset which correlates positively to the proximity and extension of the urban continuous area, expansion in the Paris dataset correlates positive to the proximity and extension to the urban discontinuous area. This can be the result of differences in the classification of Corine data between the two countries. More likely however this difference is related to the differences in the shape of the two metropolitan areas. The shape of Paris is highly radial and the urban continuous is mainly found in the center where no expansion is possible, where as the Randstad area consists of different nuclei where the urban continuous areas can also be found closer to the edges of the urban areas.

The highest correlation values are found for the (500 m) proximity and extension of industrial and commercial areas (r = 0,21) followed by the (60 km) proximity gravity map of airports (r = 0,17). Also the factor distance to town correlates quite well (r = -0,14), which is confirmed by the map-interpretation. A remarkable high positive correlation is found for the correlation with the (15 km) proximity and extension of nature (r = 0,13), but on the contrary a negative correlation is found for the proximity and extension of forest areas (r = -0,10). Also reasonable positive correlations are found for the (15 km) proximity and extension of green urban areas (r = 0,11). Quite low correlations are found for distances to railwaystations (r = -0,05), highway-exits (r = -0,05), railways (r = -0,04) and freeways (r = -0,07). Possibly this is due to the use of less accurate road and railway maps (derived from the digital chart of the world). Another reason could be the importance of the metro-net that is not part of our dataset.

On the basis of this correlation we conclude that urban expansion in Paris in the last fifteen years is highly related to the accessibility of work areas and in general to the distance to the town edge. Unfortunately we had no spatial planning maps for residential and commercial areas available, for which also high correlations were expected.

Densification

Few positive correlations are found for densification in Paris. In this case the strongest correlation is found for urban discontinuous area (r = 0,16), which is logically the area with available space for further densification. This is again different from the correlations in the Randstad where these correlations are negative. Remarkable negative correlations are found for green urban areas (r = -0.11), forest areas (r = -0.15) and (15 km) proximity and extension of leisure (r = -0.17) and water areas (r = -0.18), which could be the result of building restrictions in or near these areas. Another, but less assumable, explanation could be that forests were for example classificated as urban vegetation low, which cannot be densified according to the used definition for densification. Finally a remarkable high negative correlation is found for the distance to railway stations (r = 0.12), which could be the result of the already high building densities near these stations. Also the correlations for roadexits, rails and roads are negative. On the basis of these correlation results we conclude that densification in Paris is related to the available space in the urban discontinuous area and is limited by building restrictions in urban green and forest areas.

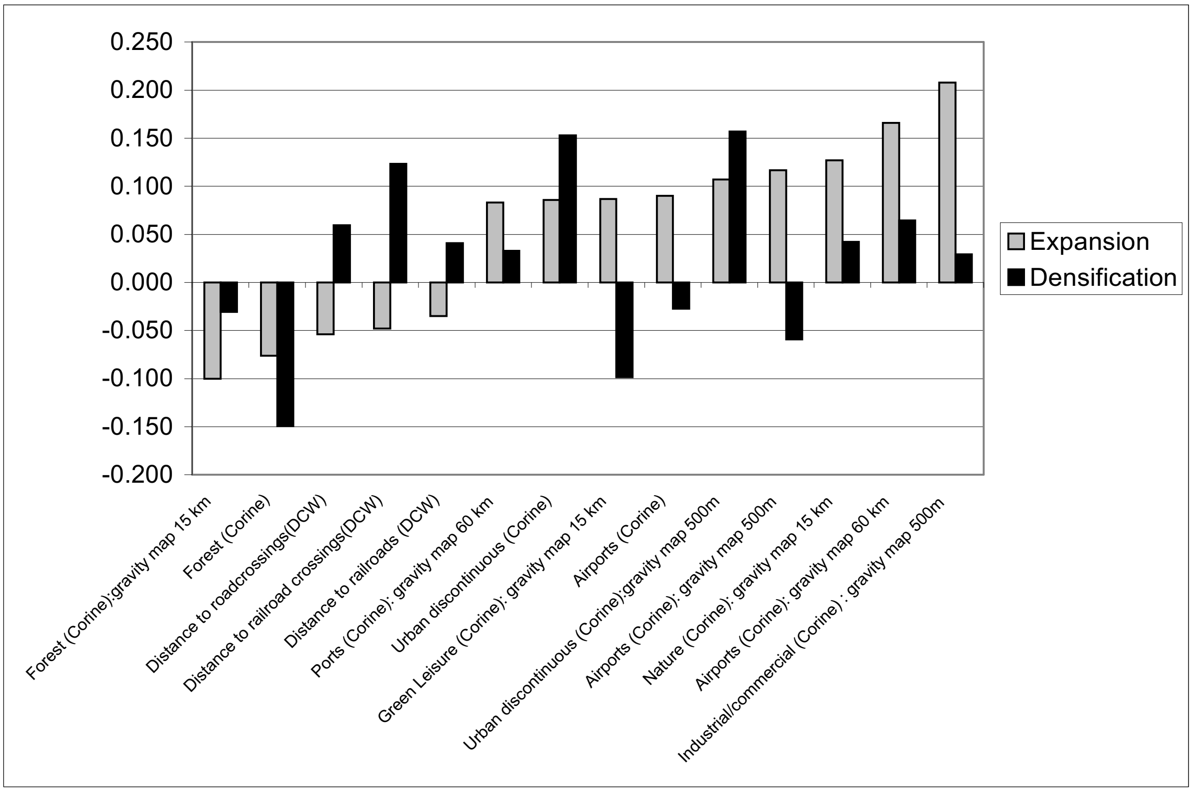

Figure 7.3 Correlations Paris (only r values less then -0.025 and more then 0.025 are shown)

7.4 Selected location factors

Although the different tables in this correlation-analysis show in general low correlation values (especially Paris and the Randstad), the described patterns visible in these values seem logical and consistent and therefore these results are considered useful. On the basis of the significance of the above described relations and the interpretation of the mutual correlations we decided to select location factors shown in the following table as the begin sets for the regression analysis.

In order to make comparison between the location factors between the test sites possible, factors that are relevant for more then one test site are listed on one line in table 7.1 on the next page.

Table 7.1: Selected location factors for the test sites

Lisbon	**Randstad Holland**	**Paris**
Urban built-up/bare (Landsat): gravity map 500m	Urban built-up/bare (Landsat): gravity map 500m	
Urban bare (Landsat): gravity map 500m	Urban bare (Landsat): gravity map 500m	
		Urban continuous (Corine): gravity map 500m
		Urban discontinuous (Corine): gravity map 500m
	Industrial/commercial (Corine): gravity map 500m	Industrial/commercial (Corine) : gravity map 500m
	Industrial/commercial (Corine): gravity map 60 km	
Ports (Corine): gravity map 500m	Ports (Corine): gravity map 500m	Ports (Corine)*: gravity map 500m
Airports (Corine): gravity map 500m	Airports (Corine): gravity map 500m	Airports (Corine): gravity map 500m
	Construction sites (Corine):	
		Green urban area (Corine)**
		Green urban area (Corine)*: gravity map 15 km
Urban vegetation low (Landsat) gravity map 15 km		
Urban vegetation high (Landsat) gravity map 15 km	Landsat urban vegetation high: gravity map 500m	
Leisure (Corine): gravity map 15 km	Leisure (Corine): gravity map 15 km	
		Forest (Corine)**
Forest (Corine): gravity map 15 km	Forest (Corine): gravity map 15 km	Forest (Corine)*: gravity map 15 km
Nature (Corine) gravity map 15 km	Nature (Corine) gravity map 15 km	Nature (Corine)*: gravity map 15 km
Wetlands(Corine): gravity map 15 km	Wetlands(Corine): gravity map 15 km	
Water (Corine): gravity map 15 km	Water (Corine): gravity map 15 km	Water (Corine)**: gravity map 15 km
Distance to municipalities		
Distance to railway stations	Distance to railway stations	Distance to railway stations
Distance to highway exits	Distance to highway exits	Distance to highway exits
	Distance to railways	Distance to railways
	Distance to freeways	Distance to freeways
Distance to towns > 100 ha*	Distance to towns > 100 ha*	Distance to towns > 100 ha*
Distance to Lisbon		
Distance to coast		
	New towns	

* **Only expansion**
** **Only densification**

7.5 Regression analysis

The second step of the statistical analysis is a regression analysis in which the strength and the direction of relations between a set of explanatory variables and the dependent variable are determined. A logistic regression type is chosen, because this type of regression is especially feasible when the measuring scales of the independent and the dependent variables are different, which is the case. As well, the logistic regression corresponds well with the way the simulation model Euroscanner allocates land use, in terms of chances between one and zero. For each explanatory variable the strength and direction of the relation is expressed in the form of a regression coefficient (beta). The quality of the beta-coefficient is estimated with the t-test of statistical significance. The resulting beta-coefficients are used later on in the extrapolation of the statistical trends in the simulation model.

To get an indication of the explaining value of the different variables, we conducted a ‘stepwise regression analysis’ in which the explanatory value of each variable is tested in a structured way. The resulting set of variables of the stepwise regression analysis was used to get a general impression of the most significant variables. On the basis of expected relations and the actual regression values, variables are removed and added manually until the best explanatory combination is found. The explanatory value of each of the tested sets was evaluated by means of the residual deviance.

