Dynamics of urban regions

From theory-driven data analysis to quantitative models

Habilitation thesis

to obtain the academic degree

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Foreword

Urbanisation belongs to the most complex and dynamic processes of landscape change. Although only about four percent of the worldwide land area are urbanised and impervious surface, we claim “the millennium of the cities” since more than half of the currently 6.6 billion world population is living in urban areas. Projections for the future show that urbanisation – in terms of increasing share of population living in urban areas – is very likely to continue.

In many European countries and regions as well as Japan and the US, the population is no longer growing but the amount of urban and transportation land take is still increasing. It is a major task of geographical and landscape research to assess and evaluate the environmental impacts of this development. What is more, it still remains an open question how to achieve such assessment in an integrated manner in terms of both disciplines and methods.

At the same time, in many urban regions population density decreases due to low birth rates, ageing and migration, but per capita land consumption from urban and infrastructure development still continues to increase. Accordingly, urban regions are more and more faced with residential and industrial vacancies, demolition of large housing estates and urban brownfields. Both developments, land consumption and urban restructuring exert specific pressures on landscapes and it is assumed that these pressures lead to a fundamental transformation of natural resource availability, ecological structures and, consequently, a potential violation of ecosystem services.

Excessive urbanisation and urban sprawl are not only a problem because it contradicts a normative ideal of landscape and spatial planning. In a multitude of studies it has been shown that land consumption is usually detrimental to the environment in different regards. Its impact reduces the ability of nature to fulfil human requirements and thus impairs ecosystem services and landscape functions in various ways. Individual ecosystem services and quality of life aspects that are affected by urbanisation include the production of food, the regulation of energy and matter flows, water supply, the provision of biodiversity and of health and recreation, the supply of green space or natural aesthetic values.

However – as discussed above – population decline also offers the potential to improve environmental quality in urban regions that are deficient as regards green and open spaces. The development of a multifunctional green infrastructure at the regional (urban region) and (local) city level will be an important strategy in restructuring urban landscapes. Moreover, it could provide a major contribution to the adaptation of urban regions to socio-demographic as well as predicted climate change. Next to urban region in Europe or North America, where most of the evidence of urban population and land use dynamics comes from, we identify future hotspots of urban (land use) change in terms of Megacities developing first and foremost in the Southern hemisphere (Asia, Latin America, Africa).

Set against this background this Habilitation thesis deals with some of the most challenging questions urbanisation demands to be tackled and answered by geographical and ecological landscape science:

- What are the major drivers of urban land use and lansdscape change today, in the next future, and how can we learn from historic changes? More in particular:
    - How does demography modify human demands on natural resources, real estate, housing space and transportation networks?
    - What are the socio-environmental consequences of ongoing urban sprawl and of the opposite process of urban shrinkage characterized by large residential and commercial vacancies?
- How do form, pattern and heterogeneity of land uses affect environmental performance, ecosystem services and resource availability?
- What models and tools can we apply to contribute to urban land use planning and landscape management?

In the following, this Habilitation thesis "*Dynamics of urban regions. From theory-driven data analysis to quantitative models*" explores such research questions and theoretical considerations by bringing together different research approaches on drivers, pressures and the impact of land use change and land consumption in urban regions, explicitly including qualitative and quantitative approaches. Thereby the thesis introduces a set of new approaches for the analysis of (demographic) driving forces of urban land transformation. It explores the room for top-down and bottom-up approaches in order to deal with the impact assessment of resulting land use change in urban areas at multiple scales (European, national, regional, municipal). Because of this scale-specific approach, this work is of typical geographical nature. The thesis further highlights alternative conceptual frameworks and indicators for the empirical investigation into land use change. In doing so, I adapt existing approaches and methodologies of impact assessment of land use change to the context of urban decline and restructuring and thus helps to identify strategies for the restructuring of urban landscapes and adaptation to environmental (climate) change.

The Habilitation thesis comprises results of my research work on urban land use dynamics from 2001-2008. From a more theoretical point of view my work bases on the ideas of a.o. Naveh (2001), Brandt (2001), Wu & Hobbs (2002), Ravetz (2000), Müller (in Petrosillo et al., 2007). As indispensable prerequisite in this sense my approach of dealing with urban landscapes involves both natural and social science components, qualitative and quantitative methodologies. The papers this Habilitation thesis consists of result from a range of internationally and nationally funded research projects predominantly prepared and written by myself. Titles, objectives and methods of these projects are listed in the introduction section. Since project work is of collaborative nature, many colleagues, Diploma- and PhD-students contributed to the results presented. Therefore, I listed my own contribution to the submitted publications in the latter part of the Habilitation thesis.

I am very grateful to many persons that supported my work during the last eight years and thus contributed to the finalisation of this Habilitation thesis: first and foremost the heads of the Department of Landscape Ecology of the Helmholtz Centre for Environmental Research – UFZ, Prof. Dr. Ralf Seppelt (since 2004) and Prof. Dr. Rudolf Krönert who both supported my work at the UFZ being available for many encouraging discussions. Further, PD Dr. Sigrun Kabisch, head of the Department for Urban and Environmental Sociology, contributed to this work since she gave me the opportunity to enter the challenging field of demographic change and how social processes and pattern influence land use and shape our landscapes. Thanks also to my colleagues from the Department of Comutational Landscape Ecology, Dr. Martin Volk and Dr. Nina Schwarz who assisted whenever necessary with useful advice and revisions of single parts of the work done. Thanks to both also for many fruitful discussions on selected topics of this thesis. I wish to thank very warmely Dr. Henning Nuissl for the collaboration about impacts of urban sprawl and land consumption. Special thanks also to Dr. Volker Meyer who introduced the methodological challenge of multi-criteria-assessment to me.

In particular, I would like to thank Prof. Dr. Manfred Frühauf from the Department of Geography of the Martin-Luther-University Halle-Wittenberg for supporting the submission procedure of this thesis at the Faculty of Natural Sciences at the university of Halle and for taking over a review of the same. For reviewing the Habilitation thesis I am also very grateful to Prof. Dr. Wilfried Endlicher (Humboldt University Berlin) and to Prof. Dr. Jürgen Breuste (University of Salzbug).

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Content

1. Introduction

'Cities and thrones and powers stand in time's eye
almost as long as flowers, which do daily die,
but as new buds put forth too glad new men,
out of the spent and unconsidered earth,
new cities rise again.'
Rudyard Kipling 1906

Theorising urban dynamics

Due to the fact that nearly 80% of the European population lives in cities, the socio-economic and environmental impact of urbanisation and urban regions will tremendously increase in the developing world in the coming decades (United Nations, 2004, 2007a,b). The socio-economic development and environmental impact are decisive for the future sustainable development of the world since it defines well-being and quality of life for the major part of the world's population (Ravetz, 2000). Whereas until recently the urban world sprawls in terms of land consumption and globalised together with economy, population decline and ageing will produce shrinking cities in the Northern Hemisphere and, later on, in the Southern world, too. Many scholars working on urban demography and economics already deal with the simultaneity of growth and shrinkage from a theoretical point of view (Lutz, 2001; Haase et al., 2007).

City regions and urban landscapes are a field of study which is becoming increasingly important. Existing EU-funded programs include a.o. activities on peri-urban land use relationships acrrued under the project "PLUREL - Strategies and Sustainability Assessment Tools for Urban-Rural Linkages", a "Sustainability Impact Assessment" project (SENSOR – both in the 6th Research Framework Program), further an EU-project "Urban Sprawl: European Patterns, Environmental Degradation, and Sustainable Development (URBS PANDENS)" and an activity on "Urban development towards appropriate structures for sustainable transport (ECOCITIES)" both running in the 5th Research Framework Program.

Recently, large international research programmes like the "Alliance for Global Sustainability", the "Megacity Task Force" of the IGU, the International Human Dimension Programme (IHDP), the German National initiative on "Research on the Sustainable Development of Mega-Cities of Tomorrow", the "Informal Dynamics of Megacities" funded by the German Science Foundation and, finally, the "Integrated Earth Observation System" (EOS) of the German Helmholtz Centres had been established in the field of investigating cities, its land use, socio-demographic, health and environmental situation and vulnerabilities.

Urban regions have changed markedly over the past decades and many forward-looking studies imply that these dynamics will not abate (Champion, 1992). Land consumption due to urbanisation and the according land take for socio-economic and commercial purposes belong to the most evident environmental pressures on landscapes worldwide. In many European countries as well as Japan and the US, the population is no longer growing due to low fertility rates, ageing and migration, while per capita land consumption from urban and infrastructure development continues to increase (Kassanko et al., 2006; EEA, 2006). Accordingly, those urban regions increasingly faced with residential and industrial vacancies, some even with demolition of large housing estates and brownfields (Jessen, 2006). Both developments, land consumption and urban restructuring exert specific pressures on landscapes along the rural-urban gradient. It is assumed that these pressures lead to a fundamental transformation of ecological structures and, consequently, a potential impact on the provision of ecosystem services (Boland and Hunhammar, 1999).

The assessment of the impact of land consumption is a major task of landscape research in general (Wu and Hobbs, 2002; Naveh, 2001). Accordingly, there is a wide literature on the effects of land use transition on ecosystem services concerning, for instance, landscape clustering and fragmentation (Ewing, 1997; Pauleit et al., 2005), disturbances in the water balance (Samaniego and Bardossy, 2006), soil compaction (EEA, 2006), air pollution and noise (cf. indicator set by Wiek and Binder, 2005), or increased risk of flooding (Bertoni, 2006). Furthermore, we present first ideas on integrated assessment schemes for entire city regions, drawing on a multitude of disciplines and taking account of interlinked urban dynamics, such as suggested by Ravetz (2000), Hasse and Lathrop (2003) or, in a more participatory form, Wiek and Binder (2005). An open question remains as to how to achieve such assessments in an integrated manner applying diverse methodologies to assess the impacts of policy changes on human behaviour, on environmental resources and land use.

Research challenges and contribution of this Habilitation thesis

Large conflict potentials for the future global development had been identified and solutions are urgently needed. Integrated model systems belong to the methodological foundations of modern environmental science but still need a considerable improvement when applying it to the urban sphere. Spatial heterogeneity and extreme dynamics of processes and pattern let cities remain both “emergencies” but also “forerunners” in terms of strategic spatial solutions.

Therefore, a modern framework of analysing socio-demographic, land use and environmental processes in complex growing and shrinking urban regions is urgently needed as well as for urban regions where growth and where shrinking phenomena are dominating urban development. What is more, quantitative approaches that acknowledge the qualitative, innumerable dimension of urban socio-economy are one key to bridge theoretic expertise to urban spatial policy.

The cumulative socio-economic and environmental impacts of urban areas drive the future development of larger regions of the world in particular because firstly, changing land use relationships in cities and their surroundings influence stability, integrity and functionality of both the social dimension and the natural system. Second, urban regions deeply impact surrounding agrarian and forest ecosystems, watersheds and soil resources. In order to ensure sustainability, socio-demographic driven land use changes have to be quantified and subsequently assessed in terms of their vulnerability for the urban quality of life and urban ecosystems.

Urban landscape ecological research, as it is understood in this thesis, involves both natural science and social science methodologies when developing integrated impact assessment schemes. This makes these approaches highly interesting and relevant to solve current environmental problems of city regions with altering dynamics, multiple pattern and multi-hierarchical governance structures.

Therefore, the Habilitation thesis bridges qualitative and quantitative urban landscape ecology since it presents a variety of methodological approaches including statistics, multi-criteria indicators, qualitative mapping approaches and quantitative models to analyse urban dynamics and to explain urban pattern. Case studies at multiple scales serve as practise examples that mirror the theoretical base of the habilitation thesis. Compared to existing books on urban ecology or urban planning, this Habilitation thesis is first of all looking at primarily quantitative aspects of urban development. It involves different types of simulation models and integrated impact assessment schemes based on a critical review of existing tools. All sections focus on the potential of the quantitative analysis of the socio-economic, land use and environmental components of the urban system.

The major innovation of the thesis is a framework that presents how all the different socio-economic, planning and natural aspects of urban regions can be conceptually and quantitatively linked. As an extremely innovative part of the thesis the conceptual and quantitative analysis of urban shrinkage is discussed. The findings on shrinking processes base on a broad and unique empirical evidence and is hardly to be found in other related volumes in the field of urban research. The application of agent-based to endogenise planning and governance into urban quantitative schemes is another challenging subject of this work. Until now, urban planning often failed in steering urban land use development but it is, however, an important con-straint and framework for the future development of cities. The examples and applications discussed in the thesis will prove evidence of how support planning with quantitatively oriented tools. Last but not least, in doing so the book identifies the links of the quantitative and qualitative dimension in urban processes, actors and dynamics.

Structure of the thesis

In order to structure the complex problem setting of dynamics in urban regions and land sue change impacts the Habilitation thesis follows the heuristic model shown in Figure 1 that illustrates the basic dynamics of urban land use transition: it conceptualises human-environmental interactions as the exertion of land use pressure (chapter 3), caused by societal – in this thesis mainly demographic – and natural driving forces (chapter 2), on the natural resources, landscape fucntions and ecosystems, leading to a modified state of the environment that exerts particular impact and feedbacks to the driving forces again (chapter 4). The scheme further shows that the (multi-criteria) evaluation of land use impacts and thus the link to land use planning and governance in explicitly included into both conceptual approach and quantitative solutions (also given in chapter 4).

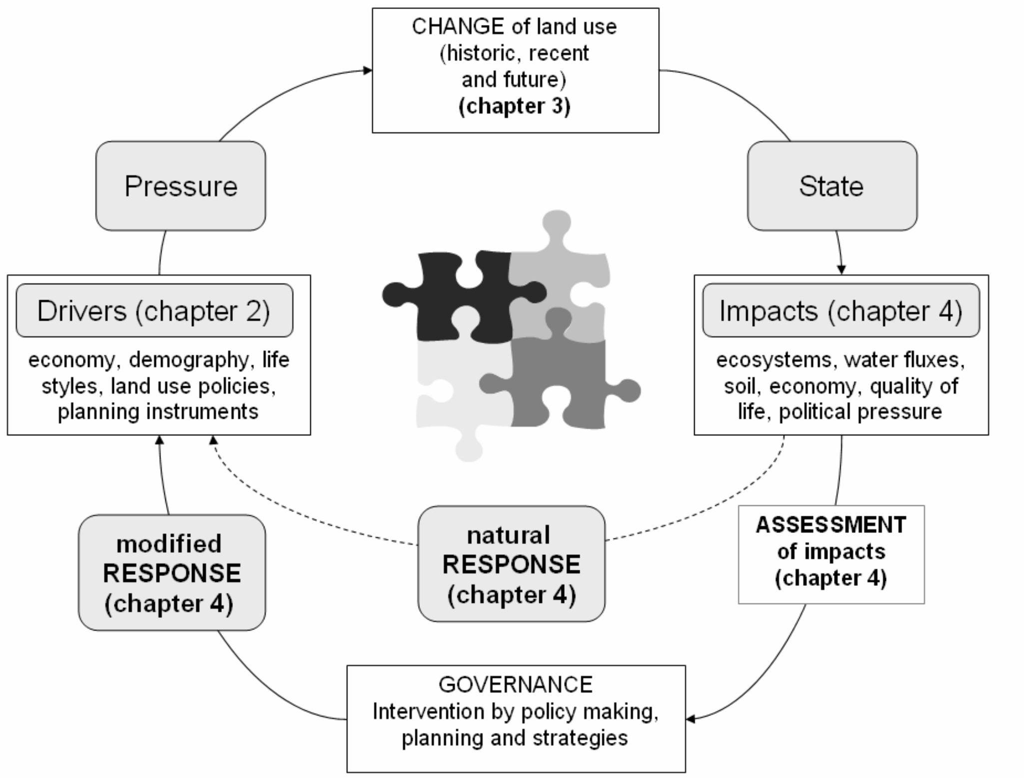

Figure 1 Structure of this Habilitation thesis which follows a heuristic flowchart that illustrates the basic dynamics of (urban) land use transition. The flowchart builds upon the model of "Driving Forces, Pressure, State, Impact and Response" (DPSIR-model) which is widely used in interdisciplinary environmental research as well as in policy documents. Basically, it conceptualises human-environment interactions as the exertion of pressure, caused by societal driving forces, on the environmental media, leading to a modified/new state of the environment that exerts particular impact. It is then essential to the DPSIR-model that this impact possibly has a feedback effect on the driving forces (Brand, 2000; Ravetz, 2000). The five key notions of the DPSIR-model are indicated at the respective places in Figure 2; the arrows in the graph reflect the chain of causation assumed by the model (cf. Nuissl et al., 2008).

Following the DPSIR-model framework, the Habilitation thesis is organised as follows:

- Chapter 1: Introduction (sketching the state-of-the-art and research challenges in the field of urban land use dynamics),
- Chapter 2: Urban land use dynamics – processes and pattern,
- Chapter 3: Model approaches analysing urban land use change,
- Chapter 4: Impact assessment of land use change,
- Chapter 5: Conclusions and outlook.

For information purpose, Table 1 lists all projects relevant for the conceptualisation and results' achievement of this Habilitation thesis and briefly introduces project title, duration, objectives, methods and funding modi.

Table 1 Projects contributing to the results and papers used for the Habilitation thesis

Project Title	Objectives	Methods	Funding
PLUREL (2007-2010)	Develop a conceptual model with quantitative response functions for regional scale land use-relationships Derive a set of socio-demographic, economic and environmental indicators to assess regional scale land use relationships Study agent behaviour and decision making using qualitative mapping and quantitative modelling approaches and derive land use demands at local level driven by individual (agent) behaviour Study land development patterns for (extreme) growth and (extreme) shrinkage scenarios at local level (selected case studies) Relate socio-demographic, economic and environmental indicators into an integrative indicator matrix as landscape response functions	Statistics (Bi-variate and multi-variate regression, cluster analysis, factor analysis, time series analysis) Cellular automata modelling (MOLAND model framework) Agent-based modelling (ABM) Rule-based modelling Habitat modelling Numerical simulation based on differential equations Mapping (GIS) Knowledge elicitation tools (Interviews, games)	EC
NeWater (2005-2009)	Participative model development (scientists & stakeholders) Incorporation of community, local and tacit knowledge into models, monitoring systems and DSS (of management regimes) Main focus on learning processes using tools and participative tool development Bridging the gaps a) between qualitative and quantitative data, b) tool development and use (improved design)	Participative modelling Causal-Loop-Diagramming Knwoledge elicitation tools (KnETs) MULINO Decision-Support-System (DSS) System Dynamics SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) Waterwise Adaptive Monitoring Information System (AMIS)	EC
FLOOD*site* (2005-2009)	Measuring and evaluation of flood impacts on landscapes	Multi-Criteria-Analysis (MCA) TRIMR2D nummercial inundation modelling	EC

3ZM-GRIMEX (2007-2009)	Modelling of urban flooding under different scenario frameworks Coupling of superficial flooding (2D simulation), drainage network and groundwater flows	Scenario technique TRIMR2D, RISOSIM inundation models HYSTEM EXTRAN drainage model PC GEOFIM ground-water model Coupling software MPCCI	National
Program-oriented research (POF, 2005-2008)	Simulation of future land use development of urban regions, analysis of resulting pattern and processes and environmental impacts (using the example of the city of Leipzig)	Rule-based modelling using SELES 3.1/3.2 Agent-based modelling (ABM) Statistics	National

2. Urban land use dynamics – processes and pattern

'The first question for any city is how it shelters its people.'
Joe Ravetz 2000

2.1. Overview

Population dynamics as driving force

Urban regions and their city cores are highly complex systems and appear in many different spatio-temporal connotations (Batty, 2008). In terms of urban population development and land consumption urban scholars stress that urbanisation is far from being a uniform, linear process and rather affects urban areas in different ways (Marshall, 2007). In this sense, the role of post-war suburbanisation is overstated in its importance for present urban development since it assumes on-going future growth (United Nations, 2004, 2007a). By contrast, Oswalt and Rieniets (2005) and Turok and Mykhnenko (2007) bring the decline of urban populations into play for a growing number of European cities and worldwide defining it as shrinkage. At the same time, a resurgence of the city core is postulated based on empirical findings from a range of case studies around the globe (Ley, 1993; Lever, 1993; Frey, 1993; Broadway and Jesty, 1998; Ogden and Hall, 2000; Badcock, 2001; Seo, 2002; Buzar et al., 2007).

Within the global context of urban development, an increasing urbanisation is observed since worldwide the share of urban population exceeds 50% and more than 75% of Europeans live in urban regions (United Nations 2007a, b; Dye, 2008; Montgomery, 2008). However, whereas the urban population increases in total numbers, urban population growth rates slow down mainly due to falling total fertility causing a negative natural population growth (United Nations, 2004). This slowdown in urban population change is interpreted as bigger change than rural population decrease which is accelerating (Champion, 2008). At least since a recent United Nations expert group meeting on population distribution, urbanisation and internal migration and development took place, the discussion on new forms of urbanisation is on the political agenda. Particularly in the focus of European urban development, the question comes up whether it is possible to identify new overall patterns of diverse urban population dynamics including urban growth and decline specified for city cores and the adjacent fringe areas.

Demographic change has become a major topic for European urban regions and their adjacent rural periphery. Growing and shrinking regions exist simultaneously next to each other within urbanised regions mainly due to low birth rates, an increase in life expectancy, changing household structures and, first and foremost, high dynamics of migration (Kabisch et al., 2006). The trend towards further urban growth and dispersion observed in the 1980s in western Europe and later on in the 1990s in East Central Europe is increasingly accompanied by processes such as urban shrinkage and perforation. Moreover, data on inner-urban migration allow us to assume a certain return of the compact city (Buzar et al., 2007). This paper argues that many of the spatial developments and land use changes in urban regions are effects of demographic change.

They are closely related to both the balance of supply and demand in changing consumer relations between space, natural resources and population.

Whereas social scientists and economists intensively discuss the impact of demographic change upon social structure, cohesion and the labour market, only a few studies refer to the spatial and land use impacts that are caused by demographic change (Heiland, 2006). What are the spatial effects of demographic change in urban regions? Does a population decline automatically mean a reduced number of consumers of urban ecosystem services (water, energy consumption; urban green) or a decrease in urban land consumption? Or will population decline simply lead to an increase in unused and waste land, and low density urban areas (Berg et al., 1982)?

To answer these questions, we need first of all to shed light on the spatial distribution of population, age spectra, households and migration in urban regions. Second, we have to identify on the relationship between population change, residential mobility and the demands on residential land, urban infrastructure and recreation areas. Referring to stability and security aspects, in particular the long-term stabilisation of urban regions under demographic decline in terms of compactness of settlements and consumption of natural resources is of interest. Set against this background, it is the purpose of the chapter to analyse the trends and spatial pattern of the impact of demographic changes in urban regions.

Demographic change and land use dynamics

Demographic change is becoming increasingly more important in political and planning discussions, given that it is considered to be an important factor for future land use development and urbanisation throughout the whole of Europe (United Nations 2007a,b). The Millennium Ecosystem Assessment states that demographic development is an essential driver for ecosystem and land use change (Nelson et al., 2006; EEA, 2006). As in most European countries, demographic development in Germany is mainly characterised by a declining and rapidly ageing population due to a fertility that is below replacement and an increasing life expectancy (Edmonston, 2006). Another important aspect of demographic change is the decline of the average household size in line with what demographers describe as the Second Demographic Transition (SDT; Lesthaeghe and Neels, 2002; Steinführer and Haase, 2007). However, long-term data sets on household dynamics and household types put into relation with land use dynamics are still rare (Haase and Haase, 2007).

In addition to a decrease in fertility, migration can be an even more determining factor that influences population size and age structure (Flöthmann, 2003). Ever since the German reunification in 1990, migration fluxes from eastern to western Germany and from the core cities to the suburban regions have been observed (Nuissl and Rink, 2005). Rural regions in eastern Germany have particularly suffered from population decline and a growing proportion of elderly people whereas most suburban and rural regions in the western part of the country are still experiencing population growth (Müller and Kilper, 2005). Demographic processes, of which the migration rate is of prime importance, are having significant impacts on urbanisation. Ruderalisation and land abandonment in rural areas are becoming more and more observable. However, ongoing construction activities in the suburban areas of eastern Germany's shrinking cities are creating an urban-sprawl and resulting in the perforation of residential areas, and a decreasing settlement population density (Nuissl and Rink, 2005).

Currently, population decline is regarded as an opportunity to increase the sustainability of land use by decreasing the further sealing of open areas for housing and transport (Haase et al., 2007), although there is still almost no evidence on the accuracy of this relationship. Through its national sustainability strategy the German Federal Government (Federal Statistical Office, 2007) hopes to limit new land consumption for housing and transport purposes to 30 ha per day up until 2020. This target, however, still seems to be well out of reach, as a noticeable trend towards a decreasing amount of land consumed for housing and transport is not yet visible. Thus, the effects of a declining and ageing population on the development of residential and transport areas are of particular interest to national and regional policy makers.

In the current literature, contradicting assumptions about the relationship between demographic change and land use have been found. A declining population is not necessarily followed by a decline in development or even a decrease in urban land (German Federal Environment Agency, 2003; Couch et al., 2005). The reasons for this can be attributed to a decreasing household size and a rise in housing demand regardless of population decline. In contrast, Wolf et al. (2004) expect a future decline in urban area growth in regions with a decreasing population. In addition, abandoned agricultural land and the growth of forest and natural land following the depopulation of rural areas are considered to be a likely scenario (Bruns et al., 2000). However, a quantitative analysis of a relationship between demographic and land use change at the regional scale is still missing.

Voices of return? Demographic reasons for a resurgence of cities and reurbanisation as a process of (re-)densification of core city areas

Since the beginning of the post-socialist transition in 1989, east German cities have been affected by dramatic processes of population loss, mainly due to out-migration to western Germany, suburbanisation, a decrease in birth rates to lowest-low levels (Kohler et al., 2002) and subsequent ageing processes. At the end of the 1990s, almost all cities and towns in east Germany were shrinking: in only ten years, they experienced a loss of more than 15% of their inhabitants. Especially the big cities such as Leipzig, Dresden, Halle etc. lost between 1989 and 1998 10-20% of their population. At present, east Germany is forming a "pole of shrinkage" together with other post-socialist countries of eastern Europe (Turok and Mykhnenko, 2007; Haase, D. et al., 2008a).

Since 2000, however, a reversal of trends has been observed: Some cities and bigger towns are no longer losing population, but re-gaining inhabitants. Positive migration balances are mainly based on intraregional in-migration (from east German regions) and a considerable decline in out-migration. People increasingly prefer to stay in the city, while suburbanisation processes, artificially pushed by subsidies during the 1990s, have almost stopped (Herfert, 2007). In this vein, a discourse about a "comeback" of urban living i.e. reurbanisation, as a future scenario for a number of big cities in eastern Germany has evolved (Haase, A. et al., 2005a; Haase, D. et al., 2008b; Köppen, 2005).

Reurbanisation is discussed at present also in the UK and other European countries (Buzar et al., 2007; Colomb, 2007) and the US (Cheshire, 2006). However, the east German case shows an "atypical" or somehow "specific" pattern, insofar as it refers to shrinking cities and, even more, parts of entire landscapes. It has become an issue of scientific and planning debate against the background of the achievement of sustainable urban development with respect to declining population numbers, under-use of urban infrastructure and endangerment of the functionality and liveability of cities. To be able to make reliable conclusions on both current and future trends of urban stabilisation, reurbanisation needs to be analysed in more detail concerning its major characteristics, progress and resulting socio-spatial dynamics. First and foremost, it has to be determined whether reurbanisation represents a long-term trend of inner-city stabilisation in eastern Germany or features only short-term tendencies.

The following publications comprehensively and innovatively contribute to answer the theoretical questions raised above using methods of quantitative, mostly statistical data analysis and distilling the information of the listed publications.

2.2. Urban population dynamics in Europe

Kabisch, N., Haase, D. submitted. Diversifying European agglomerations: evidence of urban population trends for the 21st century. *Population, Space and Place*.

(Reprint of the paper cf. Annex A1)

Summary and Conclusions

Urban scholars stress that urbanisation is far from being a uniform process. Often the role of post-war suburbanisation is overstated in its importance to present urban development. At the same time, the resurgence of the city core is postulated. To shed light on current urban population change this paper examines recent trajectories of European urban agglomerations. It represents the first comparative analysis of 158 agglomerations of the EU-27. Using contingent population data from 1991 to 2004, evidence of diversifying population trends for city cores and fringe areas is highlighted.

A data base on European urban regions at the spatial NUTSX level was developed. The analyses we choose were applied to different spatial scales of an urban agglomeration: the city core (national political, administrative definitions) and the fringe area (urban hinterland of the surrounding municipalities from which a significant share of the commuters origin). The distinction was made, since an urban agglomeration is more than the built-up area of a city (which serves rather as a morphological criterion to distinguish different land uses within the agglomeration itself), and functionally comprises the commuting zone around a city core. The same concept of the "Functional Urban Region (FUR; Commission of the European Communities, 2004)" was already used by Berg et al. (1982). To identify stages and trajectories of urban development, time series variance analyses were conducted for three time slots, that is 1991-1996, 1996-2001 and 2001-2004.

The population change rate serves as the explanatory variable for the variance analysis of the complete data sample and of the sub-samples by size, which were distinguished according to their total population number in 2004: small LUZ with <400,000 inhabitants, medium sized LUZ with a total population of ≥0.4 and <1 million inhabitants and large LUZ with ≥1 million inhabitants. It was also used for the regional sub-samples for Northern, Western, Southern and Eastern Europe (United Nations, 2008).

We found that particularly the sequence of suburbanisation, desurbanisation and reurbanisation altered. Whereas suburbanisation reinforces, desurbanisation partially decreases in favour of an initial reurbanisation. Smaller agglomerations of less then 400,000 inhabitants decline, whereas the city cores of larger agglomerations tend to regain residents. European cities result to be very heterogeneous in recent population change dynamics. They form clusters of growth and decline trajectories after 1990 and support a new spatial picture of the urbanisation of European agglomerations.

Basing on significant statistical relations, this paper presented a first comparative analysis from different urban agglomerations of the EU-27. Their long-term population trajectories on city core and fringe area level were analysed by using consistent population data of 158 agglomerations which date from 1991 to 2004. Further, it was explored whether there are important differences in population development due to the size of the agglomerations and their regional distribution in Europe.

It is concluded that there is evidence of diversifying population trends of both city cores and the fringe areas across Europe. Particularly the city cores' population decreases since 1991 but shows positive values since 2001, whereas on the other side, the fringe areas face positive population change rates over the entire time. With respect to the cyclic model of the stages of urban development our findings show that the consecutive order of the stages, the sequence, has changed or reversed, that is a "push back" into suburbanisation, but also an acceleration in the frequency of the cycle, that is a disappearance of the desurbanisation stage in favour of an emergence of reurbanisation. Varying population dynamics for different city sizes were presented. Here, positive population change rates of the large and medium sized cities were identified, meaning increasing change rates over time whereas the small agglomerations appeared with barely growing change rates entering total decline in 2001.

Regarding the attribute of location in Europe a rise in suburbanisation in Western and Southern Europe appeared since 1996 accompanied by a drop of desurbanisation in favour of evolving reurbanisation processes. Contrary trajectories were found regarding Eastern Europe that has to tackle severe decline but experienced a recent slight recovery of the LUZ. The regional clusters and population dynamics behind found clearly support a new spatial picture of the urbanisation of European agglomerations. What is more important, since time-series data and analyses were used, the trajectories of different European urban agglomerations can be explained in terms of their stability. The new patterns showed over time add to present urban research and planning since they give the opportunity of thinking about a long-term urban policy development.

2.3. Land use impacts of demographic change

Haase D., Seppelt R., Haase, A., 2007. Land use impacts of demographic change – lessons from eastern German urban regions. Petrosillo, I., Müller, F., Jones, K.B., Zurlini, G., Krauze, K., Victorov, S., Li, B.-L., Kepner, W.G. (Eds.) Use of Landscape Sciences for the Assessment of Environmental Security. Springer, pp. 329-344.

(Reprint of the paper cf. Annex A1)

Summary and Conclusions

Demographic change has become a major topic regarding the use and stability of European urban regions. It can be seen as the major driving force responsible for "growth" and "non-growth" or "decline" pathways in urban regions for the coming decades. Growing and shrinking urban regions do exist simultaneously next to each other. The trend towards further urban sprawl and dispersion observed in the 1980s in western Europe and the 1990s in East Central Europe accompanying the transition process are about to be replaced by shrinkage and perforation. This is mainly due to the recent decrease in birth rates, ageing and shifting household structures. This chapter analyses the trends and spatial patterns of the impact of demographic changes in urban regions. In the first part different features of demographic change are presented. In the second part, the paper expands on how demographic change affects urban land use, fabric, housing markets, infrastructure and greenery. Since eastern Germany has been shrinking substantially since 1990, the paper uses this example to show a case in point embedded into the overall European context.

As discussed in this paper, demographic change considerably impacts on recent shrinkage and perforation processes in eastern German urban regions. Except singular empiric results, a comprehensive quantification of these impacts on land use pattern is still to be done. Does, for example, a decreasing population reduce land consumption at the urban periphery in a long-term perspective (Heiland, 2006)? Up to present, there is no evidence for a direct relation between the two processes. And further, does shrinkage allow for the improvement or, at least, for a stabilisation of environmental quality in formerly growing, densely built urban areas?

Demographic change means above all a change in the total number of people, age class distribution, a modification in household structures and a rising impact of migration. Whereas population decline in western German urban regions is yet on a moderate level (Ø -1496 inhabitants per year from 1995 to 2004), eastern German urban regions are affected already for 15 years by significant shrinkage processes: low birth rates, high out-migration and ageing rates (Ø -10365 inhabitants per year from 1995 to 2004). There, we find a coincidence of seemingly contradictory urban processes: first, although on a low level since the late 1990s, there are traces of prevailing dynamics of suburban growth (single and semi-detached house settlements, new 'housing parks') with adjacent land consumption (commerce and industry) at the urban fringe. Second, at many places, increasing process of depopulation and related shrinkage calculated according to residential vacancy, perforation, demolition and deconstruction in the core city areas can be observed. A thinning out of recent urban fabric and population densities are the consequence. Third, counteracting decline, we find also processes of stabilisation of the housing function as well as increasing population numbers in some inner-city areas.

The analysis further discussed the fact that demographic change already endangers the infrastructural viability in urban areas that are affected by massive decline. With a declining population density, critical thresholds for the viability of technical, transport and social infrastructures and in public facilities are reached already now. There are coming up new debates on how to ensure and finance the supply of the remained inhabitants in areas undergoing demolition of housing stock. Due to a thinning out of social and administrative infrastructure and a decrease in individual accessibility, daily travel times might increase although the population decreases. To put it differently: Demographic change on its own does not solve the problem of land and resource consumption, and it does not automatically bring about higher environmental quality for urban regions either.

I think that the questions addressed concerning the potential impact of demographic change on urban regions have to be answered jointly by demographic, social, urban and landscape science like the interdisciplinary authorship of this chapter underscores. To what extent and how demands on natural resources and space will really change under the condition of population decline and shrinking urban regions? Do we have to consider a long-term change in demand-supply-relations which result either in ecological benefits or in new threats? The question whether future land developments along the rural-urban gradient will be characterised either by polarisation between core city and surrounding areas or by a widespread lowering of densification in the form of perforation has to be left for future comprehensive and comparative analyses of urban regions throughout Europe.

Kroll, F., Haase, D. submitted. Does demographic change affect land use patterns? A case study from Germany. *Land Use Policy*.

(Reprint of the paper cf. Annex A1)

Summary and Conclusions

Recent demographic change, mainly characterised by a decreasing and ageing population, is seen as one of the main factors for future land use development in Europe. However, there is still insufficient evidence about the relationship between demographic changes and land use changes since quantitative studies dealing with these interactions are still rare. We aim to fill that gap by presenting the first comprehensive study that investigates statistical relationships and spatial differentiations between demographic and land use change for the whole of Germany. Our study is based on data for the period from 1995/96 to 2003/04. The results clearly show that in most growing regions in the West of Germany a correlation was found between land use, natural population growth and net-migration, whereas for land use change in the shrinking regions in the East of Germany economic variables are of noticeable importance. A cluster analysis reveals "gaining" and "shrinking" regions concerning both urbanisation and demographic change. Neither a decreasing nor an ageing population imply reduced land consumption for housing and transportation. Furthermore we found a decreasing settlement population density for almost all German counties regardless of population growth or shrinkage.

As one of the first comprehensive studies on quantitative relationships between demographic and land use change, our analysis shows that the declining population in core cities and rural areas in the East of Germany does not accompany a decrease in land consumption, as economic processes seem to be of far greater importance for land use changes here. So far the ageing population has not yet had any detectable effect on land use changes, but this will change in the future, if the per capita housing area of elderly people contiunes to increase. The cluster analysis reveals that the counties with the highest land consumption per capita are located in the rural areas of north-western Germany. Apart from suburban counties with significant immigration, the settlement population density decreased across all counties including both eastern and western Germany. Hence, we are striding away from the goal of sustainable land use regardless of the reality of demographic change.

The findings of the paper prove that demographic change will not “solve” the problem of land consumption in Germany. However, it clearly identifies where both demographic and land use change lead to a more concentrated or even scattered development with increasing land consumption per capita at the least. The clusters that we identified give planners more support when considering regional specific policy options for dealing with demographic and land use change rather than clutching to an overall national 30 ha goal.

2.4. Processes of reurbanisation

Haase, D., Haase, A., Bischoff, P., Kabisch, S., 2008. Guidelines for the ‘Perfect Inner City’ Discussing the Appropriateness of Monitoring Approaches for Reurbanisation. *European Planning Studies* 16(8), 1075-1100, DOI: 10.1080/09654310802315765.

(Reprint of the paper cf. Annex A1)

Summary and Conclusions

In this paper, we analyse the appropriateness of monitoring approaches for the observation of inner-city reurbanization processes. Reurbanization is conceptualized here as a process of long-term stabilization of inner-city areas by both a readiness of present residents to stay and an influx of new residents. It has been recently re-set on the top of the European urban research agenda since non-growth has proved to be a major path of future development for many European cities. Recent research evidence across Europe underscores the fact that reurbanisation depends much on local settings of institutional, socio-economic and infrastructural factors.

To foster a clearer understanding of the nature and dynamics of local reurbanization, to assess its extent and progress and, what is more, to help practitioners to shape sustainable policy initiatives appropriate to the respective context, reurbanization needs to be observed over the long term. The complex character of reurbanization sets new challenges for monitoring approaches and indicator-based tools. Due to the genuine relation of the present debate on reurbanisation to the phenomenon of non-growth or the return of the compact city, the focus in this paper is set on demographic development trends and their impact on inner-city change. In this vein, our paper presents a monitoring design and a respective newly developed indicator set for reurbanisation which focuses more on the initial recognition of reurbanization than on its long-term stability.

Methodically, chances and limits of the integration of household-related indicators and qualitative knowledge on reurbanization into monitoring tools are highlighted. Empirical and statistical evidence is taken from a recently completed EU FP 5 research project and from municipal surveys.

In this paper, we have analysed the demands and prerequisites for a monitoring of inner-city reurbanization processes. We contrasted the complex reality of reurbanization as a household-related inner-urban change with the body of hitherto existing approaches and ideas of urban monitoring. There is still missing an urban monitoring approach to detect reurbanisation in terms of both the qualitative and the quantitative. Starting from a number of new requirements that reurbanization sets up for a long-term observation of inner-city reurbanization, we introduced a set of indicators with demographic focus that were based not only on sizeable but also on qualitative information. We presented a design to study and monitor reurbanization processes in the initial (more quantitative) recognition state, which has been the focus of this paper. There is envisaged a further test and refinement of the indicators and in particular their operationalization. For the city of Leipzig, the evidence of the indicators was tested by means of small-scale municipal data for all urban districts. Cross-referencing our findings, the following conclusions can be made.

