Land Use Modelling for an Integrated Approach to Regional Development in the Swiss Alps

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SUMMARY

Changes in land use are the result of dynamic economic and societal systems. Such changes have a great impact on the availability of natural resources, the intensity of important ecosystem services and the resilience of ecosystems. High mountain regions are considered particularly sensitive to such land use changes and their consequences. In the Swiss Alps, the gradual decline of mountain agriculture and the rapid expansion of settlements are important processes which are important factors in regional development.

This thesis focuses on the development and assessment of a range of techniques for regional-scale numerical modelling of land use change in the Swiss Alps. This work is embedded into a wider inter- and trans-disciplinary research approach that establishes linkages to the regional economy, resource management and ecosystem services and involves local actors into the development of regional future scenarios.

Drawing from the findings of a literature review on state-of-the-art land use modelling, two complementary approaches to address specific questions of land use modelling are introduced, described, and the results obtained discussed. These approaches are subsequently formulated as models for application to the Alpine tourist region of Davos. The first is a spatially explicit land use allocation model which provides maps of long-term projections of land use change for further assessment. The second is a model to estimate rates of change for settlement expansion which could provide appropriate input data for the allocation model. While the allocation model is based on two Swiss Area Statistics surveys and thus operates on a 100m*100m spatial resolution, the second model uses much more detailed land use data based on cadastral data.

For the development of the regional level allocation model, a transition matrix and a regression based modelling approach with differing data requirements were compared. Subsequently, a model combining all relevant land use transition processes, i.e. settlement expansion, agricultural decline and consequent forest growth, was developed on the basis of logistic regression models. The model requires input data in the form of changing demand on land for given land use classes, which were derived from scenarios developed at a series of participative workshops and an agricultural model.

The allocation model was applied in a scenario to analyse the consequences of radical decrease in subsidies for mountain agriculture for the region of Davos. For a simulation period of 50 years, results show an expansion of forested land by about 25 %, combined with a gradually rising tree line due to land abandonment. The simulations also indicate that future expansion of the settlement towards attractive sites, which are presently still reserved for agriculture, is highly likely, assuming that planning restrictions are not relevant for the simulation.

The complementary model to estimate rates of land use change focused on the expansion of settlement area due to changes in the tourist accommodation industry. To establish the model, the area occupied by different tourist accommodation types was approximated and combined with bed capacities and numbers of overnight stays. Both the estimation of Gross External Floor Area and the settlement expansion were derived from step functions. As a result of interdisciplinary collaboration, this model was coupled with a regional economic model to assess the efficiency of resource use.

The approximation of area requirements indicates that qualitative types of tourist accommodation differ by a factor of 4 in floor space per bed. Because of low utilisation rates, vacation rentals and secondary homes show the greatest floor-space consumption, when relating floor-space requirements to the number of overnight stays (i.e. 0.38m^2/overnight stays). The assessment of alternative tourist strategies by help of the coupled model shows that a) existing capacities could be used more efficiently, b) the efficiency of floor-space use would decrease for all accommodation types if bed capacities were further increased to meet peak demands and c) estimates of settlement expansion are highly dependent on planning parameters, such as the potential for increasing floor space within the existing settlement area.

The application of these two complementary models helps to underpin the importance of land use modelling at the interface between socio-economic decision-making and ecosystem functions and services. The thesis further discusses the key assumptions, uncertainties and problems arising from these modelling approaches and their use within an integrative research approach. One finding is that, the better the focus of this approach, the more specified the interface can be, hence allowing optimally targeted use of land use modelling. It is concluded that land use modelling, because of its intermediary character, may strongly benefit from interdisciplinary perspectives and inputs, while at the same time being a powerful tool to contributing to our understanding of the complex socio-economic and ecological systems of a given region.

ZUSAMMENFASSUNG

Landnutzungsänderungen sind das Produkt sich wandelnder Wirtschafts- und Lebensweisen, und wirken sich weltweit auf die Verfügbarkeit natürlicher Ressourcen, sowie auf wichtige Umweltleistungen und Ökosysteme aus. Hochgebirgsregionen zeichnen sich durch eine besonders hohe Sensitivität gegenüber Landnutzungsänderungen aus. In den Schweizer Alpen wirken sich ein zunehmender Rückgang der landwirtschaftlichen Nutzung und eine rasche Siedlungsentwicklung auf die Landschaft und damit eventuell auch auf die Regionalentwicklung aus.

Diese Arbeit konzentriert sich auf die Entwicklung von Methoden zur numerischen Simulation von Landnutzungsänderungen. Dabei ist die Arbeit eingebettet in einen inter- und trans-disziplinären Forschungsansatz, der die Bezüge zu den Bereichen Wirtschaft, Ressourcennutzung und Umweltleistungen herstellt und die lokale Bevölkerung zur Entwicklung von regionalen Zukunftsszenarien einbezieht.

Zwei komplementäre Ansätze zur Modellierung von Landnutzungsveränderungen werden vorgestellt in dieser Arbeit, beschrieben und diskutiert. Dazu werden nacheinander zwei Modelle entwickelt und zur Analyse der Region Davos eingesetzt. Beim ersten Model handelt es sich um ein räumlich explizites Allokationsmodel, das zur Simulation langfristiger Landnutzungsveränderungen eingesetzt wird und das eine fundierte Grundlage zur weiteren Bewertung von möglichen Zukunftsszenarien bietet. Das zweite Model schätzt Veränderungsraten für die Entwicklung der Siedlungsfläche ab, die sich als Eingabeparameter für das Allokationsmodell eignen. Während das Allokationsmodell auf den beiden Datensätzen der Schweizer Arealstatistik beruht und entsprechend eine räumliche Auflösung von 100m*100m hat, bieten die deutlich höher aufgelöste Daten der amtlichen Vermessung die Grundlage für das zweite Model.

Zur Entwicklung des Allokationsmodells wurden ein Transitionsmatrix- und ein Regressions-basierter Ansatz mit unterschiedlichen Anforderungen an die Ausgangsdaten verglichen. Ein Modell, das Veränderungen der Siedlungs-, der Landwirtschafts- und Waldfläche kombiniert, wurde letztendlich auf der Basis von Regressionen entwickelt. Eingabewerte für die Simulationen zukünftiger Nutzungsmuster waren veränderte Nutzungsansprüche, die aus partizipativ entwickelten Szenarien und einem Landwirtschaftsmodell abgeleitet wurden.

Die räumlich explizite Modellierung wurde zur Analyse des Szenarios „Drastische Reduktion landwirtschaftlicher Subventionen für die Berglandwirtschaft“ eingesetzt, wo sie Ergebnisse eine fundierte Grundlage zur weiteren Beurteilung von Umweltleistung lieferten. Die Simulationsergebnisse zeigen, dass über einen Simulationszeitraum von 50 Jahren selbst im Fall einer ausgeprägten Nachfrage nach qualitativ hochwertigen, lokalen landwirtschaftlichen Produkten mit einer Ausbreitung der bestockten Fläche um rund 25% und einer allmählichen Erhöhung der Waldgrenze aufgrund von Flächenaufgaben zu rechnen wäre. Die Simulationen

deuten ausserdem daraufhin, dass eine Ausdehnung der Siedlungsfläche in attraktiven Lagen, die heute noch der Landwirtschaft vorbehalten sind, wahrscheinlich ist, wenn bei der Simulation keine Planungsmassnahmen berücksichtigt werden.

Das Model zur Ableitung von Veränderungsraten fokussiert auf die Erweiterung der Siedlungsfläche durch Tourismusunterkünfte. Es basiert auf Flächenbilanzierungen verschiedener Unterkunftskategorien und kombiniert diese mit Übernachtungszahlen. Dabei nimmt es sowohl zur Abschätzung der Bruttogeschossfläche als auch zur Ableitung der Siedlungsfläche Treppenfunktionen an. Zur Bewertung der Ressourcennutzung wurde das Modell mit einem regionalökonomisches Modell gekoppelt, das aus der interdisziplinären Zusammenarbeit hervorgegangen ist.

Die Bilanzierung des Flächenverbrauchs zeigt, dass der durchschnittliche Flächenverbrauch pro Bett sich zwischen verschiedenen Tourismuskategorien um bis zu einem Faktor 4 unterscheidet. Es wird auch deutlich, dass Zweit- und Ferienwohnungen aufgrund ihrer geringen Auslastung mit 0.38 m^2/Übernachtung einen besonders hohen Flächenverbrauch pro Übernachtung aufweisen. Die Auswertung alternativer Tourismusstrategien mit dem gekoppelten Modell zeigt, dass a) die bestehenden Kapazitäten wesentlich effizienter genutzt werden könnten, b) die Effizienz der Flächennutzung in allen Unterkunftskategorien abnehmen würde durch einen weiteren Ausbau der Kapazitäten, der sich an der Deckung von Nachfragespitzen orientiert, und c) die Abschätzung zukünftiger Siedlungsflächen-entwicklung entscheidend von Planungsparametern und ihrer konsequenten Einhaltung abhängt.

Die beiden Anwendungsbeispiele demonstrieren ausserdem die Schnittstellenfunktion der Landnutzungsmodellierung zwischen gesellschaftlichem Handeln und Umweltfunktionen. Die wichtigsten Unsicherheiten und Probleme, die sich aus den Modellierungsabsätzen und ihrer Anwendung im Rahmen eines integrierten Forschungsansatzes ergeben, werden ausführlich in der Arbeit diskutiert. Abschliessend wird argumentiert, dass die Analyse von Landnutzungsveränderungen aufgrund ihrer Schnittstellenfunktion stark von interdisziplinären Betrachtungsweisen profitieren und einen wichtigen Beitrag zum ganzheitlichen Verständnis einer Region leisten kann. Je eindeutiger dabei der Fokus der Gesamtstudie ist, umso konkreter lassen sich auch die Schnittstellen spezifizieren.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The traditional cultural landscape of the Swiss mountains is the product of a long history of cultivation. A highly adapted land management system developed since the Middle Ages has resulted in distinct land use and land cover patterns with extended open areas, forest patches and typical regional settlements. In combination with the alpine relief, these patterns clearly characterise the Swiss mountain landscape.

Switzerland's Alpine landscape fulfils numerous ecological and societal functions within densely settled Central Europe. For instance, the mountain area represents an important refuge for various species with extraordinarily high biodiversity on mountain meadows and pastures (Draeger, 2005; Fischer and Wipf, 2002; Maurer and Weyand, 2005; Zoller and Bischof, 1980). An important societal aspect is the landscape's high recreational value which attracts a great number of national and international visitors each year (e.g. OECD, 2000). Further examples include the mountain area as a source of freshwater and hydropower, but also as a source of Swiss national identity (e.g. SNSF, 2003). These examples underline why the Alpine landscape is regarded as a major natural and cultural heritage which is considered to be worth maintaining (e.g. Wiesmann, 2005).

Yet, the traditional mountain landscape has been changing dramatically because of economic, structural and technological changes that have caused modification of cultivation methods. Profound changes have occurred since the late 19th century, and have become even more rapid since the 1950s (Schneeberger, 2005). Subsequently, the landscape qualities and functions have changed to some extent. Examples of such modification include changes in scenic value through infrastructure development and agricultural abandonment (e.g. Bätzing, 2002; Hunziker, 1992; Hunziker and Kienast, 1999), the growing risk from natural hazards as a consequence of expanded residential and tourism development (e.g. Fuchs et al., 2004), but also profound modifications of ecosystems (e.g. Cernusca et al., 1999).

A large body of literature demonstrates the complexity of mountain ecosystems and the anthropogenic impacts they suffer through changes in land use (e.g. Bätzing, 2004; Beniston, 1994; Cernusca et al., 1998; Körner and Spehn, 2002; Messerli and Ives, 1997; Messerli, 1989). Land use change plays a major role at the interface between the “natural”, i.e. bio-physical setting (e.g. Cernusca et al., 1999) and the anthropogenic imprint on a region (e.g. Bätzing, 2002). Integrated approaches to landscape research with a special focus on land use change are considered useful (e.g. Tress et al., 2001). Such integrated approaches have also been conducted for mountainous areas. In the 1970’s and early 1980’s, for instance, several projects within the UNESCO programme “Man And Biosphere” (MAB6) focused on land use change and its impact on Alpine regions within Switzerland and Austria (Messerli, 1989; Patzelt, 1987). In the late 1990s, a multi-disciplinary project on “Sustainable Primary Production in the Alpine Region” (PRIMALP) contributed strongly to Alpine land use research in Switzerland with a special focus an agricultural practices (Gotsch and Riederer, 2000). The most recent research effort in this domain is the National Research Programme 48 “Landscape and Habitats in the Alps” (NRP48), which has resulted in numerous contributions to Alpine landscape and land use research in Switzerland (SNSF, 2003).

Important research foci within Alpine land use research have so far included impact evaluation (e.g. Cernusca et al., 1999; Grêt-Regamey et al., in press; Hunziker, 2000; Maag et al., 2001) and the identification of driving forces (Elsasser and Messerli, 1983; Messerli, 1989). Also, the spatial patterns of land use change within the Swiss Alps and the most important determinants to explain these patterns have been investigated on multiple scales in earlier studies (e.g. Günter, 1985; Surber et al., 1973). Within the NRP48, the aspect of land abandonment with subsequent natural reforestation was further analysed with special focus on agro-economic conditions and ecological determinants (Bebi and Baur, 2002).

For the Swiss Mountain Area, however, a significant research gap still exists in the field of predictive simulation modelling for providing the basis to estimate consequences related to land use modification: How will the landscape change in the future? How will it adapt to further changes in society, policy or climate? What rates of change can be expected? These are among the most important questions to estimate the consequences of possible external changes related to land use and regional planning.

Although a variety of land use models have already been developed, none of them is suitable for the Swiss Mountain Area. While most land use modelling approaches focus either on urbanisation, deforestation or agricultural intensification (Lambin et al., 2001), the Swiss Alpine regions face agricultural abandonment with subsequent forest expansion and the sprawl of settlements (SFSO, 2001c). This means that the transition processes of interest are different from many other regions addressed by land use simulation modelling and that they need to be combined for the Swiss Mountain Area.

Within this thesis, land use change modelling will be addressed as part of an integrated approach to regional development. The research is embedded in the networked project of ALPSCAPE, which deals with integrated regional modelling including economic, resource management and ecosystem services. It focuses on the municipality level, because many political and planning decisions relevant to land use change are made at this level of administration.

1.2 Research questions and objectives

The basic rationale of the research is that land use modelling within an integrated approach to regional development can contribute to a long-term perspective related to land use and landscape change in Swiss mountain regions. The assumptions behind this rationale are firstly that land use is one of the principal interfaces between the human and the natural environment, and secondly that the interaction between deliberate human decision-making and subsequent reactions of the bio-physical environment must be better understood in order to improve long-term regional planning and to ensure regional development. To cover the wide scope between the decision-making process and the consequences on the natural environment together with complex feedback between these systems, integrated approaches are likely to be beneficial to long-term regional development research.

The research questions addressed in this thesis reflect these rationales and aim to propose and evaluate techniques to implement land use modelling within an integrated modelling approach to regional development:

> **Research question 1.** *What is an appropriate technique for regional-level land use simulation modelling?*
>
> **Research question 2.** *What special aspects of land use change in the Swiss Mountain Area require consideration in modelling, and how should they be addressed?*
>
> **Research question 3.** *How can land use be related to other aspects of regional development in a modelling approach?*

In order to address these research questions, regional-level land use change models are developed to simulate future scenarios. The step-wise progress of the work is structured into four objectives which are subsequently elaborated:

> **First objective.** *Identification of an appropriate methodology for regional-level land use change modelling in Alpine areas within Switzerland with respect to data availability.*
>
> **Second objective.** *Development and validation of a spatially explicit land use and land cover change model which can be used for scenario simulation.*

Third objective. *Development of complex future scenarios based on local system knowledge and their preparation for numerical simulation by an integrated modelling framework.*

Fourth objective. *Promotion of a modelling approach to estimate rates of land use change and link them to a local economic model in order to assess the efficiency of land use.*

1.3 Structure of the thesis

This thesis is structured into nine chapters. The three first chapters give an introduction, provide information on the research background and present the study area with its specific problems and the data used for the research. Chapters 4 to 7 present four elements of land use research. Chapters 4, 5 and 6 form a logical sequence in land use and land cover modelling with Chapter 4 assessing data requirements, with Chapter 5 introducing the model and Chapter 6 presenting an example for the model's application. While Chapters 4, 5 and 6 focus on an spatially explicit approach to allocation modelling in particular, Chapter 7 concentrates on rates of change by combining land requirement with economic activities. The remaining two chapters discuss and summarise the findings of this work.

- **Chapter 1** introduces the topic and gives an overview of the aims of the study and its organisation.
- **Chapter 2** provides an insight into recent approaches and techniques in land use research. The research questions are related to these recent approaches and explained in detail. The conceptual idea of the thesis and how different parts of the study are connected to each other are being developed. Finally it is explained how the study is embedded into a wider research framework.
- **Chapter 3** presents the study area and gives an introduction into the relevant problems addressed. The data are described and their application specified.
- **Chapter 4** addresses the problem of data availability and evaluates whether data from a larger area can be used for regional-level land use allocation modelling. This is particularly important for land use classes with limited extent, that show great importance for the development of the land use and land cover pattern.
- **Chapter 5** introduces a numerical simulation model for land use and land cover changes on a regional level. The simulation model, based on statistical models, is developed, validated and assessed by sensitivity analysis. It is adapted to the most relevant transition processes observed in the Swiss Mountain Area in order to simulate future scenarios.
- **Chapter 6** presents an integrated scenario analysis based on a participatory approach to scenario development including the parameterisation and quantification of

qualitative scenarios. By displaying the workflow through the diverse models, it illustrates the role of land use modelling as an important interface between economic and structural driving forces and their impact on the bio-physical environment within integrated regional modelling.

- **Chapter 7** describes a model to estimate requirements on land which can directly be combined with a regional economic model in order to assess the efficiency of land use from an economic perspective.
- **Chapter 8** evaluates the findings of the four previous chapters and discusses their meaning in the context of the research questions.
- **Chapter 9** summarises the achievements of the thesis, provides conclusions and insights, and gives an outlook to further extend the research.

Three of the chapters are based on journal publications. Since all papers originate from co-operations with researchers from various institutes, it is acknowledged that the results and ideas of the papers' co-authors also contributed to parts of this thesis.

Chapter 4 is based on a paper submitted to the GISRUK Conference 2004 in Norwich, UK. The full paper has been accepted for publication in 2005. The contributions of Dr Peter Bebi and Dr Ross S. Purves include mainly support with regard to model development and valuable comments that helped improve the quality of earlier manuscripts.

Walz, A., Bebi, P. and R. S. Purves (in press): Land use simulation for small regions in the Swiss Mountain Area - comparison of two modelling techniques. In: Innovations in GIS - GIS for Environmental Decision Making. Taylor & Francis Group.

Chapter 6 is based on a paper submitted to "Landscape and Urban Planning". Dr Heiko Behrendt supported parts of the work by gathering and elaborating of the participants' local knowledge. Corina Lardelli further contributed through the detailed elaboration of the scenarios, while Adrienne Grêt-Regmay, Dr Corinne Lundström and Prof Dr Susanne Kytzia kindly provided their simulation results. Dr Peter Bebi established valuable contacts with local stakeholders and organised the participatory workshops.

Walz, A., Lardelli, C., A., Behrendt, H., Grêt-Regamey, Lundström, C., Kytzia, S. and P. Bebi (in review): Merging local system knowledge and numeric regional modelling through scenario development. Landscape and Urban Planning.

Chapter 7 is based on a manuscript to be submitted to "Tourism Management". While the author of this thesis contributed with estimated on spatial requirements, Prof Dr Susanne Kytzia and Mattia Wegmann established the regional Input-Output Model and production functions. Each party conducted the according calculations for the parameter variation and the scenarios. While the results of the manuscript refer to base area ("footprint area"), the chapter relates to Gross External Floor Space as to its meaning in spatial planning.

Kytzia, S., Walz, A. and M. Wegmann. (in preparation): How can tourism use land more efficiently? - A model based approach to qualitative growth for Davos. Tourism Management.

CHAPTER 2

STATE OF THE ART IN LAND USE RESEARCH

2.1 Introduction to land use research

Landscape is the prime sphere where the combined effects of society and nature become visible through land use and land cover changes (Bürgi et al., 2004). Land use and land cover changes have shaped our recent environment since pre-historic times, when humans started farming and husbandry, and have left only a low proportion of the earth's surface in a near-to-natural state. Since the Neolithic period, phases of substantial change and irreversible damage to ecosystems and natural resources have been recorded. In central Europe, for instance, considerable soil erosion was caused by Neolithic deforestation, in early Roman times, and again in the early Medieval Period (Bastian and Bernhardt, 1993; Bork et al., 1995). Early phases of desertification are also described for occupied regions of the Roman empire in North Africa (Barker, 2002). But damage to natural resources also occurred in relatively recently colonised areas of the world, such as New Zealand, where extensive deforestation triggered increased landslide occurrence and soil loss after European settlement in the 19th century (Glade, 2003).

Cumulative land use and land cover changes on the global scale and the feedback between land use and land cover changes to natural resource availability and to regulative function of the ecosystem cause major concern on the international level of policy making (Meyer and Turner, 1994). With land use and land cover related environmental and socio-economic issues, such as irreversible damage to natural resources, but also the chance to improve living conditions in some parts of the world, land use and land cover change is one of the hot topics of the Agenda 21 (UNCED, 1992). Regulative functions of land use and land cover mainly with respect to the global carbon cycle are of major interest to the International Panel of Climate Change (IPCC) (Watson et al., 2001). Although land use and land cover research has a long history, the global environmental change and the sustainability debate have enforced new directions. Great scientific interest in future research has evolved with an emphasis on simulation modelling and scenario analysis (e.g. de Nijs et al., 2004; Fischer and Sun, 2001; Verburg et al., 2004c). Moreover, the role of land use as an interface between the bio-physical and human environment and the manifold feedbacks between these aspects has become a research focus, with an increase in complexity and the rise of integrated research designs (Naveh, 2000).

2.1.1 DEFINITIONS

Landscape

The meaning of the notion of *landscape* differs between disciplines and stakeholders according to the priorities of characterising attributes. The Food and Agriculture Organisation's shortest definition considers landscape as ”an area on the Earth's surface” (FAO, 1996). In landscape ecology, the aspect of "heterogeneity" (Turner et al., 2001) is emphasised in the definition which makes landscape "an area of land containing a mosaic of patches or landscape elements" (McGarigal and Marks, 1995) and stresses the aspect of spatial configuration (Turner et al., 2001). Further definitions relate to the bio-physical, ecological, hydrological and human-related attributes, which distinguish the landscape mosaic according to Troll's early approach to landscape ecology (1939). These definitions often associate the landscape's functions as an important natural resource and a means of regulation of natural processes (e.g. FAO, 1995; Stewart, 1968). But the landscape has been denoted more than these physical functions (e.g. Tress and Tress, 2000); qualities such as quiet, privacy, and the aesthetic appearance give a more holistic perspective (e.g. Hoover and Gierratani, 1984) and add emotional values to the landscape (e.g. Haber, 2004).

Furthermore, the landscape is described as being not only heterogeneous in space, but also in time. Since natural conditions and processes as well as human activities shaping it change over time, also the landscape is dynamic (Bürgi et al., 2004). Besides environmental change, human induced land use and land cover changes are considered the most effective triggers to landscape change over time (Wu and Hobbs, 2002).

Land use and land cover

Land use and land cover changes relate to two fundamentally different concepts and a clear distinction between the two can be made.

> *Land cover* is defined as "the bio-physical state of the earth's surface and immediate subsurface" (Turner et al., 1995a). It "describes the physical state of the land surface: as in cropland, mountains or forest" (Meyer and Turner, 1994) and is related to visual features.
>
> *Land use* is strongly human related, it denotes "the human employment of land" (Meyer and Turner, 1994) and implies "the way in which, and the purpose for which, human beings employ the land and its resources" (Meyer, 1995). In this respect it is not related to visible features but to intention or purpose.

These definitions differentiate clearly between land cover classes (e.g. grassland, forest and concrete) and types of land use (e.g. cattle raising, recreation and urban residence) by focusing on purpose and use through human beings.

Still, confusion arises because of the strong interdependency between land use and land cover. Land use change often results in land-cover change and vice versa. But changes in land cover are not necessarily the result of land use change; they might also be caused naturally due to environmental changes through time (e.g. vegetation succession, disturbance events, natural erosion). Similarly not all land use changes are reflected in the land cover.

Many datasets combine aspects of land use and land cover, for instance, by attributing land use categories to actual land cover surveys. These datasets can best be described as “land cover with aspects to land use” (Kok, 2001). This definition suits well the data used in this thesis, and will be referred to throughout the thesis (see Chapter 3). Depending on the context, the term *land use* or the term *land cover* will be used.

Land use and land cover change

Turner et al. (1995a) differentiate between *land use modification* and *land cover conversion*. The first refers to more subtle and often gradual change affecting the character of the land use type, while the second indicates a complete replacement of one land cover type by another. In this thesis, these two processes are not differentiated, as even closely related land use classes, such as intensive and extensive agriculture, are handled as separate classes and gradual transformation from one to the other cannot be accounted for.

The four processes included in the study are intensification of land use, extensification, abandonment, and vegetation succession. *Intensification* is related to an increase in economic benefit and usually results in a strong modification of the land cover, e.g. through intense fertilising or construction (Lambin et al., 2000). *Extensification* implies a diminution workpower and often also economic benefit and, particularly for agriculture, a reduced anthropogenic modification of the land. *Abandonment* stands for a halt in (agricultural) use and *vegetation succession* occurs as a natural process on land that is not regularly used and managed.

2.1.2 DRIVERS AND IMPACTS OF LAND USE CHANGE

To characterise the interaction between society and the environment, the European Environmental Agency developed the concept of DPSIR referring to systems of Driver-Pressures-States-Impacts-Responses (EEA, 1999). This concept is also valid for land use change, as it reflects how land use change impacts the bio-physical environment, which feeds back to the social system and also subsequent land use decisions. This feedback loop explains that drivers and impacts of land use change interact themselves. This is also illustrated in Figure 1 where the social system, the bio-physical/ecological system (further referred to as “natural system”, although altered through human land use in most cases) and land use are directly and indirectly interrelated with each other.

With regard to the above definitions, changes in land use are based on intentional human decision-making. Whether or not land use change occurs at a particular site depends on the bio-physical and human-related setting at various spatial, temporal and institutional scales (Figure 1). The main aspects are summarised according to Bürgi et al. (2004).

Human-related driving forces

- Socio-economic driving forces are rooted in the economy and to a lesser extent in demographics. They include the effects of market economy, globalisation and WTO agreements at the global level, and through land tenure, alternative income options and the accessibility of credits also at the local level.
- Political driving forces are expressed in policies and political programmes; they are strongly interlinked with the socioeconomic pressures as they strongly react to socio-economic pressures.
- Technological driving forces include innovations, such as the invention of the automobile, that manifest themselves, for instance, in the development of a transportation networks over the 20^{th} century.
- Cultural driving forces imprint the landscape, for instance, through traditional agricultural practices.

Bio-physical driving forces

- Site factors, such as climate, topography or soil conditions, are variable over long periods, but stable over short periods. They impact mainly on the whereabouts in land use decision-making.
- Natural disturbances profoundly modify the existing land use pattern as they strongly alter the bio-physical conditions within the effected region. Natural disturbance occurs as fast-acting processes such as snow avalanches, landslides or hurricanes, or through comparatively slow changes, such as global climate change.

Strong interactions between different driving forces at differing hierarchical levels hinder the direct reasoning about land use change in general. For instance in Figure 1, spatial planning can be regarded as part of the social system imposing conditions for the individual land owner, or as the reaction to socio-economic pressures. Schneeberger (2005) states that the global level institutional decisions, such as international trade agreements, are considered one of the most important driving forces for land use change in Switzerland, although they impact only indirectly through the individual decision-maker, mostly the land owner.

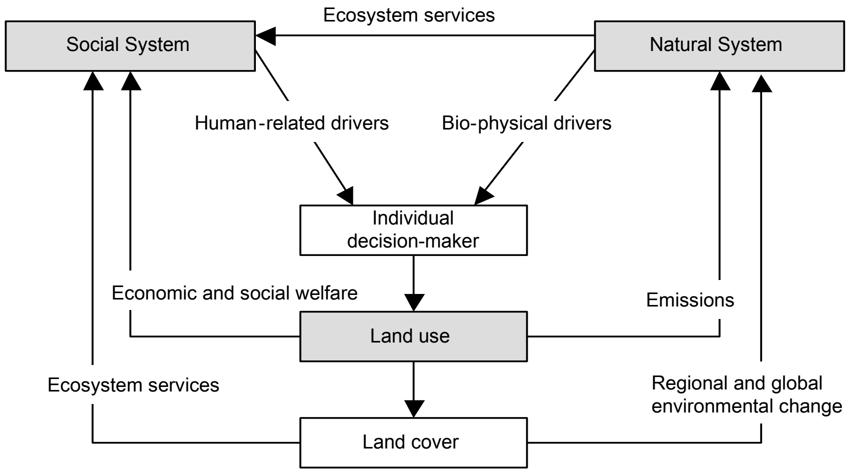


Figure 1: Relationships between components of the land use and land cover system (adapted from Turner et al. 1995a and Briassoulis, 2000)

As mentioned above, land use changes impact the bio-physical as well as social system (Figure 1). Generally land use changes are initiated to optimise social welfare including a wide range of intensions from maximising land rent and to conservation. But often these intended modifications show unwanted side-effects on the bio-physical and the social system and cause ecological (e.g. on soil qualities in Cernusca et al., 1999; or biodiversity in Linderman et al., 2005) or social damage (e.g. gentrification processes in Sairinen, 2004). Besides the direct impacts, indirect impacts on the social system through impacts on the natural system have been identified. These relations between the social and natural system are often described as ecosystem services (Figure 1), as they refer to an ecosystem's function to provide goods and services that are essential for human society (Daily, 1997). Examples related to land use include the importance of ground sealing for the generation of ground water and for flooding, or the land cover pattern for scenic enjoyment or – on an inner-urban level – the number of green spaces for local climate conditions.

Impacts on the natural system are often longer-term and considered minor in the individual case compared to quickly visible social impacts. Yet, Turner et al. (1990) point out that they are cumulative and can reach global scale. To consider both types of impacts and find an applicable compromise is the principal role of spatial planning on the local, regional and national level. It aims to co-ordinate socio-economic spatial requirements with respect to their long-term consequences on society and the bio-physical environment (e.g. Amt für Raumplanung Graubünden, 2000). Through the implementation of a legal framework, the provision for this long-term perspective is ensured for all projects related to land use change, and in particular to infrastructure development and construction activities.

2.1.3 ORIGIN OF LAND USE AND LAND COVER RESEARCH

Modern land use research began in the 19th century with the work of G. P. Marsh in North America and J. H. von Thünen in Germany, both representing fundamentally different approaches. Von Thünen (1966, originally published in 1826) viewed land as an economic resource and his research focused strongly on the optimisation of food production. In 1826, he developed an early model aiming for the optimal distribution of production sites with respect to a market. This model, based on rational theory rather than empirical observations, affected greatly urban and regional economics as well as early approaches to urban and regional planning in the 20th century. Further theories evolved from a similar socio-economic background: The Central Place Theory, developed by Christaller (1933) and further elaborated by Lösch (1940), the concept of Human Ecology developed in the 1920s by the sociologists of the Chicago School (Park et al., 1926), and Alfonso's (1964) urban land market theory represent further fundamental contributions to land use research with this focus. These theories allow normative conclusions to improve social and economic welfare on urban, regional or international level and had a strong impact on spatial planning, e.g. national spatial planning in Germany still reflects Christaller's theory.

Marsh, by contrast, studied the impact of human activity on the natural environment and published his work in "Man and Nature; or, the Earth as Modified by Human Action" in 1864 (Marsh, 2003 (originally published in 1864), originally published in 1864). He stressed the need to comprehend the natural system before human intervention to avoid devastating consequences, yet considered most human transformation desirable, if properly done. Still his research was cited by many early conservationists. His comprehensive view of the natural environment and human's effect upon it through modification laid foundation to nature-society theories and integrated land use modelling. His ideas spread quickly in the late 19th and early 20th century. They rose public awareness and soon impacted policy-making in the US (with the creation of a national conservation commission in 1907) and even in Europe, e.g. in the 1877 and 1888 forest laws in Italy (editorial by Lowenthal, in Marsh, 2003 (originally published in 1864)).

From Marsh's comprehensive view envisaging the necessity of comprehending better the natural system in order to employ it as a resource whilst minimising damage, investigations on land use impact and integrated research concepts emerged after World War II. Since then our understanding has improved mainly through environmental impact studies that assess consequences of different land use practises on soil degradation (e.g. Chantigny, 2003; Upadhyay et al., 2005), hydrology (e.g. Mahe et al., 2005), bio-diversity (e.g. Dauber et al., 2003), slope stability (Glade, 2003; Tasser et al., 2003) and many other aspects over various scales of time and space. Ecosystem-based theoretical approaches and integrated environment-economy-society models became widespread, and expanded particularly after 1970 when environmental awareness increased rapidly amongst policy-makers, researchers and the public (Briassoulis, 2000). Land use was then recognised as an important element of the broader nature-society system and as a contributor to global environmental change (Slocombo, 1993; Lutz, 1994; Manning 1988, 1991 cited in Briassoulis, 2000).

Inter- and transdisciplinary approaches to land use research

With the Brundtland Report (WCED, 1987) and Agenda 21 (UNCED, 1992), a more holistic perspective of social, economic and environmental problems has grown, and inter- and trans-disciplinary approaches are considered particularly promising also in land use research. With respect to the complexity of existing problems, solutions are sought in the integration and combination of disciplinary knowledge. While the need for such inter-disciplinary approaches in applied land use research is recognised and high expectations are held (Fry, 2001; Tress and Tress, 2001), the realisation is still a major challenge mainly due to traditional academic structures and theoretical barriers (Fry, 2001). The call for trans-disciplinary research emerged from the necessity for cooperation in order to solve complex, mainly related to global scale, problems such as poverty or global environmental change. It aims for "socially robust" knowledge generation (Nowotny, 2000) through joint problem-solving among science, technology and society and constitutes a new form of co-operative problem-solving and of mutual learning between multiple stakeholders (Klein et al., 2001). As applied land use research considers itself presently as an integrative object- and problem-related research field with links to different disciplines and an increasing orientation towards "future research" (Fry, 2001; Tress and Tress, 2001), inter- and transdisciplinary approaches have become common in land use research. Transdisciplinary land use research projects have a strong orientation towards future development and include qualitative scenario analysis (Kok et al., 2003; Tress and Tress, 2003), communication-orientated (Buchecker et al., 2003; Cernic Mali et al., 2004; Favry et al., 2004) and modelling approaches (Bousquet et al., 2002; Loibl and Toetzer, 2003).

Technological advances in land use research

Recent land use research is strongly imprinted not only by these new research concepts, but also by technological advances. Land use and land cover monitoring through remote sensing has become operational, and advances in spatial data management allow the generation of high quality land use datasets at regional to global scales (e.g. Fritz et al., 2003b; Treitz and Rogan, 2004). In addition to land use and land cover data, more information has become available as spatially explicit digital datasets. Most of these data were previously available as hardcopy maps (e.g. transportation networks), and others are the result of spatial modelling (e.g. region-wide climate information).

Due to advances in computing and availability of spatially explicit digital data, computer based modelling and associated simulations have become common tools in land use research. These models, described in detail in section 2.2, are designed for a variety of purposes, are based on various methodologies and operate at different scales. Despite exceptions, they are often criticised for their bias towards inductive analysis of vast digital data sources and for their lack of theory (Overmars et al., in press). But in general, modelling is acknowledged as "an important technique for the exploration of different pathways into the future, for conducting experiments that test our understanding of key processes, and for describing the latter in quantitative terms" (Lambin et al., 2000).

2.2 Approaches to land use modelling

The variety of computer-based land use models developed since the late 1980s covers a wide range of scopes, purposes and methodologies as well as temporal and spatial scales. As models, they represent "abstractions and approximations of reality which are achieved through simplification of complex real world relations to the point they are understandable and analytically manageable" (Briassoulis, 2000) or "abstract representations of a system or process" (Turner et al., 2001). While the first definition highlights the idea of complexity reduction from "reality" (see also Manson, 2001), the second differentiates within this "reality" between systems and processes. Land use modelling has traditionally focused on the land use system, rather than on actual processes of land use change.

In line with the differentiation between von Thünen's and Marsh's understanding of land use, two traditions of land use modelling can be differentiated. The first refers to what Briassoulis (2000) calls "location" which implies that the analysis starts from a single point and proceeds to a spatial pattern representing mainly socio-economic aspects. The second refers to a two-dimensional piece of land where changes to an already existing land use pattern are investigated. The second type of model mostly depicts spatially explicit land cover changes, which are triggered by changing requirements and usage of land. The primary purposes of such models include generally increasing understanding of drivers and impacts on land use change and possibly providing decision support for policy making (Pettit et al., 2002). They are typically combined with other disciplinary approaches, e.g. from ecology, sociology and economy, and further research methodologies, e.g. environmental impact and ecosystem services assessment.

2.2.1 CLASSIFICATION OF LAND USE MODELS

In the past, several classification schemes were proposed based on the various characteristics that land use models have. In the 1970s, Wilson (1974) proposed a classification scheme based on the dominant modelling technique. The subsequent classifications included an increasing number of characteristic qualities, such as Batty (1976) who differentiated according to two criteria, Isaaev et al. (1982) according to four criteria, and Stahl (1986) who finally added issues of theory and model purpose. Briassoulis (2000) gives a comprehensive overview of the various characteristics of land use models including purpose, theoretical grounding, role of space, spatial extent, sectoral focus, problem focus and the implementation of time (Table 1).

Table 1: Aspects to differentiate land use models (according to Briassoulis, 2000).

Characteristic	Types of specification
Purpose	Descriptive, explanatory, predictive, prescriptive and impact assessment models
Theoretical grounding	micro-/macro-economic, spatial interaction theory, integrated, a-theoretical models
Implementation of space	Spatially explicit, aspatial models
Spatial extent	Global, national, interregional, regional and local level
Sectoral focus	Urban, agricultural, forest sector models
Problem focus	Deforestation, urbanisation, land abandonment , etc.
Implementation of time	Static, quasi-dynamic and dynamic models
Modelling tradition	Statistical, programming, gravity type, simulation and integrated models

Due to the number of qualities, she suggests differentiating between only four "modelling traditions"(Briassoulis, 2000), namely statistical/econometric models, spatial interaction models, optimisation models and integrated models. This classification schemes features mainly the model design and solution techniques; specific modelling purposes, underlying theories, differentiation of land use classes as well as spatial and temporal level of analysis are not accounted for in this classification scheme.

Table 2: Classification of modelling approaches with typical techniques and examples according to modelling purpose (according to Briassoulis, 2000). Modelling approaches particularly relevant for this study are in bold.

Purpose	Typical Techniques	Typical model applications and examples
Description	Qualitative, quantitative and statistical techniques	Qualitative complex system models (Vester and von Hesler, 1980) Multiple logistic regression models (Schneider and Pontius, 2001; Wear and Bolstad, 1998)
Explanation	Theoretical economic and sociological approaches	Conceptual models (e.g. von Thünen, 1966) Human ecology models (e.g. Machlis et al., 1997)
Simulation	Multi-criteria, pattern-based, **statistical**, agent-based, and econometric techniques	Integrated allocation simulation models - Urban/metropolitan level (e.g. Salvini and Miller, 2003; Wegener, 1999) - **Regional level** (e.g. Engelen et al., 1995; Veldkamp and Fresco, 1996) - Global level (e.g. Alcamo et al., 1994) **Integrated models to derive quantity of change** (e.g. Fischer and Sun, 2001; Isard, 1972; Leontief et al., 1977)
Impact assessment	Process based, statistical, multi-criteria and indicator based techniques	Ecosystem-impact models (e.g. Turner et al., 1995b; Veldkamp and Verburg, 2004) - Deforestation on carbon flux (e.g. Hirsch et al., 2004) - Soil degradation (e.g. Donohue et al., 2003) - Biodiversity (e.g. Zebisch et al., 2004) Social system impact models (Brouwer and van Ek, 2004; Sairinen, 2004)
Prescription	Optimisation techniques	Linear programming models (Campbell et al., 1992) Utility maximization models (Nijkamp, 1980) Multi-criteria decision making models (Jansen, 1992)

Typically, the various model properties are often combined in similar ways. The purpose of the modelling exercise implies a particularly strong characterisation of the modelling process and the final model. For instance, predictive simulation modelling is particularly often included in integrated research applications, or explanatory modelling regularly applies theoretical approaches. Table 2 shows some of these typical combinations of modelling techniques with reference to modelling purposes and gives some application examples from the literature. Still, it has to be noted that the boundaries between these application examples are blurred, because some of them are strongly imprinted by the methodological approach (e.g. linear programming), whereas others are more strongly characterised by their overarching idea (e.g. integrated modelling). According to the research outline of this study, particularly these integrated approaches to land use modelling including allocation and derivation of quantities will be described in further detail.

2.2.2 LAND USE SIMULATION MODELS WITHIN INTEGRATED REGIONAL MODELLING

Integrated regional modelling aims to analyse regional development from a comprehensive perspective, including the social and the natural system. The system to be modelled is not primarily defined through the elements relevant to solve a particular problem, but through the boundary of the region. Land use modelling represents one of the prime interfaces between the social and the natural system within integrated regional modelling approaches (see also

Figure 1). It is typically used to link expected climate, economic and social changes with their impact on economy, society and the bio-physical environment based on simulation. Land use models usually do not investigate the impact directly, but provide a basis for further assessment. Since the spatial arrangement of land use change is an important aspect for impact assessment, not only the composition of the land use pattern, but also the spatial distribution is taken into account. Quantity and allocation of change are considered two complementary components in land use modelling resulting in two key questions:

- How much change is to be expected?
- Where are land use changes likely to happen?

Quantity of change is driven by demand for land, and its modelling is usually strongly based on socio-economic changes (Fischer and Sun, 2001; Hubacek and Sun, 2000; Lambin et al., 2000). For instance, population growth (Boserup, 1975; Boserup, 1985), price and labour situation (Angelsen and Kaimowitz, 1999), risk aversion behaviour (Kates et al., 1993) and technological innovations (Rounsevell et al., 2005) are important factors for changes in demand on land. Although these concepts could be, in principle, combined, they have never been linked in numerical modelling (Lambin et al., 2000). The complexity is too high due to the variety of factors, their interrelation and their interdependencies at different sectoral and hierarchical levels. One of the very few attempts to address quantities of land use change is enhanced input-output modelling which connects demands on land directly with socio-economic development (Briassoulis, 2000; Fischer and Sun, 2001; Hubacek and Sun, 2000). Future estimates of demand on land are still a very challenging task in land use research and associated with high uncertainties. One of the recently increasingly used and techniques to account for these uncertainties, is scenario analysis (de Nijs et al., 2004; Lambin et al., 2000).

The allocation question is considered easier to deal with through modelling (Veldkamp and Lambin, 2001) since the rise of geographic information technology and the expanding availability of digital spatial data. As briefly mentioned earlier, it has to be noted that most land use allocation models at regional or higher scale are not based on actual land use, but land cover data. Although the process being modelled is land use change, modelling outputs display actual land cover changes caused by these changes in utilisation (see 2.1.1). A few exceptions are found in the field of urban modelling, often with respect to transportation (e.g. Moeckel et al., 2002).

Simulation models for land use allocation

Most land use allocation models are based on raster data and a similar selection of base data. This additional information includes landscape properties, such as topographical, bio-physical and socio-economical variables, distance measures and neighbour characteristics. The model algorithms enable land use transition to be calculated on a cell-by-cell basis in accordance to these site properties. The mechanism that decides upon the location of change varies between modelling approaches: it is based on multi-criteria evaluation, on pattern analysis or on transformation probabilities derived from empirical data (e.g. neural networks, principal component analysis, multivariate regression models). The actual decision-making process, that triggers the transformation, is not directly represented in these models. In recent years, however, agent-based approaches were increasingly used in land use allocation modelling. They focus on the decision-making process through behavioural approaches. Hence, the role of site qualities and derived suitability shifted from a global suitability within the system to a relative suitability according to the agent's needs, preferences and goals.

Multi-criteria evaluation is used to identify the most suitable areas for a particular development, mostly with respect to conservation issues (e.g. Bayliss et al., 2003; Ravan et al., 2004) and for planning purposes (e.g. Dai et al., 2001). The criteria applied to the relevant landscape include, for instance, topography, proximity measures and protection status (Schneider and Pontius, 2001). The set of criteria is evaluated according to a rule-based key (e.g. Fritsch, 2002). Due to its simplicity and its ability to account for short-term planning and protection issues, multi-criteria analysis is widely used in decision-making support (Mendoza and Prabhu, 2005). However, the approach is very limited for long-term future simulations that exceed planning scopes.

Pattern-based allocation models explain land use change through preceding patterns of land use. They incorporate a temporal aspect, and have been used for predictive modelling. Transition Probability Matrix based models, where land use at time t_1 is solely based on the land use type at time t_0, represent the least complex spatially explicit land use models (Turner, 1987). Still, these models have been widely used for ecological purposes and are often referred to as Markov Chain models (Boyer, 1979; Jeffers, 1978). As they required relatively small amounts of data, they have still been used in land use change modelling in the mid 1990s (Berry et al., 1996; Turner et al., 1996) A more elaborated approach to pattern-based allocation modelling provide Cellular Automata. Cellular Automata have originally been controlled through the incorporation of neighbourhood characteristics into a rule-based modelling processes (Gardner, 1970 on Conway's "Game of Life"). The development of Cellular Automata had a great impact on spatially explicit modelling in many disciplines, and further elaborations took place also in land use modelling. First further data layers were added to the system to derive an additional intrinsic suitability of a cell, then stochastic procedures and sophisticated semi-automated techniques were developed for calibration (Clarke et al., 1996; Clarke et al., 1997; Ward et al., 1999; White and Engelen, 1997). The SLEUTH model, for instance, is based on Cellular Automata with four different algorithms for urban growth processes. These processes are calibrated against each other on the basis of historical data and then used for future simulation in urban areas with different historical and bio-physical settings (e.g. San Francisco and Lisbon in Silva and Clarke, 2002). Today the term Cellular Automata is applied to many complex spatial modelling procedures as long as they include explicitly the aspects of neighbourhood effects (Ward et al., 1999).

Statistically based land use models derive transition probability from the empirical investigation of natural and cultural landscape attributions and from the subsequent identification of the spatial determinants through statistical analysis (e.g. de Koning et al., 1998). Linear, Logistic and Multi-nominal Regressions are most widely used for such analysis (Overmars et al., in press; Schneider and Pontius, 2001; Verburg et al., 2004b). Further options include Principle Component Analysis (Li and Yeh, 2002) and Neural Networks (Kropp, 1998; Yeh and Li, 2002). As they are purely based on observations from the past, statistically based models simulate future states only according to these observations, and thus neglect the possibility of changing processes and preferences in the future. Due to good performance and clear structure, statistical models are still highly valued for simulation beyond the temporal scope of planning. The CLUE model (initial concept published in Veldkamp and Fresco, 1996) is one of the widest spread statistically based land use models. It is based on regression models and has been applied in many countries worldwide, e.g. the Philippines (Verburg et al., 2004a; Verburg and Veldkamp, 2004), China (Verburg and Van Keulen, 1999; Verburg et al., 1999), Central America (de Koning et al., 1999; Farrow and Winograd, 2001; Kok and Winograd, 2002) and most recently also for Europe (Verburg et al., 2004c).

Agent-based land use models focus on the interacting behaviour of numerous agents at various levels of decision-making. These multi-agent systems are composed of agents with different personal needs, goals, qualities, constraints and possibly even value systems, and are then combined with a cellular landscape (Ligtenberg et al., 2001; Parker et al., 2001). This approach aims to depict the process of decision-making in accordance to the agents' preferences and to their social interactions (Loibl and Toetzer, 2003). Although simulation results for land use are similarly good, agent-based modelling is widely praised due to its grounding in behavioural and economic theories (Overmars and Verburg, 2005), and thus presumed to give a greater insight into the underlying process. In practise, however, agent-based modelling suffers from vast difficulties in terms of calibration and validation in applied studies, as the amount of data demanded for agent-based modelling exceeds by far the requirements for site-property-based models and can often not be met. Interesting advances in agent-based land use modelling actively integrate local stakeholders and develop the model according to their behaviour in role-plays (e.g. the SAMBA model in Bousquet et al., 2002). Well-calibrated and validated simulation of future land use patterns is thus not the primary goal, but rather the mutual, trans-disciplinary learning process during model development.

A selection of recent examples of integrated land use allocation modelling at the local to regional level shows similarities and differences between recent models in terms of problem focus, methodologies, spatial resolution, and application (Table 3). It demonstrates that, apart from methodological differences, the problem foci and thus transition processes directly addressed in the modelling vary strongly between models. Deforestation (e.g. Felicisimo and Gomze-Muñoz, 2004; Flamm and Turner, 1994), agricultural intensification and optimisation (e.g. Carsjens and van der Knaap, 2002), and urban sprawl (e.g. Clarke and Candau, 2001) are the three principle aspects land use allocation models are in general dealing with. In most projects, these issues are modelled separately or at least the modelling focus lies with one of these processes. Few approaches combine different transition processes (e.g. de Nijs et al., 2004; Engelen et al., 1995).