For the calculation of the dependent variables the expanded and densified areas have been transformed to relative values by dividing them by the area available for respectively expansion and densification. Following the applied definitions for expansion and densification this means that the expanded area is per cell divided by the rural area in 1984/86 per cell and the densified area by the urban vegetation high area of 1984/86. In this way we get a value between zero and one, in which one implies maximal expansion.

7.5.1 Regression results Lisbon

Expansion

The resulting set of variables in the Lisbon area shows a more diverse mix of significant variables than the other test-sites do. Both the proximity and extension of the existing urban area (concentration factors) as the distance to the townborders, railway stations and roadexits are important factors. Remarkable however is the high negative value for the 60 km ports gravity map. In the correclation analyses a highly positive value was found for this variable. In the combination of variables ports have a relative negative influence on city expansion. The removal of the ‘distance to central Lisbon variable’ indicates that the accessibility to local economical and social centers and accesspoints to main infrastructure is apparently more important. Also the accessibility of leisure, forest and waterbodies seems to have a significant influence on expansion in Lisbon.

Table 7.2 Obtained regression results for expansion in the Lisbon area

Variable	Coefficients:	Std-Error	t-value
Constant	-2.3387	0.28668	-8.1578
Urban built-up/bare (Landsat): gravity map 500m	0.0271	0.00466	5.8182
Urban bare (Landsat): gravity map 500m	0.0429	0.00789	5.4359
Ports (Corine): gravity map 60 km	-11.8735	2.46310	-4.8205
Airports (Corine): gravity map 60 Km	3.4233	0.74499	4.5951
Leisure (Corine): gravity map 15 km	1.8375	0.29506	6.2274
Forest (Corine): gravity map 15 km	0.0291	0.00721	4.0379
Wetlands (Corine): gravity map 15 km	-0.7812	0.17450	-4.4767
Water (Corine): gravity map 15 km	0.0835	0.02035	4.1072364
Distance to municipalities (in Km)	-0.0335	0.0140	-2.3927
Distance to highway exits (in Km)	-0.0687	0.0173	-3.9725
Distance to railway stations (in Km)	-0.0815	0.0198	-4.1058
Distance to towns > 100 ha (in Km)	-0.1016	0.0155	-6.5505

Densification

The relation of variables with the growth of densification patterns however is less clear. This is probably the result of the few densification processes in Lisbon compared to the big expansion processes still going on. Relatively strong negative relations are found with the distance to the coast and the distance to the center of Lisbon. A reasonable positive relation is found with the distance to highway exits and to railway stations.

Table 7.3 Obtained regression results for densification in the Lisbon area

Variable	Coefficients:	Std-Error	t-value
Constant	-1.3215	0.5406	-2.4442
Urban bare (Landsat): gravity map 500m	0.0160	0.0040	3.9522
High vegetated areas (Landsat): gravity map 15 km	-0.1936	0.0714	-2.7095
Wetlands (Corine): gravity map 15 km	-0.2898	0.2565	-1.1295
Water (Corine): gravity map 15 km	0.0552	0.0233	2.3633
Distance to highway exits (in Km)	-0.0409	0.0265	-1.5400
Distance to railway stations (in Km)	-0.0286	0.0298	-0.9606
Distance to Lisbon (in Km)	0.0525	0.0211	2.4861
Distance to towns > 100 ha (in Km)	-0.0673	0.0337	-1.9965
Distance to the coast (in Km)	0.0924	0.0231	3.9923

7.5.2 Regression results Randstad

Expansion

In general the results of the correlation analysis are confirmed, although the t-values in this data-set can be considered low. An important factor in the Rotterdam-Randstad area seems to be again the distance to existing townborders which reflects the compact city policy and the location in a newly planned town. Also the distance to railway stations gives a relative high explanatory value in this dataset. The proximity and concentration of work, airports and the existing urban area have quite low but significant values.

Table 7.4 Obtained regression results for expansion in the Randstad Holland area

Variable	Coefficient	Std Error	t-value
Constant	-2.4026	0.3801	-6.320
Urban built-up/bare (Landsat): gravity map 500m	0.0766	0.0289	2.6510
Industrial/commercial (Corine): gravity map 500m	0.0157	0.0067	2.3210
Airports (Corine): gravity map 500m	1.9239	0.8206	2.3443
Construction sites (Corine):	0.0226	0.0049	4.5278
Landsat urban vegetation high: gravity map 500m	-0.0209	0.0092	-2.2624
Nature (Corine): gravity map 15 km	-0.1659	0.0676	-2.4526
Wetlands(Corine): gravity map 15 km	0.2091	0.0532	3.9260
Distance to railway stations (in Km)	-0.2009	0.0496	-4.0469
Distance to highway exits (in Km)	-0.2853	0.1375	-2.0737
Distance to towns > 100 ha (in Km)	-1.2585	0.1650	-7.6261
New towns	1.6808	0.2258	7.4420

Densification

For densification one of the most important variables is the existing urban area, which is logical according to the definition of densification. The proximity of urban green areas, forests and wetlands however respond negatively (compared to the other factors) to increase of densification. Especially roadexits and freeways seem to have meaningful relation with the increase of densification.

Table 7.5 Obtained regression results for densification in the Randstad Holland area

Variable	Coefficient	Std Error	t-value
Constant	0.4253	0.1732	2.4555
Urban built-up/bare (Landsat): gravity map 500m	0.0105	0.0017	5.9462
Urban bare (Landsat): gravity map 500m	-0.0158	0.0124	-1.2702
Industrial/commercial (Corine): gravity map 500m	0.0061	0.0029	2.0556
Industrial/commercial (Corine): gravity map 60 km	-0.0953	0.0465	-2.0493
Landsat urban vegetation high: gravity map 500m	-0.0177	0.0031	-5.7055
Forest (Corine): gravity map 15 km	-0.3358	0.0590	-5.6830
Wetlands(Corine): gravity map 15 km	-0.2118	0.0414	-5.1159
Water (Corine): gravity map 15 km	0.0570	0.0151	3.7722
Distance to highway exits (in Km)	-0.1161	0.0963	-1.2050
Distance to highways (in km)	-0.3611	0.1093	-3.3024

7.5.3 Regression results Paris

Expansion

According to the regression results the expanded areas around Paris are especially strongly related to the distance to existing townborders, the proximity of workareas and the distance to railway stations.

Table 7.6 Obtained regression results for expansion in the Paris area

Variable	**Coefficient**	**Std Error**	**t-tvalue**
Constant	-4.7834	0.3261	-14.6673
Urban discontinuous (Corine): gravity map 500m	0.0164	0.0028	5.8451
Industrial/commercial (Corine): gravity map 500m	0.0316	0.0037	8.3904
Ports (Corine): gravity map 500m	-9.1579	2.5745	-3.5570
Airports (Corine): gravity map 60 Km	1.0351	0.3324	3.1136
Wetlands(Corine): gravity map 15 km	0.8186	0.1898	4.3119
Distance to railway stations (in Km)	0.3670	0.0464	7.9059
Distance to highway exits (in Km)	0.1190	0.0279	4.2583
Distance to towns > 100 ha (in Km)	-1.1396	0.0848	-13.4369

Densification

Also in Paris the densification is mainly related to the existing urban area and the distance to railwaystations. The negative values for forest and water seem to be coincidental, a result of the spatial distribution at larger distance from the densification processes.

Table 7.7 Obtained regression results for densification in the Paris area

Variable	**Coefficients:**	**Std Error**	**t-value**
Constant	-0.2461	0.1561	-1.5767
Urban discontinuous (Corine): gravity map 500m	0.0082	0.0013	5.9278
Industrial/commercial (Corine): gravity map 500m	0.0076	0.0034	2.2160
Urban green (Corine)	-0.0071	0.0021	-3.2341
Forest (Corine)	-0.0086	0.0018	-4.6931
Water (Corine): gravity map 15 km	-0.3417	0.0520	-6.5611
Distance to railway stations (in Km)	0.1375	0.0320	4.2877
Distance to highway exits (in Km)	0.0407	0.0222	1.8366

8 IMPLEMENTATION

8.1 Introduction

After determining the historic land use change that has occurred in the last decade in the test sites (chapter 5), establishing the driving factors behind land use change (chapter 6) and deriving the equations that give a numeric description of the locational trends in land use change over the last decade (chapter 7) it is possible to simulate land use in the test sites with the simulation model Euroscanner.

In this chapter several kinds of simulations are discussed. First the regression equation is filled with the same historical data (variables) the equation is derived from. In other words, we try to simulate the historical found urban expansion and densification derived from the satellite images for the period 1984/1986 - 1998/1995. Secondly, the variables in the regression equation are updated with recent spatial data. In this way the simulation shows us how the land use in the rural urban fringe will change in the future if the driving forces, and thus the location preferences, remain valid. This simulation can be considered as a trend analysis. In the third kind of simulation the variables derived from the Lisbon area are used to simulate land use in Randstad Holland and vice versa. These simulations demonstrates how land use in the urban rural fringe will change if alternative driving forces or planning scenarios are implemented.