First, it became clear through evidence that previous monitoring approaches did not fully apply for reurbanization as a complex development. This complexity is especially evident because of the close interplay of reurbanization with demographic and household shifts and the related altering housing preferences that need to be considered. Second, according to these aforementioned specifics, the indicator set is based on demographic indicators. It further incorporates additional ones to monitor a more complete picture of what is reurbanization. In particular, the approach presented here meets the specifics of reurbanization in a primarily qualitative demographic understanding. Third, for the first example of Leipzig, the baseline indicators and the whole set, represented by some examples, passed the test and confirmed the assumptions made previously for reurbanization-sensitiveness of inner-city districts in Leipzig. Fourth, hitherto results demand further application for other local contexts, a feedback discussion of the indicator set by using newly-gained knowledge from the statistical tests and, in addition, an enlargement of the tests in terms of further indicators, rankings and cross-comparison of dependent indicators.

The monitoring design is predominantly understood to serve as an academic instrument for scientific cooperation. It further supports scientist-stakeholder communication. Observed from a more operational angle, the indicator set can be incorporated into different existing (monitoring) instruments and thus serve as a completion tool for specifically recognizing reurbanization processes. For the case of Leipzig, the monitoring design and indicator set presented here represent, without a doubt, a qualitative enhancement of the existing residents' survey ("Bürgerumfrage"), as well as the annual monitoring programmes (Stadt Leipzig, 2003, e.g. for the residential market the questionnaire-based expert-panel "Wohnungsmarktbarometer"). For the latter, the new indicator set offers precise characteristics and distribution of residents who relocate. At a more scientific stage, it is planned to include reurbanization into a web-based observation system for urban sustainability (IGNIS; Hartmuth et al., 2006) or into already existing web-presentations of cities (e.g. City of Bologna).

Kabisch, N., Haase, D., Haase, A. accepted. Evolving reurbanisation? Spatio-temporal dynamics exemplified at the eastern German city of Leipzig. *Urban Studies*.

(Reprint of the paper cf. Annex A1)

Summary and Conclusions

After a decade of tremendous population loss indicating severe decline, some big east German cities have been displaying signs of reurbanisation since the late 1990s. Using the example of the city of Leipzig, this paper identifies major characteristics, progress and underlying spatio-temporal dynamics of reurbanisation. It examines whether it is a long-term process of urban living or features only short-term tendencies. It applies socio-demographic indicators to observe the development of inner-city districts. At the spatial scale of municipal districts time series data are analysed for the years 1993 to 2005. The paper argues that reurbanisation has occurred primarily in inner-city districts and has undergone considerable progress since the early 1990s. However, the spatio-temporal distribution of relevant indicators shows that reurbanisation is far from being a homogeneous process. In light of this, the paper presents a ring of reurbanisation-sensitive local districts around the city centre.

In this paper, we have presented quantitative spatio-temporal analyses of reurbanisation based on socio-demographic indicators out of an interdisciplinary indicator set for reurbanisation processes. Using the example of the east German city of Leipzig, we set up five hypotheses to identify basic characteristics of reurbanisation. We further explored whether reurbanisation is related to certain local settings of spatial, socio-economic and residential-environment factors. Moreover, we analysed whether reurbanisation shows tendencies to be a long-term process instead of being only a temporary phenomenon. In order to test these assumptions, small-scale municipal time-series data for the 63 urban districts from 1993 to 2005 were analysed.

Summarising, we come up with the following conclusions: Firstly, we found small (i.e. one and two-person) households to be the drivers of reurbanisation in Leipzig. Set against the background of overall trends of downsizing of households and increasing importance of living alone, it became clear by evidence that the current reurbanisation is favoured by these trends. Secondly, we identified young households, particularly the age class of the 20..30s, as reurbanites who settle in inner-city districts making use of their central location what means short distances to work or education as well good connection to other urban amenities.

Comparing the direct indicators of reurbanisation with some other, seemingly related indicators, we found, thirdly, both increasing as well as decreasing correlations. While the statistical analysis points to a positive relation between reurbanisation and the numbers of doctors and SME, it is not the case for kindergartens and schools. We unveiled that it is indispensable to look at the processes behind the data to be able to interpret them properly.

Through a cluster analysis, we determined, fourthly, those districts where reurbanisation processes are observable since the end of the 1990s. A considerable share of these districts showed consistent significant characteristics of reurbanisation from 1999 to 2005 and were therefore classified as the "Young Reurban Cluster" with at least a mid-term perspective.

We conclude that Leipzig is a case in point to analyse reurbanisation processes that focus on the inner city and younger households but might even affect outer districts and other residential groups like families and elderly in the future. Comparative views to other east German and even East Central European cities (Haase, A. et al., 2007) show that the described trends are of an overarching importance and not locally specific. Whether they are really long-term or merely represent a phase of inner-city reconsolidation within a broader cycle of development under the conditions of population decline has to be left for future research.

3. Model approaches analysing urban land use change

'Prediction is never easy,
especially where it concerns the future.'
Paul Dirac

3.1. Overview

Mapping of land use change

Unlike in previous ages, landscape development in Central Europe is currently characterised by mainly anthropogenic processes affecting almost the entire landscape (Ravetz, 2000; Antrop, 2000; Konold, 1996). Many of these processes are almost imperceptible when viewed over shorter periods and appear to be of little consequence. In the long term, however, they may well lead to changes in the carrying capacity, water balance and usability of the landscape. Landscapes in this paper are understood as dynamic and open systems where biophysical, social and economic factors mutually interact and are structured in heterogeneous patterns in different space and time frameworks. Cultural landscapes have a strong historical background to be considered today (Bastian and Steinhardt, 2002). Changing landscapes, especially changes in the way in which land is used, result in alterations to the landscape structure—and, hence, also to the abiotic and biotic functions and potential of a landscape. The general trend of landscape development in Central Europe is heading towards more monotonous, less diverse landscapes combined with the impairment of landscape functions over large areas (Antrop, 2000). The diverse conditions characterising natural areas are being increasingly narrowed down while the landscape balance is being permanently altered.

In Central Europe, a region dominated by anthropogenic development for housing, trade, industry and intensive agriculture, in addition to their natural attributes landscapes are mainly characterised by multiple usage and -, hence, usage conflicts (Antrop and van Eetvelde, 2000). Not just a 20th-century phenomenon, this multiple usage has in fact evolved over a period of centuries - although the period since World War II has been dominated by the human exploitation of natural resources such as soil, water and flora, fauna and space/area itself due to urban expansion on a far greater scale than ever before (Bastian and Schreiber, 1999; Nuissl and Rink, 2005). The expansion of the land used for forestry, water, urban settlement and transport is continuing unabated. Moreover, at present the phenomenon of shrinking urban settlements due to population decline (decreasing birth rates, out-migration) and resulting land abandonment and residential vacancy characterises large parts of Central Europe (Lutz, 2001, 1996). Although population growth, the major driver for land use and landscape change over centuries, has lost its dynamic in Central Europe, increasing migration fluxes at the regional and international level must nevertheless be taken into consideration. Furthermore, open spaces are subject to greater fragmentation by technical infrastructure owing to intensive road construction arising from an increased mobility of our society and related transport infrastructure construction (Jaeger, 2002; Walz, 2005b). The intensification of farming has resulted in an increase in the average size of individual areas used for agriculture, increasingly attributed to land redistribution and drainage combined with the disappearance of structural elements of the landscape (Dosch and Beckmann, 1999). Especially in the Eastern part of Europe, the socialist planning regime led to extremely large management units. On the other hand, the total amount of land used for agriculture is declining due to economic development and agri-environmental policy of the European Union (BBR, 2002; ESDP, 1999).

Modelling urban land use change: opportunities and challenges

Urbanisation belongs to the most complex and dynamic processes of landscape change. Although only about 4% of the worldwide land area are urbanised and impervious surface (Ramankutty et al., 2006), we claim “the millennium of the cities” since more than half of the currently 6.6 billion world population is living in urban areas (UN, 2007; PRB, 2007; EEA, 2006; Kassanko et al., 2006). Projections for the future show that urbanisation – in terms of increasing share of population living in urban areas – is very likely to continue (Batty et al., 2003; EEA, 2006; Lutz, 2001). Urbanisation is not only a problem because it contradicts a normative ideal of landscape and spatial planning. In a multitude of studies it has been shown that land consumption is usually detrimental to the environment in different regards (e.g. Johnson 2001; Antrop, 2004). Its impact reduces the ability of nature to fulfil human requirements and thus impairs ecosystem services and landscape functions in various ways (De Groot et al., 2002; MEA, 2005; Curran & Sherbinin, 2004). Individual ecosystem services and quality of life aspects that are affected by urbanisation include the production of food, the regulation of energy and matter flows, water supply, the provision of biodiversity and of health and recreation, the supply of green space or natural aesthetic values (Nuissl et al., 2008).

Modelling land use relationships helps to understand underlying drivers of land use change, to create future land use scenarios and assess possible environmental impacts (Lambin et al., 2006). A variety of land use change models particularly for urban landscapes already exists, ranging from specific case studies to generic tools for a variety of urban regions. These models differ largely regarding their structure, their representation of both space and human decisions, and their methodological implementation. Compared to land use change models in open landscapes, urban areas are shaped particularly by human activities, societal processes and human-nature interactions (Couclelis, 1997).

Additionally to implemented simulation models, a number of articles and book chapters elaborate on the “ideal” integrated model, theoretically necessary causal feedback loops et cetera. Often, authors use frameworks like the DPSIR-framework (drivers, pressures, state, impact, responses) of the European Environment Agency (EEA) to conceptualise model structure. According to Verburg, “the main drawback of using these analytical frameworks is the assumption of one-directional processes between driving factors and impacts” (Verburg, 2006), because in reality, it is difficult to differentiate between impacts and drivers in a system. Bürgi et al. (2004) distinguish five major types of driving forces: socioeconomic, political, technological, natural, and cultural. Furthermore, they differentiate between primary, secondary and tertiary driving forces as well as between intrinsic and extrinsic driving forces (Bürgi et al., 2004). In their introduction to urban simulation Waddell and Ulfarsson (2004) sketched urban markets and agents, choices and interactions in an “ideal” urban (land use) model.

Timmermans (2003) criticizes that present urban models focus on functional chains like the following: demand causes allocation across space which in turn causes traffic flows, based upon that a transportation model calculates travel times, which in turn explain residential choice. Timmermans votes to include other aspects of integration in urban land use models, such as task allocation within households, residential choice, job choice, vehicle holding decision, scheduling of activities, competition and agglomeration of land uses and actors, co-evolutionary development of demographics, employment sectors, land use and activity profiles and a fuller treatment of varying time horizons, including anticipatory and reactive behaviour. According to Miller et al. (2004), an integrated urban systems model with focus on transport should include socio-demographic components (evolution of population demographics (demographic change and migration into and out of region), decision-making (location choices of households and firms), economic variables (labour market, import/export of goods and services), transportation (activity and travel patterns of population, goods and services depending upon urban structure and economic interchanges, performance of road and transit systems) and respective effects for land use (evolution of the built environment) and environment (atmospheric emissions generated by transportation and industry; Miller et al., 2004). As Verburg (2006) points out, an integration of social and biophysical systems could be enhanced by including feedback mechanisms in land use models, e.g. the feedback between driving factors and effects of land use change (here understood as impacts), the feedback between local and regional processes, and the feedback between agents and spatial units (Verburg, 2006). "Less common in land use modelling is the simulation of feedbacks between impacts on socio-economic and environmental conditions and the driving factors of land use change" (Verburg, 2006).

The following publications present quantitative studies of land use change analysis and modelling driven by theoretical considerations rised above.

3.2. Modelling and monitoring land use change

Haase, D., Walz, U., Neubert, M., Rosenberg, M., 2007. Changes to Saxon landscapes - analysing historical maps to approach current environmental issues. *Land Use Policy* 24, 248-263.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

The issues of historical landscape analysis and the influential driving factors of landscape development provide an essential basis for tackling current environmental questions in spatial planning. Therefore, this paper focuses on the objectives and methods of historical landscape analysis with the example of Saxony, Central Germany. The different ways in which such investigations can be applied and the results achieved are shown using four case studies. The main objective is to discuss methodological aspects of spatially explicit GIS-based landscape analysis and ways of making full use of the information contained in historical maps. Examples of suitable maps of Saxony dating back to 1780 are presented. In addition to historical land-use information, valuable additional information can also be gained from this kind of data, such

as on the historical pattern of landscape functions, potentials and structures. These findings can be used to predict and optimise future landscape development.

The approaches presented here combine methods of classical landscape analysis with modern techniques such as geographic information systems (GIS), the approach of landscape metrics (LSM) or deterministic models (e.g. ABIMO), which can be used to serve spatial analysis, and tools for analysing landscape structure.

The case studies presented here portray the development of land use and how its structure has changed in various types of Central European cultural landscapes such as urban and rural ones, floodplain and mountain situations. The methods developed enabled an extensive database to be created which was then used to analyse how usage has changed and how these changes affect selected structures, functions and potentials of landscapes. Regarding the methodology used in historical landscape analysis, the following conclusions with respect to spatial land use planning can be drawn:

- Historical maps can be integrated into a GIS with sufficient accuracy. As a result, the development of land use can be shown quantitatively over a period of more than 200 years. Statistics can then be compiled on the development of the proportions of linear elements and areas of certain usage types so that the interpretation of landscape development can be quantitatively substantiated.
- The structural changes between landscapes past and present can be quantified by means of indices. This makes a contribution to a functionally orientated assessment of landscape development. By contrast, simple analysis of the proportions of land used for certain purposes sheds light on the possible functional relationships in the abiotic antibiotic landscape balance (Berger and Walz, 2004).
- Taking into account landscape functions in assessment brings home how important it is to consider the 'loss' of not only land in the meaning of total area but also resources and landscape functionality (Krönert et al., 2001; Walz, 2005a).
- Finally, the quantification of long-term land use change and its environmental impact enables us to reduce the existing uncertainty to predict future landscape change in land use change or biophysical models.

Currently, the most serious processes of landscape change with a considerable environmental impact are extensive development caused by processes of urbanisation, especially urban sprawl, the fragmentation of landscapes by infrastructure development which finally leads to a
decline of large continuous habitat patches (Kühn et al., 2004), and changes to the structure of farmland. Simultaneously, current land abandonment due to shrinkage will lead to land use changes in the form of extensive development and thus offers new chances for re-naturation or ''ecologicalisation''. For example, one result of the further liberalisation of farming is that agriculture is withdrawing from areas whose suitability for cultivation is limited (owing to relief, soil and climate conditions as well as farm sizes, etc).

On the other hand, the intensity of farming is increasing on land which is more suitable for cultivation (high productive soil regions such as the Loess regions of Europe). However, the authors are aware of the fact that the historical and current development of cultural landscapes described here has a high relevance for many other regions of Europe, but at the same time there exist also contrarian trends that shape landscapes such as field aggregation due to the socialist agricultural policies in Central Eastern Europe. As far as the development of land for human settlement is concerned, regional decline and shrinkage processes caused by the declining population and the resulting derelict residential and commercial sites contrasts with strong growth and urban expansion in other regions (Stanbeck, 1991; Nuissl and Rink, 2005).

These processes will result in sharp changes to the cultural landscape throughout Europe. Sustained usage pressure opens up a whole range of developmental options for the conversion
of abandoned sites. Unused land could, for example, be left fallow and left to natural succession of vegetation (‘‘ecologicalisation’’), reforested, or used for nature conservation or countryside protection. Nevertheless, open and unsealed spaces are still in danger of being paved in the near future and the tendency of land use intensification will continue, even in shrinking or declining landscapes. These processes will not be limited to agglomeration areas because land and open space are not unaffordable goods and available for land uses such as housing and industry. But as far as the development of cultural landscapes is concerned, attention must be paid to ensuring that the functionality of landscapes is sustainably maintained and landscape planning has to meet the specific requirements of a multifunctional land use in our cultural landscape. For landscape planners and regional planning authorities, the conclusions presented here should facilitate them to acquire better awareness of the importance of historical knowledge and material available for current and future shaping of the landscape. The paper does not intend to give concrete decision support for planners because of the multitude of pattern and processes and of landscapes in general. However, taking into consideration the history and the changes derived thereby would be a large step forward for landscape planning in many parts of Europe (German Soil and Nature Protection Act 1998, 2002; Kühn et al., 2004). The intent of this paper has been that, since intensive land utilisation has a long tradition in Central Europe, we must recognise what kind of changes are occurring within recent history and calculate this into the budget of future landscape development.

Haase, D., 2003. Holocene floodplains and their distribution in urban areas – functionality indicators for their retention potentials. *Landscape and Urban Planning* 66, 5-18.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Floodplains are among the natural areas in central Europe which - depending on the formative power of flowing water - possess a high natural potential for the regulation of water and matter flows. Many floodplains and urban development share a long common history in central Europe. Numerous, sharply varying historical views exist on how to distinguish European floodplains. Therefore, the aim of this paper is to examine relevant indicators such as floodloam expansion, groundwater table, relief and land use to see how useful they are for characterising current floodplain functionality in urban areas and to ‘flesh them out’ for a case study.

Judging by the criteria meadow loam, relief, vegetation and water table depth, the floodplains account for large areas of the Leipzig district. The north-west of the city can for example be described as relatively natural. In the core areas, the floodplains have been ravaged but are still to be seen. The urban green spaces are important here since they augment and in some cases replace the natural vegetation. Things are more difficult regarding the natural soil functions of the floodplain soils, which have not been restored following backfilling, excavation and surfacing. In many areas south of Leipzig, the floodplains have been completely destroyed by lignite mining, and hardly any of the valleys of receiving watercourses like the Parthe and the Zschampert can now be described as floodplain-typical ecosystems. Concerning flood retention areas there have to be re-discussed river embankment and renaturation measures for the City of Leipzig, although there exist in form of the new lakes in the former mining area big retention areas collecting floods from the mountains, etc.

Floodplains and floodplain forests in urban areas have been made scarce by centuries of human influence. Their natural functionality as retention areas and pollutant sinks has in many cases completely disappeared which could have disastrous consequences such as in Central Germany in August 2002 (http://www.dfd.dlr.de/images hochwasser/index.html). When the geochemical milieu conditions change and the soils' cohesive and buffer capacity is reduced, floodplains can quickly become sources of pollution (Haase, 1999). On the other hand, floodplains and relicts of floodplain forests have become important places of recreation and nature perception for many European cities (Ward Thompson, 2002; Daniel, 2001). The recreation function has replaced the production function of floodplains and floodplain forests in the Elster–Pleiße–Parthe floodplains in Leipzig discussed here. ". . . The floodplain forest is a green swathe cutting through the city of Leipzig and the surrounding rural district. Its countenance has been shaped by many generations, who have turned this original forest and marsh landscape into a much-visited green belt . . . " (Müller and Zäumer, 1992, p. 55).

Yet the analysis contained here shows that these green swathes (also sometimes referred to as 'green lungs') in towns and cities are not adequately protected against land surfacing, blockage and contamination. The usage pressure exerted by inner-city areas repeatedly prompts discussion over open spaces (Haase, 2001). Regarding the problem of the development of land use by towns and cities, Lichtenberger (1993) states that for economic reasons the rising density of built-up areas is regarded as positively as the increasing usage of undeveloped open spaces since they are cheap. And this could well prove to be a vicious circle for relict urban floodplains.

Floodplains and floodplain forests should of course serve as multifunctional areas: recreation areas for the urban population as well as a source of information on relicts of the flora, fauna and morphology of the natural fluvial landscapes of central Germany (such as in the case of Leipzig) and central Europe. But they must not be allowed to deteriorate ". . . into a fairground" (Müller and Zäumer, 1992, p. 56).

Haase, D., Gläser, J. submitted. Determinants of floodplain forest development illustrated by the example of the floodplain forest in the District of Leipzig. *Forest Ecology and Management.*

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

This paper discusses determinants of the historical and current spatial extent of the floodplain forest in Leipzig as well as its tree species composition using a GIS-data based delineation model and historical forest inventories for the floodplain forest in the district of Leipzig in Germany from the 19th to the 20th century. We found that the spatial extent of the floodplain forest remained considerably stable in spite of an overall decline in the entire floodplain area from the period where the city first experienced industrialisation in the 19th century until now. However, with river regulations and the alteration of forest management from coppice-with-standards forest to high forest in the 19th century, major changes can be found in the tree species composition of the floodplain forest. Comparing these findings with references from other European floodplain forests we discuss the impact of historical and current forest management as well as the city location's influence on the extent and tree species composition of urban floodplain forests. For urban forest management in particular there is a great need to integrate biophysical, historical and forestry knowledge when predicting future developmental trends.

When applying the knowledge gained in this study to today's floordplain forest management, we argue to retain and even to extend the current proportion of Quercus robur in the floodplain forest in the district of Leipzig in the future due to its ecological value and niche function for many organisms. Hence, small parts of the floodplain forest should be used as a coppice-with-standards forest since this management system can be conducive to a higher occurrence of Quercus robur and, above all, a high biodiversity in the floodplain forests. This implies no further reduction of the current floodplain forest extent which represents major parts of the holocene floodplain remnants. Further research work has to incorporate spatial and structural data for the urban surface (i.e. transport network, housing areas, greenery) as well as distance and connectivity indices to evaluate, in a more quantitative way, the spatio-functional relationships such as accessibility and fragmentation of the urban area, its residents and the remnants of floodplain forests.

3.3. Modelling and monitoring urban shrinkage

Haase, D., Schwarz, N., accepted. Simulation models on human-nature interactions in urban landscapes – a review including system dynamics, cellular automata and agent-based approaches. *Living Reviews in Landscape Research*.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Urbanisation belongs to the most complex and dynamic processes of land use and landscape change. At present, we claim "the millennium of the cities" since more than half of the currently 6.6 billion world population is living in urban areas. Due to the huge impact of urban consumption, this paper provides a review of existing urban land use models. The review analyses system dynamics, cellular automata and agent-based model approaches by addressing the respective conceptual approach, model components and causal relationships including feedbacks. Based upon the review, conclusions are drawn the future development of urban landscape models and regarding indispensable causal relationships and their representation when modelling urban systems.

The main purpose of this review was to analyse causalities and feedback-loops in current urban land use change models. Therefore we analysed 17 simulation models stemming from three different simulation methodologies: system dynamics, cellular automata, and agent-based modelling. The main conclusion of this review is that there is a range of comprehensive urban land use change models but no unique approach to represent urban landscapes and human-nature interactions. Each author or working group has its own view and focuses on other parts of and relationships in the urban system.

Most of the approaches bear the potential to model local and regional urban processes as they provide a multitude of components and variables but currently, only a few models integrate direct or indirect feedback-loops from environmental and landscape-related impacts of urban land use change on environment to the respective driving forces in the human sphere of the systems. The reason for this we see in the gap between social science methods/findings and computational models (cf. Geist and Lambin, 2004; 2002). The former comprehensively cover behavioural heuristics on decision making but are often qualitative in nature. The latter need quantitative (sometimes spatially explicit) input data or at least simple rules to be coded and thus incorporated into the models. Moreover, empirical data for formulating a resilient feedback-loop resulting from environmental impacts on human quality of life and decision making is rarely available. As urban systems are open systems not depending on local or regional natural resources and ecosystem services neither individual nor policy decisions strongly depend on the availability and state of nature of the surroundings (cf. Haase and Nuissl, 2007). Relationships between local and regional scale are realised only with respect to housing markets, as single choices on the local scale are able to influence regional markets and vice versa.

Schwarz, N., Haase, D. submitted. Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage. *Environment and Planning B.*

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Simulation models on urban land-use change provide help for understanding urban systems and assist urban planning. A new challenge for simulating urban regions in Europe as well as in North America or Japan is urban shrinkage, where de-industrialisation, massive population losses and ageing cause unforeseen (or unexpected) commercial and housing vacancies in cities. In order to set up a conceptual framework for model improvement to assist such challenges, this paper reviews recent urban land use change simulation models, using three different modelling approaches: system dynamics, cellular automata, and agent-based modelling. The focus of the review is to assess causalities and feedback mechanisms implemented in these models.

The results show that simulation models are very heterogeneous in implemented mechanisms leading to urban land use dynamics. Only a few models include feedback mechanisms from the socio-economic including demographics or environmental impact of urban land use changes on the respective drivers, such as population dynamics. Conclusions are drawn regarding future simulation efforts and applicability of these simulation models to phenomena such as urban shrinkage. Agent-based models appear as the most-promising approaches for modelling phenomena such as urban shrinkage.

The main purpose of this review was to ascertain potentials and challenges regarding future simulation efforts and the applicability of these simulation models to phenomena like urban shrinkage based on existing model approaches for urban land use change. Therefore, we analysed 17 simulation models stemming from three different simulation methodologies: system dynamics, cellular automata, and agent-based modelling.

The main conclusion of this review is that there is no unique approach to modelling cities. Each author or working group has its own view and focuses on other parts of and relationships in the system. We further conclude that only a few models deal with aspects of urban shrinkage, namely vacancies and demolition measures. Only a few models integrate environmental factors into determination of the attractiveness of cells or regions which, doubtless, could be very important for shrinking cities because housing is affordable.
Furthermore, the review shows that

- feedback loops from the impact of land-use change on environment to driving forces of land-use change are seldom integrated into simulation models,
- representation of human decision-making focuses mainly on households or individuals (residential location) and local business and industries; planning processes are no explicit part of the models, and
- infrastructure-related problems are not dealt with in these models.

Moreover, a lack of data necessary for calibrating and validating simulation models was identified, especially with respect to decisions made by households instead of individuals. In addition, we conclude that an ABM approach to planning or steering urban land use change processes initiated through shrinkage will be very valuable: This is the only approach which enables researchers to explicitly include household location choice, housing market development and urban planning in an explicit way. Furthermore, it holds the potential to simulate innovative land use projects as an emerging characteristic of urban communication and governance.

Banzhaf, E., Kindler, A., Haase, D., 2007. Monitoring, mapping and modelling urban decline: a multi-scale approach for Leipzig. *EARSeL eProceedings* 6(2), 101-114.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Urban remote sensing research and approaches to modelling residential mobility focus predomi-nantly on growth patterns. In this paper, the phenomenon of extreme urban decline, named 'shrinkage', is scrutinised. The different characteristics of urban decline are illuminated using a multi-scale approach. Selected patterns of the spatial growth and shrinkage are first calculated by means of satellite imagery for the City of Leipzig, Germany. Here, Landsat data for 1994 and 2005 provide information regarding different phases of urban land use dynamics, thereby revealing a pattern of spatial expansion into the peri-urban surroundings. In addition, potential drivers of this detected pattern are investigated through analysis of municipal statistical data, at the local district level, providing evidence that urban growth in general and particularly shrinkage are results of population fluxes and migration. Because urban shrinkage can be found in both the central and peripheral parts of Leipzig City, an even more detailed scale, using a very high resolution (VHR) colour-infrared data set has then been integrated with the local district data, in order to achieve detailed information on intra-urban differentiation of both urban structure and fabric. Finally, using predictor variables such as fertility, life expectancy, migration and residential preferences, a proto-type model approach is presented that analyses recent patterns of residential use and the related building vacancies that characterise the housing sector of a shrinking city.

The presented study comprises monitoring of land use changes and mapping of socio-demographic dynamics right after the political transition in eastern Germany, combined with model-ling of residential mobility. After having identified spatial suburbanisation processes, which were accompanied by urban growth at the urban fringe and urban shrinkage in the central part of the city, a new focus in urban land use monitoring activities was taken, deriving urban structure types from very high resolution (VHR) data. With respect to remote sensing methods two different data sets and approaches were applied: the multispectral classification and post classification compari-son of TM imageries supported the monitoring of urban growth and shrinking processes in this very dynamic region. The object-oriented fuzzy classification of a VHR data set is compared with ATKIS (official topographic-cartographic information system of Germany) data in order to produce a change detection for the process of demolition of houses, which is a special feature of the massive residential vacancy typical for shrinking cities.

The assignment of demolished houses to specific urban structure types is another special contribu-tion arising from the application of the approach presented here. Beside their obvious dependence upon economic variables, urban land use changes are mainly related to the demographic devel-opment of a city. In the integrated monitoring and model approach presented above, we assume that there is a causal relation between the built-up environment (housing and infrastructure), the configuration of urban open spaces and demographic processes (first of all migration). Initial re-sults of this model of residential mobility in Leipzig and a respective picture of residential vacancy support the presumption that different household types prefer different housing environments and structures, and that, under a typical pattern of residential behaviour, residential vacancies are cre-ated. To validate the model results and to set a relationship between residential vacancy and demolition processes there is the need to create valid data of urban land use change at building level. This brings the model and the paper back to the VHR based object-oriented classification where next steps in the research will be focused on investigating how data sets on urban structure types can be reliably reproduced so that demolition and, respectively, new built-up areas can be monitored regularly on a local scale.

Haase, D., Holzkämper, A., Seppelt, R., 2006. Beyond growth? Decline of the urban fabric in Eastern Germany. A spatially explicit model approach to predict residential vacancy and demolition priorities. In: Koomen, E., Stillwell, J., Bakema, A., Scholten, H. (eds). Modelling Land Use Change. Springer Dordrecht, pp. 339-353.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Urban growth has been replaced by decline of the urban fabric in many parts of Europe. Reasons for this shrinkage are to be found in processes of demographic change and migration in city regions. This chapter presents relevant indicators and a rule-based modelling approach to residential change and building demolition in Eastern Germany. The first part will focus on the research objectives and briefly discusses the urban decline phenomenon and the need for a new modelling approach in order to understand the current shifts in urban development. Besides this, relevant predictor variables for identifying spatial shrinkage and residential vacancy are discussed. Finally, their integration into a GIS-based spatially explicit model completes the chapter.

The first model results of simulated demolition priorities indicate that the overall concept of ‘maintenance of city centre’ is far from becoming reality in the chosen study area. None of the combinations of the identified predictor variables results in the envisaged compact city pattern. This conclusion is supported by observed and planned demolition in the study site. On the other hand, the apparent correlations of the MC analysis give an idea of how Grünau could develop in the next 5-10 years, as these correspond with the planned demolition within the housing complexes at the central and (north) western part of the city. Another general aspect which arose in the analysis is that deriving general conclusions for the whole city is not feasible, probably because the selected study area of Leipzig-Grünau was too small and the applied social statistical data were not detailed enough.

To improve the promising model results for Leipzig-Grünau, information from a housing estate specific social survey will be included to allow for a spatially more differentiated description of residential vacancy. The assumption of linear relationships between the predictor variables and demolition priority can be altered, as it is possible that there are important interactions between the variables. Furthermore, interactions and feedbacks need to be incorporated into the model. Dynamics can be incorporated by making demolition priorities depend spatial configuration of housing in the previous time step. Underlying population dynamics and the household pattern and behaviour (housing preferences, migration) can then be considered as dynamic input variables that change over time. The model can also be improved by incorporating more detailed social and demographic data at district level. For the 'city level' (ndistrict = 63), the annual statistical reports of Leipzig are supposed to be a sufficient data base (static and dynamic approach coupled with a population and household dynamics model). Thus, it is proposed to apply the model to the whole city of Leipzig including the old, prefabricated and the new built-up housing estates. In addition, model transferability to other cities dealing with similar phenomena will also be tested.

Kabisch, S., Haase, A., Haase, D., 2006. Beyond growth – urban development in shrinking cities as a challenge for modeling approaches. In: Voinov, A., Jakeman, A., Rizzoli, A. (eds). Proceedings of the iEMSs Third Biennial Meeting: "Summit on Environmental Modelling and Software". International Environmental Modelling and Software Society, Burlington, USA. CD ROM. ISBN 1-4243-0852-6 978-1-4243-0852-1.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Urban growth has been replaced by stagnation and shrinkage processes at many places in Europe during the last decades. Demographic changes and out-migration because of lack of jobs belong to the main impact factors. Urban planners are challenged by this new and dramatic development that impacts on housing markets, the utilization of infrastructure, local labor markets and the whole viability of urban structures. Urban Research is requested to elaborate new concepts and strategies for cities loosing population, facing a big amount of vacant building stock and a large-area re-use of brown-fields.

The purpose of this paper is to analyze the chances and limits of urban modeling to explain and assess urban shrinkage proc-esses in their quantitative and qualitative dimension. First, expertise of new shrinkage processes is investigated in order to explain the need for urban modeling concepts. Second, it is discussed to what extend often misrepresented 'fuzzy' social sci-ence knowledge about urban shrinkage can be brought methodically together with 'sizable'-data-based urban models. Third, variables and a prototype model structure are presented to approach to an urban shrinkage model. Finally, novel scientific questions and recommendations for further cooperation of social science and urban modeling are presented.

To conclude from this study, shrinkage, population losses and vacancies unhinge the balance of existing urban struc-tures, and produce new patterns of cityscapes. An innova-tive model approach that takes into consideration the con-sequences of demographic change needs to be developed to come to a better understanding of the complex interac-tions of the included variables. The model structure and the relationships base on relevant predictor variables as well as urban policy contextual constraints. To allow for a more comprehensive look at shrinkage, weightings of model variables as well as proxy-data for 'not-sizable' variables have to be integrated. For a start, the model to be finally developed should be able to give an idea to sci-entists what kinds of future scenarios are imaginable, how desirable ones can be reached or supported respective inconvenient trends being omitted. With this approach, new insides and knowledge could be generated which needs further accompanying empirical research which mirrors the model results. Discussing the strengths and weaknesses of such a combined research strategy and find a common language for modelling shrinkage is an excit-ing challenge.

3.4. Agent-based modelling to explain urban land use change

Haase, D., Seppelt, R., in revision. Applying social science concepts: modelling and simulating residential mobility in a shrinking city. *Environmental Modelling and Software*.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

Urban shrinkage has recently been coming into discussion more and more among urban planners and policy makers in Europe following demographic transitions in the form of fertility decline and out-migration. Shrinking cities are characterized by huge oversupplies of dwellings and resulting residential vacancies. Although existing worldwide, particularly the shrinking eastern German city of Leipzig has been identified as a challenge to study residential mobility and the creation of housing vacancy using modeling techniques: social scientists developed a novel concept of demography-related household types based on a range of empirical surveys that together form a unique base to build a data-based agent model.

The spatially explict agent based simulation model RESMOBcity presented here 'translates' empirical data upon 'new and non-classical' household types that find their origin in concepts of the Second Demographic Transition into household agents. Applying behavioural rules to each of the agents spatially explicit household patterns, housing demands, residential vacancies and demolition potentials emerge out of the system. In the results we show that population will stabilise within the coming 20 years. The number of households is expected to further increase. We demonstrate that a selective demolition of vacant housing stock might counteract the enormous oversupply of dwellings and better level out both housing demand and number of available flats. In terms of model quality particularly the spatial pattern and trends of residential vacancy were found in good accordance with measured municipal data and estimates by experts.

Using the example of the eastern German city of Leipzig, the specific local conditions – high vacancy rates, tenants' market – were set in relation to the residential preferences of household types who form the agents of the model. The findings of our model, in the form of household patterns and trends of residential vacancy created by the model, were found in considerably high and spatially plausible accuracy with measured municipal data and estimates by local experts. We showed that an increase in the total number of households reduces residential vacancy only in the event of a simultateous demolition and 'sanitation' of the housing market. Assuming that today's residential behaviour is valid for the near future, we have to expect an increase in the spatial segregation of households in the city: the younsters and very old concentrate in the centre, whereas families still direct outwards. Residential vacancy will decrease and level out at a 10%-rate in 2020. It will move from the Wilhelminian estates of the inner city to the 20-40ies and 60ies housing estates that lose attractiveness for most of the household types.

The model concept of RESMOBcity, we believe, is a useful one in terms of evaluating demographic scenarios and their impact on residential land use in urban regions. We were able to demonstrate how and where potential re- or de-densification of urban housing structures up to the year 2020 will most probably occur. The same is true for the future allocation and concentration, or even the disappearance, of residential vacancy.

Future work will focus on the incorporation of additional economic variables considering the economic constraints the households are faced with, their choices concerning transport modes and travel distances, as well as scenarios of decreased or modified infrastructure supply due to shrinkage. Another improvement will be a more detailed incorporation of the local housing market as well as contextual constraints for land-use policy and planning in the form of scenario alternatives.

3.5. Data mining for models

Haase, D., Haase, A., 2007. Do European social science data serve to feed agent-based simulation models on residential mobility in shrinking cities? Grözinger, G., Matiaske, W., Spieß, K. (eds.) Europe and its Regions. The usage of European Regionalised Social Science Data. Cambridge Scholar Publishing, pp. 227-250.

(Reprint of the paper cf. Annex A2)

Summary and Conclusions

In this paper, we analyse the potential of European social and economic data sets and regionalised panel data for their suitability for a micro-simulation model on residential mobility at the city region level. The micro-simulation approach refers to the social unit of the household which is assumed to be decisive for residential migration and the housing sector, respectively. Social science data are required firstly for the individual profile of the model agents and secondly for the parameterisation of the urban environment where the agents move. In particular, the challenge of transferring socio-economic variables into the space, represented through a GIS, is discussed. The city region of Leipzig, East Germany, being faced with shrinkage and large scale housing vacancies provides both an illustrative example and a real world challenge of how an innovative micro-simulation approach could profit from European survey and panel data.

In this paper we discussed to what extent European social science data sets can serve as a database to feed agent-based micro-simulation models of residential mobility in cities with particular respect to the context of non-growth or shrinkage. Using the example of the East German city of Leipzig, the specific local conditions – high vacancy rates, "tenants' market" – were set in relation to the residential preferences of household types who form the agents of our model. The needed range, scale and quality of agent-related data was identified by means of municipal statistics and a household-based questionnaire survey based on an SDT-driven concept of demographic change and its implications for housing. By comparison with available European social science data it became obvious that a) data sets do not always meet the needs of scale and grain, b) do not provide a clear definition of households, c) suffer from a lack of contextual information in terms of defining the impact of shrinkage and oversupply of housing stock, amenities and urban infrastructure, d) do not always allow for local differentiation in terms of urban small-scale areas (sub-city level). Up to the present, this missing information can only be acquired by using survey data or expert panels that exist for single cases, and merely for more than just a limited period of time, as the Leipzig example shows.

Therefore, we see a need to improve European social science databases in the following manner: a) add variables for the context of local non-growth or shrinkage processes, b) try to define a common household term, c) plead for bringing in survey and expert panel information on a more regular base, d) provide information on the transferability of the data to either another spatial grain or national/cultural context. Since urban development beyond growth and respective residential mobility behaviour are likely to determine urban futures in Europe, it is crucial to think about an improvement of European regionalised data to provide a more promising database for this new challenge. As a pre-condition, it is, however, indispensable to identify the required contexts, variables, terms and inter-linkages for a case in point, as it was presented here for the city of Leipzig.

4. Impact assessment of land use change

'Logic gets from A to B,
but with imagination you circle the universe.'
Albert Einstein 1948

4.1. Overview

The transformation of natural, open or agricultural land into urban land is one of the major en-vironmental impacts in most urbanized countries and regions (OECD, 1997). Moreover, along the urban rural gradient this land consumption is often characterised by dispersed developments, mono-functional and low density land uses and reliance on private car ownership – thus displaying the typical features of veritable urban sprawl (Torrens & Alberti, 2000). This is also true for Europe, although European cities and towns have traditionally been rather compact (Kassanko et al., 2006). In Germany for instance, between 1993-2004 daily land consumption has amounted to 80-130 hectare (BBR, 2007). Accordingly, the share of urban land (settlement and transportation) of the total territory of Germany in 2007 is some 12.8% compared to 7.1% in 1950 – a ratio which is only exceeded by smaller and more densely populated states such as the Netherlands (18%) or Belgium (14%; EEA, 2006).

Land consumption is not only a problem because it contradicts a normative ideal of spatial planning. In a multitude of studies it has been shown that land consumption is usually detrimental to the environment in different regards (e.g. Johnson 2001). Its impact reduces the ability of nature to fulfil human requirements and thus impairs ecosystem services in various ways (De Groot et al., 2002; MEA, 2005; Curran & Sherbinin, 2004). Individual ecosystem services that are affected by land use transition include the production of food, regulation of energy and matter flows, water supply, supply of recreational space, biodiversity or natural aesthetic values.