Table 3: Selected examples of integrated allocation simulation models on local to regional level.

Model	Key References	Problem focus	Application example	Land use classes	Methodology	Spatial resolution	Model input
Environ-ment Explorer	de Nijs et al. (2004)	Urban expansion and agriculture	Netherlands	17 types of forest and nature, agriculture, built-up and others	Cellular automata	500 m * 500 m	Demand on land acc. to scenarios
NoName	Engelen et al. (1995)	Urban expansion	Prototype „Caribbean Island"	12 types of forest, agriculture, built-up, and natural	Cellular automata	Not given	Demand on land acc. to demogr. and econ. sub-modules and scenarios
SLEUTH	Clarke and Gaydos (1998)	Urban expansion	San Francisco	Urban, 2 types of agriculture, forest	Cellular automata	300 m * 300 m	Historical development
LUCAS	Turner et al. (1996), Wear (1996)	Deforestation	Appalachian Highland and Olympic Pen-insula	forest, grass-land, unvegetated land	Transition-Probability Matrix	90 m * 90 m	Distinction between private and public land
CLUE	Veldkamp and Fesco (1996), Verburg et al. (1999)	Food production	China	Forest, 3 types of agriculture, natural, built-up	Regression	32 km * 32 km	Demand on land acc. to scenarios
CLUE-S	Verburg et al. (2002)	Deforestation	Sibuyan Island, Philippines	Forest, 3 * agriculture, others	Regression	250 m * 250 m	Demand on land acc. to scenarios
STAU	Loibl and Toetzer (2003)	Sub-urbanisation	Vienna, Austria	Forest, agriculture, built-up, others	Agent-based	100 m * 100 m	Demand for housing and commercial development acc. to scenarios
ILLUMAS	Moeckel et al. (2002)	Urban development with reference to transport	Dortmund, Germany	Different types of residential and commercial uses	Agent-based	100 m * 100 m	Transportation and land use policies acc. to scenarios

Advances to estimate quantity of land use change

Few techniques have been proposed to model demand on land and subsequent quantity of change (Veldkamp and Lambin, 2001). Demand driven derivation of land use change, in contrast to availability of suitable land, is interpreted as a function of economic and demographic changes (Lutz, 1994). One of the few economic modelling approaches to derive quantity of land use change is input-output modelling (e.g. Fischer and Sun, 2001; Hubacek and Sun, 2000). An input-output model consists of a matrix displaying commodity flows into and out of different industries, including all economic sectors. Since the 1960s, it has been used to display complex inter-industry relations and to assess changes in these relations and impacts on the system through external impulses (Leontief, 1966, awarded the Nobel Prize in Economics in 1973). In the late 1960s and early 1970s, the incorporation of environmental issues, including land use issues, was proposed by various authors (such as Daly, 1968; Isard, 1972; Leontief, 1970). The idea was to estimate the intensity of unwanted "side-effects" directly from economic activities or products. Typical examples are the derivation of impacts on the transportation system (e.g. Fischer et al., 2000) or emission rates of CO_2 (e.g. Miyawaki et al., 2005). Mostly, the intensity of the "side-effect" is incorporated into such modelling approaches through a linear productivity function.

Briassoulis (2000) differentiates between compact input-output models that incorporate land use directly in their matrix (e.g. the United Nations World Model developed by Leontief et al., 1977), and modular models, in which input-output models are part of an integrated modelling framework (Engelen et al., 1995). The Population-Development-Environment model (PDE) represents an attempt to derive demand on land from population and economic development through demographic and input-output models which are then distributed within the area in an iterative process according to a rule-based system (Lutz, 1994). A similar, but spatially explicit approach was followed by Engelen et al. (1995), already mentioned due to their use of cellular automata for allocation modelling. Recent approaches address mainly agricultural land and its ability to meet future consumption (Fischer and Sun, 2001; Hubacek and Sun, 2000; Li and Ikeda, 2001). In all these models, demand is linearly calculated from the activity of certain industries and the related demand on land. In comparison with alternative derivation of demand on land from scenarios or trend analysis, this concept seems favourable. However, it has been strongly criticised for its simplicity rooted in this linear treatment, as intensity of use and productivity per land area are highly adaptive to demand in reality (Ferng, 2001).

Methodologically closely related to input-output modelling to estimate quantities of land use change is the concept of ecological footprint (Erb, 2004; Hubacek and Giljum, 2003; McDonald and Patterson, 2004; Wackernagel and Rees, 1996). The concept of ecological footprint also connects spatial requirements with socio-economic activities, namely consumption patterns, but applies area requirements as an indicator of sustainability (Doughty and Hammond, 2004; Knaus et al., 2005; Rees and Wackernagel, 1996).

2.2.3 SCENARIO ANALYSIS IN INTEGRATED LAND USE MODELLING

First scenario analyses were conducted in the 1960s by Herman Kahn and Anthony J. Wiener, who were working for one of the so-called “think tanks” that advised the U.S. government on strategic planning at the time (Kahn and Wiener, 1967). Since then scenario analysis has spread into business (e.g. Shell develops long-term scenarios every three years to better plan future business "with respect to critical uncertainties" in Shell, 2001), technology assessment (e.g. for chemical factories in Battelle Institute, 1976, cited in Scholz and Tietje, 2002), and environmental science (e.g. "The Limit of Growth" in Meadows et al., 1972) and has also become very popular in land use research (e.g. Favry et al., 2004; Kok et al., 2003; Kok et al., 2004).

Scenario analysis describes potential future developments for environmental, economic and socio-cultural factors based on logically plausible chains of future events and their interactions. It focuses on causal processes and decision points, and thus helps to identify and investigate crucial uncertainties for future development. One analysis usually produces several scenarios, with a range of scenarios illustrating these uncertainties. The identification of uncertainties is one of the primary goals of a scenario analysis (Anastasi, 2003; Scholz and Tietje, 2002). A second important goal is the assessment of the potential consequences due to these uncertainties, for instance possible consequences of global environmental change on water availability (Alcamo, 2001). Scenarios can be classified according to their purpose of answering either explorative questions (“What if, x, y and z happens?”) or strategic questions (“How could x, y and z be achieved?”), the degree of formality in the development process, and the degree of complexity (van Notten et al., 2003).

Integrated numerical modelling is commonly combined with scenario analysis (Lambin et al., 2000). As scenario technique per definition points on possible different and even opposed directions of change, the technique is adequate to derive different sets of input parameters values for the simulation. Many of these scenarios are simple and similar to parameter variations with plausible values (e.g. Berry et al., 1996), others derive expected quantities of change purely from extensive literature study (e.g. Verburg and Veldkamp, 2001), and only recently numerical simulation and participatory scenario development have been combined (e.g. Kok et al., 2004). Depending on the scope of the analysis, experts, stakeholders or the public are involved into the process (Kok et al., 2004).

Different techniques have been experimented with during the past decade in order to bring simulation modelling and participatory scenario development together (e.g. Barreteau, 2003; Greiner, 2004; Ozesmi and Ozesmi, 2004; Siebenhüner and Barth, 2005). One option to involve local actors into the scenario analysis is the use of system-orientated qualitative modelling with a strong focus on the cause-effect relationship (Sendzimir et al., 1999). Although not numeric, these models can help to mediate and stimulate regional decision-making processes as well as simulate scenarios for alternative decisions (Antunes et al., 2005; Roux and Heeb, 2002). A second option is to include the process of development directly into the participatory co-operation (e.g. Bousquet et al., 2002). This results in a highly adaptive model building process with the generated numerical models being usually very specific for the local situation.

If existing numerical models are applied or the modelling proceeds separately from the gathering and processing of local system knowledge, a third option is applied that involves local actors purely in the development of regionally adapted scenarios (such as IPCC scenarios (Nakicenovic and Swart, 2000), UNEP’s GEO-3 scenarios (UNEP, 2002) or the European VISIONS project (Rotmans et al., 2000)). In this case, local actors are either directly involved in the formulation of scenarios, or provide the essential local knowledge, from which the research team actually draws plausible regional scenarios from this basis (e.g. Flückiger et al., 1998). In both cases, the process of participative collaboration focuses rather on the development of preliminary qualitative scenarios. Appropriate methodologies to parameterise and quantify them in order to reduce them to sets of input parameters values is still a major challenge in numerical integrated research (Kok and van Delden, 2004).

2.3 Research gaps

The literature review identifies the following research gaps in land use modelling approaches within integrated regional modelling.

(1) The review shows the variety of approaches to land use and land cover research and particularly related simulation modelling. Allocation models and few approaches to estimating quantities of change through numerical modelling have been introduced. We have seen that allocation models operate at various spatial scales and with different priorities to particular land use transitions. The review indicates that land use allocation models mostly focus on one particular transition process, be it deforestation, abandonment, intensification of agricultural land or urban sprawl. These priorities emerged due to the global importance of these processes and their cumulative impact on the ecosystem (Lambin et al., 2001). However, these processes do not take place in isolation, but usually interact with each other. It is therefore useful to combine them in a simulation model without prioritising one particular process. However, only few models address urban sprawl and agricultural change simultaneously (e.g. "Environment Explorer" and "STAU"; Table 3).

(2) Most approaches to land use modelling address deforestation, agricultural intensification or urbanisation (Lambin et al., 2001). These processes are the most relevant at the global level and have great impact on global environmental change. Yet, at the regional level different land use transition processes might be more relevant. The Swiss Alps, for instance, undergoes rapid land use change facing a strong decrease in agricultural use with subsequent vegetation succession, and rapid housing and infrastructure development (SFSO, 2001c). Structural change (Bätzing, 1993; Brugger et al., 1984; Messerli, 1983), subsequent land use transformations (Bätzing, 2004; Günter, 1985; Lauber et al., 2004), and their consequences (Cernusca et al., 1999; Newesely et al., 2000; Tappeiner et al., 1998; Tasser et al., 2003) have been investigated intensively in the Alps for decades. But so far, these phenomena have not been approached by spatially explicit land use simulation modelling. In combination with the increasing tendency to future-orientated transdisciplinary research (e.g. Favry et al., 2004) and increasing availability of numerical impact assessment techniques (e.g. Nienhoff et al., 2002; Wegehenkel, 2002), spatially explicit simulation modelling has become an attractive approach to assess and visualise future land use scenarios also in the Swiss Alps.

(3) The results of numerical simulation depend strongly on assumptions inherent to the model and, most obviously, the range of values of input parameters. These values are preferably derived from scenario analysis (Lambin et al., 2000), as it accounts for the uncertainties within the range of possible futures that a complex regional system encounters. Great advantages are recognised in bringing together these two methodologies (Greiner, 2004). By combining participatory scenario development with numerical modelling approaches, we can

expect a) mutual learning effects in the scenario development process, b) an improved foundation of input values for numerical scenario simulation, and c) complex system response on the scenario derived from numerical modelling (Kok and van Delden, 2004). However, a major research gap exists between approved participatory scenario development and the use of scenarios in modelling. Simulation input requires numerical data, whereas complex scenarios often use narratives or images to actually condense their primary meaning (Favry et al., 2004; Nakicenovic and Swart, 2000; Tress and Tress, 2003). An improved as well as approved technique to formulate, parameterise and quantify future scenarios with respect to integrated modelling would allow for more transparency in the development of scenarios and the interpretation of their results.

(4) Estimating quantities of change is a big challenge in land use simulation modelling. As shown earlier, input-output models have been used to estimate changes in land use only for agriculture and forestry (Eiser and Roberts, 2002; Fischer and Sun, 2001). Although built-up areas are derived within the methodologically similar approach to ecological footprint assessment (e.g. Hubacek and Giljum, 2003), this has never been realised to estimate quantities of land use change. The application of demand driven estimates of quantities of change for built-up spaces allows a) identifying important parameters in terms of planning and construction and b) direct linking of land use to socio-economic development. With respect to the intensity of residential development in the Swiss Alps (SFSO, 2001c), which is primarily caused through second home development (RVM, 1997), the linkage between tourism structure and residential development seems promising for estimating quantity of change. Moreover, the economic efficiency of alternative land use options can be assessed via linking regional economy with tourism structure (Kytzia et al., in prep.).

In summary, the literature review has identified four important research gaps in integrated regional land use modelling, with particular regard to the Swiss Mountain Area:

- Only few simulation models have combined land use and land cover transition processes without a particular priority on either urban sprawl or changes in agriculture and forest.
- So far, simulation modelling has not yet addressed land use transformation processes in the Swiss Alps.
- Also, parameterisation and quantification in complex scenarios development for integrated numerical modelling have rarely been addressed in the literature.
- A modelling approach to estimate quantities of change for tourism driven settlement expansion in the Swiss Alps has not yet been realised, particularly with respect to major regulative parameters and land use efficiency.

The first, the second and the fourth research gap will directly be addressed in this research. Although also the third research gap is considered relevant, particularly in interpreting the modelling results presented in Chapter 6, it can only be touched within the scope of this thesis.

2.4 Conceptual framework of the research

Land use modelling in this thesis is placed within an integrated simulation modelling framework which aims for a trans- and inter-disciplinary system analysis following Marsh's intention of improving understanding of the natural system's reaction to human modification in order to benefit long-term from it.

Figure 2 illustrates the underlying conceptual framework. As stated earlier, land use is treated as a prime interface between the natural and social system within *integrated regional modelling*. To derive impacts for these systems is the key goal of this research. For instance, direct impacts on the *natural system* can include modifications of wildlife habitat and a direct impact on the *social system* might be the long-term loss of cultural land due to forest expansion after abandonment. Further, indirect effects of land use change on the social system can be encountered through the modification of natural ecosystem function.

Land use simulation modelling occurs in two subsequent steps (Figure 2). First, *demand on land* is specified, and then the *allocation model* simulates a spatially explicit *land use and land cover pattern*. These two key properties to future simulation of land use change are separately addressed.

The allocation model is developed with particular reference to regional-level modelling for the Swiss Alps (Chapters 4 and 5). The model is applied for the simulation of scenarios within the integrated modelling framework (Chapter 6) with the *development of the scenarios* being based on a *participatory process* and addressing the elaboration of quantitative input parameter sets for numerical modelling (Chapter 6). The spatially explicit simulation results can be used as a basis for impact assessment on the *natural and the social system* (Chapter 6).

Whereas estimates for the reduction of agricultural land are derived by a "Local Agricultural Model" (Lundström et al., in review) for the complex scenarios (Chapter 6), *estimates of change for residential areas* are derived from a demand-driven numerical model, which allows a close link to the regional economic structure (Chapter 7).

The conceptual framework illustrated in Figure 2 will be gradually developed and implemented in the course of the following chapters. At the start of each of these chapters, Figure 2 will be used to explain the chapter's focus and position within the overall conceptual framework.

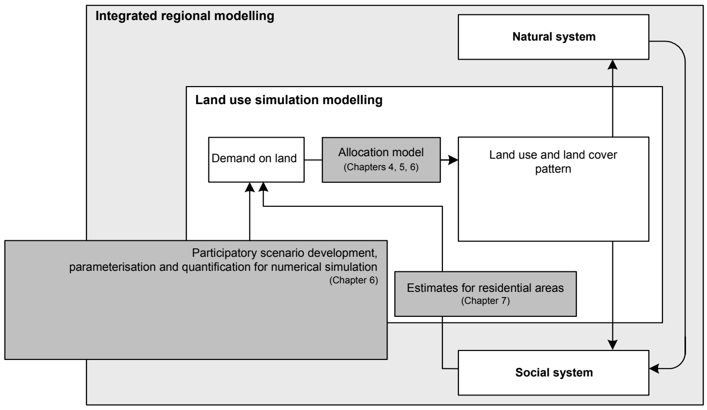


Figure 2: The conceptual framework of this research: the role of land use modelling and the scenario development within integrated regional modelling. The shaded boxes indicate the aspects elaborated in this PhD thesis and relate to the according chapters.

2.5 Project environment

This PhD project is embedded in the ALPSCAPE project and as such is part of the National Research Programme NRP 48 on “Landscape and Habitats in the Alps”. The research programme addresses the sustainable use of the Swiss Mountain Area. It “supports the discussion on the future of this habitat, and the active shaping of processes that enable a sustainable use of this valuable resource”, and “intends to close gaps in the knowledge, reach across disciplinary boundaries, and develop new approaches to research.” (SNSF, 2003). The 35 NRP48-projects are organised according to five aspects:

i. Processes of perception
ii. Processes of change
iii. Designing goals of landscape evolution
iv. Land use and adding value
v. Virtual representation

The ALPSCAPE project contributes mainly to the third research topic by investigating the interaction between the regional economy, management of natural resource and landscape changes on a regional level through integrated modelling (Bebi, 2001). The integrated regional modelling framework is used for future simulations based on scenarios developed in cooperation with local stakeholders (Bebi, 2001). It, thus, represents an inter- and trans-disciplinary research approach to regional development. For model development, the study focuses on the region of Davos, located in the canton of Grisons, Switzerland. Davos is one of the major tourist destinations in the Swiss Alps, popular mainly for winter tourism.

2.5.1 THE INTEGRATED REGIONAL MODELLING FRAMEWORK

To better understand the role of the land use approach presented in this thesis within the context of integrated regional modelling, the modelling framework and its application will be briefly explained.

The integrated modelling framework designed in ALPSCAPE is based on the idea of Dr Peter Bebi (Swiss Federal Institute for Snow and Avalanche Research SLF Davos) and Prof Dr Susanne Kytzia (Institute for Spatial and Landscape Planning, ETH Zurich). Dr Corinne Lundström (Swiss Federal Institute for Snow and Avalanche Research SLF Davos) coordinated the development of the modelling framework and constituted the theoretical background. The modelling framework incorporates four different types of models (Lundström et al., in review):

(1) A *regional Input-Output Model* (Figure 3) depicts financial fluxes between industries within the region. Import quota, export quota and value-added to the region are common outputs of regional input-output models. Based on the assumption that the interrelations between industries remain constant, the impact of changing demand in one industry can be estimated for the entire regional economy (Isard, 1998). Prof Dr Susanne Kytzia and Mattia Wegmann developed, calibrated and validated the model for the region of Davos (Wegmann and Kytzia, 2005).

(2) *Regional Resource Flux Models* (Figure 3) include a *Material Flux Analysis* investigating construction material and food, and an *Energy Flux Analysis* focusing on energy generation and consumption. These models depict resource consumption and availability within a region (Baccini and Bader, 1996). They are used to analyse the efficiency of resource management and the autonomy of the region within the context of sustainable development (Hug and Baccini, 2002). Prof Dr Susanne Kytzia and Dr Corinne Lundström cooperated in the development of the *Material and Energy Flux Analyses*.

(3) The *Land Use Allocation Model* is applied for spatially explicit simulations (Figure 3). The model incorporates all transition processes relevant for the region. It is based on a set of logistic regression models partly resulting from Gillian Rutherford's work on natural forest expansion due to land abandonment (Rutherford, 2004). With respect to their strong reference to neighbourhood characteristics, the model represents an elaborated type of cellular automata. The land use simulation results provide a basis for further assessment through ecosystem services (see next paragraph), and for derivation of landscape-related sustainability indicators based on landscape metrics (e.g. Antrop and van Veen, 2000; McAlpine and Eyre, 2002). The development of the simulation model forms the main contribution of this thesis. Its conceptual background, its validation, its sensitivity analysis and finally its application in the integrated modelling context are described in detail in Chapter 4, 5 and 6.

(4) To assess the impact of scenarios, *Ecosystem Services* (Figure 3) are assessed and valued on the basis of the spatially explicit outcomes of the land use simulation (Grêt-Regamey, 2003). As mentioned earlier, *Ecosystem Services* include all goods and services provided to the human society through ecological processes (Daily, 1997). As changes in *Ecosystem*

Services are derived as monetary values (Heal, 2000), the concept allows to compare changes in the natural system for various functions, and even with the value added through an activity with unintended side-effects on the natural system. Adrienne Grêt-Regamey works on the spatially explicit assessment of *Ecosystem Services* for her PhD at the Institute for Spatial and Landscape Planning, ETH Zurich, with Prof Dr Willy Schmid.

(5) In addition to these four basic components of the ALPSCAPE modelling framework (Bebi et al., 2005), an addition model has been applied in for the scenario analysis presented in Chapter 6. This *Local Agricultural Model* includes parameters of agricultural production at the level of local farming structures to estimate quantities of land use change for agricultural land, production volumes and demand generated by the agricultural sector within the region. The model was developed by Corinne Lundström and is described in detail in Lundström et al. (in review).

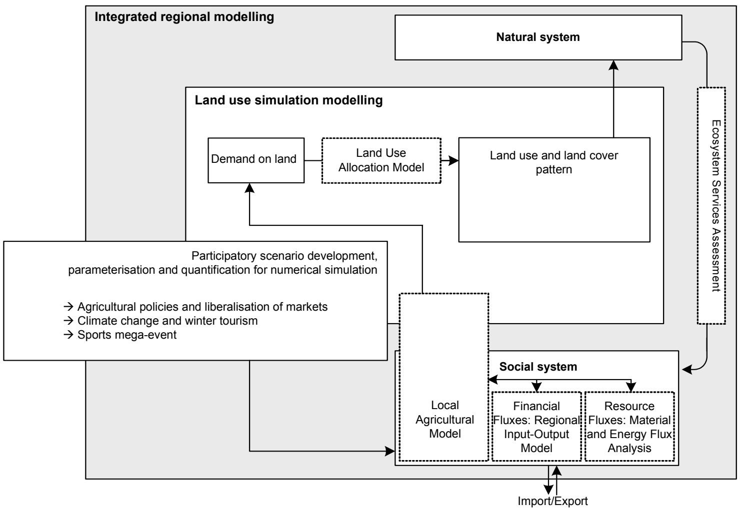


Figure 3: The integrated modelling framework of ALPSCAPE from a land use perspective. The dotted boxes show the five numerical approaches which are combined in the ALPSCAPE project to contribute to the analysis of the agricultural scenario referred to in this thesis.

The simulation models, namely the *Input-Output Model*, the *Resource Flux Models* and the *Land Use Allocation Model*, are linked through three mechanisms: (i) rule-based actor choices (similar to Alberti and Waddell, 2000), (ii) rule-based, quantitative linkages between production and consumption of money, material and energy, and finally (iii) estimates of demand on land (Lundström et al., in review). All these links are considered linear, and can be modified according to scenarios.

The structure of the modelling framework is constituted through the operational order in which the simulation models are applied. It is not fixed, but can be adapted for each scenario. Due to the flexibility of the modelling framework, a wide range of topics can be addressed in scenario analyses. Three different topics of regional relevance have been focused on within the project (Bebi et al., 2005):

- Agricultural policies and liberalisation of markets
- Climate change and winter tourism
- Realisation of an international sports mega-event

For each of these topics two scenarios were developed with respect to a major uncertainty (Lardelli, 2004). In the agricultural scenario, consumers' willingness to pay for local agricultural products is addressed; snow security and expected changes in attitude towards skiing tourism (Elsasser and Bürki, 2002) are addressed in the climate scenario; and finally the long-term impact on the region's reputation is addressed in the mega-event scenario (Lardelli, 2004). Based on workshops with local stakeholders and an extended literature review in each of these fields, Corina Lardelli (Swiss Federal Institute for Snow and Avalanche Research SLF Davos) worked on the scenarios. In this thesis only the agricultural scenario will be referred to as an excellent application example of the Land Use Allocation Model (Chapter 6).

CHAPTER 3

STUDY AREA AND DATA

3.1 Study area

Davos is a mountain resort town at 1560 m a.s.l. in the canton of Grisons, Switzerland. The population comprises around 11'000 permanent residents, and during peak season in winter up to 28'000 tourists can be accommodated. The total area of Davos is about 25'500 ha, making it one of the largest municipalities of Switzerland. Because of its extent and its historic evolution out of several small settlements (Figure 4), Davos is also often referred to as a "region".

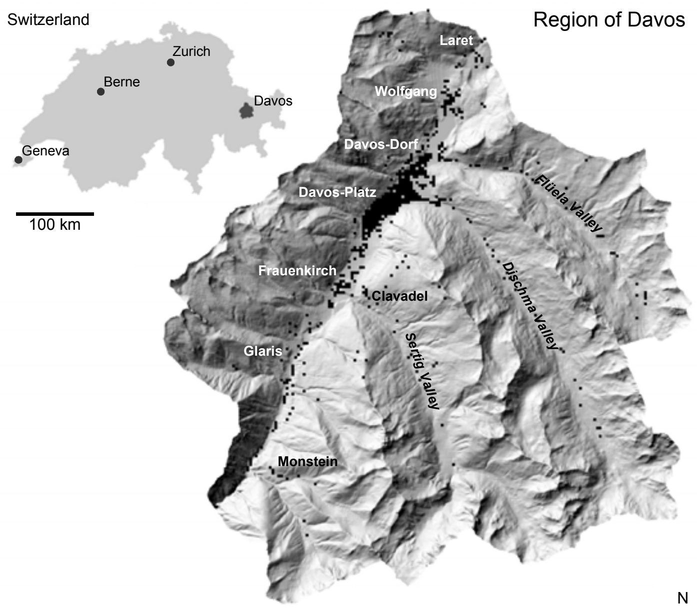


Figure 4: The location of Davos within Switzerland and an overview of the region. Davos-Platz and Davos-Dorf form the „urban centre" whereas the remaining area is dominated by traditional agricultural landscape, scattered settlements and alpine terrain. (DEM reproduced by permission of swisstopo (DV033492), Housing and Infrastructure from Land Use Statistics 1992/97 reproduced by permission of BFS GEOSTAT, municipality and country boundaries reproduced with permission of the BFS GEOSTAT).

The landscape is well-structured through its topographic characteristics and distinct population distribution (Figure 4). The central part of the main valley hosts the core settlement of Davos-Platz and Davos-Dorf with well-established urban and tourist infrastructure. The rest of the main valley and the three side valleys have remained relatively rural with a few small, scattered settlements and a landscape still strongly dominated by mountain agriculture.

The pre-tourism period

During the Medieval climate optimum, in the 13th century, the "Walser" people originally coming from the Valais started to settle in the Davos region (described in detail in Bär, 1983). Fourteen small farming settlements developed, spread over the entire region (Figure 5), and formed the origin of the disperse settlement that remained without a particular centre until the end of the 19th century. Over subsequent centuries the number of farms increased to about 150, and the population to 3500 persons at the beginning of the 17th century. From the 17th to the late 19th century, famine, diseases, wars and later also emigration caused a strong decrease in population. When Davos was incorporated into the canton of Grisons in 1853, the population was about 1'700 persons with about 30 persons per year emigrating mainly to the United States or Russia (Brunner, 1996).

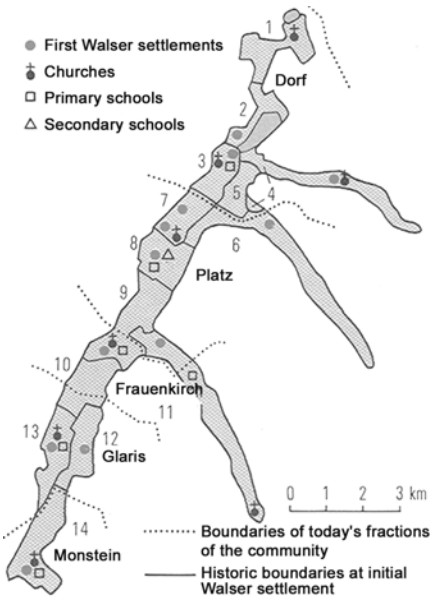


Figure 5: The typically disperse settlement by the Walser people in the 14th century (Bär, 1983).

The Walsers cleared the land for farming. They grew crop and potato for self-supply. Sheep, goat and increasingly more intensive cattle farming was profitable enough to allow trade with neighbouring regions, and crops that would not grow at the altitude of the valley could be imported from the area of Lake Constance or the Etsch Valley (Jäger, 1994). Ore (lead and zinc) was exploited at several places within the region during the 15th to 17th century. In order to reduce the growing impoverishment in the area, local authorities restarted mining between 1805 and 1847, before the mine was finally closed due to low profits (Krähenbühl, 1994). Emigration was a favourable option to escape poverty, and some people from the Davos region succeeded and became famous for their confectionery in Moscow, St. Petersburg, Amsterdam and elsewhere.

Tourism development

The history of Davos as a health resort begins in 1853 and is closely linked with the name of Alexander Spengler. Sentenced to death for his participation in the March Revolution in 1848, he sought refuge in Davos. As the local country doctor, he soon recognised the beneficial effect of the high-altitude climate, and in the early 1860s the first tourists arrived for tuberculosis treatment. Tourism took off quickly, after Alexander Spengler and Willem Jan Holsboer (whose wife was amongst the first patients to be treated in Davos) built the first health clinic in 1868.

The establishment of tourism had a strong impact on the poverty-stricken region. From a scattered rural settlement Davos quickly developed into a major health resort. Willem Jan Holsboer founded the Rhaetian Railway in the 1880s to connect Davos with the national railway network, which was achieved by 1890. Besides sanatoriums for the poor, hotels, guest houses and luxury clinics were established and attracted tuberculosis patients from all over Europe. Davos rose to be a cultural centre with various contemporary artists visiting. Family and friends of long-term tuberculosis patients often stayed for months or years to visit, and they soon started summer and winter sports in Davos. In 1931 the first part of the mountain railway "Parsennbahn" was opened to the public.

The general appearance of Davos changed profoundly. The construction of sanatoriums and health tourism related infrastructure concentrated on the relatively small area of Davos-Platz and Davos-Dorf within the dispersedly settled main valley (Figure 9). This area developed to the centre of the Landschaft Davos, and became what has constituted the "urban centre" since.

When antibiotics were invented in the 1940s, the number of tuberculosis patients decreased quickly with equally strong consequences for the local economy. Through a profound structural change, Davos established itself as one of the early winter sport resorts. In the 1950s, sanatoriums were converted to hotels, and the construction of transportation for winter sports was encouraged. Between 1960 and 1970, the number of annual overnight stays almost doubled from 1.65 Mio to 2.31 Mio. In the 1980s, it reached a maximum with 2.59 Mio overnight stays. Since then the number of overnight stays has been relatively stagnant with a slight tendency to decrease (Figure 6). In 2000, about 2.32 Mio overnight stays were counted. Despite this situation accommodation capacities have still been augmented over recent decades (Figure 6).

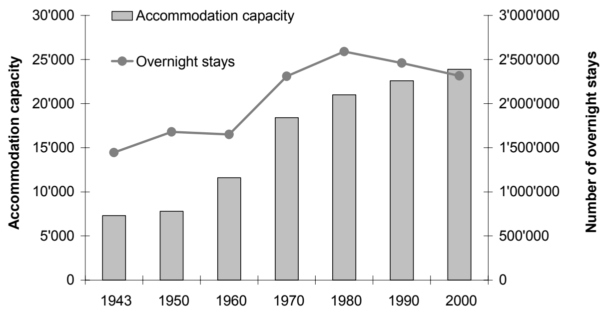


Figure 6: Tourism development since 1943 in Davos according to Davos Tourism (2001).

Important reasons for this development are firstly the increased mobility and flexibility of tourists with increasing numbers of very “last minute” weekend trips instead of a two week winter holiday no matter the weather and snow conditions (Bieger and Laesser, 2005). To react to this tourist behaviour, hotel capacities were augmented to serve peak demand. Secondly, the construction of second homes and vacation rentals, with a much lower utilisation rate of about 20% compared to 35% for hotels, contributed very strongly to this increase (Figure 7).

Closely liked with the increase in tourism capacities is the on-going land consumption for housing and infrastructure development with a rise of 12.3% between 1985 and 1997, i.e. from 512 ha to 566 ha according to official Area Statistics of the Swiss Federal Statistical Office (SFSO, 2001). This land consumption is a major concern to local stakeholders (von Ballmoos and Bebi, 2003) and enabled the implementation of a new spatial planning initiative restricting future development to the already existing settlement. In this regard, estimates of further land consumption and alternative tourist strategies are investigated in Chapter 7.

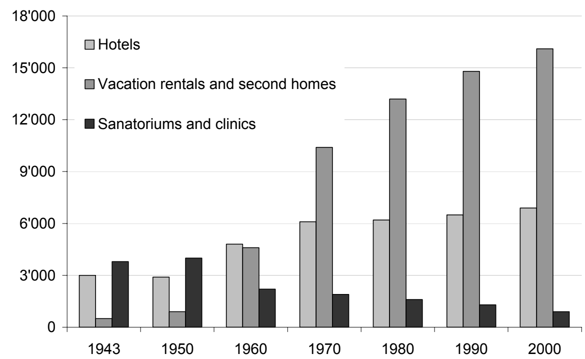


Figure 7: Increase in accommodation capacity since 1943 for different types of accommodation according to Davos Tourism (2001).

Although the proportion of developed land is still low (~ 2.1% of the total area), construction development is a major concern to local stakeholders. Firstly, the establishment of high tourist capacity that matches only the most popular skiing season conflicts strongly with attempts to introduce more sustainable regional development. Secondly, the most attractive areas for construction often coincide with the most productive land for agriculture. Consequently the selling of this land constitutes a long-term threat to the future of mountain agriculture and its distinctively shaped landscape. Finally, construction development impacts on the appearance of the alpine landscape, which is considered a major resource for the local tourism industry.

Agricultural changes since the rise of tourism

By offering alternative sources of income, tourism has changed the economic structure of the community strongly. While in 1850 the number of farms was still 311, only 200 farms remained fifty years later (Senn, 1952 cited in Günter, 1986). Due to high demand for dairy products by health tourism, they increasingly specialised on milk production, and reduced meat production and crop farming. The number of farms reduced further with the beginning of winter sport tourism with about 90 farms remaining in 2001.

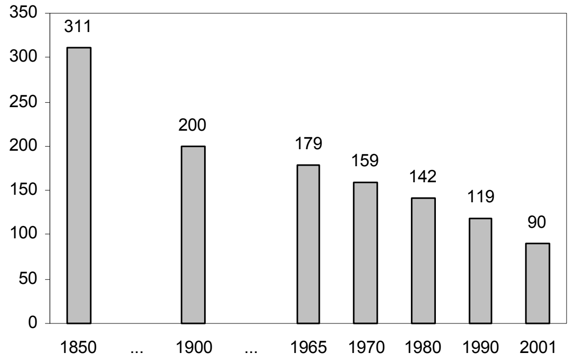
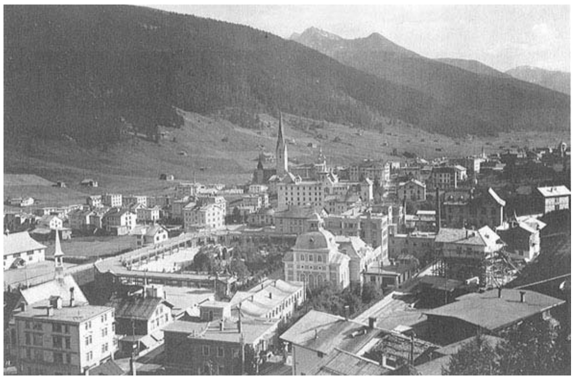


Figure 8: Decreasing number of farms since 1850 in Davos (Bauernverband Davos, 2001).

Alongside the reduction of farms, the area of agriculturally used land has decreased. However, land use changes did not develop as rapidly as the number of farms due to extensification. For instance, extensively used, high elevation meadows shifted towards even less extensively used pasture. Günter (1985) states an abandonment of agricultural land by 14% between for 1900 and 1984 for the study area of the UNESCO “Man And Biosphere” (MAB) project which represented about 40% of the total area of Davos. According to Area Statistics, another 2.5% were lost between 1985 and 1997.

With the reduction in mountain agricultural activities, the historically grown, agricultural landscape, considered a principal cultural heritage and source of national identity, was increasingly under threat. Consequently, the role of mountain agriculture shifted from production-orientated farming to more and more landscape-orientated farming during the post-war period. In late 1970s, area-based subsidies started. By the late 1990s, “direct payments” to support mountain agriculture had reached about 2.5 billion CHF/year (Schneider, 2005), while public and political consensus about the support of mountain agriculture slowly began to decrease. With the federal agricultural policies “Agrarpolitik 2002” and “Agrarpolitik 2007”, public subsidies started to decline and an increasing liberalisation of the agricultural markets is occuring (e.g. Zuber and Wildisen, 2001).


Davos Platz in 1871 (Siegrist et al., 1999a)


Davos Platz in 1906 (Siegrist et al., 1999b)


Avalanche protection in 1925 (Siegrist et al., 1999b)

First ski lift at Bolgen in 1935 (Siegrist et al., 1999b)

Fields in Monstein in 1918 (Siegrist et al., 1999b)


Disperse settlement in Clavadel and Frauenkirch in 1900 (Siegrist et al., 1999a)


The urban centre of Davos, 1909 (Siegrist et al., 1999a)


The urban centre of Davos, 2000.

Figure 9: Historic photographs of Davos (Siegrist et al., 1999a; Siegrist et al., 1999b)

3.2 Data

The data to investigate and model land use changes for the area of Davos are mostly spatially explicit datasets and originate from a number of official sources (Table 4). In this section, first the original data is briefly introduced. These data contain land use information and explanatory data that was used for statistical modelling. The two types of land use data are further explained in this chapter, and details of the application of the remaining data for statistical modelling are given in Rutherford (2004).

The data to investigate and model land use changes for the area of Davos are mostly spatially explicit datasets and originate from a number of official sources (details in Table 4). The Swiss Federal Statistical Office (SFSO) provided information on land use and land cover, on ecological parameters and census data on population, apartments and buildings for Davos. Topographic information is supplied by SwissTopo, including a digital elevation model and the road network extracted from the digital topographic dataset Vector25. The official Land Information System of the municipality of Davos (LIS Davos) provided the base areas of buildings, the premises and local spatial planning parameters from its cadastral database. The number of floors for buildings in the core settlement area, as used in Chapter 7, was partially surveyed by students of the University of Applied Science Liechtenstein and verified and completed by myself.

As shown in Table 4, two different land use datasets are used. The Swiss Area Statistics was applied for the derivation of statistical models and used for simulation modelling and the Land Information System for the evaluation of land consumption which was, as an example, calculated for the tourism industry. They differ in spatial extent, spatial resolution and class aggregation.

*Table 4: Data origin and properties for spatially explicit datasets. The deduced datasets marked with * were calculated and described in detail by Rutherford (2004).*

Original Data	Sources	Used information	Use	Type	Spatial Resolution
Land use and land cover	Land Use Statistics 1992/97, and Land Use Statistics 1979/85 (revised data), BFS GEOSTAT	- Aggregated sets of land use classes - Distance measures - Neighbourhood characteristics	Derivation of statistical models and simulation modelling (Chapters 4 and 5)	Point samples and derived raster	100m*100m
Census data on population, apartments and buildings	Census 1990, BFS GEOSTAT		Derivation of existing area consumption for tourist accommodation (Chapter 7)	Point samples and derived raster	100m*100m
Digital Elevation Model	DHM25©2005 swisstopo (DV033492)	- Elevation - Slope - Radiation* - Topographic* - Position* - Wetness Index* - Sine of aspect* - Cosine of aspect*	Derivation of statistical models and simulation modelling (Chapters 4 and 5)	Raster	25m*25m
Road network	Vector25©2005 swisstopo (DV033492)	- Distance to road	Derivation of statistical models and simulation modelling (Chapters 4 and 5)	Vector	Effective mapping scale: 1:25´000
Soil Properties	BEK200: Bodeneignungs-karte der Schweiz, SFSO, 1992. BFS GEOSTAT / BUWAL	- Soil depth - Soil permeability - Soil stoniness	Derivation of statistical models and simulation modelling (Chapters 4 and 5)	Raster	100m*100m (based on an effective mapping scale: 1:200´000)
Climate	Zimmermann and Kienast (1999) derived from Climate Station Data 1961 – 1990 and DHM25©2005 swisstopo (DV033492)	- April Moisture Index - July direct solar radiation	Derivation of statistical models and simulation modelling (Chapters 4 and 5)	Raster	100m*100m
Land use and land cover	LIS Davos	- Plan base area of buildings - Primary use of buildings - Premises	Derivation of current area consumption for tourist accommodation (Chapter 7)	Vector	Effective mapping scale: 1:2´500
Spatial Planning	LIS Davos	- Planning zones	Derivation of potential to increase floor area within the existing settlement (Chapter 7)	Vector	Effective mapping scale: 1:2´500

Swiss Area Statistics

Official Swiss Area Statistics (further referred to as ASCH) are derived from a nationwide land use and land cover survey based on aerial photographs by the Swiss Federal Statistical Office (SFSO). The information available in the datasets is acquired mainly from visual air photo interpretation, and hence the data represent land cover enhanced by references to land use, rather than actual land use data. We therefore do not use the term Swiss Land Use Statistics, as suggested by the SFSO (SFSO, 2001a), but prefer the term Swiss Area Statistics as used in many publications (e.g. SAEFL, 2002; Waser et al., 2001).

Area Statistics surveys have been conducted since the 1940s, but only the two last survey periods of 1979/85 and 1992/97 (further referred to as ASCH79/85 and ASCH92/97) are comparable due to earlier changes in the survey techniques (SFSO, 2001b). Land use and land cover types are extracted on the basis of point samples at 100 m intervals from a regular point lattice overlain on aerial photographs. Information on the actual land use is visually identified and stored for each intersection point of the lattice. With respect to the 100m*100m intervals, each classified sample point thus represents the area of one hectare. The actual conversion from the point-based dataset to the raster dataset takes into account the sample point at the lower left intersection of the grid cells as prime information which can – in certain cases – be modified on the base of the weighted incorporation of the neighbouring sample points (Peter, 1997).

The error due to the point sampling survey technique depends strongly on the number of sample points of each land use class within the evaluation area and varies between types of land use categories. The SFSO (1999, 2001) recommends applying the original Area Statistics only at the national level and for large cantons. Through the aggregation of land use classes, the Area Statistics are also valid for smaller areas. To use the Area Statistics for the region of Davos (represented by 25’443 sample points compared to 2.5 million sample points for the entire Swiss Mountain Area, see Figure 10), an aggregation of land use classes is required.

The original datasets, which feature 69 and 74 land use and land cover classes respectively, were re-aggregated into 9 and 5 classes for the analysis, model development and validation (Table 5). In accordance to Table 5, the *Forest* includes *Closed Forest*, *Open Forest*, and *Overgrown Areas*. The *Agricultural Land* comprises various types of agricultural land use classes that are differentiated in the Area Statistics, including the specialised cultivations, such as vines, pomiculture and horticulture (coded as 71-78 in Table 5). With the exception of one sample point of *Gardening*, these specialised cultivations can not be found in Davos and were excluded from the statistical analysis. The *Agricultural Land* is divided into *Intensive* and *Extensive Agriculture*, with *Intensive Agriculture* encompassing effectively only two classes, i.e. *Machine accessible meadows* and *Meadows with limited machine access* (coded as 81 and 82 in Table 5) and being found on the valley floors. The land use class *Housing and infrastructure* comprises built-up areas, e.g. residential or commercial buildings, roads and car parks, as well as open areas, e.g. parks, golf courses, and other sports facilities.

Table 5: Aggregation of the Area Statistics dataset based on the land use class definitions of ASCH92/97 (SFSO, 2001b).

Land use classes as coded in SFSO (2001b)	9-Class Aggregation	5-Class Aggregation
11, 14, 09, 10	Closed Forest (CF)	Forest (F)
12, 13, 18	Open Forest (OF)	
15, 16, 17, 19	Overgrown area (OA)	
71, 72, 75, 76, 77, 78, 81, 82	Intensive agriculture (IA)	Agricultural land (AL)
83, 84, 85, 88, 89, 86, 87, 88, 89	Extensive agriculture (EA)	
95, 96, 97	Unproductive grassland (UG)	Unproductive land (UL)
90, 98, 99	Bare land (BL)	
20, 21, 23, 24, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 41, 46, 47, 48, 49, 51, 52, 53, 54, 56, 59, 61, 62, 63, 64, 65, 66, 67, 69	Housing and Infrastructure (H&I)	Housing and Infrastructure (H&I)
91, 92, 93	Water (W)	Water (W)

The Swiss Area Statistics builds the basis for the land use allocation modelling approach despite its relatively coarse spatial resolution and constraints due to the point sampling. The dataset was chosen for two reasons. First, two identically surveyed datasets are available which allows detecting of changes in land use and land cover and derivation of statistical models from these observations. Secondly, the datasets are available for the entire country which enables the application of the simulation model to different regions within the Swiss Mountain Area.

The derivation of statistical models, representing the first step towards simulation modelling, is based on Area Statistics ASCH79/85 and ASCH92/97 encompassing the Swiss Mountain Area. This area includes the regions supported by the “Swiss federal law of investment assistance for mountain areas” (Rey-Rojas, 1983), the Upper Engadine and Davos. Although the aim is a regional model of Davos, data from the entire Swiss Mountain Area are used for two reasons. First, it improves the database for rare land use transformations in the area of Davos, such as the development of *Housing and Infrastructure* (Chapter 4). Second, it matches the coverage of earlier analyses which could be applied for the development of the simulation model (Rutherford, 2004). The same data are also used for land use change modelling and simulations, but concentrate on the extent of Davos. Within the 25,443 ha area of Davos, a large proportion is covered with *Agricultural Land*, *Forest* and *Unproductive Land* according to ASCH92/97, and only 566 ha are used for *Housing and Infrastructure*. While the *Agricultural Land*, *Forest* and *Unproductive Land* are further differentiated (Table 5), further differentiation of *Housing and Infrastructure* was not possible due to the limited area.

After ortho-rectification of historical aerial photographs from 1954, a third dataset was re-constructed for Davos by applying the identical surveying technique as used for the latest Area Statistics (Kukucova, 2003). The re-constructed Area Statistics dataset, which will be referred to as AS54, is used for model validation in Chapter 4 and Chapter 5. Due to problems in differentiating between different types of forest and agriculture on the 1954 black-and-white aerial photographs, the validation dataset was aggregated according to the five-class aggregation presented in Table 5. The 1954 aerial photographs cover about 40% of the area of Davos, including the areas of predominant change within the valleys and below the tree line (Figure 10).

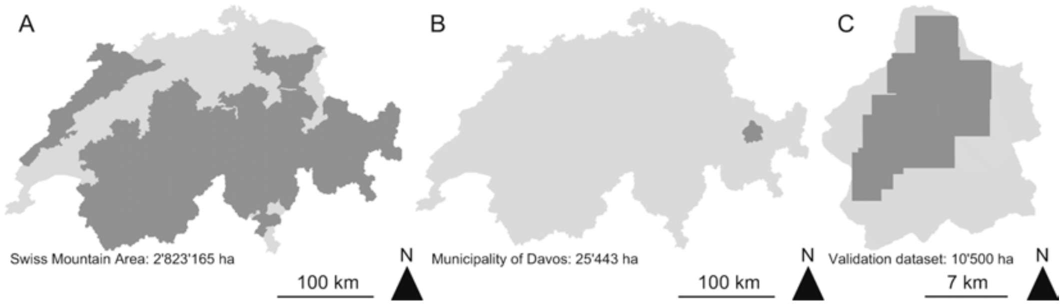


Figure 10: The Area Statistics is used in three extents: (A) displays the Swiss Mountain Area as used in the study, (B) shows region of Davos within Switzerland, and (C) displays the extent of the AS54 validation dataset within the region of Davos. (Municipality and country boundaries reproduced with permission of the BFS GEOSTAT).

As mentioned earlier, the Area Statistic is based on visual air photo interpretation. Although it differentiates between various types of grassland and partly refers to their particular usage in agriculture, e.g. the land use class of '*Maiensässe', Hay Alps, Mountain Meadow* (coded as 85 in Table 5), the dataset is primarily a land cover dataset. Accordingly the particular type of use and the intensity of use is not directly reflected in the data. To a limited degree of differentiation and accuracy, it can be inferred for agricultural and forested land based on the visual appearance and the topographic setting (e.g. differentiation between *Intensive* and *Extensive Agriculture*) and allows linking the land with particular economic activities. Despite the wide range of land use classes and their references to intensity of use in the original dataset, such a differentiation could not be kept for the land use class *Housing and Infrastructure* as to the limited extent of *Housing and Infrastructure* in the region of Davos.

Land Information System Davos

The Land Information System contains mainly information collected for local spatial planning purposes. It is a collection of highly accurate, 2D-vector datasets, holding cadastral information on the location and extent of the built-up infrastructure, its primary use and the planning zones. This 2D-information was enhanced by recording the number of floors of buildings, to better estimate the available built-up space. Thanks to the linkage between buildings and their primary use, it is possible to estimate the currently used space for particular activities and the potential to increase this space, as restricted by current spatial planning policies. The Land Information System thus provides an adequate basis to combine land cover data with type and intensity of land use particularly for built-up spaces and allows one to draw the linkage between the local economy and area consumption.