As discussed in chapter 3 several inputs are necessary for a simulation:

Land use claims

For all simulations the land use claims are derived from the satellite images. For all three test sites the amount of land that was subject to expansion and densification in the past is determined. This amount of land will be allocated, also for the simulation of the future trend as well as for the alternative scenarios. Consequently, the assumption is when the future trend is simulated both claims and driving forces (behind land use change) remain the same. Whereas in alternative scenarios the claims remain the same but the driving forces differ.

Suitability maps

Because both expansion and densification will be simulated two suitability maps have to be derived that show the locational preferences of both urbanisation processes. The suitability maps used in the simulations are derived from the equations found with the statistical analyses. As discussed above the simulation of the historic expansion and densification is carried out with the same data as used to determine the equation. For the simulation of the future urbanisation trend these variables are updated. For alternative scenarios additional data is incorporated in the suitability map.

Additional constrains

Some additional constraints are used in the simulations. As described in chapter 7 the definition of expansion and densification implies that expansion only occurs in areas that are classified as rural in the start situation, while densification is limited to vegetated urban areas.

Most driving forces tend to diminish gradually in space and also the maps that are the operationalisation of these forces do not often have sharp boundaries. This implies that, together with the properties of the allocation algorithm described in chapter 3, the simulated land use changes tend to blur out. In order to prevent this, the minimum amount of allocated land is set to 1 hectare or 4% per gridcell. This is in accordance with the minimum area expansion and densification determined from the satellite images. This threshold is operationalised by running the allocation algorithm for each simulation two times. First with all land available for expansion and densification. In the second simulation gridcells in which less than 4% expansion or densification is allocated are excluded.

Application of alternative planning scenarios implies the use of additional data. For example a simulation is carried out that includes the new airport that is foreseen in the Lisbon area. The gravity map that is the operationalisation of the attraction of this airport is incorporated in the suitability map for this alternative simulation Also the boundaries of the airport itself are included in order to prevent urban expansion on the airport itself in this simulation. Although it may even be necessary to exclude certain areas in the proximity of the airport as building ground due to legal constraints concerning noise nuisance or safety, this restriction is not incorporated in the simulation. Another kind of alternative simulation that is carried out is the implementation of the historical trend found in Lisbon area in the Randstad Holland area and vice versa. For these simulations additional maps with driving forces are used to derive the suitability map. In the following paragraphs the simulation results for the three test sites will be shown and discussed.

8.2 Simulation results Lisbon

In figure 8.1 and 8.2 the simulated expansion and densification patterns are shown together with the historic expansion and densification for the Lisbon area. The simulated expansion and densification look similar to the historic patterns found between 1984 and 1998. Expansion is good simulated at the fringe of Lisbon and on the East site of the river Tagus, although it tends to blur out. This is due to the properties of the suitability map as discussed before. High suitability values near Lisbon cause an underestimation of expansion in villages at a greater distance from this major city.

The simulated densification is similar to the historical densification, this accounts both for the found patterns as for the amount per cell. Different in the simulated densification and the actual found densification is the high densification values simulated near the coast.

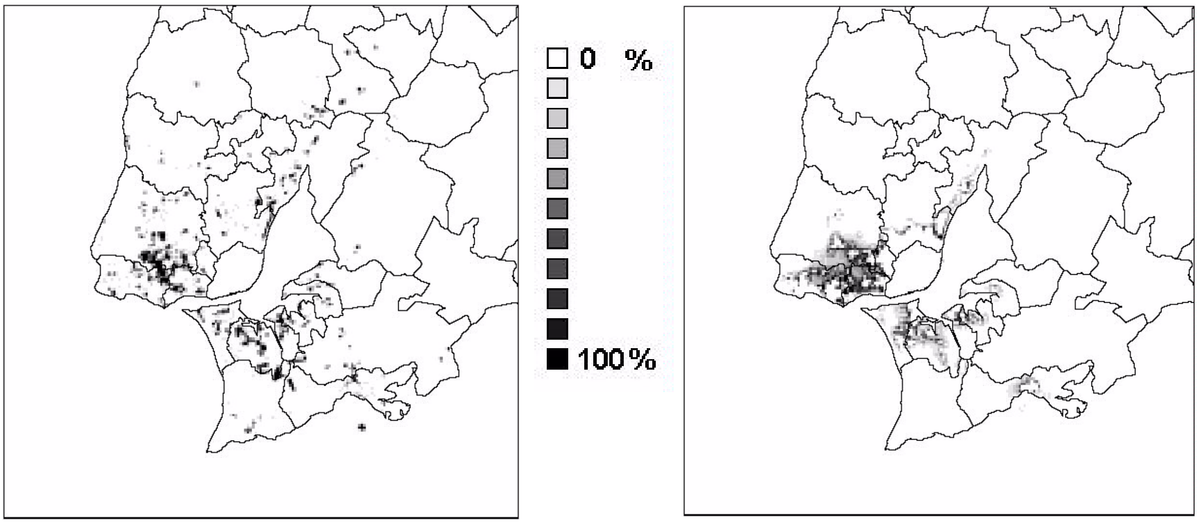

Figure 8.1 Historical (left) and simulated (right) expansion for the period 1984 - 1998

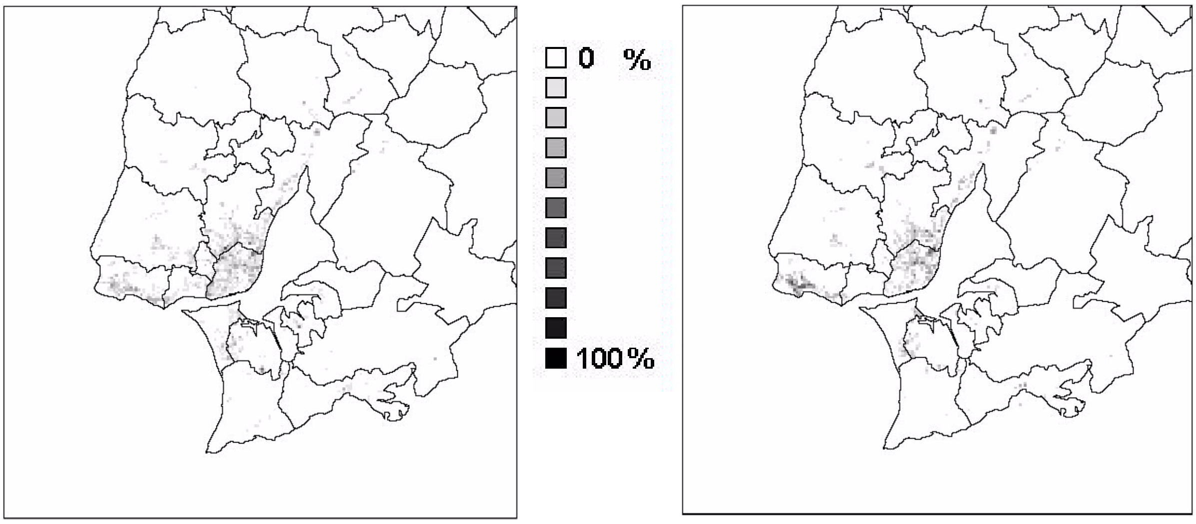

Figure 8.2 Historical (left) and simulated (right) densification for the period 1984 - 1998

In figure 8.3 the simulated expansion and densification for the period 1998 - 2012 can be found. The amount of land subject to rural-urban conversion in this period is assumed to be the same as in 1984 - 1998 and also the locational preferences for expansion and densification are assumed to remain the same. Updated are the boundaries of rural and urban areas, where respectively expansion and densification can occur. From the regression variables listed in table 7.2 and 7.3 the variables derived from Landsat TM 1984 images are updated with those of 1998. This also includes the distance to towns, in which the town locations are derived from the satellite images.

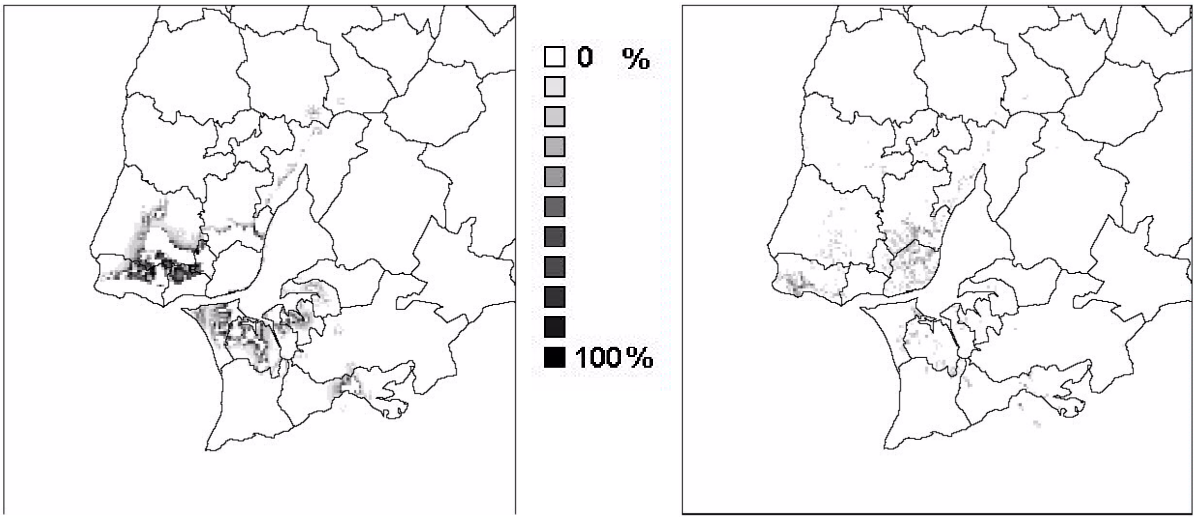

Figure 8.3 Simulated expansion (left) densification (right) for the period 1998 - 2012