It is widely accepted in the field of land use policy that the incessant consumption of open land demands intervention and regulation. At EU level, documents such as the European Landscape Convention (CoE, 2000), the European Spatial Development Plan (1999), or the guidelines for the funding schemes of the common structural and agricultural policies call for the reduction of land development. Whilst these documents are not legally binding for the member states, the EU further requires the introduction of an environmental impact assessment for spatial plans. This latter instrument has the po-tential to considerably reduce the negative impact of urban development and land use transitions, pro-vided there is a sound methodology of impact assessment at hand that can be applied in practice.

At the national level an array of different policies for addressing the challenge of land con-sumption are being discussed in the different EU member states. In Germany, the Netherlands or the UK, for instance, the discussion on strategies and instruments to inhibit the further growth of settle-ment and transport areas is a high priority on the agenda of environmental politics. Besides the regulatory means of both the planning system and environmental policy, this discussion also highlights more informal instruments – such as spatial development concepts, municipal resource management schemes aiming at the reuse of brownfield land, and inter-regional cooperation initiatives – as well as so called economic instruments – such as changes in land taxation, or the introduction of a scheme of tradable development permits (German Council of Sustainable Development, 2004; Bundesregierung, 2004). Above and beyond these instruments, the Federal Government of Germany has defined the so called "30-hectare-goal" (Bundesregierung, 2004): It thus committed itself to the goal of reducing the daily rate of land consumption from currently around 110 to only 30 ha in 2020. This figure might be seen as a political manifestation rather than a strict quantification of a land use policy goal, but it clearly provides political guidance towards the goal of mitigation of land consumption. However, the "30-hectare-goal" is abstracted from the context-sensitivity of land use transition impact, such as deterioration of water balance, soil functions or habitat quality, which differ tremendously depending on where the 'consumed' land is located. This leads to the question whether such general goals can be specified and differentiated in terms of where the incremental development that is still deemed ac-ceptable should take place (EEA, 2006) – i.e. how the 'remaining' development can be steered to the most desirable locations.

Generally speaking, the different policy approaches and instruments on the containment of land consumption aim at two interrelated but distinguishable goals (Schröter-Schlaack & Ring, 2006): firstly a reduction of the (aggregated) amount of land development; secondly, an improvement of (particular) land use and development patterns, i.e. the achievement of a development pattern that is least detrimental in terms of deterioration of ecosystem services (ES). In practice however, only if it suc-ceeds in pursuing both goals at the same time can land use policy successfully mitigate the environ-mental impact of land consumption. In other words: A quantitative reduction in land consumption will only substantially contribute to the preservation of ecosystem services if supplemented by efforts to break it down to the regional and local level. Such efforts should be substantiated by scientific knowl-edge of the impact – or at least on the methodology of assessing the impact – of land use transition. Compared to more complex and innovation-related definitions (Elzen et al., 2004; Wiek et al., 2006) the term 'transition' in this paper is understood as the change of one type of land use to another.

The assessment and evaluation of the impact of land use transition, including both land consumption and land abandonment, is a major task of landscape research in general (Wu & Hobbs, 2002; Naveh, 2001). Accordingly, there is affluent expertise on the effects of land use transition on ES concerning, for instance, landscape clustering and fragmentation (Ewing, 1997; Pauleit et al., 2005), disturbances in the water balance (Samaniego & Bardossy, 2006), soil compaction (EEA, 2006), air pollution and noise (cf. indicator set by Wiek & Binder, 2005), or increased risk of flooding (Bertoni, 2006). However, as a rule these studies are highly sophisticated contributions to the research on individual aspects of land use transition and employ a scientific methodology which could hardly be copied in practical spatial planning.

On the other hand, we find integrated assessment schemes for urban regions, drawing on a multitude of disciplines and taking account of interlinked urban dynamics, such as suggested by Ravetz (2000), Hasse & Lathrop (2003) or, in a more participatory form, Wiek & Binder (2005). However, the primary focus of these studies is not the problem of land use transition but rather the conceptualization and evaluation of urban development processes in general. Hence, a systematic, scale-spanning and practically applicable approach to the integrative assessment of the impact of (urban) land use transition on natural resources and urban ecosystems is still missing. In particular, the various forms of land use transition in the housing sector need a more detailed analysis so as to enable an assessment of its impact at the relevant spatial scales.

The publications of section 4 report different quantitative modelling approaches to approach the above mentioned research challenge using examples from the abiotic environment and from ecosystems. As an innovative step following the work by Boland and Hunhammar (1999) the framework of urban ecosystem services (UES) will be used in order to realise a range of simulations and evaluation studies that quantify the impact of urban land take.

4.2. Impact on abiotic resources

Haase, D., Rosenberg, M., 2003. The changing face of the landscape, *Research for the Environment* 4, 86-93.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

One of the factors that has the most lasting impact on the condition and function of the landscape is land use. The land around us was and still is intensively used in many places, yet all too often this clashes with the aim of protecting the biotic and abiotic resources mankind needs. Central Germany is doubtless an extreme case given the extensive ravaging of the landscape by lignite mining and the subsequent complete reshaping of the areas concerned. But all over the world, the questions of how far mankind can go be natures's regulatory mechanisms finally collapse has become highly relevant. Landscape ecologists are using cutting-edge technology to tackle this issue internationally. One of their key findings is that a landscape's history also needs to be taken into account.

The scientific work on the transformation of the usage and structure of a landscape as well as its influence of the productivity of the natural balance provides an important basis for landscape and regional planning and serves as decision-support instruments for regional and local planning agencies. They are also important for a broad section of the local population as well as researchers from the State Department of Construction and Regional Planning dealing with the long-term trends of spatial development in Germany since they show how the surrounding landscape changes and how planners' ideas will actually appear in the landscapes.

So how far can mankind go before the natural regulatory mechanisms collapse? Our investigations back up the opinion that a whole range of natural regulatory mechanisms such as runoff and flood regulation can only function to a limited extent and in some cases fail locally owing to the continuing consumption of floodplains and open spaces for construction. In the future, it is necessary to undertake additional specific investigations into trends of zoning development and their influence on natural landscape functions and natural resources. This can be regarded as a module to helpt achieve genuinely sustainable "co-operation" between mankind and nature in the multifunctional central European cultural landscape.

Haase, G., Haase, D., 2002. Approaches and methods of landscape diagnosis. In: Bastian, O., Steinhardt, U. & Z. Naveh (eds). Development and Perspectives of Landscape Ecology, Kluwer, pp.113-122.

(Reprint of the paper cf. Annex A4)

Summary and Conclusions

The current land use processes and land use changes in the last centuries make it necessary for all natural, socio-economic and cultural conditions to be carefully considered in the socio-economically dominated processes of landscape management and planning. The socially necessary benefit-cost ratio of securing natural processes of regulation in physical regions, especially for both simple and extended reproduction of natural conditions, is increasingly becoming a driving force in the determination of the economic and social effectiveness of land use. Extensive and intensive use of processes, functions and characteristics of the physical or natural resources can be accomplished without major disturbances only if the utilization requirements and the existing natural equipment develop proportionally to each other. These proportions are results of, on the one hand, active technical and natural principles (properties of natural-technical geo-ecosystems) and on the other hand, the socio-economic conditions and requirements under which the activities of society are taking place in landscapes, respectively (including urbanized areas).

At the current stage of modern landscape ecology as an applied science the following methodological approaches seem to be the core of managing the process of landscape diagnosis in a complex synthesis:

- remote sensing as a tool for landscape evaluation,
- Geoinformation Systems,
- methods determining the structural properties of landscapes or landscape pattern,
- theory of fuzzy sets or fuzzy logic and
- modeling approaches to simulate landscape functioning depending on thedifferent landscape components and processes.

The solution of methodological problems in interpreting landscape structures has received strong impulses from operation research, system engineering, and economics of natural resources or landscape economics. At present there are only initial approaches available to a consistent methodology. Participation in the development is among the major tasks to be accomplished by landscape research in the next couple of years.

Nuissl, H., Haase, D., Wittmer, H., Lanzendorf, M. 2008. Impact assessment of land use transition in urban areas – an integrated approach from an environmental perspective. *Land Use Policy* 26, 414-424. doi:10.1016/j.landusepol.2008.05.006.

(Reprint of the paper cf. Annex A4)

Summary and Conclusions

Land consumption due to residential development, economic growth and transportation belongs to the most serious environmental pressures on landscapes worldwide, in particular in urbanised areas. Accordingly, the aim of containing the development of land is rated increasingly high on the agenda of environmental policy, at least in densely populated countries such as Germany, Belgium, the Netherlands or the UK. As a result, different strategies and instruments to prevent excessive land consumption are being discussed. However, many of these strategies and instruments adopt a rather general approach, while it seems more effective to define the particular areas where the goal of reducing land consumption is to be pursued. Such an approach must draw on information about how detrimental specific land use transitions are with regard to, for instance, the functionality of soils, water balance or habitat quality at specific locations. This paper introduces a conceptual framework for the impact assessment of land use transition in urban areas which highlights how such information can be acquired. This framework includes the differentiation of two levels of impact assessment: the level of the single land unit and the context level which takes into account regional and aggregated impacts of land use transition bound to the spatial context. The conceptual framework provides a basis to disaggregate (supra-)national policy targets regarding land use, to scale them downto the regional level, and thus to clarify the spatially explicit implications of land use policies.

The paper presented a conceptual framework for an integrated assessment of the impact of land use transition in urban regions. This framework provides a basis for an empirical quantification and evaluation of such impact in concrete study regions. It introduces a few new features to the discussion of land use transition and the assessment of its impact:

- the distinction between two levels of impact-assessment of land use transition,
- the classification of land uses in a land use typology (allowing a detailed distinction of different possible transitions),
- the derivation of regional impact of land use transition from aggregate statistical figures, and
- the consideration of a variety of potential impacts. At present our approach accounts for several disciplines – such as hydrology, soil science, landscape ecology, biology, transport geography, and economics – but it is also open for the inclusion of additional fields that have so far not been included.

The integrative character of our approach brings added value into a discussion which is very much focussed on 'space' and 'hectare-figures'. More specifically it can support regional and local decision makers in their attempt to not only gear land use management and planning to the normative idea of sustainability but also to make a qualified contribution to the achievement of 'global' (i.e. national) targets regarding the reduction of land consumption. In other words: Since an assessment of land use transition impact draws the attention to the consequences of alternative land use management and planning decisions, it has the potential to orient urban development to the 'right' places. This will become increasingly important in the near future as we face a simultaneity of growth and decline in many European regions that opens up the chance for new land development strategies. However, in particular under the condition of decline, the evaluation of land use transition should also include socio-economic aspects, such as infrastructure costs or socio-spatial segregation. In this regard, at least in the medium run, the presented conceptual framework should be expanded to further 'impact dimensions'.

Haase, D. accepted. Effects of urbanisation on the water balance – a long-term trajectory. *Environment Impact Assessment Review.*

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

The amount of land consumption required for housing and transport severely conflicts with both the necessity and the legal obligation to maintain the ecological potential afforded by open spaces to meet the needs of current and future generations with regards to the protection of resources and climate change. Owing to an increasing intensity of soil use, soil conditions appear to have deteriorated in most city regions around the world, namely their filter and runoff regulating functions are impaired by land surfacing. As such soil functions depend on the soil's biophysical properties and the degree of imperviousness, the impact on the water balance caused by urban growth varies considerably. In response to the demand for sustainably secure urban water resources, it needs to be assessed exactly how land surfacing affects the functions concerned. Analysing and evaluating urban land use change on the long-term water balance should improve our understanding of the impact of urbanisation on the water household. Therefore, this paper analyses the impact of urban land use change and land surfacing on the long-term urban water balance over a 130-year trajectory by using simple model approaches that are based on data available to the public. The test site is the city of Leipzig. In particular, attention is to be paid to estimating changes of evapotranspiration, direct runoff and groundwater recharge.

The long-term observation of urban growth and sprawling land consumption has proven that it is the cumulative impact of land use change and surface sealing, rather than short-term consequences that is likely to impair the urban water balance. It highlights the problems that can arise in the long run due to this cumulative impact of land use change over time on the city or regional scale and thus gives an example of how severely urban growth on a city's fringes can affect environmental processes such as the water balance in quantitative terms.

Urban sprawl potentially leads to an increased flood risk produced by increasing direct runoff and a resulting higher release of water out of the urban system. This could restrict a city's chances for future development in that technical precautions necessary to mitigate these problems may become extremely expensive. However, it is fairly clear that the long-term effects of urban land uptake on the environment in general, and water balance in particular, not only depend on the amount but also the distribution of the land to be developed, or the spatial pattern of land conversion, as well as the previous quality of this land (Newman, 2000; Burchell and Mukherji, 2003; Nuissl et al., 2008).

From an environmental point of view, the compact city generally seems to be the most desirable form because it allows a preservation of the largest possible patches of 'natural' landscape. On the other hand, intensification and an increase of impervious surfaces in existing urban areas tends to be accompanied by a considerable decline in environmental quality. This was recently shown with regard to urban microclimates by Pauleit et al. (2005) and has been illustrated for water balance in this paper. To illustrate this with the results obtained from this paper: a fall in the sensitive ETa flow increases the vulnerability of the cities' residents to increasing summer temperatures that are assumed to occur due to climate change as the evaporative process supports cool urban areas (Gill et al., 2007).

Further research concerning the effect of a decrease in soil water on the temperature of urban sealed and constructed land surfaces and air temperature is required in order to provide scientific support for spatial planning and intelligent land development options in times of climate change.

Magnucki, K., Haase, D., Frühauf, M., 2004. Auswirkungen urbaner Siedlungsflächen-entwicklung auf den Wasserhaushalt – das Beispiel der Stadt Leipzig 1870-2003. *Berichte zur deutschen Landeskunde* 78(4), 473-507.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Die Zunahme an versiegelten Oberflächen prägt seit Jahrzehnten große Teile mitteleuropäischer Landschaften. In Deutschland entstehen täglich ca. 130 ha versiegelte Fläche. Neben dem Verlust von Lebensraum führt eine zunehmende Versiegelung auch zur Einschränkung bzw. zum Verlust abiotischer Landschaftsfunktionen, beispielsweise des Wasserhaushaltes. Für die Planung und das Management urbaner Räume ist es daher wichtig, diese Veränderung von Landschaftsfunktionalität sowie den Verlust von Ressourcen (Boden, Sickerwasserrate, Rückhalt von Oberflächenabfluss) räumlich explizit zu quantifizieren.

Der Beitrag diskutiert die mit der Siedlungsflächenerweiterung einhergehende Veränderung relevanter Wasserhaushaltsgrößen am Beispiel der Großstadt Leipzig seit 1870 (130 Jahre) in mehreren Zeitschnitten. Dabei wird ein methodischer Ansatz gezeigt, welcher es ermöglicht, diese Abschätzung GIS-basiert sowie auf der Basis öffentlich verfügbarer analoger bzw. digitaler Daten vorzunehmen.

Im Ergebnis der Untersuchungen zum Wasserhaushalt in Leipzig seit 1870 kann folgendes festgehalten werden: wichtige Wasserhaushaltsfunktionen werden aufgrund zunehmender Versiegelung in zunehmend geringerem ausreichend Maße erfüllt, in einigen Stadtbereichen haben die Oberflächen bzw. Böden keine regulierende Funktion auf den urbanen Landschaftshaushalt mehr. Klar ist aber ebenso, dass ein urbaner Raum nicht primär zum Erhalt von Bodenfunktionen bzw. der Realisierung wasserhaushaltlicher Funktionen dient, sondern als Aktionsraum des Menschen (Haase, 2001).

Trotz alledem scheint es unter dem Trend einer anhaltenden Bodenversiegelung in Deutschland geboten, Maßnahmen zur Erhaltung der natürlichen Wasserhaushaltsfunktionen sowie im Interesse des Bodenschutzes auch im urbanen Raum zu forcieren. Dies trägt auch der Tatsache Rechnung, dass in Deutschland immer mehr Menschen im urbanen Raum leben werden. Folgende Überlegungen sollten daher in die zukünftige Flächennutzungsplanung bzw. –politik Eingang finden: Eine Verbesserung der Abflussregulationsfähigkeit kann im Falle von Starkniederschlägen erreicht werden durch:

- gezielte Entsiegelung überbauter Flächen bei Abriss,
- eine in die Flächenhaushaltspolitik der Stadt integrierte Limitierung der Neuversiegelung im Innen- und Außenbereich,
- die Verwendung durchlässiger Baumaterialien,
- Möglichkeiten der Regenwasserversickerung statt –ableitung in Baugebieten (Neubau und Rekonstruktion, gegebenenfalls Regenwassersammelbecken in den Gründerzeitgebieten) sowie
- gezielte Erhöhung des Waldanteils an den Frei- bzw. Grünflächen.

Insbesondere die Niederschlagsversickerung besitzt den Vorteil der Zwischenspeicherung von Hochwasserabflüssen und gleichzeitig eine Reduzierung von Spitzenwasserabflüssen sowie, v.a. mit dem Blick auf das menschliche Wohlbefinden eine Erhöhung der Verdunstungsraten im urbanen Raum und damit positive Auswirkungen auf das Stadtklima. Jedoch sollten die Einflüsse der Regenwasserversickerung detailliert untersucht werden, um negative Folgen wie die Gefährdung der Grundwasserqualität und Gebäudeschäden zu verhindern (Coldewey et al., 2001).

Es ist weiterhin festzuhalten, dass anhand der durchgeführten Bewertungen die Veränderun-gen im Wasserhaushalt durch die Versiegelung seit 1870 erfasst werden konnten. Bei einer gegebenen Prognose möglicher Siedlungsentwicklung in die Zukunft wird es somit möglich sein, Aussagen zu treffen, wie zukünftige Versiegelungen den Wasserhaushalt beeinträchtigen werden. Zu beachten ist, dass die Ergebnisse entscheidend von den Eingangsdaten abhängig sind. Im Einzelfall sind diese sicherlich zu überprüfen, um genauere Ergebnisse zu erhalten.

Haase, D., Magnucki, K., Frühauf, M., 2004. Zum Verlust von Bodenfunktionen durch Siedlungserweiterungen und Oberflächenversiegelung in den Stadtgebieten von Halle und Leipzig, Wichmann, S. 161-178.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Böden besitzen wesentliche Funktionen imWasser- und Stoffhaushalt der Landschaft. Sie stellen Lebensgrundlage und Lebensraum für Menschen, Tiere, Pflanzen und Bodenorganismen dar. Im Ökosystem wirken sie als Abbauund Ausgleichsmedium sowie als Quelle stofflicher Einwirkungen (§2 (2) BBodSchG). Aufgrund ihrer Speicher und Transformationsleistung reagieren Böden oft erst mit großer Verzögerung auf Beeinträchtigungen, wobei die entstandenen Veränderungen dann meist lange erhalten bleiben (Blume 1992). Neben ihren natürlichen Funktionen haben Böden auch Nutzungsfunktionen als Fläche für Siedlungen und Verkehrswege, der land- und forstwirtschaftlichen Produktion oder für Erholungszwecke (§2 (2) BBodSchG) zu erfüllen. Natürliche und Nutzungsfunktionen des Bodens stehen in starker Konkurrenz zueinander, insbesondere in urbanen Räumen, da hier Freiflächen mit naturnahen Böden meist nur noch sehr begrenzt verfügbar sind.

Urbane Räume stellen heute einen wesentlichen und zunehmend bedeutenden Lebensraum des Menschen dar. Zwar erscheint der Anteil der Siedlungs- und Verkehrsfläche an der Gesamtfläche Deutschlands mit 12,3 % (Statistisches Bundesamt 2002) eher gering, aber infolge steigender Ansprüche an Wohnfläche sowie zunehmender Freizeit- und Konsummobilität wächst seit Jahrzehnten die Fläche für Wohnen, Verkehr, Freizeit und Erwerbsarbeit. Die Siedlungsflächenzunahme ist dabei heute eng mit dem gewachsenen materiellen Wohlstand verknüpft. Die tägliche Flächeninanspruchnahme für Siedlungs- und Verkehrszwecke ist in Deutschland auf etwa 129 ha pro Tag gestiegen (Statistisches Bundesamt 2002), wobei sich die Zunahme der Siedlungsflächen seit dem Beginn der Industriellen Revolution relativ konstant entwickelt hat (Dosch & Beckmann 1999).

Im Zuge der Wiedervereinigung nach 1990 bestand gerade im Osten Deutschlands ein deutlicher Nachholbedarf im Verkehrswege- und Wohnungsbau. Der Flächenverbrauch hat dabei mit einem täglichen Siedlungsflächenzuwachs von 40 ha (Mittelwert 1997-2001) einen momentanen Höchststand erreicht, wobei vor allem Flächen für Wohnen, öffentliche Zwecke, Handel- und Dienstleistungen überdurchschnittlich zunahmen (Dosch & Beckmann 1999). Der Flächenverbrauch für Siedlungs- und Verkehrszwecke steht in deutlichem Widerspruch zu der Notwendigkeit und gesetzlichen Verpflichtung, die ökologischen Potentiale der Freiflächen für die Lebensbed ürfnisse gegenwärtiger und zukünftiger Generationen zu erhalten. Die flächensparende und bodenschonende Nutzung des Bodens ist im 1998 novellierten Bau- und Raumordnungsgesetz (BauROG) festgeschrieben und im von der Bundesregierung 1998 verabschiedeten „Gesetz zum Schutz des Bodens und zur Sanierung von Altlasten" (BBodSchG) bekräftigt. Ziel ist es nach BBodSchG § 1, die Funktionen von Böden nachhaltig zu sichern oder wiederherzustellen.

Durch die steigende Intensität der Bodennutzung hat sich der Zustand des Bodens in der Vergangenheit vielerorts verschlechtert (SRU 2000). Die natürlichen Bodenfunktionen werden durch die Versiegelung stark beeinträchtigt oder ganz unterbunden. Damit wird die Leistungsfähigkeit des gesamten Naturhaushaltes verringert (Bunzel 1992). Entsprechend der Ausprägung der physikalischen und chemischen Bodeneigenschaften kann der Verlust an Bodenfunktionalität durch Versiegelung unterschiedlich groß sein (Mohs & Meiners 1994).

Im Hinblick auf die Forderung einer nachhaltigen Sicherung oder Wiederherstellung von Bodenfunktionen, ist es notwendig, die Eingriffswirkungen der Versiegelung auf die betreffenden Funktionen zu beurteilen. Dabei kann die Analyse und Bewertung des Flächennutzungswandels und der Veränderungen in der Versiegelungsintensität unter Berücksichtigung der Wechselwirkungen zwischen Flächennutzungsstrukturen und den Bodenfunktionen zu einem besseren Verständnis der gegenwärtigen Veränderungen in der Flächennutzung und deren Folgen führen.

Ziel des vorliegenden Beitrages ist es daher, den Verlust an Bodenfunktionalität durch die Siedlungserweiterungen und Bodenversiegelungen in den Stadtgebieten der Städte Halle (Saale) und Leipzig im Zeitraum von 1940 bis heute zu bilanzieren. Dabei sollen vor allem die Flächennutzungsänderungen, die damit verbundenen Bodenversiegelungen und deren Einfluss auf die Bodenfunktionen im Mittelpunkt der Betrachtung stehen. Im Beitrag werden folgende Punkte thematisiert:

- die Erfassung des Flächennutzungswandels und der Neuversiegelung in drei Zeitschnitten (1940, 80er und 90er Jahre)
- die Bewertung ausgewählter Bodenfunktionen anhand standardisierter Bewertungsverfahren bzw. Modelle raumexplizit mittels eines GIS sowie
- die anschließende Darstellung der Ausprägung der Bodenfunktionen sowie deren Veränderungen in den drei Zeitschnitten.

Zusammenfassend kann festgestellt werden, dass in beiden Städten die reale Evapotranspiration mit zunehmendem Versiegelungsgrad stark abnimmt, während der Oberflächenabfluss zunimmt. Das bedeutet eine Verschiebung des Wasserhaushaltes zugunsten des Oberflächenabflusses. Bezogen auf das Jahr 1940 erhöht sich der Oberflächenabfluss in Halle bis zum Jahr 2001 um 20%. Die reale Evapotranspiration beträgt im Jahr 2001 nur noch 96% der für das Jahr 1940 ermittelten Verdunstung, die Sickerwassermenge nur noch 95%. Für das Untersuchungsgebiet Leipzig bedeutet die Versiegelungsentwicklung seit 1940, dass die Verdunstung um 13% abnahm und der Oberflächenabfluss um 70% zunahm.

Als Fazit der Arbeit ist festzuhalten, dass anhand der durchgeführten Bewertungen die Veränderungen der Bodenfunktionen durch die Versiegelung seit 1940 erfasst werden konnten. Es ist somit möglich Aussagen zu treffen, wie zukünftige Versiegelungen die Bodenfunktionen beeinträchtigen werden. Die detailliertesten Aussagen konnten dabei vor allem hinsichtlich des Wasserhaushaltes gemacht werden, während bei der Einschätzung der Filterfunktion und der Hemerobie nur sehr grobe Aussagen getroffen werden können, welche hier nicht vorgestellt wurden. Zu beachten ist, dass die Ergebnisse jedoch sehr stark von den Eingangsdaten abhängig sind. Im Einzelfall sind diese sicherlich zu überprüfen, um genauere Ergebnisse zu erhalten.

Weber, N., Haase, D., Franck, U. submitted. Airborne particle number concentration and acoustic noise in inner city areas. *Journal for Environmental Management.*

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Acoustic noise and ultrafine particle (UFP) emissions are high on the list of environmental health stressors in urban areas as they are considered to belong to the main environmental sources for cardiovascular diseases among urban residents. Often both stressors occur simultaneously because the sources have the same origin, i.e. urban traffic. Particularly little is known about the spatio-temporal distribution of UFP concentrations in residential areas as well as the relation between noise and particle exposure.

To fill these gap, this paper focuses, in the form of a pilot study, on compiling and evaluating data obtained from in-situ measurements in inner urban areas. As for larger particles, also for UFP concentration and noise level a positive relationship has been found, particularly for traffic-prone streets before and after the weekend. The study further shows the potential of in-situ experiments in form of high resolution information directly gathered in the housing area. It underscores that urban traffic results in double exposure to both, UFP and acoustic noise.

This study shows that in the residential areas of a city the highest noise exposure can be found along frequently used streets, a lower exposure in rarely used streets. For example, the values detected at the sites “high traffic 1”and “high traffic 2” are assumed to increase the risk of ischemic heart diseases through acoustic noise levels of 65-70 dB (A) (Peters et al., 2001; Leksmono et al., 2006). In addition to this, high day- and night-time particle counts lead to an increase in heart infarction risk for individuals with ischemic heart diseases (Babisch, 2004). This pilot study demonstrates the associations between these two types of human exposure. Based on the results of this study, we propose urban planning to firstly, monitor and, secondly, find ways to reduce car traffic densities in residential areas. Thirdly, it will be very reasonable to prevent “low-traffic” streets from additional cars when generally reducing the car density in residential areas since they represent low-exposure living sites in dense residential areas with a comparatively low health risk to both UFP and noise exposure.

Weichel, T., Schulz, K., Haase, D., 2006. Effektive Ansätze zur Beschreibung des Hochwasserrisikos urbaner Bereiche. *Forum für Hydrologie und Wasserbewirtschaftung* 16.06 (3), 177-180.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Urbane Räume benötigen aufgrund ihrer Werteakkumulation und Schadenspotentiale eine besondere Effektivität und Nachhaltigkeit hinsichtlich des Hochwasserschutzes. Die Autoren beschäftigen dazu mit Fragen der Bewertung der Effektivität hydrodynamisch ausgewiesener Hochwasserrisikoflächen, welche eine wesentliche Basis raumplanerischer Entscheidungen darstellen. Die Ergebnisse sollen als Entscheidungsgrundlage für effektive kommunale Hochwassermanagementstrategien mit dem Ziel der Minderung von Schadenspotentialen exponierter urbaner Strukturen dienen. Methodisch werden dazu die Berücksichtigung und Qualität ausgewählter hydrodynamischer Prozessgrößen sowie deren raum-zeitliche Veränderlichkeit bzw. Unsicherheiten untersucht.

Urbane Räume unterliegen aufgrund zahlreicher Interessen und Ansprüche in besonderer Weise einem dynamischen Flächennutzungs- und Flächenwertewandel. Die Entwicklungen der Vergangenheit gingen dabei oftmals zu Lasten der potentiellen Überschwemmungsgebiete (Haase, 2003). Die Ausweisungen von Hochwasserrisikoflächen (WHG 2005) berücksichtigt diese Trends sich verändernder Wertakkumulationen jedoch nicht. Um langfristig angelegte Hochwasserschutz-maßnahmen effizient umzusetzen, könnte die Integration potentieller städtebaulicher Entwicklungstrends, eine sinnvolle Erweiterung des Konzeptes der Hochwasserrisikoflächenausweisung darstellen. Über die Zielgröße Flächennutzung sollen der dynamische Landnutzungs- und Schadenpotentialwandel urbaner Räume in die Modellergebnisse bzw. die Erstellung von Hochwasserrisikokarten integriert werden. Dadurch erhöht sich deren nach-

nachhaltige Belastbarkeit. Als Prozessvariablen werden neben dem flächennutzungsabhängigen Rauhigkeitsverhalten (Werner et al., 2005), Änderungen der Topographie betrachtet und auf ihre Wirksamkeit (Aronica et al., 1998) in der hydrodynamischen Modellierung hin analysiert. Dazu wird u. a. die Erfassung hydrodynamisch wirksamer Veränderungen mittels flugzeuggetragener Laserscannersysteme (LIDAR) untersucht. Über die bidirektionale Kopplung an ein räumlich explizites Stadtmodell werden die Arbeiten diesbezüglich weitergeführt.

Die Autoren verwenden zur hydrodynamischen Modellierung des Oberflächen-wassers das Programm TRIMR2D (Transient Inundation Model for Rivers-2 Dimensional). TRIMR2D ist ein 2-dimensionales hydrodynamisches Modell, welches ursprünglich als Modell TRIM (Casulli, 1990) für die Modellierung von Küstengewässern entwickelt und später durch den U.S. Geological Survey (Walters and Denlinger, 1999) für Fließgewässer weiterentwickelt wurde. Es basiert auf einer semi-impliziten numerischen Umsetzung der Kontinuitäts- und Massenerhaltungs-gleichung mittels semi-Lagranian Finite Differenzen Methode. Neben der hohen Stabilität des Modells, auch für große Untersuchungsgebiete, stellte die „open source“ Nutzung einen wesentlichen Grund für die Auswahl des Programms hinsichtlich der projektbezogenen Modellkopplung dar.

Haase, D., H. Neumeister, 2001. Anthropogenic impact on fluvisols in German Floodplains. Ecological processes in soils and methods of investigation. *International Agrophysics*, 15(1), 19-26.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

The region of the Leipzig floodplain areas (Germany) with one of the most beautiful floodplain forests in Europe as well as partly degradated soils contains. The rivers of the Weisse Elster and Pleisse and it’s catchments are examples of very strong human impact on wetland ecosystems in Germany. The open cast lignite coal mining in the south of Leipzig as well as the chemical industries were the source of mil-lions of tons of toxic organic and inorganic contaminants of which some have been accumulated in the floodplains of the Weisse Elster and Pleisse rivers and their floodplains. In recent years international investigation dealing with the ecological problems of the region has been undertaken. This paper considers some examples of soil investigation having been done at the geographical department of the Leipzig University. Most of all questions of the soil matter flows (mobilization, complexing) of nutrients and harmful substances (e.g. heavy metals) will be discussed here.

The acidity of the upper horizons of the fluvisols in the floodplain forests of Leipzig strongly depend on the spatial distribution of the trees. As well, the soil acidity depends on the season, the troughfall and on the kind of tree. With the run-off of the trees there occurs also an input of organic humic acids into the upper soil horizons. Within the soil body the acid inputs lead to element specific mobilization and chan-ging of the bonds. Not only acid input is followed by the solution of nutrients and metals but also alcaline deposition provokes leaching of heavy metal-humic-complexes (Cu, Pb).

The results of the investigation show that the pH, measured in-situ, as well as the buffering qualities of the soil body can be considered as main parameters (master variables) to describe the actual processes occuring in fluvisols. Such kind of results are urgent requirement of the construction of a long-time-monitoring of the positive and harmful effects on soils in floodplain forests including both, regional fluctuations and a long time registration. At least a database is needed for the forest management and forest economy as a requirement to build up a soil information system (SIS) of the floodplains, require-ment for the decision making to create or to enlarge environ-mental protection areas within the floodplain forests.

4.3. Impact on ecosystems

Haase, D., 2008. Urban ecology of shrinking cities: an unrecognised pportunity? *Nature and Culture* 3, 1-8.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Whereas environmental and social impacts of urban sprawl are widely discussed among scholars from both the natural and social sciences, the spatial consequences of urban decline are nearly neglected when discussing the impacts of land transition. Within the last decade, “shrinkage” and “perforation” have arisen as new terms to explain the land use development of urban regions faced with demographic change, particularly decreasing fertility, aging, and out-migration. Although shrinkage is far from being a “desired” scenario for urban policy makers, this paper argues that a perforation of the built-up structure in dense cities might bring up many positive implications.

To summarise, Urban shrinkage allows us to contemplate a “resurgence” of nature into inner cities that are densely populated and have been built up “for ages.” In this vein, ideas regarding “urban wilderness” for recreational and educational purposes are of concern among urban planners and landscape architects who are confronting this shrinkage (Rink 2005). The eastern German city of Leipzig, a “model city,” has made the novel suggestion of creating urban greenery in the form of temporary gardens at core city demolition sites (as a kind of planned alternative) and spontaneous and ruderal nature on former brownfields (as a kind of unplanned alternative). De Sousa (2003) perceives green sites developed from inner-city brownfields as “flagships” or “experimental fields” that serve as models for future greening endeavors to improve both local biodiversity and human livelihoods. Besides total demolition of houses, shrinkage also leads to a deconstruction of multistory housing stock in the form of a transition toward more spacious housing and living conditions in densely urbanized environments: bigger apartments with nonclassical layouts and integrated patios and terraces, as well as higher shares of urban green and “landscape” within the neighborhood.

Doubtless, there is considerable potential for social, residential, and ecological improvement in shrinking cities, which, through exploring opportunities as discussed above, might attract new residents for a longer period of time and keep local dwellers in the city, instead of having them choose the detached-house alternative. This opens a new pathway to counteracting urban sprawl. Such as perspective argues that residential and commercial vacancies and the subsequent demolition represent an opportunity for the enlargement of urban green networks and, to some extent, the ecological restoration of cities.

Strohbach, M., Haase, D., Kabisch, N. submitted. Birds and the city - urban biodiversity, land-use and socioeconomics. *Urban Ecosystems*.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Cities cover roughly 3% of the earth surface, but they are home to more than a half the world's population. The accelerating urbanization has negative impacts on biodiversity and there are concerns that it leads to an increasing separation of humans from nature. However, urban areas provide heterogeneous habitats and thus hold a considerable potential for biodiversity. In addition, for North America recent empirical evidence suggests, that urban bird diversity not only mirrors land-use patterns, but also human quality of life within a city.

This paper presents a study of the bird diversity of Leipzig, Germany, in relation to land-use patterns and socioeconomic variables indicating quality of life. The results show significant correlations between diversity and major quality of life variables such as population density, household income and natural green space. Urban districts with high amounts of urban green and waters but also with higher income resulted to host the highest number of species.

In this paper we presented a study of the spatial distribution of bird diversity in Leipzig, Germany, in relation to land-use pattern and socioeconomic variables. The results clearly show significant correlations between the species diversity and major quality of life variables such as population density, household income and urban land-use. Municipal districts with high amounts of urban green and open waters host the highest number of species but there is also evidence that districts with higher social status experience a higher bird diversity.

We found highest species richness of birds along bio-physical structures, in particular water and floodplain areas. In this sense, smaller numbers of species were found in densely built up areas, residential areas with a high population density and in commercial and industrial areas. Regarding the relationships between socioeconomic variables and breeding bird diversity we identified, residential areas of higher socioeconomic status to tend to have a higher bird diversity due to their location along forests, parks and rivers and presumably higher quantity and quality of greenery and gardens. What implications does this have for biodiversity in a city with a shrinking and aging population? What effect does renewal or restructuring of the built-up area in the city brings about for bird species diversity? How should the built environment be designed?

The role of urbanisation in the loss and degradation of global biodiversity was acknowledged in the local Agenda 21 (United Nations, 1992) processes and in the Convention on Biological Diversity in 1992 (CBD, 1992). However, whilst cities pose major challenges for protecting biodiversity, simply in terms of representing places where nature and people interact, the opportunities they offer have, so far, been understated. Cities are both important experimental areas and fields of experience in the interrelationship between humans and nature. Experiencing urban biodiversity will be the key to halt the loss of global biodiversity, because people are more likely to take action for biodiversity if they have direct contact with nature as has been stated in the Erfurt Declaration (URBIO, 2008). We think that land use changes in accordance with urban renewal Leipzig is currently facing offer the chance to enhance the quality of life of many people by developing green spaces in districts that where formerly lacking them (City of Leipzig, 2007). In order to make experience of nature possible and to avoid and minimize environmental injustice (Low and Gleeson, 1998, cited in Heynen, 2003), much effort should be put in a biodiversity enhancing design and connectivity of the habitats, especially in poorer areas where people will most likely have less resources to spend on travel. Also great effort should be put on conserving the natural green spaces that still exist, from development. This is far from being altruistic if one considers the benefits humans get from green spaces like climate mitigation, attractiveness or health (Ulrich, 1984). Only recently, Mitchell & Popham (2008) have shown that exposure to high quality green spaces can actually mitigate socioeconomically induced health inequalities. This paper is a contribution to shed light on the spatial and social dimension of this urban human-nature interaction relating bird species diversity with land-use and residents' quality of life.

Mehnert, D., Haase, D., Lausch, A., Auhagen, A., Dormann, C.F., Seppelt, R., 2005. Bewertung der Habitateignung von Stadtstrukturen unter besonderer Berücksichtigung von Grün- und Brachflächen am Beispiel der Stadt Leipzig. *Naturschutz und Landschaftsplanung* 2, 54-64.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Die Berücksichtigung von tierökologischen Fragestellungen in der landschaftsplanerischen Praxis ist häufig mit Schwierigkeiten verbunden. Im Rahmen von faunistisch-tierökologischen Beiträgen in der Landschaftsplanung (z.B. Landschaftsplan, Eingriffsregelung) sind oftmals Defizite bezüglich Erfassung sowie Bestandsanalyse und -bewertung erkennbar (Brinkmann 1998). Habitatmodelle ermöglichen die Formalisierung der Beziehung zwischen Tierarten und ihrer Umwelt. Es existieren zahlreiche Arbeiten zur Modellierung von Habitaten als Grundlage für den Artenschutz in der freien Landschaft, wohingegen wenige Arbeiten diese Thematik im urbanen Raum behandeln.

Die vorliegende Untersuchung zeigt eine Methode zur Bewertung von Stadtstrukturen basierend auf der Habitatmodellierung, welche faunistische Vorkommensdaten sowie allgemein verfügbare abiotische und biotische Daten nutzt. Mit Methoden der Geoinformation und angewandter Statistik (ENFA – Ecological Niche Factor Analysis) werden die Stadtstrukturen hinsichtlich der Habitateignung für die zwei ausgewählten Zielarten Dorngrasmücke (*Sylvia communis*) und Grünspecht (*Picus viridis*) bewertet. Die ENFA ermöglicht sowohl die Berechnung der Habitateignung (HSI – Habitat-Suitabiltiy-Index) als auch die Erstellung von Habitateignungskarten (HSI-Karten). Die ermittelten HSI-Werte dienen als Grundlage für die Bewertung der Stadtstrukturen und unterstützen so städtische Planungsentscheidungen in der Stadtentwicklungs- und Landschaftsplanung.