Compared with the Area Statistics datasets, the information provided in the Land Information System seems superior as to spatial resolution and the more precise information on the utilisation of spaces. However, the differentiation of usage is only high for built-up spaces and not for agricultural or forested land. Furthermore, at least a second survey would be essential to derive statistical models on land use and land cover *transformation*. Finally, the Land Information System holds only data from Davos, while the Area Statistics and any other data to be used for the statistical modelling are available for the entire country. To develop a model on the basis of datasets that cover the entire country facilitates the potential for the model's applicability to different regions within the Swiss Mountain Area. For these reasons, the Area Statistics' qualities are considered more appropriate for the development of a land use change model.

CHAPTER 4

COMPARISON OF TWO TECHNIQUES FOR REGIONAL LAND USE ALLOCATION MODELLING

In this chapter, the methodological approach to land use allocation modelling is described (Figure 11). Data availability, the study area and the purpose of scenario simulations are taken into account as important constraints for an appropriate modelling technique. Figure 11 shows the position of this chapter focus within the conceptual framework of integrated regional modelling, as presented in section 2.4 (Chapter 2: Figure 2). Figure 2

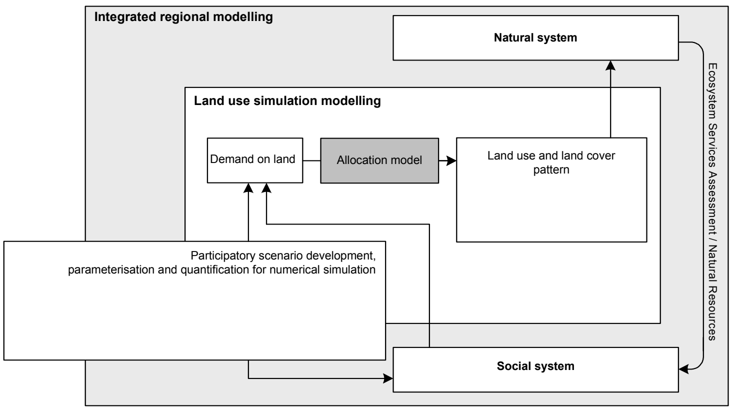


Figure 11: In this chapter an approach to allocation modelling is sought that matches given data constraints and will facilitate scenario simulation. For these investigations, two modelling techniques were implemented and compared with a preliminary focus only on settlement expansion.

A variety methodological approaches to land use allocation models have been described in Chapter 2.2.2. Amongst the four principal options, multi-criteria based modelling approaches were considered useful to optimise land use change, particularly on the level of single projects, but less useful for long-term simulation. Further, agent-based allocation approaches were rejected due to heavy data requirements and the problem of validation.

The remaining two methodologies include pattern-based allocation modelling (including Transition Probability Matrices) and statistically based allocation modelling. For sufficiently large sample sizes, statistical models can be derived from data within the same region, and preferably even only from some part of the region in order to retain data for validation. These statistical models then provide the basis for a simulation model. For small sample sizes, though, the potential of statistical analysis is limited and alternative approaches are required to derive a basis for modelling. As the data requirements are lower, Transition Probability Matrix (TPM) based modelling (e.g. Turner, 1987) constitutes such an alternative, although the concept of TPM refers to a very limited number of site characteristics compared to statistically based modelling.

We face the problem of small sample size with the expansion of settlement in the study area. In Davos, only 63 cells changed to *Housing and Infrastructure* between ASCH79/85 and ASCH92/97. Although this is an increase of more than 10% and is therefore an important land use change process, the sample size is too small for statistically significant results, particularly as the observations are highly spatially auto-correlated.

In this chapter, we assess the validity of using data from a larger area to overcome the problem of small sample size for statistically based modelling. Therefore we present a regionally derived, TPM-based modelling strategy and a supra-regionally derived, statistically based modelling strategy. While the first option concentrates on data from only within the study area, the second is based on the entire Swiss Mountain Area (Figure 10). The simulation results of both models are then compared for *Housing and Infrastructure* development and assessed for an independent validation period.

As mentioned in the introduction, this chapter is based on a conference contribution of the GISRUK Conference 2004 in Norwich, UK.

Walz, A., Bebi, P. and R. S. Purves (in press): Land use simulation for small regions in the Swiss mountain area - comparison of two modelling techniques. In: Innovations in GIS - GIS for Environmental Decision Making. Taylor & Francis Group.

4.1 Methodology

4.1.1 OVERVIEW

As discussed above the two modelling approaches differ in the amounts of data they require. First, we used a TPM-based approach (e.g. Turner, 1987; Turner et al., 1996). It does not require large amounts of data in order to deduce systematic rules, but can subsequently be improved, for instance through the incorporation of neighbourhood rules (e.g. Turner, 1987). Only data from the Davos region was applied to implement this model (Chapter 3: Figure 10A). Second, we used multiple logistic regressions which were derived from random samples from the entire Swiss Mountain Area (Chapter 3: Figure 10B). Thus, the number of observations was sufficiently high to extract statistically significant models. Figure 12 underpins the assumption adopted in the regression-based approach – that is that changes in the whole Swiss Mountain Area are similar to those in Davos. Further analysis of the transition processes is presented in Chapter 5 where the principal transition processes are identified in greater detail.

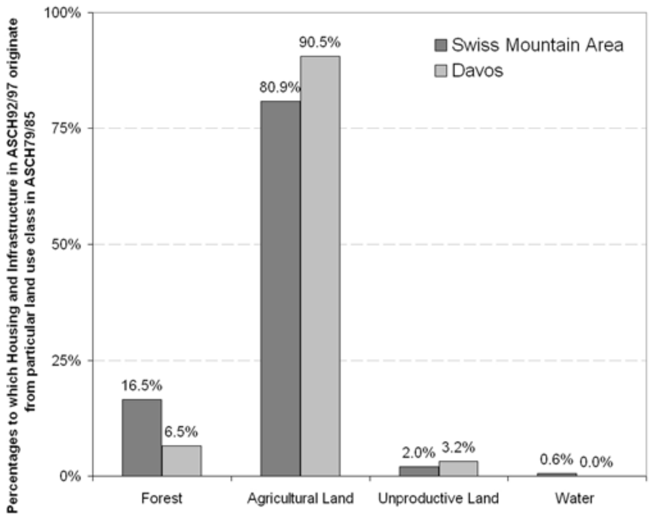


Figure 12: Distribution of land use in ASCH79/85 that had transformed into Housing and Infrastructure in ASCH92/97.

4.1.2 TPM-BASED APPROACH

A TPM provides transition probabilities empirically derived from the transition rates between two time steps (see for instance Turner et al., 1996). The principal idea behind the approach is that the future state of a pixel depends strongly on the recent state of the pixel. The TPM derived from ASCH79/85 and ASCH92/97 for Davos is presented in Table 6. The matrix shows the probability that any pixel of a particular land use class in ASCH79/85 changed to another land use class in ASCH92/97 (or remained in the same land use class). Thus, for instance, any pixel representing agriculture in ASCH79/85 had a probability of 0.0059 of changing to *Housing and Infrastructure* in the dataset ASCH92/97.

Table 6: Transition matrix with absolute numbers of observed transitions and derived transition probabilities (in italics) for Davos.

		ASCH92/97					
		F	**AL**	**UL**	**H&I**	**W**	Total
ASCH79/85	**Forest (F)**	616	2	14	4	0	6'181
		0.9968	*0.0003*	*0.0023*	*0.0007*	*0*	*1*
	Agricultural Land (AL)	190	9427	11	57	0	9'685
		0.0196	*0.9734*	*0.0011*	*0.0059*	*0*	*1*
	Unproductive Land (UL)	26	6	8808	2	0	8'842
		0.0029	*0.0007*	*0.9962*	*0.0002*	*0*	*1*
	Housing and Infrastructure (H&I)	1	8	0	503	0	512
		0.0020	*0.0156*	*0*	*0.9824*	*0*	*1*
	Water (W)	1	0	1	0	221	223
		0.0045	*0*	*0.0045*	*0*	*0.9910*	*1*
	Total	6379	9443	8834	566	221	25443

In an unmodified TPM approach, neither the spatial context (e.g. neighbouring land use) nor further properties of the location are taken into account. In our research, however, the TPM was enhanced according to both these aspects. A stratification of the dataset allowed inclusion of site properties, and the transition probabilities were further modified according to neighbouring land uses.

Stratification of the dataset according to classification tree analysis

Instead of using one matrix for the entire region of Davos, the dataset was stratified and matrices derived for each part of the dataset. A classification tree analysis helped to identify optimal stratification criteria for the transition processes (Figure 13). In a classification tree analysis, a dataset is split into increasingly homogeneous subsets in terms of a factor response variable through a binary recursive partitioning technique (Clark and Pregibon, 1992). The various possible transition processes (expressed as factor response variables) were to be classified according to site properties (expressed in numeric predictor variables) in this analysis (Figure 13). For the analysis the pixels with land use change between ASCH79/85 and ASCH92/97 were selected and their site properties derived from GIS query (Table 7).

According to cross-validation testing, the optimal classification results were achieved with four terminal nodes. The criteria identified as being most favourable for stratifying the dataset were based on “elevation” and “distance to road”. After the dataset had been stratified, corresponding transition probability matrices were calculated for each of the resulting subsets.

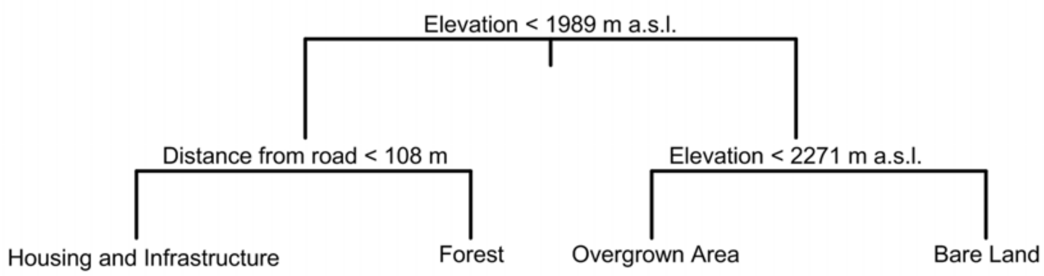


Figure 13: Classification criteria and boundary values for systematic stratification of land use changes according to classification tree analysis.

Incorporation of neighbourhoods

Further modification of the basic TPM took into consideration the neighbouring cells of pixels with transformation between ASCH79/85 and ASCH92/97, and thus introduced considerations of spatial adjacency into the model. This analysis showed that the land use classes of neighbouring point samples have a strong influence on future land use at a given location. Figure 14 shows the distribution of transformations to *Housing and Infrastructure* according to the number of neighbours with the same land use class. The low values for 4 and

5 neighbours in the Davos dataset demonstrate once more how small the purely regional sample size is.

A transition probability $P_{n(L,N)}$ based on neighbourhood conditions was derived. For that the number of cells that changed to a land use class *L* are related to the total number of cells with the same number of land use class *L* neighbours (Equation 1). To enhance the influence of neighbouring points of the relevant land use class *L*, the derived probability $P_{neighbours(L,N)}$ was transformed into an exponential function (Equation 2).

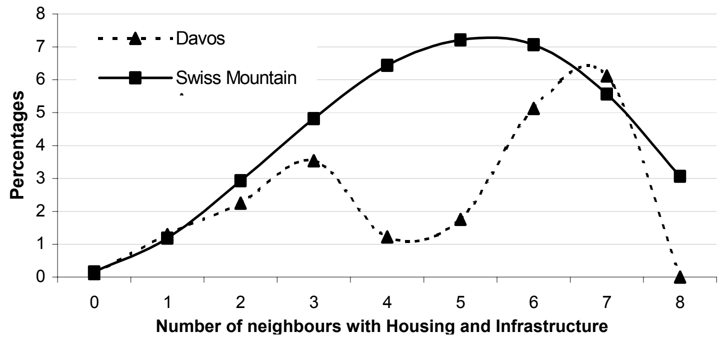


Figure 14: Distribution of all points that transformed to housing and infrastructure between ASCH79/85 and ASCH92/97 according to their number of neighbours a) for Davos and b) for the mountain area.

$$P_{n(L,N)} = \frac{A_{(L,N)}}{T_{(L,N)}} \tag{1}$$

$$P_{neighbours(L,N)} = e^{k*P_{n(L,N)}} \tag{2}$$

with:
L = Land use class
N = Number of neighbours of a land use class L
k = Constant calibration factor
$A_{(L,N)}$ = Number of points being transformed to a land use class L and with a number of neighbours N of this land use class L
$T_{(L,N)}$ = Total number of points with a number of neighbours N and in a land use class L

Simulation

For each set of possible transitions in the TPM (e.g. *Agricultural Land* to *Housing and Infrastructure*) a point with the respective land use class (e.g. *Agriculture*) is randomly selected. The site properties of the point are then retrieved (distance to road, elevation etc.) and the point is associated with the according subdivision of the stratified dataset and its corresponding TPM. The properties of the neighbouring pixels are examined and a combined transition probability is assigned to the point. This transition probability is then tested against a random number. For that a number between 0 and 1 is randomly selected, and if this number is lower than $P_{neigh(L,N)}$, the transition is performed. This process is repeated until either the required numbers of transitions have been reached or 300 consequent “failed” transitions have occurred.

4.1.3 REGRESSION-BASED APPROACH

A second approach attempted to overcome data density problems by using regression analysis to determine the probability of a certain point *i* being transform into *Housing and Infrastructure*. Since the dataset for Davos shows only 63 of these transformations within the observation period out of a total of 503 transitions, a larger area was used to perform the analysis. For that sub-samples of the entire Swiss Mountain Area were taken. Differences in transition intensity are described in detail in Chapter 5.

Sub-sampling of data within the Swiss Mountain Area

The ASCH dataset encompasses 2.5 million point samples for the mountain area. To limit the dataset to the relevant areas, we identified the areas where most *Housing and Infrastructure* between ASCH79/85 and ASCH92/97 had occurred through preliminary tests. Sites with elevations <2’000m, slopes <30° and a maximum distance of 1 km to the nearest road covered about 90 % of the transitions towards *Housing and Infrastructure*. Subsequently an area of interest was constituted on the base of these criteria. From this area of interest about 1’400 samples were randomly selected. To reduce the effects of spatial auto-correlation, the minimum distance between the samples was 5 km.

Variables

For these datasets a similar set of variables was extracted from the GIS as for the classification tree analysis used in the TPM approach. Besides topographic data, distance measures and environmental parameters, previous land use and a characterisation of any pixel’s neighbourhood were included directly in the set of variables (Table 7). A univariate analysis of the predictive power of variables for development of housing and infrastructure was carried out, and only those with a *P*-value < 0.05 were included in the subsequent analysis.

Table 7: List of variables that are used in the classification tree analysis and in the logistic regression.

Class of Variable	Variables Classification Tree Analysis	Variables Regression	Data type
Topography	Elevation	Elevation	Continuous
	Slope	Slope	Continuous
	Aspect	Aspect	Continuous
	Curvature	Curvature	Continuous
Distance measures	Distance to tarmac road	Distance to tarmac road	Continuous
	Distance to river	Distance to river	Continuous
	Distance to centre		Continuous
Previous land use In different levels of aggregation	Forest ¹	Forest	Categorical
	Agricultural Land ¹	Agricultural Land	Categorical
	Housing and Infrastructure ¹	Housing and Infrastructure	Categorical
	Unproductive Land ¹	Unproductive Land	Categorical
	Water Surface ¹	Water Surface	Categorical
Neighbourhood in 3*3 window	No. of Forest 3*3 ²	No. of Forest 3*3	Continuous
	No. of Agricultural Land 3*3 ²	No. of Agricultural Land 3*3	Continuous
	No. of Housing and Infrastructure 3*3 ²	No. of Housing and Infrastructure 3*3	Continuous
	No. of Unproductive Land 3*3 ²	No. of Unproductive Land 3*3	Continuous
	No. of Water Surfaces 3*3 ²	No. of Water Surfaces 3*3	Continuous
Neighbourhood in 5*5 window	No. of Forest 5*5 ²	No. of Forest 5*5	Continuous
	No. of Agricultural Land 5*5 ²	No. of Agricultural Land 5*5	Continuous
	No. of Housing and Infrastructure 5*5 ²	No. of Housing and Infrastructure 5*5	Continuous
	No. of Unproductive Land 5*5 ²	No. of Unproductive Land 5*5	Continuous
	No. of Water Surfaces 5*5 ²	No. of Water Surfaces 5*5	Continuous
Other	Soil characteristics	Soil characteristics	Categorical
	Climatic suitability	Climatic suitability	Categorical
	Geology	Geology	Categorical
Dependent	Land use class in ASCH92/97 for pixel that transformed between ASCH79/85 and ASCH92/97	Transformed to housing and infrastructure or not within the observation period	Boolean

Note: Variables marked with ¹ are incorporated in the model through the basic TPM and variables marked with ² through the incorporation of a neighbourhood based transition probability.

Logistic Regression

Stepwise logistic regression was carried out to determine the controls that explain best whether a pixel undergoes *Housing and Infrastructure* development. Assuming that site characteristics and decision-making criteria will remain similar in the future, the suitability for future *Housing and Infrastructure* development is deduced on the basis of Equation 3. P_i represents the transition probability according to the derived statistical model.

$$Log\left(\frac{P_i}{1-P_i}\right)=\beta_0+\beta_{1,i}*X_{1,i}+\beta_{2,i}*X_{2,i}+\ldots+\beta_{n,i}*X_{n,i} \qquad (3)$$

Simulation

To perform a simulation of future land use change using a regression model, only the amount of desired change of the land use class being modelled is required (in this case *Housing and Infrastructure*). The changes in demand on land (in full hectares) and the simulation period are the principal input parameters for simulation. The demanded transitions are then distributed on the basis of the transition probabilities derived from the statistical model. Similar to the TPM-based model these transition probabilities are tested against random numbers to decides whether a transition is accepted or not. If the random number is above the regression-derived transition probability, the transition is not accepted. The order in which the pixels are checked depends on their transition probability. First the pixel with the highest P_i-value is selected and then the pixel with the second highest P_i; and so on. When the requested number of transitions is reached or all possible pixels were rejected, the simulation stops.

4.1.4 IMPLEMENTATION

The TPM-based model was implemented in VBA with ArcGIS8.3 (ESRI, 2003). For the regression-based model the data were extracted from the GIS environment and processed in a bespoke C++ program.

4.1.5 VALIDATION AND COMPARISON OF THE MODELLING RESULTS

The models were validated by use of an independent dataset. We used the dataset reconstructed from 1954 aerial photographs to produce an independent time slice between 1954 and 1985. This is most suitable, particularly for the TPM-based model which cannot be transferred to a different area without prior modifications. While the rate of change between the AS54 and ASCH79/85 was inherent through the TPM in the first model, it had to be entered as an input parameter for the regression-based model.

The simulation results for the validation period from 1954 to 1985 are compared with the observed data of ASCH79/85. The results were investigated both by pixel-to-pixel comparison and with a assessment technique accounting for some spatial uncertainty by matching pixels with neighbours in a 5*5 moving window. As matches were found, they were removed from the dataset in an iterative procedure, ensuring that no double-matching was permitted. Contingency tables (e.g. Monserud and Leemans, 1992) were calculated for both validation techniques (Table 9).

Kappa statistics are an established technique for map comparison and have been described and critically discussed in many earlier contributions (e.g. Hagen, 2003; Monserud and Leemans, 1992; Pontius, 2000). Based on Cohen's Kappa Index (Cohen, 1960) the goodness of fit between the simulated and the observed data were summarised in order to compare the two modelling approaches.

4.2 Results

4.2.1 DETERMINING FACTORS FOR ALLOCATION OF HOUSING AND INFRASTRUCTURE DEVELOPMENT

The classification tree analysis used in stratification for the TPM identified "elevation" and "distance to road" as the two key criteria to categorize land use changes in the Davos area. For the first, it suggests differentiating between three elevation classes (see Figure 13). While the lowest elevation band is characterised by a mixture of *Housing and Infrastructure*, *Intensive Agriculture* and *Forest* with an increase in *Housing and Infrastructure* and *Forest*, the second is dominated by *Extensive Agriculture*, *Unproductive Grassland* and increasing *Overgrown Area* and the third by increasing *Bare Land*. The second classification criterion "distance to road" allows distinction between the areas with increasing *Housing and Infrastructure* and the increasingly forested land within the lowest band. Within the lowest elevation band and up to 100m from the roads, 75% of the transitions to *Housing and Infrastructure* occurred between ASCH79/85 and ASCH92/97.

For the logistic regression several sets of variables were tested to avoid high correlation between variables. The optimal set of variables along with the *P*-values is shown in Table 8. In accordance with the classification tree analysis topography and accessibility were assessed as being significantly with *P*-values at least <0.05. It also indicates the significance of land use in the neighbourhood of a location which is also a key factor in the final TPM-based model. The initial land use class was not identified as significant in the logistic regression model.

Table 8: Predictors of built-up area in the Swiss mountain region, including coefficients and significance ("ns" = not significant).

Predictors	P-value	Coefficient (β_i)
(Intercept)		4.6
Distance to road	< 0.001	-3.2×10^{-4}
Distance to valley floor	< 0.001	-6×10^{-5}
Elevation	< 0.001	-3.8×10^{-6}
Slope	< 0.05	-2×10^{-2}
Previous land use: agriculture	ns	
Previous land use: forest	ns	
Previous land use: unproductive land	ns	
Neighbouring cells: Forest	< 0.001	-2×10^{-1}
Neighbouring cells: Agriculture	< 0.001	-1.8×10^{-1}
Neighbouring cells: Unproductive land	< 0.001	-2.6×10^{-1}
Neighbouring cells : Housing & Infrastructure	< 0.01	2.3×10^{-1}

4.2.2 SIMULATION OUTCOMES AND VALIDATION

For validation we used the reconstructed dataset AS54 to start simulations and then ran the simulation until 1985 for both models. The resulting patterns of *Housing and Infrastructure* for the simulation period 1954-1985, further referred to as SimTPM and SimReg respectively, the initial dataset AS54 and the observed dataset ASCH79/85 are displayed in Figure 15.

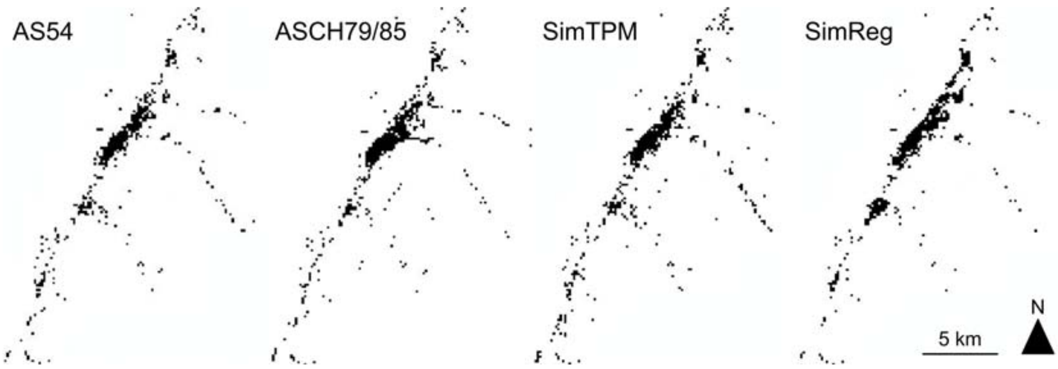


Figure 15: The initial dataset AS54, the observed data ASCH79/85 and the simulation results of both modelling approaches.

Contingency tables and associated Kappa Indices for these results are shown in Table 9. Based on exact comparison and the moving window assessment technique, differences in the Kappa Index for both modelling approaches are negligible with $\kappa_A = 0.72$ (respectively $\kappa_C = 0.83$) for the TPM-based approach and $\kappa_B = 0.73$ (respectively $\kappa_D = 0.81$) for the regression-based approach.

Table 9: Contingency tables and Kappa Indices to compare the survey data and the simulated results for the validation period from 1954 to 1985.

Pixel-To-Pixel Match							
A κ_A **= 0.72**		**Survey 1985**		**B** κ_B **= 0.73**		**Survey 1985**	
		H&I	Other			H&I	Other
SimTPM	Housing and Infrastructure (H&I)	9901	125	**SimReg**	H&I	9900	127
	Other	127	347		Other	128	345
Moving Window Match							
C κ_C **= 0.83**		**Survey 1985**		**D** κ_D **= 0.81**		**Survey 1985**	
		H&I	Other			H&I	Other
SimTPM	Housing and Infrastructure (H&I)	9901	69	**SimReg**	H&I	9900	99
	Other	90	403		Other	84	418

4.3 Discussion

4.3.1 FACTORS FOR THE SPATIAL DISTRIBUTION OF NEW HOUSING AND INFRASTRUCTURE

For both datasets similar variables are key controls for the development of *Housing and Infrastructure* in the alpine landscape. Elevation is the most important variable for the classification of the Davos dataset and it is also an important factor in the logistic regression model. The distance to roads is an important criteria both in the stratification of the TPM and the regression model. Notably, both variables are treated a little differently by the two modelling approaches. First, the ranges of elevation investigated in both attempts vary. While the Davos data also included elevations without major *Housing and Infrastructure* development, the area of interest in the second attempt included the elevation range with the highest density of *Housing and Infrastructure* development. Second, the incorporation of the variables differs in both modelling approaches. While the stratification of the TPM causes a strict division with strongly varying transition probabilities for closely located sites near the threshold value, the regression based transition probabilities change gradually with an increase in elevation.

The TPM-based model builds on the idea that previous land use is a strong determinant when modelling land use change in alpine regions. However, the variable "previous land use" has not turned out to be significant in the logistic regression model. This poses fundamental questions to the TPM approach. In addition to the basic TPM, the approach incorporated site properties and neighbourhood-related site properties similar to many previous studies (e.g. Clarke et al., 1997; Engelen et al., 1995). Both, the stratification of the data set through site properties, and the incorporation of neighbourhood criteria seem to have had a great impact on the simulation results given the low significance of the variable "previous land use" in the regression analysis (Table 8). How strongly the performance of the TPM-based model was particularly imprinted by the incorporation of neighbourhood variables has not been tested separately. These findings suggest that a *pure* TPM approach for simulation land use change in Swiss mountain regions is inappropriate, and that rather an approach based on neighbourhood relations, i.e. cellular automata, would be more appropriate. The strong influence of neighbourhoods in the regression model suggests further the validity of such an approach.

4.3.2 SIMULATION RESULTS

The comparison between validation results of the two modelling approaches indicates discrepancies caused by the different specific modelling techniques, and shows some limitations of land use modelling in general.

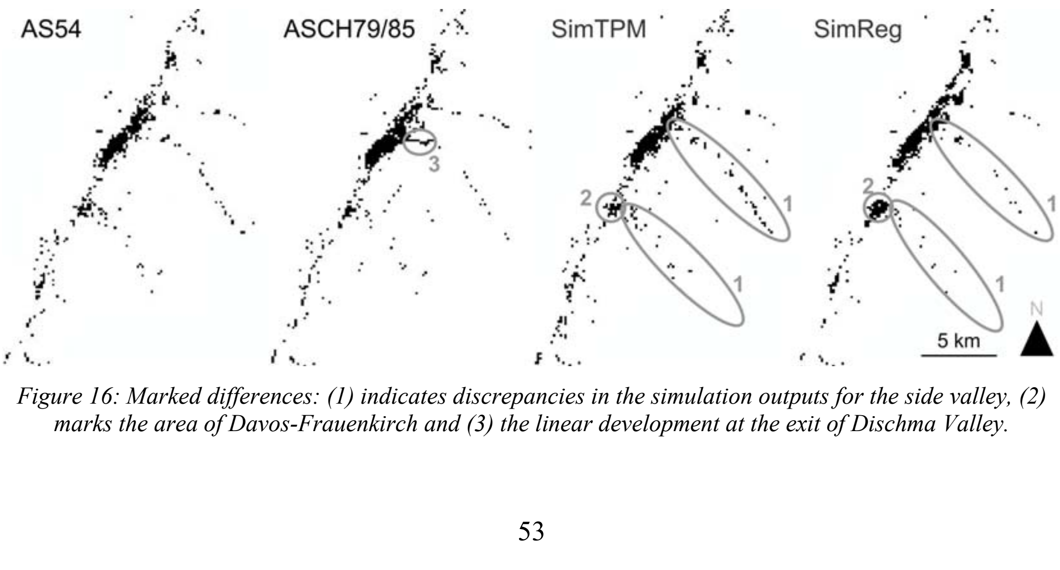


Figure 16: Marked differences: (1) indicates discrepancies in the simulation outputs for the side valley, (2) marks the area of Davos-Frauenkirch and (3) the linear development at the exit of Dischma Valley.

The main difference between the TPM-based and the regression-based approach is the intensity of *Housing and Infrastructure* development in the rural side valleys. It is over-estimated by the TPM-based and under-estimated by the regression-based model (Figure 16).

One reason for the underestimation of disperse settlement in the side valley through the regression-based approach is that using a larger source area effectively integrates over multiple stages of land use development and cultural regions within Switzerland. Due to land use policies in place between ASCH79/85 and ASCH92/97 and due to these cultural differences with many regions showing much denser historical settlement structures, concentrated settlement expansion is favoured in the modelling procedure.

A second reason which is even more crucial is the difference in the simulation procedures. The regression-based model selects sites through ranking the suitability of all possible sites. The most suitable sites are tested first and therefore also very likely developed first. Since a sufficient number of sites with high suitability are found in the main valley, few transitions occur in the side valleys. In contrast, the TPM randomly selects the next pixel to be tested amongst all pixels that are not yet occupied with *Housing and Infrastructure.* If the selected site is accepted through the random number, a change to *Housing and Infrastructure* occurs independently of other, possibly more suitable, pixels. This simulation technique is more favourable for a relatively sparse settlement pattern as it prevails in the side valleys.

Both simulation results show a dense structure of the settlement and an enlargement of the small settlement Davos-Frauenkirch (Figure 16) as a consequence of strong neighbourhood effects. This effect is partly derived from the observation period (between ASCH79/85 and ASCH92/97) when more restrictive spatial planning was introduced to limit disperse development outside of already developed areas. However, prior to the 1970s no such policies were in place, and therefore the influence of neighbouring developments may have been too strong for the validation period between 1954 and 1985. This effect shows a limitation of all statistically-based land use models which cannot simulate land use change under profoundly different conditions, such as major changes in land use policy.

Both models failed to predict the linear development at the exit of the Dischma Valley (Figure 16). This development is in fact a expansion of the local golf course by about 20 ha in the 1960s (Wagner, 2004). Such single development project cannot systematically be represented by either model, and illustrate general limitations of predictive land use simulation modelling that build on observations of the past.

4.3.3 SUITABILITY OF THE MODELLING APPROACHES FOR THE SWISS MOUNTAIN AREA

A key aim of this chapter was to investigate the suitability of the two different modelling approaches to land use change simulation in Swiss mountain regions, and in particular to consider the validity of using supra-regional data to represent regional processes. Furthermore, a future aim will be to extract the spatial structure of landscape change. We now consider how effective the two modelling strategies presented here are in addressing these aims.

Global statistics in the form of Kappa-values are very similar for both models. Using a moving-window approach improved the Kappa-scores by a similar amount in both cases, reflecting similar spatial uncertainty for both models. With some differences in spatial structure (as discussed in the previous section), the two modelling approaches produced broadly similar overall results.

Thus, it is evident that the regression-based approach using data from a much wider area is valid in this case. Development in Davos seems to follow broadly similar patterns to that in the whole Swiss Mountain Area and can be simulated on the basis of the derived regression model.

The advantage of the TPM-based model is in the better replication of spatial structure of *Housing and Infrastructure* development in Davos, namely the sparse development in the side valleys. This is mainly because the simulation procedure is not based on an absolute ranking of suitabilities which enhances a more dispersed settlement pattern.

However, the regression-based model is considered more suitable to scenario simulation in a regional modelling framework. The model can be applied for a wide range of possible scenarios, as future demand of *Housing and Infrastructure* is the prime input parameter for simulation. Such an input value can be relatively easily derived from scenario development or aspatial scenario-based modelling (Chapter 6).

In order to perform a scenario simulation with the TPM-based model, predicted transitions for all land use classes and their interaction (Table 6) are required. This requirement is a severe limitation for scenario simulation. Whilst an economic model or a scenario may provide input describing future demand for *Housing and Infrastructure*, it is unlikely to also quantify the interaction between all remaining land use classes too. Therefore, TPMs are better suited to trend-based scenarios, where it is assumed that current demand will continue for some period in the future.

4.4 Conclusions

The results demonstrate that the use of data from the Swiss Mountain Area is valid also for regional-level land use modelling. The assumption of similarity between land use change in the Swiss Mountain Area and in the Davos region is correct over the time periods studied and the derived regression-based model appears appropriate for regional level simulation. According to the findings, here, the supra-regionally established regression-based model is similarly successful in reconstructing observed increase in *Housing and Infrastructure* at a regional scale to a regionally derived TPM-based model. For the validation period the disperse settlement in the side valleys was better reconstructed in the TPM-based approach due mainly to conceptual changes in the modelling procedure. However, the regression-based approach shows strong advantages for the implementation of future scenarios because of its higher adaptability to a wide range of possible future configurations and simpler input requirements.

The main constraints in statistically based simulation modelling are the inability to display single large-scale development projects, which would much better be addressed by, for instance, multi-criteria approaches, and the neglect of changing planning policies which will determine most allocation for future *Housing and Infrastructure* development. Both modelling approaches represent modified forms of cellular automata given the strong effect of neighbourhood qualities in both models.

In Chapter 5, the development of a land use allocation model will be continued with focus on the regression-based approach. The model described here will be improved through incorporating further processes of land use change identified to be relevant for the area of Davos.

CHAPTER 5

LAND USE ALLOCATION MODELLING FOR SWISS ALPINE REGIONS

In this chapter, the regression-based approach for the development of *Housing and Infrastructure* as tested in Chapter 4 is extended to a more comprehensive land use allocation model that includes all relevant transition processes within the study area. According to the overall aims of the study, the focus of the model lies still on the allocation of changing demands on land derived from scenarios or aspatial modelling (Figure 17). The final purpose of the allocation model is to project land use and subsequent land cover changes for complex future scenarios such as those introduced in Chapter 6, and to provide a spatially explicit basis for evaluation, e.g. through ecosystem services (Grêt-Regamey, 2003).

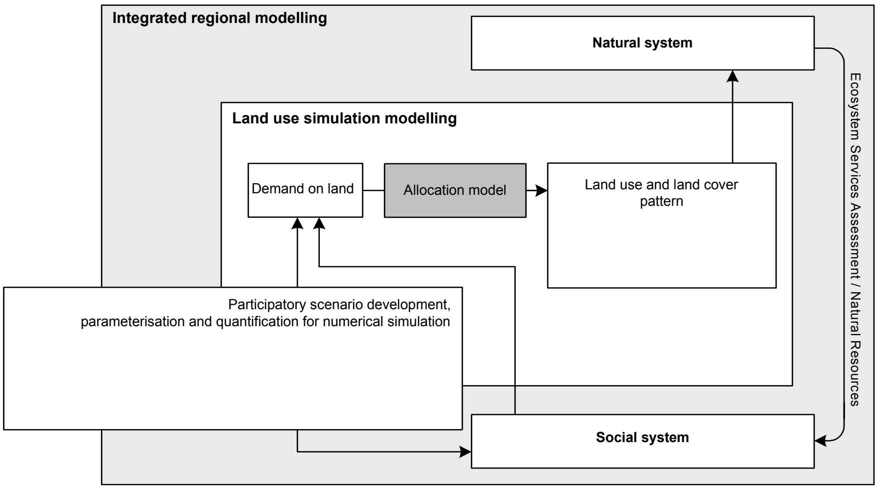


Figure 17: In this chapter, the allocation model will further be developed on the basis of logistic regressions which has been assessed a favourable modelling technique for the given purposes in Chapter 4. All relevant land use transition processes will be incorporated and the model will be validated and tested.

In order to elaborate a spatially adaptive allocation model that fulfils these requirements, the principal processes of land use transition were identified. These processes are incorporated into the simulation model based on similar techniques to those introduced for the regression-based model for *Housing and Infrastructure* development in Chapter 4. The model is then validated, and finally explored in a sensitivity analysis.

5.1 Overview of the methodology

5.1.1 DATA

The base data and the different aggregation of schemes for the Area Statistics have already been described in detail in Chapter 3. The statistical and simulation modelling are based on the 9-class aggregation as described in Chapter 3. To identify the most relevant transition processes and to validate the model, the 5-class aggregation was applied. Although the re-constructed dataset AS54 originally differentiated between the 74 land use classes used in the official Area Statistics survey, the data was re-aggregated into nine classes for simulation modelling. The dataset was further aggregated into five classes for the validation procedure in order to reduce inconsistencies between AS54 and ASCH79/85.

5.1.2 PROCESS IDENDIFICATION

The principal land use transition processes for the Swiss Mountain Area are identified on the basis of contingency tables and descriptive statistics at different spatial levels. For that, the region of Davos, the entire Swiss Mountain Area and regions differentiated according to the socio-economic structure of individual municipalities are investigated (Figure 18).

The Swiss Federal Statistical Office differentiates these types of municipalities on the basis of the 1990 census data 1990 (Schuler and Joye, 2000). All nine socio-economic types occur in the Swiss Mountain Area, but the frequency varies strongly between them. Particularly in terms of spatial extent, agricultural and tourist-type municipalities dominate the inner-alpine region (Figure 18). Also Davos is referred to as a tourist-type municipality in this classification.

At all three spatial levels of investigation, GIS queries were used to extract zonal statistics for each transition process. Contingency tables were used to identify relevant transition processes based on the absolute area affected by a process and on relative rates of change (Figure 20 and Figure 22). The percentages are to be read as the proportion of all hectares belonging to a certain land use class in ASCH92/97, which were of a given previous type in ASCH79/85. All municipalities of a certain socio-economic type were aggregated to derive the transition rates displayed in the contingency tables (Figure 20). Outliers for each transition process were excluded from the dataset on the basis of quantiles, i.e. values smaller than the 5%-quantile and greater than the 95%-quantile were neglected.

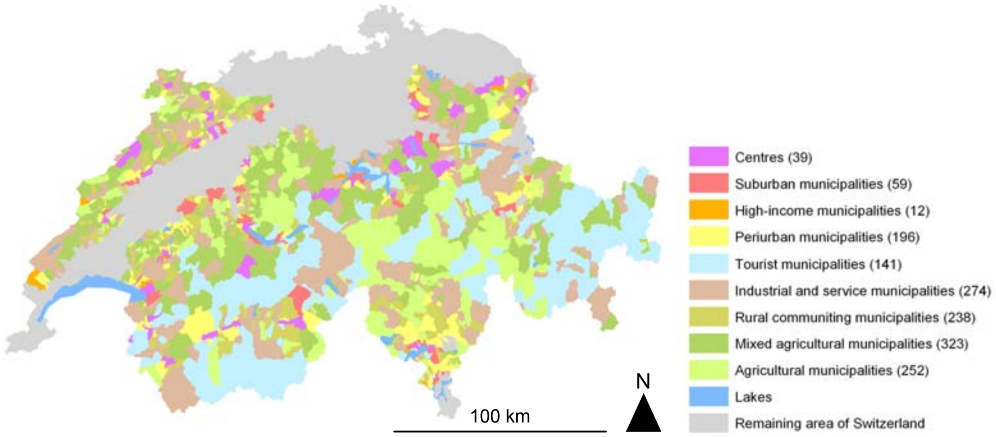


Figure 18: Socio-economic types of municipalities as differentiated by the SFSO (2000), including the number of municipalities for each type in the Swiss Mountain Area.

The variance in intensity of transition processes within each socio-economic region is further investigated by use of an ANOVA (Chambers et al., 1992). For that, each transition processes was separately examined. The ANOVA calculated the variance of observed transition rates within a given socio-economic types and compared it with the variance within other socio-economic types. A pairwise comparison between all socio-economic types gave the degree of significance by which the transition rates varied between single socio-economic types. For this analyses, the five-class aggregation of land use classes was applied (Section 3.2). Out of these five classes, the land use class *Water* was excluded, because changes between ASCH79/85 and ASCH95/97 were found to be of marginal extent and interest for this investigation. All possible transitions between the remaining four land use classes were analysed.

In a further analysis, the nine-class aggregation (Section 3.2) was used to investigate also the intensity of transition between different types of forest and of agricultural land in contingency tables. Only the Swiss Mountain Area and the region of Davos were included into this analysis.

5.1.3 STATISTICAL MODELS

A set of logistic regressions (Table 10) was calculated based on ASCH79/85 and ASCH92/97, topographic data, ecological data including aspects of soil and climate and distance measures. The data used as explanatory variables for the regression analysis are described in detail in Rutherford (2004).

Transitions between agricultural and forested land are described in a matrix of 25 regressions displaying all relevant changes between *Intensive Agriculture*, *Extensive Agriculture*, *Open Forest*, *Closed Forest* and *Overgrown Areas* (■ in Table 10). The methodology to derive these multivariate logistic regression models are described in detail Rutherford (2004).

Further models were derived for the development of *Housing and Infrastructure* (■ in Table 10, described in detail in Chapter 4), and the distribution of *Unproductive Grassland* (■ in Table 10).

Table 10: Land use transformations included into the model are marked with x.

	IA	EA	CF	OF	OA	UG	H&I
Intensive Agriculture (IA)	x	x	x	x	x	x	x
Extensive Agriculture (EA)	x	x	x	x	x	x	x
Closed Forest (CF)	x	x	x	x	x		x
Open Forest (OF)	x	x	x	x	x		x
Overgrown Area (OA)	x	x	x	x	x		x
Unproductive Grassland (UG)			x	x	x		x
Housing and Infrastructure (H&I)							x

■ Transition processes modelled by Rutherford (2004)
■ Application of the model for Unproductive Grassland.
■ Application of the models from Extensive Agriculture to the respective land use classes.
■ Application of the model for Housing and Infrastructure.

The logistic regression model addressing *Unproductive Grassland* is based on a random sample drawn out of all hectares occupied with *Unproductive Grassland* in ASCH92/97. Due to limited numbers of transformations between *Agricultural Land* and *Unproductive Grassland*, it was not possible to use only sample points that had undergone this transition between ASCH79/85 and ASCH92/97. As for the *Housing and Infrastructure* model described in Chapter 4, this analysis is also based on the methodology described in Rutherford (2004). The final model is presented in Table 11 including the predictor variables, their significance in the reduced model and the coefficients to derive transition probabilities for particular sites.

Similar problems occurred for vegetation succession on *Unproductive Grassland,* hence for the shift from *Unproductive Grassland* to *Closed Forest*, *Open Forest* or *Overgrown Area.* This is why the statistical models derived for the *Extensive Agriculture* to any of these classes were used for these transitions (■ in Table 10).

Table 11: Predictors of change to Unproductive Grassland in the Swiss Mountain Area, including coefficients and significances for the reduced model.

Predictors	**P-value**	**Coefficient (β_i)**
(Intercept)		-1.592
Distance to road	< 0.001	3.915×10^{-4}
Elevation * Elevation	< 0.001	2.372×10^{-5}
Slope	< 0.001	2.722×10^{-2}
Neighbouring cells: Closed Forest	< 0.001	-7.669×10^{-5}
Neighbouring cells: Intensive Agriculture	< 0.001	5.787×10^{-5}
Soil Depth	< 0.001	-5.806×10^{-2}

5.1.4 MODEL STRUCTURE

Four transition processes are differentiated within the modelling process:

- expansion of the settlement,
- abandonment of intensively used agricultural land,
- abandonment of extensively used agricultural land, and
- vegetation succession.

These processes are assumed to occur in a hierarchical structure according to their economic relevance. The development of *Housing and Infrastructure* is assumed to be the dominating process, i.e. it implies the highest economic value to the decision-making landowner. The use or abandonment of *Intensive Agricultural Land* is assumed to be of secondary importance, and the use or abandonment of *Extensive Agricultural Land* is of minor economic importance. Land cover changes due to vegetation succession, which concentrates on non-agricultural vegetated areas, such as forest and unproductive grassland, are assumed to occur in absence of any profit-orientated land cover modification.

The model input includes the simulation period and the number of hectares that are expected to transform for the land use classes *Housing and Infrastructure*, *Intensive Agriculture* and *Extensive Agriculture*. The model allocates the number of required land use transformations spatially according to the probabilities derived from the statistical models.

The structure of the simulation model depicts the assumed hierarchical structure (Figure 19). After having deduced rates of change for a time unit, each transformation process is simulated in a separate "blocks" to allocate the required number of hectares. These blocks are iteratively worked through for each simulation period. Within one block, transition probabilities are derived from the statistical models. For each hectare to be allocated, the location with the highest transition probability is identified. Whether a transition is accepted for the identified location, is decided by comparing a random number with the probability to change.

Within each block, this method differs slightly (Figure 19). For *Housing and Infrastructure*, location are selected and tested in the order of their probability to change to *Housing and Infrastructure*, beginning with the highest probability. By contrast, the location of the lowest probability to remain *Agricultural Land* is located if a reduction of *Agricultural Land* is to be simulated. Then one of the transition processes is randomly selected from *Open Forest*, *Closed Forest*, *Overgrown Area*, *Unproductive Grassland* or *Extensive Agriculture* and tested against a random number. For changes in demand on intensive and extensive agricultural land, the procedures are identical. For vegetation succession, all locations, which are not developed with *Housing and Infrastructure* or which are not agriculturally used, are assessed for each time step. A transition process is selected randomly for each of them and acceptance is decided once more according to a random number.

To simulate scenarios relevant for the region, including climate change or extreme changes in mountain agriculture and their influence on the development of *Housing and Infrastructure*, the model includes optional adaptations:

(A) To simulate long-term effects of vegetation changes for a climate scenario, the user can reduce the elevation values. A decrease of elevation values by 100m corresponds very roughly to an increase in temperature by 0.6 °C.

(B) To simulate extreme scenarios on mountain agriculture with decrease in *Agricultural Land* exceeding the statistically derived rates of change, the remaining *Agricultural Land* is reduced through a deterministic function. The function takes first the site with the lowest probability to remain agricultural land and turns it into unproductive grassland, then it takes the site with the second lowest probability, and so on. The function finishes when the number of hectares to remain agricultural land corresponds to the demand on land for agricultural land in the scenario.

(C) To demonstrate the interaction between changes in *Agricultural Land* and *Housing and Infrastructure*, the model allows *Agricultural Land* to be transformed into *Housing and Infrastructure* independently from demand on land for *Housing and Infrastructure*. Without activating this option, changes to *Housing and Infrastructure* are strictly controlled by the demand $D_{H\&I}$ (as in Figure 19) and the described modelling procedure that starts by testing the pixel with the highest probability to change to *Housing and Infrastructure*. The option, however, assumes that the expansion of *Housing and Infrastructure* could also occur as a result of decreasing competition for land.

In accordance with the ASCH, the spatial resolution of the model is 100m*100m (Section 3.2). The temporal resolution of the model is 12 years. This is in line with the time interval between the Area Statistics surveys (Section 3.2) and the temporal dimension inherent in the derived transition probabilities. One modelling iteration, therefore, represents a 12-year simulation period.

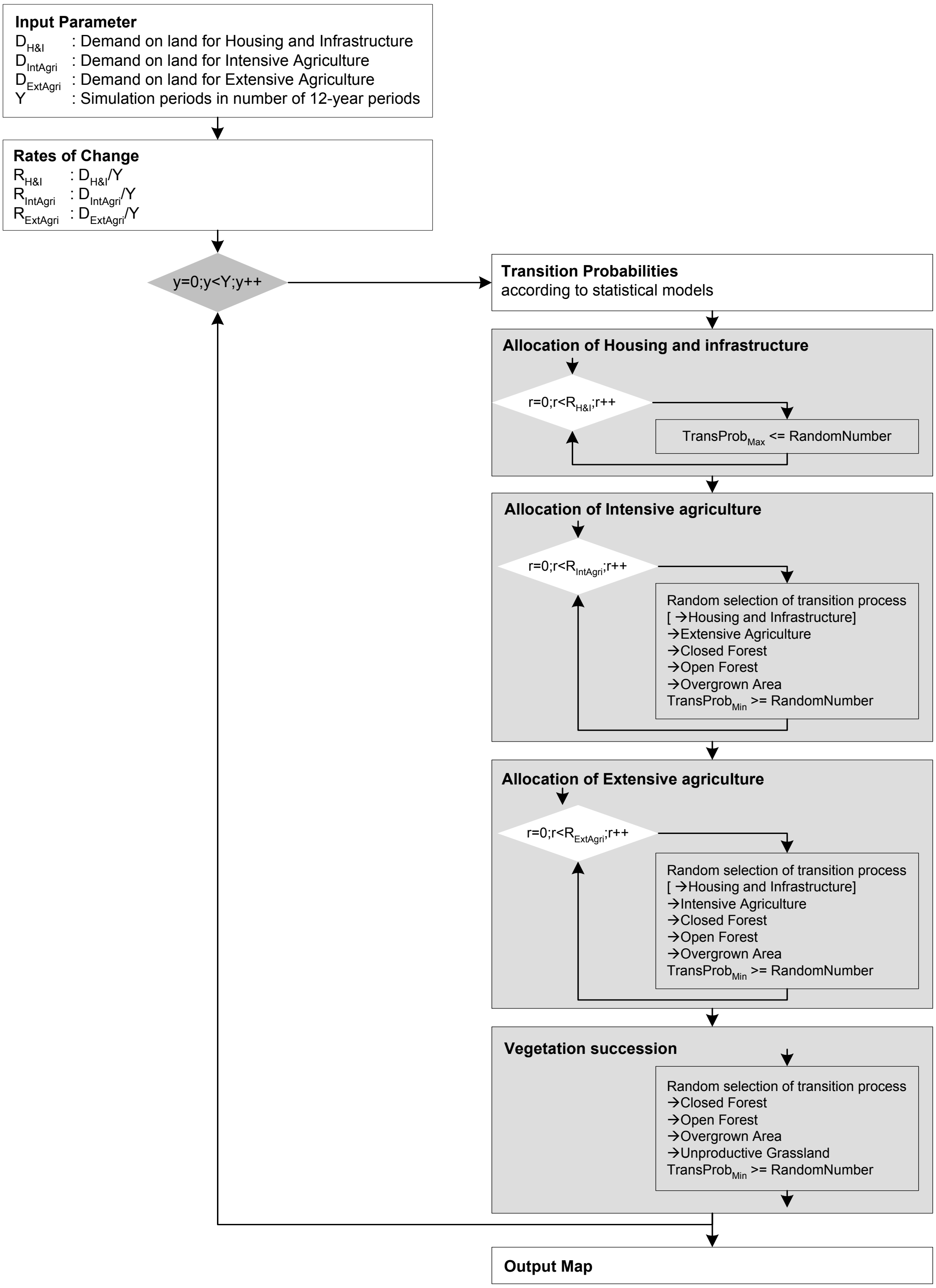


Figure 19: Structure of the land use change allocation model. The option to allow changes to Housing and Infrastructure due to agricultural abandonment is added in brackets (explained in 5.1.4).