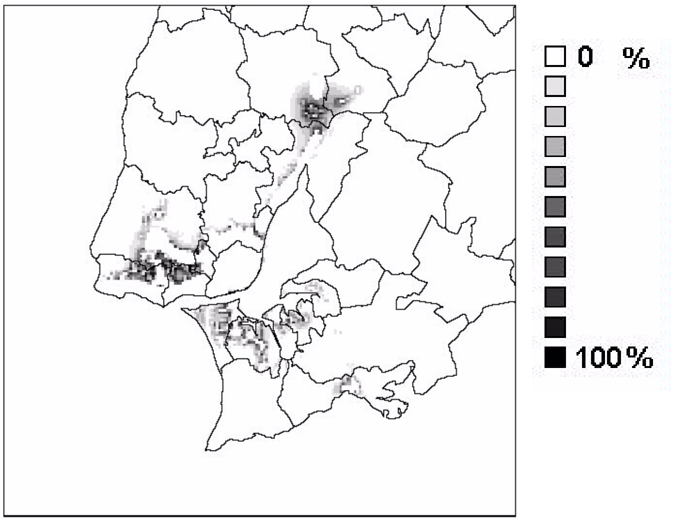

Figure 8.4 Simulated expansion for the period 1998 - 2015 with the establishment of a new airport in the Lisbon Metropolitan Area.

As can be expected the historical trends are in general continued. However, for expansion some differences can be observed. The expansion at the Northern fringe of Lisbon is not as distinct as found in the simulation for 1984 - 1998. For the area East of the river Tagus more expansion is simulated, also the amount allocated per cell is higher in this area.

Figure 8.4 shows the effects of an alternative scenario for the Lisbon area; the impact (only expansion) of the new airport that is planned North of the Lisbon Metropolitan area. The coefficients used in this simulation are the same as those used for the trend simulation. The only difference is the new airport which is added as a variable (with the coefficient found for airports in the Lisbon area). Due to the enormous size of the new airport, it was chosen to rescale the variable in accordance with the values found for the existing airport. Looking at figure 8.4 it can be observed that the expansion near the new airport tends to blur out, although also some cells at the south of the foreseen airport show high expansion values. An explanation for this is that the airport will be build in a rather empty area where no other locational features are present yet, Comparison with figure 8.3 shows that the impact of the new airport will be enormous and will lead to a diversion of urban expansion from central Lisbon to the area north of the capital in the vicinity of the new airport.

Another alternative planning scenario is the incorporation of the for the Randstad Holland derived variables in Lisbon region. This illustrates how the expansion and densification pattern in the Lisbon area would look like if the driving forces had been similar to those found in Randstad Holland.

In comparison with the historical found expansion and densification the simulation results shown in figure 8.5 are more compacted. Striking is that in this scenario expansion near Lisbon is limited and occurs for a large part in the East bank of the river Tagus, while densification only occurs in Lisbon, with very high densities in the center of town.

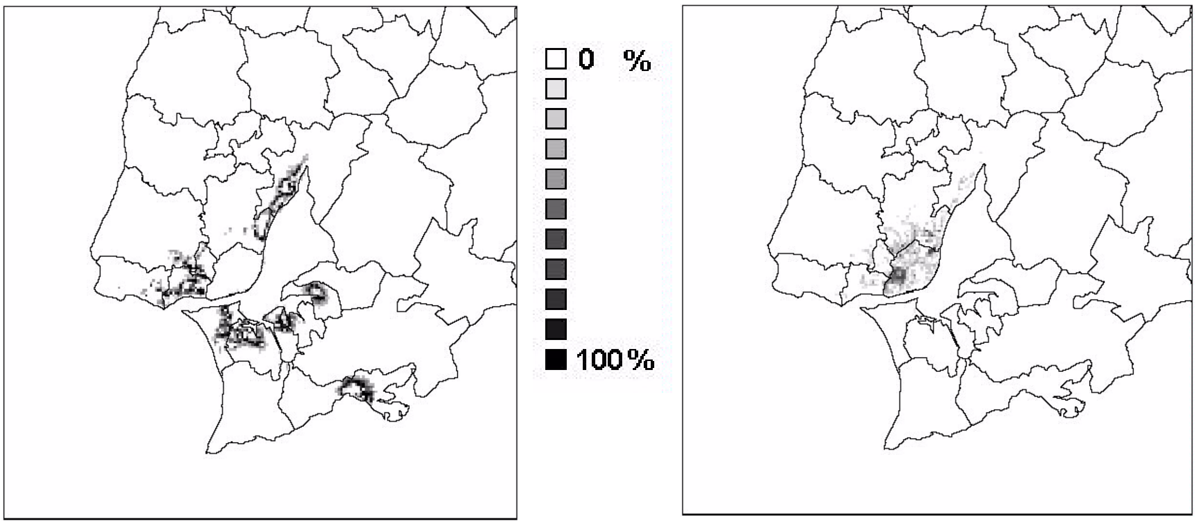

Figure 8.5 Simulated expansion (left) densification (right) for the period 1984 - 1998 making use of the driving forces (variables) determined for Randstad Holland.

8.3 Simulation results Randstad

Figure 8.6 shows the historic expansion in Randstad Holland for the period 1986 - 1984 and the simulated expansion for the same period.

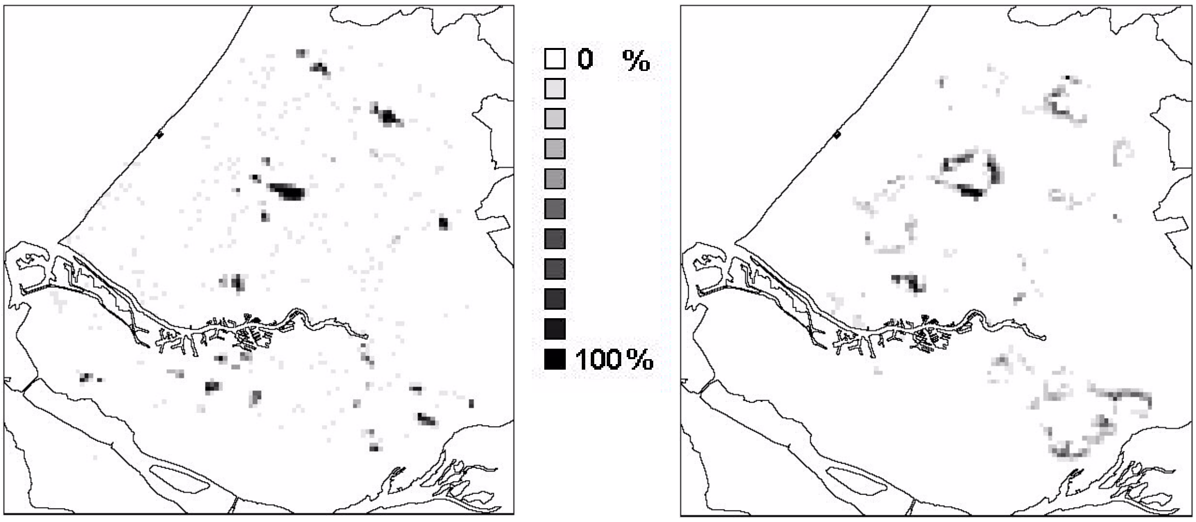

Figure 8.6 Historical (left) and simulated (right) expansion for the period 1986 - 1995

The expansion pattern is in essence reproduced but small villages do not expand in the simulation and areas with high expansion values tend to blur out. The enlargement of small villages is not reproduced because they are probably to small to have an impact in the regression analysis. A possible explanation of the fact that large building sites are not pinpointed to an exact location is that urban expansion in the Netherlands is mainly determined by policy. In the time frame considered the policy was to assign whole municipalities as being subject to rapid urban growth and a map with these municipalities has been used in the simulation. The densification pattern simulated (figure 8.7) is quite similar to the historic densification, except that high densification values are not obtained in the centre of Rotterdam but in the centre of Vlaardingen.