Die Berechnung der Habitateignung mit angewandter Statistik (ENFA) und die Übertragung der Habitateignungswerte auf die Geometrien der Stadtstrukturen erwies sich als zielführende Methode, Stadtstrukturen auf der Grundlage von allgemein verfügbaren faunistischen sowie abiotischen und biotischen Daten flächendeckend hinsichtlich Habitateignung zu bewerten. Die ENFA stellte sich als geeignetes Verfahren zur Bestimmung der Habitatpräferenzen heraus. Insbesondere die Vorteile (z.B. Präsenzdaten ausreichend, GIS-Implementierung, kostenlose Verfügbarkeit von Biomapper, gute Visualisierung, dokumentierte und wissenschaftlich akzeptierte Methode) gegenüber anderen statistischen Verfahren wurden deutlich.

Die im Modell verwendeten Daten können als bedingt geeignet angesehen werden. Problematisch erscheinen die inhaltliche und räumliche (mitunter zu geringe) Auflösung (z.B. Klimadaten) sowie die Aktualität. Ein weiteres Problem besteht in der Verfügbarkeit von flächendeckenden abiotischen und biotischen Daten für die Stadt Leipzig in den aktuellen Stadtgrenzen, insbesondere, da sich die Stadtfläche seit der Wiedervereinigung 1989 nahezu verdoppelt hat (von 150 auf ca. 300 km^2). Problematisch erscheint die Nutzung der Vorkommensdaten als 500x500 m-Raster. Es wird davon ausgegangen, dass die Art in diesem Raster vorkommt und damit auch der Aktionsradius mit diesem Raum übereinstimmt. Eine andere Herangehensweise ist möglich, wenn Punktdaten zur Verfügung stehen. In diesem Fall wird ein Puffer gebildet, der als Aktionsraum der Art angenommen wird. Für diese Art von Analyse ist allerdings eine Voruntersuchung notwendig, in wieweit dieser Radius adäquat für die Art ist. Im urbanen Raum ist aufgrund seiner Heterogenität und dem großen Strukturreichtum die Frage nach der Repräsentativität von punktuellen Daten noch brisanter (Breuste, 2002).

Die für die ENFA notwendige Datenaufbereitung ist relativ aufwendig. Allerdings beruht der hier vorgestellte Ansatz auf ausschließlich allgemein verfügbaren digitalen Daten und ist somit auch in anderen urbanen Räumen für vergleichbare Zielstellungen anwendbar. Die ausgewählten Zielarten erwiesen sich als weitestgehend geeignet für die Bewertung der ausgewählten Stadtstrukturen. Die Dorngrasmücke als Offenlandart meidet eng bebaute Bereiche und kann daher für die Bewertung von innerstädtischen Brachflächen nur bedingt Aussagen treffen. Des Weiteren ist die Dorngrasmücke eher eine euryöke Art und damit nur eingeschränkt als Zielart geeignet. Möglicherweise ist für diese Zwecke eine andere Art oder eine Art einer anderen Tiergesellschaft, z.B. Amphibien, Reptilien besser geeignet. Auch die Bildung von Tierartengruppen kann zu einer Verbesserung der Ergebnisse führen. Begrenzend kann allerdings auch hier wieder die Datenlage der vorhandenen Präsenzdaten sein.

Kritisch müssen die vielfältigen Faktoren mit Einfluss auf das Modellergebnis gewertet werden. Dies betrifft insbesondere die Qualität der Datengrundlage und die Stimmigkeit der Daten in Raum und Zeit. Auch die Auswahl der Parameter und die Quantifizierbarkeit beeinflussten das Ergebnis. Es ist ebenso nicht auszuschließen, dass relevante Parameter nicht betrachtet wurden. Außerdem ist es möglich, dass die inhaltliche Auflösung der Stadtbiotopkartierung zu gering ist und somit Habitatstrukturen, die für das Vorkommen der Arten relevant sind, gar nicht erfasst wurden (Jedicke, 1996).

Die Ergebnisse zeigen, dass einige Hypothesen zu den Habitatpräferenzen der Arten nicht angenommen werden konnte. Im Modell der Dorngrasmücke wurden 71% und im Modell des Grünspechts 57% der Hypothesen bestätigt. Daraus kann man aber nicht schließen, dass diese Habitatpräferenzen nicht für in der Stadt vorkommende Arten gelten. Die Ablehnung hat andere Gründe, so z.B. die Lage einiger präferierter Stadtstrukturen innerhalb der Stadt. Wichtig ist, dass generelle Vorlieben der Arten für bestimmte Biotope bzw. Stadtstrukturen bestätigt werden konnten und somit möglicherweise mit den Habitatpräferenzen der Arten in der freien Landschaft übereinstimmen. Insbesondere die Brachflächen, die eine relativ neue Form von Land Cover in Leipzig darstellen und mit einem negativen Image besetzt sind, erhielten hauptsächlich im peripheren Bereich der Stadt hohe Wertstufen. Dies gilt ebenso für die Grünflächen, die sich in unmittelbarer Umgebung der Auen, als überregional und national bedeutsames Relikt, befinden.

Für die Wertübertragung der HSI-Werte auf die zu untersuchenden Flächen sind Mittelwertberechnung und Überkreuzung-intersect als zielführend einzuschätzen, da eine für die Planung notwendige Differenzierung erhalten bleibt. Die Analyse zum Grünen Ring zeigte, dass die Flächen nur bedingt für den Grünspecht geeignet sind. Somit kann man für die Planung schließen, dass auch innerstädtische Grünflächen und Stadtstrukturen jeder Größe, für den Arten- und Biotopschutz von Bedeutung sind. Demnach wäre im Folgenden zu prüfen, inwieweit diese Flächen dem Leitbild des Grünen Rings entsprechen und somit integriert werden können. Der Anwendung der Ergebnisse in der Planung sind Grenzen gesetzt. Will man Vorhersagekraft erreichen, sind die erzielten Ergebnisse anhand von Felddaten zu validieren. Ebenso ist die Betrachtung weiterer nicht erfasster Parameter von Bedeutung.

Habitatmodelle dienen der Prognose von Umweltauswirkungen im Rahmen von planungsrelevanten Entscheidungen (z.B. Eingriffe oder Kompensations- und Pflegemaßnahmen), um die Transparenz, Nachvollziehbarkeit und Objektivität in der Planung zu erhöhen (Schröder, 2000). Dabei erleichtern die ermittelten Ergebnisse die Bewertung und Beurteilung, landschaftsplanerische Fragestellungen betreffend. Besonders interessant für urbane Räume wäre die Untersuchung von Arten, die eine hohe Bindung an den urbanen Raum haben, z.B. Gebäudebrüter. Demzufolge wäre es zu prüfen, ob es Möglichkeiten gibt, mit vertretbarem Aufwand relevante Daten zu erheben. Habitatmodelle erklären nur einen Teil des Vorkommens der Arten. Mit Populationsmodellen wären, im Gegensatz zu Habitatmodellen, umfassendere Beurteilungen von Eingriffen in Natur und Landschaft im Rahmen von Eingriffsbewertungen und Umweltverträglichkeitsprüfungen möglich.

Generell ist es das Ziel, die Vorhersagekraft und Güte von Habitatmodellen und somit die Bewertung und Beurteilung im Rahmen von landschaftsplanerischen Fragestellungen zu verbessern. Nach Blaschke (2004) werden Modellierungen in den nächsten Jahren im Blickpunkt der Forschung stehen, da flächenhafte Aussagen mit „Mut zur Unschärfe“ beispielsweise für Monitoringaufgaben (Natura 2000-Netzwerk) benötigt werden. Modelle sind in jedem Fall Abstraktionen und beinhalten Probleme hinsichtlich Aussagekraft und Gültigkeit. Habitatmodelle können für die Naturschutzforschung und –praxis wesentlich sein, wenn sie „predictive power“ besitzen, Potenziale benennen und somit für die Prognose des Vorkommens und der Überlebensfähigkeit von Arten geeignet sind.

4.4. Multi-criteria and integrated assessment approaches

Haase, D., Nuissl, H., 2007. Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870-2003. *Landscape and Urban Planning* 80, 1-13.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Assessment of the environmental impact of urban sprawl being understood here as the conversion of non-urban to urban land is still a subject for debate. Another shortcoming of the current discourse on urban sprawl is that it largely fails to reflect the interconnection of environmental and socio-economic aspects. In presenting a case study on the German city of Leipzig and applying the conceptual framework of driving forces, pressure, state, impact, and response (DPSIR-concept), this paper strives to assess the impact of urban sprawl on water balance and explores the repercussions of this impact upon the causation of and policies on urban sprawl. The study establishes that urban sprawl and related surface sealing have considerable impact on water fluxes and the urban water balance that may become imminent in the longer run. However, the study also shows that societal reactions on urban sprawl, first of all the attempts of both authorities and public initiatives to contain sprawl, are hardly motivated or influenced by concerns about environmental problems in a particular place (affected by urban sprawl). These attempts are mainly carried out on a national and regional level and reflect a general orientation in environmental politics rather than the desire to respond to individual urban developments. The study thus shows that the environmental impact of sprawl elicits only indirect repercussions in society.

Drawing on a long-term observation of land-use change in the city of Leipzig this paper proves that urban sprawl has considerable impact on the urban water balance. It highlights the problems that can arise in the long run due to the accumulation of this impact on the city or regional scale and thus gives an example of how severely urban growth on a city's fringes can affect environmental features such as water balance in quantitative terms. The paper further discusses the extent to which the impact of urban sprawl on the water balance has a feedback on how society handles and regulates the use of land. It has been found that, even though several actors do pay attention to the problem of urban sprawl, they are usually not concerned about its impact on the environment in general, or water balance in particular, in a specific region. It is therefore possible to conclude that land-use policy will not adapt automatically to the environmental challenges posed by urban sprawl. Rather it is a question of political argument on all levels of policy making and spatial planning whether these long-term hazardous challenges will be tackled.

Schetke, S., Haase, D. 2008. Multi-criteria assessment of socio-environmental aspects in shrinking cities. Experiences from Eastern Germany. *Environmental Impact Assessment Review* 28, 483-503.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Demographic change and economic decline produce modified urban land use pattern and densities. Compared to the beginning of the 90s after the German reunification, nowadaysmassive housing and commercial vacancies followed by demolition and perforation come to pass in many cities of the formerGDR. In consequence, a considerable surplus of urban brownfields has been created. Furthermore, the decline in the urban fabric affects social infrastructure and urban greenery of local neighbourhoods. Here, urban planning enters into 'uncharted territory' since it needs to assess the socio-environmental impact of shrinkage.

In order to carry out such an evaluation quantitatively, amulti-criteria assessment scheme (MCA) was developed and applied. Firstly, we identified infrastructure and land use changes related to vacancy and demolition. Secondly, demolition scenarios for the coming 20 years were applied in order to give an idea for a long-term monitoring approach at the local district level. A multi-criteria indicator matrix quantifies the socio-environmental impact on both urban greenery and residents. Using it, we set demolition scenarios against urban 'quality of life' targets. Empirical evidence comes from Leipzig, in eastern Germany, a representative case study for urban shrinkage processes.

The results show that shrinkage implies socio-environmental changes of residential livelihoods, however, does not simply increase or decrease the overall urban quality of life. The integrated assessment of all indicators identifies environmental and social opportunities, as well as the challenges a shrinking city is faced with: Land use and urban fabric development in shrinking cities are still in need of micro-scale findings of empirical research. We presented an innovative study that differentiates all the heterogeneous processes and phenomena of shrinkage in order to illustrate its impact on the socioenvironmental urban dimensions. As a result of this study, we have found that for a neighbourhood such as Leipzig-Grünau, increasing demolition can lead to blurred structures, while for parts of East Leipzig it can be a blessing.

Based on the results of the MCA, the authors see different development options for both test areas under conditions of further shrinkage. Perforation turns Leipzig-Grünau into a greener and more nature-oriented area and creates space for more spacious livelihoods with seminatural biotopes. Following current trends of the housing sector development in Germany, there is still a continuous 'thirst for land' by land developers and project planners despite declining population numbers. Thus, urban expansion seems to be another option, too. Districts such as East Leipzig might counteract urban sprawl since re-densification and re-urbanisationwill take place. Here, in particular a quality enhancement of urban green will lead to a higher quality of life and thus attract urban dwellers to these neighborhoods.

Taking into account what has been found in this study, the indicator set gives an idea for a long-term monitoring approach of sustainable urban open space development

and urban greenery at the district level (according to the initial ideas of URGE, and thus as a kind of enhancement). Scientific evidence is needed that clearly sets out the socio-economic benefits and multiple contributions of urban green spaces to the quality of urban life (Bryant, 2006). Only then, an influence of local decisionmaking in European cities towards reinforcing the contribution of the greenery to a healthy living environment is possible, particularly for a case involving a shrinking city. The MCA presented here provides a valuable contribution through combining different dimensions of sustainability when looking at urban shrinkage as required by Ravetz (2000) or Wiek and Binder (2005).

The study has further proved that there exists a strong overlap of the different functions of urban green such as stated in Turner (2006): scenic value, ecological value, hydrological value and recreational value. Normally, these values overlap. They are not likely to be co-incident and they are not likely to be confined to open space in public ownership. Yet, each of them is needed by landscape planning in order to conserve and enhance the quality of the environment. Still missing are indicators looking at acceptance, utilization and economic value of urban green (Breuste, 2003). They might supply an answer as to whether demolition influences urban green spaces positively, or if it has less importance. The results of this study clearly show that the structure of the urban fabric - huge open lawns in Leipzig-Grünau or cosy backyards in Leipzig East - has a strong influence on the shape of open and green spaces after demolition. In conclusion, the development and application of such amulti-criteriamethodology forms a sound scientific base for an overall and more integrated socio-environmental planning in relation to population, urban fabric, green and infrastructure network of shrinking cities.

Haase, D., Schetke, S. in press. Potential of biodiversity and recreation in shrinking cities: contextualisation and operationalisation. Blackwell Academic Publishing "Conservation Science and Practice Series".

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Whereas environmental and social impacts of urban sprawl are widely discussed among scholars from both the natural and social sciences, the spatial consequences of urban shrinkage are almost neglected when discussing the impacts of land use change. Within the last decade, shrinkage and perforation have arisen as new terms to explain the land use development of urban area faced with demographic decline, particularly decreasing fertility, aging, and out-migration. Although shrinkage is far from being a “desired” scenario for urban policy makers, this paper argues that a perforation of the built-up structure in dense cities might bring up many positive implications and potential for urban biodiversity. The paper introduces firstly an approach how to set shrinkage along with biodiversity into context. Furthermore, this approach is to be extended by presenting an integrative indicator matrix focussing on especially ecological but also social impacts of shrinkage embedded in scenario analysis.

As we have shown in this paper, there is considerable potential for biodiversity and the improvement of urban green systems within shrinking cities. The same counts forsocial and residential improvement, which has been outlined peripherally in the last section. Exploring opportunities as discussed above using the example of the city of Leipzig, might attract new residents for a longer period of time and keep local dwellers in the city, instead of having them choose the detached-house alternative. We have learnt about the positive structural enrichments of shrinkage due to landscape metrics in relation to single species and newly emerging spatial pattern. In addition to that we presented a MCA-scheme extending the findings on landscape metrics and embedding them into a set of ecological as well as scoial indicators. Here the paper shows an indicator-based integrated assessment approach to contextualise shrinkage and quantify its effects. Interdisciplinary decision making requires integrative tools for assessment in order to overcome optimization on sectoral output at the cost of higher interdisciplinary synergy and of the total value of urban green spaces. This is a valuable contribution in combining different dimensions of sustainability in urban shrinkage and to assess its socio-environmental impacts within a long-term scenario analysis.

Based on the findings of biodiversity and greenspace potentials, the paper argues that residential and commercial vacancies and the subsequent demolition represent an opportunity for the enlargement of urban greenspace and, to some extent, the ecological restoration of cities.

Meyer, V., Haase, D., Scheuer, S., 2009. A multicriteria flood risk assessment and mapping approach. In: Samuels, P. et al. (eds). Flood Risk Management Research and Practice. Taylor & Francis, pp. 1687-1693.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Flood risk analysis and assessment are integral parts of the flood risk management approach.
However, some deficits can be recognised in today's practice with regard to the following aspects: a) The focus of flood risk assessment is still very much on economic flood risks. Social and environmental flood risks are often neglected. Consequently, the results of risk assessment can be incomplete and biased. b) The spatial distribution of risks as well as of the benefits of flood mitigation measures is rarely considered. c) Uncertainties in the results of risk assessment are often ignored. In this paper we want to present a GIS-based multicriteria flood risk assessment and mapping approach.

Our approach can be used for an integrated assessment of economic, as well as social and environmental flood risks. Furthermore, the spatial distribution of these multiple risks as well as of the effects of risk reduction measures can be shown by this mapping technique. Moreover, possibilities are shown how to deal with uncertainties in criteria values and to demonstrate their influence on the overall assessment. The approach is applied to a pilot study at the River Mulde in Saxony, Germany, heavily affected by the hazardous flood in 2002. Therefore, a GIS-dataset of economic as well as social and environmental risk criteria was built up. Two different multicriteria decision rules, a disjunctive approach and an additive weighting approach are used to come to an overall assessment and mapping of flood risk in the area. Both, the risk calculation and mapping of single criteria as well as the multicriteria analysis are supported by a software tool (FloodCalc) which has been developed for this purpose.

The approach introduced in this paper aims to improve flood risk assessment in three ways: Firstly, to include non-monetary risks in the overall flood risk assessment. Secondly, to show the spatial distribution of these multicriteria risks. Thirdly, to show possibilities for dealing with the uncertainties associated with the criteria evaluation. Therefore, we developed a framework for a GISbased multicriteria analysis which can be applied for an integrated assessment and mapping of flood risks.

This approach was applied to a pilot site, the Vereinigte Mulde in the federal state of Saxony, Germany. First of all a set of evaluation criteria was selected which encompasses economic as well as environmental and social flood risk indicators. For each of the criteria, damage evaluation methods were applied in order to produce risk maps. Two different MCA approaches were tested in order to aggregate these different criteria risk maps: a disjunctive approach and an additive weighting approach. Our pilot study showed that both are appropriate for use within the framework of multicriteria risk mapping. The additive weighting approach would furthermore be applicable to show the spatial distribution of benefits of certain flood risk reduction measures. As documented for the economic criterion, uncertainties in flood risk assessment can be considered in a simple way by calculating mean, minimum and maximum risk estimations.

As a further result, an alpha version of a software tool was developed (FloodCalc; Meyer et al., 2008), which supports not only the calculation and mapping of the different damage and risk criteria, but also the two different MCA-procedures mentioned above. However, our approach should be seen only as a first step towards an integrated risk mapping approach. Several points need further improvement. Firstly, the set of criteria could be extended or improved and the methods for the calculation of these risk criteria could be further refined. Secondly, uncertainties are documented only for the economic criterion. This could be extended also to the other criteria.

Finally, and maybe most important, the selection and weighting of criteria are crucial parts of any multicriteria approach which have high influence on its outcomes. Here, rules and procedures have to be further elaborated for the involvement of decision makers and stakeholders to ensure the legitimacy of judgements.

Meyer, V., Scheuer, S., Haase, D. 2008. A multi-criteria approach for flood risk mapping exemplified at the Mulde river, Germany. *Natural Hazards* 48, 17–39. DOI: 10.1007/s11069-008-9244-4.

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

In this paper we develop a GIS-based multicriteria flood risk assessment and mapping approach. This approach includes flood risks which are not measured in monetary terms; it shows the spatial distribution ofmultiple risks, and it is able to deal with uncertainties in criteria values and to show their influence on the overall flood risk assessment.Additionally, the approach can be used to show the spatial allocation of the flood effects if risk reduction measures are implemented. The approach is applied to a pilot study for the River Mulde in Saxony, Germany, heavily affected by the hazard-

ous flood in 2002. Therefore, a GIS database of economic, social and environmental risk criteria was created. Two different multicriteria decision rules, a disjunctive and an additive weighting approach, are utilised for an overall flood risk assessment in the area. For implementation, a software tool (FloodCalc) was developed supporting both, the risk calculation of the single criteria as well as the multicriteria analysis.

To summarise, in this paper we have shown an approach to improve flood risk assessment in three ways: Firstly, to include non-monetary risks in the overall flood risk assessment. Secondly, to do this in a spatially differentiated way, i.e. to describe also the spatial distribution of these multicriteria risks. Thirdly, to show possibilities for dealing with the uncertainties associated with the criteria evaluation.

Therefore, we developed a framework for a GIS-based MCA which can be applied for an integrated assessment and mapping of flood risks. This approach was applied to a pilot site, the Vereinigte Mulde in the federal state of Saxony, Germany. First of all, a set of evaluation criteria was selected which encompasses economic as well as environmental and social flood risk indicators. For each of the criteria, damage evaluation methods were applied in order to produce risk maps. Two different MCA approaches were tested in order to aggregate these different criteria risk maps: a disjunctive approach and an additive weighting approach. Our pilot study showed that both are appropriate for use within the framework of multicriteria risk mapping. The additive weighting approach would furthermore be applicable to show the spatial distribution of benefits of certain flood risk reduction measures. Regarding the consideration of uncertainties, at least for the economic criteria, an approach was shown as to how such uncertainties can be documented and dealt with.

Meyer, V., Haase, D., Scheuer, S. in press. Flood Risk Assessment in European River Basins - Concept, Methods and Challenges. *Integrated Environmental Assessment and Management.*

(Reprint of the paper cf. Annex A3)

Summary and Conclusions

Flood risk assessment is an essential part of flood risk management, a concept that is becoming more and more popular in European flood policy and is part of the new European Union flood directive. This paper gives a brief introduction into the general concept and methods of flood risk assessment. Furthermore, 3 problems in the practical application of flood risk assessment, particularly on the river basin scale, are discussed: first, uncertainties in flood risk assessment; second, the inclusion of social and environmental flood risk factors; and third, the consideration of the spatial dimension of flood risk. In the 2nd part of the paper a multicriteria risk mapping approach is introduced that is intended to address these 3 problems.

The new paradigm of flood risk management is obviously getting more and more popular in flood policy in Europe, and it is the conceptual background for the new European Union flood directive. The assessment of flood risks is an essential part of this approach. This paper briefly described the general concept of assessing flood risk as well as different approaches for flood damage evaluation. We furthermore outlined 3 problems in the current practical application of flood risk assessment:

1. How to deal with uncertainties in the results of flood risk assessment;
2. How to include social and environmental flood risks;
3. How to properly consider the spatial distribution of flood risks.

We introduced a multicriteria risk mapping approach which tries to consider these 3 problems. First, at least for the economic criterion, methodological uncertainties in the results are documented by mean, maximum, and minimum risk values. Second, our approach includes an exemplary set of economic as well as social and environmental flood risk criteria. These different criteria can be aggregated by means of a multicriteria decision rule being a simple additive weighting approach. Third, the spatial distribution of flood risks as well as risk reducing effects can be displayed by a GIS-based risk mapping approach (i.e., all risk assessment calculations are carried out for a grid with a resolution of 10 m).

However, our approach should be seen only as a first attempt to deal with these problems. The approach still has some limitations and further research tasks can be identified. First, with regard to uncertainties, our approach documented such uncertainties only for the economic criterion. Furthermore, only 2 sources of model uncertainties were considered: uncertainties resulting from the choice of the spatial allocation key and the set of damage functions. Uncertainties resulting from the inundation model used were not yet considered. Hydraulic models show some uncertainties especially in urban areas, where fluid water flow modelling is highly complex due to the variety of urban structures and thus fluid flow cannot be expressed as overland flow. Furthermore, the documentation of uncertainties in flood risk assessment is of course only a first step. Further research is still needed on how to deal with such uncertain information in the decision-making process in flood risk management and how to determine an appropriate level of accuracy for the different decision problems.

Second, our approach showed how social, environmental, and economic risk criteria can be aggregated, but it also unveiled how important the involvement of decision makers in the evaluation process is, as the selection of criteria and the determination of weights given to them substantially determine the results of the assessment process. In our example we did not involve stakeholders yet, so the exemplary results shown are still arbitrary. However, literature provides some examples and procedures for how to integrate stakeholders in multicriteria analysis (e.g., Proctor and Drechsler 2006; Salgado et al. 2006). Consequently, the next step would be to interlink such participation approaches with our multicriteria assessment approach.

Third, a number of problems also arise from the mapping of flood risk. The accuracy of spatial flood risk assessment depends on the resolution of the underlying grid. However, the use of high resolution grids is limited by at least 2 factors: computational implementation (i.e., system memory availability and addressing) and the level of detail and resolution of the corresponding input data like inundation and land use data. This also means that the mapping of flood risk is always associated with inaccuracies or uncertainties and the right level of spatial resolution is maybe not easy to find. Furthermore, if spatial disparities are identified by risk mapping it is still an open question how to deal with them. Our approach is able to identify high risk areas but it does not yet answer the question of how much they should be reduced and how risk reduction efforts can be distributed ''fairly'' in river basins (Johnson et al. 2007).

5. Conclusions and outlook

'Cities save landscapes from being consumed by man'.
Inside from the author 2008

Recent uneven land use dynamics in urban areas resulting from demographic change, economic pressure and the cities' mutual competition in a globalising world under climate change challenge landscape science. Processes of urban growth and decline specifically affect the urban environment, the requirements of the residents on the environment and natural resources. Geographical research is interested in a better understanding and ways of explaining the interactions between society and environment in urban areas. And it is also needed for making life in cities attractive, secure and affordable on the one hand and sustainable on the other despite of uneven dynamics.

Chapter 2: Urban land use dynamics – processes and pattern

Concerning urban demographic change, one of the major drivers of land use change, the results of my work show that particularly the sequence of suburbanisation, desurbanisation and reurbanisation altered. Whereas suburbanisation reinforces, desurbanisation partially decreases in favour of an initial reurbanisation. European cities result to be very heterogeneous in recent population change dynamics. They form clusters of growth and decline trajectories after 1990 and support a new spatial picture of the urbanisation of European agglomerations. Basing on significant statistical relations, the presented work on urban population change is the first comparative analysis from different urban agglomerations of the EU-27. Future research will be supplemented by analyses on the drivers of growth and decline for city core and fringe area. Demographic and socioeconomic indicators, such as fertility rate, household size, unemployment rate, cost of living, house prices or GDP will be used to test with the dataset how they affect urbanisation. The integration of these indicators related to demographic change is a next challenge to capture the development of European urban systems in more detail. An exhaustive explanation of these phenomena at European but also at case study level will be interpreted in an upcoming paper.

The findings concerning the impact of demographic change on land use prove that demographic change will not "solve" the problem of land consumption in Germany. However, it clearly identifies where both demographic and land use change lead to a more concentrated or even scattered development with increasing land consumption per capita at the least. The clusters that we identified give planners more support when considering regional specific policy options for dealing with demographic and land use change rather than clutching to an overall national 30 ha goal. The results presented in Chapter 2 make clear that demographic change means above all a change in the total number of people, age class distribution, a modification in household structures and a rising impact of migration. Particularly in eastern Germany, we find a coincidence of seemingly contradictory urban processes: first, although on a low level since the late 1990s, there are traces of prevailing dynamics of suburban growth with adjacent land consumption at the urban fringe. Second, at many places, increasing process of depopulation and related shrinkage calculated according to residential vacancy, perforation, demolition and deconstruction in the core city areas can be observed. A thinning out of recent urban fabric and population densities are the consequence. Third, counteracting decline, we find also processes of stabilisation of the housing function as well as increasing population numbers in some inner-city areas. Since the spatial and land use effects of demographic change certainly shape concentration and deconcentration processes and respective distribution pattern of demand and release of land also at a spatial level beyond the district scale, future research has to focus on conducting a comparable analysis as done for the German districts at the municipality level using high-grain socio-demographic and land use/land cover data.

Chapter 3: Model approaches analysing urban land use change

Cultural landscapes all have their distinctive and unique history. It has often been stated that this history is a valuable basis for spatial and environmental planning, as it has the potential to improve description, prediction and prescription of planning processes in these cultural landscapes. In the future, we have to address the question, how landscape history can serve as a tool in landscape planning. What exactly are the advantages of integrating historical aspects into planning processes? Is it really true that incorporating history improves the quality of spatial and environmental planning? And what obstacles have to be overcome in this interdisciplinary discourse?

I see landscape ecology as an important link between landscape history and landscape planning, as it offers a wide array of methods and approaches which bear the potential to facilitate the integration of historical information on landscapes and land use into planning processes significantly, as shown in this Habilitation thesis. Historical maps and data can be integrated into a GIS to follow the development of land use quantitatively over a long period of time and to assess the main trajectories of change. Statistics can be compiled on the development of selected landscape elements and aspects so that qualitative and expert based interpretation of landscape development can be quantitatively substantiated. Furthermore, structural changes between landscapes past and present can be quantified by means of indices. This makes a contribution to a functionally orientated assessment of landscape development.

Land use change model approaches have their strengths in setting up causal relationships between variables and to quantify them. Since models generally aim at depicting multiple relationships and complex systems in a formalised and less complex way, they use major variables to realise important stocks, flows and communication processes to reduce the real complexity to a point where we can see and analyse the influence of single parameters of the system. In urban land use change modelling there have been developed different modelling approaches such as system dynamics (SD), cellular automata (CA), and agent-based modelling (ABM).

GIS-based knowledge of historic land use changes are an important prerequisite for the simulation of land use changes using CA model approaches such as the MOLAND model which is used by the European Commission for the projection of land use change in urban regions of Europe.

Despite such cell-based model approaches, many questions raised are in close connection to what concerns landscape change and resource planning or management. Land use change models and GIS had been presented in Chapter 3 of this Habilitation thesis as a kind of relational and mutually feeding methodologies that support applied research and provide planning and land use policy with quantitative tools. It remains a challenge to better incorporate agent behavior and heuristics of decision-making as a key to better understand land use changes. Often, land use transitions are closely connected with humans acting on the real estate and land market. Land use changes thus can be understood as the consequences of actions. Since they are a heterogeneous group the behaviour of the "urban actors" is characterized by highly heterogeneous and controversy decisions that directly impact on and shape of land use change in terms of the intensification of land cultivation, the amount of land take as well as forms of land abandonment. This is the field of social sciences (sociology, political science, psychology, spatial planning) which carry out field research on effects of such drivers like demographic change, urban sprawl and shrinkage as identified in chapter 2 of this Habilitation thesis. Their work delivers innovative empirical results in form of questionnaire survey data, series of interviews, perception data, agent profiles, behaviour settings through document analysis and observation.

Land use dynamics of shrinking city regions

Modelling urban shrinkage remains a challenge for current simulation models, as most of the models presently focus on urban growth and sprawl. In order to include processes of urban shrinkage in such models, nothing less than a shift in paradigms from ever-growing urban regions to stagnation or even shrinkage is necessary. This assertion is not only valid for the field of urban simulation but for urban research in general: Only if processes of urban shrinkage are analysed and empirically quantified, simulation models can be built. In more detail, several challenges need to be addressed when modelling urban shrinkage: To incorporate residential vacancies and demolition / deconstruction in non-spatial simulation models is rather easy compared to spatially explicit models in which the question where vacancies or demolition will take place needs to be tackled. In order to simulate which areas in a city will stagnate or even decline, one needs information on attractiveness of and future investments in these areas, and, if applicable, random events that encourage or discourage people from moving there. Simulating urban shrinkage is a challenge especially for CA models: detecting residential vacancies using statistical data, official municipal registration sources or space-/air-borne remote sensing data is very difficult; therefore the data basis for calibrating CA models in shrinking regions needs to be reassessed.

To model urban shrinkage in a spatially explicit way, the ABM approach seems very promising: Modelling urban shrinkage requires the incorporation of decision-making processes of households, planners, investors and owners of buildings and land since these actors' behaviour and decision making changes land use; ABM are – at least theoretically – able to integrate decisions of various agents and therefore social science knowledge. Accordingly, present ABM approaches could be modified and enlarged to incorporate these decisions as well and therefore to arrive at a basic representation of urban shrinkage.

Chapter 4: Impact assessment of land use change

Urban Ecosystem Services (UES) have been identified as a suitable concept to analyse the service function of the physical environment in terms of natural resources and ecosystems in urban regions. UES represent a clear target for valuing natural resources and ecosystems in urban areas since the concept combines natural functions and resources with land use and human demands. The UES framework enables to quantify, monetarise (if necessary) and to relate ecosystem functionality to human demand (in so far „economic“ concept). As shown in chapter 4 of this Habilitation thesis, there is a range of models and data available to quantify UES.

The concept enables an improved understanding of the benefits nature and ecosystem functionality provides for urban residents on the one hand. On the other, thinking in categories of UES we uncover the benefits nature gains from compact settlements in favour of low-density ones.

Since an assessment of land use transition impact draws the attention to the consequences of alternative land use management and planning decisions, it has the potential to orient urban development to the ‘right’ places. This will become increasingly important in the near future as we face a simultaneity of growth and decline in many European regions that opens up the chance for new land development strategies. However, in particular under the condition of decline, the evaluation of land use transition should also include socio-economic aspects, such as infrastructure costs or socio-spatial segregation.

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List of publications

2010 and forthcoming

1. Schwarz N, Kahlenberg D, Haase D, Seppelt R submitted. A generic framework for collaborative agent-based model development. Environmental Modelling and Software.
2. Scheuer S, Haase D., Meyer V submitted. Towards a flood risk assessment ontology integrating a multicriteria flood risk assessment approach and local knowledge. Computers, Environment and Urban Systems.
3. Haase D, Kabisch N submitted. The endless city: On the growing mismatch of population development and land consumption. Global Environmental Change.
4. Strohbach M, Haase D submitted. Estimating the carbon stock of a city: a study from Leipzig, Germany. Landscape and Urban Planning.
5. Strohbach, M.W., Arnold, E., Haase, D., revisions. The carbon mitigation potential of urban restructuring – a life cycle analysis of green space development. Landscape and Urban Planning.
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7. Bastian O, Haase D, Grunewald K submitted. Ecosystem properties, potentials and services - the EPPS conceptual framework and an urban application example. Ecological Indicators.
8. Scheuer S, Haase D, Meyer V submitted. Operationalization and evaluation of an integrated multicriteria flood risk assessment approach. Environmental Modelling and Software.
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11. Schetke S, Haase D, Kötter T revisions. Innovative urban land development – a new methodological design for implementing ecological targets into strategic planning of the City of Essen, Germany. Environmental Impact Assessment Review.
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18. Haase D, Tötzer T in press. Urban-rural linkages – Analysing, modelling and understanding drivers, pressures and impacts of land use changes along the rural-to-urban gradient. Environment and Planning B.

19. Lauf S, Haase D, Seppelt R, Schwarz N in press. Simulating demography and housing demand in an urban region under scenarios of growth and shrinkage. Environment and Planning B.

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21. Scheuer S, Haase D, Meyer V in press. Exploring multicriteria flood vulnerability by integrating the economic, ecologic and social dimensions of flood risk and coping capacity. Natural Hazards.

22. Haase D, Tötzer T in press. Urban-rural linkages – Analysing, modelling and understanding drivers, pressures and impacts of land use changes along the rural-to-urban gradient. Environment and Planning B.

23. Lauf S, Haase D, Seppelt R, Schwarz N in press. Simulating demography and housing demand in an urban region under scenarios of growth and shrinkage. Environment and Planning B.

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41. Kabisch N, Haase D, Haase A. 2009. Evolving reurbanisation? Spatio-temporal dynamics exemplified at the eastern German city of Leipzig. Urban Studies 47(5) 967–990.
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2. Schetke S, Haase D 2008. Multi-criteria assessment of socio-environmental aspects in shrinking cities. Experiences from Eastern Germany. Environmental Impact Assessment Review 28, 483-503.

3. Haase D, Haase A, Bischoff P, Kabisch S 2008. Guidelines for the 'Perfect Inner City' Discussing the Appropriateness of Monitoring Approaches for Reurbanisation. European Planning Studies 16(8), 1075-1100, DOI: 10.1080/09654310802315765.

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56. Weichel T, Schulz K, Haase D 2006. Effektive Ansätze zur Beschreibung des Hochwasserrisikos urbaner Bereiche. Forum für Hydrologie und Wasserbewirtschaftung, Heft 16.06, Bd.3, S. 177-180.

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66. Haase D, Neumeister H 2001. Anthropogenic impact on fluvisols in German Floodplains. Ecological processes in soils and methods of investigation. International Agrophysics, 15(1), 19-26.

Own contribution to the submitted publications

In this section, for each submitted and issued publication of the habilitation thesis my own contribution to the work is differentiated by idea, concept, and realization of the analysis/publication.

Publications in order of submission:

Kabisch, N, Haase, D in press. Diversifying European agglomerations: evidence of urban population trends for the 21st century. Population, Space and Place.
The idea and major parts of this paper including one key analysis scheme were developed by myself.

Kroll F, Haase D 2010. Does demographic change affect land use patterns? A case study from Germany. Land Use Policy 27, 726-737.
The idea to work on the relationships between demographic change and land use transformation was developed by myself. Concept and major parts of the statistical analysis were elaborated by myself in addition to 50% of the entire manuscript.

Haase D, Gläser J 2009. Determinants of floodplain forest development illustrated by the example of the floodplain forest in the District of Leipzig. Forest Ecol. Manage. 258, 887-894.
The idea, the concept of the paper, the GIS floodplain delineation model and major parts of the manuscript were elaborated by myself.

Weber, N., Haase, D., Franck, U. submitted. Airborne particle number concentration and acoustic noise in inner city areas. Journal for Environmental Management.
The idea for the Diploma thesis the paper bases on (by Nicole Weber) and the concept of this research work and major parts of the final manuscript were elaborated by myself.

Schwarz N, Haase D, Seppelt R. 2010. Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage. Environment and Planning B 37, 265-283.
The concept of reviewing existing simulation models on urban land use change and the text of the manuscript were elaborated together with Nina Schwarz. The causality model to explain urban shrinkage processes and pattern is product of my work.

Haase D, Schwarz N 2009. Simulation models on human-nature interactions in urban landscapes – a review including system dynamics, cellular automata and agent-based approaches. Living Reviews in Landscape Research 3, 2.
The core idea of the spidergram assessment scheme which is the central figure of the discussion part of this paper is genuine part of my work. Further, I elaborated about 80% of the paper.

Haase D 2009. Effects of urbanisation on the water balance – a long-term trajectory. Environment Impact Assessment Review 29, 211-219.
This work was done exclusively by myself (including idea, concept, and realization).

Kabisch N, Haase D, Haase A. 2009. Evolving reurbanisation? Spatio-temporal dynamics exemplified at the eastern German city of Leipzig. Urban Studies 47(5) 967–990.
The idea for the Diploma thesis the paper bases on (by Nadja Kabisch) and the concept of this research work and major parts of the final manuscript were elaborated by myself. Half of the paper was elaborated by my Diploma student Nadja Kabisch and one section by A. Haase.

Haase D, Lautenbach S, Seppelt R 2010. Applying social science concepts: modelling and simulating residential mobility in a shrinking city. Environmental Modelling and Software 25, 1225-1240.
This work was majorily done by myself (including idea, concept, and realization). My co-author reviewed and edited final version of the manuscript before submission.

Meyer, V., Haase, D., Scheuer, S., 2009. Flood Risk Assessment in European River Basins - Concept, Methods and Challenges. Integrated Environmental Assessment and Management 5, 17-26.
The core concept of a multi-criteria flood risk assessment was elaborated by Volker Meyer and myself. I further contributed to the FloodCalc-tool development in setting up the ecological assessment part.

Haase D, Schetke S 2010. Potential of biodiversity and recreation in shrinking cities: contextualisation and operationalisation. In: Müller N, Werner P, Kelcey JG (eds) Urban Biodiversity and Design. Blackwell Academic Publishing "Conservation Science and Practice Series" No.7, pp 518-538.
This work was done majorily by myself (including idea, concept, and realization).

Meyer, V., Haase, D., Scheuer, S., 2009. A multicriteria flood risk assessment and mapping approach. In: Samuels, P. et al. (eds). Flood Risk Management Research and Practice. Taylor & Francis, pp. 1687-1693.
The core concept of a multi-criteria flood risk assessment was elaborated by Volker Meyer and myself. I further contributed to the FloodCalc-tool development in setting up the ecological assessment part. For this paper, I took over the final editiorial work, too.