5.1.5 VALIDATION PROCEDURE

The model was validated with respect to its ability to simulate spatial patterns of land use and land cover changes for the validation period from 1954 to 1985. Similar to the validation procedure described in Section 4.1.5, the re-constructed land use and land cover dataset for 1954 (AS54) was used as the initial state for simulation runs. Input parameters for demand on land were taken from observed transitions that occurred between 1954 and 1985 according to AS54 and ASCH79/85. The simulation outcomes were compared with the observed ASCH79/85 using contingency tables. Once again, Kappa statistics according to Cohen (1960) were used to summarise the contingency tables and to reduce the effect of hits by chance.

As mentioned in Section 4.1.5, contingency tables and Kappa statistics are based on cell-by-cell comparison, they only reflect exact matches and cannot measure the degree of spatial disagreement. In Chapter 4, this has been accounted for by applying a moving window approach in addition to the cell-by-cell assessment, but the results did not provide many more insights.

In this chapter, an addition techniques is applied, that measures how far apart observed and simulated changes are located. For that, the observed data ASCH79/85 and the simulated data Sim85 are compared based on Equation 4 (Pontius, 2002). The technique compares the matches between two datasets with decreasing resolution. In the iterative process, cells are increasingly merged and the land use information of the initial cells is stored as proportions of the merged pixel. The proportion of agreement between the two datasets is derived from the minimal agreement between corresponding merged cells of both datasets. The degree of agreement for each land use class is finally plotted against the increasing number of initial cells that constitute the coarser low-resolution cells.

$$\text{Agreement at resolution g} = \frac{\sum_{n=1}^{N_g}\left[W_n \sum_{j=1}^{J} \min\left(R_{n,j}, S_{n,j}\right)\right]}{\sum_{n=1}^{Ng} W_n} \tag{4}$$

Where:

$R_{n,j}$ = Proportion of category j in grid cell n of map R
$S_{n,j}$ = Proportion of category j in grid cell n of map S
J = Number of categories
N_g = Number of coarse cells that constitute the dataset at a resolution g
W_n = Number of fine resolution cells that constitute a coarse cell.

5.2 Results

5.2.1 IDENTIFICATION OF THE PRINCIPAL PROCESS

The absolute values and percentages for each transition process indicate the importance of increase in forested and settled area for the Swiss Mountain Area (Figure 20A). *Forest* expanded by 27'135 ha and *Housing and Infrastructure* by 15'839 ha between ASCH79/85 and ASCH92/97. The expansion of *Forest* is thus the predominant process in terms of absolute spatial extent. Relative increase of *Forest*, however, is at 2.9% considerably lower than the increase in *Housing and Infrastructure* at 16.0%. Hence, the development of *Housing and Infrastructure* is identified as the most rapid transition process (Figure 20A). Both land use types expanded mainly on *Agricultural Land*. In total the *Agricultural Land* was reduced by 35'753 ha. It contributed by 20'114 ha to forest expansion and by 13'136 ha to the spreading of settled area, i.e. 74.1% of the newly developed *Forest* and 82.9% of the newly developed *Housing and Infrastructure* was *Agricultural Land* in ASCH79/85.

Differentiation between socio-economic regions

To distinguish possible links between the socio-economic situation within the area and land use transition processes, Figure 20B focuses on the socio-economic types of municipalities as classified in SFSO (2000). It displays the rate of transition in contingency tables for each of these types of municipalities in percentages. The overall result shows that the principal transition processes, as identified for the Swiss Mountain Area, occur similarly in all types of municipalities. Nevertheless, differences in process intensity are also observed between types of municipalities. The spreading of settled areas is most rapid in periurban municipalities (+19.6%) and commuter municipalities (+19%), while the lowest rate is found for the high-income type of municipalities (+11.8%). Forest expansion is found with values of +3.9 % and +3.4% to be highest in tourist- and agricultural-type municipalities.

(A) Transformations between ASCH79/85 and ASCH92/97 for the Swiss mountain area

Swiss Mountain Area — Absolute Values (ha)		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	921'544	4'795	1'385	2'415
	AL	20'114	931'067	2'503	13'136
	UL	6'276	1'511	786'930	288
	H&I	745	1'687	142	82'789

Swiss Mountain Area		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	97.1%	0.5%	0.2%	2.4%
	AL	2.1%	99.1%	0.3%	13.3%
	UL	0.7%	0.2%	99.5%	0.3%
	H&I	0.1%	0.2%	0.0%	83.9%

(B) Average transformations according to socio-economic types of municipalities in 1990 (SFSO, 2000)

Centres		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	98.5%	0.6%	0.9%	1.4%
	AL	1.1%	98.9%	1.9%	12.8%
	UL	0.2%	0.1%	96.7%	0.1%
	H&I	0.2%	0.4%	0.5%	85.7%

Industrial & service		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	97.5%	0.6%	0.2%	2.4%
	AL	1.8%	99.0%	0.3%	12.6%
	UL	0.6%	0.1%	99.5%	0.3%
	H&I	0.1%	0.2%	0.0%	84.6%

Suburban		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	97.2%	0.5%	0.2%	1.8%
	AL	2.0%	98.9%	0.2%	12.1%
	UL	0.5%	0.1%	99.6%	0.0%
	H&I	0.3%	0.6%	0.0%	86.1%

Rural commuting		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	97.6%	0.6%	0.3%	3.3%
	AL	1.9%	99.1%	0.6%	15.5%
	UL	0.5%	0.1%	99.1%	0.3%
	H&I	0.1%	0.2%	0.0%	81.0%

High-income		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	99.0%	1.5%	0.5%	2.7%
	AL	0.9%	98.5%	1.0%	9.0%
	UL	0.1%	0.0%	98.5%	0.0%
	H&I	0.0%	0.0%	0.0%	88.2%

Mixed agricultural		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	97.7%	0.5%	0.2%	2.0%
	AL	1.8%	99.2%	0.4%	14.7%
	UL	0.5%	0.1%	99.3%	0.2%
	H&I	0.1%	0.1%	0.0%	83.1%

Periurban		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	97.4%	0.9%	0.3%	3.5%
	AL	2.0%	98.6%	0.7%	15.7%
	UL	0.5%	0.1%	99.0%	0.3%
	H&I	0.1%	0.4%	0.0%	80.4%

Agricultural		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	96.6%	0.5%	0.2%	3.4%
	AL	2.5%	99.3%	0.3%	12.3%
	UL	0.8%	0.1%	99.4%	0.6%
	H&I	0.0%	0.1%	0.0%	83.7%

Tourist		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	96.1%	0.4%	0.1%	2.6%
	AL	2.9%	99.2%	0.2%	11.8%
	UL	1.0%	0.3%	99.6%	0.4%
	H&I	0.1%	0.1%	0.0%	85.2%

(C) Davos		ASCH92/97 F	AL	UL	H&I
ASCH79/85	F	96.6%	0.0%	0.2%	0.7%
	AL	2.9%	99.8%	0.1%	10.1%
	UL	0.4%	0.1%	99.7%	0.4%
	H&I	0.0%	0.1%	0.1%	88.9%

F: Forest AL: Agricultural Land UL: Unproductive Land H&I: Housing and Infrastructure Not included: Water Surfaces

Figure 20: Contingency tables of absolute and relative changes at different spatial extend and according to types of socio-economic regions (SFSO, 2000). Relative changes are calculated as percentages of the recent land use type in ASCH92/97 that used to be of a different land use type in ASCH79/85.

How different are intensities of transition processes in different socio-economic regions? Plotting means and standard deviations of process intensity for all socio-economic regions shows that differences in rates of change are within the bounds of standard deviations (Figure 21).

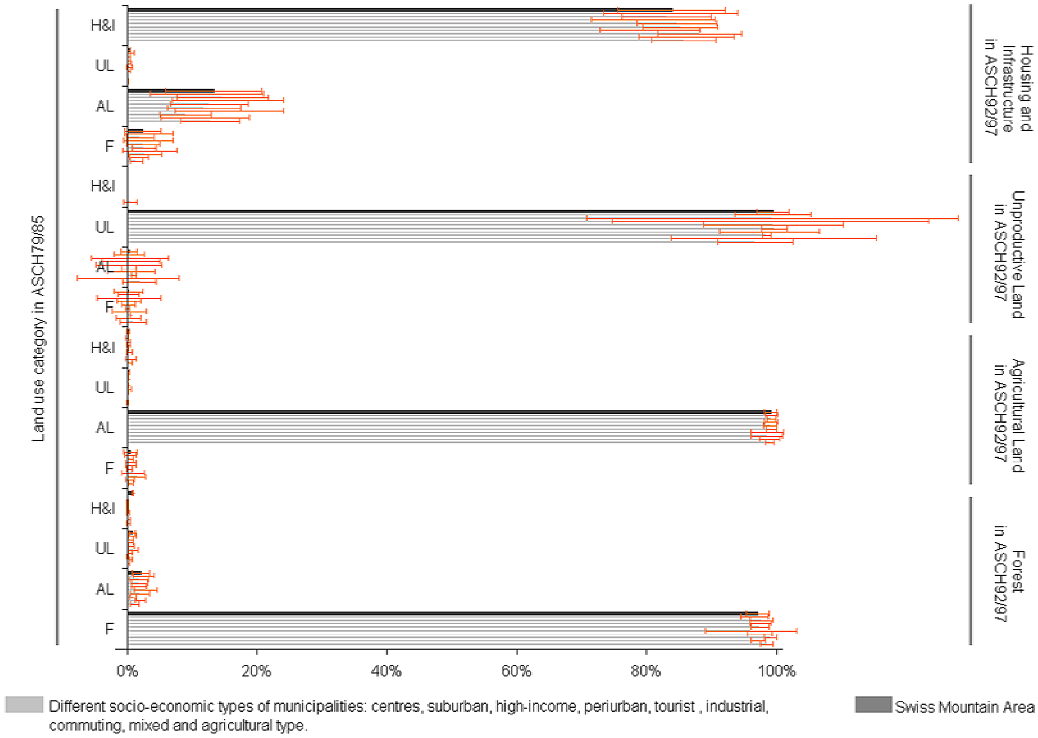


Figure 21: Rates of change and their standard deviations between municipalities for each socio-economic type of municipalities and cumulative for the Swiss Mountain Area.

However, ANOVA reveals statistically significant differences for individual transition processes between socio-economic types of municipalities. For none of the socio-economic regions, statistically significant differences in transition rates were identified for all processes (Table 12). But single processes out of the 16 processes were tested significantly different. For instance the transition intensity from Agricultural Land to Forest differs for tourist municipalities to all other socio-economic types with P values below 0.001 (Table 12). Although the overall transition process intensities are similar, these results suggests further research in this area.

Table 12:Results of the ANOVA analyses for all transition processes.

Forest > Forest

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	*	-					
T	***	***	***	***				
I&S	-	*	-	-	***			
RC	-	-	-	-	***	-		
MA	-	**	-	-	***	-	-	
A	*	***	-	*	***	***	***	***

Forest > Agricultural Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	**	***	-					
T	-	-	-	***				
I&S	-	-	-	***	-			
RC	-	-	-	***	-	-		
MA	-	**	-	***	***	-	-	
A	-	-	-	***	-	-	-	-

Forest > Unproductive Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	-	-	-	-				
I&S	-	-	-	-	-			
RC	-	-	-	-	-	-		
MA	-	-	-	-	*	-	-	
A	-	-	-	-	-	-	-	-

Forest > Housing and Infrastructure

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	*	***	-					
T	-	-	-	***				
I&S	-	-	-	***	-			
RC	-	-	-	-	-	-		
MA	-	-	-	***	-	-	*	
A	-	-	-	-	-	-	-	*

Unproductive Land > Forest

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	***	***	***	***				
I&S	-	-	-	-	***			
RC	-	-	-	-	***	-		
MA	-	-	-	-	***	-	-	
A	-	*	-	*	***	-	-	***

Unproductive Land > Agricultural Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	***	***	***	***				
I&S	-	-	-	-	***			
RC	-	-	-	-	***	-		
MA	-	-	-	-	***	-	-	
A	-	-	-	-	***	-	-	-

Unproductive Land > Unproductive Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	-	-	-	-				
I&S	-	-	-	-	-			
RC	-	-	-	-	*	-		
MA	-	-	-	-	***	***	-	
A	-	-	-	-	-	-	-	***

Unproductive Land > Housing and Infrastructure

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	-	*	-	***				
I&S	-	-	-	-	**			
RC	-	-	-	-	***	-		
MA	-	-	-	-	***	-	-	
A	-	-	-	-	-	-	-	-

Agricultural Land > Forest

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	*	-					
T	***	***	***	***				
I&S	-	-	-	-	***			
RC	-	-	-	-	***	-		
MA	-	*	-	-	***	-	-	
A	*	***	-	-	***	***	***	***

Agricultural Land > Agricultural Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	*	***	-					
T	-	-	-	***				
I&S	-	-	-	***	-			
RC	-	-	-	***	-	-		
MA	-	-	-	***	-	***	-	
A	-	-	-	***	-	-	-	-

Agricultural Land > Unproductive Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	-	-	-	-				
I&S	-	-	-	-	-			
RC	-	-	-	-	-	-		
MA	-	-	-	-	-	-	-	
A	-	-	-	-	-	-	-	-

Agricultural Land > Housing and Infrastructure

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	*	-					
T	-	-	-	*				
I&S	-	-	-	**	-			
RC	-	-	-	-	**	-		
MA	-	*	-	-	***	***	-	
A	-	-	-	**	-	-	**	***

Housing and Infrastructure > Forest

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	-	-	-					
T	***	-	-	*				
I&S	-	-	-	-	-			
RC	***	-	-	**	-	-		
MA	***	-	-	***	-	***	-	
A	***	-	-	***	-	***	-	***

Housing and Infrastructure > Agricultural Land

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	**	***						
P	-	-	-					
T	***	***	-	***				
I&S	-	-	-	-	**			
RC	***	***	-	***	-	***		
MA	***	***	-	***	-	***	-	
A	***	***	-	***	-	***	-	-

Housing and Infrastructure > Unproductive Land

	C	S	HI	P	T	I&S	RC	MA
S	***							
HI	***	-						
P	***	-	-					
T	***	-	-	-				
I&S	***	-	-	-	-			
RC	***	-	-	-	-	-		
MA	***	-	-	-	-	-	-	
A	***	-	-	-	-	-	-	-

Housing and Infrastructure > Housing and Infrastructure

	C	S	HI	P	T	I&S	RC	MA
S	-							
HI	-	-						
P	***	***	***					
T	-	-	-	***				
I&S	-	-	-	***	-			
RC	-	**	-	**	-	-		
MA	-	**	-	***	-	-	-	
A	-	-	-	***	-	-	-	-

Socio-economic types of municipalities: C = Centres, S = Suburban, HI = High-Income, P = Periurban, T= Tourist, I&S = Industrial and Service, RC = Rural Commuting, MA= Mixed Agricultural
Degree of significance: P>0.05: - ; P<0.05: * ; P<0.01: ** ; P<0.001: ***

Vegetation succession

The contingency tables in Figure 22 depict changes between different types of forested areas and agricultural land in more detail. For the Swiss Mountain Area, the tables show only a marginal proportion of former *Agricultural Land* transformed directly into *Closed Forest*, and suggest several steps of vegetation succession between *Agricultural Land* and a *Close Forest* stand. Closely forested areas in ASCH92/97 were classified as *Open Forest* or *Overgrown Area* in ASCH79/85 by 2.1% and 1.5% respectively. Areas transformed to *Open Forest* and *Overgrown Area* originate mainly from agricultural land, and in the case of *Overgrown Areas* also from *Unproductive Grassland* (2.2%). For areas of *Open Forest* in ASCH92/97 about 1.8% were classified *Intensive Agriculture* in ASCH79/85 and about 3.7% were *Extensive Agriculture*. For *Overgrown Areas* in ASCH92/97 about 0.8% used to be *Intensive Agriculture* in ASCH79/85, and about 5.7% was *Extensive Agriculture*. All these transition processes suggest land abandonment triggering a natural process of subsequent vegetation succession below the tree line.

Changes in intensity of agricultural use

Observations are less clear for changes of intensity of agricultural use above the tree line (Figure 22). With almost 10’500 ha changing from *Intensive* to *Extensive Agriculture*, an pronounced extensification of agricultural land use can be observed for the Swiss Mountain Area. But in the same period over 5’000 ha changed in the opposite direction from *Extensive* to *Intensive Agriculture*. Despite the generally strong abandonment of agricultural land, only about 1’600 ha changed from *Extensive Agriculture* in ASCH79/85 to *Unproductive Grassland* in ASCH92/97. This effect, however, is a methodological artefact within the dataset. As the Area Statistics are based on the interpretation of aerial photographs, differentiating between abandoned Alpine grassland and extensively used agricultural land in the Alpine environment is almost impossible. For the first survey, the alpine pastures were therefore mapped from the “Alpkataster” registered between the 1950 and the early 1970s. Transitions between the two land use and land-cover types were only included into the survey if they were obvious or known to the surveyor (e.g. through the establishment of nature protection areas) (Anton Beyeler, pers. comm., 2005).

Main processes and their implementation

As the transition matrixes (Figure 20) indicate clearly, expansion of *Forest* and *Housing and Infrastructure* are the two principle processes within the Swiss Mountain Area. Both processes consume mainly *Agricultural Land* and occur in all socio-economic regions with great intensity (Figure 20). The transition rates derived for Davos are comparable except for the proportion of *Forest* that changes to *Housing and Infrastructure* (Figure 20C). This underpins the findings of Chapter 4 which suggest that land use transition processes are similar between the Swiss Mountain Area and the region of Davos and data from the supra-regional level can be used for simulation modelling on the regional level.

Swiss Mountain Area

ASCH79/85 \ ASCH92/97 — Absolute Values (ha)	CL	OF	OA	IA	EA	UG	BL	H&I	W
CL	646'955	1'357	961	311	463	373	236	1'075	207
OF	8'648	92'503	987	1'124	1'576	178	47	510	11
OA	7'715	2'823	159'647	645	677	331	220	830	199
IA	934	1'900	1'391	400'353	10'476	265	76	11'400	47
EA	1'899	3'828	10'165	5'038	515'223	1'645	517	1'736	156
UG	603	446	3'849	111	305	178'626	241	120	59
BL	186	194	999	83	1'012	2'074	606'406	168	107
H&I	395	62	288	1'313	374	120	22	82'792	43
W	98	10	154	18	38	143	105	90	30'861

Swiss Mountain Area

ASCH79/85 \ ASCH92/97	CL	OF	OA	IA	EA	UG	BL	H&I	W
CL	96.9%	1.3%	0.5%	0.1%	0.1%	0.2%	0.0%	1.1%	0.7%
OF	1.3%	89.7%	0.6%	0.3%	0.3%	0.1%	0.0%	0.5%	0.0%
OA	1.2%	2.7%	89.5%	0.2%	0.1%	0.2%	0.0%	0.8%	0.6%
IA	0.1%	1.8%	0.8%	97.9%	2.0%	0.1%	0.0%	11.5%	0.1%
EA	0.3%	3.7%	5.7%	1.2%	97.2%	0.9%	0.1%	1.8%	0.5%
UG	0.1%	0.4%	2.2%	0.0%	0.1%	97.2%	0.0%	0.1%	0.2%
BL	0.0%	0.2%	0.6%	0.0%	0.2%	1.1%	99.8%	0.2%	0.3%
H&I	0.1%	0.1%	0.2%	0.3%	0.1%	0.1%	0.0%	83.9%	0.1%
W	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.1%	97.4%

Davos

ASCH79/85 \ ASCH92/97 — Absolute Values (ha)	CL	OF	OA	IA	EA	UG	BL	H&I	W
CL	3'407	16	2	0	0	3	0	2	0
OF	74	699	1	1	0	0	0	1	0
OA	55	15	1'891	0	1	5	6	1	0
IA	4	9	6	1'803	4	0	2	44	0
EA	4	29	136	7	7'616	0	9	13	0
UG	0	1	18	0	0	2'391	3	2	1
BL	0	1	6	0	6	6	6'409	0	0
H&I	0	1		6	2	0	0	504	0
W	1	0	0	0	0	1	0	0	222

Davos

ASCH79/85 \ ASCH92/97	CL	OF	OA	IA	EA	UG	BL	H&I	W
CL	96.1%	2.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.4%	0.0%
OF	2.1%	90.7%	0.0%	0.1%	0.0%	0.0%	0.0%	0.2%	0.0%
OA	1.6%	1.9%	91.8%	0.0%	0.0%	0.2%	0.1%	0.2%	0.0%
IA	0.1%	1.2%	0.3%	99.2%	0.1%	0.0%	0.0%	7.8%	0.0%
EA	0.1%	3.8%	6.6%	0.4%	99.8%	0.0%	0.1%	2.3%	0.0%
UG	0.0%	0.1%	0.9%	0.0%	0.0%	99.4%	0.0%	0.4%	0.4%
BL	0.0%	0.1%	0.3%	0.0%	0.1%	0.2%	99.7%	0.0%	0.0%
H&I	0.0%	0.1%	0.0%	0.3%	0.0%	0.0%	0.0%	88.9%	0.0%
W	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.6%

Figure 22: Transition processes between ASCH79/85 and ASCH92/97 for the Swiss Mountain Area and Davos with a differentiation between nine land use and land cover types.

For the implementation of the model the interaction between land use transition processes also needs to be considered. While the development of *Housing and Infrastructure* is considered as an intensification of land use based on necessary investment, the expansion of *Forest* stands for extensification and abandonment. This implies that for the first process (*Agriculture* to *Housing and Infrastructure*), an increase of demand for the target land use type (i.e. *Housing and Infrastructure*) triggers the processes, whereas a lack of demand for the original land use type (i.e. *Agricultural Land*) triggers the second process (*Agricultural Land* to *Forest*). For modelling purposes, this suggests to implement the two processes slightly differently. While the probability to change to *Housing and Infrastructure* forms the basis of modelling the first process, the probability to remain *Agricultural Land* is the basis for the second process. As a function of time, vegetation succession and forest expansion affect only land which is neither under cultivation nor occupied by *Housing and Infrastructure*.

5.2.2 MODEL VALIDATION

The initial dataset for AS54, the observed data ASCH79/85 and the simulation results for the validation period 1954-1985 are displayed in Figure 23. From a visual impression, the overall simulation result for 1985 reaches strong agreement with the observed data from 1985. In Chapter 4, the principle disagreement for *Housing and Infrastructure* is already described as expansion of small core settlements being overestimated by the simulation and single large projects not being represented, e.g. the expansion of the golf course in 1967. For the remaining land use classes, the simulated patterns appear also plausible, particularly because rates of change are small compared to changes in *Housing and Infrastructure*. According to a cell-by-cell comparison the agreement between the two maps is 94.7% and the Kappa value, taking into account hits by chance, is 91.7% (Table 13A).

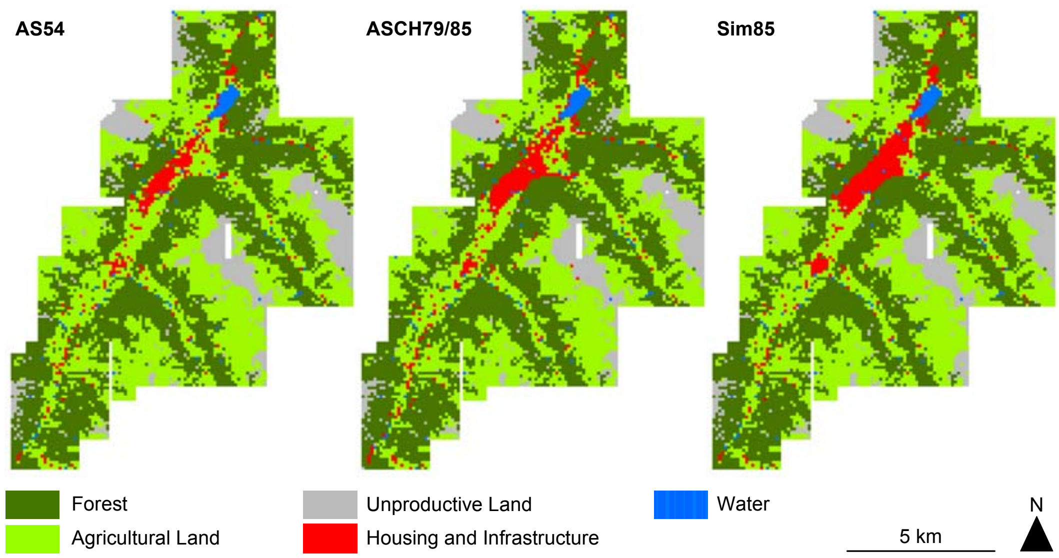


Figure 23: The three datasets to be compared for validation: the reconstructed AS54, the official Swiss Area Statistics ASCH79/85 and the simulated land use/ land cover pattern Sim85 (Land Use Statistics 1979/85 (revised data) reproduced by permission of BFS GEOSTAT)

Table 13: Contingency tables to compare the AS54, ASCH79/85 and Sim85 with each other based on cell-by-cell comparison and the corresponding Kappa Values.

A K_A = 0.917		Sim85 F	Sim85 AL	Sim85 UL	Sim85 H&I	Sim85 W
ASCH79/85	F	4349	165	32	9	0
	AL	70	3923	86	75	2
	UL	12	12	1072	0	0
	H&I	26	55	1	386	1
	W	0	0	2	0	123

B K_B = 0.935		ASCH79/85 F	ASCH79/85 AL	ASCH79/85 UL	ASCH79/85 H&I	ASCH79/85 W
AS54	F	4348	26	8	23	0
	AL	175	4107	18	122	0
	UL	31	15	1070	1	2
	H&I	1	6	0	322	0
	W	0	2	0	1	123

C K_C =0.958		Sim85 F	Sim85 AL	Sim85 UL	Sim85 H&I	Sim85 W
AS54	F	4394	0	0	11	0
	AL	63	4155	74	130	0
	UL	0	0	1072	0	0
	H&I	0	0	0	329	0
	W	0	0	0	0	126

F: Forest; AL: Agricultural Land; UL: Unproductive Land; H&I: Housing and Infrastructure; W: Water Surfaces.

Agreement was also measured with increasing "spatial fuzziness" (Hagen, 2003). Here, the datasets were increasingly re-aggregated to lower resolutions according to the presented technique (Pontius, 2002), and the proportions of agreement per aggregated cell between the two datasets were taken into account. Agreement increases quickly with decreasing resolutions for *Forest*, *Agricultural Land* and for *Housing and Infrastructure* (Figure 24), and thus reflects that a great proportion of disagreement is due to near-misses between the two datasets. Agreements for *Agricultural Land* and for *Housing and Infrastructure* augment further until the maximum cell size is reached and thus indicates also far-misses for these two land use classes. *Forest* and *Unproductive Land*, by contrast, reach maximum agreement at a window size of about 40 by 40 initial cells, but reach only a lower level of overall agreement (Figure 24).

Disagreement at the lowest resolution reveals differences in the number of cells designated to a given land use class between the two datasets (Figure 24). Thus, the number of cells for *Agricultural Land* and *Housing and Infrastructure* correspond to over 99.9% between the two datasets, while *Unproductive Land* and *Forest* only reach agreement between 99.4% and 99.5%. As the total areas of *Housing and Infrastructure* and *Agricultural Land* are the direct results of the input parameters values derived as the difference between AS54 and the observed AS79/85, the only errors due to rounding cause the remaining disagreement for these two land use classes. In contrast, the expansion of *Forest* and *Unproductive Land* are not entered as input parameters, and therefore their final numbers are the product of changes in the two above land use classes in the simulation.

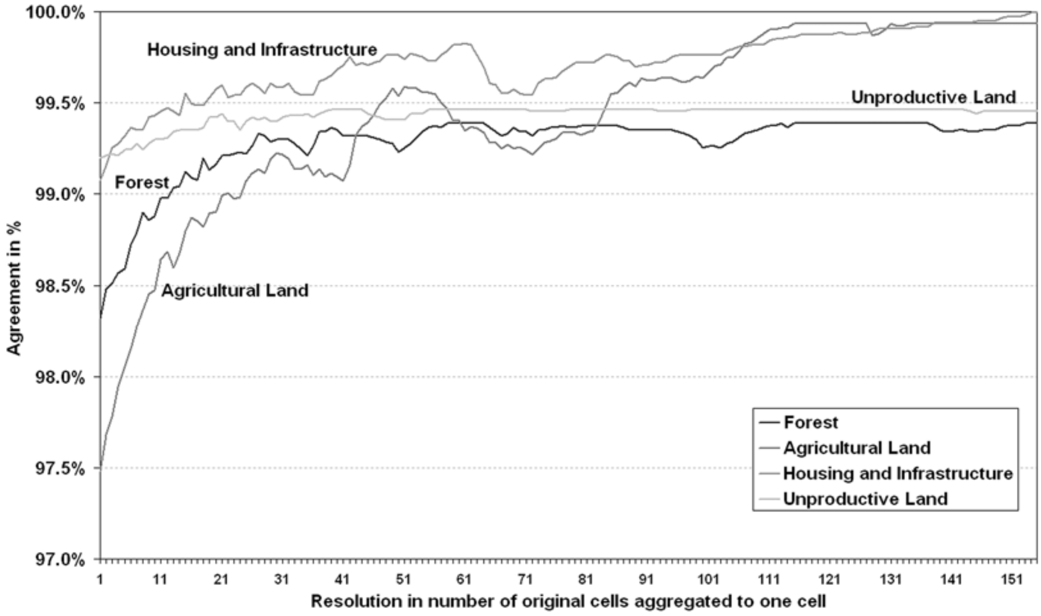


Figure 24: Spatial agreement between observed ASCH79/85 and simulated Sim85 with decreasing resolution.

Persistence

These validation results, however, overestimate the performance of the simulation model, as a great proportion of agreement is due to the low number of actual transitions between the initial dataset AS54 and both the observed ASCH79/85 and the simulated Sim85.

Contingency tables for cell-by-cell comparison between all three datasets indicate the crucial impact that the initial dataset AS54 has upon the simulation result Sim85 (Table 13). In line with Pontius (2004), agreement between AS54 and ASCH79/85 (K_B = 0.935) is greater than between Sim85 and ASCH79/85 (K_A = 0.917). Highest agreement, however, is reached between AS54 and the simulated data Sim85 (K_C = 0.958). This observation indicates the high degree of persistence between the initial and the simulated dataset and demonstrates that the simulation results are strongly controlled by the initial dataset.

Data quality

In addition to net changes between land use classes, the contingency tables (Table 13) also reveal a high degree of swapping between AS54 and ASCH79/85 between the land use classes *Forest*, *Agricultural Land* and *Unproductive Land.* These could not be re-produced by simulation due to the limited number of processes incorporated into the model (reflected in Table 13C).

A great proportion of the swapping between *Forest*, *Agricultural Land* and *Unproductive Land* are the result of the data inaccuracies in the reference dataset AS54 re-constructed from historical air photographs. The photos were rectified, but the degree of overlap between neighbouring photos was not sufficient to get the required spatial accuracy in the high mountain environment. Due to the point sampling technique used for Area Statistics surveying, this spatial inaccuracy has a crucial impact on the quality of the re-constructed data. Figure 25 shows an extreme example where small spatial disagreement through insufficient accuracy in ortho-rectification caused considerable disagreement in the survey data: Although the forested area has not changed between the historical air photos and air photos of 2000, two out of three sampling points have moved from forested to non-forested area.

This effect results in a considerable amount of change between the datasets AS54 and ASCH79/85 which is due to this methodological artefact and not a real transition. This also explains the shift from *Forest* to *Agricultural Land* of 206 ha between AS54 and ASCH79/85 (Table 13) which conflicts strongly with the observation of Günter (1985) stating a decrease in agriculturally used land between 1950 and 1982 for the region of Davos.

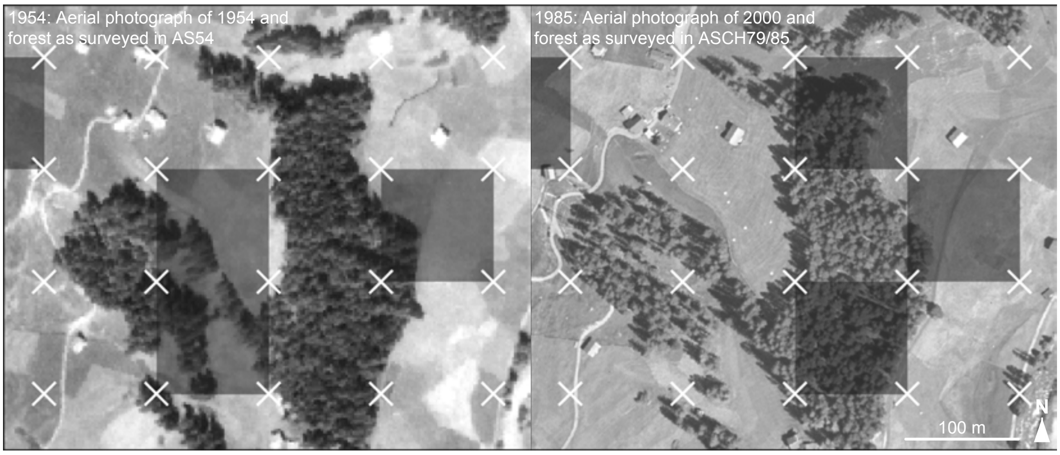


Figure 25: Comparison between the surveyed forest of AS54 and ASCH79/85 and the corresponding aerial photographs shows how small inaccuracies in ortho-rectification cause great differences between the datasets. **X** *indicates the location of the sample point, which represents the lower left corner of the corresponding hectare in the Area Statistics dataset. (Land Use Statistics 1979/85 (revised data) reproduced with permission of BFS GEOSTA)*

Model validation on a second simulation period between ASCH79/85 and ASCH92/97

Because of these data quality problems, the model was also tested on the basis of the two official, and spatially highly consistent land use surveys ASCH79/85 and ASCH92/97. To derive the statistical models applied in the simulation model, Rutherford (2004) used random sample points from the entire Swiss Mountain Area. Thus, simulations for any sub-region within the Swiss Mountain Area are not strictly independent from the data used for model development. The test runs can still give an indication of the model's performance as changes between the ASCH79/85 at the initial time t_1 and the observed situation at time t_2 ASCH92/97 are based on data of the same spatial accuracy.

Again, the first impression (Figure 26) suggests high agreement between ASCH92/97 and the simulation results Sim97. Similarly to the results for the validation period between 1954 and 1985, the model overestimates the expansion of core settlements and doesn't reproduce more disperse development of housing and infrastructure.

The contingency tables D, E and F (Table 14) compare the three datasets with each other. Table 14E demonstrates that the degree of swapping between the two observed datasets ASCH79/85 and ASCH92/97 is considerably lower than for the independent validation period (Table 13). While Table 13B indicates 175 changes from *Agricultural Land* to *Forest* and 26 from *Forest* to *Agricultural Land* for the independent validation period , Table 14E shows 190 changes from *Agricultural Land* to *Forest* and 2 from *Forest* to *Agricultural Land*.

Kappa values K_D, K_E and K_F, in Table 14 show a similar pattern of agreement between the three datasets but on a higher level of agreement. This confirms the strong dependency of the simulation results from the initial dataset due to high persistence.

These findings are not unusual for land use and land-cover models (Pontius, 2005). After having tested several, partly well established land use allocation model, Pontius (2005) states that the initial situation agrees better with the observation at time t_2 than the simulated data in many cases. The main reason for the high agreement between initial dataset (referred to as Null-model in Pontius, 2004) and the observed dataset in t_2 is the high degree of persistence within the validation period. However, when simulating scenarios, the degree of persistence can be much lower, particularly for extreme scenarios as described in Chapter 6.

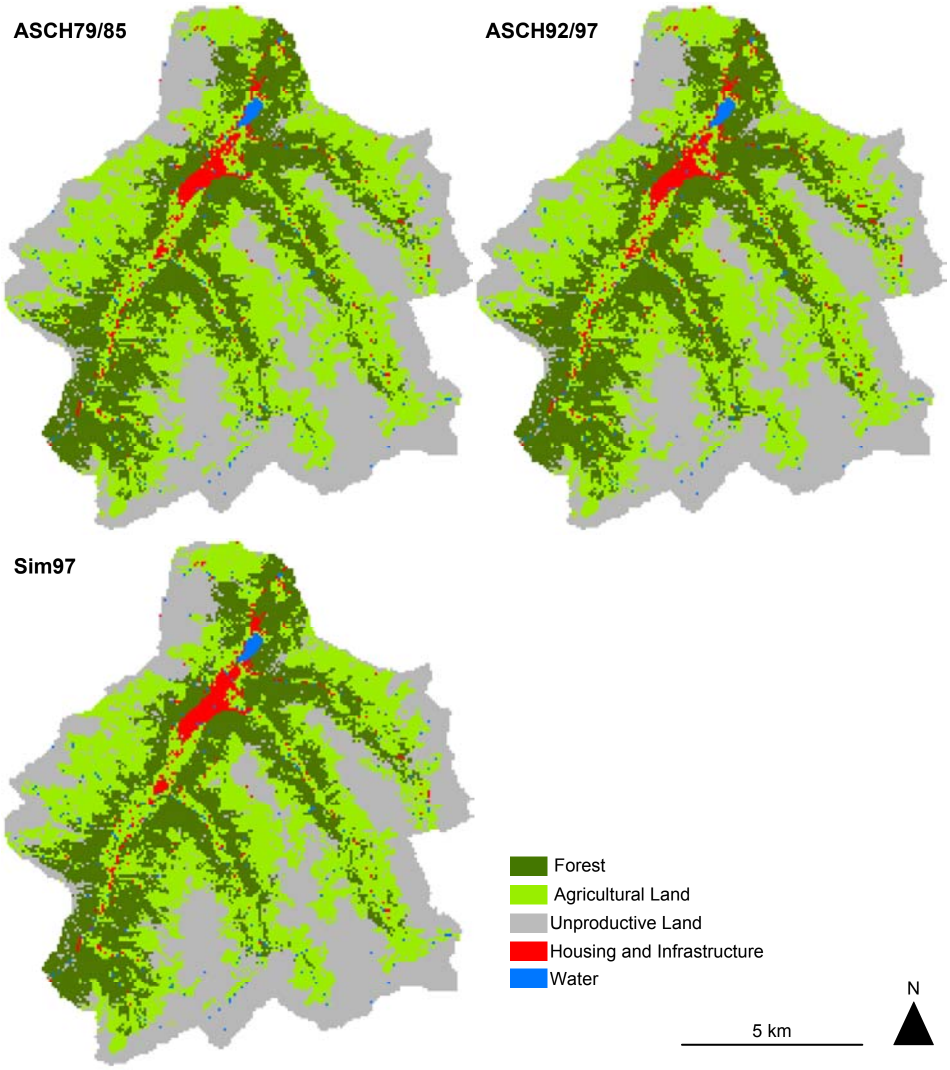


Figure 26: The initial dataset ASCH79/85 for the test run between 1985 and 1997, the observed situation ASCH92/97 at time t_2, and the simulation results Sim97 for time t_2 (Land Use Statistics 1992/97 and Land Use Statistics 1979/85 (revised data) reproduced with permission of BFS GEOSTAT).

Table 14: Contingency tables to compare the ASCH79/85, ASCH92/97 and Sim97 with each other on based on cell-by-cell comparison and the corresponding Kappa Values.

D (K_D = 0.968)		Sim97				
		F	**AL**	**UL**	**H&I**	**W**
ASCH92/97	**F**	6159	186	26	7	1
	AL	35	9196	162	50	0
	UL	15	10	8807	0	1
	H&I	4	51	2	509	0
	W	0	0	1	0	221

E (K_E = 0.981)		ASCH92/97				
		F	**AL**	**UL**	**H&I**	**W**
ASCH79/85	**F**	6161	2	14	4	0
	AL	190	9427	11	57	0
	UL	26	6	8807	2	1
	H&I	1	8	0	503	0
	W	1	0	1	0	221

F (K_F = 0.986)		Sim97				
		F	**AL**	**UL**	**H&I**	**W**
ASCH79/85	**F**	6175	0	0	6	0
	AL	38	9443	156	48	0
	UL	0	0	8842	0	0
	H&I	0	0	0	512	0
	W	0	0	0	0	223

F: Forest; AL: Agricultural Land ; UL: Unproductive Land ; H&I: Housing and Infrastructure; W: Water Surfaces.

5.2.3 SENSITIVITY ANALYSIS

Simple scenarios are simulated to demonstrate and evaluate the model's behaviour. The scenarios represent parameter variations which combine changes of demand for given land use classes with varying simulation options (introduced in section 5.1.4). The combinations of input parameter values address the following questions:

- Sensitivity Analysis I: How does the model handle extreme values for demand on land?
- Sensitivity Analysis II: To what extent do simulation results differ if the development of *Housing and Infrastructure* is allowed as a consequence of land abandonment?
- Sensitivity Analysis III: How is time incorporated into the simulation model? What is the role of the input parameter *Y* which controls the number of 12-year simulation periods?
- Sensitivity Analysis IV: How many 12-year simulation periods are needed to reduce the extent of *Agricultural Land* to a minimum?
- Sensitivity Analysis V: How sensitive is the model to a reduction of elevation? Is it possible to use it for the simulation of simple climate scenarios?

Table 15: Input parameters for simulations according to scenarios. Each of the above questions is referred to in a separate parameter variation (I-V) including several combinations of input parameters (referred to in upper-case letters).

Parameter Variation		Changes in demand on land for IA	Changes in demand on land for EA	Changes in demand on land for H&I	Number of simulation periods	Allowing H&I as a result of decrease in agriculture	Simple climate change scenario	Including disturbance
I	A	0	0	+550 (+100%)	4			X
	B	-998 (-100%)	0	0	4			X
	C	0	-8448 (-100%)	0	4			X
	D	0	0	+2000 (+364%)	4			X
	E	0	0	0	4			X
II	A	-998	0	0	4			X
	B	-998	0	0	4	X		X
	C	-998	-8445	0	4	X		X
	D	-998	0	+550	4	X		X
III	A	-998	-8445	0	1	X		X
	B	-998	-8445	0	10	X		X
	C	-998	-8445	0	100	X		X
	D	0	0	+550	1	X		X
	E	0	0	+550	10	X		X
IV	A	-998	-8445	0	?	X		X
V	A	-998	-8445		4	X	0 m	X
	B	-998	-8445		4	X	-150 m	X
	C	-998	-8445		4	X	-300 m	X

Sensitivity Analysis I: Extreme values for the input parameters

The first set of simulations shows the impact of extreme input values. The simulations for the high input parameters were all run over four 12-year simulation periods, roughly representing the 50-years period, which is the time horizon aimed for in the scenario analysis presented in Chapter 6. An increase in *Housing and Infrastructure* by 550 ha corresponds roughly to an increase of 100%. The simulation result (Figure 27A) shows that *Housing and Infrastructure* spread most strongly around the centres of settlement, i.e. the core settlement of Davos-Dorf and Davos-Platz and around more peripheral centres, such as Davos-Wolfgang or Davos-Frauenkirch. In addition *Housing and Infrastructure* increased along the main road and around the lake, except for the eastern, steep and forested shore. This simulation pattern reflects well the principal regression parameters based on neighbourhood characteristics, distance to road and distance to water, as shown in Chapter 4.

The percentage of land that turned into *Housing and Infrastructure* originates 51.6% from *Intensive Agriculture*, 43.6% from *Forest*, and 4.9% from *Extensive Agriculture*. When an input value of 2’000 ha is used (Figure 27D), the simulation also shows *Housing and Infrastructure* development in the side valleys, mainly the northern most Flüela Valley, reflecting the road classification system in the swisstopo Vector25 dataset, which the statistical analysis was based upon (see Chapter 4).

Extreme input values of 100% reduction are also used for simulation of *Intensive Agriculture* and *Extensive Agriculture*. The simulation results show that within 4 simulation periods the area occupied by *Intensive Agriculture* was only reduced by 567 ha of the 998 ha initially classified as *Intensive Agriculture* (Figure 27B). The percentage of transformed land changed 12.3% into *Extensive Agriculture* and 87.6% into forested areas, including 22.9% of *Closed Forest*, 22.6% of *Open Forest* and 42.2% of *Overgrown Area*. For *Extensive Agriculture*, the simulation results show a transformation of 5924 ha of the 8445 ha initially classified as *Extensive Agriculture* within 4 simulation periods (Figure 27C). Most of them transformed into *Unproductive Grassland* (76.4%), the remaining ones changed to forested areas, with 9.0% into *Closed Forest*, 9.4% into *Open Forest*, and 5.3% into *Overgrown Areas*.

Simulation E was run to demonstrate changes due to disturbances of the forested areas. For that, changes in demand were 0 for all three input parameters (Figure 27). The simulation results show that the proportion of *Agricultural Land*, *Forest* and *Housing and Infrastructure* remains stable in that case, but transformations occur within the forested area. While the forested area in ASCH92/97 is dominated by *Closed Forest* and bands of *Overgrown Areas* near the tree line on north-facing slopes, the simulation shows an increasingly heterogeneous forest structure with small isolated patches of *Closed Forest*, *Open Forest* and *Overgrown Areas* (Figure 27E). As later simulations show this patchiness increases with the number of simulation runs (Figure 29A-C).

Sensitivity Analysis II: Housing and Infrastructure as a result of abandonment of agricultural land

The second set of simulations investigates the relationship between *Housing and Infrastructure* and *Agricultural Land* (Figure 28). When a change in demand for *Housing and Infrastructure* $D_{H\&I}$ is entered as an input parameter, the model calculates transition probabilities and tests them starting with the highest probabilities (see section 5.1.4 , Figure 19). The number of hectares to be transformed then corresponds with the change in demand $D_{H\&I}$ entered as an input value. Additionally, *Housing and Infrastructure* can increase as a function of land abandonment. In this case, the probability of agricultural land being transformed into *Housing and Infrastructure* is similarly tested as for any other subsequent land use class (see section 5.1.4). Here, the number of additional *Housing and Infrastructure* hectares can well exceed the value of $D_{H\&I}$.

The simulations in Figure 28 demonstrate that a decrease of *Intensive Agriculture* causes a strong expansion of *Housing and Infrastructure* (Figure 28B). To allow transformation of *Intensive Agriculture* into *Housing and Infrastructure* leads to 143 additional hectares of *Housing and Infrastructure* in Figure 28B. Only 12.6% of the pixel which are classified as *Housing and Infrastructure* through this simulation procedure overlap with hectares, that are also tested through the direct allocation procedure triggered by expressively entered change in demand for *Housing and Infrastructure* (Figure 28D).

When high changes in demand are to be simulated in a limited number of simulation periods, it happens that not all requested transitions can be realised during the simulation (see also Sensitivity Analysis I and III). When *Intensive Agriculture* is to be reduced by 100% within 4 simulation periods, only about 550 ha are successfully transformed. By allowing the transformation into *Housing and Infrastructure* as a result of land abandonment, the reduction of *Intensive Agriculture* is only marginally higher than without. The reduction of *Intensive Agriculture* varies by 11 ha between the two options (see Figure 28A and Figure 28B) which represents only 1.1% of the original extent.

The reduction of *Extensive Agriculture* does not lead to the same increase in *Housing and Infrastructure* (Figure 28C). The transition probabilities are too low at high-elevation sites with bad accessibility and great distances to the next settlement as they are typical for extensively use agricultural land.