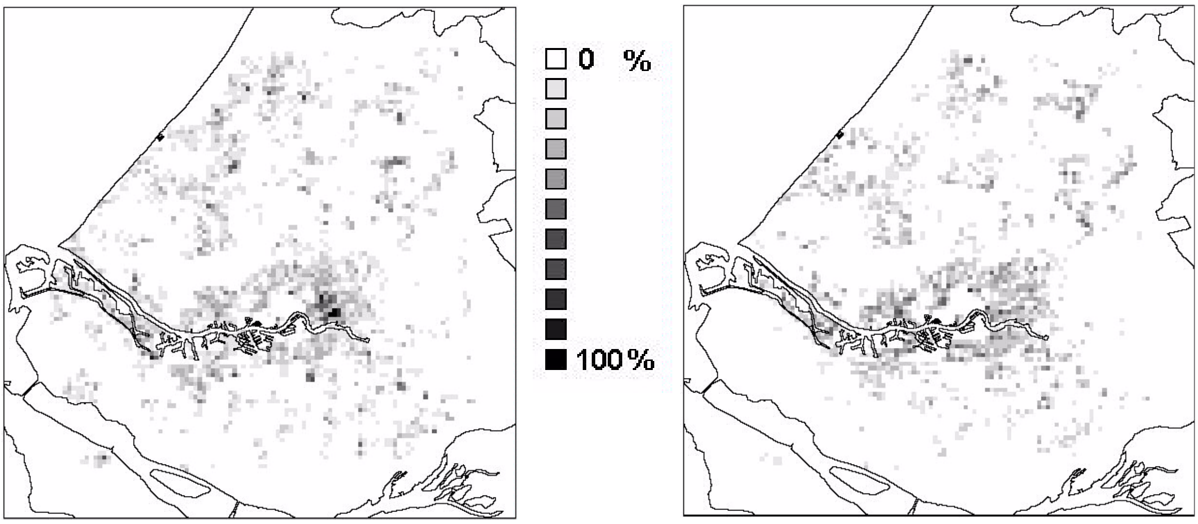

Figure 8.7 Historical (left) and simulated (right) densification for the period 1986 - 1995

For the simulation of future expansion and desification (figure 8.8) the period between 1995 - 2010 is taken into account. This is accordance with the VINEX policy that is the current national policy regarding strategical physical planning and will end in the year 2010.

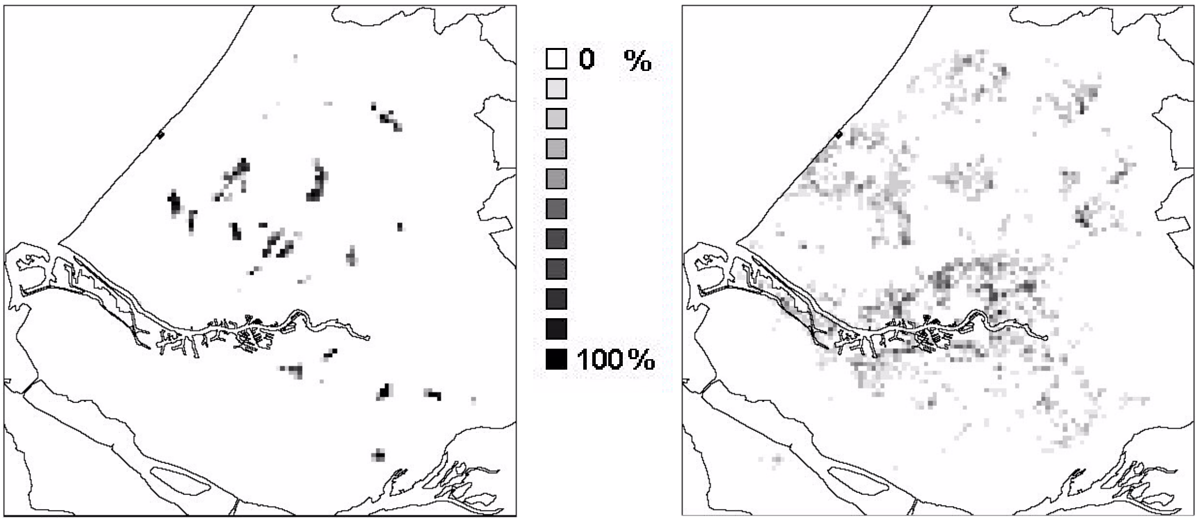

Figure 8.8 Simulated expansion (left) densification (right) for the period 1995 - 2010

For the simulation of expansion not only the variables in the regresion were updated but also an additional map was incorporated. This policy map shows future building locations (both housing and industry/commerce) according to the VINEX. These so called VINEX locations are considered as building sites and as new planned towns .
Looking at the expansion in figure 8.8 it is remarkable that the VINEX building locations are reasonably filled. Outside these building locations, only some limited expansion occurs. This is due to the fact that the area of these appointed building locations is 2.6 times bigger than the historical found expansion that was used as the expansion claim that has to be allocated. Expected is that if a higher claim for expansion will be incorporated in the simulation also building locations will occur outside the assigned building locations.
The simulated densification for the period 1995 - 2010 (figure 8.8) looks like the historic found (and simulated) densification. Only in the city of Rotterdam more cells with high densification values occur. This is due to the fact that between 1986 and 1995 a lot of densification has taken place here and consequently the gravity map of urban bare / build up area, that is the main driving factor, has significant high(er) values in 1998.

The alternative planning scenario simulated for Randstad Holland is the incorporation of the for the Lisbon derived variables in the Randstad region. This illustrates how the expansion and densification pattern in Randstad Holland would look like if the driving forces had been similar to those found in Lisbon.
In comparison with the historical found expansion and densification the results shown in figure 8.9 show a totally disperse pattern with low expansion and densification values.

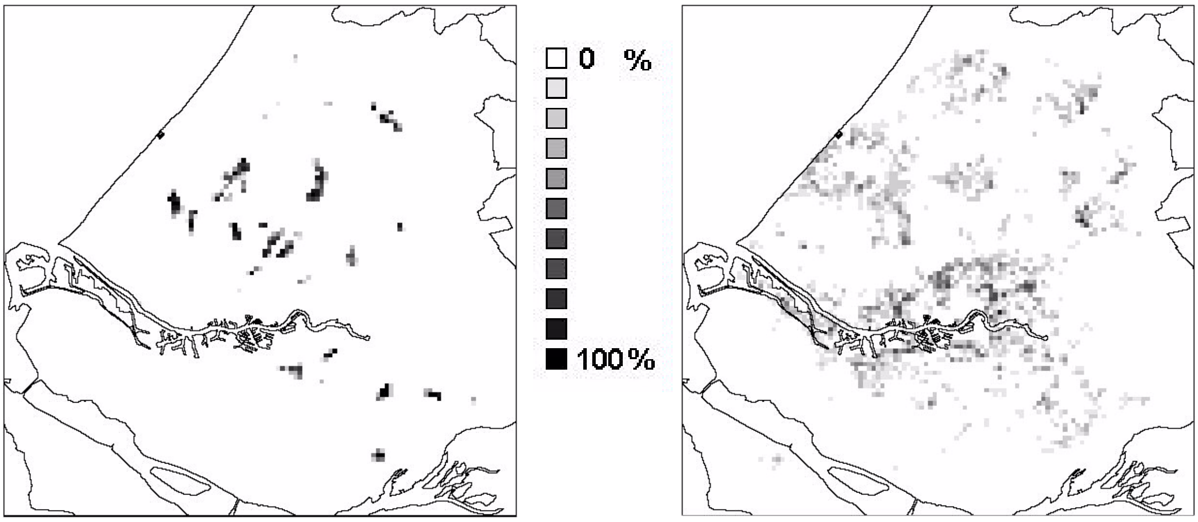

Figure 8.9 Simulated expansion (left) densification (right) for the period 1986 - 1995 making use of the driving forces (variables) determined for Lisbon.

8.4 Simulation results Paris

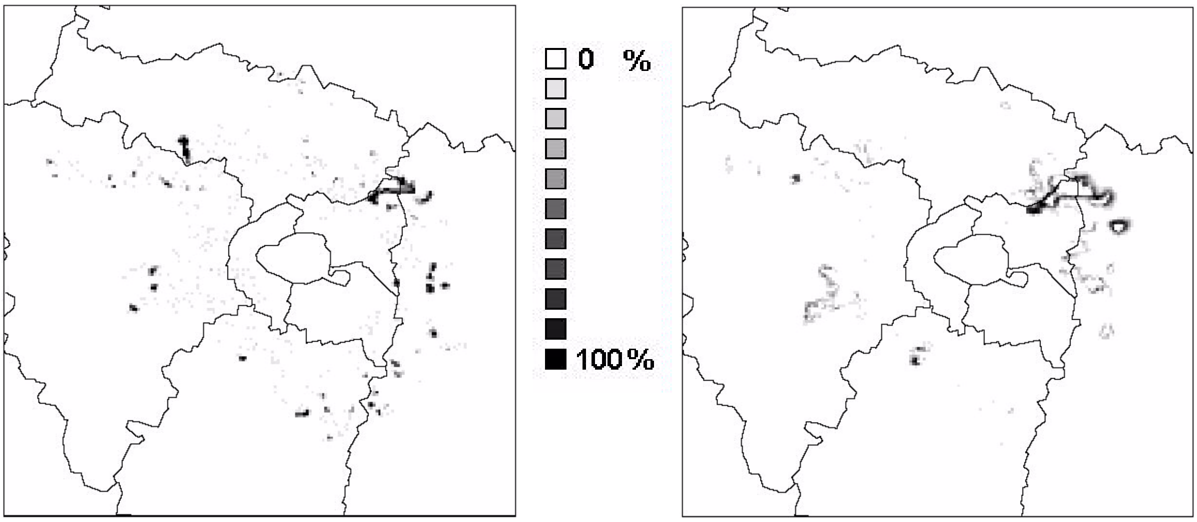

Figure 8.10 Historical (left) and simulated (right) expansion for the period 1984 - 1998