Nuissl, H., Haase, D., Wittmer, H., Lanzendorf, M. 2008. Impact assessment of land use transition in urban areas – an integrated approach from an environmental perspective. Land Use Policy 26, 414-42,.
The interdisciplinary assessment scheme for land consumption was majorily developed by Henning Nuissl and myself in an UFZ-funded project. A series of workshops and meetings which finally led to the issued paper was organised by Henning Nuissl and me. Further, I conceptualised the paper draft and elaborated the quantitative examples which serve for illustrative purpose of our concept/scheme.

Meyer, V., Scheuer, S., Haase, D. 2008. A multi-criteria approach for flood risk mapping exemplified at the Mulde river, Germany. Natural Hazards 48, 17–39.
The core concept of a multi-criteria flood risk assessment was elaborated by Volker Meyer and myself. I further contributed to the FloodCalc-tool development in setting up the ecological assessment part. For this paper, I took over the final editiorial work, too.

Schetke, S., Haase, D. 2008. Multi-criteria assessment of socio-environmental aspects in shrinking cities. Experiences from Eastern Germany. Environmental Impact Assessment Review 28, 483-503.
The idea for the Diploma thesis (by Sophie Schetke) comes from me and I further elaborated more than half of the manuscript.

Haase, D., Haase, A., Bischoff, P., Kabisch, S., 2008. Guidelines for the 'Perfect Inner City' Discussing the Appropriateness of Monitoring Approaches for Reurbanisation. European Planning Studies 16(8), 1075-1100.
My key contributions to this paper are the concept and structure of the paper, the quantification of the indicator set using data from the test case of the city of Leipzig and more than 50% of the writing of the manuscript.

Haase, D., 2008. Urban ecology of shrinking cities: an unrecognised opportunity? Nature and Culture 3, 1-8.
This work was done by myself exclusively (including idea, concept, and realization).

Strohbach M, Haase D, Kabisch N 2009. Birds and the city - urban biodiversity, land-use and socioeconomics. Ecology and Society 14(2), 31.
The idea of the research topic and concept was developed by myself. A part of the statistical analysis and major parts of the text body were elaborated by myself.

Banzhaf, E., Kindler, A., Haase, D., 2007. Monitoring, mapping and modelling urban decline: a multi-scale approach for Leipzig. EARSeL eProceedings 6(2), 101-114.
Next to a joint discussion on the idea of this paper my most important contribution to this work are both the modelling section and a comprehensive integration of the monitoring and modelling sections, too.

Haase, D., Nuissl, H., 2007. Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870-2003. Landscape and Urban Planning 80, 1-13.
This work was done majorily by myself (including idea, concept, and realization). Henning Nuissls' contribution covers in major parts the "planning and governance section" at the end of the paper.

Haase, D., Walz, U., Neubert, M., Rosenberg, M., 2007. Changes to Saxon landscapes - analysing historical maps to approach current environmental issues. Land Use Policy 24, 248-263.
This work was done majorily by myself (including idea, concept, and realization).

Haase, D., Haase, A., 2007. Do European social science data serve to feed agent-based simulation models on residential mobility in shrinking cities? Grözinger, G., Matiaske, W., Spieß, K. (eds.) Europe and its Regions. The usage of European Regionalised Social Science Data. Cambridge Scholar Publishing, pp. 227-250.
This work was majorily done by myself (including idea, search for databases and data sets, concept, and realization).

Haase D., Seppelt R., Haase, A., 2007. Land use impacts of demographic change – lessons from eastern German urban regions. Petrosillo, I., Müller, F., Jones, K.B., Zurlini, G., Krauze, K., Victorov, S., Li, B.-L., Kepner, W.G. (Eds.) Use of Landscape Sciences for the Assessment of Environmental Security. Springer, pp. 329-344.
This work was majorily done by myself (including idea, concept, and realization).

Kabisch, S., Haase, A., Haase, D., 2006. Beyond growth – urban development in shrinking cities as a challenge for modeling approaches. In: Voinov, A., Jakeman, A., Rizzoli, A. (eds). Proceedings of the iEMSs Third Biennial Meeting: "Summit on Environmental Modelling and Software". International Environmental Modelling and Software Society, Burlington, USA, July 2006. CD ROM. Internet: http://www.iemss.org/iemss2006/sessions/all.html, ISBN 1-4243-0852-6 978-1-4243-0852-1.
This work was majorily initiated and the paper written by myself (including idea, concept, and realization).

Weichel, T., Schulz, K., Haase, D., 2006. Effektive Ansätze zur Beschreibung des Hochwasserrisikos urbaner Bereiche. Forum für Hydrologie und Wasserbewirtschaftung, Heft 16.06, Bd.3, S. 177-180.
I am one of the UFZ supervisors of the PhD thesis of Thilo Weichel. In doing so, I am responsible for the idea and the concept of the paper. In addition, I set up the TRIMR2D model at the UFZ.

Haase, D., Holzkämper, A., Seppelt, R., 2006. Beyond growth? Decline of the urban fabric in Eastern Germany. A spatially explicit model approach to predict residential vacancy and demolition priorities. In: Koomen, E., Stillwell, J., Bakema, A., Scholten, H. (eds). Modelling Land Use Change. Springer Dordrecht, pp. 339-353.
This work was majorily done by myself (including idea, concept, and realization).

Haase, D., 2004. Development and Perspectives of Landscape Ecology. Landscape Ecology 19, 567-569.
This work was exclsuively done by myself (including idea, concept, and realization).

Mehnert, D., Haase, D., Lausch, A., Auhagen, A., Dormann, C.F., Seppelt, R., 2005. Bewertung der Habitateignung von Stadtstrukturen unter besonderer Berücksichtigung von Grün- und Brachflächen am Beispiel der Stadt Leipzig. Naturschutz und Landschaftsplanung 2, 54-64.
The idea and the concept for this paper stem from me. I further drafted 50% of the manuscript.

Magnucki, K., Haase, D., Frühauf, M., 2004. Auswirkungen urbaner Siedlungsflächen-entwicklung auf den Wasserhaushalt – das Beispiel der Stadt Leipzig 1870-2003. Berichte zur deutschen Landeskunde 78(4), 473-507.
The idea for the Diploma thesis (by Kristin Magnucki) comes from me and I further elaborated more than half of the manuscript. I also contributed to the modelling work.

Walz, U., Neubert, M., Haase, D., & M. Rosenberg, 2004. Sächsische Landschaften im Wandel – Auswertung historischer Kartenwerke für umweltwissenschaftliche Fragestellungen, Europa Regional 11, 126-136.
This work was done majorily by Ulrich Walz (IÖR in Dresden) and myself (including idea, concept, and realization).

Haase, D., Magnucki, K., Frühauf, M., 2004. Zum Verlust von Bodenfunktionen durch Siedlungserweiterungen und Oberflächenversiegelung in den Stadtgebieten von Halle und Leipzig, WICHMANN, S. 161-178.
This work was majorily done by myself (including idea, concept, and realization).

Haase, D., 2003. Holocene floodplains and their distribution in urban areas – functionality indicators for their retention potentials. Landscape & Urban Planning 66, 5-18.
This work was exclusively done by myself (including idea, concept, and realization).

Haase, D. & M. Rosenberg, 2003. The changing face of the landscape, Research for the Environment 4, 86-93.
This work was majorily done by myself (including idea, concept, and realization).

Haase, G., Haase, D., 2002. Approaches and methods of landscape diagnosis. In: Bastian, O., Steinhardt, U. & Z. Naveh (eds). Development and Perspectives of Landscape Ecology, Kluwer, pp.113-122.
This work was majorily done by myself (including idea, concept, and realization).

Haase, D., H. Neumeister, 2001. Anthropogenic impact on fluvisols in German Floodplains. Ecological processes in soils and methods of investigation. International Agrophysics, 15(1), 19-26.
This work was majorily done by myself (including idea, concept, and realization).

Appendix

Kabisch, N., Haase, D. in press. Diversifying European agglomerations: evidence of urban population trends for the 21st century. *Population, Space and Place*.

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Diversifying European Agglomerations: Evidence of Urban Population Trends for the 21st Century

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ABSTRACT

The beginning of the 21st century marks the first time in history that more than half of the world's population lives in urban areas. In Europe, more than 70% of the population lives in urban areas today. This number is likely to increase to 84% by 2050. However, a shift from growth to decline of urban population is already present for a growing number of cities. The paper examines urban population trends for 158 European agglomerations and assesses the dynamics behind one particular development of growth or decline. Using data from 1991 to 2004, we present statistical evidence of diversifying population trajectories for core cities and fringe areas. The quantitative results are contrasted with the widespread accepted cyclical urbanisation model that has been expounded as a theoretical approach to describe previous and future stages of European urban development. The structural approach of the model is discussed because we believe that such concepts do not reflect the dynamics of present urban development in Europe. The paper argues that the urban agglomerations studied do not show a single evolutionary stage of urban development. Rather, we found a coexistence of intensifying suburbanisation and developing reurbanisation, which is mainly driven by younger households.

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Keywords: urbanisation; population development; core city; urban fringe

INTRODUCTION

For the first time in history, more than half of the world's population lives in urban areas. It has been observed that this urbanisation is projected to increase further and make up 70% by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2008; Population Reference Bureau, 2008). In Europe, already 72% of the population lives in urban areas and is likely to increase to 84% by 2050 (*ibid*.).

Despite the fact that European urban population is increasing in total numbers, growth rates have slowed down over the last few decades (United Nations, Department of Economic and Social Affairs, Population Division, 2008). The shift from growth to decline of urban population is already evident today in a growing number of cities (Turok and Mykhnenko, 2007). In particular, old-industrialised cities, such as Liverpool and Manchester in the UK or the Rhine-Ruhr-area in Germany, show processes of population decline reinforced by specific circumstances of economic, political, geographic, and demographic developments (Oswalt and Rieniets, 2006; Schetke and Haase, 2008). Most notably, the aged industrial countries and the post-socialist countries of Eastern Europe show the highest number of declining cities that have been summarised under the term 'shrinking cities' (Oswalt and Rieniets, 2006). These cities' paths of development have been shaped by deindustrialisation,

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suburbanisation, and its urban consequences of vacancy and demolition (Hall, 2006).

At the same time, a resurgence of a range of European but also non-European cities has been observed since 1990 (Lever, 1993; Ley, 1993; Broadway and Jesty, 1998; Ogden and Hall, 2000; Seo, 2002; Buzar *et al.*, 2007a). This urban revival has been called reurbanisation and mostly affects inner city areas (Haase *et al.*, 2003). Reurbanisation is mainly driven by the immigration of non-traditional households such as young one-person households or flat-sharers. Many of the new household groups stem from the demographic changes framed by the 'second demographic transition' (Buzar *et al.*, 2007b) in Europe since the late 1980s that shows many different trends: declining fertility rates, ageing population, postponement of child-bearing and marriage, growing household numbers, smaller household sizes, and non-traditional household structures, to name a few (van de Kaa, 1987; Lestheaghe and Neels, 2002). The immigrating population groups are likely to be attracted by specific characteristics a city is believed to possess (Lever, 1993; Haase *et al.*, 2005; Kabisch *et al.*, in press). Amongst these are economic, social and educational possibilities, services and amenities, which are available to firms and urban residents particularly in larger cities (Bettencourt *et al.*, 2006; Montgomery, 2008).

In this manner, larger cities thus offer a better provision of these basic services and are currently characterised by a better position relative to smaller ones (Turok and Mykhnenko, 2007). Several studies also suggest a considerable association of city size and variations in the population growth rates of urban areas (Hall and Hay, 1980; van den Berg *et al.*, 1982; Cheshire, 1995; Gans, 2000; 2005; Batty, 2008). Turok and Mykhnenko (2007), e.g. stress that in terms of population change, the position of large European cities is better since the mid-1990s and significantly better since 2000, compared with smaller ones.

The overarching purpose of this paper is to give statistical evidence of present population trends for European agglomerations and to assess the dynamics behind a particular development of urban growth and decline. In order to do this, we look at two interlinked issues by using data of 158 urban agglomerations for 1991–2004.

Firstly, we have confined our interest to the identification of new population trends specified for core cities and adjacent fringe areas of European agglomerations. We explored whether there are two factors associated with specific population dynamics, namely city size and location in Europe.[1] These have been regarded as key dsicrminators in the US and UK context of urban demographic research (Turok and Mykhnenko, 2007). We determine whether larger cities are currently better placed than smaller cities, i.e. growth rates of larger cities exceed the average growth rates of smaller ones. In addition, we focus on the attribute of location in Europe to identify whether it is directly associated with either population growth or decline. Many studies identified wide differences in urban population change between and within European countries for several decades (van der Berg *et al.*, 1982; Cheshire, 1995; Turok and Mykhnenko, 2007). Processes related to demographic, economic, and political change (e.g. the societal and economic transition in Eastern Europe at the beginning of the 1990s), amongst others, are regarded as the mechanisms behind different development trajectories (Mykhnenko and Turok, 2008).

Secondly, we apply the classic cyclical urbanisation model (van den Berg *et al.*, 1982) that is widely accepted when looking at urban change (Cheshire and Hay, 1989; Lever, 1993; Cheshire, 1995). We use the model as the theoretical background for our research because it relates to the identified different population dynamics of urban growth and decline. These are outlined in four sequential stages[2] – urbanisation, suburbanisation, desurbanisation, and reurbanisation. As new trends of current European urban development are evolving, which are assumed not to be reflected by the conceptual structure of this state-of-the art model, we scrutinise its validity against our results. This analysis is further supplemented by a multivariate statistical method in order to look beyond the population trends to other characteristics such as socio-demographic factors that might drive a specific population development.

This paper begins with a section that touches on the hypothesis of a cyclical urban development and examines the structural approach and several applications of the urbanisation model (van den Berg *et al.*, 1982). The next section refers to the methodological design of our study, i.e. the database used, the spatial levels of analysis, the main indicators, and the statistical methods.

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The fourth section reports on the major findings that result from the analysis of population development and the association with city size and location in Europe. The population dynamics identified are then contrasted with the cyclical van den Berg (1982) model. The stages of urban development in Europe that emerge are discussed and contrasted comprehensively with findings from other European studies and against the results from the multivariate analysis on the driving forces. Finally, conclusions are drawn while summarising and assessing the objectives made at the outset.

THE HYPOTHESIS OF A CYCLICAL DEVELOPMENT – THE MODEL OF THE STAGES OF URBAN DEVELOPMENT (VAN DEN BERG *ET AL*., 1982)

Several comparative studies of European urban development trends exist for the second half of the 20th century. One of them has been carried out by van den Berg *et al.* in the early 1980s. Based on their results over the period 1950–1975, they expounded a four-stage sequential model of urban development that was consistent with the urbanisation process in Europe from the early 19th century onwards (Fig. 1). Using the proxy population (change) of a functional urban region (FUR) – divided into a core city and a surrounding fringe – three main stages were outlined: *urbanisation*, *suburbanisation*, and *desurbanisation*.

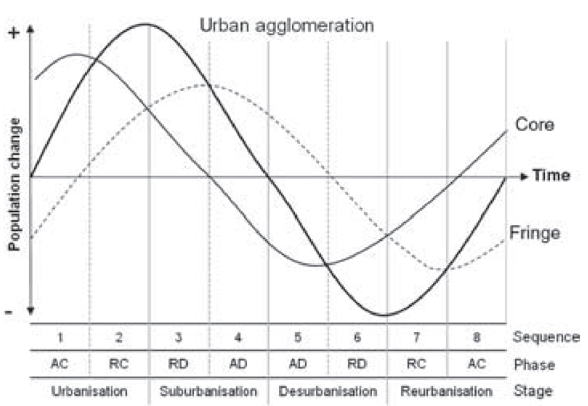

Figure 1. Cyclical model of the stages of urban development.
Source: After van den Berg *et al.* (1982).
Notes: AC: absolute centralisation; RC: relative centralisation; RD: relative decentralisation; AD: absolute decentralisation.

The *urbanisation* stage is the core city's total population gain also relative to the respective fringe area. It should represent centralisation – the mass migration from rural to urban areas due to industrialisation. *Urbanisation* is followed by *suburbanisation*,[3] a phase of relative population decentralisation from the core city to the fringe of agglomerations that are still growing. At this stage, the suburban areas were expanding rapidly due to former city inhabitants (mainly families) searching for higher quality living locations beyond core cities. This dynamic was enabled by increases in income and improvements in motorised transport. Suburbanisation took place in Western Europe mainly during the 1950s and 1960s (van den Berg *et al.*, 1982).

Ongoing *suburbanisation* processes led to a decline in the core city and to a *desurbanisation* phase, where population decline appears everywhere in the core city and the fringe area, and finally ends up in negative population growth rates in the entire urban region. This stage is characterised by a dispersal of activities to rural areas and satellite towns and is sometimes referred to as 'counterurbanisation' (Antrop, 2004). *Desurbanisation* processes followed suburbanisation in Western Europe in the 1970s, when migration took place from central urban and suburban areas to the surrounding countryside and also to small and medium-sized towns in the region (Fielding, 1982; Cheshire and Hay, 1989).

In order to complete the cycle, a more hypothetical fourth stage, *reurbanisation*, is defined as a phase of relative population gain in the core city after extreme losses. This link represents the core city with a reduced rate of decline contrasted with an increasing fall in the fringe population numbers followed by a positive population growth rate of the core city and a reduction in decline rates at the fringe.

van den Berg *et al.* (1982) treated the first and second stages of the model mainly in a historical context, whereas *desurbanisation* was understood as an ongoing and *reurbanisation* as an unlikely future process of European FURs (van den Berg *et al*, 1982: 40). In each of the four stages there is, additionally, a period of relative or absolute increase (centralisation) or decrease (decentralisation) in the population. Each stage, therefore, is subdivided into two phases.

The analysis by van den Berg *et al.* (1982) has been updated by Cheshire and Hay (1989) for

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the period 1971–1984 and later by Cheshire (1995) and Champion (1995) referring to census data from 1990–1991. Their main finding was that decentralisation processes slowed down in the 1980s. Cheshire and Hay (1989) even saw possibilities of an urban revival due to the urban orientation of service economies and certain demographic trends.[4] However, they underline that no single trajectory exists for European agglomerations due to emerging complex development patterns and wide differences between the analysed countries (Champion, 1995; Cheshire, 1995).

Turok and Mykhnenko (2007) extended this research using data for 310 European urban areas dated from 1960–2005. They identified a slowing down of growth rates over the second half of the 20th century and suggest a recovery of cities after 2000. Their study is based on the application of the concept of a continuous built-up area to define a city and they do not distinguish between the core city and the fringe area. In conceptual terms, therefore, they do not refer to the respective stages of urban development as van den Berg *et al.* (1982), Cheshire and Hay (1989), Cheshire (1995) and Champion (1995) did.

So far, no comparative study on European functional urban regions applying the van den Berg model exists for the 2000s. Nevertheless, at the case study level, recent studies have used the definitions and specific terms of the four stages. They mainly identified tendencies of reurbanisation (Haase *et al.*, 2005; Buzar *et al.*, 2007a) and also used terms of re-densification (Lever, 1993), renaissance, revival of, or return to the inner city (Kujath, 1988; Helbrecht, 1996). These tendencies of reurbanisation are not meant to be a fundamental reversal of ongoing desurbanisation or decline as it is proposed by van den Berg *et al.* (1982). They mainly turn from a macro scale to selected inner city areas where reurbanisation processes were observed (Haase *et al.*, 2003).

The model described by van den Berg *et al.* (1982) has also been discussed and criticised. For example, Antrop (2004) and Hugo *et al.* (2003) point to the application of the definition of the FUR that refers to the division of an urban agglomeration into core city and fringe area. The approach mainly involved specific thresholds of commuting measures to determine the fringe and thus the extent of the total agglomeration. The problem remains on how to define the boundary of the core city and the suburban area around an urban core. The core city is mainly defined by administrative borders that can differ between countries, creating important problems of comparison. If aggregated by spatial units, data do not always reflect the changing spatial structure of a city (Antrop, 2004). Furthermore, the fringe area is delineated by the commuting zone of journey-to-work data. Hugo *et al.* (2003) noticed that 'commuting represents a declining proportion of all journeys origination from households . . .' (p. 288) and thus other types of interaction data should be discussed to define these areas.

Furthermore, in this model, only FURs of more than 200,000 inhabitants were included in the study. This means that smaller cities are omitted from the analysis (Nyström, 1992). The use of the total change in population as the main measure of population development is also questionable. As a result, other processes that affect and might cause the area migration become obscured.

It is further argued that the sequence of the stages would not lead to a cyclical development and that the shifts between the four stages are not as inevitable as the model suggests (*ibid.*). In terms of reurbanisation processes, findings from a recent study indicate contemporary processes of inner-city reurbanisation and ongoing dynamics of counterurbanisation and suburbanisation (Buzar *et al.*, 2007b: 80). In turn, this means that the stages in the van den Berg model do not necessarily follow one another in strict sequencial order.

DATA AND METHODS

Data

Our analyses of urban development trends are applied to the spatial scales of an urban agglomeration: the core city (national political, administrative definitions) and the fringe area (urban hinterland of the surrounding municipalities from which a significant percentage of commuters originate). We used this distinction because an urban agglomeration is more than the built-up area of a city (which serves rather as a morphological criterion to distinguish different land uses within the agglomeration itself). The approach uses the interaction criteria of a commuting zone

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to delimit the whole area that is functionally linked to the core city (Hugo *et al.*, 2003). The same concept of a FUR was used by van den Berg *et al.* (1982). The results of this study, therefore, are comparable with earlier studies.

The data for analysis were compiled using the Urban Audit of Europe (UA) (European Commission, 2004; Urban Audit database, 2008) supplemented with data from selected national statistic agencies.[5] At present, data are available for four points in time: 1991, 1996, 2001, and 2004. Using the UA seemed most reliable for our analysis because it provides data for the spatial scales of interest: the core city and the Larger Urban Zone (LUZ), which is approximately estimated using groups of nomenclature of territorial units for statistics (NUTS)[6] level 3 [or, if available, Local administrative Units (LAU) level 1 or 2] to define a commuting zone. The term LUZ represents a proxy for the concept of the FUR (European Commission, 2004: 9) and is defined as the sum of the population in the core city and the population in the fringe area.

Methods

We conducted time series analyses for three time periods, that is 1991–1996, 1996–2001, and 2001–2004, to identify stages and trajectories of urban development. We used the annual population growth rate[7] (ΔP_i) as this is consistent with previous research (van den Berg *et al.*, 1982; Cheshire and Hay, 1989).

$$\Delta P_{abs,i} = \frac{P(t_{i+1}) - P(t_i)}{t_{i+1} - t_i} \quad (1)$$

where P is the population in the year t_i with I = 1, . . . , 4 and t_1 = 1991, t_2 = 1996, t_3 = 2001, t_4 = 2004.

$$\Delta P_i = 100 \frac{1}{P_i} \Delta P_{abs,i} \, [\%] \quad (2)$$

The subsamples by population size were distinguished according to their total population number in 2004.[8] Three clear size bands were identified: small LUZ with <400,000 inhabitants (37% of the total sample), medium sized LUZ with a total population of ≥0.4 and <1 million inhabitants (32%) and large LUZ with ≥1 million inhabitants (31%).

Population growth rate was also used for the regional subsamples that represent the classification of Northern, Western, Southern, and Eastern Europe based on the United Nations 'Composition of macro geographical Regions' (United Nations, 2008).

We applied a paired-sample *t*-test to look for significant differences in mean growth rates for the subsamples. We also used Box-Whisker-Plots and bivariate correlation analysis to explore whether a positive or negative population growth in either the core or the fringe results in the opposite effect on the respective other spatial level within the same time period, or even phase-delayed in one of the next periods.

In regard to the analysis of the urbanisation model (van den Berg *et al.*, 1982), the 158 agglomerations were grouped by considering the value and direction – positive or negative – of the population growth rate of the core city, fringe area, and LUZ. In so doing, spatial clusters of similar population change dynamics throughout Europe are identified. They refer to the application of the stages in the cyclical van den Berg model and lead in their combination to the respective stage of urban development in the different time periods. The clusters are therefore based on the definitions of the four stages of the van den Berg model: urbanisation, suburbanisation, desurbanisation, and reurbanisation (see Table 1 and Fig. 1).

Table 1. Cluster definitions of the stages of urban development.

Core	Fringe	LUZ	Sequence	Stage
++	–	+	1 AC	Urbanisation
++	+	+++	2 RC	
+	++	+++	3 RD	Suburbanisation
–	++	+	4 AD	
– –	+	–	5 AD	Desurbanisation
– –	–	– – –	6 RD	
–	– –	– – –	7 RC	Reurbanisation
+	– –	–	8 AC	

Source: after van den Berg *et al.*, 1982; Lever, 1992.
+, ++, +++ = population growth, slow (+) to fast (+++).
–, – –, – – – = population decline, slow (–) to fast (– – –).
AC: absolute centralisation; RC: relative centralisation; RD: relative decentralisation; AD: absolute decentralisation.
LUZ: Larger Urban Zone.

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Finally, we used a multivariate statistical method to identify the factors that are assumed to drive a specific population development, causing an urban agglomeration that is classified into one of the four stages. A one-way analysis of variance (ANOVA[9]) and subsequent *post hoc* tests for multiple comparisons were performed to explore whether the classification is meaningful and the clusters of the agglomerations differ on several explanatory factors. We used some basic socio-demographic variables that might predict the location within the stages: population of working age, total household number, youth and old age dependency, population aged 20–<25 years, and unemployment rate. These variables were chosen because previous research suggested significant connections between population changes in urban areas (Haase *et al.*, 2005; Buzar *et al.*, 2007a) and partly for reasons of data availability for the respective time periods.

EVIDENCE OF POPULATION TRAJECTORIES OF EUROPEAN URBAN AGGLOMERATIONS AFTER 1990

Population Trajectories

Figure 2 shows the recent population development of the 158 agglomerations at the different spatial levels of the core city, fringe area, and LUZ displaying Box-Whisker-Plots of the annual population growth rate. A somewhat biased development was identified: on the one hand, there is an increasing number of declining core cities up to 1996 (mean = –0.21, Table 2, first column). On the

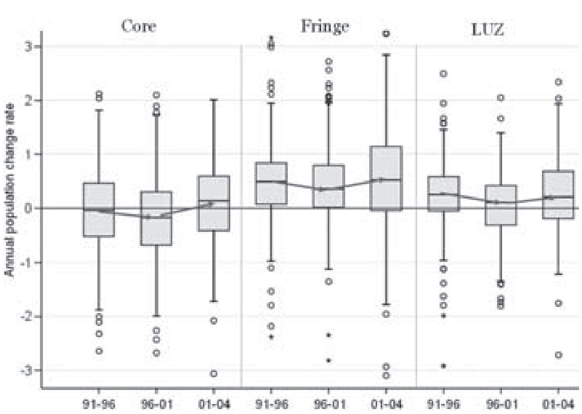

Figure 2. Box-Whisker-Plots of the annual population growth rate for urban agglomerations (n = 158) for the three different time periods.

Table 2. Mean values of the annual population growth rate in European Agglomerations according to geographical location and city size.

	All (n = 158)	Small (n = 58)	Medium (n = 51)	Large (n = 49)	Western (n = 42)	Southern (n = 40)	Eastern (n = 46)	Northern (n = 30)
Core								
1991–1996	**−0.05**	**0.29**	−0.18	−0.32	−0.16	−0.22	**0.20**	−0.05
1996–2001	**−0.21**	**−0.21**	**−0.17**	**−0.25**	**−0.11**	**−0.09**	**−0.55**	0.04
2001–2004	**0.19**	**0.05**	**0.30**	**0.26**	**0.35**	**0.55**	**−0.30**	0.24
Fringe								
1991–1996	0.48	0.18	0.58	0.71	0.58	**−0.59**	0.36	0.35
1996–2001	0.44	0.33	0.37	0.65	0.46	**0.39**	0.48	0.42
2001–2004	0.46	0.23	0.38	0.82	0.36	0.33	0.64	0.50
LUZ								
1991–1996	**0.22**	**0.24**	**0.21**	0.20	**0.25**	0.25	**0.26**	0.07
1996–2001	**0.03**	**−0.15**	**0.10**	**0.18**	**0.15**	**0.20**	**−0.31**	0.17
2001–2004	**0.25**	−0.02	0.26	**0.56**	**0.35**	**0.43**	**−0.04**	0.30

Notes: The mean values are shown in bold when they are significantly different from the comparison group of the next time period at the 95% confidence level (t-test for difference between sample means, assuming normality but not equal variances).

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other, they show positive growth rates after 2001 (0.19). Positive growth rates were also found for the fringe area, averaging 0.46 in combination with a high variation in the data after 2001. The overall trajectories for the LUZ report a consolidated positive development at the mean level of 0.25 (2001–2004) with a slight increase in the LUZ facing a decline only for the second time period. Notably the development of the core cities seems to determine that of the LUZ since in the *t*-test pairs only the mean values of the core cities and the LUZ were found to be significantly different (Table 2). This is in agreement with studies claiming the recently resurgence of cities (e.g. Beauregard, 2004), which therefore, are able to dominate an urban agglomeration.

The correlation analysis identified significant relationships for the whole sample for the time periods 1996–2001/1996–2001 and 2001–2004/ 2001–2004 (see Table 3, first column). Significant negative correlations appeared with $R = -0.172$ and $R = -0.164$. The coefficients indicate a dependent contrary development of both the core city and the fringe area: the growth of the fringe occurs 'at the cost' of the core within the same time period.

The Effect of City Size on Population Growth or Decline

To look beyond the total values presented in section 4.1, we explored whether population growth or decline is associated with the size of cities. In the following, we discuss whether there are any obvious variations to population growth rates within small LUZ compared with medium-sized and large LUZ.

Results of the *t*-tests (Table 2) show significant differences in the mean values particularly for the core cities and LUZ of all sizes. Most of the annual population growth of the core cities appears to be negative up to 2001, regardless of the city size. The last time period (2001–2004), however, shows a turnaround: a considerable number of core cities experienced positive population growth rates; the medium and large core cities clearly showed the highest mean values (0.30 and 0.26), meaning that they significantly gained population since 2001.

Looking at Figure 3, the scatter plots present the LUZ's development. They are sorted by size along the x-axis of the diagram. Reference lines were added at the 400,000 and the 1 million population points using a linear regression model.[9] In the case of the first time period ($R^2 = 0.001$) no significant trend could be identified, but the last time period ($R^2 = 0.11^{**}$) strongly indicates that the larger the population size of an agglomeration, the greater the positive growth rates and vice versa. In addition, a considerable proportion of the small agglomerations of less than 400,000 inhabitants showed negative values. This suggests that larger agglomerations in particular seem to be able to extend their current growth rates, while most of the small agglomerations show population decline by 2001.

This corresponds with earlier findings in other studies that provide clear evidence that the position of large and small European cities has been reversed since the mid-1990s and markedly so after 2000 (Turok and Mykhnenko, 2007). Even though Turok and Mykhnenko (2007) stress that these processes are still very recent, they might be caused by a better provision of basic administrative, health and education services, cultural and social amenities, and employment opportunities in large as compared with smaller cities (Bettencourt *et al.*, 2006; Montgomery, 2008).

Differences of Regional Population Change Across Europe

While looking for geographical effects of population change in urban Europe, the data sample was divided according to regional European levels (United Nations, 2008; see Fig. 4). Predominantly, Western European agglomerations show negative core city growth rates for 1991–1996 (–0.16, Table 2) and 1996–2001 (–0.11). They then switched to a strongly positive trend after 2001 with more than 75% of areas displaying positive values (0.35). By comparison, the population development of the fringe areas hardly changed over time and the *t*-tests did not identify any significant differences in the mean population growth rates. Furthermore, the correlation values (Table 3) show a significant mutual influence between the core city and the fringe area, with negative values for the second time period (1996–2001/1996–2001: $R = -0.552$). However, we found a positive correlation for the last time period (2001–2004/2001–2004: $R = 0.512$), indicating that both the core city and the fringe area experienced positive growth rates.

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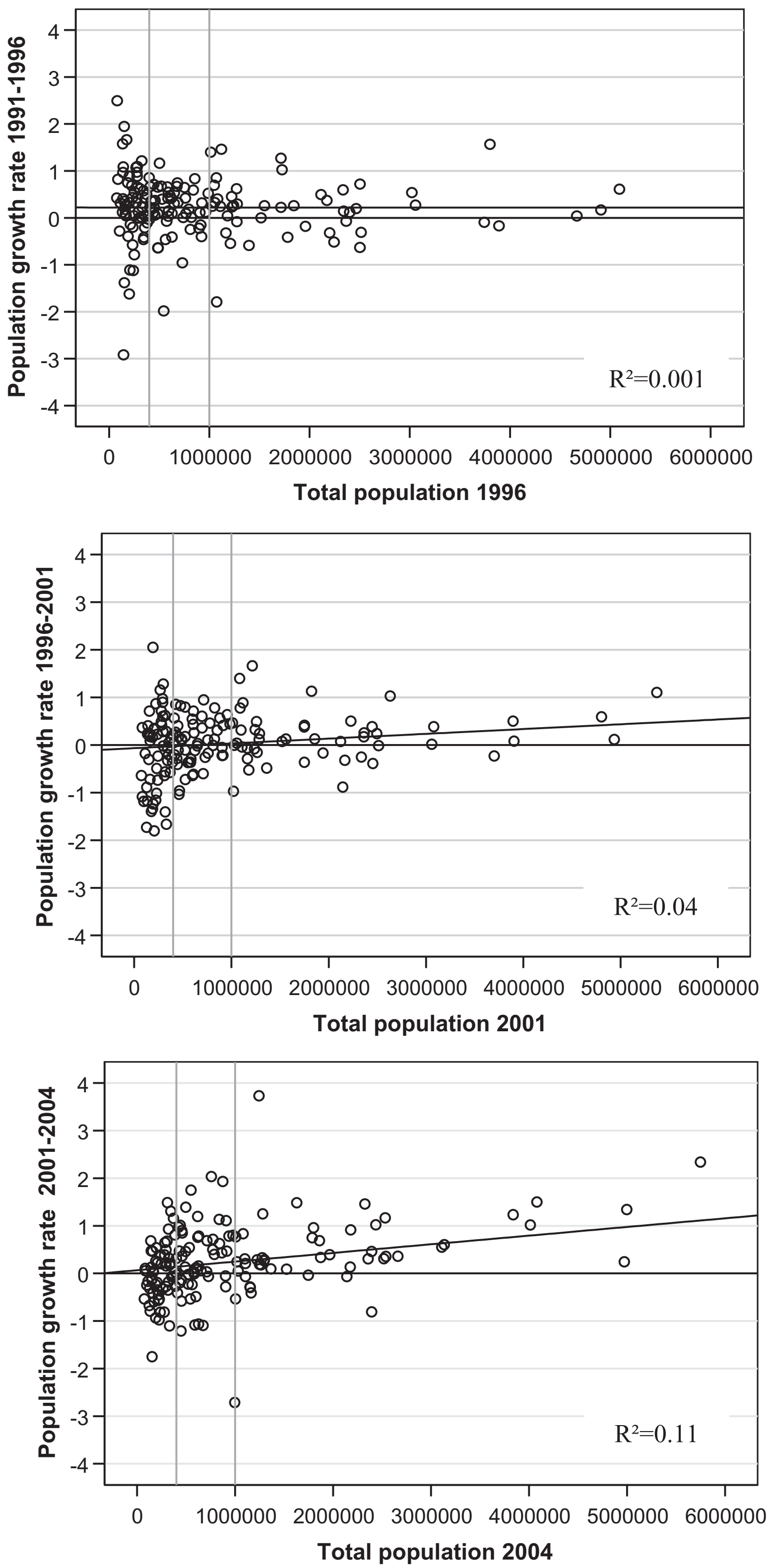

Figure 3. Scatter plots showing the annual population growth rate and the total population of the LUZ for 158 European agglomerations at the three different time periods.

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Table 3. Cross correlation between the respective annual population growth rate of core city and the annual population growth rate of the fringe area of European urban agglomerations (n = 158) according to geographical situation and city size.

Time period: Δ pop city/fringe	Correlation coefficient R							
	All (n = 158)	Small (n = 58)	Medium (n = 51)	Large (n = 49)	Western (n = 42)	Southern (n = 40)	Eastern (n = 46)	Northern (n = 30)
1991–1996/1991–1996	0.030	0.219	–0.074	0.087	–0.066	–0.408**	0.012	0.538**
1991–1996/1996–2001	0.078	0.217	–0.062	0.085	0.094	–0.446**	0.082	0.597**
1991–1996/2001–2004	–0.031	0.012	0.083	–0.068	0.514**	–0.489**	0.052	0.324
1996–2001/1996–2001	–0.172*	–0.102	–0.436**	0.012	–0.552**	–0.339*	–0.151	0.657**
1996–2001/2001–2004	–0.053	–0.352**	0.182	0.210	0.494**	–0.412**	–0.247	0.330
1996–2001/1991–1996	0.135	0.188	0.018	0.218	0.254	–0.257	0.261	0.358
2001–2004/2001–2004	–0.164*	–0.459**	0.031	–0.055	0.512**	–0.228	–0.552**	0.012
2001–2004/1991–1996	0.009	0.027	–0.166	0.013	0.055	–0.301	–0.213	0.002
2001–2004/1996–2001	0.124	0.171	0.143	0.026	0.263	–0.172	0.434**	0.135

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
Small LUZ < 400,000 inhab.; Medium LUZ ≥ 0.4 – <1 Mio. Inhab.; Large LUZ ≥ 1 Mio. inhab.
LUZ: Larger Urban Zone.

Such trends were also identified in the case of cities in western Germany; Gans (2000) observed a reversal from deconcentration, meaning suburbanisation, during the 1970s and 1980s to urban concentration at the end of the 1980s. However, he emphasised that this reversal was a temporary process that was mainly driven by migrating persons of foreign nationality, while the German population still followed a deconcentration process (Gans, 2000: 1510).

The trends in Southern European core cities appear similar to those of Western core cities: from a state of predominant population decline from 1991 to 2001, which occurred in favour of a positive population development for the fringe areas, most of the core cities experienced significant positive population growth rates after 2001 (0.55). However, they were also faced with an increasing variance in the data. The development of the core city combined with increasing positive growth rates for the fringe area resulted in an also increasing positive population number at the LUZ level.

By contrast, the trajectories for Eastern European cities tell a different story. Population growth of the fringe was identified and has been occurring significantly at the expense of the core (2001–2004/2001–2004: R = –0.552, Table 3). This process of suburbanisation is in accordance with qualitative empirical observations in East–Central Europe, namely in Polish and Czech cities (Steinführer and Haase, 2007). However, the observed positive values for the fringe (1991–2004: 0.36–0.64) cannot account for the tremendous fall in total population for the core cities after 1996 (–0.55). This severe decline presents a dominant process and is thought to be mainly associated with the political and economic upheaval of the 1990s (Schetke and Haase, 2008). It appeared in most of the Eastern LUZ, even though the negative growth rates recovered slightly after 2001. The development of a slight recovery has been caused by a slow down of negative growth in the core cities and positive values for the fringe areas. This corresponds with findings by Turok and Mykhnenko (2007: 174) who underlined the negative trend's deceleration after 2000 even though city growth rate still remains negative.