***Sensitivity Analysis III: The role of simulation period* Y**

The third set of simulations demonstrates the role of the input parameter Y and reveals the temporal dimension of the model. The same rates of transformations $D_{IntAgri}$ and $D_{ExtAgri}$ are used for A, B and C, and combined with different numbers of simulation periods *Y* (Figure 29). In one iteration 18.7% of the agricultural land transforms into any other land use class

(Figure 29A). When the same input values are allocated within 10 simulations, the degree of abandonment has increased to 81.5% (Figure 29B). For 100 simulation periods, the abandonment reaches 97.6% (Figure 29C). The considerable differences between values of simulation periods originate from the importance of neighbourhood variables within the regressions (see Rutherford, 2004, and Chapter 4). It demonstrates the ecological importance of the distance of forest as a source of seeds for the natural expansion of the forest on abandoned land. From a modelling point of view, it demonstrates the importance of how many times the neighbourhood variables are updated during a simulation.

Another well illustrated aspect is the increasing patchiness of the forest with simulation periods. In ASCH92/97 (Figure 30), the forested area is dominated by *Closed Forest*. After a first simulation period (Figure 29A), *Open Forest* and *Overgrown Area* begin to replace *Closed Forest*, if disturbances are allowed in the simulation. After four simulation periods (as shown in Figure 27E) the forested area reaches the maximum patchiness, which remains stable after 10 simulation periods (Figure 29B) as well as 100 simulation periods (Figure 29C).

Similar simulations were run to test the effect of an increasing number of simulation periods *Y* for *Housing and Infrastructure*. An identical change in demand $D_{H\&I}$ was once simulated in one simulation period and once in ten simulation periods. Both simulations could place additional 550 ha of *Housing and Infrastructure*, but the patterns varied with the number of simulation periods. In the simulation based on only 1 simulation period, *Housing and Infrastructure* is found primarily along the main road (Figure 29D), whereas the simulation based on 10 simulation periods lead to a more radial expansion, mainly around the central settlement of Davos-Platz and Davos-Dorf (Figure 29E). This, again, reveals the effect of neighbourhood parameters and their up-dating in each simulation periods.

Sensitivity Analysis IV: Decrease of Agricultural Land with number of iterations

The fourth set of simulations reveals how many simulation runs of one 12-year period it takes to dispose all *Agricultural Land* (Figure 30). After ten simulation runs of one simulation period, the *Intensive Agriculture* has reduced to 84.0% and *Extensive Agriculture* to 93.1%. After 24 simulation runs 99.3% and 99.9% are reached, respectively, and with 25 simulation runs the last agricultural land has disappeared in both classes.

This experiment also reveals differences between number of simulation runs (Figure 30) and simulation periods (Figure 29). In the third set of simulations (Figure 29), the rate of change is divided by the number of simulation periods, and within each 12-year simulation, only a proportion of the complete rate was to be transformed. In contrast, the model attempts to transform the entire rate of change during each simulation run in this experiment (Figure 30). When ten simulation runs are simulated with $Y = 1$ is simulated, the overall conversion was found greater than for one simulation with $Y = 10$. The differences between the two simulations added up to 80 pixel or 8.0% for *Intensive Agriculture* and 767 hectares or 9.1 % for *Extensive Agriculture* (Figure 29B and Figure 30).

The simulation results of extreme decrease in agricultural land in all four sensitivity analyses reveals that a stochastic and purely regression-based modelling approach is not be able to realise extreme changes in demand within short time periods. After having allocated many hectares of change, only sites with low transition probabilities are left and it becomes less and less likely that a transition is accepted by the random number. With additional iterations, this can be compensated, but leads to a different simulation result which overestimates the expansion of forest for the given simulation period.

This is the reason, why a special function was implemented into the model which optionally forces the reduction in *Agricultural Land* for extreme scenarios. The function replaces deterministically the *Agricultural Land* with *Unproductive Grassland* until the changes in demand on agricultural land are met beginning with the sites of highest probabilities to be covered by *Unproductive Grassland* (see 5.1.4).

Sensitivity Analysis V: Decrease of elevation

The fifth set of simulations tests the possibility of simulating simple climate scenarios through the manipulation of elevation values. For a that a reduction by 100m corresponds a rise in annual mean temperature by about 0.6°C. As changes in forest extent occur only when agriculture retreats, we combine a reduction of elevation with a decrease in agricultural land use to simulate the effect of climate change on forest expansion. Several simulations were run for different reductions of elevations. The simulated land use patterns were then assessed in terms of forest distribution over 25m-elevation classes. Simulations were run without any reduction of elevation (standing for a forest expansion only due to abandonment), for a reduction by 150 m and a reduction by 300 m.

The results indicate that the number of forest pixel increase most at higher elevations in all three experiments (Figure 31), even if the elevation is not manipulated (Figure 31 A). This disproportionate expansion of forest at higher elevation is partly caused by the existing forest pattern with increasingly fewer forest patches at higher elevations. However, the result indicates that this is rather caused by agricultural cultivation than because of natural conditions. This findings are in agreement with previous studies (e.g. Bugmann et al., 2005) that suggest that present forest line is notably lower today than under natural conditions because of present and historical agricultural use.

When the elevation is reduced, the total number of hectares that transform into forest increases with the degree of reduction. Without any manipulation of elevation, the simulation shows 8’095 ha of *Forest* after 4 simulation periods, a manipulation by 150m resulted in

8’325 ha and a manipulation by 300m in 8’522 ha. This additional forest are found at all altitudes, but with a slight bias towards the elevations beyond 1900 m a.s.l..

Although the simulations suggest an overall increase in high-elevation forest and the forest distribution within the elevation range shifts to higher elevations, the range itself did not widen. In ASCH92/97 isolated hectares of *Forest* occurred up to an elevation of 2’500 m, where only single trees are usually found. These outliers were not surpassed in the 50-year simulations, not even if climate change was approximated through the reduction of the elevation.

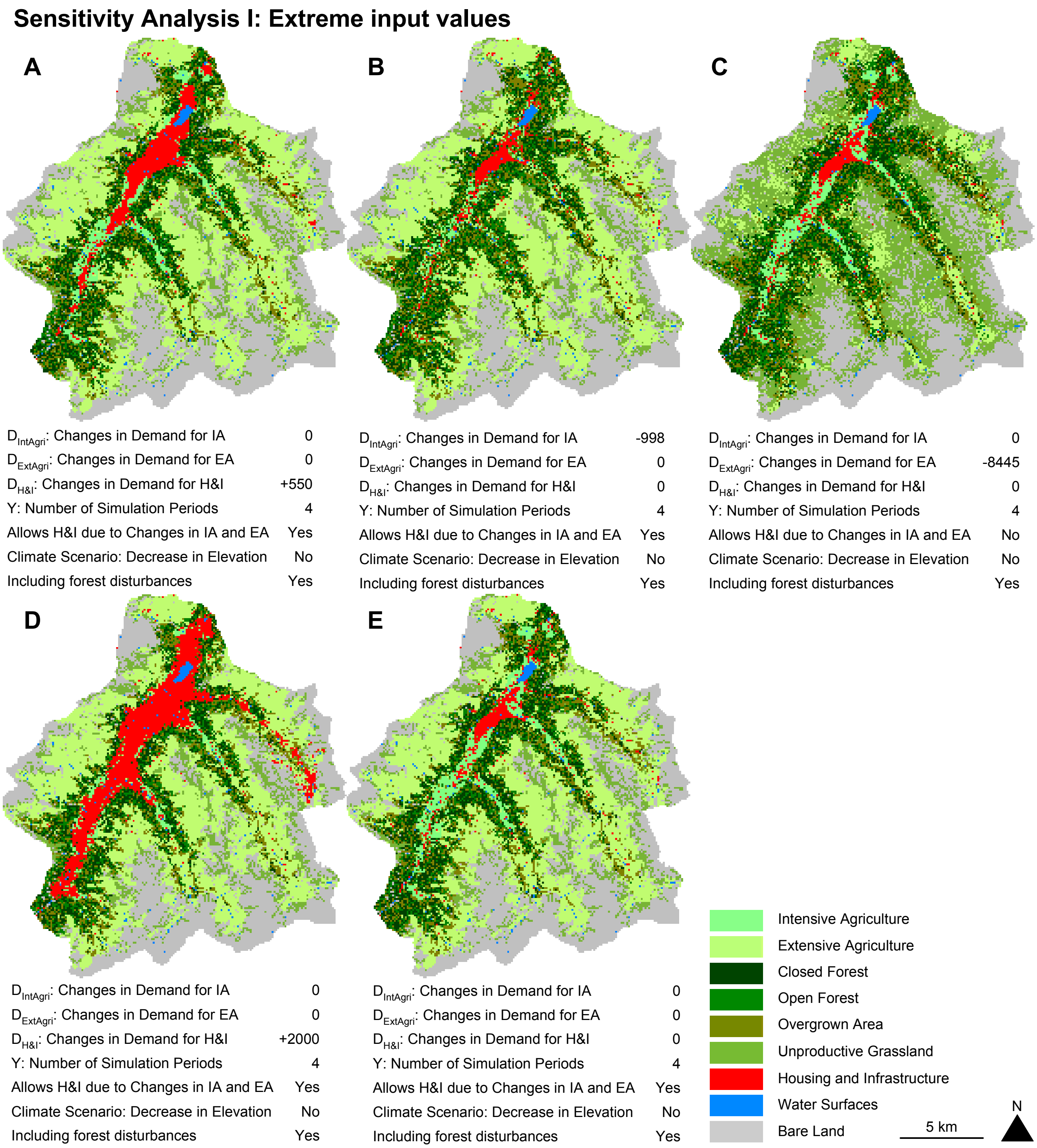
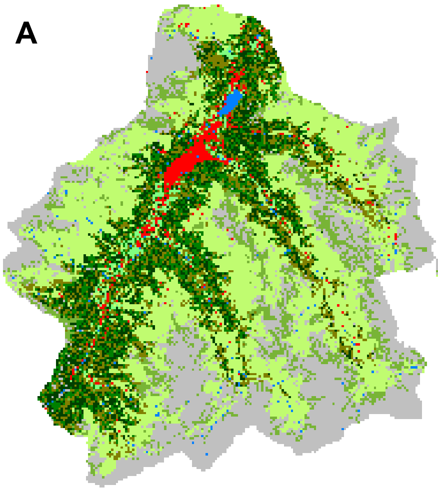


Figure 27: Demonstration of simulations based on extreme input values. Simulation results A-E refer to different parameter variations (Table 15). Details on the input parameter values are given below each simulation result.

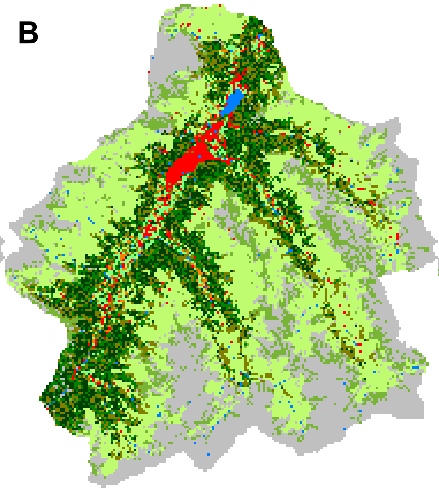
Sensitivity Analysis II: Housing and Infrastructure as a result of land abandonment

A



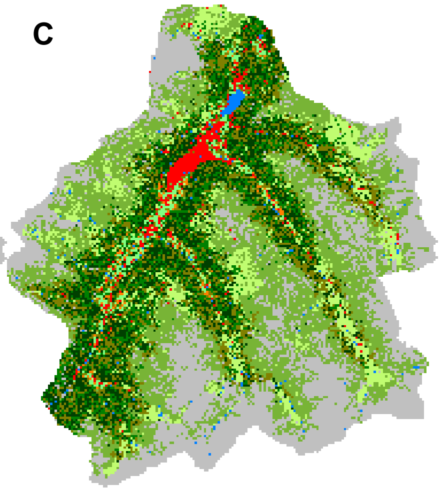
$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	0
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	No
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	Yes

B



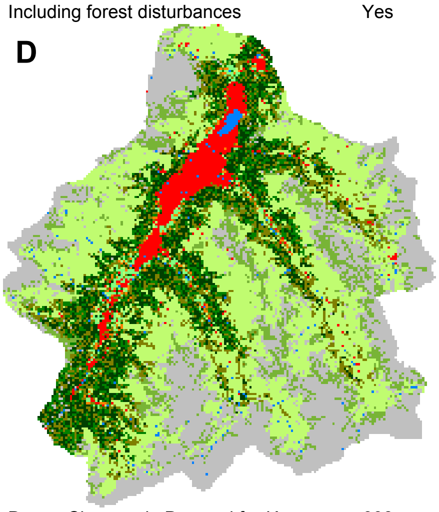
$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	0
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	No

C



$D_{IntAgri}$: Changes in Demand for IA	0
$D_{ExtAgri}$: Changes in Demand for EA	-8445
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	Yes

D



$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	0
$D_{H\&I}$: Changes in Demand for H&I	+550
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	Yes

Comparison of simulation results

	? IA	? EA	? H&I
A	-567	0	0
B	-578	0	+143
C	0	-5899	0
D	-736	0	+550+125

Intensive Agriculture
Extensive Agriculture
Closed Forest
Open Forest
Overgrown Area
Unproductive Grassland
Housing and Infrastructure
Water Surfaces
Bare Land

5 km

N

Figure 28: Housing and Infrastructure as a result of land abandonment. The table shows the resulting rates of change for each parameter variation A-D (Table 15). Details on the input parameter values are given below each simulation result.

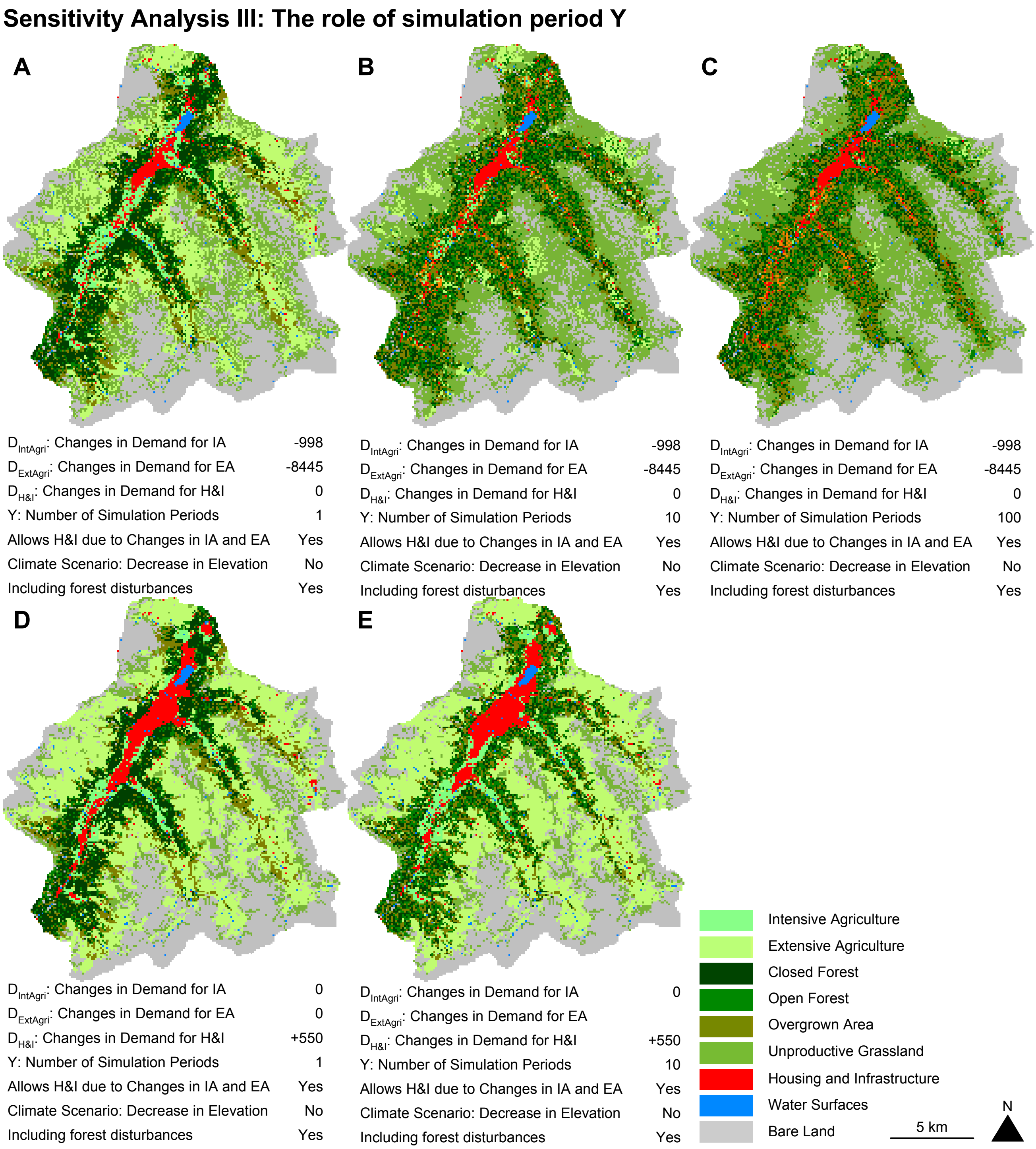
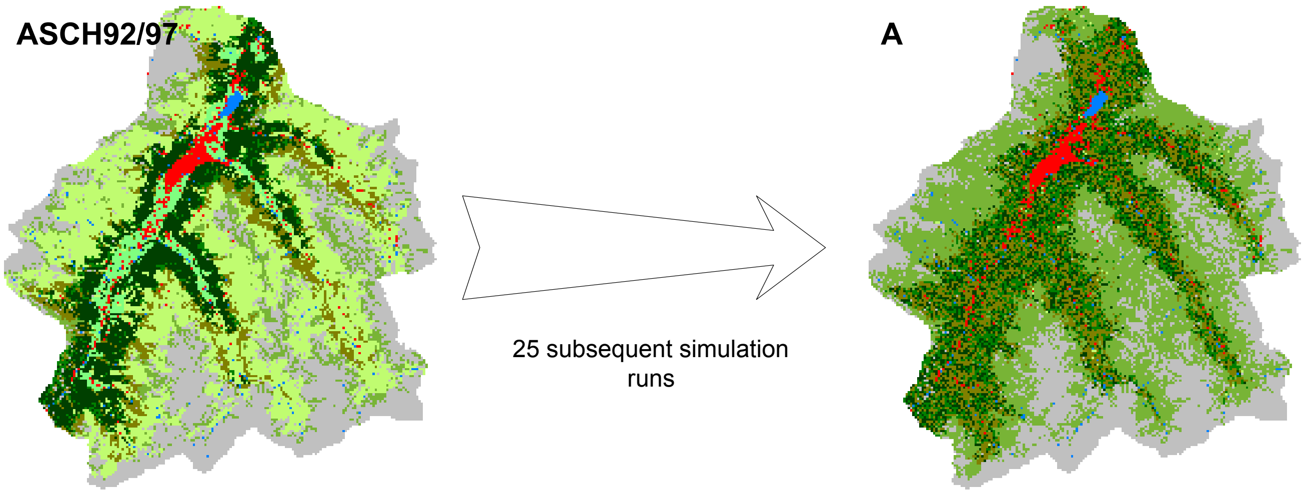


Figure 29: Demonstration of the role of the input parameter Y in the simulation model. Simulation results A-E refer to different parameter variations (Table 15). Details on the input parameter values are given below each simulation result.

Sensitivity Analysis IV: Decrease of IA and EA with number of simulation runs

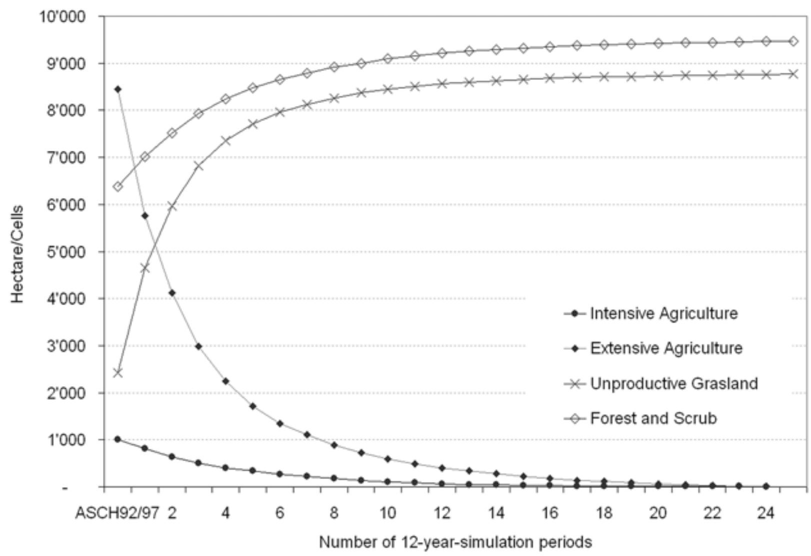


ASCH92/97

$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	-8445
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	1
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	Yes

A

$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	-8445
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	25
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	Yes



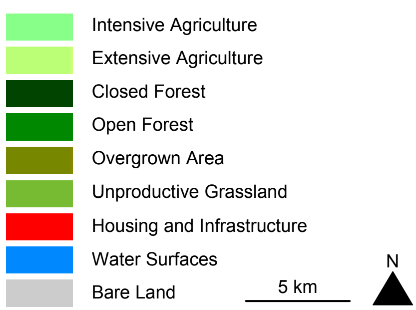
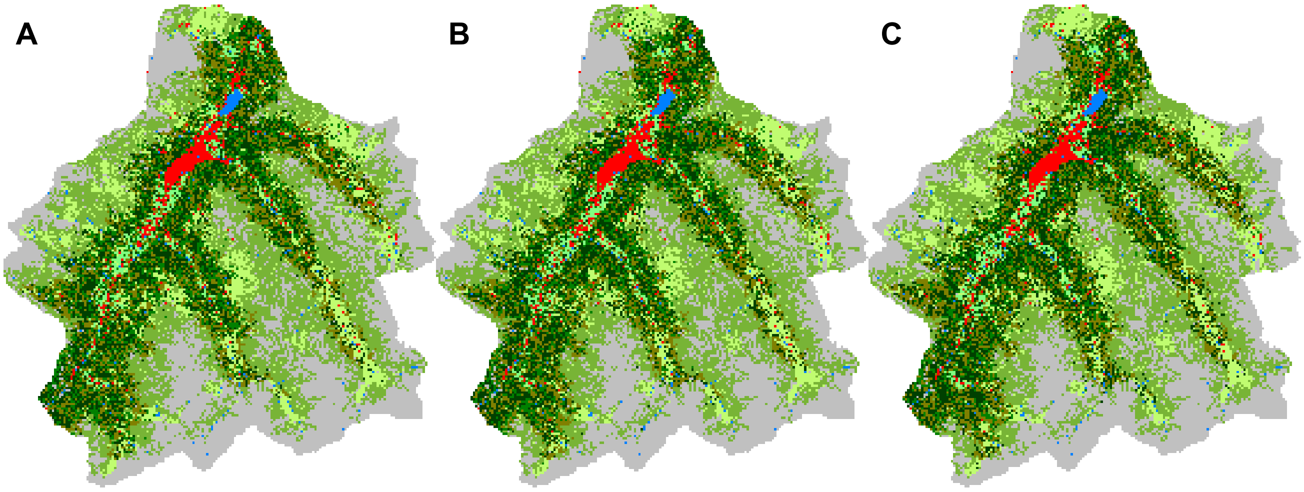


Figure 30: Number of simulation runs necessary to eliminate Agricultural Land completely. Details on the input parameter values are given below each simulation result. Simulation result A shows to final state of the simulation after 25 simulation periods. The rates of decrease in Agricultural Land with each simulation period are displayed in the graph.

Sensitivity Analysis V: Decrease of elevation



A

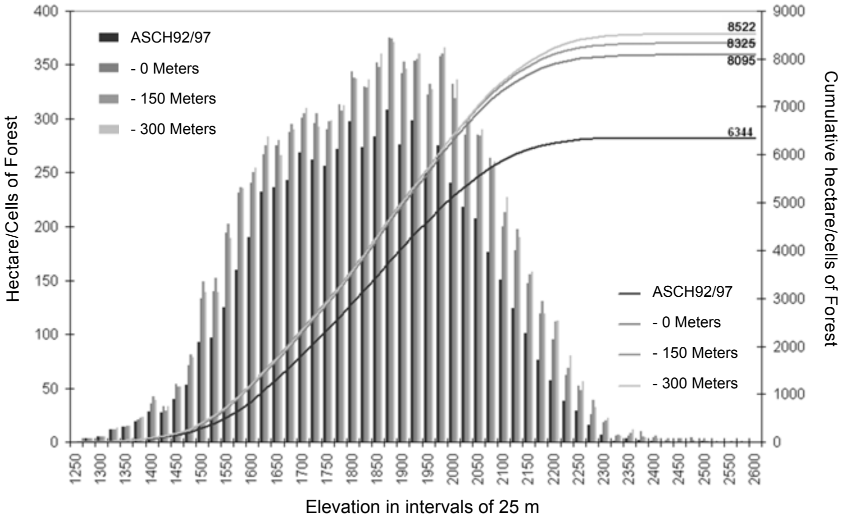
$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	-8445
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	No
Including forest disturbances	Yes

B

$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	-8445
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	-150 m
Including forest disturbances	Yes

C

$D_{IntAgri}$: Changes in Demand for IA	-998
$D_{ExtAgri}$: Changes in Demand for EA	-8445
$D_{H\&I}$: Changes in Demand for H&I	0
Y: Number of Simulation Periods	4
Allows H&I due to Changes in IA and EA	Yes
Climate Scenario: Decrease in Elevation	-300 m
Including forest disturbances	Yes



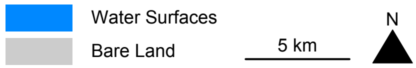


Figure 31: Simple climate change simulations. Simulation results A-C refer to different manipulations of elevation for the simulation (Table 15). Details on the input parameter values are given below each simulation result. The graphs shows the number of ha that classified either as Closed Forest, Open Forest or Overgrown Area

5.3 Discussion

5.3.1 IDENTIFICATION OF TRANSITION PROCESSES

The identification of the most relevant transition processes within the Swiss Mountain Area (defined in Section 3.2) is based on the investigation of transition matrices at different levels of spatial extent and land use class aggregation. The Swiss Mountain Area, socio-economic regions and the region of Davos have been analysed.

The transition matrices differentiating between nine land use and land cover classes (Figure 22) reveal surprisingly low transition rates from *Intensive Agriculture* to *Extensive Agriculture* (2.0% for the Swiss Mountain Area and 0.1% for Davos) and from *Extensive Agriculture* to *Unproductive Grassland* (0.9% for the Swiss Mountain Area and 0.0% for Davos). The observed transitions between ASCH79/85 and ASCH92/97 suggest that agricultural land was hardly abandoned above the tree line where it would change to *Unproductive Grassland*, and that intensively used agricultural land was abandoned and changed towards *Housing and Infrastructure* or to *Forest*, but not used less intensively. Whether these observations reflect the actual transition processes has to be considered critically, though. As the Area Statistics are based on visual air photo interpretation, the type and the intensity of land use cannot be surveyed as such with this method. Only visible land cover and changes and visible indicators for land use types can be surveyed from the air photographs.

According to the survey technique, the Area Statistics is a land cover dataset. However, to improve the monitoring of agricultural land, the „Alpkataster“ enhanced the information originating from air photo interpretation for ASCH79/85 (Anton Beyeler, pers. comm., 2005). In the “Alpkataster” all alpine pastures were registered between 1947 and 1972 with regard to this contribution to support national self-supply. For the Area Statistics survey in 1979/85, grassland above the tree line was classified as *Agricultural Land* or *Unproductive Grassland* on this basis regardless of its age. For the ASCH92/97, the ASCH79/85 was used as a basis and only obvious changes were registered. As the visual appearance of extensively used alpine pastures and abandoned alpine grassland cannot be distinguished from aerial photographs, extensively used agricultural land appears rarely to be abandoned, when ASCH79/85 and ASCH92/97 are compared. Transformations were mainly recorded in areas that were known to have been abandoned by the surveyor from additional sources, e.g. due to the establishment of nature conservation parks (Anton Beyeler, pers. comm., 2005). Hence, the extent of *Agricultural Land* has to be considered overestimated already in ASCH79/85, and the area affected by abandonment between the two surveys is most likely underestimated.

The attempt to improve the differentiation between *Agricultural Land* and *Unproductive Grassland* by using agricultural zones according to the Swiss Federal Office for Agriculture (FOAG, 2002), failed due to insufficient spatial differentiation of the FOAG's classification scheme. For to the same reasons, an extensification of agricultural use can only be observed to a limited extent of 2% from the Area Statistics. In the simulations, the very low proportion of intensively used agricultural land that changes to *Extensive Agriculture* reflects this. In most simulation runs none of the hectares, which transform from *Intensive Agriculture* to any other land use class, change towards *Extensive Agriculture*.

The intensity of transition processes is compared for all socio-economic regions through ANOVAs. The pairwise comparison identified the regions with significant differences and revealed that most differences occurred only for single processes. With significant differences in the intensity of transition for five processes, the tourism-orientated municipalities showed the strongest divergence (Table 12). This result supports the findings of Gellrich et al. (in review) and Gellrich & Zimmermann (in review) who investigated patterns of forest expansion in the Swiss Mountain Area. However, when the average process intensity for each socio-economic region was plotted including standard deviations, even the tourist regions were within the bounds of standard deviations.

This finding confirmed that, despite minor differences in the intensity of the process, the transformation of *Agricultural Land* to *Forest* and to *Housing and Infrastructure*, respectively, are the dominant transition processes for all socio-economic regions in the Swiss Mountain Area. The differences in intensity, however, suggest further investigations of the census-based parameters that lead to the socio-economic categorisation of municipalities within Switzerland to further reveal the socio-economic drivers of land use change at the municipalities' level.

The analysis focuses on the intensity of the transition processes, it does not take into account the spatial occurrence of transitions within these areas. Rutherford (2004) and Gellrich et al. (in review) describe in detail the importance of spatial determinants for land use change with respect to ecological and socio-economic aspects.

5.3.2 LOGISTIC REGRESSION MODELS

Statistical models provide the basis for the simulation model. These statistical models are based on random samples from the entire Swiss Mountain Area. Overall, the models appear suitable to describe the spatial pattern of land use change for Davos. The usage of more statistical models based on data of the entire Swiss Mountain Area will be favourable when the model is to be applied to different regions; and after all the information captured in the Area Statistics or conceptual alternatives are considered more critical to the simulation results than the logistic models.

Still, the appropriateness of the model to simulate land use change on the regional level for the study area of Davos could have been tested and eventually optimised. As mentioned in the previous section, the intensity of some transition processes are significantly different in tourist regions compared to other socio-economic regions. Are the spatial patterns also different? It would be interesting to derive statistical models based purely on samples from within tourist municipalities and compare the new simulation results. Due to the great climatic, topographic and biological variety within the Swiss Mountain Area, the use of bio-physical parameter could also help to further optimise the sampling.

5.3.3 SPATIAL AND TEMPORAL RESOLUTION OF THE MODELLING APPROACH

The spatial and temporal resolution of the simulation model originate from the Area Statistics dataset which the statistical models are based on.

The temporal resolution is determined by the period that lay between the orthophotos that served as a basis for the two methodologically identical surveys of ASCH79/85 and ASCH92/97. In accordance to the survey interval for most regions including Davos, the temporal resolution of the model is 12 years. The results of the sensitivity analysis show that this interval is particularly meaningful if extreme land use change scenarios are simulated. Although the model implementation allows to use any rates of change to be simulated, the simulation of extreme scenarios is constrained by the rates of change observed in the past and analysed in the statistical models. For instance, a sudden stop of agricultural land can not be simulated purely based on the statistically derived transition probabilities. If rates of change exceed greatly the observed rates of change, transition probabilities become too small during an iteration to result into frequent acceptance through the random number.

The Area Statistics is based on an equidistant 100m*100m lattice of sample points from which grid datasets of the same spatial resolution were derived. Although originally based on point samples, the 100m*100m cells are used as if they represented hectares of land. In the model as well as in the surveyed datasets, the spatial resolution is constant over space and across all land use classes. In a mountainous area the actual land area represented in one pixel, however, might be considerable larger than indicated in the dataset.

Yet, the constant resolution across land use classes is even more relevant for the model. Some land use classes occur typically in large patches, but are divided into regular 100m*100m cells which behave almost independently from the patch in a pixel-based approach. The simulation results for the extensively used agricultural land are a good example of such behaviour. Initially the patches of extensively used land are relatively large and are divided into numerous independently behaving cells. But neighbour characteristics determine strongly the transition probability for each pixel and cause the extensively used land to decrease from the boundary zones to other land use classes. This leaves single cells in the centre of the initial patch with extensive agriculture which can only be compensated for by an increasing number of simulation runs as neighbourhood characteristics slowly change also with decreasing patch sizes.

Similar problems occur for land use classes which would preferably be surveyed in a higher spatial resolution, such as the *Housing and Infrastructure*. With a resolution of 100m*100m the relatively small patch sizes in which *Housing and Infrastructure* occurs cannot be represented very systematically. One option to adapt spatial resolution for specific land use classes could be to combine the raster based information of the Area Statistics with the Local Information System LIS available for the study area (see Chapter 3).

5.3.4 SIMULATION RESULTS

The validation confirms that the simulation model is able to reproduce changes in land use pattern from the past to a reasonable degree. The agreement between observed and simulated data is with a Kappa value of 0.917 well above the expected value for random agreement and spatially explicit validation illustrates that many of the cells that are incorrectly classified in the simulated dataset are near-misses. However, the value has to be considered critically because of the high percentage of persistence between the initial dataset AS54 and the reference dataset ASCH79/85. To improve the validation procedure, the persistent cells between the initial and the simulated dataset should be excluded from the analysis, or according to Pontius et al. (2004) the “Null-model” is to be used for reference. Another option to reduce the map comparison to the cells that have changed since the initial situation, could be based on a swapping technique briefly explained in Purves & Walz (2005).

The sensitivity analysis shows the basic mechanisms of the model, its sensitivities, its potentials and limitations. Experimenting with the role of time within the simulation process revealed that the number of accepted changes in agriculture is mainly dependent on the number of times the neighbourhood parameters are re-evaluated. The number of cells that are tested during one simulation period is comparably of minor importance.

The parameter “elevation” is revealed as an important factor to determine the expansion of forest in the logistic regressions that the model is based upon. The “elevation” represents mainly an ecological proxy. It corresponds with harsher climate conditions that prevail at higher elevations and reduce the survival probability and growth trees. Simple climate change scenarios can be simulated, thus, through the manipulation of the “elevation” within the model. The results show that the model is sensitive to such manipulations. The amount of forest at higher elevation increases with greater reduction of the “elevation”, and results in a slow displacement of the forest line as forest pixel become denser at higher elevations. The total range of the elevation distribution, however, remains constant. No further hectares transformed to forest above the isolated pixel that can already be found in ASCH92/97 at an elevation of about 2500 m a.s.l.. The results indicate the importance of the neighbourhood characteristics for the transformation into forest. Ecologically this effect can be explained with the distances that tree seeds are usually transported. According to Lässig et al. (1995), about 90% of all seeds fall to the ground within a 10m distance to the tree.

The increasingly heterogeneous structure of the simulated forest must partly be interpreted as a result of the underlying statistical models. One reason is the application of statistical models developed from data of the entire Swiss Mountain Area (Rutherford, 2004). This source area includes sub-alpine regions with considerably lower tree lines than presently found in Davos and also large areas of forest that were damaged during the Vivian storm event in 1990 (Schönenberger, 1994). But apart from this methodological explanation, the simulations still considered quite plausible and in line with results of a similar study (Adrienne Grêt-Regamey, pers. comm., 2005). At present, the forest stands are quite homogenous in Davos due to the abrupt termination of intensive extraction of wood for heating and building as well as the termination of grazing by goats in the beginning of the 20th century. With respect to that, it seems likely that the forest will become more heterogeneous in future (Oliver and Larson, 1990).

5.3.5 MODEL STRUCTURE

The model outline is systematically based on the transition probabilities derived from the statistical models. Extra restrictions and modifications were avoided in order to keep the simulation results interpretable. However, the statistical model to derive transition probabilities for *Unproductive Grassland* has to be established through a slightly different methodology as a result of data constraints. Two further exceptions are a) the option to simulate with or without allowing *Housing and Infrastructure* to increase as a result of land abandonment and b) the option to force the reduction of agricultural land to the degree the input parameter suggests. These two options, however, are valuable adaptations to allow the application of the model for a wide range of scenarios. With respect to the modelling concept, both modifications are clearly implemented and indicated as "options". Whereas the enforced reduction of agricultural land seems simple enough to interpret, the consequences of the option to simulate *Housing and Infrastructure* as a results of land abandonment are not so obvious. Because of that this option was analysed in detail in the sensitivity analysis (Sensitivity Analysis II, see Figure 28).

The model outline established a clear focus on allocation modelling. The rates of change for the relevant land use classes, namely the *Agricultural Land* and *Housing and Infrastructure*, are entered as input parameters and control strongly the simulation results. In the context of scenario analysis, in which the model is to be applied, this quality makes the model adaptive to a wide range of scenarios. The feedback between the simulation of *Housing and Infrastructure* due to changes in demand and abandonment resulting in *Housing and Infrastructure* could still be improved to avoid conflicting simulation results due to this interference.

5.4 Conclusions

The model structure is particularly designed to meet the requirements of scenario analysis. Scenario-derived changes in demand on land for agricultural cultivation and the expansion of settlements are the prime input parameters to run simulations. The simulation model uses statistical models based on multivariate logistic regressions to derive transition probabilities and then identify likely sites of transformation within the study area. Until the rates of change are met, transformations are allocated based on a stochastic procedure that tests a random number against the transition probabilities.

The statistical analysis of the transformation processes observed between ASCH79/85 and ASCH92/97 identified the most important transition processes for the Swiss Mountain Area. These processes, namely the expansion of the settlements and the abandonment of agricultural land often leading to forest expansion, are integrated into the land use model.

The analysis and the findings from Chapter 4 suggest that the usage of statistical models from the entire Swiss Mountain Area is a reasonable solution. By using data from the entire Swiss Mountain Area, the number of observed transitions is increased also for low-frequency transitions (see Chapter 4) and the applicability of the model to different regions is ensured.

The sensitivity analysis illustrates the mechanics, strength and weaknesses of the model. It reveals the importance of neighbourhood parameters, and reflects some shortcomings of the input data. For instance, the surveying technique of the Area Statistics based on visual air photo interpretation shows weaknesses in differentiating types of open land. This failing is still visible in the simulation results. The sensitivity analysis also shows that the model can be applied to test the interference between development of settlement and land abandonment and to simulate simple climate change scenarios.

Despite plausible simulation results, the validation results for the independent time period 1954-1985 confirmed only fairly good agreement between the simulated land use pattern for 1985 and the observed pattern of ASCH79/85. Methodological limitations, in particular difficulties with the dataset AS54 reconstructed from historical air photos, had a further negative impact on the validation results.

Finally, a regional-level land use allocation modelling could be developed that will suit the requirements for scenario simulation. The model is well adapted to the relevant land use transition processes for the study area, and it allows control of rates of change according to the externally derived scenario specifications. In Chapter 6 the model will be applied as part of the integrated modelling framework introduced in Chapter 2 to address the consequences of agricultural decline in a scenario analysis.

CHAPTER 6

LAND USE ALLOCATION MODELLING AND PARTICIPATORY INVOLVEMENT WITHIN AN INTEGRATED SCENARIO ANALYSIS

According to the conceptual framework of the thesis (Chapter 2: Figure 2), this chapter puts allocation modelling into the context of the integrated approach to regional development. Whereas allocation modelling has been so far addressed mainly from a methodological point of view (Chapters 4 and 5), this chapter links causes and impact of changes in the land use and land cover pattern to the simulation results the Land Use Allocation Model. For that, references to many models of the ALPSCAPE modelling framework are drawn in this chapter (Figure 32). Within the conceptual framework of the thesis, this means that the “social system” so far not further differentiated is referred to as an assemblage of the Local Agricultural Model, the regional Input-Output Model and the Resource Flux Analysis (Figure 32) and that the impact on land use and land cover change is explicitly addressed through the Assessment of Ecosystem Services.

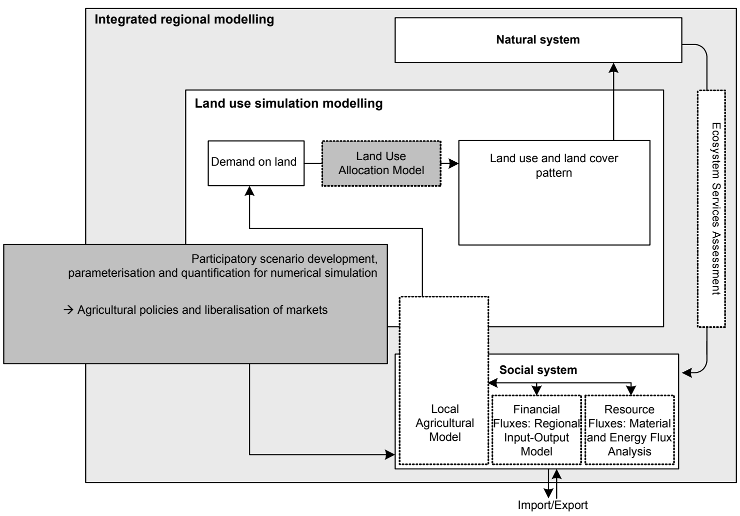


Figure 32: This chapter demonstrates the role of the Land Use Allocation Model within integrated regional modelling. The scenarios which are analysed in this chapter have been derived through a participatory approach which will furthermore be documented and discussed in this chapter.

Furthermore, this chapter documents and evaluates a participatory approach to scenario development and the elaboration of complex scenarios for numerical modelling (Figure 32). The involvement of local actors into scenario development in the ALSCAPE project aimed a) to improve the basis to formulate future scenarios for the region through local knowledge and b) to increase attention to long-term issues of regional development within the local community. How and to what extent these aims were achieved is explained and discussed in this chapter. The scenario presented here addresses the impact of changing agricultural policies and liberation of markets on the region of Davos.

The chapter is based on a journal publication which emerged from close collaboration of all members of the ALPSCAPE team and includes the results of all authors. Heiko Behrendt provided the technique to acquire local system knowledge and further evaluated it; Corina Lardelli contributed most to the establishment and quantification of the scenarios; Corinne Lundström, Susanne Kytzia and Adrienne Grêt-Regamey contributed with the numerical results, except for the ones of the Land Use Allocation Model; and Peter Bebi established the contact to the local actors and organised the workshops.

Walz, A., Grêt-Regamey, A., Behrendt, H., Lardelli, C., Lundström, C., Kytzia, S. and P. Bebi (in review): Merging local system knowledge and numeric regional modelling through scenario development. Landscape and Urban Planning.

A chapter based on this publication is included into this thesis because it provides a good example for the application of the Land Use Allocation Model within the integrated regional modelling framework. The aspect of participatory scenario development for integrated numerical modelling is further stressed with reference to the lack of well-elaborated or even established methods in this field, discussed in Section 2.2.3 (e.g. Kemp-Benedict, 2004; Kok and van Delden, 2004).

6.1 Scenario background

In common with many other mountain regions in the Alps, Davos was strongly dominated by agriculture until health tourism started in 1865 (Chapter 3). Since then the number of farms has dropped from 310 in the mid-19th century, to 120 farms in 1950, and about 90 farms remained in 2000 (Flury, 2002). Due to decreasing farming activity in the region, the traditional agricultural landscape is changing. Forest expansion, loss of cultural land, and the decay of traditional barns as landmarks with an almost symbolic character (Felber, 2005) are considered one of the principal threats to landscape attractiveness (Bätzing, 2004; Kianicka et al., 2004) with possible consequences for the tourist industry.

Until recent years, landscape conservation has been strongly promoted by subsidising mountain agriculture mainly through “direct payments”. These payments are partly linked ecologically sound farming techniques and the high product quality typical for mountain agriculture (e.g. BLW, 2001; Rösti, 1997). Accordingly, these payments are not directly related to the production volume, but rather to type and area of land under cultivation; for instance, they encourage continuation of farming on unfavourable slopes too steep for machine mowing in order to maintain the cultural landscape. The total amount of direct payment for mountain agriculture reached on average of 2.3 Billion CHF per year between 2000 and 2003. Mainly because of these costs and international pressure to reduce the protection of national markets, public and political attitudes are changing. If financial support is considerably reduced in the near future, drastic impacts are expected on mountain agriculture. Questions arise for the future of mountain agriculture. What economic, social and cultural consequences as well as impacts on the landscape must we expect?

The scenario analysis focuses on possible outcomes of a radical decrease in subsidies for mountain agriculture and market liberalisation. It is considered an *Extreme Scenario* due to the radical reductions that are assumed, and the 50-year simulation period during which no further policy adaptations are assumed. Although social and cultural effects are also to be expected, the analysis concentrates on economic, resource-related and landscape-related aspects, as these are the fields the ALPSCAPE integrated modelling framework can contribute to.

6.2 Methodological approach

6.2.1 OVERVIEW OF THE INTEGRATION PROCESS

Before presenting the sequence of techniques to develop and simulate complex scenarios, the overall framework of the integration approach is introduced (Figure 33). The entire scenario analysis, consisting of the participatory scenario development and numerical simulation, is displayed as a circular process (Figure 33) starting with the involvement of local actors in participatory workshops and going back to them with the results of the scenario analysis.

Beginning with the organisation of workshops, local system knowledge is first acquired and processed. Qualitative system models result from the workshops where the actors, interests and circumstances considered most important for the region are identified and inter-related. For the development of a specific scenario, a subset of relevant elements is selected. The qualitative scenarios are drawn from logical chains of plausible developments for each of these elements. The process of scenario development includes a feedback-loop with the workshop participants to validate the scenario's relevance and logic for the region.

To further elaborate the qualitative scenarios for numerical simulation, a comprehensive list of modelling input parameters is drawn from the modelling framework. The list provides the requirements to "code" the scenarios for modelling, and thus to parameterise the scenarios. To determine the input values for the simulations, the parameters are quantified based on an in depth literature review (Lardelli & Lundström, unpublished). In a further step, the integrated modelling framework uses these values to simulate the scenarios and feeds the results to the scenario table. The enhanced scenario table is the basis for an “enhanced scenario story” which allows communicating the analysis´ results more easily back to local stakeholders.

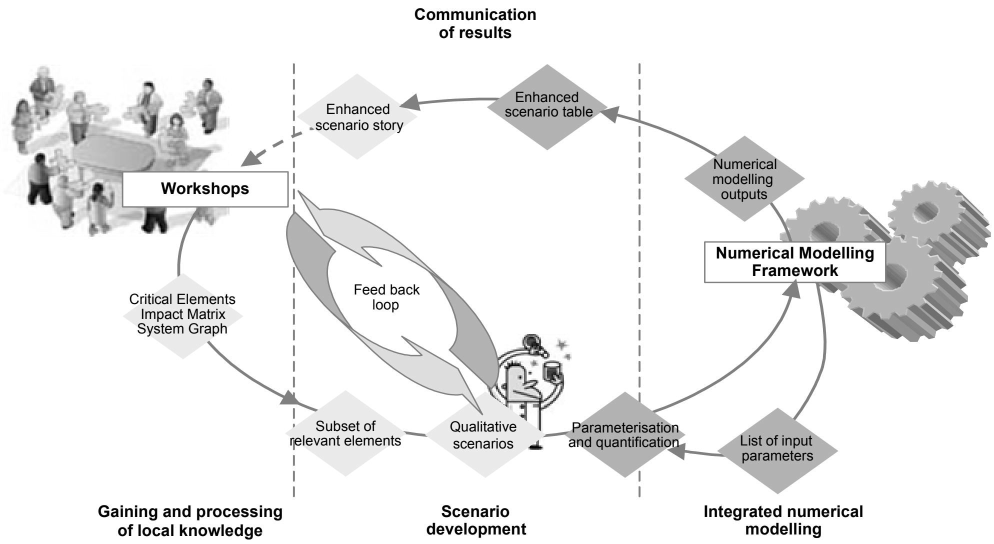


Figure 33: Schematic representation of participatory scenario analysis including a) the acquirement of local knowledge, b) the actual scenario development and preparation for numerical modelling, c) the numerical simulations and d) finally the communication of results back to local actors. The diamonds show the different steps and how they evolve from each other. The light grey diamonds represent quantitative system knowledge and the dark grey diamonds represent model-based numerical knowledge.

6.2.2 THE NUMERICAL MODELLING FRAMEWORK

The numerical modelling framework of ALPSCAPE depicts inter-related processes of land use change, resource fluxes and economic issues by combining four simulation models (Section 2.5). Each of these aspects is represented by a separate modelling approach including a regional Input-Output Model, a Resource Flux Model, a Local Agricultural Model and the Land Use Allocation Model presented Chapter 4 and 5 and an assessment tool to derive changes in ecosystem services (Lundström et al., in review).