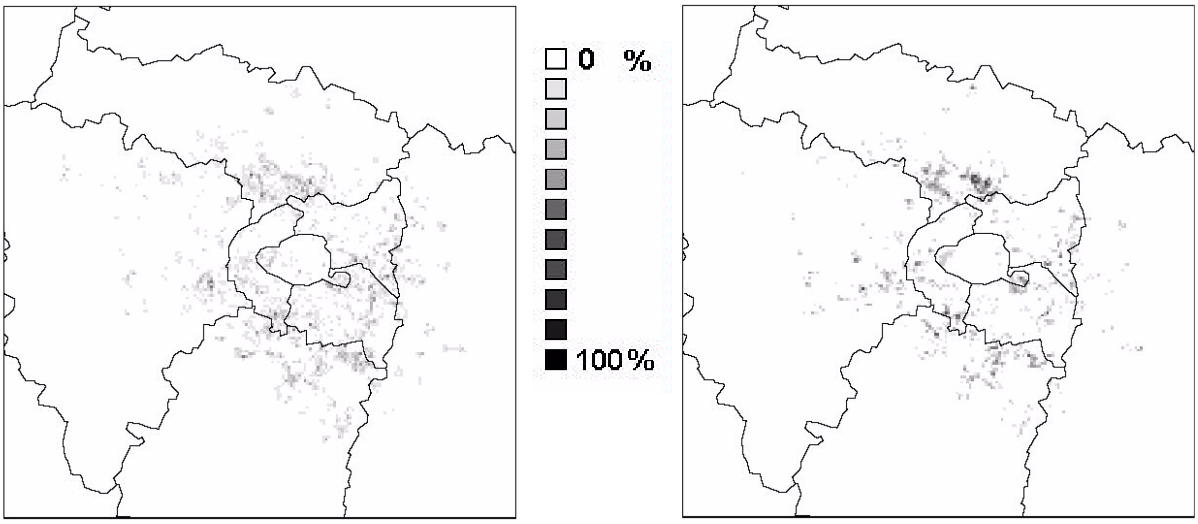

Figure 8.11 Historical (left) and simulated (right) densification for the period 1984 - 1998

The two figures above show historic expansion and densification and the simulation of past urbanisation, while figure 8.10 on the next page shows the expected future land use change for the Paris metropolitan area.

The results show that the larger areas northeast of Paris with high historical urban expansion rates are simulated well. But, as in the simulation for Lisbon and Randstad Holland, these areas tend to blur out and also the low urban expansion near small towns in the area is not simulated well. The simulated densification shows great resemblance with the actual found densification, but in some of the grid cells the simulated amount is higher than historically found. This occurs especially North of Paris.

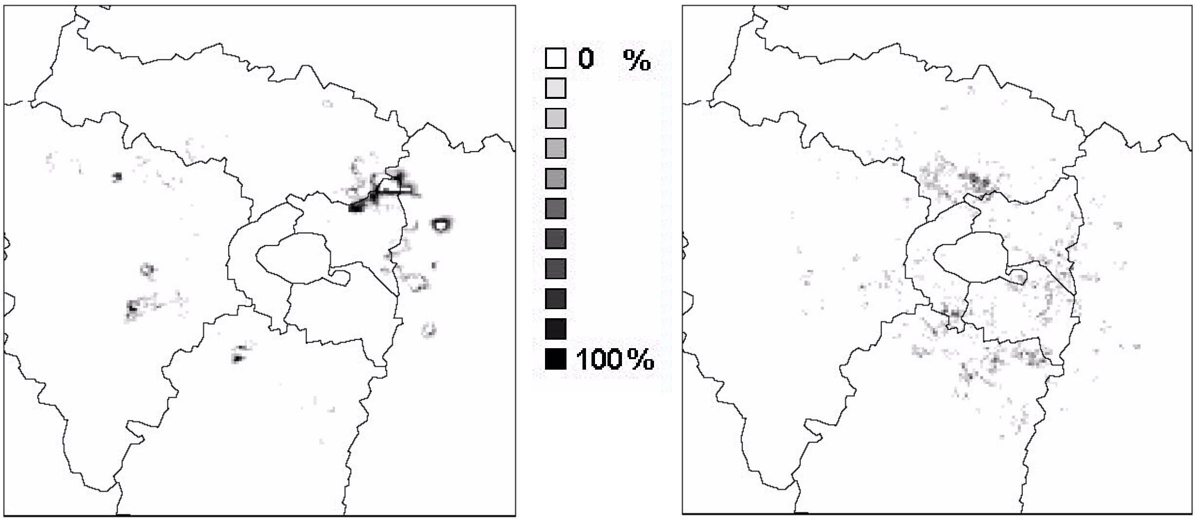

Figure 8.12 Simulated expansion (left) densification (right) for the period 1998 - 2012

The simulations for the future (8.12) show the same patterns as the historic simulations (8.10 and 8.11). This can be expected because due to limitations in data availability (only variables derived from Corine were incorporated, as can be seen in tables 7.6 and 7.7) the variables in equations could not be updated with recent maps. Only the boundaries of rural and urban areas, where respectively expansion and densification can occur, were updated using the 1998 satellite images.

8.5 Simulation results Europe

Simulation of land use change with the developed prototype based on the (quantitative) statistical method applied to Lisbon, Randstad Holland and Paris is unfortunately limited to the three selected test sites. This is both due to practical and theoretical reasons. The practical reason is the lack of European data that describes the main driving factors on an appropriate scale level. From a theoretical point of view the difference in scale level between the test site and Europe has to be overcome.

However, a qualitative approach to simulate land use change on a European scale level is indeed possible. Just as with a quantitative approach information regarding the amount of land subject to change is needed and also the driving factors that determine the location of the different kind of land uses have the be described. The latter is done on a qualitative manner. With the help of experts the main driving forces are translated with avialable datasets into maps showing the spatial distribution of these factors.

The simulation is carried out for the period 1990 - 2010. A total of 3 land use types are distinguished; urban, nature and agriculture. For 1990 the Corine database is aggregated into the three land use types mentioned while for 2010 the base line scenario was chosen. In this scenario the amount of agricultural land subject to conversion into urban and nature is known for each European country. Assumed that 20 % of the agricultural land subject to change will be converted into urban and 80 % into nature (van Vliet et al, 1999). The actual area of agricultural land taken out of production is given in appendix V.

In order to make reallocation possible the attractivity from a agricultural and natural perspective are taken into account, consequently additional urban areas will occur in areas not attractive to both agriculture and nature. From an agricultural point of view the driving forces that determine the location is the soil quality and the distance to urban areas.