A decreasing variation in the data over time was found for Northern European urban agglomerations that did not present any significant

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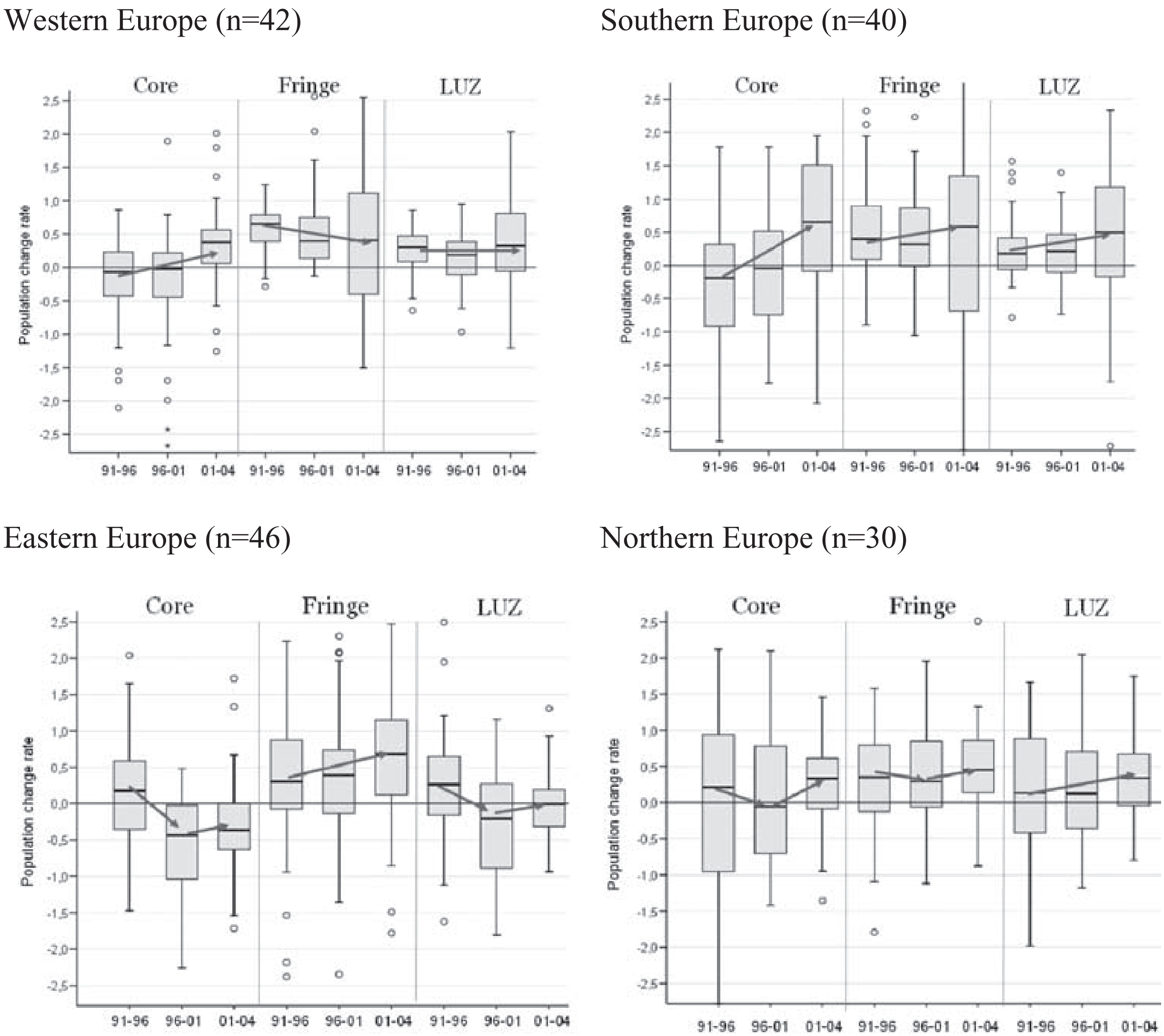

Figure 4. Box-Whisker-Plots of the annual population growth rate for European urban agglomerations for the three different time periods.

differences in mean population growth rates. Nevertheless, they show positive growth rates at all levels, notably in the last time period (Table 2).

CYCLICAL EUROPEAN URBAN DEVELOPMENT?

Stages of Urbanisation in Europe after 1990

Our analysis attempts to scrutinise the validity of the model since we assumed that such concepts do not necessarily reflect the dynamics and trajectories of urban development after the political and economic transition in 1990.

The flow chart in Figure 5 impressively illustrates the current urbanisation phases from 1991 onwards. A considerable proportion of the agglomerations appear to experience suburbanisation mainly in the first but also again in the third time period. According to the definition of this stage, a relatively higher population growth within the fringe area was identified compared with a slower growth or a population decline in the core city.

Desurbanisation, defined above as the total decline of the population in the entire LUZ,

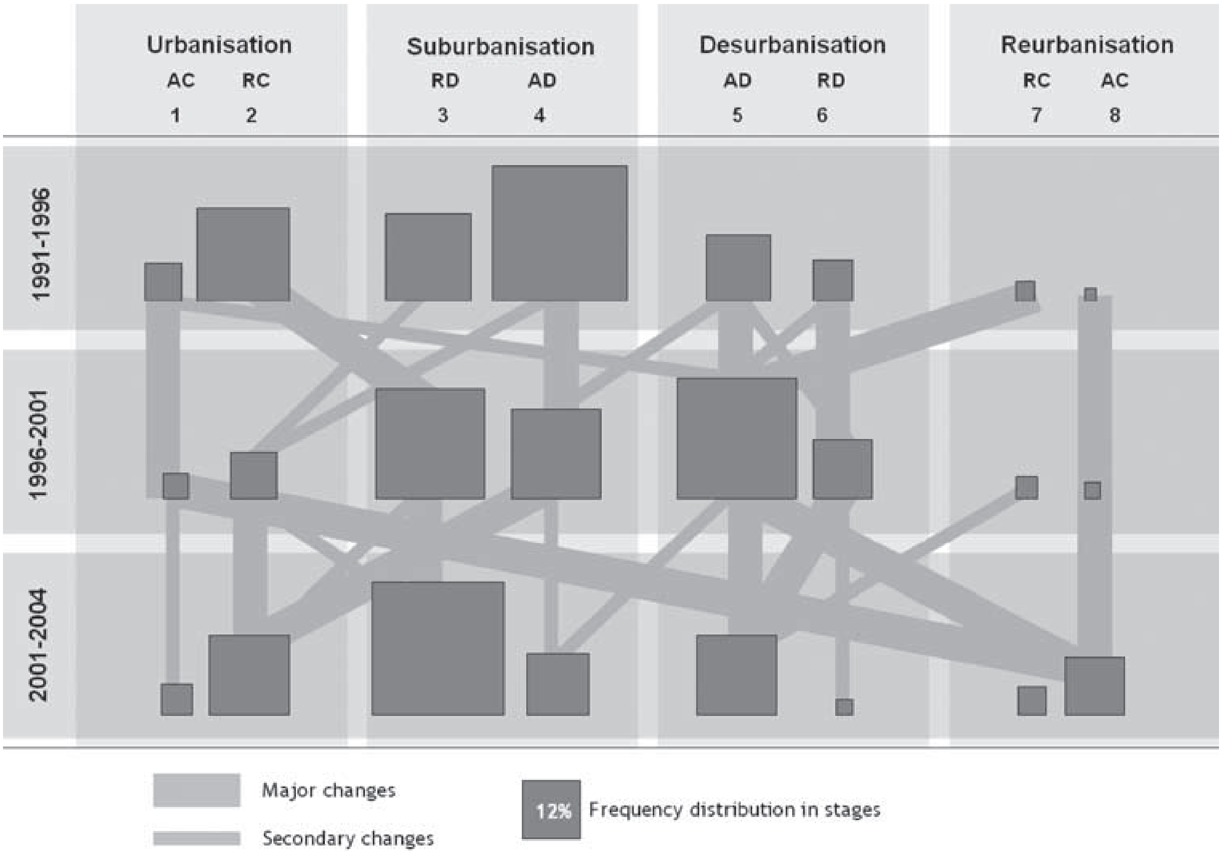

Figure 5. Flow chart showing the transition of urbanisation phases of European agglomerations for 1991–2004. *Notes*: AC: absolute centralisation; RC: relative centralisation; RD: relative decentralisation; AD: absolute decentralisation. The size of the boxes represents the frequency distribution in the urban development stages; vertical lines in the diagram show that a number of cities remain at one stage of urbanisation for more than one time period; diagonal lines mean that a number of cities change from one urbanisation stage to another.

decreases for the last time period. This is because most of the LUZ showed positive values from 2001 to 2004. However, the numbers for an absolute decentralisation are higher than those for a relative decentralisation, indicating that the LUZ's population loss is due to negative population growth rates of both core city and fringe area.

The fourth stage, reurbanisation, becomes most prominent after 2001. However, the percentage of agglomerations facing reurbanisation is not as high as agglomerations in other stages. Reurbanisation, therefore, does not evolve as a dominant population trend after 2001 but coincides with other stages.

In accordance with findings by Storper and Manville (2006), we proved that the hypothetical reurbanisation stage of the van den Berg model exists for a very specific number of agglomerations using statistical data. Interestingly, a similar trend is true when focussing on the urbanisation stage, which seems to recur in higher proportions for the last time period.

In conclusion, no consecutive order of the stages of urban development was identified. Rather, we would support the idea that the regular onward cycle of the stages of urban development (van den Berg *et al.*, 1982) was proven to have been reversed due to the trends of reinforcing suburbanisation and developing reurbanisation after 2001.

Cheshire (1995: 1058) has already recognised a slowing down and even reversal of decentralisation for European agglomerations between 1981 and 1991. He argued that existing regularities, as presented by van den Berg *et al.* (1982) and Hall and Hay (1980) 'should be expected to break down with some reversal of decentralisation . . .' (Cheshire, 1995: 1047). Champion described these findings as an effect of changes pushing 'the urban systems back into the suburbanization stage' (Champion, 2001a: 154). Accordingly, a single evolutionary trajectory cannot be expected in the future but rather a mix of population trajectories leading to a coexistence of different stages. A similar conclusion was drawn already by Nyström (1992) in the early 1990s: he predicted that 'general tendencies in the development of city regions in Europe may be even more difficult to detect in the 1990's than they were in the 1980's' (143). The results of our study confirm that this statement became true in the 1990's, and even more clearly, in the 21st century.

Regional Distribution of Urban Development Stages

Figure 6 shows the percentage change in frequency distributions of LUZ according to their stage of urban development in the van den Berg model and location in Europe. In addition, Figure 7 shows the spatial distribution of the 158 agglomerations within Europe for 1991–1996 and 2001–2004.

We found more than 21% of Western European agglomerations, in particular in eastern Germany, within the reurbanisation stage after 2001. A similar tendency could also be noted for Southern European urban systems in southern Italy and Greece (33%) and also for some Northern European agglomerations (10%), which can be interpreted as 'signs of reurbanisation'. In his study, Cheshire (1995) identified increasing recentralisation or reurbanisation processes in similar regions, that are mainly ancient university cities with historic cores in the UK,[10] western Germany and Benelux, which managed to attract skilled residents.

Reurbanisation is thought to be accompanied by present-day demographic changes within Europe including an increase in the number and a decrease in the size of households along with an increase in one-person households, and diversifying lifestyles (Champion, 2001b; Buzar *et al.*, 2005, 2007a). These non-traditional households are a wide range of population groups who favour core city living due to its advantages, providing a central location with diverse city amenities and therefore leading to evolving reurbanisation (Kabisch *et al.*, in press).

By comparison, after 2001, 50% of Western and 40% of Southern European cities showed suburbanisation. Examined more closely, suburbanisation processes are predominantly observed within western Germany and Italy but also present in Northern Europe, i.e. England, Finland, and Sweden. As mentioned above, this trend is also significantly apparent in Eastern Europe, particularly in Slovakia, Slovenia, and somewhat in Poland and the Czech Republic. Recent research on Eastern Europe claims that suburbanisation has been the most spectacular process in changing the spatial system but appeared to be chaotic in some areas (Kotus, 2006). At this point, it has to be mentioned that the transition of the former socialist Europe in the aftermath of the fall of Communism was not at all foreseeable by van den Berg and his colleagues when they conceptualised their cyclical model.

We conclude that the 'push back' to the suburbanisation stage (Champion, 2001a) mentioned above could be perceived in our own study. Suburbanisation, which continued to unfold throughout the 1990s and since 2000 is suggested to be connected to transformations of employment, increase in commuting, improvements of infrastructure networks, changes in housing patterns, and socio-economic trends (Buzar *et al.*, 2007b). It is also connected to increases in income over time, mainly in families with two parents and children, which are likely to favour the fringe areas of urban agglomerations.

Interestingly, a recent study on demographic change in Paris suggests that demographic structures related to the second demographic transition which have been observed originally in inner city areas are evolving in the suburban areas or the fringe areas, too (Ogden and Schnoebelen, 2005). Further research is needed to capture fully the impacts of population and household changes against the background of the second demographic transition on the whole urban agglomeration, that consists of not only the core city, but also the fringe areas.

In the context of agglomerations recently experiencing desurbanisation, overall we detected a decrease from 28.5% (1996–2001) to 4.8% (2001–2004) in Western Europe. However, it is clearly apparent in Eastern Europe, i.e. in Poland and the Czech Republic but also in Northern Europe

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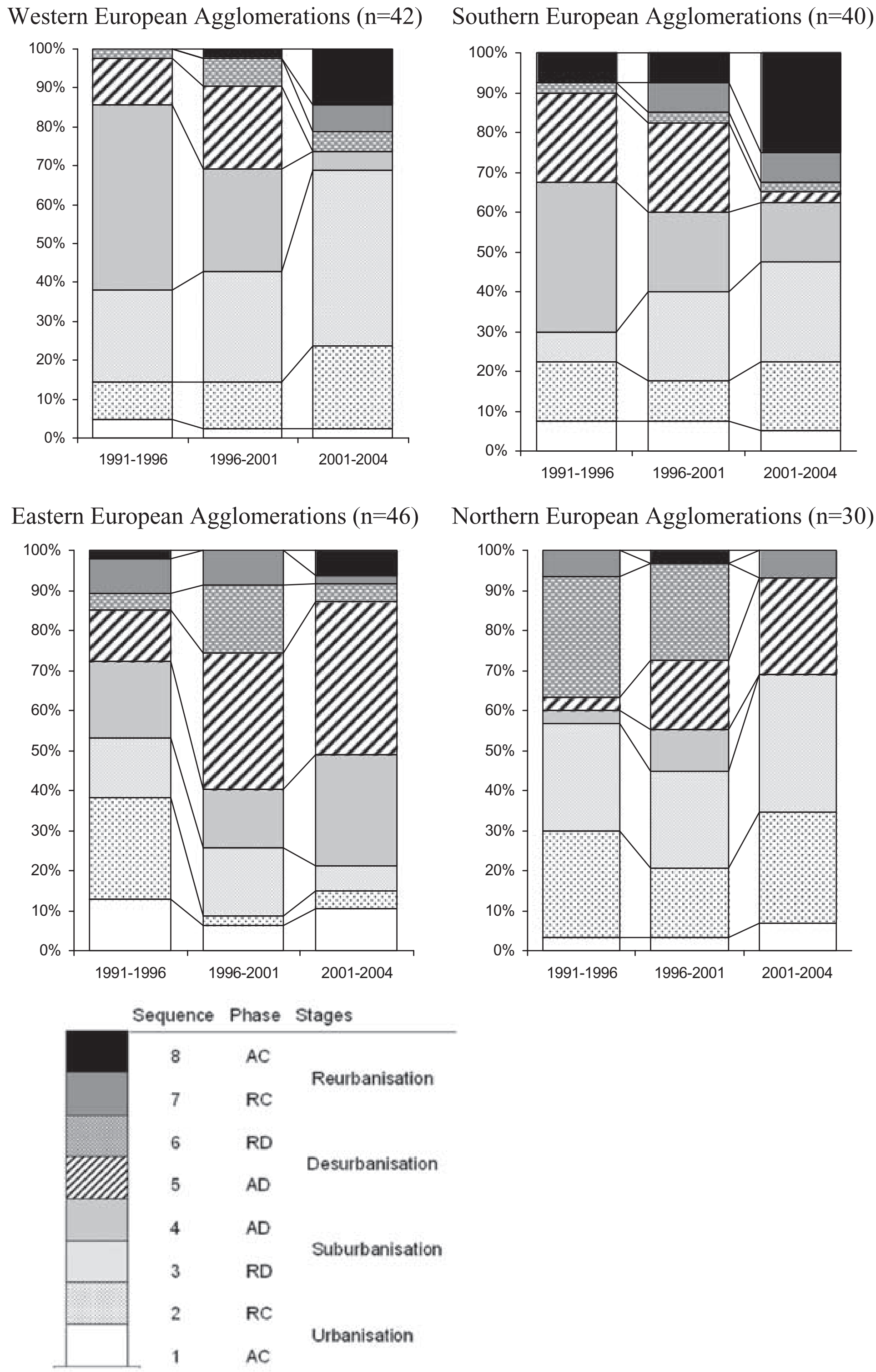

Figure 6. Change in frequency distributions of LUZ by the stage of urban development.
Notes: AC: absolute centralisation; RC: relative centralisation; RD: relative decentralisation, AD: absolute decentralisation.

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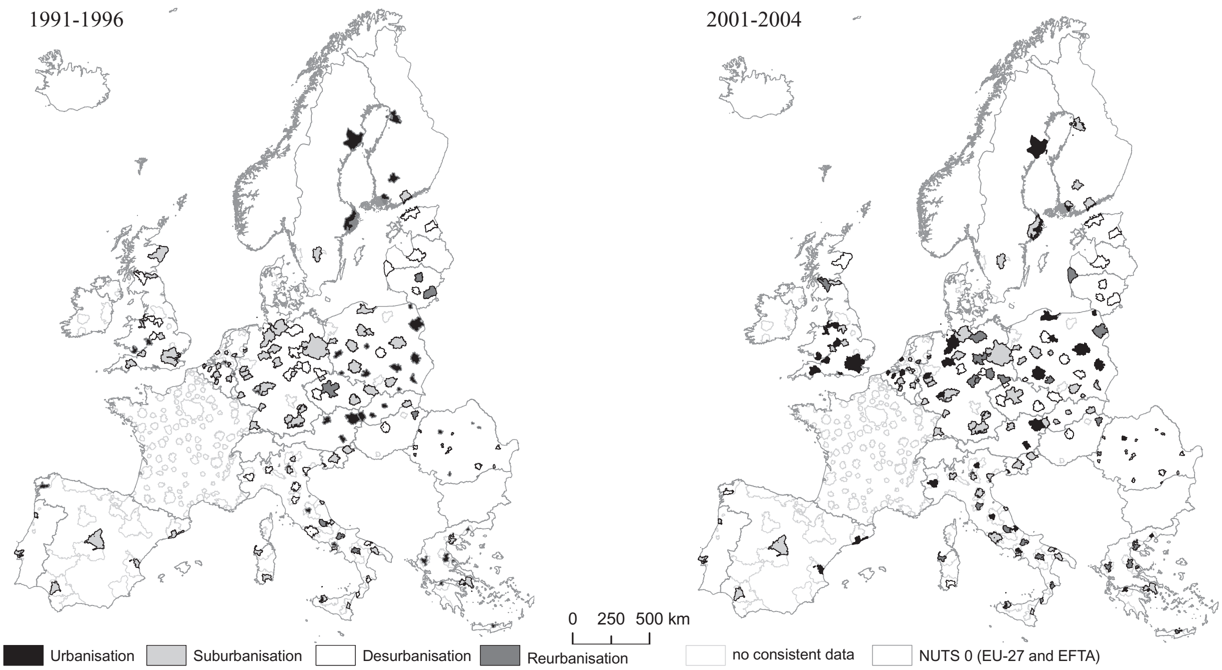

Figure 7. Clusters of urban development change trajectories 1991–1996 and 2001–2004
Source: Maps for spatial analysis was generated from data by *GISCO – Eurostat (European Commission)* © EuroGeographics for the administrative boundaries (*http://epp.eurostat.ec.europa.eu/porta).*
Notes: Author of Maps: Nadja Kabisch; Date: 24 March 2009.

in the Baltic States. We could not identify desurbanisation over the whole time period in parts of urban Europe namely in England, the Netherlands, Belgium, Luxembourg, and Spain. In other parts, by contrast, it has been very apparent since the mid 1990s (the Baltic States) and more frequently, as demonstrated by a total of 31 agglomerations after 2001 in Eastern Europe.

Drivers of Population Trajectories in Urban Agglomerations

In this section we discuss the explanatory factors that are assumed to drive a specific population dynamic leading to one of the four stages. We used the annual change rate of the four sociodemographic variables within the three time periods.

Table 4 displays the mean values of the variables and the results of the multiple *post hoc* comparisons. Amongst them, the biggest differences exist for the annual changes in population of working age, which is not surprising as the stages of urban development are based on the population change of an urban agglomeration. In addition, the variables of the annual changes in the total number of households and population aged 20–<25 years show significant mean differences, particularly for the last time period. The means indicate that cities within the urbanisation and the reurbanisation stage obviously show a significant increase in their household numbers accompanied by a rise in younger population groups (aged 20–<25). Against this background, the rise in population of the core city that characterises the two stages seems to be driven by an influx of younger and probably smaller households leading to an increase in the total household number.

Collectively, these findings are broadly consistent with the results of recent studies that mainly identified processes of reurbanisation accompanied by changes in the household structure and lifestyle that are significantly connected with the second demographic transition (Buzar *et al.*, 2007b). Accordingly, young and smaller households tend to migrate to core cities indicating new patterns of population structure and

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Table 4. Descriptive statistics (means) and multiple *post hoc* comparisons of variables.

Variable	Urbanisation	Suburbanisation	Desurbanisation	Reurbanisation
1991–1996				
Δ Population of working age core	1.30[2,3,4]	0.01[1,3]	−1.14[1,2]	−0.23[1,3]
Δ Total number of households core	1.82[2,3]	0.90[1]	0.51[1]	1.22
Δ Population aged 20 to <25 core	1.96[2,3]	−1.42[1]	−2.15[1]	−0.66
Δ Youth dependency core	−0.95	−0.51	−0.53	−0.87
Δ Old age dependency core	0.19[3]	0.25[3]	0.54[1,2]	0.51
Δ Unemployment rate core	0.63	0.59	0.96	1.5
1996–2001				
Δ Population of working age core	1.33[2,3]	−0.06[1]	−0.49[1]	0.50
Δ Total number of households core	1.98[2]	0.40[1]	0.75	1.10
Δ Population aged 20 to <25 core	1.94[2,3,4]	−0.08[1]	−0.07[1]	−2.16[1]
Δ Youth dependency core	−0.85	−0.37[3]	−1.19[2]	−0.79
Δ Old age dependency core	0.10	0.25	0.38	0.45
Δ Unemployment rate core	−0.21	−0.49	0.35	n.a.
2001–2004				
Δ Population of working age core	1.06[2,3,4]	0.32[1]	−0.30[1,4]	0.42[1,3]
Δ Total number of households core	1.48[3]	1.54[3]	−0.46[1,2,4]	1.71[3]
Δ Population aged 20 to <25 core	1.95[2,3]	−0.80[1,4]	−1.87[1,4]	0.57[2,3]
Δ Youth dependency core	−0.39[3]	−0.53[3]	−1.08[1,2,4]	−0.57[3]
Δ Old age dependency core	0.07[3,4]	0.22[4]	0.46[1]	0.40[1]
Δ Unemployment rate core	0.40	−0.04	−0.25	0.42

[1] Statistically significant difference in Tamhane's T2 *post hoc* test comparing the mean values in the stage with those in urbanisation stage (P-value <0.05).
[2] Statistically significant difference in Tamhane's T2 *post hoc* test comparing the mean values in the stage with those in suburbanisation stage (P-value <0.05).
[3] Statistically significant difference in Tamhane's T2 *post hoc* test comparing the mean values in the stage with those in desurbanisation stage (P-value <0.05).
[4] Statistically significant difference in Tamhane's T2 *post hoc* test comparing the mean values in the stage with those in reurbanisation stage (P-value <0.05).

behaviour that are in line with recent processes of reurbanisation (Ogden and Hall, 2000). This has been further shown by a range of case studies in European inner city areas (Léon, Bologna, Leipzig, Ljubljana: Manchester, Glasgow: Seo, 2002; Buzar *et al.*, 2007a; Leipzig: Kabisch *et al.*, in press).

Interestingly, significant mean values of the reurbanisation and urbanisation stage appear similar in terms of a population gain in the core city that is, according to van den Berg *et al.* (1982), characteristic for both stages. The differences between the mean values of the socio-demographic variables in both stages are significant compared with the cities in the suburbanisation and desurbanisation stage. Thus, agglomerations in the urbanisation and reurbanisation stage seem to have the same characteristics.

Furthermore, the changes in the young- and old-age dependency show similar mean values in the core cities of all stages. Notably, the high mean values for desurbanising core cities suggest that demographic ageing will be extremely severe in cities already facing shrinkage in the whole agglomeration. Old-age dependency, however, is projected to double in all industrialised countries due to declining fertility and mortality and will also affect the entire world population (Reher, 2004; United Nations, Department of Economic and Social Affairs, Population Division, 2004).

The *post hoc* comparisons also indicate that the means of the population of working age and the total number of households representing the desurbanisation stage significantly differ from the others. As identified above, Eastern European cities in particular are in the desurbanisation stage facing overall population decline. As the mean values report negative changes, the results support the idea that decline is the dominant urban trajectory in Eastern Europe.

CONCLUSIONS

In this paper, a comprehensive data set of European agglomerations was analysed in terms of their annual population growth rates for the core cities and fringe areas. For the first time, new population development trends were identified for the period after 1990 when major societal and economic transitions in Europe occurred.

Our findings indicate a positive population trajectory for Europe's large and medium sized agglomerations which are currently better placed than smaller ones. They seem to be able to extend their growth rates whilst most of the small agglomerations were showing population decline by 2001. One of the main reasons here is the provision of certain social and economic services and amenities that large cities are supposed to be better provided with compared with smaller agglomerations. Focussing on the attribute of location in Europe, we found that Western and Southern European core cities are mainly associated with population growth since 2000, but were declining in the 1990s. By contrast, the trajectories for Eastern European cities showed severe decline as the dominant process since the mid 1990s. Population decline here is thought to be mainly associated with processes initiated by the political and economic upheaval of the 1990s. However, a slight recovery emerged after 2001.

The quantitative and rather descriptive results were, then, contrasted with the classic cyclical urbanisation model (van den Berg *et al.*, 1982), in order to examine the current viability of the model and its four stages framework.

Our findings show that the consecutive order of the stages has changed or reversed: we found an urban revival or reurbanisation that emerges as an increase of population in the inner parts of the city in spite of suburbanisation and to a smaller extent, desurbanisation significantly taking place in the 21st century. Additionally, an increase of agglomerations in the urbanisation stage was found, leading to an obvious parallelism of reurbanisation and urbanisation at the same time. These two stages are defined in a different way by van den Berg *et al.* (1982) but appear similar in quantitative terms and also when looking at the driving forces behind the stages. Increases in the household number and younger people (aged 20–<25) are trends associated with the second demographic transition, which seem to drive reurbanisation and also urbanisation. We conclude therefore that the urbanisation and reurbanisation phase – separated in the van den Berg model – may coexist in specific cases. As such, the present urban development would mainly consist of three stages – (re)urbanisation, suburbanisation, and desurbanisation. In this sense, the sequential approach of the van den Berg model in its original version does not appear to be applicable if it is no longer possible to identify one general tendency in European urban development but rather a mix of different trends taking place at the same time.

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NOTES

(1) For spatial analysis the Data source *GISCO – Eurostat (European Commission)* © EuroGeographics for the administrative boundaries was used.
(2) We use the word 'stage' since we refer to the van den Berg model and respective other papers that all use this term for the phases of urban development.
(3) The term 'urban sprawl' is also commonly used as synonym for 'suburbanisation', see also Nuissl and Rink, 2005.
(4) These demographic trends are referred to by an increase in single households, couples with no children and with two or more people in work, amongst other trends indicating the second demographic transition. These unconventional

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household structures are likely to favour city locations due to the proximity of city amenities and core city employment (Cheshire and Hay, 1989).

(5) Austria: www.statistik.at; Spain: http://www.ine.es/; Poland: http://www.stat.gov.pl. Unfortunately, data is not available for all of the cities involved for each of the respective years. In order to analyse a consistent data set representing the whole time period, some countries (e.g. France) had to be omitted from this study.

(6) The NUTS classification was set up by EUROSTAT to be a single, coherent system of territorial groupings in order to compile EU regional statistics. For the average size of NUTS 3, the NUTS Regulation lays down a minimum (150,000) and maximum population threshold (300,000). LAUs are low level divisions and basic components of the NUTS regions. LAU-1 and LAU-2 were previously called NUTS-4 and NUTS-5, respectively. (http://ec.europa.eu/eurostat/ramon/nuts/basicnuts_regions_en.html [accessed 7 November 2008]).

(7) For convenience, the term 'growth rate' is used in our study instead of the term 'change rate' (van den Berg *et al.*, 1982) because in several recent studies it is commonly used (Turok and Mykhnenko, 2007; United Nations, Department of Economic and Social Affairs, Population Division, 2004, 2008).

(8) The timing (2004, towards the end of time series) of the application was chosen because it can be compared with previous studies (van den Berg *et al.*, 1982; Cheshire and Hay, 1989; Turok and Mykhnenko, 2007). Furthermore, all LUZ were left inside the study even if their population number is less than 200,000. This is the threshold in the van den Berg *et al.* (1982) study. However, we aim at getting results also for small and medium-sized LUZ.

(9) As a part of performing the ANOVA, tests for required distributional assumptions were done. The Levene statistics were observed to assess the equal variance assumption. The Levene statistics revealed that in some cases the variances for the variables were not equal. Thus, Welch statistic is reported and Tamhane's T2 – post-hoc test were used as multiple comparison tests, which do not assume equal variances.

(10) Here, we use R^2 (coefficient of determination), because we use linear regression to identify (non)significant relationships.

(11) In his study Cheshire (1995) defined the UK, Germany (West), Benelux and Denmark as Northern Europe. In our study the UK belongs to Northern Europe and Germany, Benelux and Denmark to Western Europe.

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LAND USE IMPACTS OF DEMOGRAPHIC CHANGE – LESSONS FROM EASTERN GERMAN URBAN REGIONS

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Abstract. Demographic change has become a major topic regarding the use and stability of European urban regions. It can be seen as the major driving force responsible for "growth" and "non-growth" or "decline" pathways in urban regions for the coming decades. Growing and shrinking urban regions do exist simultaneously next to each other. The trend towards further urban sprawl and dispersion observed in the 1980s in western Europe and the 1990s in East Central Europe accompanying the transition process are about to be replaced by shrinkage and perforation. This is mainly due to the recent decrease in birth rates, ageing and shifting household structures. This chapter analyses the trends and spatial patterns of the impact of demographic changes in urban regions. In the first part different features of demographic change are presented. In the second part, the paper expands on how demographic change affects urban land use, fabric, housing markets, infrastructure, and greenery. Since eastern Germany has been shrinking substantially since 1990, the paper uses this example to show a case in point embedded into the overall European context.

Keywords: Demographic change; shrinkage; perforation; land use impacts; eastern Germany

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1. Demographic change versus stability – a challenge for landscape sciences

Demographic change has become a major topic for European urban regions and their adjacent rural periphery. Growing and shrinking regions exist simultaneously next to each other within urbanised regions mainly due to low birth rates, an increase in life expectancy, changing household structures and, first and foremost, high dynamics of migration (Kabisch et al., 2006). The trend towards further urban growth and dispersion observed in the 1980s in western Europe and later on in the 1990s in East Central Europe is increasingly accompanied by processes such as urban shrinkage and perforation. Moreover, data on inner-urban migration allow us to assume a certain return of the compact city (Buzar et al., 2007). This paper argues that many of the spatial developments and land use changes in urban regions are effects of demographic change. They are closely related to both the balance of supply and demand in changing consumer relations between space, natural resources, and population.

Whereas social scientists and economists intensively discuss the impact of demographic change upon social structure, cohesion, and the labour market, only a few studies refer to the spatial and land use impacts that are caused by demographic change (Heiland et al., 2006). What are the spatial effects of demographic change in urban regions? Does a population decline automatically mean a reduced number of consumers of urban ecosystem services (water, energy consumption; urban green) or a decrease in urban land consumption? Or will population decline simply lead to an increase in unused and waste land, and low density urban areas (cf. Berg et al., 1982)?

To answer these questions, we need first of all to shed light on the spatial distribution of population, age spectra, households, and migration in urban regions. Second, we have to identify on the relationship between population change, residential mobility and the demands on residential land, urban infra-structure, and recreation areas. Referring to stability and security aspects, in particular the long-term stabilisation of urban regions under demographic decline in terms of compactness of settlements and consumption of natural resources is of interest. Set against this background, it is the purpose of the chapter to analyse the trends and spatial pattern of the impact of demographic changes in urban regions.

Although demographic changes affect many parts of Europe (Kazepov, 2005; Couch et al., 2005), eastern Germany is something like a "fore-runner" in terms of rapid urban shrinkage due both natural population decrease and out-migration (Kabisch, 2005). Therefore, the paper illustrates its pre-assum-ptions and findings using representative examples from eastern German urban regions and embeds them into the overall European context. To start, in the following section the specifics of eastern German urban development are briefly discussed.

1.1. THE "FORE-RUNNER" ROLE OF EASTERN GERMANY IN POPULATION DECLINE

Currently, large parts of Europe are undergoing a considerable demographic change (Antrop, 2004; Cloet, 2003; Lutz, 2001). In Germany, as far as a general population development is concerned, we find in the coming 20 years a simultaneity of population growth and decline (cf. Figure 2). The population is declining in a long-term perspective (Klingholz, 2004): according to the recent prognosis of the German Federal Agency for Population and Spatial Development (BBR, 2005), the German population will decrease from 82.56 million (2002) to 80–82 million inhabitants up to the year 2015. Up to 2025 a further decline to 77–79 million is expected, followed by an ongoing negative trend up to 2050 (Figure 1). The main reasons therefore are demographic ones: low birth rates (birth rate per woman is about 1.4 in Germany), an increasing number of one-person and childless households, postponement of child-bearing, ageing and interregional migration.

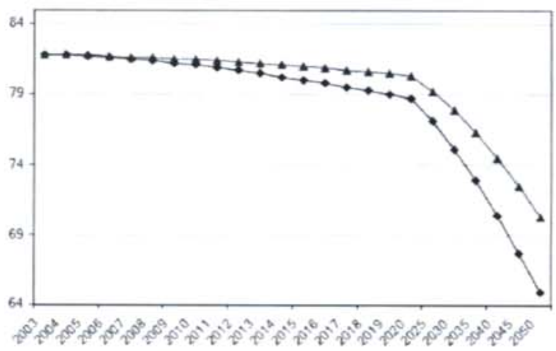

Figure 1. Population prognosis for Germany 2003–2050 in million inhabitants: ▲ = optimistic; ■ = pessimistic estimation. (StBA, 2000.)

In particular eastern Germany has been faced with a dramatic loss of population since the reunification in 1990 due to the above mentioned fall in birth rates (to lowest low rates of meanwhile 0.77) and exorbitant outmigration to the western part of the country: with a birth rate of 1.2, the total population of eastern Germany decreased about 6% from 1990–2005 (>2 million including death surplus). In this vein, the most dramatic population losses from 1989–1998 of nearly 10% can be found in the federal states of Saxony-Anhalt and

Brandenburg; cf. Figures 2 and 3). Those numbers exceed by far values reached in other European countries such as Sweden or Finland and other transition states such as the Baltic States and Romania where the population decline from 1995–2001 reaches –5% to –2% in both welfare countries such as (EUROSTAT, 2006). Looking at urban regions such as Leipzig, Halle, Zwickau, or Chemnitz, more than 15% of their population left the city for either western Germany (labour migration) or suburban settlements (residential migration; see here Figures 5 and 6 in Section 1.4). As Figure 2 suggests, the current population prognosis up to 2020 for eastern German federal countries, except Berlin, anticipates a further population decrease of 10 to >15%.

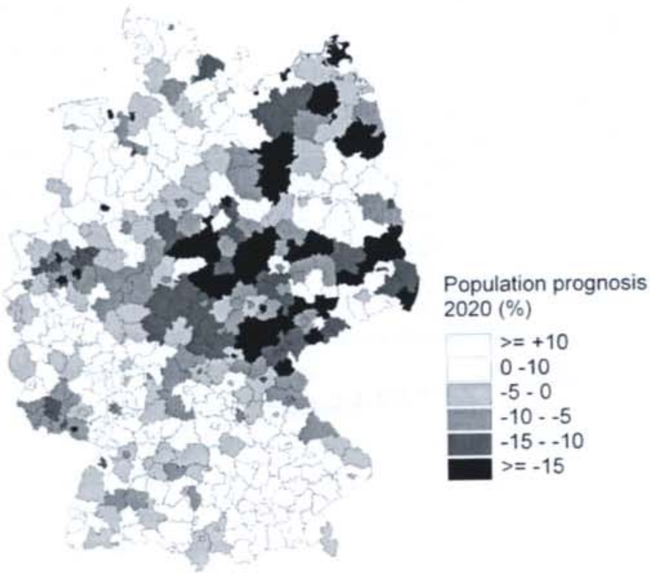

Figure 2. Population prognosis for Germany 2000–2020. (own calculation; modified after BBR, 2005.)

1.2. AGEING

As a result of the decrease in birth rates, the postponement of birth giving and an increase in life expectancy, East German city regions are moreover faced with ageing and an increase in elderly residents (Bösch-Supan et al., 2005).

This trend has a strong spatial component with a dramatic increase in residents aged >75 in urban and rural parts of northeastern Germany, namely Mecklenburg and Brandenburg (Figure 3). In the whole of eastern Germany, the mean age value will grow from 38.2 in 1998 to >50 in 2050. Due to the already existing high share of retired people in most of the urban regions of eastern Germany, the process of ageing is seen as irreversible for the coming decades.

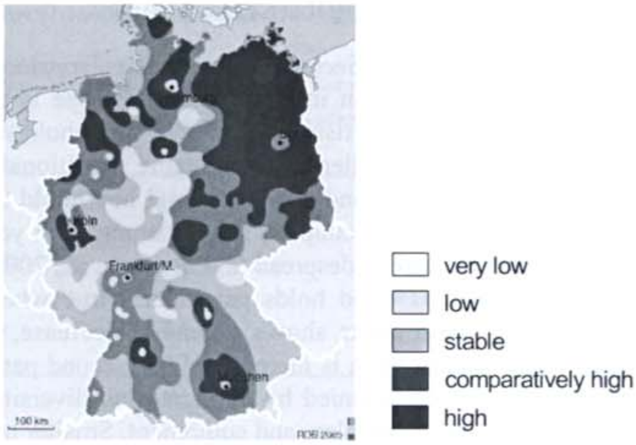

Figure 3. Share of age classes >75 in Germany 2002–2015. (BBR, 2005.)

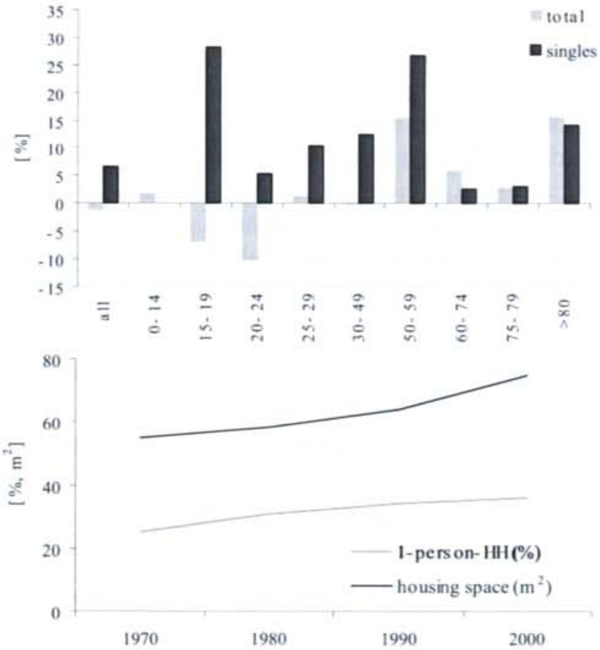

Figure 4. Increase in one-person households in total numbers and distributed over the whole age spectrum in eastern Germany (upper diagram; 1990–2006) and in relation to the housing space requirements. (Data source: EUROSTAT, 2006.)

1.3. DIVERSIFICATION OF HOUSEHOLD STRUCTURES

According to the processes of the *Second Demographic Transition* (SDT; van de Kaa, 2004) the urban population in the whole of Europe is undergoing a further differentiation in terms of a rising diversity of household structures.