For the scenario analysis, changes in the agricultural structure of the region are used as an input to the Local Agriculture Model which estimates the modifications of production volumes, demand on regional economy generated by the agricultural sector and land requirements for agriculture. The regional Input-Output Model further reflects the impact of changes in demand through the agricultural sector on the regional economy and the Resource Flux Model derives the impact on the degree of self-suffiency for food and energy. Changes in land requirements for agriculture are used as input parameters for the Land Use Allocation Model. The spatially explicit simulation outcomes provide further the basis to assess changes in ecosystem services. All models as well as their linkages have already been described in Section 2.5 and in Lundström et al. (in review).

Thus, the input parameters for the Local Agricultural Model form the key to implementing the scenario and simulating their consequences through the integrated modelling framework. By contrast to a parameter analysis with single values being modified and tested, the implementation of complex future scenarios involves the simultaneous alteration of several input parameters. To gain a comprehensive overview of the input, regulative and output parameters, which can be altered in scenario simulation, a complete list of possible input and output parameters for each model is assembled. This list comprises about 120 parameters for possible alteration, and is further used to parameterise the scenarios (Figure 33).

6.2.3 GAINING AND PROCESSING OF LOCAL SYSTEM KNOWLEDGE

As several topics were to be addressed through scenario analysis in the ALPSCAPE project, local system knowledge is first derived in general. The focus of the workshops was on an improved understanding of the structure, stability and fragility of the local system. In a later stage of the collaboration, scenarios prepared by the researchers were discussed with the participants and adapted to their feedback.

The group of participants included key stakeholder, such as policy-makers and official representatives of stakeholder groups, as well as the public with differences in their specific interests, in the degree of active involvement in the regional development process and in the degree of relevance of their decision-making for the public. As participants of all three groups were involved in workshops, they are referred to as “local actors”.

Organisation of workshops

A four-step-approach was applied to optimise the knowledge gathering process through workshops (Figure 34). In the first workshop, representatives of the local government, of different stakeholder groups (e.g. tourism, agriculture) and the public (e.g. teachers, pastors) were invited to build an advisory group and to establish a common understanding on the research question, the relevance of the study to the local community and the role of the participatory co-operation. To increase the number of people involved and thus improve the source of information, each representative was asked to find at least another five persons and launch a satellite group. In the following six workshops, the satellite groups gathered to establish regional system models with respect to their individual perspectives. Due to the differing background of each group, the individual outcomes of each satellite group could be used to zoom into specific issues, e.g. the results of the satellite group “agriculture” were directly re-consulted, when the scenario on agricultural policies was developed. When the advisory group met again, the results of the satellite groups’ work and the early versions of the scenarios and first modelling results were presented and discussed. Another workshop is intended for November 2005 to present the final results of the scenarios analysis including scenario-based modelling results, and possibly allow further adjustment before final publishing of the results at the local level.

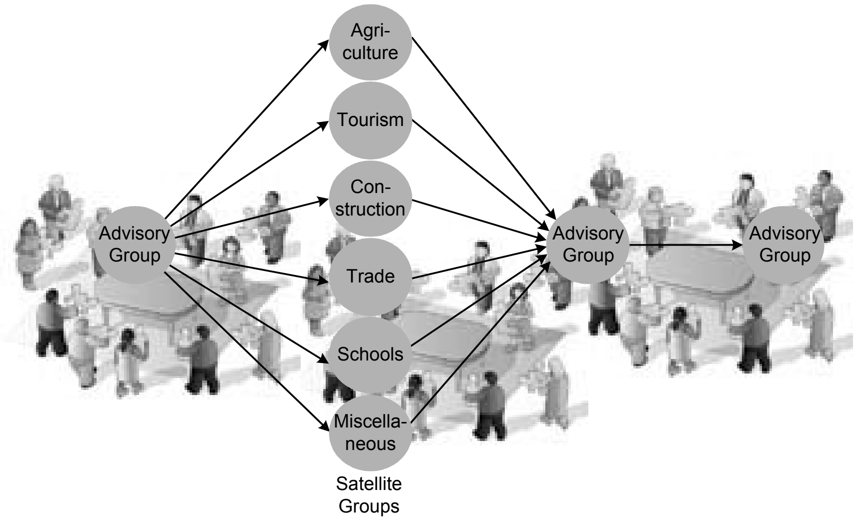


Figure 34: Organisation structure of workshops with local actors.

Elaboration of qualitative system models in satellite groups

In order to elaborate in a step-wise fashion graphical system models for each satellite group, we used the methodology of sensitivity models as described in Vester & von Hesler (1980) and applied often since (e.g. Scholz and Tietje, 2002). The participants of the satellite groups were asked to identify the elements within the region they considered most relevant for the development of the region. These elements could include “factors, actors and sectors” (according to Kok et al., 2003; Rotmans et al., 2000), such as stakeholders, interests, environmental conditions, economic sectors or social values. After a first brainstorming session, the group condensed these elements down to the 17 most critical elements in a group discussion. A clear definition of these elements was created by the participants to ensure a common understanding of each element.

The elements were entered into a symmetrical matrix, so that the impact of one element on any other could be estimated within the matrix by a rating. As suggested in Vester & von Hesler (1980) and Scholz & Tietje (2002), the participants were asked to assess only direct impacts of one element on another, and take care not to include indirect impacts an element might have through another element. Each member of the satellite group filled in the impact matrix individually using a four-level rating scale: 0 = “no or very little impact”, 1 = ”medium impact”, 2 = “high impact”, 3 = “very high impact”. The matrices of all participants were then combined in a single matrix, which represented average ranking of the group. Two original impact matrices are displayed as examples in Figure 35 showing the results of the satellite groups “Schools” and “Agriculture”.

The impact matrices indicate characteristic qualities for each element, such as “Impact Strength” and “Involvement” (Scholz and Tietje, 2002). Both measures are based on the sum of all impacts that one element has on all others (sum of rows = “active sum”), and that one element experiences from all others (sum of column = “passive sum”). The “Impact Strength” is calculated by dividing the active sum by the passive sum for an element; it identifies the elements that strongly impact on other elements and are also prone to external impacting. If the ratio is > 1, the element has an active role in the system, if it is < 1, the element is strongly influenced by other elements. The “involvement” is calculated by multiplying the active and passive sums of an element and shows how strongly an element is interlinked with the system.

The matrices reflect the viewpoint of the particular satellite group and indicate that they had particular knowledge in their own field of expertise. To benefit from these insights, each satellite group was asked to explicitly assess the regional system from their own point of view. Consequently the set of elements considered most relevant and the rankings differed substantially between satellite groups, and provided – with a certain overlap between all groups – more detailed information for particular fields (Figure 35).

Each satellite group developed a system graph in accordance to their impact matrix, including the elements and impacts identified as most relevant. In the system graphs of the groups “Schools” and “Agriculture” displayed in Figure 35, all impacts rated greater than 2.7 and the according elements are included. The attempt to integrate the results of all satellite groups into one single system graph failed because of the high number of elements and different aggregation levels used in each group. Altogether 60 elements were named by the satellite groups and aggregated differently, depending on the satellite group’s background. Although not formally combined, all impact matrices and system graphs were used for scenario development and its validation (Figure 33).

In the impact matrix of the satellite group “Schools”, the importance of tourism and the landscape for the region are indicated through the high values of impact strength; and agriculture is assessed to have a strong impact on the landscape. From the viewpoint of the group “Agriculture”, public subsidies have a strong effect on the agricultural use of land, and strong linkages are drawn between landscape attractiveness, tourism and demand on agricultural products.

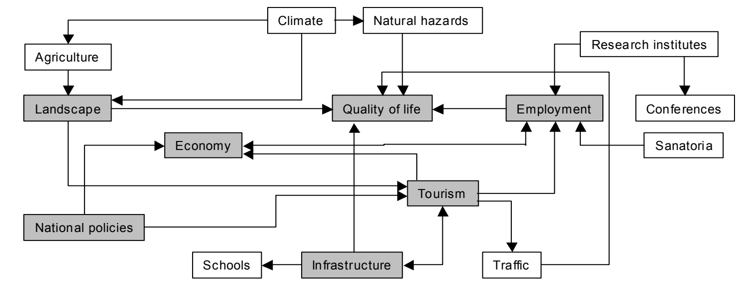
However, the matrices also show inconsistencies, mainly because of errors that occurred during the completion of the matrix when the participants were asked to fill in the forms quickly and intuitively. These errors included confusions of “element in column impacts element in row” and disrespect of the element definitions which was agreed upon in the preceding group discussion.

Impact Matrix "Schools"

"Element in column impacts element in row"

	Agriculture	Quality of life	Research institutes	Schools	Economy	Climate	National policies	Sanatoria	Tourism	Conferences	Employment	Traffic	Natural hazards	Infrastructure	Social life	Landscape	Senior citizens	**Aktive Sum**	**Impact Strength**
Agriculture		1.3	0.0	0.3	2.3	0.3	1.3	0.5	2.3	0.3	1.5	1.3	1.5	1.5	0.3	2.8	0.8	**17.8**	**1.0**
Quality of life	0.5		0.5	1.5	2.3	0.0	2.0	1.0	2.3	0.5	1.8	1.8	1.5	1.3	1.5	1.0	2.0	**21.3**	**1.2**
Research institutes	1.0	0.8		1.8	2.0	0.3	0.8	1.5	1.0	2.8	2.8	0.5	2.3	0.8	0.3	1.8	0.5	**20.5**	**1.1**
Schools	0.5	1.8	1.8		1.8	0.3	1.0	0.5	0.8	0.5	2.0	1.0	0.5	1.5	2.0	0.8	0.5	**17.0**	**0.9**
Economy	2.0	1.8	1.3	1.5		0.3	2.8	0.8	2.3	1.5	3.0	2.0	0.5	1.8	0.8	1.0	1.3	**24.3**	**1.3**
Climate	2.8	2.5	1.3	0.5	1.8		0.5	2.0	3.0	1.0	0.8	1.0	3.0	1.3	0.8	3.0	1.8	**26.8**	**1.5**
National policies	1.3	1.5	0.8	1.8	2.0	0.3		0.8	2.8	2.0	1.3	1.8	1.3	2.0	1.0	1.3	1.3	**22.8**	**1.3**
Sanatoria	0.3	1.3	2.3	0.8	2.3	0.3	0.3		1.5	1.5	2.8	1.0	0.0	1.0	0.3	0.5	1.5	**17.3**	**1.0**
Tourism	1.8	2.3	0.8	0.8	3.0	0.8	2.0	1.3		1.5	3.0	3.0	1.0	3.0	0.8	2.3	1.3	**28.3**	**1.6**
Conferences	0.3	0.8	2.3	0.3	2.0	0.3	1.5	0.8	2.5		1.8	1.3	0.5	1.5	0.5	0.5	0.3	**16.8**	**0.9**
Employment	1.3	2.8	1.5	1.0	3.0	0.5	1.8	1.8	2.5	0.8		1.5	0.3	0.8	1.3	1.0	1.5	**23.0**	**1.3**
Traffic	0.8	2.8	0.3	0.5	1.5	2.5	0.5	0.5	1.8	0.3	0.8		0.8	1.8	0.3	2.5	1.0	**18.3**	**1.0**
Natural hazards	2.3	2.8	1.5	0.8	1.0	0.0	0.5	0.5	2.3	1.0	1.0	1.8		2.0	0.0	1.3	1.5	**20.0**	**1.1**
Infrastructure	0.8	2.8	0.8	2.8	1.8	0.3	0.8	1.5	3.0	2.0	1.8	1.3	1.0		2.3	1.8	1.3	**25.5**	**1.4**
Social life	0.0	2.5	0.3	2.0	0.8	0.3	1.0	0.0	1.5	0.3	0.5	0.3	0.0	1.8		1.3	2.0	**14.3**	**0.8**
Landscape	2.5	3.0	1.8	0.8	1.3	1.5	0.8	1.0	3.0	0.8	0.8	1.0	2.5	2.0	1.8		1.8	**26.0**	**1.4**
Senior citizens	0.3	1.3	0.5	0.3	1.0	0.3	1.8	1.5	2.0	0.5	1.0	1.3	0.3	1.0	1.5	0.3		**14.5**	**0.8**
Passive Sum	**18.0**	**31.5**	**17.3**	**17.0**	**29.5**	**7.8**	**19.0**	**15.8**	**34.3**	**17.0**	**26.3**	**21.5**	**16.8**	**24.8**	**15.0**	**22.8**	**20.0**		
Involvement	**320**	**669**	**354**	**289**	**715**	**207**	**432**	**272**	**968**	**285**	**604**	**392**	**335**	**631**	**214**	**592**	**290**		

System Graph "Schools"



Impact Matrix "Agriculture"

"Element in column impacts element in row"

	Natural hazards	Tourism	Ecology	Public acceptance	Climate	Demand local products	Secondary income	Local policies	Public subsidies	Loans	National policies	Processing industry	Innovations	Landscape attractiveness	Cultural heritage	Agricultural land	Housing development	**Aktive Sum**	**Impact Strength**
Natural hazards		2.8	1.5	1.8	2.0	0.3	0.8	2.3	0.8	0.0	1.5	0.5	0.5	2.5	0.8	2.0	2.8	**22.5**	**0.9**
Tourism	2.3		2.3	1.5	1.5	2.5	3.0	2.0	1.0	0.8	2.0	2.3	2.3	2.0	2.0	3.0	2.8	**33.0**	**1.3**
Ecology	2.3	1.5		2.3	2.0	0.8	0.8	1.0	3.0	0.0	2.0	0.8	1.3	2.8	1.0	2.0	1.0	**24.3**	**1.0**
Public acceptance	1.8	1.5	1.8		1.3	1.8	0.5	1.8	2.5	0.3	2.3	1.8	1.8	3.0	2.8	2.8	2.5	**29.8**	**1.2**
Climate	3.0	3.0	2.5	1.5		1.3	2.0	2.3	1.0	0.5	2.0	1.8	1.8	2.8	1.0	2.3	2.0	**30.5**	**1.2**
Demand on local products	0.3	0.5	1.0	1.8	0.5		2.0	0.5	1.0	1.0	1.3	2.0	2.8	2.0	1.5	1.5	1.3	**20.8**	**0.8**
Secondary income	0.8	2.3	0.8	0.5	1.0	1.5		1.3	1.5	2.0	1.0	1.0	1.8	1.3	1.3	1.0	1.0	**19.8**	**0.8**
Local policies	2.0	1.5	1.0	1.0	0.5	0.3	1.8		1.8	1.0	2.8	1.3	1.0	2.0	0.8	2.0	1.5	**22.0**	**0.9**
Public subsidies	1.0	1.5	2.3	2.0	1.5	1.5	1.8	2.3		3.0	3.0	2.8	2.3	2.5	1.5	2.8	2.5	**34.0**	**1.4**
Loans	0.8	2.5	0.5	1.0	0.5	0.3	2.3	2.3	2.3		1.5	2.8	3.0	1.3	0.5	1.3	1.3	**23.8**	**1.0**
National policies	1.5	3.0	3.0	2.0	1.0	1.5	1.8	2.8	3.0	2.3		2.8	1.5	1.5	0.8	2.5	3.0	**33.8**	**1.4**
Processing industry	0.5	1.8	1.3	1.3	0.8	2.0	2.5	1.0	1.3	2.5	1.5		1.8	1.5	0.5	0.8	1.5	**22.3**	**0.9**
Innovations	0.5	1.5	0.8	1.5	0.5	3.0	2.3	0.5	1.8	1.5	0.8	1.8		1.5	1.3	1.0	0.8	**20.8**	**0.8**
Landscape attractiveness	2.5	3.0	2.3	2.5	1.0	2.8	2.0	2.5	2.5	0.8	2.3	1.5	1.5		2.0	2.3	2.8	**34.0**	**1.4**
Cultural heritage	1.0	1.8	1.3	2.3	0.5	2.3	1.3	1.0	1.3	0.3	1.0	1.8	1.8	2.0		1.8	1.8	**22.8**	**0.9**
Agricultural land	2.3	2.3	2.5	1.5	1.3	2.0	0.5	2.3	2.5	1.5	2.0	1.3	1.3	2.3	2.3		2.0	**29.5**	**1.2**
Housing development	2.8	2.8	1.8	2.8	1.3	1.8	2.0	2.3	2.5	0.8	2.0	1.5	1.3	2.8	2.0	2.3		**32.3**	**1.3**
Passive sum	**25.0**	**33.0**	**26.3**	**27.0**	**17.0**	**25.3**	**27.0**	**27.8**	**29.5**	**18.0**	**28.8**	**27.3**	**27.3**	**33.5**	**21.8**	**31.0**	**30.3**		
Involvement	**563**	**1089**	**637**	**803**	**519**	**524**	**533**	**611**	**1003**	**428**	**970**	**606**	**565**	**1139**	**495**	**915**	**976**		

System Graph "Agriculture"

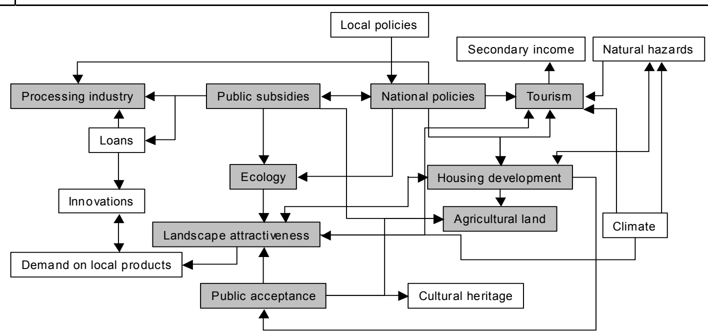


Figure 35: The original impact matrices of the satellite groups "Schools" and "Agriculture" and the derived system graphs for both groups. The elements of highest "Impact Strength" are shaded in grey in the system graphs.

6.2.4 SCENARIO DEVELOPMENT

Due to the ability to account for fundamental uncertainties, the scenario technique is an adapted and well-established method to illustrate potential future development of highly complex systems (de Jouvenal, 1967; Kahn and Wiener, 1967). Scenarios are described as "hypothetical sequences of future events" (Kahn and Wiener, 1967). As such, they can describe the dynamic development of complex systems, representing plausible sequences of events over a period of time. Scenarios do not predict, instead they acknowledge fundamental uncertainties with regard to future development. By developing different scenarios, possible system evolution is investigated by elaborating different, logical sequences for future changes in the system with respect to these uncertainties.

Scenario setting

To develop scenarios for any issue, the settings have to be clearly defined and expressed. A clear question has to be formulated, and the temporal and spatial frame allowing the investigation of this question has to be formed. The issues investigated in the three scenario analyses are a) regional change due to decrease in subsidies for mountain agriculture and liberalisation of markets, b) climate change with consequent changes for the skiing and tourism industry and c) a mega-sports event. In this example, the scenario on regional change through decrease in subsidies for mountain agriculture and liberalisation of markets is presented in detail. The issue is very controversial and is of great public interest at a national level, but also within the region due to high public affection towards the historically grown cultural landscape and due to the landscape's importance as a natural resource for tourism in the area.

The time horizon of the scenarios is from 2000 to 2050. Within this time period, namely in 2011, a complete reduction of subsidies is expected in the scenario caused by decrease of public and political willingness to support the mountain agriculture and by liberalisation of agricultural markets. Crucial for the development of mountain agriculture after 2011 is therefore the cost-effectiveness of production and demand for regional products despite increases in consumer prices. Three scenario phases are distinguished in accordance: a pre-event phase before 2011, an event-phase in 2011, and a post-event phase after 2011-2050.

Identification of principal uncertainties

To assess hypothetical future situations in a scenario analysis, the identification of the principle uncertainties within the triggered process is fundamental. The analysis of the public discourse and group discussions within satellite and experts groups reveal these uncertainties. If subsidies for mountain agriculture decline considerably, the price of agricultural products will better reflect production and processing costs, and thus product prices will have to rise. At the same time a liberalisation of the market will cause greater competition. Consumer behaviour, on which farmers will rely strongly, is thus considered a principle uncertainty and builds the basis of the analysis: How will consumer behaviour adapt to increases in prices due to policy changes?

This uncertainty builds the axis within a one-dimensional scenario space (Figure 36). According to the identified axis, two distinctively different scenarios are placed within this scenario space. Scenario A assumes that demand for local products will increase despite augmentation of consumer prices, scenario B assumes that demand will reduce strongly and expensive, non-supported products will not be sold in the future.

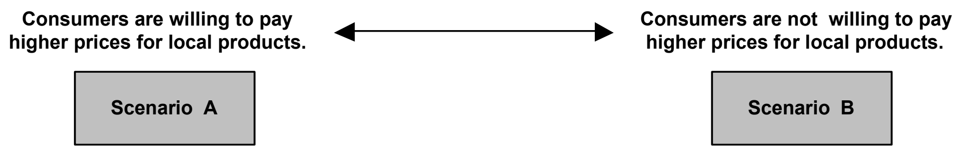


Figure 36: Scenario space for the case study of decrease in subsidies for mountain agriculture and liberalisation of markets. The scenarios A and B depict rather extreme positions in this range of possible scenarios.

Qualitative elaboration of scenarios

For scenario specification, the most relevant elements and their development in accordance to the scenario issue are re-selected. To identify these elements, impact matrices and system graphs of the satellite groups are used. For the scenario issue “Decrease in subsidies for mountain agriculture and liberalisation of markets”, special reference is given to the outcome of the satellite group “agriculture” including farmers, food processors and professional users of local agricultural products, such as hotels. To gain a coherent set of the most relevant elements for the scenario, some of the elements are aggregated and re-grouped. Based on these elements, a scenario-specific system graph is developed displaying graphically the interrelations within the set (Figure 37).

The elements “Agricultural policies and markets” and “Consumer behaviour” play a key role in the implementation of the scenarios. How these two elements develop, is very strongly imprinted by the scenario assumptions. The development of all other elements is conducted from cause-effect relationships as described in Figure 37.

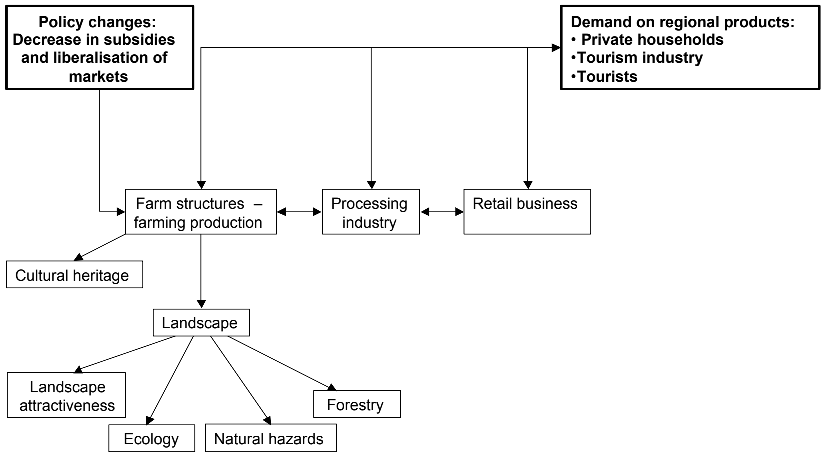


Figure 37: Scenario-specific system graph in the case of decreasing subsidies for mountain agriculture and liberalisation of markets with high uncertainties in future demand.

Parameterisation and quantification of scenarios

The scenarios are prepared for modelling by parameterisation and quantification of the elements in the third section of the scenario table. Potential input parameters taken from the list of all possible input parameters to the numerical modelling framework are used to describe the elements. Some elements, although considered important within the context of the decreasing subsidies for mountain agriculture and liberalisation of markets, are not parameterised, as they are not addressed by the modelling framework developed for the ALPSCAPE project.

In the case of the agricultural scenario, parameter quantification and numerical simulation are interwoven processes (see Figure 38). For the input parameters characteristic values have to be deduced for scenario simulation. The four models incorporated are briefly described in Chapter 6.2.2 . The Local Agriculture Model delivers outputs that are further used in the other models. Thus, primary input parameters for the numerical simulation of the scenarios are limited to the input parameters of the Local Agriculture Model (Table 17).

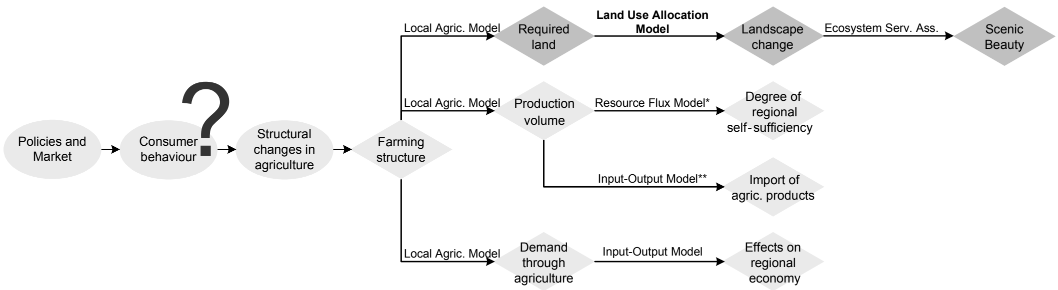


Figure 38: Workflow for the agricultural scenario. The ellipses indicate scenario assumptions and the diamonds numerical modelling inputs and outputs. How the Land Use Allocation Model is used within the workflow, is indicated by dark grey shading. (: Assumption that only the regional market is delivered; **: Assumption that consumer baskets remain the same).*

6.2.5 COMMUNICATION OF THE MODELLING RESULTS

The communication of the simulation results is considered the second interface between numerical modelling and local actors' knowledge (Figure 33) in the participatory process. In this phase of the project, research feeds back to the local community and thus needs to provide adequate means of communication. Members of the advisory group and the satellite groups underlined this requirement when they expressed their doubts about their ability to understand the outcomes of the numerical modelling.

Besides the organisation of further workshops and other public events, which allow presentation of the results of the scenario analysis personally, we used "enhanced" storylines (Figure 33) to communicate the results by combining the qualitative and numerical aspects of the scenario analysis. Similar to a conventional scenario storyline (e.g. Arnell et al., 2004; Schoemaker, 1993), an enhanced storyline utilises the advantages of a narrative. It uses narrative language that local actors are familiar with and sets elements into context, such as scenario assumptions, the qualitative estimates for elements that are not subject to modelling or principles of the numerical modelling framework. Additionally, the "enhanced" scenario story incorporates the indicators derived from the numerical simulation and demonstrates clearly parallels and differences between the scenarios (Box 1).

Table 16: Section 1 and 2 of the scenario table display the subset of element considered most relevant for the scenario and the qualitative description about their behaviour over three scenario phases.

Section 1	**Section 2**			
Relevant Elements	**Qualitative Scenario Specifications**			
	Initial state in 2000	**2011**	**Scenario A** **No subsidies, but market**	**Scenario B:** **No Subsidies, no market**
Agricultural Policies and Market	Area-related subsidies for mountain agriculture and protected national market	Decrease in subsidies and liberalisation of market	No subsidies	No subsidies
Consumer Behaviour	Consumers use local agricultural products. Prices are slightly higher than for competitive products.	Consumer prices rise rapidly for local agricultural products.	Consumers are willing to pay increased prices for local, high-quality products.	Consumers buy cheaper products from the lowlands.
Farming Structure	Divers farming structure mostly producing milk and meat. Milk is then processed and distributed by the local dairy.	Many farms cannot meet the harsh competition and stop farming. Due to decreasing amounts of milk, the dairy closes down.	Few large farms remain which can produce, process and distribute meat and milk cost-effectively. Additionally a few part-time farmers will produce, process and distribute meat.	Mountain agriculture has stopped. No more farms.
Landscape	Typical, historically grown cultural landscape with pastures and meadows	/	Decrease in agricultural land with forest expansion below the timber line	Loss of agricultural land with forest expansion below the timber line
Resource Management	Food: Local agricultural productivity satisfied about 30% of the local consumption of dairy and meat products. Electricity: Several little power stations generate about 10% of the electricity consumed in the area.	/	Food: The milk production volume decreases due to reduction of farming activity while demand on local dairy products raise. Electricity: Agriculture requires less electricity as before.	Food: As demand for costly local dairy products is marginal, production has almost stopped. Electricity: Hardly any consumption through agriculture.
Regional Economy	Tourism is the dominating economic sector. Agriculture employs 117 persons and processing industry another 30.	/	With decreasing farming activity, employment in agriculture are reduced and all jobs in the processing industry are lost. Other industries are not strongly impacted.	With a stop of farming, employment in agriculture and processing industry vanish. Other industries are not strongly impacted.
Ecological Situation	High biodiversity of mountain meadows and pastures.	/	Decrease of plant biodiversity, but improvement of forest boundary habitats.	Loss of biodiversity on mountain meadows, forest boundary habitats improve.
Protection from Avalanche Hazard	Forest at steep slopes reduce the chance of avalanche release. Forest above infrastructure and housing reduces the risk against avalanche hazards.	/	With forest developing at steep slopes above settled areas, the protection function increases.	With even more forest expanding at steep slopes above the settlement, the protection function might increase even more.
Scenic Beauty	The traditional agricultural landscape is assumed highly attractive and a resource for tourism.	/	Character of scenic appearance becomes “wilder” with increasingly expanding forest.	Scenic appearance is dominated by forest below the timber line.

6.3 Results

Corresponding to the assumed changes in agricultural policy and consumer behaviour, we assume that structural changes in agriculture will take place after 2011. Experiences from the past, experts on mountain agriculture and discussions with local farmers revealed that many farmers would have to stop their production, and farming structure would shift. Large, fully professional farms with their own milk processing, and small farms concentrating on labour-extensive meat production with secondary, non-agricultural income are likely to develop. For Scenario A assuming a vivid market for local agricultural products, we assume that 5 large, fully-professional farms and about 15 small part-time farms would remain within the region. For Scenario B, 6 part-time farms without any commercial distribution of their products are assumed. These values are used as input to the *Local Agriculture Model*. In the scenario table (Table 17), the initial input parameters are indicated through grey shading in the third section.

According to estimates on the agricultural structure, the *Local Agricultural Model* (Section 2.5) outputs the production volumes for dairy products and meat and the agricultural area expected for Scenario A and B. For Scenario A, it suggests a reduction of milk to less than 20%, and a reduction of meat production to about 11,5% of the 2001/2002 volume. In accordance, the agricultural land is estimated to decline to about 32% of the intensively used land in 1997 and to about 17% of the extensively used land in 1997. In the case of a complete stop of professional agriculture within the region, the outputs go down to 0. The outputs of the Local Agricultural Model were used as input parameters for the economic Input-Output Model, the Resource Flux Model and the Land Use Allocation Model.

The results of the regional *Input-Output Model* (Section 2.5) suggest that the proportion of added value to the region through agriculture and processing industries declines from 0.2% to 0.04% for Scenario A and down to 0% for Scenario B. The reduction of the Gross Domestic Products amounts to 1.5% for Scenario A and to 1.8% for Scenario B. Hence, the impact of a decrease as well as a complete stop in agriculture show limited direct impact. This is mainly because agriculture plays a minor role already within the regional economy. For Scenario A, about 2.3% of full-time employment in 2001/2002 would be lost, which still adds up to about 152 jobs. For Scenario B, 160 full time equivalents are estimated to be lost.

The *Resource Flux Models* (Section 2.5) suggest considerable decrease in self-sufficiency for food within the region due to reduced productivity in both cases. While the degree of self-sufficiency reached about 27.4% for dairy and meat products in 2001/2002, the expected production volume in Scenario A would only supply about 8.1% of the regional demand. For Scenario B, only about 0.1% of the region's consumption could be satisfied and the region would rely almost completely on imports for these products. The self-sufficiency rate for electricity is hardly impacted by the agricultural scenarios. As electricity consumption declines only slightly with the reduction or stop of agriculture, the sufficiency rates rise by 0.08% or respectively 0.1% for Scenario A and Scenario B.

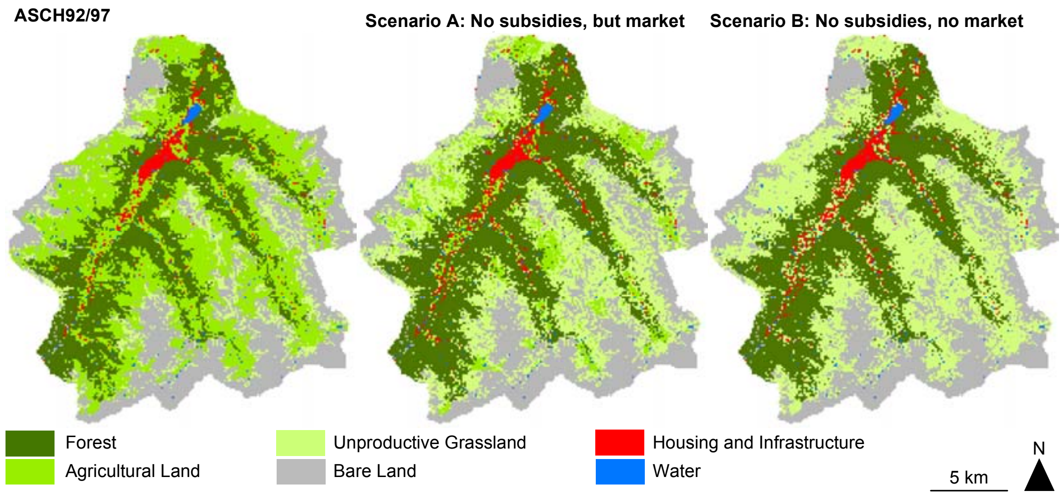


Figure 39: Simulation results of the Land Use Allocation Model for Scenario A and Scenario B, and the initial situation in 1997 (Land Use Statistics 1992/97, BFS GEOSTAT).

Based on the requirements for land calculated in the Local Agricultural Model, the *Land Use Allocation Model* suggests strong impacts on the landscape for both scenarios. Within the 50-year simulation period over 1'700 ha of abandoned land are estimated to be overgrown or forested for both scenarios. Forest expansion differs only by about 50 ha between the scenarios. It constitutes a complete band of forest or at least overgrown land, on all slopes below the tree line with very few spots of open grassland (Figure 39). With this, the proportion of forest within the study area thus increases from 25.1% to 31.7% for Scenario A, and 32% for Scenario B. The forest-open land boundary which is considered an important indicator for scenic beauty (Franco et al., 2003) increases considerably for both scenarios. This increase is mainly due to the expansion of forest in the upper side valleys where no forest was present in 2000. For the remaining extensively used agricultural land in Scenario A, the simulation suggests large contiguous areas above the tree line. The formerly intensively used agricultural land seems to be more likely to be abandoned than to be extensively used, which corresponds with the observations between the two Area Statistics surveys. At the abandoned areas on the valley floors forest develops quickly due to favourable ecological conditions, and a great proportion is likely to be used for further development of *Housing and Infrastructure*. This indicates that abandonment of agricultural land on the valley floors is likely to favour an expansion of *Housing and Infrastructure* in future due to decreasing competition for land. Of course, spatial planning is restrictive at the moment, but we can assume that spatial planning will adapt to future situations in the long run. For both scenarios the extent of unproductive grassland increases substantially. In 2000, about 9.5% of the study area is covered with unproductive grassland; in 2050 a proportion of 30.2% is reached according to Scenario A, and 39.0% according to Scenario B. Although landscape diversity increases at some locations, e.g. at the top-end of the side valleys, the Shannon's Diversity Index calculated for the entire region indicates a reduction in landscape diversity. Related to the reduction of landscape diversity is also a likely decrease in biodiversity (Hietala-Koivu et al., 2004).

Finally, the impacts of the land use pattern changes was further assessed and monetarised by changes in *Ecosystem Services* (Table 17) (Grêt-Regamey et al., in review). The flagship species *capercaillie*, used to evaluate the changes in wildlife habitat, benefits especially from an increase in forested area. Furthermore, avalanche protection increases due to the protective function of the increased forest area. The increase in forested area did not have a significant impact on people's preference for a view, but the likely expansion of *Housing and Infrastructure* on the previously agriculturally used land is considered to have a negatively effect scenic beauty region (Grêt-Regamey et al., in press).

The simulation and assessment results (Table 17) are summarised in a narrative to bring them into context and better communicate them to be the local public (Box 1).

Box 1: The enhanced scenario story combines the scenario assumptions and simulation results from numerical modelling

Assumptions

After 2011, mountain agriculture reacts to decrease of subsidies and liberalisation of markets. High production costs due to harsh production conditions in the mountain environment have to be covered by consumer prices. According to discussions with local farmers, mountain agriculture would stop to sell milk, but specialise in high-quality local products.
Depending on consumer behaviour, demand for local, high-quality, costly agricultural products can differ strongly. Scenario A assumes an augmentation in that market despite consumer prices, due to a general increase in environmental and regional awareness, Scenario B assumes that this market dies out due to high competition and low awareness.

Scenario A: No Subsidies, but market for local products

With increasing demand on high-quality, costly agricultural products, a small number of large, fully-professional farms can meet the requirements of this market to work cost-efficiently. Smaller farms are only to adapt if they are not mainly reliable on income through their agricultural activities. We assume that 5 large farms with an increased number of cattle and 15 highly diverse small lifestyle farms remain within the area of Davos. The milk processing industry has to close down as the total volume of milk decreases and the farms process their milk to high-quality, costly dairy products, which they also distribute. According to a local agriculture model that provides us information on typical productivity and land requirements in the region based on recent practices, this development results in a strong reduction in agricultural land and production volume.
The results of an economic model, displaying the regional economic network based on the financial fluxes between different economic sectors in 2002, show that the reduction of agricultural activity is marginal for the local economy with the Gross Domestic Product decreasing by 1.5%. However, about 152 jobs in food production and processing are lost. This is mainly because currently the tourism dominates the local economy and agriculture plays a minor role.
According to a resource model, that displays resource availability and consumption within the region, strong effects are expected for the degree of self-sufficiency within the region. At the moment, regional agricultural production can supply 27% of dairy product and meat consumption. But with the decreasing total volume of milk, the region will rely on to about 92.5% on imports for these products.
The greatest impact is expected on the landscape due to abandonment. A landscape model shows an increase of forested areas by about 60%. This development reduces landscape diversity with impact on the regional biodiversity, although in the upper side valleys we can expect greater diversity to forest establishment. The abandonment of agricultural is also very likely to reduce the competition for land and to result in further housing development at the valley floors.
With changes in the landscape, also ecosystem services will change, including an increase in protection of avalanche hazard through forest expansion, an increase in open forest habitats (such as the forest grouse) and a reduction in scenic beauty due to further housing development.

Scenario B: No Subsidies, no market for local products

If demand on high-quality local agricultural products is not sufficiently high, the complete stop of professional agriculture shows stronger impacts on the region. The degree of regional self-sufficiency for dairy products, which is still around 7.5% in Scenario A, is reduced to 0.1% and the region is fully relying on food imports. The number of jobs losses in agricultural production and food processing is expected to be 160, and thus comparable to Scenario A. The proportion of added value generated by the agriculture is reduced to 0%. According to the land use model, effects on the landscape include the expansion of forested areas even on the most favourable agricultural sites at the valley floor of the main valley, if no conservation measures are taken. Ecosystem services develop also similar as in Scenario A, but the impacts are stronger.

Table 17: Section 3 and 4 of the scenario table show the results of the scenario simulations of all models and numerical tools including the Local Agriculture Model (LAM), the Land Use Allocation Model (LUA), the Resource Flux Model (RFM), the Input-Output Model (IOM) and the Ecosystem Services Assessment (EcoServ). The shaded zone in Section 3 indicates the prime input values, and the shaded zone in Section 4 the final simulation outputs.

Section 1	**Section 3**				**Section 4**			
Relevant Elements	**Input parameters and values for numerical modelling** **(Origin of the input parameter value→Type of model to be used)**				**Scenario outputs based on numerical modelling (Type of model) or based on qualitative scenario specifications**			
	Parameters	**2000**	**Scenario A No subsidies, but market**	**Scenario B No subsidies, no market**	**Parameters**	**2000**	**Scenario A No subsidies, but market**	**Scenario B No subsidies, no market**
Agricultural policies and market	/	/	/	/	/	/	/	/
Consumer behaviour	/	/	/	/	/	/	/	/
Farming structure	Number of large, fully professional farms with milk and meat production, processing and distribution (→LAM)	2	5	0	Land requirements (LAM): Intensive agricultural use Extensive agricultural use	 998 ha 8445 ha	 318 ha 1400 ha	 0 ha 0 ha
	Number of part-time farming with meat production, processing and distribution (→LAM)	0	15	6	Production volume (LAM): Milk Meat	 5 Mio. kg $252*10^3$ kg	 0.9 Mio. kg $29*10^3$ kg	 0 kg 0 kg
	Others of various sizes but without food processing and distribution (→LAM)	74	0	0				
Landscape	Demand on land for intensive agricultural use	998 ha	318 ha	0 ha	Land use pattern (LUA)	ASCH92/97	Map Scenario A (Figure 39)	Map Scenario B (Figure 39)
	Demand on land for extensive agricultural use (LAM→LUA)	8445 ha	1400 ha	0 ha	Landscape structure (LUA): Forest-Open Land boundary %-age of Unprod. Grassland %-age of Forest	 6'064 km 9.5% 25.1%	 6'919 km 30.2% 31.7%	 7'022 km 39.0% 32.0%
					Area (LUA): Close Forest Open Forest	 3545 ha 773 ha	 3386 ha 3581 ha	 3801 ha 3831 ha
Resource Management	Production volume for milk per month (LAM→RFM)	410'000 kg	100'000 kg	0 kg	Self-sufficiency for food (RFM)	27.4%	7.3%	0.1%
	Demand on local products per month (Scenario Assumption→RFM)	130'000 kg	200'000 kg	0 kg	Self-sufficiency for electricity (RFM)	10.08%	10.16%	10.18%
Regional Economy	Demand on other economic sectors (Scenario Assumption→IOM)	100%	20%	0%	Gross Domestic Product of the region (IOM)	627.7 Mio CHF	618.2 Mio CHF	616.2 Mio CHF
					Proportion of added value by agriculture of total added value in the region (IOM)	0.2%	0.04%	0%
					Total Employment (IOM)	6'474	6'322	6'314
					%-age of food products of all imports	13%	14%	15%
Ecological Situation	Land use change (LUA)	ASCH92/97 (Figure 39)	Map A (Figure 39)	Map B (Figure 39)	Landscape Diversity (LUA): Shannon's Diversity Index	1.59	1.48	1.25
	Land use change (LUA→EcoServ)	ASCH92/97 (Figure 39)	Map A (Figure 39)	Map B (Figure 39)	Habitat modification of the forest grouse (*capercaillie*) (EcoServ)	/	+5'300 CHF * year	+6'000 CHF * year
Protection from avalanche hazard	Land use change (LUA→EcoServ)	ASCH92/97 (Figure 39)	Map A (Figure 39)	Map B (Figure 39)	Change in risk against avalanche hazard (EcoServ)	/	+58'000 CHF * year	+86'345 CHF * year
Scenic Beauty	Land use change (LUA→EcoServ)	ASCH92/97 (Figure 39)	Map A (Figure 39)	Map B (Figure 39)	Change in scenic beauty (EcoServ): Due to forest expansion Due to further construction	/	 +/- 0 CHF -7'000 CHF * year	 +/- 0 CHF -6'200 CHF * year

6.4 Discussion

6.4.1 RESULTS OF THE SCENARIO SIMULATION

The scenario analysis investigates the impact of a radical decrease in agricultural subsidies on the region of Davos. It thereby focuses on the question of what consequences differing consumer behaviour might have on regional development in such a case. A strict decrease or stop of financial support of mountain agriculture without any re-modification of this policy was assumed. In that regard, both scenarios are not "realistic", but they demonstrate that the effect of consumer behaviour is minor compared to financial support and even a positive development in the market of high quality local agricultural products can most likely not compensate it.

For the landscape changes, the two scenarios show almost identical forest expansion. Even in the case of a complete halt of financial support for mountain agriculture, the simulation suggests unproductive grassland at sites most favourable for forest growth, such as the valley floors (Figure 39: Scenario B). A reason for that is the importance of neighbourhood characteristics in the allocation model, that make forest expansion only likely in the neighbourhood of forested areas. This aspect can be ecologically explained through the distances of seed transportation (e.g. Lässig et al., 1995). A further reason lies in the statistical approach that has been applied for the simulation model. Between the two Area Statistics surveys in 1979/85 and 1992/97 only a few favourable sites at the valley floors experienced a shift to forest due to abandonment in the Swiss Alps. Thus, the statistical models produce low transition probabilities for these sites to transform into forested areas, and within a 50-year simulation period these sites are thus unlikely to change to forest. This problem has been addressed earlier in Chapter 5, where simulation results of the Sensitivity Analysis IV indicate that a complete replacement of agricultural land below the tree line by forest would take considerably longer due to these phenomenon.

The simulation results show strong effects on the landscape structure, related ecosystem services and the degree of self-sufficiency, but only a marginal effect on the local economy. This result reflects the minor role of agriculture and food processing industry within the contemporary economic structure, which is clearly dominated by tourism. However, as the landscape is considered one of the major resources to attract tourists, indirect effect are expected through the agricultural abandonment and subsequent landscape changes. The ecosystem service "scenic beauty" addresses this aspects when the value of the landscape as a resource for tourism is estimated through a willingness-to-pay survey (Grêt-Regamey et al., in press) and the results are applied to the simulated land use patterns. According to these findings, the likely expansion of the settlement would reduce the value of the ecosystem service. The difference can be expressed as a monetary value which reflects how much less tourists are likely to spend for their accommodation during a visit owing to a less beautiful view (Bebi et al., 2005; Grêt-Regamey et al., in press). These values suggest an adaptation of the consumption volume of tourists in the Input-Output Model to demonstrate the effect of landscape pattern on the economy of the region.

For the scenario analysis, the Land Use Allocation Model, the Resource Flux Model and the Input-Output Model were run separately, but the scenario provides a common environment to derive systematically tuned input parameters for all of them. It brings the results into context and shows a more holistic perspective of the region. Differences in temporal and spatial scales, degrees of detail and interfaces between individual models have to be considered critical within any integrated modelling approach. These potential sources of error and misinterpretation can be coped with by making fundamental assumptions explicit and by well documenting data transfers from one model to the other in order to make the interfaces between individual models transparent.

6.4.2 THE ROLE OF THE LAND USE ALLOCATION MODEL IN THE INTEGRATED MODELLING APPROACH

The scenario analysis clearly reveals the role of land use allocation modelling as an important interface between social and natural systems within integrated approaches to regional modelling. In line with the understanding that changes in land use are the result of dynamic economic and societal systems, quantities of change are derived from the "social system" (Figure 32). These quantities give already a first indication about the possible impact on the "natural system". However, due to the heterogeneity of the landscape, land use changes do not impact the natural system equally at all locations within the region, and thus the location of change makes a difference to the impact. Land use allocation modelling estimates a likely spatial distribution of the derived rates of change within the region and provides an essential basis for environmental impact assessment.

In the presented study, quantities of land use change were derived from the Local Agricultural Model which refers to structural changes in local agriculture due to policy-driven socio-economic modifications (Figure 32). The Land Use Allocation Model further located quantities of land use change within the region according to mechanisms described and critically discussed in Chapter 5. The land use and land cover maps projected for the scenarios finally provided a well-documented, methodologically comparable and interpretable basis for spatially explicit assessment of ecosystem services.

It, thus, translated quantities in land use change into spatial patterns which was of crucial relevance to assess the impact of land use changes. An obvious example of the importance of spatial distribution of land use and land cover classes is the ecosystem function "protection against natural hazards" which was calculated for snow avalanches on the basis of a risk assessment (Grêt-Regamey et al., in review). For instance, the protection function of forest depends a) on the forest structure, b) on topographic characteristics of and above the forest area, and c) on its position relative to potential damage areas, i.e. residential areas and infrastructures. Estimates on quantities of change could have not provided the essential input for such an assessment and therefore neither on the potential loss of ecosystem service according to the scenario assumption.

6.4.3 THE ROLE OF PARTICIPATORY INVOLVEMENT IN SCENARIO DEVELOPMENT

Participatory involvement can fulfil numerous functions within research projects (Antunes et al., 2005; Siebenhüner and Barth, 2005). In the ALPSCAPE project, the involvement of local actors aimed for their contribution of local knowledge to the development of regional scenarios, and for the increased understanding and discussion of long-term future issues including the interaction between natural and social system. The active involvement into the project occurred through a number of participatory workshops. But some key stakeholders were already engaged when the project idea was formulated, and also the public was approached through the local and regional press at an early stage of the project.

The first intension of participatory scenario development resulted in a systematic gathering of local system knowledge in the satellite group workshops in order to enable and improve regional scenario development. From the viewpoint of knowledge generation, however, the participatory involvement could not contribute as much as expected to the development of the scenarios. One problem was that the outcomes of the satellite groups varied strongly in terms of elements included, and did not match up with each other to form one comprehensive system. The identified elements and system graphs produced during the workshops, therefore, had to undergo several steps of further re-selection and post-processing by the research team until qualitative scenarios could be drawn from them. If a set of elements would have been suggested by the researchers, this problem could have been possibly reduced, but might have had also the negative effect of attenuating the group discussions. Furthermore the participatory process could not contribute to the critical process of scenario parameterisation and quantification. The transformation of qualitative scenarios into sets of coherent input parameter values remained with the researchers, mainly because it would have required very specific and detailed knowledge of the numerical modelling framework. Still, the participatory involvement deepened and validated the existing system understanding of the researchers profoundly and ensured relevance, logic, consistency and validity of the elaborated scenarios.