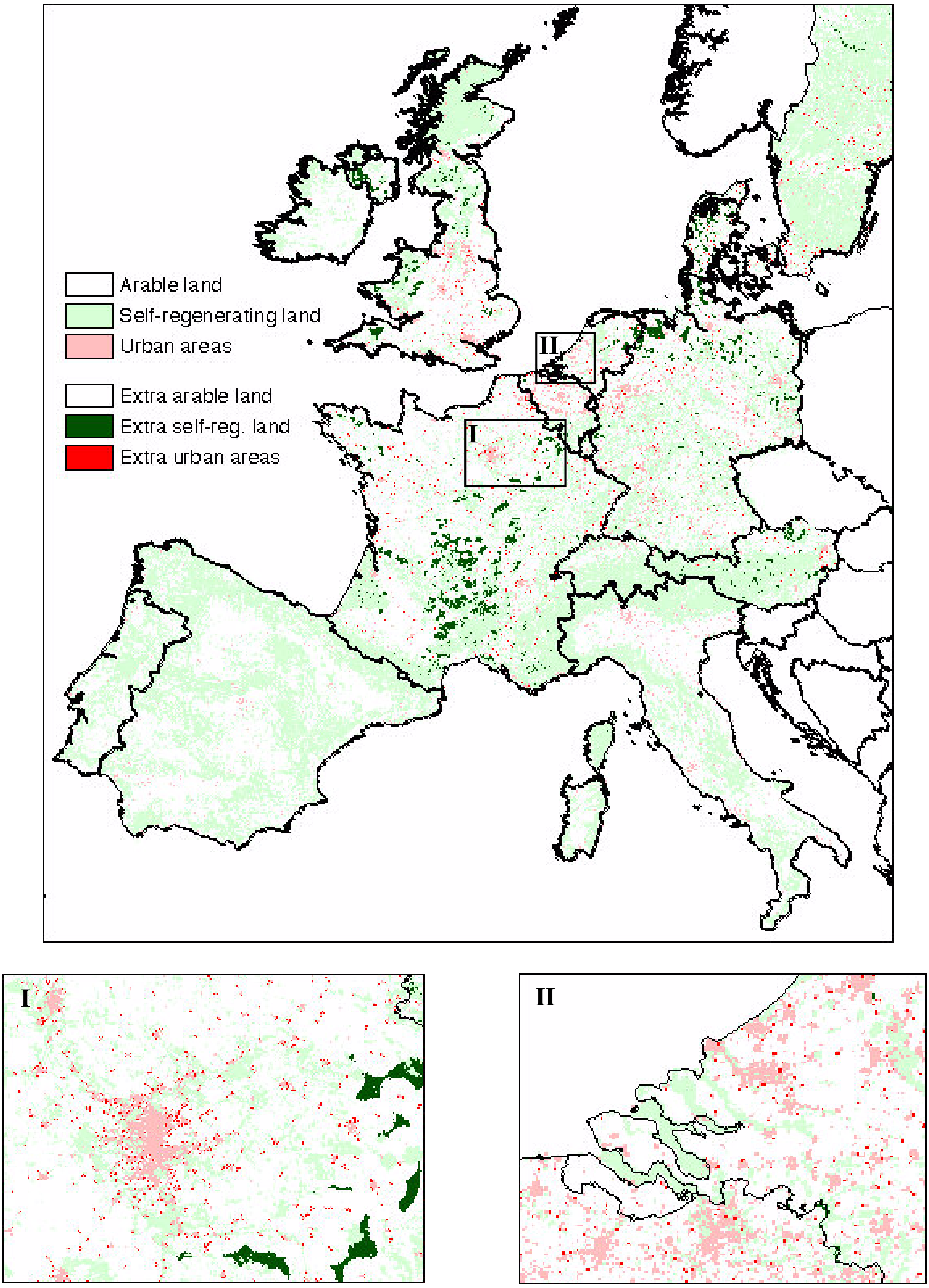

Figure 8.13 Simulated land use change according to the baseline scenario (1990 - 2010)

Cells with a high yield reduction due to the soil quality and at a large distance to urban areas will be converted into other land uses first. From a nature conservation point of view the environmental pressure that limits the biodiversity is taken into account, together with the connectivity between current natural areas and the distance to urban areas. Cells with a low environmental pressure, high connectivity and larger distance to urban areas will be converted into nature. As mentioned before cells containing agriculture in 1990 and neither agriculture nor nature in 2010 will be converted into urban.

The simulation result is shown in figure 8.13 on the next page. Presented is the land use (change) for the whole of Europe with details of Randstad Holland and Paris. The figure shows different amounts of land use change in each country. This is determined by the given amount in the baseline scenario. Because the baseline scenario assumes that in Portugal the amount of agricultural land will not decrease until 2010 and hence no land use change is present the test site of Lisbon is not enlarged. Moreover, the operalisation of the driving forces result in natural areas to appear in large connected patches while urban expansion will occur more scattered near existing urban areas

This qualititive approach, of which an example described in this paragraph, is especially suited to determine the effect of driving forces that are not in accordance with historically found trends or to evaluate the impact of e.g. European spatial policies

9 LAND USE SIMULATION AND THE ADDED VALUE OF REMOTE SENSING

9.1 The role of remote sensing in land use simulation

The in this report described model for the simulation of land use requires different kinds of data in order to run:

- A database that describes the land use in the start situation (often the current land use)
- A set of maps or datasets with the main driving factors that result in the reallocation of certain land use types
- A database that contains the land use claims of the land use types simulated

In the developed modelsystem land use is simulated with resolution of 2 kilometers for Europe and 500m for the test sites. Consequently, the database describing land use in the start situation has to have the same (or even more detailed) resolution. As mentioned in chapter 4 all recently developed European land use databases having the required resolution on a continental scale are based on remote sensing imagery and ancillary geographic information. For the test sites Randstad Holland and Lisbon also land use database are available, although they are not used in this study. For the Netherlands this are the land use statistics developed by the Dutch Central Statistical Office. From 1981 to 1996 several land use statistics are available describing land use with a 500m resolution. The earlier versions are based on information provided by municipalities the recent versions are derived from aerial photography.
The second kind of inputs are maps that describe the driving factors that determine the (re)allocation of land use. Different kinds of driving forces can be distinguished. Driving forces based on (the restrictions of) the physical environment (e.g. soil, climate). Maps showing policy regulations (e.g. housing and nature conservation plans) and characteristics in relation to neighboring cells. Remote sensing plays an important role by detecting and determining the latter kind of driving forces because it can detect the morphological changes caused by a driving factor on the required resolution and for all relevant land use types.
The third kind of inputs are the land use claims. These claims only give the amount of land, used by a certain type, in the start year and the year simulated. These data can be obtained in different ways. For the historical and current situation land use statistics can be derived either from satellite imagery or from statistical databases. The advantage of remote sensing is that both the nomenclature as the method can be standardized. Disadvantage is that for every period image classification has to be performed, whereas statistical databases are already available. For the future amounts can be derived from sectoral models forecasting the land use claims at a much lower level of spatial resolution (countries or regions).

9.2 Evaluation of the value of Remote Sensing

In the previous paragraph is discussed that remote sensing and remote sensually derived products are incorporated in different parts of the land use simulation process.
Remote sensing is the main source for the land use databases describing the current on a European level.

The in chapter 4 mentioned databases are available and can be obtained by paying the handling costs or can be purchased:

- Pelcom (free of charge):
- Corine (approx. 200 Euro, handling costs)
- IGBP (handling costs)
- 10 minutes database (free of charge)

In this report is also described how trends in land use change are detected and linked with the driving forces behind these changes. Historical and recent satellite imagery is input for classification in order to determine the change of land use in the urban - rural fringe. Because we are not only interested in the amount of change but also in the spatial pattern of this phenomenon land use data with a high resolution is needed. The cost of the classification to determine the trends in land use change for the three test sites is as follows:
Purchasing 3 current en 3 historic Landsat-TM images costs approx. 10 000 Euro
Processing and classification of the imagery costs approx. 30 000 Euro.
The alternative for remotely sensed obtained imagery are land use statistics. Although these are relatively cheap on a European scale level (approx. 2300 Euro for the Eurostat and GISCO database) the spatial resolution of Nuts 3 regions is so course that no spatial patterns can be extracted. A dataset that in the future might be available is the updated Corine database. In combination with the current available version of this database land use changes including the spatial patterns might be possible on the scale level needed. As mentioned earlier for the Netherlands there are land use historical land statistics developed by the Dutch Central Statistical Office. The cost of each land use databases is approx. 1200 Euro. However, the proposed update (using the 1 : 10000 vector map of the Ordnance Survey) will cost significant more (approx.more then a factor 30).

The amount of land use change is, in this study, also obtained from satellite imagery. Chosen is to extract this amount from imagery because after the classification of the images. This is a simple procedure and one remains close to the definition of the studied phenomenon's expansion and densification. However, for simulations that cover the whole of Europe and in which more land use type are distinguished available land use statistics (like Eurostat) are recommended. Also because these statistics are in line with sectoral models that forecast land use change on high scale levels (e.g. Nuts regions or countries).

Overall one can conclude that currently no databases showing land use changes with the resolution needed for this type of land use simulation are available. This account for Europe as well as for the test sites (exept the Netherlands). With the proposed update of Corine such a database will become available. It depends on the pricing policy and the quality if Corine can replace the classification of satellite imagery as used in this study. The same accounts for data focussing on new land use use change detection techniques currently in development.

10 CONCLUSIONS AND RECOMMENDATIONS

In chapter 4 is shown that all recently developed land use databases on a continental scale are based on remote sensing imagery and ancillary geographic information. The advantages of the use of remote sensing is that the databases can be characterised as consistent, detailed, fixed in time and can be updated frequently.

When land use changes are based on trend analyses historical and recent data is needed to determine the land use change that has occurred. On a European scale no databases are available that include information regarding historical and recent land use on the scale level that is in line with the scale most driving forces occur that cause the change of land use. With the proposed update of the Corine database a datasource will become available that covers the whole of Europe and makes the detection of land use changes possible on a scale level that is required for applications in spatial planning. The comprehensive nomenclature and detail resolution makes it possible to determine the amount and location of land use changes and gain insight in the factors behind change. However, to determine land use change it is important that the nomenclature is identical to the current version. The same accounts for the guidelines and methods used for the interpretation of the satellite images.

In order to determine the historical land use changes on a regional scale throughout Europe the use of remote sensing is preferable above statistical data. The use of satellite data in test sites makes it possible to determine the same land use changes on an objective manner, whereas most of the available statistical databases have different nomenclatures and, like the European databases, lack the needed detail. That makes it impossible to compare the land use changes that occur at the different sites.

Chapter 7 shows that it is possible to determine land use changes on a quantitative way by correlation and regression analysis. Chapter 8 shows that with, the mains of regression derived equations, it is also possible to extend current trends in land use in the urban-rural fringe to the future. Moreover, by applying the equation as derived for the Lisbon area in Randstad Holland and vice versa insight can be obtained in the effects of alternative planning scenario's based on historically found trends.

Simulation of land use change with the developed prototype based on the (quantitative) statistical method applied to Lisbon, Randstad Holland and Paris is unfortunately limited to the three selected test sites. This is both due to practical and theoretical reasons. The practical reason is the lack of European data that describes the main driving factors on an appropriate scale level. From a theoretical point of view the difference in scale level between the test site and Europe has to be overcome.
However, a qualitative approach to simulate land use change on a European scale level is indeed possible. With the help of experts the main driving forces are translated with available datasets into maps showing the spatial distribution of these forces. This qualitative approach is especially suited to determine the effect of driving forces that are not in accordance with historically found trends or to evaluate the impact of e.g. European spatial policies.