Households are becoming smaller and less stable, traditional concepts of the family are losing importance, and non-traditional household types such as one-person households, cohabiting couples, single parents, and younger adults sharing a flat are becoming more widespread (a.o. Buzar et al., 2005).

For eastern Germany, this trend holds particularly true when looking at Figure 4: although the youth quota shows a general decrease, the share of one-person households among them is increasing. The second part of Figure 4 shows that this process is accompanied by an increasing diversity of housing requirements in terms of size, floor plan, and equipment. Smaller households do not necessarily demand for smaller flats. This fact contraries the assumption of lowering land consumption due to population decline.

1.4. SPATIAL PATTERNS OF DEMOGRAPHIC CHANGE

Demographic change, individualisation and related changes in housing preferences combined with a simultaneous rise in the disproportion of existing supply of urban housing, social and technical infrastructure – which is seriously outweighing the demand – challenge the debate on respective land use and landscape effects in urban regions of eastern Germany (Hannemann, 2003). In light of basic knowledge of the correlations between land development processes and population (Ravetz, 2000; Hall, 1992; Himiyama et al., 2005), there have to be assumed considerable spatio-temporal effects of shrinkage such as, generally speaking:

- An increase in *segregation* (spatial separation) between growing and shrinking areas next to each other in a city region
- A small-scale *fragmentation* (spatial separation) of the urban population (fragmented housing geography; Buzar et al., 2007)
- A considerable number of *residential vacancies* in most parts of the urban fabric (Table 1)
- *Large-scale urban brownfields* in both inner-city and suburban areas
- *Outmigration* from the large cities (Figure 5) and related *land abandonment* processes in suburbia, that might have been recently started (Figure 6)

TABLE 1. Number of dwellings and residential vacancies in eastern Germany 1990–2002. (BBR, 2005.)

Federal country	Development of the number of dwellings 1990–2000 (%)	Total residential vacancy 2002 (%)	Residential vacancy in housing cooperatives (%)
Brandenburg	14.2	13.1	14.7
Mecklenburg-Vorpommerania	13.1	11.8	10.7
Saxony	6.9	17.6	19.6
Saxony-Anhalt	7.4	16.9	20.8
Thuringia	6.7	10.2	15.8

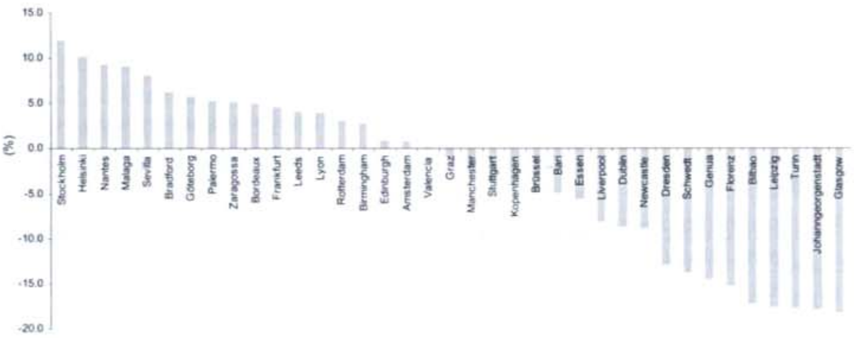

Figure 5. Demographic development of European cities >200,000 inhabitants from 1981–1996. These data prove evidence of the population decline in East German cities and set them into relation to the pan-European change (EUROSTAT, 2006).

- *Perforation* (=patchwork settlement structures without a compact core) of particularly urban landscapes and a respectively related creation of low-density counter settlements (with implications for lower sealing rates, building and population densities)
- *Deconstruction* and large-scale *demolition* of parts of the urban housing stock in cities and possibly suburbia (Haase, D. et al., 2006b)
- A *decreasing* and *modified demand* for technical, transport and social *infrastructure* (demand for schools will decrease compared to the increase in retirement homes and medical infrastructure)
- Remaining trends in *sprawling* land (use) development such as land consumption around cities (2003: 93 ha, 2005: 118 ha, 2020 (prognosis): 104 ha; cf. Nuissl and Rink, 2005)

- New waves of *reurbanisation* that allow one to assume a resurgence of living in the inner city and thus might come along with a revival of the compact city (cf. Figure 6; Buzar et al., 2007; Haase, D. et al., 2006a)

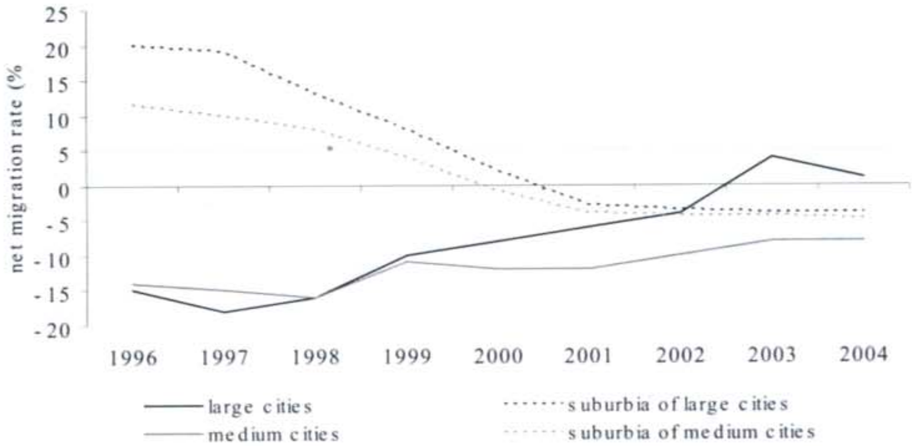

Figure 6. Net migration rate (%) along the rural–urban gradient in eastern Germany 1996–2004. (BBR, 2005.)

The above described land development pathways implicate a major spatial relevance for future land use pattern in eastern German urban regions. It leads to high regional discrepancies between growing and shrinking parts with unstable and differing dynamics along the rural, peri-urban, gradient (Figure 6). Figure 6 clarifies that, compared to the early 1990s, big cities in particular have recently been regaining population from suburbia. However, eastern German urban regions are characterised by decreasing residential densities, perforation into urban clusters and massive residential vacancies on the one hand and, simultaneously, "islands of up-grading" on the other. Is this development comparable to other European city regions? Does this imply a revision of urban policies? For eastern Germany, the described spatial effects of demographic changes in the urban space are under discussion among planners, whereas in major parts of western Europe they are still neglected in the current debate on urban policy (Müller and Siedentop, 2004; Herfert, 2002).

2. New land use patterns?

In this section, selected examples for impacts of demographic change on land use are presented. Although there is a need for more empirical ground, assumptions are made based on causal and logic loops drawn from data explored from demographic and land use statistics for eastern Germany.

2.1. FRAGMENTATION

To improve knowledge regarding environmental effects of demographic change, with particular respect to decline, the spatial allocation of shrinkage (i.e. of restructuring and demolition) at different scales needs to be investigated. Here, old industrialised urban regions in both Western and Central Europe (e.g. Scottish Clydeside, northern England, Lorraine, and Ruhr basin) that have undergone economic and population decline already during the last decades may serve as forerunner examples. Literature reports that shrinkage processes started in most cases with economic decline, the development of brownfields in the inner city and an exodus of population from those areas (Power and Mumford, 1999; Couch et al., 2005). From recent studies on cities such as Liverpool, Manchester, and Newcastle we know, however, that recently there have been started comprehensive, area-based renewal activities that resulted in a revitalisation or – at least – a stabilisation of districts like Manchester-Castlefields and the Ropewalks in Liverpool (Ravetz, 2000; Seo, 2002). Simultaneously, differences between successful and disadvantaged neighbourhoods are increasing (Morrison, 2003).

Eastern Germany is a special case or a "laboratory" to investigate the complex spatial and societal consequences of shrinkage because of the speed of those processes after 1989. Here, deindustrialisation coincided with an enormous outmigration and a demographic "shock" due to the political and societal transition. Evolving housing vacancies of more than 1 million flats are unique in Europe up to present (Haase, A. et al., 2005). The same holds true for the restructuring programme developed by the government for 2002–2009 that foresees subsidies for the demolition of 350,000 flats (Lang and Tenz, 2003). What we find today in eastern Germany is an increasing polarisation between stabilising urban regions such as Leipzig, Dresden, Erfurt, and Jena whose inner cities undergo even processes of household-driven reurbanisation (Haase, A. et al., 2005), and declining cities that keep locked in the shrinkage trap (Halle, Madgeburg, Chemnitz). At the same time, a low-level suburbanisation goes along with the resurgence of inner-city areas. These processes result in a "splintered urban population" (Buzar et al., 2007) at a small scale. Hence, it is fragmentation that will determine the further development of urban space in Europe, and the scholarly as well as planning debate will be on how to focus at best limited financial resources and on giving up declining regions as settlement areas in favour of stabilising others.

2.2. PERFORATION

Undergoing demographic change, eastern German urban regions and respectively their land use patterns might be confronted with an evolving type of urban landscape that "accepts" shrinkage as a development pathway: the *perforated urban landscape* which is less dense and more heterogeneous (in terms of land use and the mixture of open and sealed land), possesses a higher share of typical peripheral or suburban land uses (such as open land, single family houses or commercial units) than densely built up core cities from former times. More people live in higher dense clusters in suburban housing estates than in the inner and the core city. The term of *perforated* cities had been created during the debate on massive residential vacancies and the resulting "scattering" of the remaining urban fabric after demolition activities (Sander, 2006; Lütke-Daldrup, 2001).

Still, there exists no clear idea of how perforation might look like, but initial ideas of this urban type in terms of residential land uses have been already developed (cf. Figure 7): for example, the urban core could be divided into two settlement cores, the development of a poly-centric structure with less dense or even empty areas between tiny cores is imaginable as well as to "laissez faire" the current development what will lead to a fragmented urban body.

Comparing with a western European example, initial ideas of a cohesive but less dense core area of the city had been developed by the Newcastle City Council (NCC, 2000). Here, planners defined "green", "red", and "amber" areas according to their economic growth and quality of life for identifying priority demands of (e.g.) demolition or regeneration.

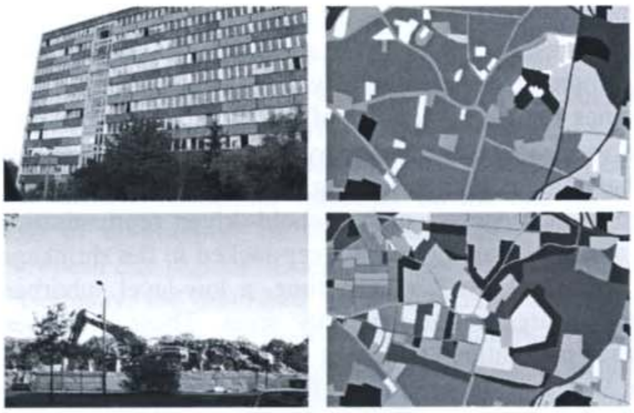

Figure 7. Forms of demolition in Leipzig-Grünau (left) and urban fabric perforation (upper map: continuous grey colour) in the eastern part of Leipzig (right) (Data source: authors' elaboration.)

Perforation implies that urban areas with strong demographic decline are however sprawling. Thus a heterogeneous mosaic of growing, stabilising and declining urban structures is developing. Formerly compact settlements, old and new built up districts actually change into a mixed urban fabric comprising very different house types, sizes, roof heights, and surrounding open space. Moreover, non-growth and shrinkage are bringing forward residential segregation, further spatial differentiation and small-scale fragmentation ending up possibly in an extreme perforation. To put it differently: high density areas are intertwined with areas of abandonment. Up to present it remains unclear if such structures will lead to an increase or decrease of the demand on natural resources (recreation space, water supply, clean air).

Assuming that urban perforation appears more frequently, do we thus lose the typical compact city and its spatial connectivity? Are we then facing a transport-network-determined land use development between perforated housing and open space clusters? Perforation definitely needs to be further investigated in terms of its structural, density and functional aspects in order to clarify its impact on land use and environmental resources.

2.3. ADAPTATION OF URBAN INFRASTRUCTURE

Besides changes of the urban fabric, infrastructure-related impacts have to be considered as a consequence of demographic change, first and foremost in shrinking city regions. In eastern Germany, we register a considerable underutilisation of the technical infrastructure for water supply and canalisation, which has already begun to underpin efficient operation and increases costs. Moreover, underutilisation causes toxic effects and water resources pollution (Koziol, 2004). For the water consumption since 1990 until today, for example, we state a decrease of 45% in all eastern German federal states. This is purported to be the result of two processes after the societal transition in 1990: (a) an increased sense of responsibility as regards water use due to the "capitalist" water price system and (b) population decline. In the years to come, housing service and maintenance costs are likely to rise in shrinking or perforating communities. To avoid or at least limit higher ancillary costs and the conesquent worsening of local conditions in the municipalities affected, low-cost urban renewal strategies of the spatial adaptation of the technical urban infrastructure need to be set on the agenda (examples are given in Table 2). The aspect that a change of household structures and sizes arises (cf. section 1.3) implies changes in water and energy use (Koziol, 2004).

Infrastructure developments in shrinking urban regions are assumed to be determined by a decrease in specific water, heating, and electricity consumption owing to changes in consumer behaviour. Hereby, declining consumption due to the extensive outmigration in eastern German urban regions will lead to a deconcentration of the service area: this requires an adaptation of the infrastructure network (cf. again Table 3).

TABLE 2. Adaptation of infrastructure networks to shrinking or perforating contexts.

Spatial form of adaptation	Land use and transportation impact
Increasing accessibility	Increase in traffic and road network demand
Reduction	Decrease in traffic and road network demand
Centralisation	Decrease in traffic and road network demand
Decentralisation (local networks)	Increase in traffic and road network demand
Temporal-mobile structures	Optimisation of spatial structures
New structures and substitution	No effects for spatial configuration but for total net consumption

Looking at the transportation sector, traffic requirements in the form of road network are supposed to increase by 2015 by approximately 24%, assuming a continuation of the recent trend in transport infrastructure development in eastern Germany. Whereas in compact urban regions travel distances and related noise and air pollution can be limited to a certain extent, spatial segregation and perforation definitely lead to increased travel distances and all its negative effects on urban quality of life (in terms of noise and air pollution). Today, >12% of the total population in eastern Germany need >45 min using the private car for daily commuting compared to 9% in 1995 (INKAR, 2003; BBR, 2005). Subsequently, the decline in population itself does not necessarily contribute to an increase in environmental quality within shrinking urban regions.

2.4. INCREASE IN URBAN BIODIVERSITY?

Turning to the positive side effects of demographic decline, residential and commercial vacancies in inner-city and peripheral areas and related demolition should be understood as a chance for ecological restoration and development of green networks in city regions, too. Mehnert et al. (2005) found a positive correlation between the amount of urban green and the habitat suitability of urban breeding birds (*Picus viridus*). Generally, urban fallow lands are seen as niches for rare specialist species. Thus, demolished sites can be left partially open in order to develop hotspots of urban biodiversity.

However, general positive or negative effects of demographic change for urban ecosystems and biodiversity are not verified yet through empirical studies (Lüthi, 2001). In particular residential vacancy, simple land abandonment (excluding a de-sealing) and perforation are not subsequently followed by positive effects for nature and ecosystems. On the contrary, inefficient solutions could lead to higher environmental impact and more land consumption in shrinking landscapes when, despite an existing urban brownfield, open land at the periphery becomes sealed.

Processes and forms of urban perforation are assumed to have the potential to considerably contribute to structural enrichment and an increase in edge densities (Bolund and Hunhammar, 1999). They let one further think about a *bringing back* of nature to former densely populated and built urban centres. At least *wilderness ideas* (Rink, 2005) in urban landscapes for recreational and educational purposes are in discussion among urban planners and landscape architects. A concept from the eastern German Leipzig suggests newly developed urban greenery in the form of temporary gardens for demolition sites (planned variant) and vacant succession lots at former brownfields (unplanned variant). According to the opinion of the authors, there is potential for more urban green and nature which may retain people in the city and counteract urban sprawl. But going into detail here would exceed the limited space of this chapter.

3. Insights concerning land use impacts arising from demographic change and urban perforation processes

As discussed in this paper, demographic change considerably impacts on recent shrinkage and perforation processes in eastern German urban regions. Except singular empiric results, a comprehensive quantification of these impacts on land use pattern is still to be done. Does, for example, a decreasing population reduce land consumption at the urban periphery in a long-term perspective (Heiland et al., 2006)? Up to present, there is no evidence for a direct relation between the two processes. And further, does shrinkage allow for the improvement or, at least, for a stabilisation of environmental quality in formerly growing, densely built urban areas?

Demographic change means above all a change in the total number of people, age class distribution, a modification in household structures and a rising impact of migration. Whereas population decline in western German urban regions is yet on a moderate level (Ø -1496 inh./a from 1995 to 2004), eastern German urban regions are affected already for 15 years by significant shrinkage processes: low birth rates, high outmigration and ageing rates (Ø -10365 inh./a from 1995 to 2004; cf. again Figure 1). There, we find a coincidence of seemingly contradictory urban processes: first, although on a low level since the late 1990s, there are traces of prevailing dynamics of suburban growth (single and semi-detached house settlements, new "housing parks") with adjacent land consumption (commerce and industry) at the urban fringe. Second, at many places, increasing process of depopulation and related shrinkage calculated according to residential vacancy, perforation, demolition and deconstruction in the core city areas can be observed. A thinning out of recent urban fabric and population densities are the consequence. Third, counteracting decline, we find also processes of stabilisation of the housing function as well as increasing population numbers in some inner-city areas.

Our analysis further discussed the fact that demographic change already endangers the infrastructural viability in urban areas that are affected by massive decline. With a declining population density, critical thresholds for the viability of technical, transport, and social infrastructures and in public facilities are reached already now. There are coming up new debates on how to ensure and finance the supply of the remained inhabitants in areas undergoing demolition of housing stock. Due to a thinning out of social and administrative infrastructure and a decrease in individual accessibility, daily travel times might increase although the population decreases. To put it differently: Demographic change on its own does not solve the problem of land and resource consumption, and it does not automatically bring about higher environmental quality for urban regions either.

It is our strong belief that the questions addressed concerning the potential impact of demographic change on urban regions have to be answered jointly by demographic, social, urban and landscape science like the interdisciplinary authorship of this chapter underscores. To what extent and how demands on natural resources and space will really change under the condition of population decline and shrinking urban regions? Do we have to consider a long-term change in demand–supply relations which result either in ecological benefits or in new threats? The question whether future land developments along the rural–urban gradient will be characterised either by polarisation between core city and surrounding areas or by a widespread lowering of densification in the form of perforation has to be left for future comprehensive and comparative analyses of urban regions throughout Europe.

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Does demographic change affect land use patterns? A case study from Germany

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Cluster analysis

ABSTRACT

Recent demographic change, mainly characterised by a decreasing and ageing population, is seen as one of the main factors for future land use development in Europe. However, there is still insufficient evidence about the relationship between demographic changes and land use changes since quantitative studies dealing with these interactions are still rare. We aim to fill that gap by presenting the first comprehensive study that investigates statistical relationships and spatial differentiations between demographic and land use change for the whole of Germany. Our study is based on data for the period from 1995/1996 to 2003/2004. The results clearly show that in most growing regions in the West of Germany a correlation was found between land use, natural population growth and net-migration, whereas for land use change in the shrinking regions in the East of Germany economic variables are of noticeable importance. A cluster analysis reveals “gaining” and “shrinking” regions concerning both urbanisation and demographic change. Neither a decreasing nor an ageing population imply reduced land consumption for housing and transportation. Furthermore we found a decreasing settlement population density for almost all German districts regardless of population growth or shrinkage.

Introduction

Demographic change is becoming increasingly more important in political and planning discussions, given that it is considered to be an important factor for future land use development and urbanisation throughout the whole of Europe (UN, 2007; UNPF, 2007). The Millennium Ecosystem Assessment states that demographic development is an essential driver for ecosystem and land use change (Nelson et al., 2006; EEA, 2006). As in most European countries, demographic development in Germany is mainly characterised by a declining and rapidly ageing population due to a fertility that is below replacement and an increasing life expectancy (Edmonston, 2006). Another important aspect of demographic change is the decline of the average household size in line with what demographers describe as the Second Demographic Transition (SDT; Lesthaeghe and Neels, 2002; Steinführer and Haase, 2007). However, long-term data sets on household dynamics and household types put into relation with land use dynamics are still rare (Haase and Haase, 2007).

In addition to a decrease in fertility, migration can be an even more determining factor that influences population size and age structure (Flöthmann, 2003). Ever since the German reunification in 1990, migration fluxes from eastern to western Germany and from the core cities to the suburban regions have been observed (Nuissl and Rink, 2005). Rural regions in eastern Germany have particularly suffered from population decline and a growing proportion of elderly people whereas most suburban and rural regions in the western part of the country are still experiencing population growth (Müller and Kilper, 2005). Demographic processes, of which the migration rate is of prime importance, are having significant impacts on urbanisation. Marginalisation and land abandonment in rural areas are becoming more and more observable. However, ongoing construction activities in the suburban areas of eastern Germany's shrinking cities are creating an urban-sprawl and resulting in the perforation of residential areas, and a decreasing settlement population density (Nuissl and Rink, 2005).

Currently, population decline is regarded as an opportunity to increase the sustainability of land use by decreasing the further sealing of open areas for housing and transport (Haase and Nuissl, 2007), although there is still almost no evidence on the accuracy of this relationship. Through its national sustainability strategy the German Federal Government (German Federal Statistical Office, 2007) hopes to limit new land consumption for housing and transport purposes to 30 ha/day up until 2020. This target, however,

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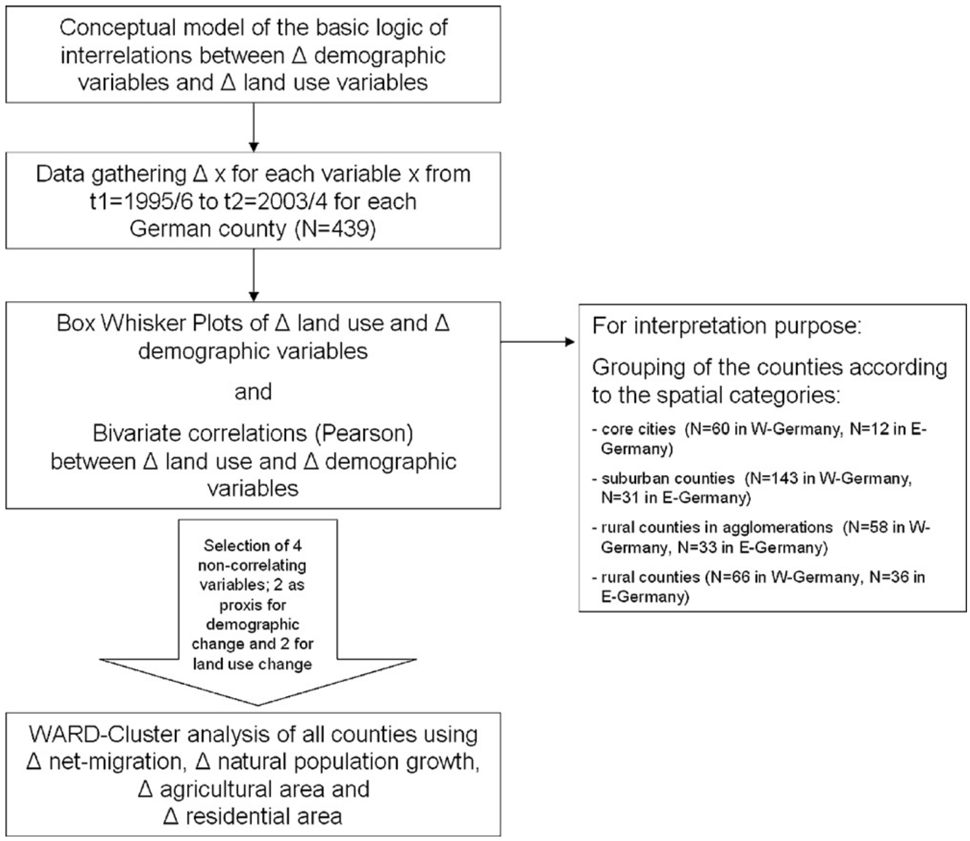

Fig. 1. Main components and sequence of the methodical approach.

still seems to be well out of reach, as a noticeable trend towards a decreasing amount of land consumed for housing and transport is not yet visible. Thus, the effects of a declining and ageing population on the development of residential and transport areas are of particular interest to national and regional policy makers.

In the current literature, contradictory assumptions about the relationship between demographic change and land use have been found. A declining population is not necessarily followed by a decline in development or even a decrease in urban land (German Federal Environment Agency, 2003; Couch et al., 2005). The reasons for this can be attributed to a decreasing household size and a rise in housing demand regardless of population decline. In contrast, Wolf et al. (2004) expect a future decline in urban area growth in regions with a decreasing population. In addition, abandoned agricultural land and the growth of forest and natural land following the depopulation of rural areas are considered to be a likely scenario (Bruns et al., 2000).

However, a quantitative analysis of the relationship between demographic and land use change at the regional scale is still missing.

Objectives and case study

We aim to fill that gap by using Germany as an example and looking for, firstly, statistical relationships between demographic and land use changes and, secondly, the spatial differentiation and heterogeneity of demographic and land use change variables.

Germany is extremely well suited as it is the most populous country of the EU and has shown significant demographic changes since 1990. At the same time, Germany has one of the highest rates of daily land consumption (a current average of 113 ha in 2006; German Federal Statistical Office, 2008). Therefore, we looked for correlations among the most significant demographic, socio-economic and land use variables since 1990 in order to depict statistical relationships, which identify possible causalities. We focused on both the entire country and its urban, suburban and rural regions. This enabled us to explore varying relationships depending on regional specifics as major differences between eastern and western Germany were expected. Such quantitative knowledge of statistical relationships between demography and land use can be used to support policy makers and help them to cope with population growth and decline when "planning" sustainable spatial development.

The paper is organised as follows: in the first part, after an introduction, the components of the methodical approach are presented, followed by the results of the statistical analyses. In the subsequent part the results are discussed and in the final part the final conclusions are drawn.

Data and methods

In order to build a statistical model including land use and socio-demographic processes, we identified key land use and socio-demographic variables. The respective variable selection was restricted by data availability at the district level. We chose the spatial level of the 439 German districts as a compromise between a high spatial resolution and the availability of comparable data for all entities. After collecting the data, the changes for 1995/1996–2003/2004 were computed before conducting a variance, correlation and cluster analysis. Fig. 1 summarises the main components of the methodical approach.

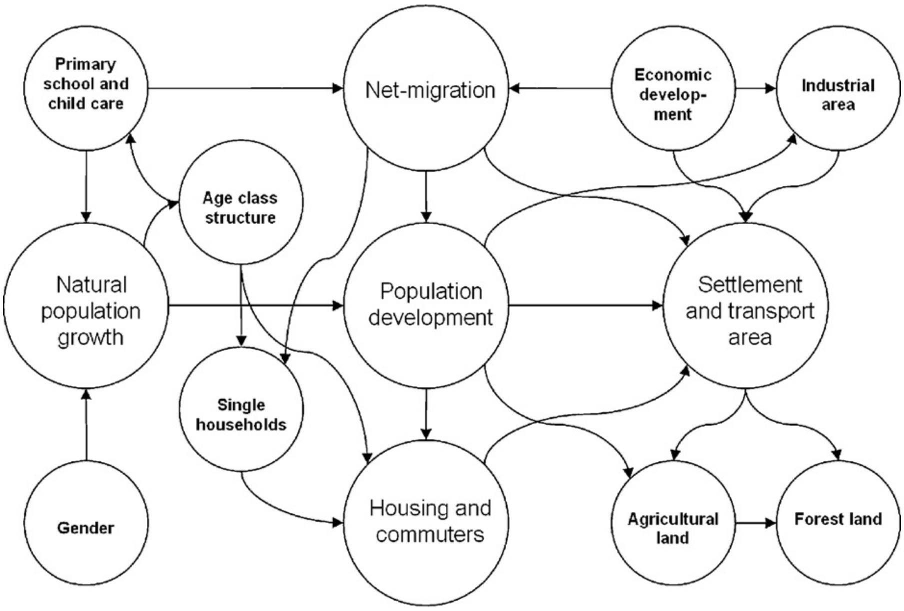

Fig. 2. Conceptual model of the basic logic and assumed cause–effect relationships between demography and land use.

Land use data

The German Federal statistical agencies provide the "Genesis-regional" database (www.genesis-online.de/regional) that holds data for the country on different land use types at the district level. From these we selected agricultural land, forest land, settlement and transport areas, residential areas, transport areas, commercial and industrial areas and recreational areas for our analysis. We calculated the absolute rate of change Δx for each land use variable x in hectares from $t_1 = 1996$ to $t_2 = 2004$ at the district level ($N = 439$), as comparable data for the eastern part of Germany were not available for dates prior to this due to this part of Germany being the GDR until 1990.

Socio-economic data

Current literature identifies population growth as a dominant driving force of landscape change (Verburg et al., 1999; Serneels and Lambin, 2001; Wang and Zhang, 2001). Population decrease on the other hand does not necessarily lead to a decrease in built-up areas, as many authors point out (Müller and Kilper, 2005; German Federal Environment Agency, 2003; Heiland et al., 2005). The (positive) development of the rural population size is expected to reduce agricultural and forest land (Bruns et al., 2000). Therefore, we chose population growth as a demographic variable to test its relationship with land use change. As population growth in turn depends on the natural population development and net-migration rate, we included both variables in our analysis to identify whether one variable better explained population growth than the other.

Besides population development, the influence of the age class structure on land use is the second most important issue. Kristensen et al. (2001) assumed the age structure to have an indirect effect on the growth of urbanisation via the percentage of single households, commuters, cars and housing areas per capita—therefore, we included these variables in our analysis in addition to the age class structure. We assumed a correlation between these variables, as older people often stay in their homes even when they are living alone and do not need a lot of space. Waltersbacher (2006) listed the ageing of the population in Germany as one main reasons for a rising demand for housing area. In order to capture the relationship of young and elderly age classes both young and old-age dependency rates[1] were computed.

As the amount of cars and the volume of commuters depend on the population age class structure (Scheiner, 2006) it is assumed that they have an influence on the transport area. To identify the role of economic development on land use change, we also included employees per economic sector, GDP per economic sector and investments in industry in our analysis.

According to the land use variables, we calculated the absolute rate of change Δx for each demographic variable x from $t_1 = 1995/1996$ to $t_2 = 2003/2004$ at the district level (for instance Δnet-migration rate = in-migrants from $t_1 = 1995$ to $t_2 = 2004$ − out-migrants from $t_1 = 1995$ to $t_2 = 2004$). All our hypotheses are combined in a conceptual model, which presents the basic logic and assumed cause–effect relationships between demography and land use (Fig. 2).

For the socio-economic variables we first obtained data from the "Genesis-regional" database (time span 1995–2004). Secondly, data was taken from the database "INKAR" (time span 1995–2003), provided by the German Federal Office for Building and Regional Planning.

Regionalisation

The German Federal Office for Building and Regional Planning grouped the 439 German districts into nine different spatial categories according to their population density (German Federal Office for Building and Regional Planning, 2006): core cities in agglomerations, core cities in urbanised areas, highly densified districts in agglomerations, densified districts in agglomerations, densified districts in urbanised areas, rural districts in agglomerations, rural districts in urbanised areas, rural districts of high population density and rural districts with low population density. To extend the number of cases within one category for statistical analysis we aggregated these given nine categories to the following four: core

[1] Young-age dependency rate is $\sum$age 0–19/$\sum$age 20–60; old-age dependency rate is $\sum$age >19/$\sum$age 20–60.

Table 1
Pearson's correlation coefficients *r* between statistical land use and socio-economic data.

Variable 1	Variable 2	All districts	Western districts	Eastern districts	Core cities		Suburban districts		Rural districts in agglomerations		Rural districts	
					West	East	West	East	West	East	West	East
Population development	Net-migration	**0.90****	**0.91****	**0.93****	0.24	**0.90****	**0.88****	**0.54****	**0.92****	**0.97****	**0.96****	**0.96****
	Natural population growth	**0.64****	**0.69****	0.21*	**0.69****	**0.72****	**0.65****	0.36	**0.63****	0.13	**0.74****	0.34
	Settlement and transport area	0.34**	**0.53****	0.26*	0.41**	0	**0.54****	−0.13	**0.57****	0.35*	**0.54****	0.11
	Residential area	**0.50****	**0.53****	0.47**	0.46**	0.45	**0.52****	0.15	**0.65****	0.46*	**0.61****	0.12
	Transport area	0.26**	0.36**	0.28*	0.19	−0.42	0.41**	0.21	0.36*	0.15	0.28*	0.33
	Agricultural land	−0.40**	**−0.5****	0.16	−0.40**	−0.23	**−0.50****	−0.22	−0.30*	−0.20	**−0.6****	−0.40*
	Forest land	0	0.11*	0	0	0	0.1	−0.10	−0.21	−0.12	0.33*	−0.13
	Industrial and commercial area	0.39**	**0.52****	−0.12	**0.56****	−0.13	0.49**	0.28	**0.52****	−0.22	0.42*	0
	Commuters	0.43**	0.28**	0.45**	0.34**	0.40	0.28**	0.11	**0.56****	**0.77****	**0.51****	**0.50****
	Cars	**0.65****	**0.61****	**0.69****	**0.50****	**0.85****	**0.64****	−0.21	**0.64****	**0.95****	**0.81****	**0.70****
	Houses	0.17**	0.41**	0.42**	0.26*	0	**0.52****	0	0.3*	**0.62****	0.38**	0.24
Migration rate	Settlement and transport area	0.22**	**0.55****	0.24*	0.16	0	**0.61****	−0.4*	**0.57****	0.32	0.48**	0.20
	Residential area	0.35**	**0.55****	0.46**	0.18	0.10	**0.59****	0.10	**0.66****	0.49*	**0.53****	0.20
	Transport area	0.11*	0.36**	0	0.16	−0.31	0.47**	0	0.11	0.16	0.29*	0.31
	Employees in tertiary sector	**0.5****	0.4**	0.40**	0.11	**0.5***	**0.5****	0.14	**0.50****	**0.60****	**0.50****	**0.50****
	GDP in tertiary sector	0.23**	0.26**	0.42**	0.10	**0.64***	0.22*	−0.13	0.35*	0.48*	0.47**	0.21
	Employees in secondary sector	0.36**	0.19**	0.41**	0	**0.66***	0.1	0.47*	0.28	0.14	0.24	0.39*
	GDP in secondary sector	0.22**	0.16**	0.16*	0.10	0.35	0	−0.12	0.13	0.1	0.49**	0.16
	Housing area per capita	**−0.5****	−0.30**	**−0.50****	−0.11	**−0.80****	**−0.5****	−0.4*	**−0.5****	−0.3	−0.20	**−0.6****
	Single households	−0.31**	−0.20**	0	−0.32*	−0.3	−0.30**	0.20	−0.3*	−0.3	0.20	−0.32
	Old-age dependency	−0.33**	0.10*	**−0.50****	0	**−0.80****	0.1	−0.40*	0	**−0.5***	0.31*	**−0.70****
	Young age dependency	0.41**	0.24**	0.13	0	0.17	0.35**	0.28	0.38*	0.41*	0	0.37*
	Primary schools	0.42**	0.27**	0.21*	0.21	**0.55***	0.29**	0	0.3*	0.44*	0.22	0.14
	Day-care centre	0.44**	0.45**	0.17	−0.20	0.22	**0.54****	0	**0.67****	0.1	0	0.41*
Natural population development	Distribution of sexes	0.34**	0.15*	0	0.20	0	0	0	−0.1	0.25	0.10	0.46**
	Primary schools	0.48**	0.28**	0.33**	0.24	0.31	0.37**	**0.64****	0	0.36*	0.42**	0.39*
	Day-care centres	0.35**	0	0.21*	−0.30*	0.44	0.1	0.22	0	0.33	0.42**	0
Old-age dependency	Commuters	−0.31**	0	−0.3**	0.12	**−0.50***	0	−0.10	**−0.5****	−0.4*	−0.11	**−0.70****
	Cars	−0.23**	**−0.52****	−0.4**	0	**−0.60***	0	0	−0.2	**−0.7****	−0.13	**−0.70****
	Housing area per person	0.48**	0.10*	**0.59****	**0.56****	**0.81****	0	0.41*	0	**0.62****	0.12	**0.6****
	Single households	0.24**	−0.11*	0.15	−0.20	0.41	0	0	0.1	0	0	0.24
Settlement and transport area	Employees in tertiary sector	0.23**	0.19**	0.38**	0.15	−0.14	0.24*	−0.40*	0.32*	0.40*	0.30*	0
	GDP in tertiary sector	0.23**	0.19**	0.38**	0.24	−0.13	0.2*	0.24	0.15	0.43*	0.37**	0.35*
	Employees in the secondary sector	0.13*	0.12*	−0.22*	0.24	−0.25	0	0	0.27*	0	0.13	−0.32
	GDP in the secondary sector	0	0.11*	0	0.21	−0.22	0	0.15	0.15	0.18	0.12	−0.22
	Investments in industry	0.11*	0	0.34**	0	−0.31	−0.13	0.41*	0.26*	0.28	0.11	**0.63****
	Industrial and commercial area	0.12*	**0.62****	−0.30**	**0.60****	0.24	**0.54****	**0.90****	**0.71****	**−0.50****	**0.67****	−0.11
	Agricultural land	**−0.53****	**−0.8****	−0.21*	**−0.90****	**−0.9****	**−0.90****	**−0.60****	**−0.80****	**−0.60****	**−0.70****	−0.22
	Houses	0.30**	0.45**	0.12	0.38*	0.26	0.48**	0.11	**0.57****	0.12	0.48**	0.27
Agricultural area	Forest land	−0.20**	−0.12*	0.20*	**−0.50****	0	−0.31*	**−0.60****	−0.32*	−0.12	**−0.60****	0.34

* $p < 0.05$.
** $p < 0.01$.

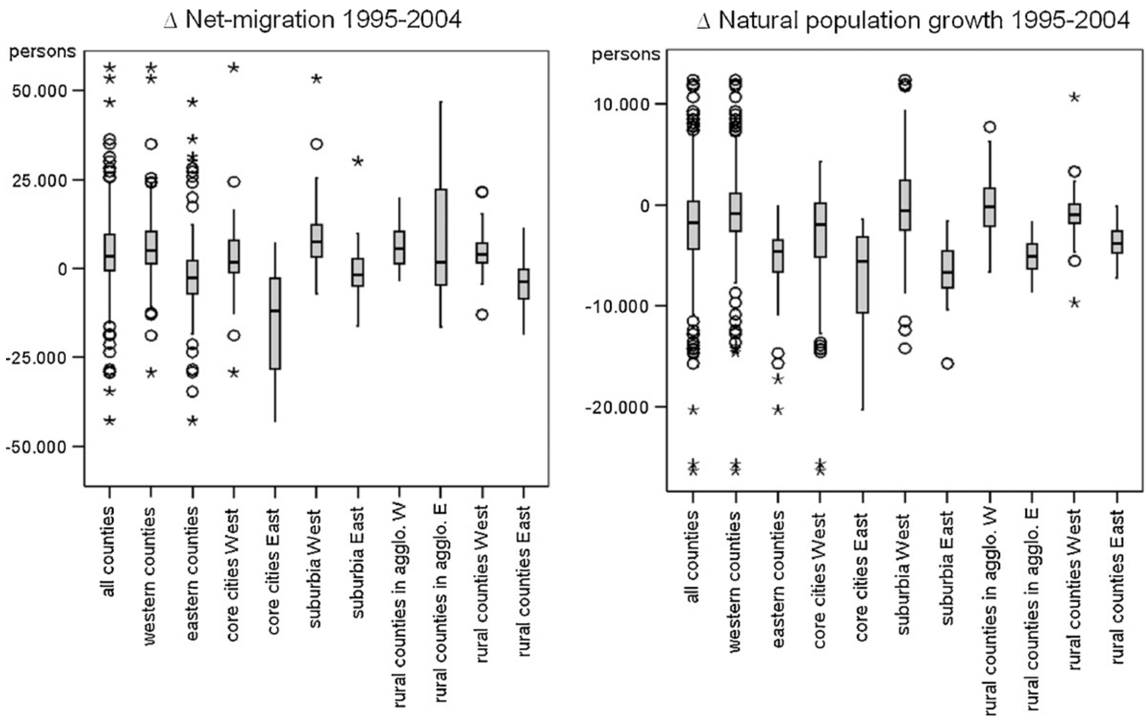

Fig. 3. Variance of natural population development 1995–2004 and net-migration 1995–2004 for different spatial types.

cities, suburban districts, rural districts in agglomerations and rural districts outside agglomerations. However we additionally distinguished between the districts in the East part and West part of Germany since we expected particular differences between post-socialist Germany in the East and West of Germany. All statistical analyses were conducted separately for the eight resulting spatial categories in order to find out whether or not relationships differed depending on the region and the spatial category.