The second intention was to address the key stakeholders and local public through involvement into the project in order to discuss long-term future options of the region. The people involved in the advisory group represented indeed key stakeholders and important decision-makers and therefore main addressees of the study. For them the workshops were a unique platform to discuss long-term issues in such a diverse group. They also showed great interest beyond the direct scope of the project, for instance through inviting the research team to the local executive in order to present the research results and discuss them with the policy makers. The organisation of the satellite group workshops was a successful multiplier which involved additional local actors without a specific representative function within the community.

In brief, the participatory approach was a success in terms of facilitating the discussion on long-term regional development, although the workshops could not contribute to the development of regional scenario for the numerical simulation to the extent expected.

6.5 Conclusions

This chapter demonstrates the role of the Land Use Allocation Model within the integrated regional modelling framework and evaluates the effect of participatory involvement into scenario development.

Within the integrated approach to regional modelling, the Land Use Allocation Model could link the social and the natural system by providing likely and spatially explicit simulation results of land use and land cover patterns. This is in particularly relevant, as changes in land use and land cover impacts the natural system in a different manner and to a different degree depending on locations of change. The modelling technique, on which the simulation outcomes are based, is well-documented, and the simulation outcomes form an interpretable and methodological comparable basis for further impact assessment through the ecosystem service approach.

The trans-disciplinary approach to future scenarios of regional development resulted into two major findings. First, the participatory collaboration could not contribute to the development of future scenarios to the extent expected. Reasons for that include methodological problems in the acquirement and systematisation of local knowledge, and the complexity of the integrated modelling framework. Second, the participatory involvement could increase the local participants' understanding of interactions between the social and natural system, and could rise their attention to long-term regional development issues, which exceeded the scope of planning and policy making by far. As also key stakeholders of the Davos region could get involved, principle addressees of the research were reached in this process, who finally showed interest into the research beyond the direct scope of the project.

CHAPTER 7

ESTIMATING QUANTITIES OF LAND USE CHANGE FOR SETTLEMENT EXPANSION AND EFFICIENCY ASSESSMENT

In this chapter, a method to derive rates of land use change for settlement expansion from changes in tourist overnight stays is introduced. The estimates on settlement expansion are derived in a two steps approach that derives Gross External Floor Area (GEA) from the number of overnight stays for given accommodation types first, and then draws the settlement expansion from these outcomes by accounting for spatial planning parameters. While the GEA is further used to assess the efficiency of area consumption, the results for settlement expansion illustrate the complexity and uncertainties of estimating future rates of land use change.

The chapter is based on a journal publication that assesses the efficiency of land use for tourist accommodation by combining estimates of land use change with regional Input-Output Modelling (IOM) for the region of Davos. As mentioned earlier, the development of the IOM and the establishment of production functions are the work of Susanne Kytzia and Mattia Wegmann and accordingly the economic results throughout this chapter originated from Susanne Kytzia's analysis.

Kytzia, S., Walz, A. and M. Wegmann. (in preparation): How can tourism use land more efficiently? - A model based approach to qualitative growth for Davos. Tourism Management.

Herein, the research methodology of the paper is adapted to demonstrate how rates of land use change can be estimated for settlement expansion due to tourism development, and how they can contribute to assessing alternative development options. Because of the customized structure of the land use model and the IOM, it was possible to link area consumption directly to the output of the regional economic model, which allowed assessing the efficiency of land use for alternative development options (Kytzia et al., in prep.). As opposed to the approach chosen in the paper, this chapter refers to Gross External Floor Area (GEA) because of its relevance in spatial planning and therefore for the expansion of the settlement area.

Within the conceptual framework of the thesis, this approach links the regional economy with demand on land (Figure 40). Based on the same input parameters, the regional IOT and the model on estimates of area requirements can be coupled, for instance, to assess the efficiency of area consumption. At the same time the estimates on area requirements are further used to approximate the settlement expansion and therefore could provide input values for the allocation model.

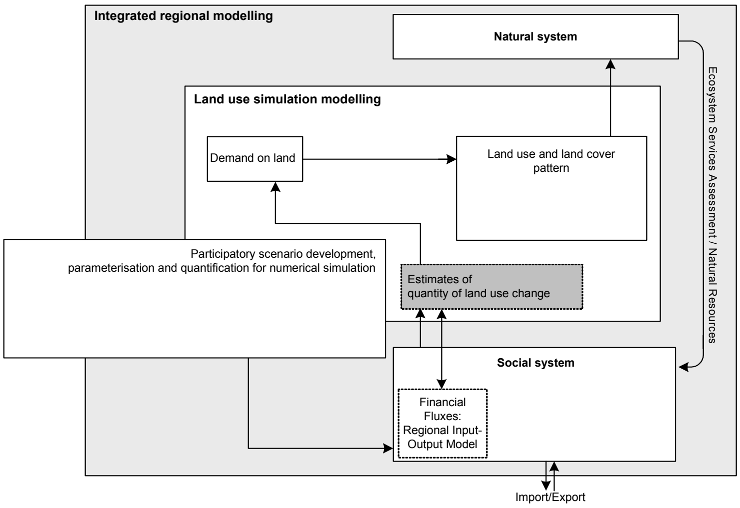


Figure 40: The method presented in this chapter derives area requirements and demand on land from changes in the social system. Due to the customised structure of the model, the results can be directly related to the regional economy in order to assess the efficiency of area consumption.

7.1 Methodology

A model to estimate possible future area requirements for alternative tourism development will be established for the region of Davos. The area requirements are measured in Gross External Floor Area (GEA) and are derived as a function of the number of overnight stays, their distribution over accommodation categories and further factors (Figure 41). The estimates of GEA are applied to derive their possible implications for settlement expansion with respect to spatial planning parameters (Figure 41). Similar to the approach presented in Kytzia et al. (in prep.), the efficiency of area consumption is furthermore assessed for alternative tourism development through linking the outcomes of the model with their impacts on the regional economy derived from the regional IOM (Figure 41),

The model to estimate area requirements and settlement expansion is developed to demonstrate the effect of alternative tourism development and to identify the principles uncertainties and controls of settlement expansion. Settlement expansion is implemented in a two-step manner, that indicates the importance of structural changes in tourism as well as planning parameters.

The coupled model combines the changes in the tourism structure, with their impact on the regional economy and their area requirements. A sensitivity analysis reveals crucial parameters of resource-efficient tourism development, and a scenario analysis allows to compare development options in terms of their efficiency in area consumption and their impacts on settlement expansion.

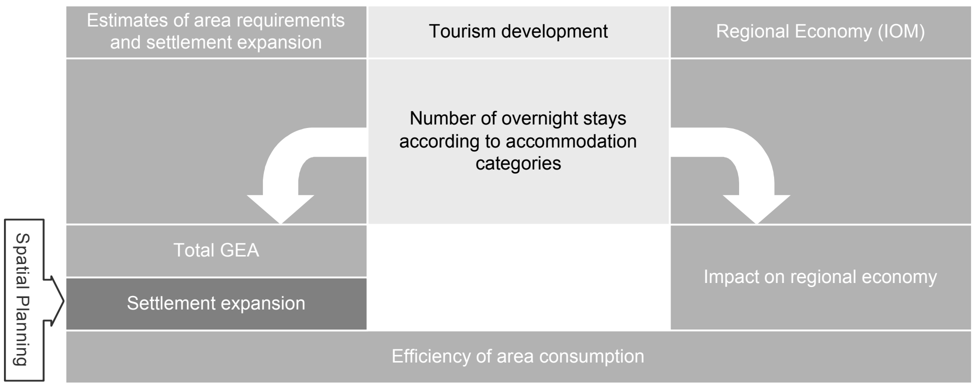


Figure 41: The model presented estimates area requirements expressed in Gross External Floor Area (GEA) for alternative tourist development. In addition to spatial planning parameters, the GEA is an important factors to further derive possible settlement expansion. The model can directly be linked to the regional IOM in order to assess the efficiency of area consumption.

7.1.1 ESTIMATES OF AREA REQUIREMENTS AND SETTLEMENT EXPANSION

Specification of "Gross External Floor Area" and "Settlement Area"

Kytzia et al. (in prep.) calculated quantities of change using the base area or "footprint area" of buildings. However, this base area is less compatible with estimates of settlement expansion and therefore also with the derivation of input parameters for the Land Use Allocation Model. Complementing Kytzia et al. (in prep.), an approach is used here, where area measures are expressed in "Gross External Floor Area" and "Settlement Area".

- The *Gross External Floor Area* (GEA) is defined as the sum of all spaces that are used for living, working or trading including walls, but excluding, for instance, basements, staircases and underground car parks (Landschaft Davos Gemeinde, 2001). The GEA represents a convenient measure to derive the total area affected by settlement development, since in Swiss spatial planning the Construction Capacity Factor (CCF), which regulates housing density in development zones, is defined as the ratio of GEA and a premises' area (Landschaft Davos Gemeinde, 2001).

$$CCF = \frac{GEA}{Area_{Premises}} \tag{5}$$

where
CCF = Construction Capacity Factor
GEA = Gross External Floor Area
$Area_{Premises}$ = Area covered by premises.

- The *Settlement Area* is specified as the area of buildings, their gardens or other areas visually belonging to the building for the focus area (i.e., the classes 45 - 49 for "Gebäudeumschwung" in SFSO, 2001b). This corresponds to the definitions of Area Statistics survey classes and their aggregation, used in the allocation model (Chapter 3). Therefore, it will provide the most suitable input for the allocation model. Within the densely developed focus area, we assume that these areas represent the premises

$$Area_{settl} = \frac{GEA}{CCF} \tag{6}$$

where
$Areas_{ettl}$ = Settlement area according to the above definition.

Model-based estimates of GEA

The estimates of required GEA for alternative tourism developments are based on a theoretical value of "GEA per overnight stay". The GEA per overnight stay strongly depends on utilisation rate *U* and average GEA per bed *D* for the different accommodation types. While *U* indicates the ratio of number overnight stays per possible number of overnight stays, *D* represents building design and utilisation for each accommodation type. Both parameters change over time. However, *D* is less flexible, and becomes only relevant, if we assume the construction of a new building or the fundamental renovation of an existing building

$$GEA_T = f\{U, D, x\} \tag{7}$$

where
GEA_T = Gross External Floor Area required for tourist accommodation
U = Utilisation Rate
D = GEA per bed
x = Number of Overnight stays.

Model-based estimates of settlement expansion

Estimates for settlement expansion for different tourism development alternatives suitable as an input to the allocation model (Chapters 4, 5 and 6) are based on the estimates of GEA. Two important aspects are taken into account in this regard.

First, if we assume "greenfield development", i.e. the further construction activity outside of the recent settlement area, the spatial planning, namely the assumed CCF, plays an important role. The CCF regulates the GEA allowed per site. The CCF within the settlement area of the Davos region ranges between 1.25 for the centre zone and 0.35 for the outer zones (Figure 44). If we assume the development of further tourist accommodation outside the present settlement area, the CCF has to be assumed to be rather low (e.g. 0.3).

Second, the remaining potential to expand GEA within the recent settlement area needs to be taken into account (Figure 44). This remaining potential provides an important reference point, as the expansion of GEA does not necessarily lead to an expansion of the settlement

$$Area_{Sett} = f\{GEA_T, CCF, GEA_{PlanPot}\} \tag{8}$$

where
$Area_{settl}$ = *Settlement expansion*
$GEA_{PlanPot}$ = *Potential to expand Gross External Floor Area within the scope of spatial planning.*

Conceptual basis to estimate area requirements

Models to derive space requirements from economic activities often assume a linear relation between space requirements and economic activities (e.g. Engelen et al., 1995; Hubacek and Sun, 2000; Thomson and Psaltopoulos, 2005). In the case of the tourism accommodation industry, the assumption of a constant linear relation between overnight stays and area requirements implies that U and D remain constant. Therefore, an increase in overnight stays should always result in an increase of capacity (Figure 42A). This is a great simplification, but depicts well the strongly seasonal utilisation of tourist accommodation with accommodation capacities being designed to meet peak demands.

In this research, however, the effects of changes in U, D and, in the case of capacity expansion, planning parameters will be also addressed. Kytzia et al. (in prep.), therefore, assume a step function that relates the number of overnight stays with the space requirements (Figure 42B). A step function is considered to better reflect the relation between overnight stays and area requirements because of large “buffers” in space utilisation. The step function takes into account that present U is below full occupancy. This indicates a great potential to increase the number of overnight stays without any expansion of capacities and settlement area. Space requirements, GEA_T, are therefore alternatively incorporated as a function of U, D and the number of overnight stays, x. As long as the area requirement, $GEA_{T(U,\ D,\ x)}$, falls below the value of available space (referred to as “Initial State” in Figure 42B), x can increase without a shortcoming of beds and without capacity expansion. This technique allows simulating alternative tourism planning scenarios, for instance a strategic focus on the reduction of seasonal fluctuation patterns.

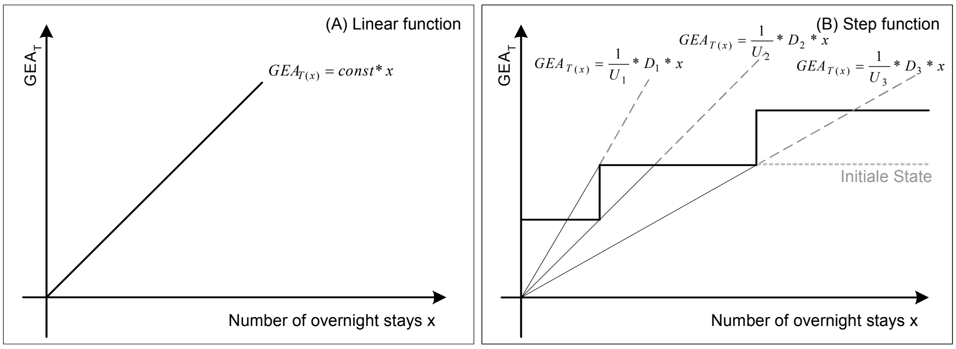


Figure 42: Concepts for the implementation of area requirements (A) as a linear function $GEA_{T(x)}$, and (B) as a step function $GEA_{T(U, D, x)}$ for i and j examples of fixed values of U_i and D_j (Kytzia et al., in prep.). Note that (A) is a special case of (B), where D_j/U_i = constant.

Whether and to what extent an increase in capacities results in an expansion of settlement area is determined by building design and planning parameters. Similar to the estimates of GEA, the settlement expansion also can be estimated from a step function. Use of a linear function neglects the potential to expand GEA within the existing settlement area. An expansion of the settlements corresponds with the product of the estimated ΔGEA_T and the *CCF*.

$$\Delta Area_{settl} = CCF*\Delta GEA_T \quad (9)$$

where
$\Delta Area_{settl}$ = *Settlement expansion*
ΔGEA_T = *Additional Gross External Floor Area required for tourist accommodation.*

If the potential to increase GEA within the settlement area is accounted for, an increase in settlement area is only necessary if $\Delta GEA_T > \Delta GEA_{PotPlan}$.

$$\Delta Area_{settl} = 0 \qquad , \text{if } \Delta GEAT <= GEA_{PotPlan} \quad (10)$$

$$\Delta Area_{settl} = CCF*(\Delta GEA_T - GEA_{PotPlan}) \qquad , \text{if } \Delta GEAT > GEA_{PotPlan} \quad (11)$$

Procedure to estimate area requirements and assess efficiency of land consumption

Similar to the regional IOM, the model of space requirements consists of a look-up table (Table 18). Within the rows, five accommodation types are distinguished which are related to particular buildings within the GIS database. The columns differentiate between space requirements and utilisation of each accommodation category.

The first block of columns incorporates the empirically derived information from the GIS database and tourism information as provided by the local tourism authority for the business years 2002/2003 and 2003/2004 (Davos Tourismus, unpublished data). In this block, ratios are calculated for *D* and D_{overn}. While *D* as a measure of GEA per bed indicates the prevailing standards of building design and potential utilisation, the required space per overnight stay

D_{overn} can be derived as a constant factor from empirical data (Table 18), or alternatively as a function of U and D.

Within the second block of columns, simulations of tourism strategies can be run. First the required area F is derived as the product of D_{overn} and the number of overnight stays, x. Then the derived $GEA(x)$ is compared with the potential still available to increase GEA within the existing settlement, $GEA_{PotPlan}$. For the proportion of $GEA(x)$ that cannot be covered by $GEA_{PotPlan}$, the expansion of the settlement is calculated on the basis of the planning parameter CCF which controls the density of housing development. For the areas at the boundary of the presently developed area of Davos, CCF is 0.35 (Figure 44).

The third block of columns relates the simulated area requirements $Area_{settl}$ to the corresponding value added to the region. The ratio of value added to the region and space requirements indicates how efficiently the land resource is used in economic terms according to recent consumption patterns and economic structures.

Table 18: Model to estimate requirements of GEA and settlement expansion from tourism structures, and assess them in combination with the regional economic model in terms of resource efficiency.

	Empirical relations derived from spatial database						Estimates of required GEA	Estimates for settlement expansion			Economic assessment	
Accommodation Categories	Number of overnight stays	Capacity [Number of beds]	Occupancy Rate [%]: U	Available Space in GEA [m²]	GEA/bed D_i [m²/bed]	Required space in GEA/overnight stay: D_{overn} [m²/overnight stay]*	$GEA(U,D,x)$ [m²]	Construction Capacity Factor [m² GEA/ m² premises]	Potential to expand GEA within existing settlement [m²]	Expansion of settlement: $\Delta Area_{Settl}$ [m²]	Value added to the region triggered by the additional overnight stays x_j [CHF]	Efficiency of in GEA: Eff_{GEA} [m²/kCHF]
Luxury Hotels	X_1	B_1	$\frac{X_1}{n_{PotStays}}$	F_1	$\frac{F_1}{B_1}$	$\frac{F_1}{X_1}$	$\frac{1}{U_1} * D_1 * x_1$	CCF	$GEA_{PotPlan}$	$CCF * \left(\frac{1}{U_1} * D_1 * x_1 - GEA_{PotPlan}\right)$	v_1	$\frac{\Delta Area_{settl}}{\Delta v_1}$
Standard Hotels	…	…	…	…	…	…	…	…		…	…	…
Budget Hotels	…	…	…	…	…	…	…	…		…	…	…
Group Accommodations	…	…	…	…	…	…	…	…		…	…	…
Vacation Rentals and Secondary Homes	X_n	…	…	…	…	…	…	…		…	…	…

Calibration of area requirements through spatial database

To approximate the parameter values required for model-based estimates, empirical data from a focus area between Davos-Frauenkirch and Davos-Wolfgang (Figure 43) was used. This focus area covered about 4.2% of the region of Davos, but over 90% of the available tourist beds.

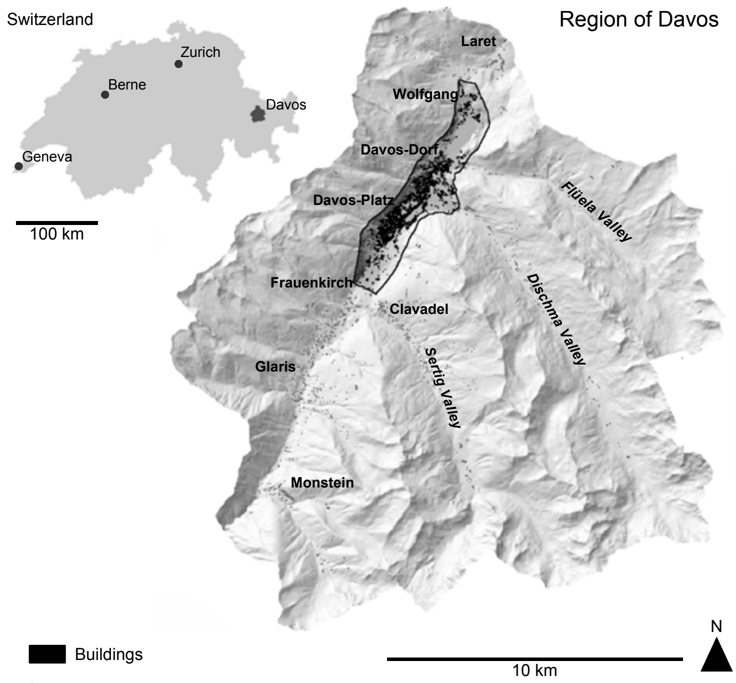


Figure 43: Focus area for estimating quantities of change for tourist accommodation in Davos. (DTM reproduced by permission of swisstopo (DV033492), building data courtesy of the Municipality of Davos, Source: LIS Davos)

Total GEA for each accommodation type were derived from estimates based on the cadastral database of the Municipality of Davos, LIS Davos (Chapter 3). The spatial database includes the plan base area of all buildings with their predominant use, the premises and the planning zones. Figures on the number of floors of residential buildings were added from an address-based database including 1080 buildings (Pfister and Jurkiewicz, 2004). The remaining 45.7% of residential buildings within the focus area were mapped in the field. The product of the base area of the buildings, the number of floors above ground and a correction factor of 0.8 (Max Brunner, pers. comm., 2004) were used to approximate GEA for each building.

For hotels and group accommodation, the standard and the number of beds were added to the database based on the official brochure of Davos Tourismus (2003). Subsequently, the total GEA and the bed capacities were directly extracted from the spatial database. Average GEA per bed D and average GEA per overnight stay D_{overn} were derived for these four categories (Table 18).

For vacation rentals and secondary homes, the procedure was different, as no spatially explicit data are available at the scale of individual buildings. As the cadastral database includes the prevailing type of utilisation, the total GEA used for residence could be derived and combined with the proportion of GEA used as “temporarily used living space“ within the focus area according to census data (Census 1990, SFSO GEOSTAT). Survey data on accommodation capacities in vacation rentals and secondary homes from the local tourist authority (Davos

Tourismus, 2003, unpublished data) built the base to derive area requirements per bed (Table 18).

Contemporary spatial planning was used as an important reference point to compare the estimates for expansion of GEA with the existing limitations. The potential GEA is calculated for each premises on the basis of a planning zone's CCF, while the difference between the existing and the potential GEA gives the additional development potential (Figure 44).

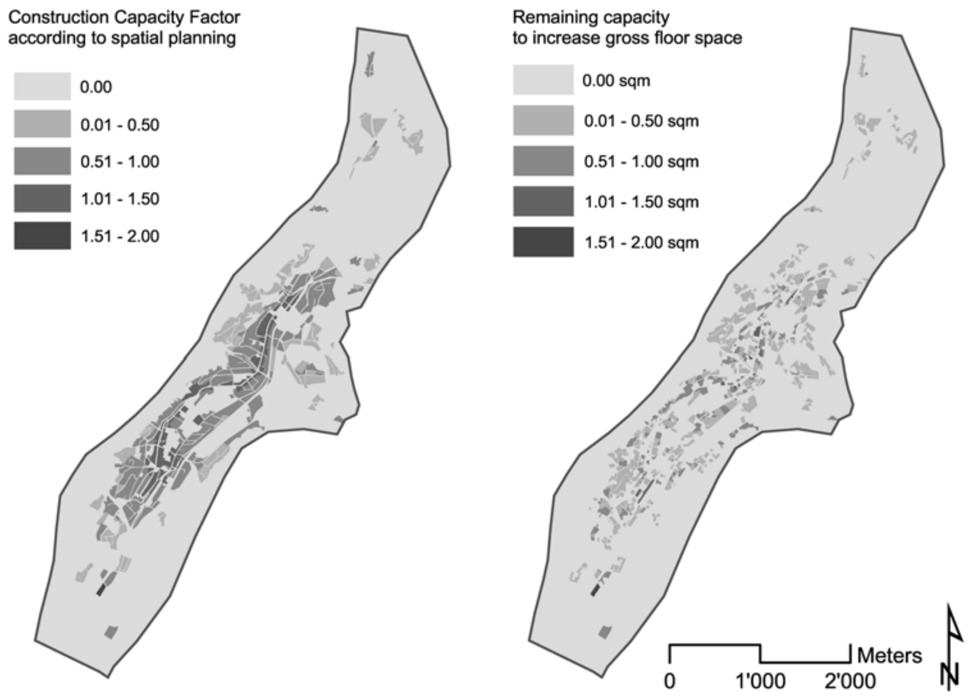


Figure 44: Spatial planning zones with their Construction Capacity Factors (CCF), and the remaining capacities as difference between existing and potential GEA. (Reproduced with permission of the Municipality of Davos, Source: LIS Davos.)

7.1.2 REGIONAL ECONOMY

The economy of the region is displayed in the regional Input-Output Model, which is described in more detail elsewhere (Kytzia et al., in prep.; Wegmann and Kytzia, 2005). Regional IOMs are used to display the economic structure of a region through financial flows between different industries within the region and import/export quota. They are based on the assumption that the input used in producing a product or providing a service is related to the output by a linear and fixed coefficient (Leontief, 1966, cited in Isard, 1998). The principal element of an IOM is a matrix in which the relevant industries are displayed in columns as well as in rows. One industry is related to all other industries through the proportion of total input of the industry to its supply industries (Table 19). Once the coefficients and the net final demand have been derived, the IOM can be transformed to demonstrate the impact of changes in final demand on the regional economy (further explained in Isard, 1998; and Wegmann and Kytzia, 2005).

Table 19: Example of an Input-Output Model, containing the empirically derived flows between industries and accounts. The consumption coefficients c_i per unit of output are displayed in brackets (according to Wegmann and Kytzia, 2005).

	Industry 1	Industry 2	Industry 3	Net Final Demand	Total Output
Industry 1	0 [0.0]	20 [0.1]	45 [0.3]	35	100
Industry 2	30 [0.3]	0 [0.0]	30 [0.2]	140	200
Industry 3	0 [0.0]	80 [0.4]	0 [0.0]	70	150
Value Added	70 [0.7]	100 [0.5]	75 [0.5]		
Total Input	100	200	150		

For the establishment of regional IOMs, Wegmann and Kytzia (2005) combined existing information on financial fluxes between industries on a different spatial level or in a different region with new surveys within the target study area. The regional IOM for Davos is based on an existing IOM for the Steiermark region in Austria (Fritz et al., 2003a), which was adapted to the economic structure of Davos and validated through a survey within the region (Wegmann and Kytzia, 2005). The Steiermark region was selected due to similarity in its economic structure, namely the important role of alpine tourism for the regional economy. The validation of the data and the derived model included a full survey of the primary focus sectors, including mountain railways, accommodation and catering industry, clinics and the municipality. In the initial regional IOM, tourism accommodation is only one out of 22 industries.

Focus on tourism

In order to focus particularly on tourism structures, final demand for tourist accommodation had to be isolated and disaggregated according to consumption patterns (Kytzia et al., in prep.). A survey in the canton of Valais, Switzerland (Rütter et al., 2001) could be applied to distinguish demand in tourism for five classes of tourists according to consumption patterns and budgets. These distinguished categories are related to accommodation standards as differentiated in the spatial database: Luxury hotels, standard hotels, budget hotels, group accommodations and vacation rentals and secondary homes (Table 18).

To reflect variation in total demand, consumption patterns and utilisation ratios between summer and winter season, the IOM is split into two seasons in Kytzia et al. (in prep.), i.e. May to October and November to April (Table 20). In winter, all classes of tourists tend to spend more than in summer. As many come for alpine skiing, the greatest proportion of this additional spending is used for the mountain railways, but also the ratio of expenses to other industries differ slightly between summer and winter consumption (Table 20).

The regional IOM with focus on tourism reacts to changes in tourism structure, more specifically to the absolute numbers of overnight stays in each tourist category for both seasons. The number of overnight stays in particular accommodation categories represent the trigger of the model (Figure 41). They generate a proportional demand in various industries and allow deduction of the total value added to the region.

Table 20: Consumption coefficients (c_i) for all tourist categories considered in the model (Kytzia et al., in prep.).(Not including hospitals and other health services)*

Expenses (in kCHF)	Luxury Hotels		Standard Hotels		Budget Hotels		Group Accommodations		Vacation Rentals and Secondary Homes	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Accommodation	0.196	0.1741	0.0836	0.0908	0.0715	0.0715	0.0394	0.0485	0.0329	0.041
Food	0.0439	0.0546	0.0342	0.0347	0.0283	0.0304	0.0267	0.0186	0.0221	0.0246
Transport	0.0036	0.0044	0.0055	0.0026	0.004	0.0011	0.0032	0.0033	0.0042	0.0012
Mountain railways	0.0126	0.0287	0.0084	0.0136	0.0085	0.0257	0.0048	0.0182	0.0061	0.0194
Sport courses	0.0014	0.0059	0.0013	0.0039	0.0014	0.0029	0.0081	0.0021	0.0024	0.0041
Education	-	0.0022	0	0.0006	-		-	0.0005	-	0.0001
Retailing	0.0429	0.0267	0.0131	0.0115	0.01	0.0101	0.0069	0.0062	0.0151	0.0201
Entrance fees	0.0002	0.0006	0.0007	0.0005	0.0004	0.0002	0.0004	0.0004	0.0004	0.0003
Health services *	0.0024	0.0003	0.0006	0.0019	0.0002	0.0004	0.0004	0.0002	0.0006	0.0009
Rental equipment	0.0059	0.0075	0.0004	0.0027	-	0.0048	0	0.0025	0.0002	0.0031
Others	0.0081	0.0017	0.0063	0.001	0.0018	0.0012	0.0017	0	0.0015	0.0009
Sum per capita and day	0.317	0.3067	0.1541	0.1638	0.1261	0.1485	0.0918	0.1006	0.0854	0.1154
Number of overnight stays	177000	231000	138000	186000	56000	99000	27000	89000	376000	670000
Total	56116	70850	21269	30465	7059	14698	2478	8950	32114	77298

7.2 Results

Economic values presented in this section are the result of Susanne Kytzia's calculations. Different to the results in Kytzia et al. (in prep.), the values for the efficiencies are based on GEA instead of base area ("footprint area" in Kytzia et al., in prep.).

7.2.1 STATUS QUO

By combining the existing spaces with the number of overnight stays for each tourist category, the spatial database illustrates how built-up area is recently used through tourism. GEA per bed and the occupation of available space vary significantly between different tourist categories (Table 21). The ratio between value added to the region for an increase of 1'000 overnight stays in one specific tourist category and the GEA required to host this number of people in this category indicates how efficient built-up area is used.

The tourism structure is characterised by a great proportion of overnight stays (over 40%) in vacation rentals and secondary homes (Table 21). With 16'100 beds or 65.8% of all available tourist beds, vacation rentals and secondary homes dominate the existing capacities, but show low utilisation rates, mainly over the summer (12%). Although *D* is low with 22.4 m^2/bed compared to the hotel categories, the total GEA occupied by vacation rentals and secondary homes adds up to 360’820 m^2 and accounts for 60.9% of all GEA consumed by tourist accommodation. The total value of goods and services produced through vacation rentals and secondary home tourism contributes with 25.1% CHF strongly to tourism-driven value added to the region. But due to a generally low *U*, the efficiency in terms of resource consumption is low with an average of only 0.16 kCHF/ m^2 in summer and 0.22 kCHF/ m^2 in winter.

Although the available capacities are considerably smaller with 2’689 and 2’270 beds, luxury and standard hotels contribute to the total of overnight stays with 19.9% and 15.8%, respectively (Table 21). Due to higher occupancy rates, the lower *D* with 41.4 m^2/bed and 33.6 m^2/bed is compensated in terms of space used per overnight stay. The economic efficiency of space utilisation of standard hotels exceeds vacation rentals and secondary homes by a factor of 4. With about 0.16 kCHF/m^2, luxury hotels produce a high added value per area, surpassing standard hotels by a factor of 2.

Table 21: Status-quo for characteristics of area consumption through tourist accommodation.

Accommodation category	Season	Number of overnight stays	Capacity [Number of beds]	Occupancy rate *U* [%]	Total GEA [m^2]	GEA/bed *D* [m^2/bed]	GEA/overnight stay D_{overn} [m^2/overnight stay]	Efficiency of Area Consumption Eff_{GEA} [kCHF/m^2]
Luxury hotels	**Summer**	224'800	2'690	45.8%	111'458	41.4	0.22	0.79
	Winter	273'800		55.8%				0.79
Standard hotels	**Summer**	374'300	2'270	45.2%	76'336	33.6	0.22	0.44
	Winter	458’300		55.3%				0.49
Budget hotels	**Summer**	13’540	1140	34.7%	34'195	30.0	0.18	0.40
	Winter	21'500		55.1%				0.47
Group accommodations	**Summer**	51’600	930	30.4%	9'547	10.3	0.07	0.78
	Winter	83'700		49.2%				0.87
Vacation rentals and secondary homes	**Summer**	372'600	16'100	12%	360'820	22.4	0.36	0.16
	Winter	646'400		22%				0.22

Due to the high *D* with 10.3 m^2/bed, the efficiency in space consumption is with almost 0.87 kCHF/m^2 for the winter season extraordinarily high for group accommodations (Table 21). However, the proportion of overnights in group accommodation account for only 5.7% of all overnight stays with the available capacities representing only 4.0% of all capacities.

Within the existing tourism structure, budget hotels play only a minor role due to low capacities and corresponding low numbers of overnight stays. In terms of resource efficiency, they show lower values than standard hotels, but are still far more resource-efficient than vacation rentals and secondary homes (i.e. by a factor of 3).

7.2.2 SENSITIVITY ANALYSIS

A sensitivity analysis illustrates relations between different factors and aims for a better system understanding by systematically modifying single parameters. Total space requirements in GEA, the value added to the region through different tourist categories and the efficiency of resource utilisation are the key indicators to better understand the interaction between tourism development and the expansion of settlements. For the sensitivity analysis, the parameters investigated are separately increased by 10%. First, the number of overnight stays is modified separately for each tourist category while keeping the space requirements constant. This modification implies a rise of *U* by 10% without any further construction development. Then, the building densities are modified for each accommodation type and the consequences for the settlement area can be discussed.

Changes in added value through modified numbers of overnight stays for each accommodation category illustrate how strong the economic impact of luxury tourism is likely to be. In absolute added values the increase by 10% in luxury tourism would cause an augmentation of added value by almost 9 Mio. CHF per year. Only an increase by 10% in vacation rentals and secondary homes would have a comparable impact on the local economy. The reasons for these strong impacts are different, though: While luxury tourists are fewer, they spend considerably greater budgets than tourists staying in vacation rentals and secondary homes. Due to the absolute number of overnight stays in vacation rentals and secondary homes, a 10% modification, however, implies a great number of additional overnight stays.

When the number of overnight stays are modified, different consumption patterns for summer and winter season become obvious. Due to higher spending in winter, a 10% modification of overnight stays shows a greater effect for the winter than for the summer season. In accordance to the observed changes for absolute values in value added to the region, the luxury hotels and the vacation rentals and secondary homes show the greatest changes for the combined indicator.

When the two values are combined in the efficiency indicator, the relative changes to the status-quo (Table 21) differ strongly from the 10% modification of the input parameter. An increase in *D* by 10% causes an increase in efficiency of resource consumption by 7.97% for vacation rentals and secondary homes. This relative change of efficiency is by far the highest change observed. This strong effect is due to the large area that is (currently rather inefficiently) used for vacation rentals and secondary homes.

Table 22: Results of the sensitivity analysis.

Parameter to be increased/ decreased by 10%			**Absolute change in value added [kCHF]**	**Absolute change in GEA [m²]**	**Relative changes in value added per GEA**
Number of overnight stays *x*	Luxury hotels	Summer	3'812.39	0	+1.93%
		Winter	4'963.99	0	+2.51%
	Standard hotels	Summer	1'441.82	0	+0.73%
		Winter	2'141.22	0	+1.08%
	Budget hotels	Summer	492.26	0	+0.25%
		Winter	1'034.46	0	+0.52%
	Group accommodations	Summer	173.20	0	+0.09%
		Winter	639.51	0	+0.32%
	Vacation rentals and secondary homes	Summer	2'129.03	0	+1.08%
		Winter	5'188.65	0	+2.62%
GEA per bed *D*	Luxury hotels		0	-11'145.8	+1.10%
	Standard hotels		0	-7'633.6	+0.90%
	Budget hotels		0	-3'419.5	+0.52%
	Group accommodations		0	-954.7	+0.13%
	Vacation rentals and secondary homes		0	-36'082.0	+7.97%

7.2.3 SCENARIOS TO ESTIMATE AND ASSESS LAND USE CHANGE

While single parameters have been tested in the sensitivity analysis, the use of scenarios allows us furthermore to combine parameters and draw a more differentiated and comprehensive picture of possible future changes. Its intention is not to predict future developments, but to demonstrate principal pathways and compare alternative strategies in tourism management with regard to the expansion of GEA, recent spatial planning, the expansion of the settlement area and the efficiency of resource use.

In terms of qualitative growth, resource consumption, i.e. area, and the impact on the local economy represent the two principal aspects of our investigations (Renn et al., 1998). According to these two aspects, two scenarios were defined:

(1) Growing capacities to meet peak demand. The first scenario assumes an expansion of capacities to further adjust to peak demand. It propose an augmentation of capacities by 250'000 beds, while *D* and *U* are assumed constant. Hence, the space required per overnight stay is kept constant, too, and a linear relation is assumed between the number of overnight stays and the area they require. The scenario is sub-divided according to the tourist accommodation categories. First, the tourist structure is assumed to be identical to 2002/03 and the capacity expansion is distributed proportionally (1A). Then, the same number of beds is developed only in vacation rentals and secondary homes (1B), or only in group accommodations (1C) or finally only in luxury hotels (1D). The expansion of tourist accommodation to meet peak demand reflects a tendency observed in many regions, including the region of Davos, and manifesting itself mainly through the construction of second homes. The input parameter values for the scenario are specified in Table 23.

Table 23: Input parameter values in number of overnight stays per tourist category for the scenario calculations.

Tourist Category	Season	Status quo	(1) Growing capacities to meet peak demand				(2) Utilisation of existing capacities	
			Recent tourist structure (1A)	Group Accommo-dations (1B)	Luxury hotels (1C)	Vacation rentals and secondary homes (1D)	Reduction of seasonal fluctuation (2A)	Increase of luxury tourism (2B)
Luxury hotels	Summer	56'000	56'000	56'000	56'000	56'000	99'000	56'000
	Winter	99'000	118'412	99'000	99'000	99'000	99'000	99'000
Standard hotels	Summer	138'000	138'000	138'000	138'000	138'000	186'000	138'000
	Winter	186'000	222'471	186'000	186'000	186'000	186'000	186'000
Budget hotels	Summer	177'000	177'000	177'000	177'000	177'000	231'000	314'667
	Winter	231'000	276'294	231'000	481'000	231'000	231'000	314'667
Group accommodations	Summer	376'000	376'000	376'000	376'000	376'000	670'000	376'000
	Winter	670'000	801'373	670'000	670'000	920'000	670'000	670'000
Vacation rentals and secondary homes	Summer	27'000	27'000	27'000	27'000	27'000	89'000	27'000
	Winter	89'000	106'451	339'000	89'000	89'000	89'000	89'000
Total		2'049'000	2'299'000	2'299'000	2'299'000	2'299'000	2'550'000	2'270'333

The outcomes for the GEA of the scenario implying a rise of capacities to serve peak demand vary between around 20´600 m^2 and 86´200 m^2 depending on the distribution of overnight stays over the accommodation categories (Table 24). An increase in capacities according to the recent tourism structure results in an augmentation of GEA by around 72´000 m^2. This increase in GEA is only slightly higher than the increase that would be caused if only luxury hotels were expanded (around 68´300 m^2). As group accommodations show dense building design in general, an increase in bed capacity leads to the least area consumption (around 20´600 m^2). The greatest increase in GEA would be caused by an augmentation of only the vacation rentals and secondary homes. The outcome of these calculations indicates again the dominant role of vacation rentals and secondary home tourism within the region regarding area consumption.

From the increase in GEA, the increase in settled area can be identified with respect to the definition of *Housing and Infrastructure* in Chapter 3. According to the contemporary local planning, the peripheral areas of the settlement are built with a *CCF* of 0.35. A *CCF* of 0.35 means that a building of 350 m^2 GEA can be constructed on a site of 1´000 m^2. We use a CCF of 0.3 to derive the expansion of the settlement and round the outcome to full hectares with respect to the input data requirements for allocation modelling (Chapter 5). Based on the assumption that the expansion of capacities occurs purely on the “greenfield”, the increase of settlement covers additional area of 7 to 29 ha depending on the accommodation category. The lowest value would be achieved if only group accommodations expand their capacities, while the highest value derives from expansion in vacation rentals and secondary homes. For comparison, the expansion by 24 ha, as derived in the case of a constant tourism structure, represents an increase by 7.21% to the 333 ha of *Housing and Infrastructure* in ASCH92/97 for the focus area. The observed changes in *Housing and Infrastructure* between AS79/85 and AS92/97 add up to 26 ha (8.11%), but construction of residential development caused only about 63.3% or 17 ha of the expansion.

Table 24: Scenario outcomes for tourism development alternatives.

	Indicators	**(1) Growing capacities to meet peak demand**				**(2) Utilisation of existing capacities**	
		Recent tourist structure (1A)	**Group Accommo-dations (1B)**	**Luxury hotels (1C)**	**Vacation rentals and secondary homes (1D)**	**Reduction of seasonal fluctuation (2A)**	**Increase of luxury tourism (2B)**
Area Estimates	**$\Delta GEA_{(U,D,x)}$ [m^2]**	+72´000	+20´600	+68´300	+86´200	0	0
Settlement expansion	**$\Delta Area_{settl}$: Settlement expansion [ha] for “greenfield” development with CCF = 0.3 [ha]**	+24	+7	+23	+29	0	0
	$\Delta Area_{settl}$: Settlement expansion [ha] if accounting for expansion potential within the existing settlement	0	0	0	0	0	0
Assessment	**ΔEff_{GEA}: relative change in efficiency of area consumption [%]**	-6.97%	-0.61%	-2.71%	-10.03%	+9.83%	+8.27%

Local planning provides a suitable reference point to compare simulated expansions of GEA with the potential to further expand tourism accommodation. In order to derive the remaining capacities for the focus area, the potential GEA according to planning zones was calculated for each site (Figure 44), and reduced by the already existing GEA. The remaining capacities add up to about 238’000 m^2, i.e. capacities could theoretically expand by 238’000 m^2 or 12.8% of the existing GEA through re-densification and without any expansion of the settlement. The potential to increase GEA within the existing settlement is still high enough to meet the simulated space requirements for all variants of the first scenario (Table 24).

(2) Utilisation of existing capacities: The second scenario implies an increase in value added to the region through the utilisation of existing capacities. This means that the assumption of linearity between the number of overnight stays and the space required is abolished. We assume a step function (Figure 42) and assess the potential that lies within the existing capacities through augmenting the utilisation ratios according to Equation 9. First, we assume a decrease in seasonal fluctuation by increasing the number of overnight stays of the summer season to the level of the winter for each accommodation category (2A). Then, only the utilisation ratio of luxury hotels is augmented to a constant utilisation ratio of 80% (2B). Both scenarios represent common and well-established tourism strategies. Input values for both scenarios are displayed in Table 23.

In accordance with the scenario assumptions, both scenarios 2A and 2B do not cause any further resource consumption (Table 23). Due to their strategy to improve the utilisation of existing capacities, the efficiency of resource consumption increases strongly. An increase of efficiency by 9.83% is reached for the reduction of seasonal fluctuation; for the promotion of luxury tourism the increase reaches 8.27%.

By contrast all scenarios implying a rise of capacities as suggested in the first set of scenarios result in a reduced efficiency of land utilisation (Table 23). Due to the relatively small increase in GEA, an increase in group accommodation shows the least negative effect on the economic efficiency of land use. The economic efficiency differs by a factor of 2.6 between expansion according to the recent tourist structure and only in luxury tourism, although the increase in land consumption varies only by 5.43% between the two options. The expansion according to the recent tourist structure results in a reduction by -6.97%. This comparatively high reduction in efficiency of land usage reflects the dominant role of vacation rentals and secondary homes again in this result.

7.3 Discussion

7.3.1 ESTIMATES OF AREA REQUIREMENTS AND SETTLEMENT EXPANSION

A two step techniques was used to estimate the settlement expansion through alternative tourism development options. First, the GEA was estimated based on two different approaches (Figure 42), once assuming a constant relation between utilisation rates *U* and GEA per bed *D*, and once incorporating them as variables. From the derived in changes in GEA, the expansion of the settlement area was estimates with reference to spatial planning parameters.

Estimates of GEA – linear versus step function

The first set of scenarios was simulated under the assumption of a constant relation between area consumption and number of overnight stays. This technique is similar to previous studies that have derived environmental effects from input-output modelling (Lonergan and Cocklin, 1985). The empirically derived space requirements per overnight stay were related to accommodation categories and – similarly to the basic idea of financial flows in an IOM – linearly extrapolated for increasing numbers of overnight stays. After all, this approach results into an expansion of the GEA for each additional person hosted. This approach is considered appropriate to estimate quantities of change particularly for an expansion of bed capacities in order to meet peak demand, it constitutes a special case in the proposed step function-based approach in which utilisation rate *U* and GEA per bed *D* are assumed constant.

However, it has to be kept in mind, that built structures do not change too much over time. Once built, the structures are likely to remain in place for an extended period of time. Fluctuations in demand and tourism structure are thus not instantly reflected in the actual amount of space provided, but in their utilisation ratios. This implies that a reduction in demand usually does not result in less space provided, but low utilisation ratios and economically inefficient land consumption through the infrastructure.

In reality, it is not true, that an increase in number of overnight stays (and additional added value) results necessarily in additional area consumption. The utilisation rates *U* and GEA per bed *D* can therefore strongly vary. If the assumption of a constant relation between overnight stays and area consumption is dropped, the model becomes more complex, but also allows simulation of alternative tourism strategies and their impact on land consumption. In this case, the proposed step function is of advantage, as *U* and *D* are taken into account.

Based on the step function approach, a second set of scenarios was simulated. Through changes in utilisation rates, an increase in value added to the region was achieved without further increase in bed capacities. Similar effects can be drawn for area expansion from a modification of architectonical and planning factors, such as *D*. In both cases, the gradient of the linear function to describe requirements in GEA is assumed to be linear, but the slope of the functions vary with *U* and *D*. Only when certain thresholds are reached (in an extreme scenarios, for instance, 100% utilisation ratio), additional GEA is required to possibly increase the number of possible overnight stays (Figure 42). Although, these thresholds are hard to quantify in practice, the step function based approach gives a more complex picture of the situation and helps to identify potentials to regulate further area consumption.

Estimates of settlement expansion – the role of planning

In a further step the expansion of settlement which would provide an input to the allocation is derived from the additional GEA estimated from the number of overnight stays. Two pathways are illustrated in the scenario analysis. First, construction is assumed to occur solely outside the existing settlement (referred to as "greenfield" development), then the potential to increase GEA within the existing settlement is acknowledged.

If the use of existing potentials is assumed in the scenarios, no further GEA is required which results in no further expansion of the settlement. Also if the remaining potential to expand GEA within the existing settlement is taken into account, the expansion of settlement is not necessary, even for extreme expansion scenarios. But if the extreme expansion scenario is combined with "greenfield" development, the expansion of the settlement range between 7 to 29 ha depending on the type of accommodation class assumed to expands. This indicates that the differentiation of different tourist accommodation categories is meaningful not only to assess the efficiency of land use, but also to estimate absolute quantities of settlement expansion for the study area. Similarly, the aspect of spatial planning is identified as an important control of land use change. Although the strategies and planning policies are not followed strictly in reality, their effects could be illustrated.

Shortcomings of the model

- One basic modelling assumption is that settlement expansion through expansion of tourist accommodation is caused by shortages in bed capacities during peak season. This, however, is not true in reality, as particularly secondary homes are popular investment objects and their increase is thus not triggered by a shortage in bed capacity during the peak season.
- A decrease in overnight stays would only reflected in a lowering of the utilisation ratio in this model, but of course it could also result in a decrease in area devoted to tourist accommodation. A redistribution of available built-up space is not encountered in this study, as besides tourist accommodation no other land use categories are included into the model.
- The model takes only expansion of the settlement into consideration that is related to tourist accommodation. Any other construction development, e.g. permanent residence, supply infrastructure or recreational use, are neglected in the model.

- The role of spatial planning has to be considered critical when the potential to increase GEA within the existing settlement is applied. First, this potential spreads almost entirely over premises which are already built. This means, to exhaust this potential would imply the extension or re-construction of almost all existing buildings. Second, spatial planning is not sacrosanct. It may change over time and allow for development outside of the existing settlement area if the pressures are high enough.

7.3.2 RESULTS IN TERMS OF LAND USE EFFICIENCY

The combination of area consumption with the regional economy allows assessment of the efficiency of land consumption (Kytzia et al., in prep.). The efficiency is determined by the construction design and usage of the buildings, by the utilisation rates achieved over the year and the consumption patterns of different tourist categories. According to our findings vacation rentals and secondary homes are least efficient in terms of value added per area unit. However, neither GEA per bed nor the consumption pattern of these tourists is so different to the other classes. The main reason are rather the low occupancy rates, mainly in summer (12%), which result in such poor efficiency. According to Bertelli & Weinert (2004), particularly secondary homes are prone to these low occupancy rates.