This report shows that the chosen approach is appropriate to derive future land use maps in general and urban land use maps in particular. This makes it interesting to apply the methodology to other land use types and different scale levels.

The developed prototype simulates only urban expansion and urban densification in a quantitative manner. Other land use types are not simulated. In order to make an integrated land use simulation possible attention has to be paid to the historical development of other land use types in a numeric way.
The developed prototype also simulates land use for Europe in a qualitative way. One scenario is incorporated in the system. Development of other scenarios is recommended. These scenarios should incorporate more land use types as well as different spatial strategies (e.g. European and national spatial strategies) for the allocation of different land use types.

The workshop organised as part of this project has created an international network of institutes and organisations. The partners are involved in the development and application of models dealing with land use and land use simulation for both policy oriented and scientific purposes. This network ensures that institutes as RIVM and Alterra and companies as Geodan will remain close to any developments in the field of European land use and land use change.

In order to understand future developments in land use and their effects, just mapping and monitoring are not sufficient. Institutes as RIVM and Alterra as well as organisations as the National Physical planning Agency (RPD) and the European Environmental Agency (EEA) are interested in the extrapolation of currently found land use trends and the development of long term alternative planning scenarios. This to assess the effects of these trends and alternative spatial changes on man and environment.

In order to gain insight in the effects of different scenarios attention has to be paid to the development of relevant indicators. However, it is the question if these should be incorporated in the system or that the derived future land use maps form input for other models.

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APPENDIX I: List of countries included in the Euroscanner grid

- Norway (exept for the Nothern Part)
- Sweden (exept for the Nothern Part)
- Denmark
- Great Brittan (exept for Schotland)
- Germany
- Belgium
- The Netherlands
- France
- Italy
- Spain
- Portugal

APPENDIX II Corine nomenclature

level 1		level 2		level 3	
1.	artificial surfaces	1.1	urban fabric	1.1.1	continuous urban fabric
				1.1.2	discontinuous urban fabric
		1.2	industrial, commercial and transport units	1.2.1	industrial and commercial units
				1.2.2	road and rail networks and associated land
				1.2.3	port areas
				1.2.4	airports
		1.3	mine, dump and construction sites	1.3.1	mineral extraction sites
				1.3.2	dump sites
				1.3.3	construction sites
		1.4	artificial non-agricultural vegetated areas	1.4.1	green urban areas
				1.4.2	port and leisure facilities
2.	agricultural areas	2.1	arable land	2.1.1	non-irrigated arable land
				2.1.2	permanently irrigated land
				2.1.3	rice fields
		2.2	permanent crops	2.2.1	vineyards
				2.2.2	fruit trees and berry plantation
				2.2.3	olive groves
		2.3	pastures	2.3.1	pastures
		2.4	heterogeneous agricultural areas	2.4.1	annual cops associated with permanent crops
			agricultural areas	2.4.2	complex cultivation patterns
				2.4.3	land principally occupied by agriculture with significant natural vegetation
				2.4.4	agro-forestry areas
3.	forests and semi-natural areas	3.1	forest	3.1.1	broad-leaved forest
				3.1.2	coniferous forest
				3.1.3	mixed forest
		3.2	shrub and/or herbaceous vegetation associations	3.2.1	natural grasslands
				3.2.2	moors and heath lands
				3.2.3	sclerophyllous vegetation
				3.2.4	transitional woodland-scrub
		3.3	open spaces with little or no vegetation	3.3.1	beaches, sand, dunes
				3.3.2	bare rocks
				3.3.3	sparsely vegetated areas
				3.3.4	burnt areas
				3.3.5	glaciers and perpetual snow
4.	wetlands	4.1	inland wetlands	4.1.1	inland marshes
				4.1.2	peat bogs
		4.2	coastal wetlands	4.2.1	salt marshes
				4.2.2	salines
				4.2.3	intertidal flats
5.	water bodies	5.1	inland waters	5.1.1	water courses
				5.1.2	water bodies
		5.2	marine waters	5.2.1	coastal lagoons
				5.2.2	estuaries
				5.2.3	sea and ocean

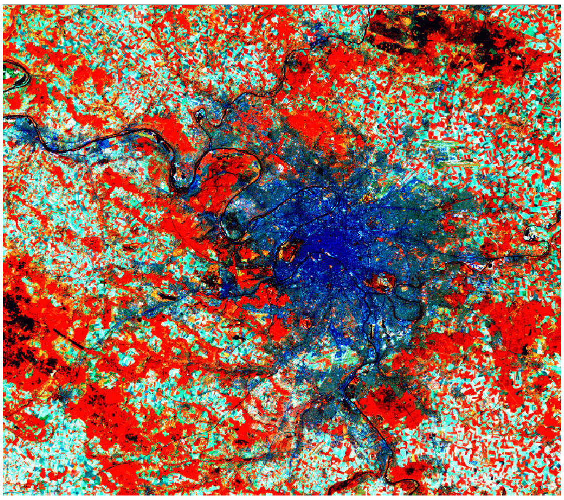
APPENDIX III PELCOM nomenclature

Nr	Class name	Code
1	Coniferous forest	11
2	Deciduous forest	12
3	Mixed forest	13
4	Grassland	20
5	Rainfed arable land	31
6	Irrigated arable land	32
7	Permanent crops	40
8	Shrubland	50
9	Barren land	60
10	Permanent Ice&Snow	70
11	Wetlands	80
12	Inland waters	91
13	Sea	92
14	Urban areas	100
15	Data gaps	110
16	Out of scope	111

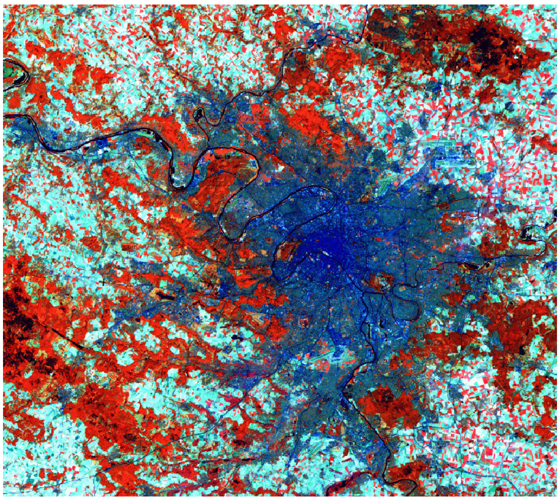
APPENDIX IV Satellite images of the three test sites

Randstad, Landsat TM 5, 03-08-1986

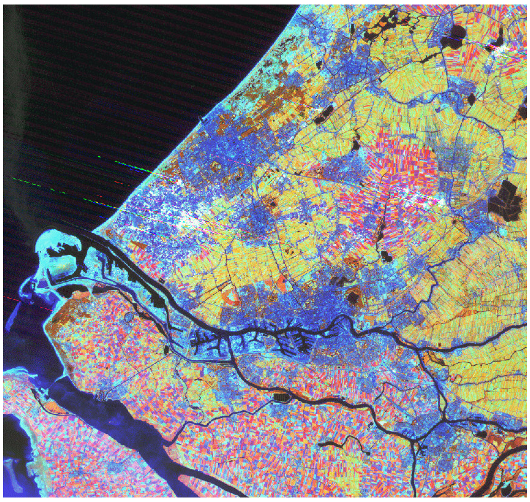
Lissabon, Landsat TM 5, 15-09-1998



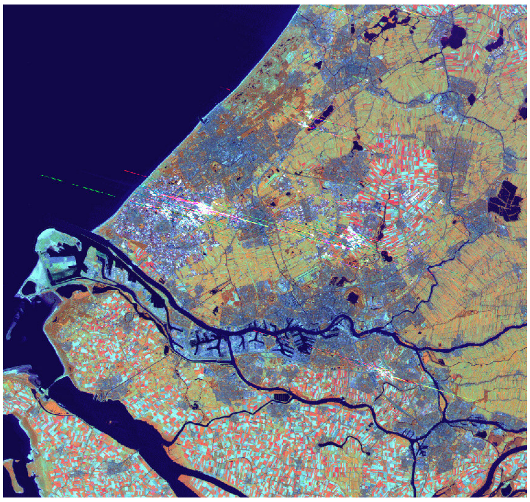
Paris, Lansat TM 5, 20-08-1984



Paris, Lansat TM 5, 11-08-1998



Randstad, Landsat TM 5, 03-08-1986



Randstad, Landsat TM 5, 12-08-1995

APPENDIX V Land use claims in the baseline scenario 1990 - 2010

country	**Area agricultural land** **Decrease (in Km^2)**	 **Increase (in Km^2)**
Belgium-Lux.	960	0
Germany	12640	0
Denmark	3460	0
Spain	0	12860
France	31580	0
Italy	0	9560
Netherlands	1690	0
Norway	0	0
Portugal	0	3410
Sweden	15360	0
UK	9250	0
Malta	0	0
Liechtenstein	0	0
Andorra	0	0