Group accommodation and luxury hotels are the two tourism categories with the highest efficiency in land consumption, but for different reasons. In group accommodations the *D* is low enough to compensate for the relative low consumption profile and the great fluctuations in occupancy, whereas in luxury tourism the great consumption volume and the relatively good occupancy rates over the entire year can compensate the vast building design.

7.3.3 FURTHER RESEARCH

The further discussion points illustrate shortcomings that could be promisingly addressed in future research.

- Through the combination with an IOM, the estimates of land requirements are linked to economic activities. This link allows to measure the efficiency of resource consumption for tourism development. The changes, however, originated from a scenario-based modification in the tourism structure which further resulted in rather separate changes in economic activity and space requirements. To better benefit from the interrelations provided in the IOM and to display secondary effects of tourism (Lenzen et al., 2003), land requirements for further industries and permanent housing should be added to the model.
- Similarly to tourist accommodation, recreational land use and land use that is not directly related to tourism could be estimated in an enhanced IOM over demand in tourism and the permanent residence. For the expansion of *Housing and*

Infrastructure in Davos, this would be an important aspect, as only 63.0% of the newly developed areas between ASCH79/85 and ASCH92/97 are classified as buildings, construction sites or premises, and mainly the expansion of recreation and supply infrastructure caused the remaining 37.0%.

- To assess the efficiency of resource consumption, a more comprehensive approach is required. Although land consumption is a big issue in many tourist regions in the Swiss Alps, additional resources should be addressed in order to comprehensively depict the impact of tourist strategies. If, for instance, energy consumption is included into the assessment, the efficiency of resource consumption for luxury tourism might be reduced due to the expanded building design and long travel distances. The aspect of energy consumption could be included into the enhanced IOM through an additional productivity function.

Finally, it has to be noted that the scenario analysis addresses only the efficiency of development strategies but neglects the feasibility of actually implementing these strategies. This shortage can not be overcome by the enhanced regional IOM, but requires further analytical tools, such as market evaluations.

7.4 Conclusions

A method to estimates of area requirements and settlement expansion from changes in tourism structure has been established and applied to tourism development alternative. Due to its customised structure, the model can be directly coupled with the IOM to assess area consumption in terms of efficiency, similar to the study presented in Kytzia et al. (in prep.).

To estimate settlement expansion a two-step approach was realised which first estimates GEA as a function of utilisation rates, GEA per bed and number of overnight stays and then derives the expansion of the settlement as a function of GEA, the potential to increase GEA within the settlement area and the CCF. Both function can be understood as step functions which reflect structural change in tourism while taking into account “buffers”, i.e. existing potentials to increase tourist overnight stays, and thus added value to the region, without expansion of capacities or without expansion of settlement. The linear functions to estimate GEA and settlement expansion directly from the additional number of overnight stays is understood as a special case of the step function. Although this special case is a strong simplification, it approximates quite reasonably the scenario of capacity increase to meet peak demand through “greenfield” development.

The presented method illustrates the complexity and high uncertainties involved in the estimation of rates of change. Although a relatively simple approach was chosen, the simulation results for the first set of scenarios, which addresses an increase in bed capacities to meet peak demand, ranged from no expansion to 29 ha. In the model, however, important controls of these range of values are directly addressed. Besides the category of tourist accommodation and building design, spatial planning plays an important role. If the available potentials of re-densification within the urban area are accounted for, all scenarios, including extreme expansion scenarios, could be realised within the existing settlement.

As shown, the link between estimates of area requirements to the regional IOM allows assessing the efficiency of area consumption (Kytzia et al., in prep.). The analyses demonstrate the low efficiency in area consumption particularly for vacation rentals and secondary homes, despite their large proportion of added value to the region in absolute figures. Indirectly, the results suggest pushing luxury tourism. But it has to be noted, that solely the efficiency of land use is addressed in this assessment and the consumption of other resources is neglected. In order to assess more comprehensively the efficiency of resource consumption, further resource types should be added to the system (Kytzia et al., in prep.). Finally, the assessment concentrates only on the resource efficiency of alternative development scenarios, but does not give any information about the feasibility of any of these scenarios (Kytzia et al., in prep.).

CHAPTER 8

DISCUSSION

This chapter aims to recapitulate the research findings of the previous four chapters which contain the key empirical contributions of this thesis. The results, methodologies and alternative approaches will be critically reviewed and evaluated with respect to the three underlying research questions.

8.1 Land use simulation modelling

> **Research question 1.** *What is an appropriate technique for regional-level land use simulation modelling?*

Two key aspects of land use simulation modelling have been addressed separately in this research. First, a spatially explicit allocation model was developed. After having discussed a TPM-based modelling technique in Chapter 4, a regression-based simulation model was developed, validated and tested in Chapter 5. It was subsequently applied in the context of regional integrated modelling in Chapter 6. Second, estimates of settlement expansion were drawn from quantified area requirements of tourist accommodations, which could directly be linked to economic activities (Chapter 7). In the following section, a) the statistical models, b) their potential and their limitations in simulation modelling, c) the estimates of quantities of change and d) the role of allocation versus quantity of change will be discussed.

Statistical models for allocation modelling for future scenarios

Statistical approaches to land use allocation modelling have been common since spatial datasets and information technology have become widespread in the late 1980s. The statistical models derived from spatially explicit data represent the core of such statistically based allocation models. The idea behind this approach is to identify the probability of locations to be occupied by a given land use class in the future on the basis of past empirical observations.

The data used to derive statistical models for land use allocation in this work include two survey periods (Chapter 3). The observation and documentation of land use change between these two survey periods build the basis to simulate likely future changes. From a methodological point of view, this is critical because it is difficult to judge whether the locations of observed changes between the two surveys are typical for the processes in general and whether they have been adequately recorded in the first place. In any case, two points in time provide only minimal support for extrapolation and forecasting or projection. Additional surveys would have certainly been helpful for validating and more profoundly testing the statistical models.

However, there are reasons why the statistical models are still considered valid and useful for simulation modelling.

First, the statistical models were based on random sample points from the entire Swiss Mountain Area. Due to the considerable differences in the socio-economic structure within this source area (Chapter 5), the shifts which might have become obvious between additional survey periods can be compensated through the variety and extent of the source area. Thus, the (regional-scale) differences in socio-economic structure may serve as possible templates for land use change over time, since they subsume a wide range of local-scale changes in land use. Taken as a whole they serve as a robust, although not excellent data source for the regression models.

Second, the statistical models identify site attributes and quantify their effect on the probability of a given land use transition in space rather than time. Although data availability precluded sufficient statistical testing, we assume that in some cases the multivariate logistic regression models would not vary considerably for a given land use class through time on the regional level. This is because, for instance, the locations of agricultural abandonment due to marginalisation and forest regeneration are largely controlled by bio-physical factors which do not change significantly during the observed period. The assumption that the impact of these factors is constant over the time period investigated seems appropriate after all, so that the statistical models developed by Rutherford (2004) are considered quite robust and meaningful although they are only based on two survey periods.

The use of statistical models to describe likely sites of future transition is more critical for land use change processes that are determined by factors that change more quickly over time, such as socioeconomic and regulative factors. For instance, the regression model for *Housing and Infrastructure* development implicitly reflects building regulations of the 1980s and 1990s. Such policies, however, may be subject to rapid and considerable change, given the modification of building codes, hazard zoning or by-pass roads, for example.

Furthermore, such policies also affect the status of *Agricultural Land* or *Forest* and modify the relevance of different transition processes. In this regard, it is important to be aware that the statistical models on land abandonment developed by Rutherford (2004) depict mainly the marginalisation of land, whereas halt of cultivation due to competition with settlement expansion is indirectly depicted by the regression model for *Housing and Infrastructure* development.

Use of statistical models for future simulations

The idea of statistically based modelling for future scenarios has to be questioned, because future development does not necessarily need to resemble that in the past. However, under what circumstances are statistically based models still suitable for future simulations? And what can we learn through statistically based simulation modelling?

The statistically based approaches have been criticised for their lack of theory and are seen as a limited contribution to improve the understanding of land use change (Briassoulis, 2000). Lambin et al. (2000) refer to statistical models as an appropriate means to analyse the past, and argue that they give insight into the processes of land use change particularly through the analysis of empirical observation. Simulation models based on such statistical models give plausible outputs mainly because they project what we have already experienced. In this regard, they are considered rather descriptive than predictive models.

However, Lambin et al. (2000) also see the potential to increase the complexity of land use modelling through the application of statistically based simulation approaches. Kok (2001) summarises the conditions essential to be met, if statistical models are applied in simulation modelling:

(1) The transition processes to be modelled and all relevant land use types have to have occurred already in the past and are documented in the datasets.
(2) The circumstances under which they occurred are assumed to be similar in future (for instance, spatial planning policies might fundamentally change over time).
(3) The temporal resolution inherent in the statistical models is accounted for in simulation modelling.
(4) Gradual differences in transition probability between different sites are acceptable for the simulation purpose.

In the presented study, these condition are largely met – or at least the applications of the land use allocation model are adapted to meet these conditions. For instance, the model has been applied in a scenario analysis addressing agricultural decline, constituting a process that has gone on in the past already and is reflected in the land use dataset (Chapter 6). The method has also limitations that apply to the prediction of certain types of land use. The model could, for instance, not be applied to simulate likely future ski runs, because a) the process of forest changing to open land for skiing runs is not sufficiently reflected in the empirical data and b) the gradual differences in transition probabilities between adjacent sites would not be adequate. A multi-criteria based modelling would, therefore, be more appropriate in such a case.

Statistically based models also show great advantages in the simulation of complex systems, although the suitability of their application has to be critically considered for each simulation,. In this study, for instance, the decline of agricultural land, consequent forest expansion and vegetation succession have been combined with the expansion of the settlement (Chapter 5). Another example for complex land use modelling is, for instance, the simulation across several spatial levels (Kok, 2001). Complex land use modelling causes great methodological difficulties when approached through theory- or process-based modelling. This is because of the different nature of processes and possible theories available to explain different transition processes. The advantage of statistically based simulation modelling is that different processes (or scales) can be approached in the same manner. This ensures a consistent model design even for complex systems. Kok (2001) and Easterling (2000) even argue that it is sometimes the only solution to successfully approach complex system modelling at all.

We agree that using statistical modelling gives a systematic basis to simulate complex systems. It provides the means to simulate through an identical and consistent modelling mechanism, and delivers indicator values and simulation results that are methodologically comparable and interpretable.

Quantity of land use change

Techniques to estimate quantities of change for scenario simulation include obtaining of rates of change on the basis of scenario assumptions or preceded modelling. In Chapter 6, for instance, rates of change were derived from prior agricultural simulation.

The technique to estimate quantities of land use change for settlement areas presented herein addressed approximations of area requirements to deduce settlement expansion (Chapter 7). This technique is based on two step functions. Within these functions, one plateau for the estimates of area, i.e. Gross External Floor Area, is determined mainly by utilisation rates, which leave great potential to increase overnight stays without any expansion of bed capacities. The other plateau refers to expansion of settlement, and is characterized by the potential to increase GEA within the existing settlement area.

The use of these step functions reflects the uncertainties inherent to estimating rates of land use change. Most important among these uncertainties is the potential to increase intensity or productivity of a given area designated to a land use class. For areas designated to tourism accommodation, the orientation towards seasonal peaks, as well as local aspects of urban planning account for much of the variability of the estimates. The dependence on the utilisation potential of both floor-space and settlement area allows valuable insights into the process of urban expansion due to trends in tourism development in Swiss mountain regions. Such aspects can not be represented by spatial allocation models. Also, it highlights impacts of spatial planning, building design and customised requirements for space, which are of high importance in urban land use. After all it demonstrates the important interrelation between land use conversion and land use modification (Chapter 2.1).

An important aspect of this is the number of hierarchy levels at which demands and decisions are encountered. In this study, the level of focus is at the region/municipality. The scenarios project the logic of driving forces onto this regional level in order to derive input parameters for the various models, and also, the models exchange their information on this level. Most models, including the model that estimates quantities of land use change, operate at one particular spatial level. For that driving forces from different higher and lower levels have to be projected onto this operational level, although these manifold driving forces actually interact over several hierarchical levels (Schneeberger, 2005). But very few models aim to actually incorporate several of these levels (e.g. Kok, 2001).

As an alternative to the regional level, it may be equally possible to relate quantities of change to individual decision-making processes. A multi-agent system could provide an overarching model structure (Bousquet and Le Page, 2004; Janssen, 2000; Parker et al., 2003). Such a system could help to identify important feedback loops between diverse interests within the relevant actor groups. However, with a focus on estimating quantities of land use change and not purely on social interaction, this modelling approach would require a great amount of additional data.

In the context of this study, the estimates of different land use changes other than tourist accommodation could be incorporated into the model to estimate changing requirements on land. Importantly for an Alpine tourist region, recreational land use seems a worthwhile addition to the model. This option could address the role of the landscape and its utilisation from a very different perspective, since e.g. the requirements on land are expected to differ according to recreational groups such as hikers, skiers, or mountain bikers.

Furthermore, the link between the landscape and its recreational value may be further additions to future models. For instance, there are strong links between mountain agriculture, which maintains the traditional "cultural" landscape, its attraction, and recreational value (Chapter 6). But if such recreational value is indeed one of the major functions of the Alpine landscape, it would be promising to address these recreational areas directly. For that, these areas need to be identified, mapped and related to recreational activities, maintenance effort as well as their economic impact. This is particularly crucial for winter sports regions, where summer and winter use of the land differs strongly and involves great costs.

Allocation versus quantity of change

How important is quantity of change compared to allocation? Lambin et al. (2000) notice that most spatially explicit land use modelling focuses on the location aspect, although they point out that quantities of change are more relevant to assess environmental impact. This, however, may not be generally applicable. Of course, extreme conversion rates of land use will most likely have a great impact. But if smaller areas are affected, the intensity of the environmental impact is particularly sensitive to the spatial arrangement. A typical example for this is habitat dissection which has great impact on wildlife populations and is caused by transformation of a relatively small extent at an unfavourable location (McAlpine and Eyre, 2002).

Of similar importance is the spatial pattern for the ecosystem services investigated within the ALPSCAPE project (Grêt-Regamey, 2003). For instance, one ecosystem service examined is the landscape's potential to protect infrastructure against natural hazards for which the spatially explicit modelling approach proves to be essential. One way to measure this is through the development of risk from natural hazards through time (Borter, 1999). The risk development for snow avalanches is, among other controls, affected by changes in the forest area and the damage potential (Ammann et al., 2002; Bebi et al., 2004). The extent, allocation and density of *Forest* partly determine the avalanche release probability, whereas the extent, allocation and type of *Housing and Infrastructure* indicate the damage value and vulnerability (Grêt-Regamey, 2003). In addition, the relative location of both land use classes to each other has a strong impact on the assessment. Thus, land use modelling needs to be spatially explicit to provide a valuable basis to assess risk development for future scenarios.

Considering these aspects discussed above in detail, we come to the conclusion that the methodologies applied and combined in this research were appropriate for regional-level approch to land use simulation modelling. Good reasons, such as the lack of a theory adressing both changes in agricultural land use and settlement expansion, argue for the application of statistical models in simulation modelling. Although this is controversially discussed, superior techniques are rare and face without exception the problem of weighting processes against each other.

Complementary to the statistically based allocation model, a technique was established to derive rates of land use change from economic activities through the combination of two step functions. These two step functions demonastrated the great uncertainties involved in estimates of quantity of land use change. At the same time, however, they also illustrated great potentials to increase the efficiency of land use within the existing settlement area.

Although quantity of land use change is an indicator concerning the environmental impact, allocation of land use change is considered as crucial particularly on the regional level. Allocation modelling can contribute to highlight hotspots of likely change in the configuration of the land use possibly resulting in habitat fragementation or a decrease in ecosystem service, as demonstrated for the risk against snow avalanches.

We argue that particularly for the simulation of scenarios, in which rates of change can be determined externally, a automated link between estimates of quantity of change and allocation modelling does not necessarily increase the quality of the simulation output as particularly uncertainties in estimating rates of change are not accounted for in such detail.

8.2 Land use modelling for the Swiss Mountain Area

> **Research question 2.** *What special aspects of land use change in the Swiss Mountain Area require consideration in modelling, and how should they be addressed?*

We argued that no suitable simulation model exists to represent and analyse land use transformations in the Swiss Mountain Areas. This is particularly true, as most commonly addressed processes in regional land use allocation modelling are not relevant for the Swiss Mountain Area. Most models focus on urban sprawl, deforestation, intensification of agriculture and the establishment of nature reserves (Lambin et al., 2001). Except for the expansion of settled areas, further transition processes with relevance to the Swiss Mountain Area, namely land abandonment, subsequent forest expansion and vegetation succession on forested areas (Chapter 5), have not been addressed before through simulation modelling. We therefore established the first simulation model that addresses these processes comprehensively.

Implementation of the transition processes

These transition processes were implemented into the model through a hierarchical structure which reflected their economic relevance. First, the expansion of housing development, then the abandonment of intensively used agricultural land and finally the abandonment of extensively used agricultural land are iteratively addressed in the modelling procedure. They all react directly to changes in demand for land. The process of vegetation succession, by contrast, is implemented as a function of time on vegetated areas neither occupied by settlement nor agriculture. This hierarchical structure seems appropriate to simulate land use change in the Swiss Mountain Area, because, in general, only individual farmers refuse to sell or use their land for construction, whereas it is hard to regain land for agriculture which is occupied by settlement.

The interference between settlement expansion and halt of agricultural cultivation was another important aspect of the modelling efforts. If settlement expansion is allowed as a result of agricultural land abandonment, the simulation results indicate that at many sites prone to abandonment a shift to *Housing and Infrastructure* is likely. As the simulations address a time span beyond the scope of planning, this indicates how likely a long-term adaptation of planning might be. Consequently, the results point indirectly to the requirements for strict planning to avoid settlement sprawl in the long-term.

Furthermore, there is an interesting scope for future research in investigating the interrelation between highly productive agricultural sites and marginal sites. As the highly productive agricultural sites are the most likely to be sold and used for *Housing and Infrastructure* development, they are likely to be lost for agriculture in the long-term. This, again, could contribute to agricultural decline in general, and eventually enforce also land abandonment of less productive land. These interrelations, however, would have to be addressed rather at the level of individual farms (for the Swiss Mountain Area see for instance Lauber et al., 2004) than at an aggregated level of the region.

Modelling techniques

Although the processes incorporated into the model strongly differ from existing models, the modelling techniques applied are similar to those of existing models. In Chapter 2, multiple techniques for land use modelling were introduced and briefly discussed. In Chapter 4, two of these techniques were tested for the simulation of *Housing and Infrastructure*. For this purpose, *Housing and Infrastructure* development was simulated to reconstruct changes between 1954 and 1985 and compared them with the observed ASCH79/85. The agreement between the simulation results and the observed data was similar for both modelling approaches. The regression-based approach was chosen for further elaboration, mainly because it was found more suitable for the simulation of scenarios (Chapter 4). Regression-based approaches are quite common in allocation modelling. Our adaptation to the mountainous environment consisted of the selection of variables used for statistical modelling rather than improvement of the technique itself.

The regression variables adequately reflected characteristics of the mountainous environment. The variable “elevation” is the most important classification criterion to describe for land use transition through Classification Analysis (Chapter 4) and is highly significant with *P*-values below 0.05 in all logistic regression models (Chapters 4, 5 and Rutherford, 2004). In most regression models the variable “slope” is also of high significance (Chapters 4, 5 and Rutherford, 2004). Both variables indicate the role of topography for land use change patterns in the Swiss Alps. Whereas one of them is often considered an important determinant in land use change pattern (e.g. Clarke et al., 1997; Verburg et al., 2004b), the combination of these two variables and the wide range of their values reflect and strengthen the effect of the topography on land use change patterns in the Swiss Mountain Area.

8.3 Land use modelling in the context of integrated regional development

> **Research question 3.** *How can land use be related to other aspects of regional development in a modelling approach?*

Within the integrated concept of modelling regional development (Chapter 2), land use and land cover modelling addresses the interface between human activity and natural environment.

In many integrated modelling approaches, socioeconomic or policy shifts are assumed to trigger modifications in land use. In a subsequent step the simulated land use pattern then provides information for assessment, regarding, for instance, the availability of natural resources, habitat changes, protection against natural hazards or other ecosystem services (see for instance Grêt-Regamey, 2003). Although these functional interrelations exist and each of them can be addressed through modelling approaches, it turns out to be very difficult to combine these different approaches meaningfully. In this regard, modelling interfaces and both spatial and temporal scales are crucial aspects.

Interfaces between models

An important consideration for allocation modelling within integrated modelling frameworks is the definition of the interfaces between different (sub-)models. These “interfaces” are constituted by information flows between one model and the next. The focus, the degree of detail as well as temporal and spatial resolution are key aspects of whether the information from one model can be beneficially used by another. Although they might all use “land use information” the specifications for each model can differ strongly.

In the practice of land use modelling, two pathways are established to overcome these often diverging data requirements.

The first pathway suggests focusing on a single particular problem (*“What happens if?”*). This problem is addressed by several disciplinary modelling approaches which are narrowly specified to display the relevant processes with sufficient detail. Such models have been established, for instance, to address changes in agricultural land use and their ecological and economic consequences (Evans et al., 2001; Lauber et al., 2004; Zammit et al., 2005). They combine economic modelling at the farm level with land use change models. In a further step, the results from land use modelling are then taken to ecological assessment or fed back into the economic model. For a tightly specified modelling focus, the land use data can be enriched with relevant additional information. One way of enriching the data is to use further attributes to the land use classes, while another is to define land use classes that are customised for the research focus. For example, Donner et al. (2004) combine information on nitrogen distribution with different land use classes, whereas Münier et al. (2004) particularly differentiate the “Natural Reserves” in their land use classification.

The second pathway aims for an improved understanding of a particular complex system (*“How does it work?”*). For that, an overarching framework is established covering various aspects of the system. Instead of one target question, the elements of a complex system are analysed to define and understand their interaction. The ALPSCAPE modelling framework is a good example of such an approach. The principal aim was to establish a framework that brings together the four elements of local economy, resource management issues, the mountain landscape and its services to society in a generic way. This framework was then tested for several regional scenarios. To demonstrate impacts on all four elements, the range of scenarios was relatively broad including an agricultural, a mega-event and a climate change scenario (Chapter 2; for details on the agricultural scenario see Chapter 6). The generic character of the modelling framework and the broad range of scenarios simulated make it difficult to specify the data requirements at the interfaces between (sub-)models.

A relatively simple, generic classification of the land use classes appears to be favourable in this case. This is because the number of land use classes and their attributes would otherwise quickly exceed practical limitations. For instance, the Local Agricultural Model (Bebi et al., 2005; Lundström et al., in review) differentiated between more than 10 agricultural land use classes for the study area, and the enhanced Input-Output Model could provide changes in demand for land for five different tourist accommodation types (Chapter 7). However, if all possible permutations of these specifications would be accounted for in the Land Use Allocation Model, the range of land use information would become impracticable to be handled by the model.

We therefore suggest to use relatively simple classification schemes and to strengthen the focus of spatial arrangement in further analysis. A good example of the relevance of spatial arrangement is the protection from natural hazards as part of the evaluation of ecosystem services: The avalanche risk is derived from site characteristics such as slope steepness (constant), forest expansion and relative location of settled areas (Grêt-Regamey, 2003).

In some cases, it is also possible to systematically re-attribute the simulation results of the land use allocation model on the basis of spatial arrangement if required by a subsequent modelling step. This procedure seems to be amplified by mountainous topography. For instance, the land use class *Intensive Agriculture* could be re-attributed with fertilisation information by identifying areas that allow the use of heavy machines according to topography, access and soil characteristics.

However, the model will never be able to provide any support for the assessment of individual site-specific land use projects. One reason for that is that the allocation model’s strength is to simulate likely patterns of rather diffuse land use change of greater extent, whereas single projects neither usually expand over more than one cell, nor are they diffuse. A recent example of a debateable construction project within the study area is the future development on the Schatzalp, Davos. The “Schatzalp Tower” will have great impact on the landscape from an ecological as well as scenic perspective, and to assess these impacts alternative concepts and methodologies will have to be applied (e.g. Baumgart, 2005).

Spatial scale

The overall focus and the degree of detail of a dataset change with the map scale that is appropriate for displaying the dataset. Closely related to the appropriate map scale is the spatial resolution or accuracy of the dataset. When working at a finer resolution or greater accuracy, the information contained is usually more detailed than on a coarser resolution, but also the range of information is usually more narrow (Figure 45). Thus, with spatial scale the focus of the data changes, and therefore also its appropriateness for different questions. It is important for integrated modelling that the spatial scale of the land use modelling matches with the focus and degree of detail of other datasets and models involved.

In the ALPSCAPE project, for instance, the regional Input-Output Model (Bebi et al., 2005; Wegmann and Kytzia, 2005) depicts the economic system of the study area in great detail. But when the Input-Output Model is being linked to the Area Statistics dataset, it turns out that practically all industries featured in the Input-Output Model refer to one land use class, namely *Housing and Infrastructure*, which accounts for only 566 ha (2%) within the region. The only exception is the industry of “Agriculture and Forestry” which impacts the landscape to a great extent: About 8222 ha of the study area were covered by *Forest* and *Agricultural Land* in 1997 with three land use classes referring to forested areas and two land use classes to agricultural land.

Because of this problem, it was not possible to derive changes in demand for *Agricultural Land* from the Input-Output Model in the scenario analysis (Chapter 6). In this case, the land use dataset provided a degree of detail that could not be satisfied by the Input-Output Model because of the lack of resolution within the industry of “Agriculture and Forest”. Instead of adapting the Input-Output Model to a higher degree of differentiation of this industry, we applied a Local Agricultural Model for this purpose.

To link the allocation model with land requirements derived from economic activities, however, the spatial scale and data focus of both datasets need to be adjusted. In Chapter 7, this was successfully realised by applying a finer level of spatial scale (Figure 45). Instead of assigning rounded values of hectares of *Housing and Infrastructure* to the tourism accommodation industry, overnight stays were linked to square metres in Gross External Area (GEA) and the number of beds available in different accommodation types.

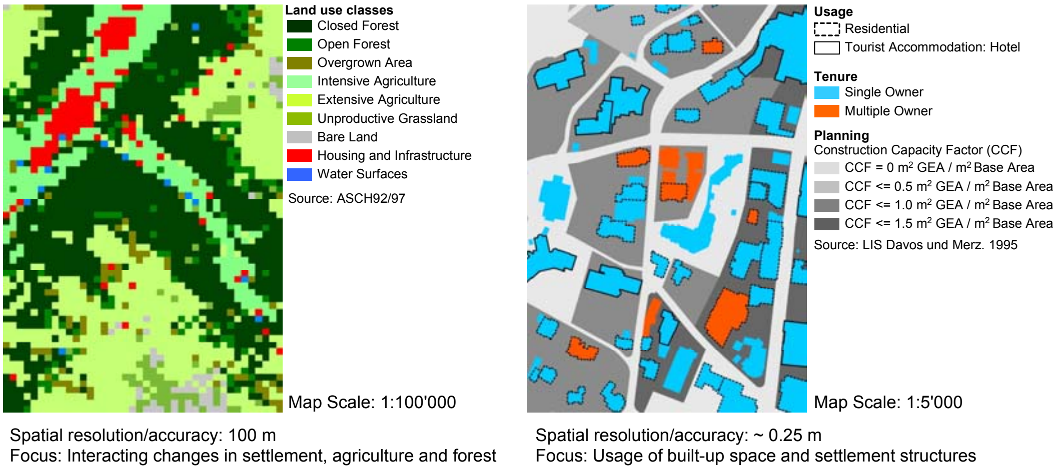


Figure 45: Different spatial scales (i.e. resolution/accuracy), foci and degrees of detail in the land use datasets applied. (Land Use Statistics 1992/97 reproduced with permission of BFS GEOSTAT, cadastral map reproduced with permission of LIS Davos)

Modular structure of the integrated modelling framework

A further aspect that needs to be highlighted is the workflow through and at the interfaces between the individual models. The workflow through the individual models might vary between scenarios, particularly, if the modelling framework aims at addressing a wide range of scenarios. Within the integrated modelling framework of the ALSPCAPE project, each model operates separately and only the information flow between the models connects them. This rather flexible design allows adapting to various scenarios with differing inherent logic. Thus, the order in which the models are applied can change (e.g. Chapter 6), so that a scenario could be driven by modifications in resource management as well as local agricultural structure. For example, scenarios could be triggered by the idea of regional self-sufficiency in building material as well as by the installation of agro-industry in the region.

Conceptual versus content-oriented approach

In general, there is a strong dilemma between the conceptual challenge in linking models for a wide range of issues concerning regional development and the content-oriented challenge of developing an integrated model that focuses on a particular question. The conceptual approach aims for the greatest possible representation of the regional system as a geographical unit, whereas the content-oriented model aims for a representation of very particular aspects relevant to the few, very closely related questions under investigation. The ALPSCAPE project clearly aims to provide a framework to analyse the regional system comprehensively as a geographical unit by permitting an open, modular structure and rather generic, but adaptable interfaces between models.

However, if the interfaces between models can be adapted to specific content-led questions, the integrated modelling framework provides high potential to also answer quite specific questions. For instance, further investigation of land abandonment with consequent forest expansion (Chapter 6), can be linked to its consequences on wood growth. This, in turn, can be further assessed in terms of its ability for carbon binding and thus its contribution to the regional C-balance (ecological indicator). It can also be assessed in terms of its potential to be processed and sold, and thus to contribute to the regional economy (economic indicator). Finally, it could be assessed in terms of its potential to contribute to the regional energy consumption (resource-based indicator). Of course, such a specific forest model should hold additional information on the forest structure, the dominant tree species, or the age of forest stands right from the beginning. But with additional information to re-attribute the modelling outcomes, the modelling framework is able to adapt to such specific questions.

CHAPTER 9

CONCLUSIONS AND OUTLOOK

This thesis presented approaches to land use modelling within a wider integrated modelling framework. The overall goal was to develop a regional-level land use model suitable for scenario simulation. In this chapter, conclusions will be drawn with respect to the achievements of the research and the insights that were gained in the course of the research. Finally, further elaborations of the approach will be suggested, providing an outlook to possible future directions in land use modelling for the Swiss Mountain Area.

9.1 Achievements

The achievements of this research are closely related to the objectives postulated in the beginning of the project. Therefore, the objectives are to be recalled and each of them will be evaluated in terms of what could be achieved in this thesis.

> **First objective.** *Identification of an appropriate methodology to regional-level land use change modelling for Alpine regions within Switzerland with respect to data availability, scenario simulation and applicability to other regions.*

In this research, appropriate methods to regional-level land use modelling could be identified for the Swiss Mountain Area. Methodological considerations were undertaken in three major steps.

First, the approaches to address *quantities of change and allocation of change were separated* in an early stage of the research (Chapter 2). The main reason for that was the complexity of driving forces which determine quantities of change. The separation of the two processes facilitated the simulation of land use pattern for a wide range of scenarios, and ensured spatially explicit simulation results for further assessment.

Second, the approach to *allocation modelling through multivariate logistic regression based on data from the entire Swiss Mountain Area* was tested against a model using Transition Probability Matrices based on data purely from within the study area in Chapter 4. The modelling technique based on multivariate logistic regression from the Swiss Mountain Area proved to be equally successful in reproducing past land use changes within the study area and promised further advantages in terms of its applicability to other regions within the Swiss Mountain Area and its adaptability to scenario simulation.

Finally, *all transition processes identified as relevant for Swiss Alpine regions* were incorporated into the model according to a hierarchical structure in Chapter 5. This model was validated for an independent simulation period, and tested in a sensitivity analysis to improve the interpretation of the simulation outcomes.

> **Second objective.** *Development of a spatially explicit land use change model which can be used for scenario simulation within an integrated approach to regional development*.

In this study, a spatially explicit model was developed, validated and applied for scenario simulation within an integrated approach to regional development. The intention to apply the model for a wide range of scenarios and within an integrated modelling context resulted in a highly adaptable land use model.

Firstly, the requirement to use the model for a wide range of future scenarios resulted in a modelling concept that allows determining *rates of change as primary input parameters* for simulation runs. As the user can determine them for individual land use classes the simulation model is highly adaptable to a wide range of scenarios. But at the same time this requirement demanded to reduce – at least optionally – the degree of interaction between land use classes.

Secondly, nine *land use classes representing a wide range of actual land use and land cover types* were incorporated into the model. This comprehensive implementation of land use types provides linkages to all aspects investigated within the ALPSCAPE project, namely the regional economy, the resource availability and the ecosystem services. Yet, all nine land use classes are relatively generic, and a greater degree of differentiation or additional information would have improved the meaningfulness of the simulation results.

> **Third objective.** *Development of complex future scenarios from local system knowledge and their preparation for numerical simulation through an integrated modelling framework.*

In collaboration with the ALSPCAPE team, complex future scenarios for the study region could be developed and elaborated for numerical simulation in Chapter 6. In participatory workshops, local system knowledge was gathered which could partly provide a basis for these scenarios. The collaboration with the local actors also promoted the *relevance, validity and possible acceptance of the scenario analysis*.

The consistent employment of a *scenario table supported transparency* in the step-by-step development of qualitative scenario, their parameterisation and quantification for numerical simulation. Within the process of scenario development for numerical simulation, the process of *scenario quantification is considered methodologically the most critical step*. The use of *Extreme Scenarios* was considered useful in order to illustrate effects on the entire regional system and to communicate them.

> **Fourth objective.** *Promotion of a modelling approach to estimate rates of land use change and to link them to the local economy for efficiency assessment.*

The aspect of quantities of land use change has been successfully addressed through *linking the area requirements for tourist accommodation with accommodation types, tourism structures and utilisation rates*. The approach is based on data from the Local Information System of Davos, which have a considerably higher spatial accuracy than the official land use surveys that have been used for allocation modelling. It estimates rates of change through modification of tourist capacities and identifies important factors to influence the sprawl of settlements due to further tourist development.

As the methodology allows *linking land use directly to economic activities*, it can also be used to derive the efficiency of land utilisation from an economic perspective and to assess and compare alternative strategies.

9.2 Insights

In-depth work on land use modelling within an integrated approach to regional development provided insights which exceed the achievements made. The iterative process of conceptual model development, adaptation to scenarios and readjustments to the project environment revealed valuable lessons on land use simulation modelling, in particular within a trans- and interdisciplinary modelling environment.

Simulation modelling based on statistical models

In Chapter 4 and 5, logistic regression models are applied for simulation modelling. These models provide the most important determinants to describe the locations where certain land use transformations have been observed in the past. Transition probabilities derived from these models display clearly the situation from the observation period and can not be adapted to fundamentally different future situations as discussed in Chapter 8. Processes not yet observed can neither be simulated with these statistical models, nor is the introduction of a new land use class possible. Alternative approaches to derive suitability maps, such as multi-criteria evaluation or optimisation modelling, are able to handle such situations better.

Spatial resolution

The uniform spatial resolution of the grid data is not appropriate to address the agricultural, forested and unproductive land as well as the settled area in a single regional-level model. When addressing transitions in agriculture, the resolution is partly too high, and produces unwanted effects due to resolution. At the same time the resolution is too low to investigate *Housing and Infrastructure* development. The combination of Area Statistics with cadastral maps (Chapter 7) is seen as a promising advance to solve this problem. By overlaying these two datasets, cells within and near the settled areas could be split, while cells of high-elevation grassland could be merged.

Simulation modelling

The advantage of simulation-oriented modelling is that datasets are achieved that display relatively likely future states, that are methodologically comparable, and that can be used to assess these situations. Still, to better understand real-world processes, the focus of the modelling approach must not lie in the simulation of future scenarios, but in the experimental application of the model. Through sensitivity analyses and experimental modifications of the model, the model behaviour and the impact of modelling techniques are better understood which greatly helps to interpret the simulation results in terms of their real-world meaning.

Land use modelling within integrated approaches

As land use is an important interface between the social and the natural environments, integrated approaches to land use research and modelling are considered promising to a better understanding of land use issues. The experiences in this research underlined that linking different disciplinary modelling approaches is possible. An adaptive and flexible land use model was developed which can relate to multiple disciplinary aspects. However, a greater degree of detail and an adequate spatial resolution of the land use data would have been advantageous to produce more meaningful modelling results.

Therefore, it appears important also for interdisciplinary research to focus on a single, clearly defined question. When new insights are to be gained through integrated modelling approaches, a strict focus provides the basis (1) to define narrow and meaningful interfaces between models, (2) to specify an appropriate spatial and temporal setting for the entire framework, and (3) to concentrate only on information relevant to this single question.

The trans-disciplinary aspect

The co-operation with stakeholders provided an interesting insight into the local community, and resulted in a *good communication* between the research team on the one hand and local stakeholders and authorities on the other hand. Yet, *the qualitative models resulting from the* *participatory workshops provided less input to the scenario development than expected*. They identified the most important factors which served as a general basis, but required strong modification for the actual elaboration of scenarios.

9.3 Outlook

This thesis presents and discusses solutions to several aspects relevant to recent land use research within an integrated simulation modelling approach. These investigations and findings can provide the basis for further investigations proposed in this final section. While the first suggestion would represent an interesting alternative to the reseach approach presented, the following ones are options to built up and continue on the already existing results.

Agent-based approach to land use and integrated regional modelling

The presented approach to integrated regional modelling was established based on a systematic analysis of the region. Changes within the regional land use pattern were thus seen as the sum of all decisions of various land owners and tenures. For instance, the areas of land utilisation were not related to land tenure and particular owners or tenants, but have been viewed only from the more abstract perspective of suitability and probability of transformation. Different to that, an agent-based approach would, stress the decision-making criteria of the individual land owner or tenant. Changes in land use would then be the cumulative result of numerous individual and interacting decisions. In the presented research, the behaviour of the individuals has as far as possible been reflected in the scenarios. Yet, to bring the modelling approach down to an agent-based approach would possibly give further insights into the mechanisms of decision-making within the region and provide an interesting additional perspective on the regional modelling.

For the establishment of an agent-based model, the definition of different agents is one of the primary challenges. Land owners and tenures, including farmers who decide about large areas within an Alpine region like Davos, as well as planners and policy makers who set the legal frame for land owners and tenures, are typical spatial agents. To model land use change as a result of their decision-making, we suggest to directly link the land through property and tenure to these spatial agents. For such a region, tourists are another important group who rather trigger or react on land use change processes without converting land use themselves. All types of agents would have to be defined through their backgrounds and preferences. Based on these profiles individual decisions could then be simulated as a result of changing external conditions, including environmental change, but also social interaction.

Such a model would help us to display and analyse the interaction between tourism and agriculture as one of the characteristic features of such an Alpine regione more directly than the presented research. It would therefore not only be a tool to simulate likely patterns of land use change, but would allow to test possible, and much debated effects and feedbacks between changes in agriculture, tourism and land use. However, it would also require large amounts of data, as preferences and interactions would have to be calibrated, weighted against each other and quantitatively validated before the model could be used for scenario simulations.

Incorporation of assessment

The land use allocation model was often referred to as a data source for further assessment. As land use is a critical input to such assessments, e.g. of wildlife habitats or risk from natural hazards, the model could be optimised to the requirements of these aspects. Possibly the numeric assessment tools could be integrated directly into the land use modelling approach and deliver valuable indicators of land use change.

Application to one particular problem

In the future, the integrated modelling framework elaborated in the ALPSCAPE project should be applied to one particular question to demonstrate its full potential. An additional study could illustrate the contributions that the adaptable framework would be able to provide. The linkages between individual models should be re-specified, and the work flow through the model adapted to this aspect. The aspect of forest expansion has already been discussed in Chapter 8 as a favourable option to combine land use change with the wood processing chain, energy potentials and ecological aspects.

Linking land use with further economic activities

To link land requirements with economic activities has proven to be a promising approach to estimate quantities of change in the case of the tourism accommodation industry. Through the incorporation of land requirements to other industries, the model could yet better benefit from the complex economic interactions displayed by the Input-Output Model. Hence, indirect effects could also be drawn from the model. Furthermore, the incorporation of recreational land utilisation would be of great interest, particularly for tourist regions.

Incorporation of inter-regional developments

Further statistical analyses of the Area Statistics could possibly distinguish land use transition patterns for different regions of the Swiss Mountain Area including the expansion of settlement. Such analyses may reveal differences and interconnection in rates and locations of land use change between regions on the basis of socio-economic data. We suggest to develop an inter-regional land use simulation model on the basis of these statistical analysis. Aspects of demographic transition, migration patterns, recreational behaviour and the role of regional and national economic centres should play an important role in such a model.

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APPENDIX A

IMPLEMENTATION OF THE LAND USE ALLOCATION MODEL

A.1 Implementation

The model is coded in C++. The Borland C++ Builder Version 6 (student package) provided a useful development environment which enabled the design of a self-explanatory user interface (Figure A-1). To output raster maps on the user interface, Michael Mueller (UFZ Centre for Environmental Research, Leipzig) kindly permitted the application of MMColorGrid as a plug-in to the Borland Builder.

Figure A.1-1 gives an overview of the most important inputs and outputs of the model, and once again explains the “options” for simulating land use allocation change.

Figure A.1-2 shows a sketch overview over the simulation procedure including the principle work flow and the most important functions.

A.2 Source Code

The source code is available on the CD accompanying this thesis.

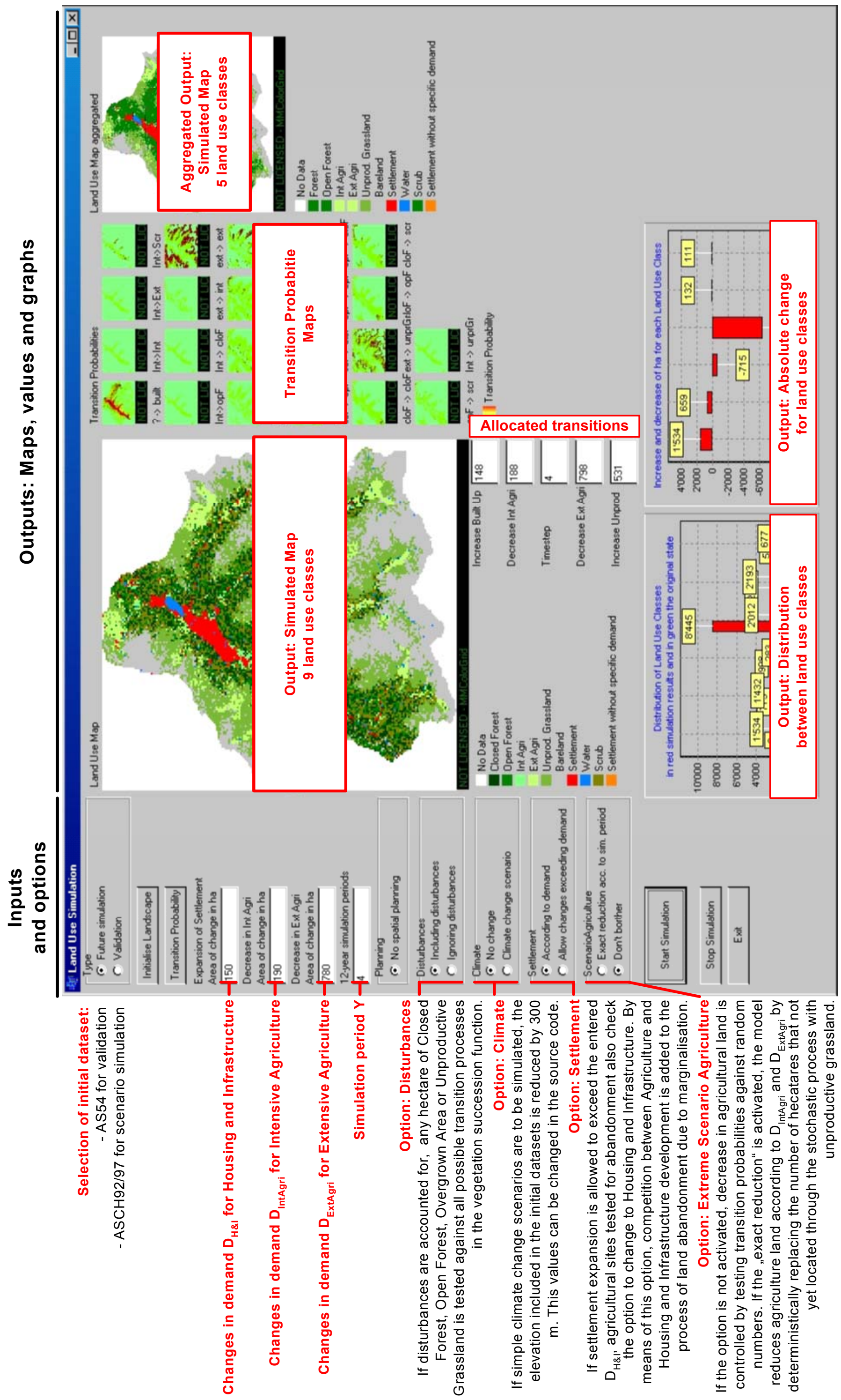

Figure A.1-2: User interface of the Land Use Allocation Model with the most important inputs and outputs of the model.

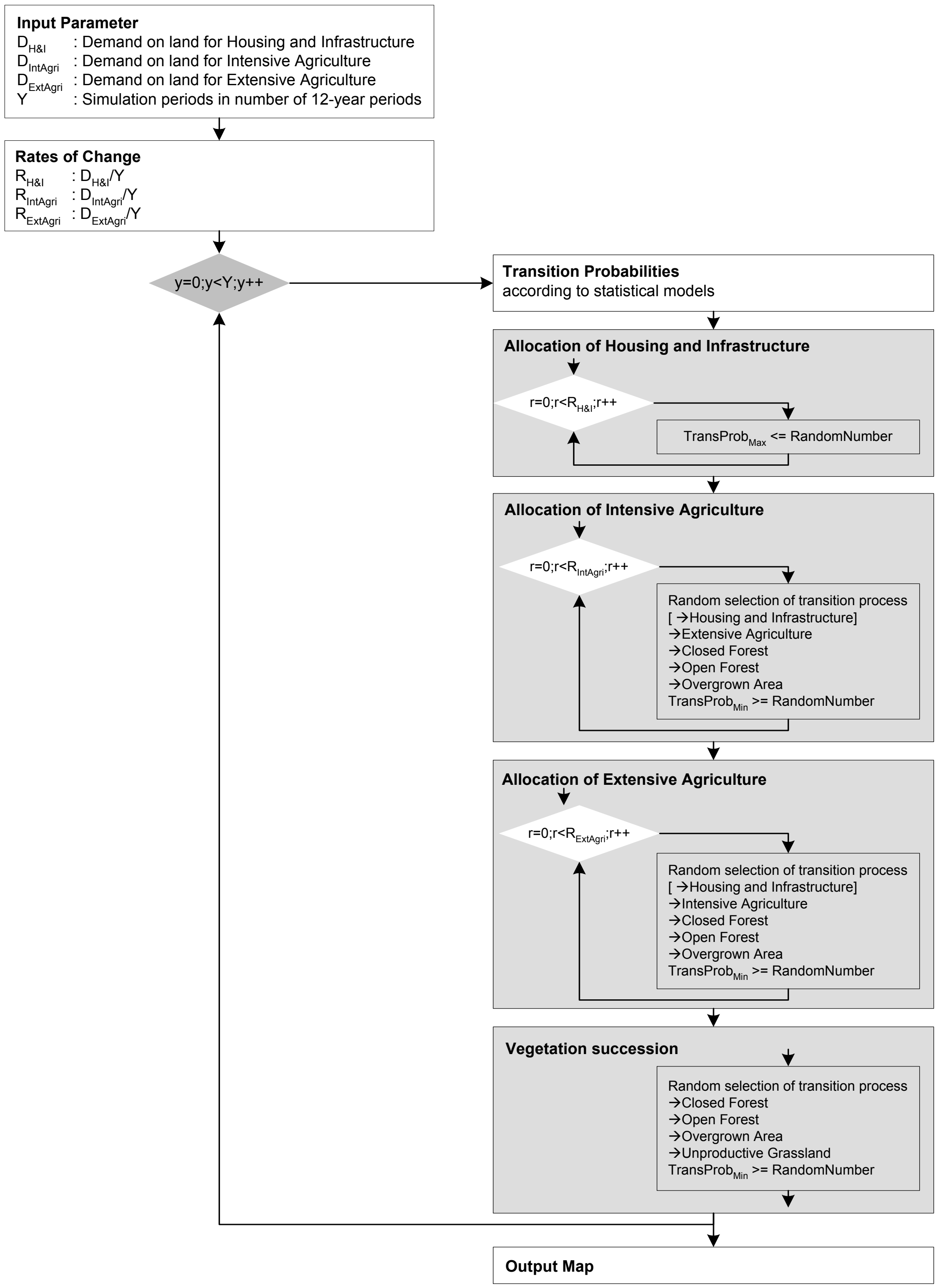

Figure A.1-2: Sketch of the workflow through the model and the most important functions.

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