Correlation analysis

First, histograms and box Whisker plots were applied to analyse the distribution and variance of data according to the spatial category. Secondly, a bivariate correlation analysis according to Pearson (because the data was mainly Gaussian distributed) was conducted using demographic, socio-economic and land use variables. We calculated the correlation coefficients r for all variables x and their change rates Δx for $t_1 = 1995/1996$ and $t_2 = 2003/2004$. Furthermore, we set-up a correlation matrix including all demographic, socio-economic and land use variables for all spatial categories, and for the West and East of Germany separately. Absolute correlation levels between ± 0.7 and ± 1.0 have been classified as very high, those between ± 0.5 and ± 0.7 as high and those between ± 0.3 and ± 0.5 as low. The variance and correlation analyses were both computed using the software package SPSS® version 14.

Bivariate statistical correlations alone do not prove a cause–effect relationship between the two variables in question, as there is the possibility of a not considered third causal variable. The existence of such a third causal variable can be excluded by applying partial correlation analyses. However, we decided to use our conceptual model (Fig. 2), which was developed on the basis of a literature review, as an orientation to decide whether an identified statistical correlation also reflects an assumed and hypothesised cause–effect relationship. All identified significant correlations that we previously expected to find, as it is documented in our conceptual model, are therefore considered as cause–effect relationships.

Cluster analysis

In order to investigate the heterogeneity of the spatial distribution of both demographic and land use variables, a cluster analysis was conducted using the software package SPSS® version 14. To capture both dimensions of interest, demographic change and land use change, the land use variables of agricultural land and residential area and the demographic variables of net-migration and natural population growth were chosen as key variables. The variable data were z-transformed to enable their comparison. Hereinafter, a WARD-hierarchical clustering was applied to all of the 439 districts. The WARD method using the squared Euclidian distance as a distance measure proved to be very suitable for spatial socio-demographic data since it builds clusters with a similar number of cases (Behrensdorf, 2006).

Results

First, the results on the spatial differentiation of demographic and land use variables are presented, followed by the statistical relationships of these. Table 1 summarises the Pearson correlation coefficients r that were obtained. High correlation coefficients are typed in bold.

Although population development shows a Gaussian distribution of values, differences between the spatial categories concerning the two components that influence population development, net-migration and natural population growth, were identified as substantial. On closer examination of the corresponding box Whisker plots, many extreme values were found in most of the spatial categories, indicating that growth and shrinkage simultaneously occur in the whole of Germany and not only in the eastern part of Germany as is often assumed (Fig. 3).

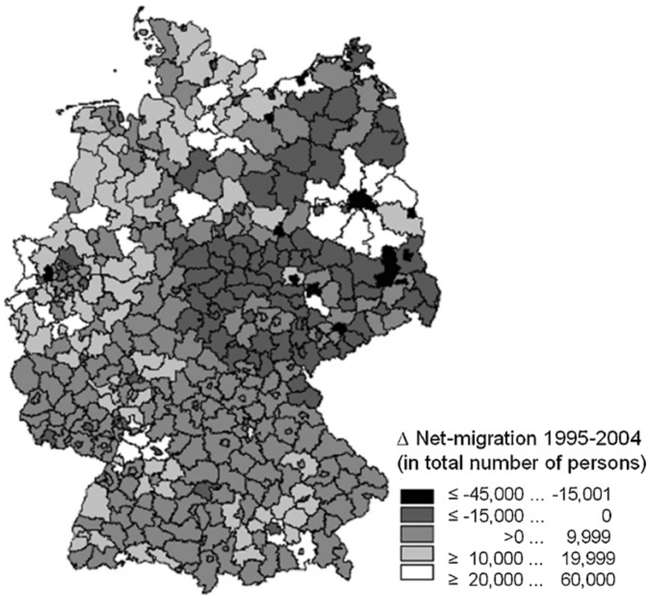

Fig. 4. The net-migration rate 1995–2004 across district-boundaries as total population/number of persons.

Core cities in the East of Germany suffered from the most severe population losses caused by both, out-migration and natural population decline. Some of the out-migrants moved to rural districts in agglomerations, namely to the surrounding areas of Berlin and Leipzig (Fig. 4), which is the reason for the positive net-migration of the eastern German rural districts in agglomerations. In addition to the surrounding area of Berlin and Leipzig, nearly all districts that gained population by immigration are situated in the surrounding areas of big cities, demonstrating that suburbanisation is an important process over the time span under consideration. In addition to the core cities, rural regions were also affected by out-migration. The change in the net-migration in this case, is positively correlated with the change in employees in the tertiary sector in six out of eight spatial categories ($r > 0.5$; Table 1).

The natural population growth also showed clear differences between the spatial categories. Here, the suburban districts showed a higher fertility compared to a clear decrease in natural population growth in all other spatial categories, indicating that families with young children prefer to live in the suburban regions. Furthermore, the natural population growth decreased more obviously in all eastern German districts: it is, however, not as important for the overall population development as the net-migration which evidently correlates with population growth in all spatial categories (cf. again Table 1).

The age structure is the other important demographic variable in addition to the absolute population development. The shift to an older population was greatest in eastern Germany's rural areas due to the out-migration of young people and low birth rates. Here, the change in the old-age dependency rate correlated with the migration rate with a correlation coefficient of −0.74 and with the change in the amount of commuters with a correlation coefficient of −0.71. Moreover, it showed a high correlation with the change in living area per person (0.59) in all eastern German districts (Fig. 5).

As examples for the spatial differentiation of land use changes, the development of settlement and transport areas (Fig. 6) and the development of agricultural areas (Fig. 7) over the time span from 1996 to 2004 are presented using Whisker box plots. To facilitate an assessment of these changes, the absolute values of the area sizes for the year 2004 are also shown. An important fact is the comparably high expansion of the settlement and transport areas in core cities in the East of Germany, in spite of the small absolute size of city districts. Agricultural area decreased in all of the spatial categories by a similar amount, but a little more intensely in the western districts.

What statistical relationships could be found between demographic and land use changes? The land use variables did not correlate with the demographic variables in eastern Germany. However, some correlations between economic variables and land use variables were found here, like for example a correlation of 0.63 between the settlement and transport areas and the investments in industry in the rural areas (Table 1). The relationships in western Germany are different from those in eastern Germany. Here, there was a high correlation between the population development and the migration rate with the change in settlement and transport areas (0.5) as well as with the change in residential areas (0.5). A slight correlation with the change in the transport area was also observed (0.36). Fig. 8 shows the different relationships between the population development and the settlement and transport areas for eastern and western Germany.

In contrast, the correlation between the population development and the change in the agricultural area was negative (−0.49). Logically, there was also a negative correlation between the settlement and transport area with the agricultural area (−0.78), meaning that the increasing settlement and transport area replaced the agricultural area. The forest area did not show any consider-

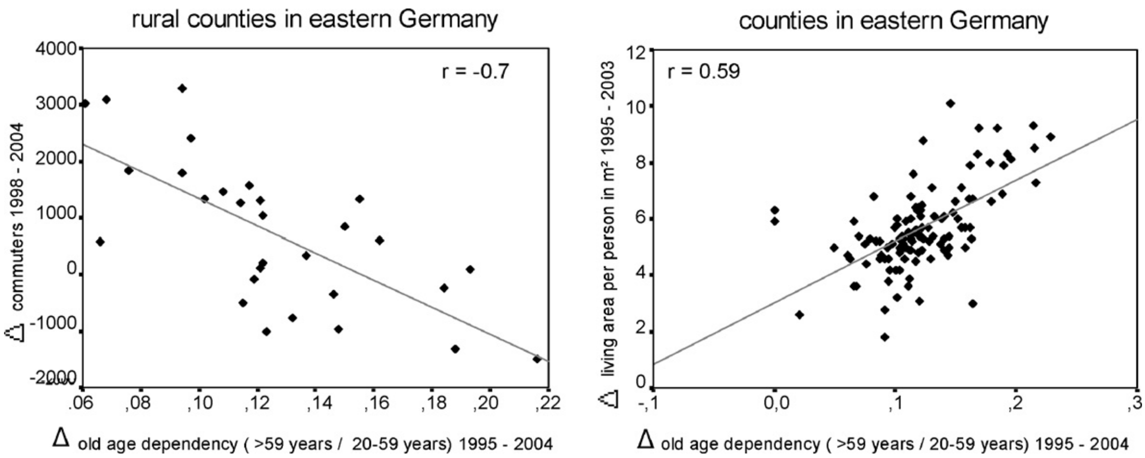

Fig. 5. Scatter plots of the Δold-age dependency (1995–2004) in districts in eastern German with Δcommuters (1998–2004) and with Δliving area per capita in m^2 (1995–2003). The old-age dependency shows a high correlation with both of the other variables.

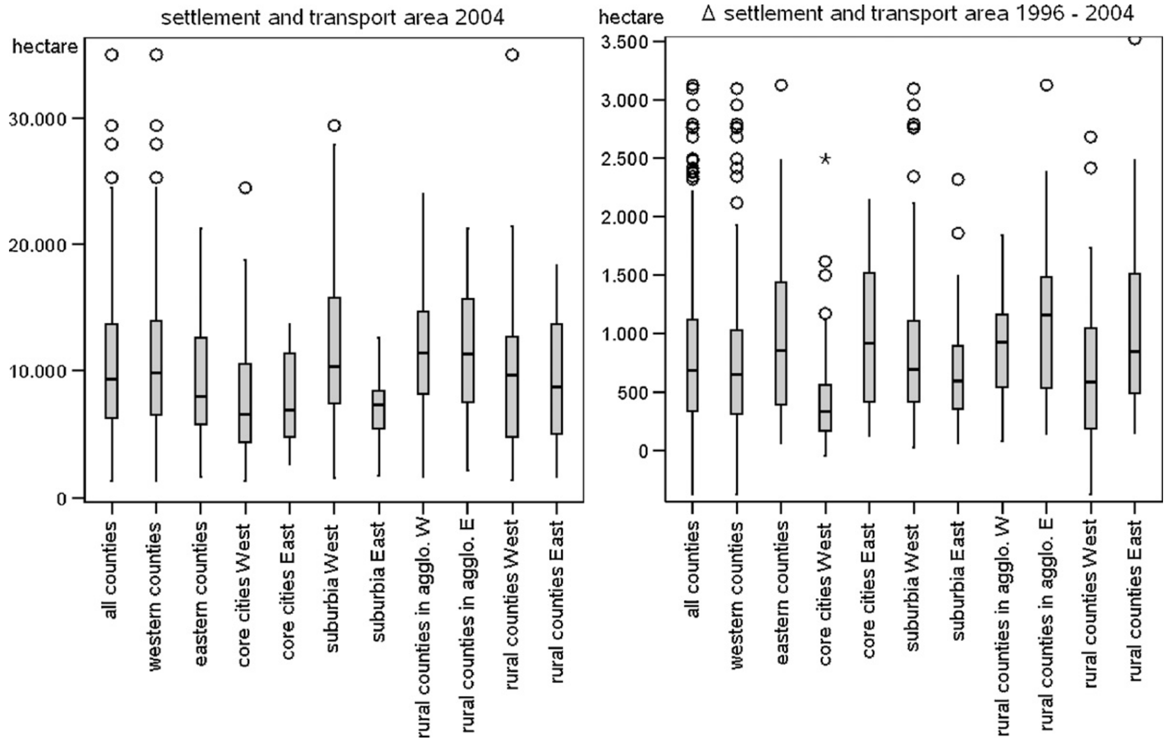

Fig. 6. The settlement and transport area in absolute values for the year 2004 and its changes from 1996 to 2004 for different spatial categories.

able correlations, either with population development or with the agricultural area.

Fig. 9 shows that the decreasing settlement population density is valid for almost the whole of Germany, whereby the settlement population density only increased in 15% of all districts. A declining settlement population density has negative environmental impacts in several respects. It affects the land and energy resource-efficiency due to a higher demand for residential area per person and a higher consumption of energy per capita for mobility purposes (Camagni et al., 2002; Newman and Kenworthy, 1988, 1989). Hence, we are striding away from the goal of sustainable land use, in spite of the reality of demographic change. It seems that the effects of a shrinking population in some parts of the country are overlaid by the effects of suburbanisation and changing household

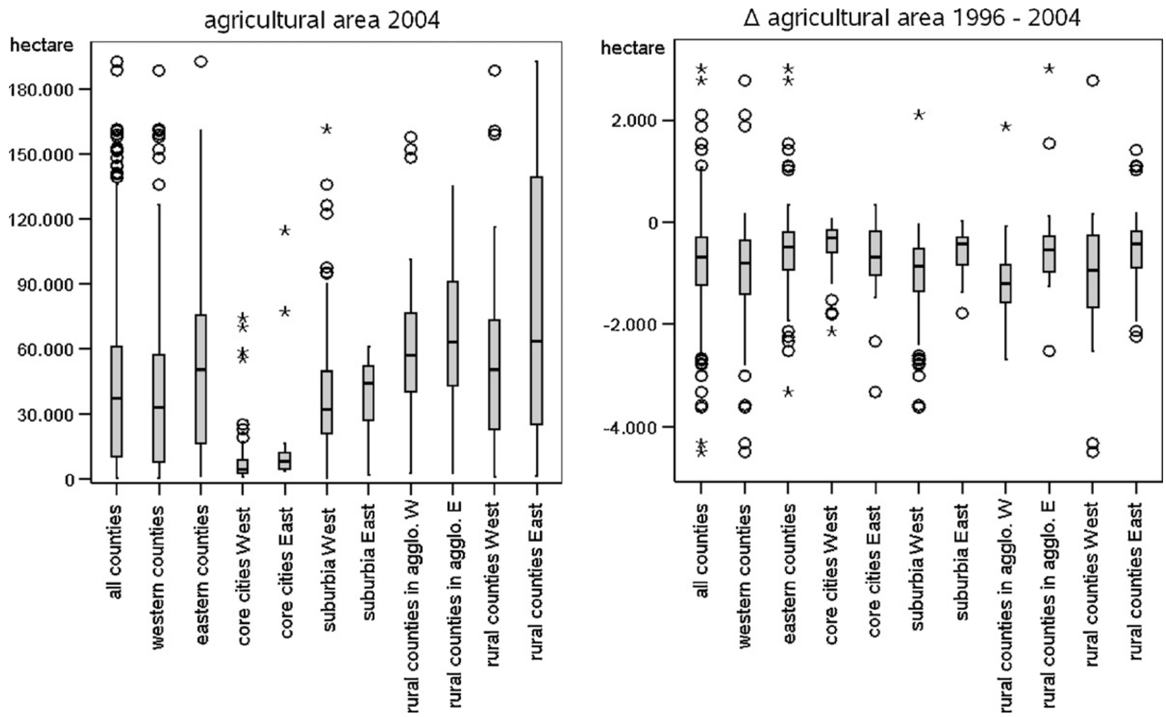

Fig. 7. The agricultural area in absolute values for the year 2004 and its changes from 1996 to 2004 for different spatial categories.

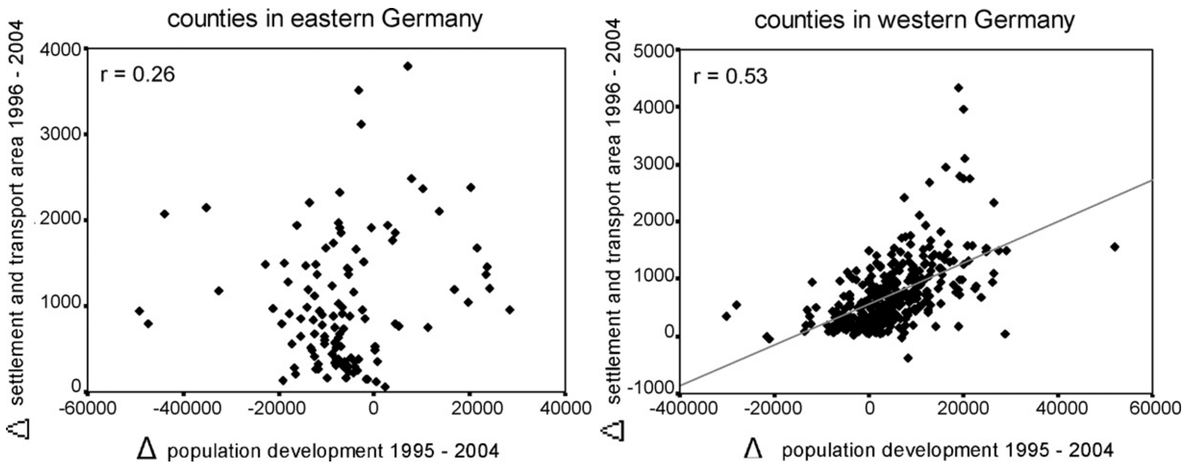

Fig. 8. Scatter plots of Δpopulation development (1995–2004) and Δthe settlement and transport area (1996–2004) for districts in eastern and western Germany. The population development only correlates in the western German districts with the development of the settlement and transport area.

structures. Therefore, it would be interesting to incorporate more household relevant variables into further research.

Furthermore, the inclusion of additional economic, tax and investment variables should reveal important results. Equally, an analysis at the municipality level, including all German municipalities, would be desirable because processes even differ within one district and can cancel each other out when observed at the district level. However, the problem of finding comparable data at the municipality level for an adequate time span hinders such an analysis.

The cluster analysis also revealed spatial differentiations in demographic and land use changes. The optimal number of clusters is the one after which the marginal gain of adding one more cluster drops sharply. As the outcome of the clustering, a solution with six clusters was chosen. Table 2 summarises the cluster characterisations, whereas Fig. 10 illustrates the cluster's spatial distribution.

The first cluster is composed of 187 western German and 42 eastern German districts. It includes 67% of all core cities, which exhibited a relatively small absolute land use change due to their small absolute area. Furthermore, the population number also changed the least in cluster 1 compared to the other clusters. 95% of the districts in the second cluster are located in western Germany, all of which are in the suburban and rural area. It is the cluster with the highest average natural population increase, with a high decrease in agricultural area and a high increase in residential area. The districts that are gathered in the third cluster are those with the highest population losses, located in eastern Germany and in the western German old-industrialised regions of the Ruhr basin and Saarland. The increase in residential area as well as the decrease in agricultural area in these districts was moderate. The fourth cluster is characterised by high immigration and a considerable land use

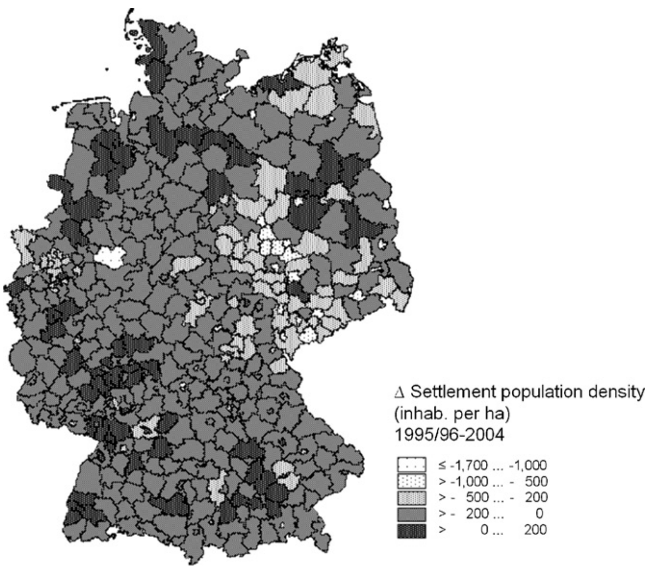

Fig. 9. Change in settlement population density and transport area (in inhabitants per hectare) from 1995 to 2004.

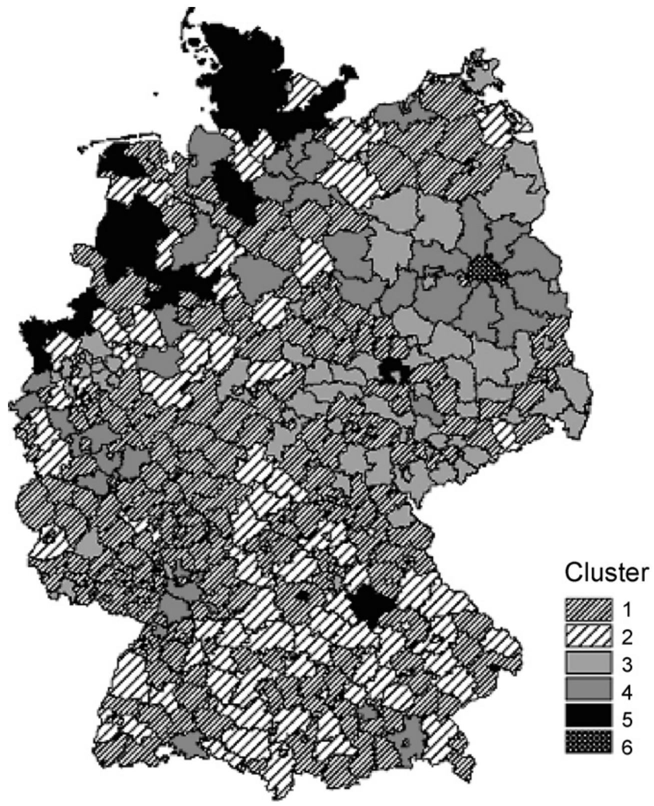

Fig. 10. Spatial distribution of the six clusters, resulting from a cluster analysis that comprises the four variables natural population development (1995–2004), migration rate (1995–2004), Δagricultural area and Δresidential area (both 1996–2004).

Table 2
Main characteristics of the clusters concerning the development of the four variables (natural population development, migration rate, agricultural area, residential area) and regarding the belonging of the districts to western or eastern Germany and to the spatial categories.

	Composition	Natural increase 1995–2004 (persons)		Migration rate 1995–2004 (persons)		ΔAgricultural area 1996–2004 (ha)		ΔResidential area 1996–2004 (ha)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Cluster 1	187 West, 42 East, 67% of core cities	−1641	2905	3243	4498	−569	391	284	223
Cluster 2	74 West, 4 East, suburban and rural	1220	3790	8970	4966	−1632	475	670	176
Cluster 3	24 West, 52 East, all spatial categories	−7078	4758	−7681	9194	−297	656	241	237
Cluster 4	23 West, 13 East, 83% suburban	−2830	6046	22855	12137	−1112	1094	1017	449
Cluster 5	18 West, 1 East, 63% rural	1142	4833	13474	5253	−3248	1659	1601	625
Cluster 6	1 core city (Berlin)	−54923	–	−29264	–	−1806	–	1150	–

change. As mentioned above, most of these districts can be found in the suburban area surrounding big cities. However, the increase in residential area was even greater in the districts of the fifth cluster, which is composed mainly of rural districts in the West of Germany. Remarkably, the population increase here was not as high as in those districts of the fourth cluster. The core city Berlin formed its own cluster, because population losses due to out-migration and natural population decrease were far more distinctive here than in any other cluster.

Hence, some typical characteristics can be found for each cluster, but the differences concerning the development of the settlement and transport areas are greatest. Furthermore, the migration rate shows considerable differences between the clusters. For most clusters, a principal region in the country can be identified, with the exception of cluster 4 whose districts are sprawled out in suburban areas all over the country (Fig. 10).

Discussion

The results of our analysis reveal that demographic variables vary considerably from district to district, depending on the spatial category and the part of the country in which the district is located. As population decline can mainly be observed in the East of Germany and in the old-industrialised regions in the West of Germany, it seems to accompany economic decline. Regions that offer more jobs in the service sector are attracting the labour force, which can

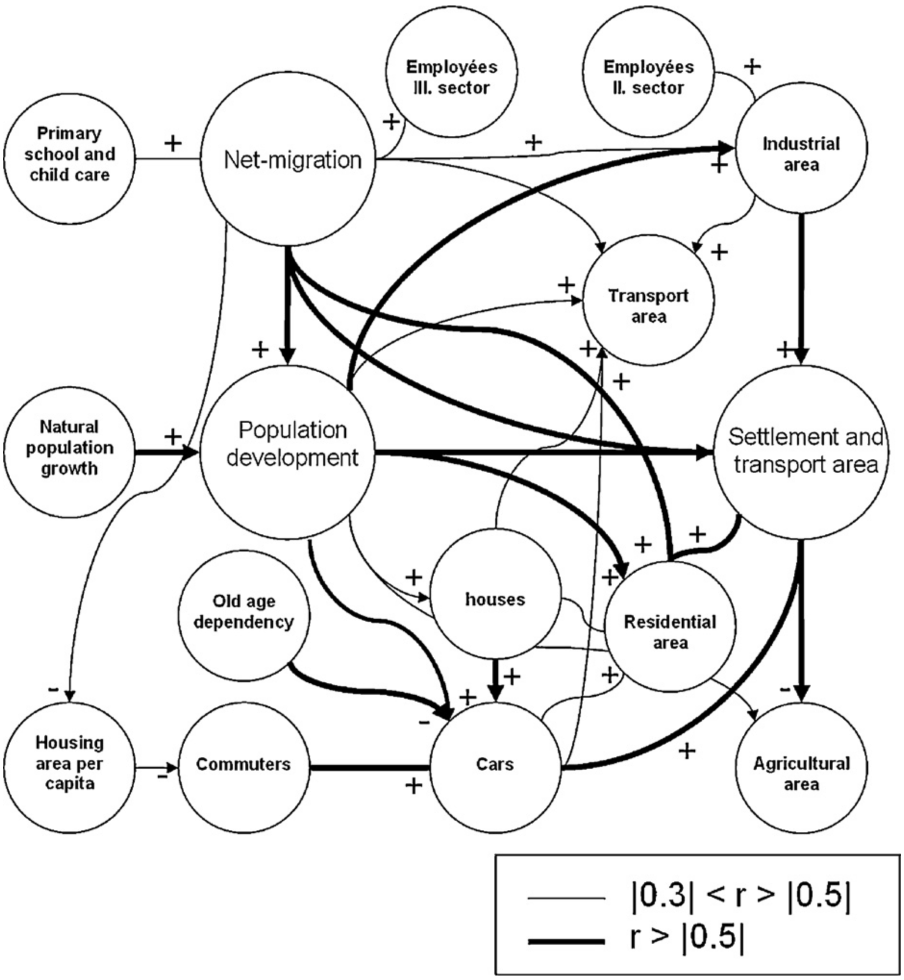

Fig. 11. Statistical relational model for districts in the West of Germany.

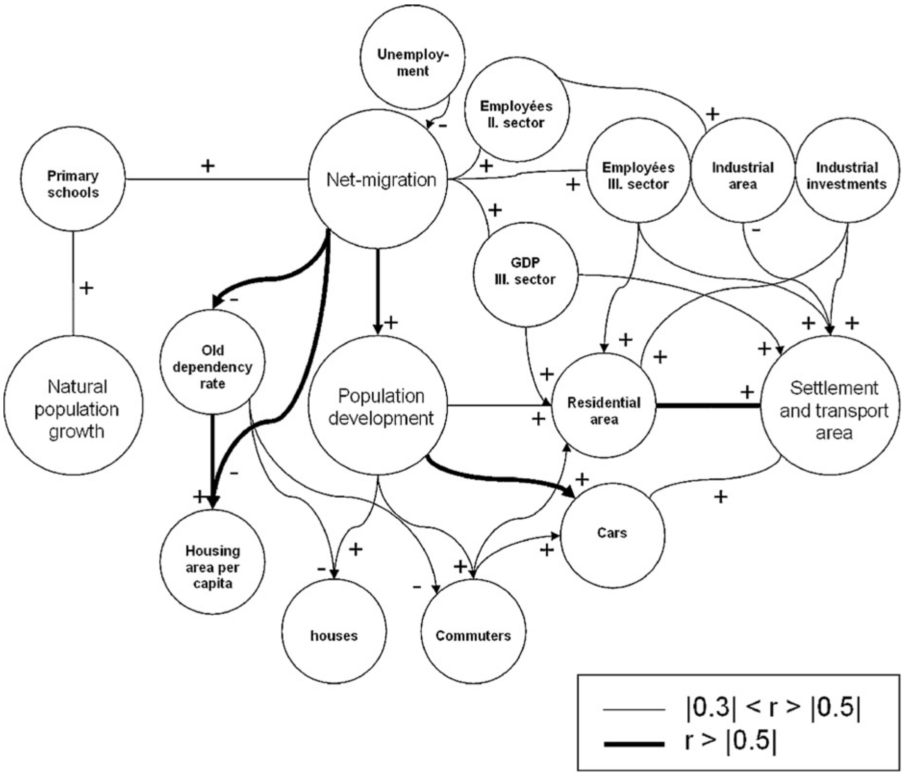

Fig. 12. Statistical relational model for districts in the East of Germany.

be assumed by the correlation coefficients between employees in the tertiary sector and the migration rate (cf. again Table 1). Core cities however are also experiencing a loss of population to the suburban districts by out-migration. This suburbanisation process is producing growing and shrinking districts that are situated next to each other. Districts that are facing population decline due to out-migration are often the ones with the most obvious change in the age class distribution, which is demonstrated by the high correlation between the out-migration rate and a growing old-age dependency (cf. again Table 1). Hence, both population shrinkage as well as an ageing population are more likely to be influenced by the migration rate than by the natural population growth. This observation is only true at the small-scale district level, although it is manifesting in the effort of the communities to attract young people.

The question as to whether these dynamics are related to changes in land use or infrastructure cannot be answered with universal validity. The change in net-migration is of particular importance for districts in the West of Germany. Because most of these districts are growing in total population, it can be concluded that in-migration contributes to the development of settlement and transport areas whereas out-migration does not. Obviously, the growth of areas for settlement and transport do not decrease considerably or even stop when the population is shrinking. One reason for this might be the ongoing land consumption at the urban fringe of shrinking cities leading to deconstruction and perforation in the city centres (Haase et al., 2008). The urban restructuring programme "Stadtumbau Ost", that was implemented by the Federal Government in 2002 receiving subsidies of 2.5 billion Euros for the demolition of 350,000 flats (Lang and Tenz, 2003; Wiechmann, 2003), still does not show any effects at the district level since district and national statistics do not cover these data yet. Several processes that started in the East of Germany after the reunification are assumed to be responsible for the missing correlation between population development and land use change, such as the improvement to infrastructure and the change in household structures.

Compared to the migration rate, the effects of the shift in the age structure on land use changes are still minor. No correlations between the change in age structure and land use changes could be found. However, the indirect impacts through the change in commuter volume, the percentage of single households and an increasing living area per person are likely to grow in the future. There is already a strong relationship between these variables and an ageing population in the East of Germany.

Figs. 11 and 12 summarise slight correlations (normal lines) and high correlations (thick lines) in absolute values between the demographic and land use variables that were found in districts in the West and East of Germany. Both figures show once again that there is a statistical relationship between population dynamics and land use changes in western Germany, whereas economic development seems to be of greater importance for land use changes in eastern Germany. The collapse of industry in East Germany after reunification and the subsequent subsidies in industry and commerce are the economic and political factors behind this situation.

Surprisingly, no important correlations could be found between the forest area and other land use types or between the forest area and demographic variables. One reason for this is the difficulty for statistical agencies to detect young forests growing on areas formerly used for agricultural purposes, as long as the ownership structure does not change. According to the survey of the National Forest Inventory which also detects areas of succession, the overall forest area is actually reported to be larger (11.1 million ha in 2002, www.bundeswaldagentur.de) than in the regional statistics that are used (German Federal Statistical Office, 2007). Unfortunately however, the National Forest Inventory data do not exist at the district level.

The cluster analysis demonstrates that the spatio-density types 'core cities', 'suburbia' and 'rural areas' indeed differ in their development, even though the more important criterion for the assignment of a district to one of the clusters was its location in the east or west part of the country. The districts with the highest land consumption for residence areas are mainly located in the rural-peripheral area of north-western Germany; they are grouped in cluster 5 (Table 2). These are for example the districts of Emsland and Cloppenburg, both known for their favourable demographic and economic development (Danielzyk and Wiegandt, 2005).

Hence, we must add that not all rural-peripheral districts are affected by population and economic decline, at least not all of those in western Germany, although these are moving away from their "rural" character by sealing more and more surfaces. Most of the other districts with a favourable demographic development, or even a natural population increase, can be found in the suburban regions of southern Germany, where families are moving to and away from the city centres. However due to the fact that a natural population increase is not related with land consumption to the extent that a positive migration rate is, these are not the districts with a strong growth in residential areas. The latter are clustered in cluster 4 (Table 2), which contains the afore-mentioned districts with the strongest immigration, e.g. the districts surrounding Berlin, Munich and Hamburg.

Cluster 3 includes the districts with the most severe population losses due to out-migration and a natural population decline. They are located in the East part of Germany and the old-industrialised regions of West Germany, but a dominant spatial category cannot be found. The land consumption for residential areas is lowest in the districts of cluster 3. This observation however should not cover the fact that the settlement population density decreased the most in cluster 3 (cf. again Fig. 9), which explains the missing correlation here between population development and land use changes.

The results of the paper permit to draw a range of spatial planning and policy implications of which the most important are as follows: firstly, federal targets such as the 30-ha target cannot "rely" on demographic decline as a key to reduce land consumption. On the contrary, other government policies such as the commuter tax allowance or the financing of suburban road infrastructure counteract a reduction of land take in demographically declining areas. Secondly, federal policies on spatial planning and infrastructure should focus more on the causations and roots of land consumption but regionally differentiated. Whereas in the flourishing growing clusters shown in Fig. 10 land consumption has to be controlled with land-saving settlement forms and maximum settlement densities of newly prepared land, predominantly in the eastern part of Germany brownfield re-use strategies and urban infill-development in combination with minimum densities might be a more appropriate bundle of spatial planning policies that take a "thinning-out" of the population better into account (BMVBS and BBSR, 2009; Kötter et al., 2009; Schetke et al., 2009).

Conclusions

As one of the first comprehensive studies on quantitative relationships between demographic and land use change, our analysis shows that the declining population in core cities and rural areas in the East of Germany does not accompany a decrease in land consumption, as economic processes seem to be of far greater importance for land use changes here. So far the ageing population has not yet had any detectable effect on land use changes, but this will change in the future, if the per capita housing area of elderly people continues to increase. The cluster analysis reveals that the districts with the highest land consumption per capita are located in the rural areas of north-western Germany. Apart from suburban districts with significant immigration, the settlement population density decreased across all districts including both eastern and western Germany. Hence, we are striding away from the goal of sustainable land use regardless of the reality of demographic change.

The findings of the paper suggest that demographic change will not "solve" the problem of land consumption in Germany, which is a striking discrepancy between the actual amount of daily land consumption (a current average of 115 ha in 2008; Federal Statistical Office, 2008) and the political goal of limiting new land consumption to 30 ha/day. However, it clearly identifies where both demographic and land use change lead to a more concentrated or even scattered development with increasing land consumption per capita at the least. The clusters that we identified give planners more support when considering regionally specific policy options for dealing with demographic and land use change rather than pursuing an overall and non-differentiated federal land consumption target of 30 ha.

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Guidelines for the "Perfect Inner City". Discussing the Appropriateness of Monitoring Approaches for Reurbanization

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ABSTRACT *In this paper, we analyse the appropriateness of monitoring approaches for the observation of inner-city reurbanization processes. Reurbanization is conceptualized here as a process of long-term stabilization of inner-city areas by both a readiness of present residents to stay and an influx of new residents. It has been recently re-set on the top of the European urban research agenda since non-growth has proved to be a major path of future development for many European cities. Recent research evidence across Europe underscores the fact that reurbanization depends much on local settings of institutional, socio-economic and infrastructural factors. To foster a clearer understanding of the nature and dynamics of local reurbanization, to assess its extent and progress and, what is more, to help practitioners to shape sustainable policy initiatives appropriate to the respective context, reurbanization needs to be observed over the long term. The complex character of reurbanization sets new challenges for monitoring approaches and indicator-based tools. Due to the genuine relation of the present debate on reurbanization to the phenomenon of non-growth or the return of the compact city, the focus in this paper is set on demographic development trends and their impact on inner-city change. In this vein, our paper presents a monitoring design and a respective newly developed indicator set for reurbanization which focuses more on the initial recognition of reurbanization than on its long-term stability. Methodically, chances and limits of the integration of household-related indicators and qualitative knowledge on reurbanization into monitoring tools are highlighted. Empirical and statistical evidence is taken from a recently completed EU FP 5 research project and from municipal surveys.*

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Introduction

Reurbanization has been discussed since the 1980s as a concept to explain the resurgence of inner-city housing as an alternative for different residential groups. It describes the stabilization of inner-city areas by means of stopping out-migration and encouraging present residents to stay as well as the influx of new residential groups. It highlights the nexus between urban transformation, newly emerging demographic and household patterns and their consequences for the use of urban structures and housing markets (Nuissl & Rink, 2005). Being closely connected to demographic and household shifts, diversification of lifestyles and related altering housing preferences, it focuses on a newly emerging "city-mindedness", i.e. urban living as a primary housing preference. It depends highly on local settings of economic and infrastructural but also historical and cultural factors.

To foster a clearer understanding of the nature and dynamics of local reurbanization, to assess its extent and progress and, what is more, to help practitioners to shape sustainable and appropriate policy initiatives, reurbanization needs to be observed over the long term. Its complex and qualitative character as well as high context dependency sets new challenges for monitoring approaches and respective tools (cf. also Morrison, 2003, pp. 129, 132; Banzhaf *et al.*, 2005).

Inner-city development is characterized by the interplay of processes in space and time (Antrop, 2004). Within recent decades, on the one hand, forecasts have been disproved quite often by a more differentiated, erratic and, subsequently, "unpredictable" reality (e.g. concerning gaps between stated housing preferences and revealed relocation decisions; consequences of residential changes, ageing, displacement and segregation). On the other hand, however, lean municipal budgets and the rising competition of cities throughout Europe and world-wide, forecasts are of a rising importance for both politicians and urban planners to exploit effectively existing potentials, to avoid dead ends in local development and to counteract unfavourable trends in the local economy, spatial and population development, etc. This caused a rising interest in the discussion of monitoring systems picturing urban processes within the scientific community. Up to the present, there is found a—hitherto—manageable body of theoretical and practice-targeted knowledge. There are more questions to be answered than those that were answered by the recent discourse of urban planning and scenario formulation (Caruso *et al.*, 2005).

Set against this background, our paper analyses the appropriateness of monitoring approaches for the observation of inner-city reurbanization. A newly developed set of reurbanization indicators is presented. The focus is set on demographic development trends and their impact on inner-city change. It shows, furthermore, how monitoring approaches are challenged by their application on urban processes determined not only by measurable impacts or settings, but also by the individual preferences and actions of residents as well the priorities and interests of social players (Haase *et al.*, 2005a). Empirical and statistical evidence is taken from a self-administered questionnaire survey, in-depth interviews carried out within the framework of the recently completed EU FP 5 research project entitled "Re Urban Mobil" aiming at analysing reurbanization in European inner city areas and from municipal statistics.

Set against this background, our paper presents a monitoring design and a respective newly developed indicator set for reurbanization. The focus of the design is set on demographic and household development trends and their impact on inner-city change. Due to the temporal complexity of reurbanization processes our approach comprises on the one

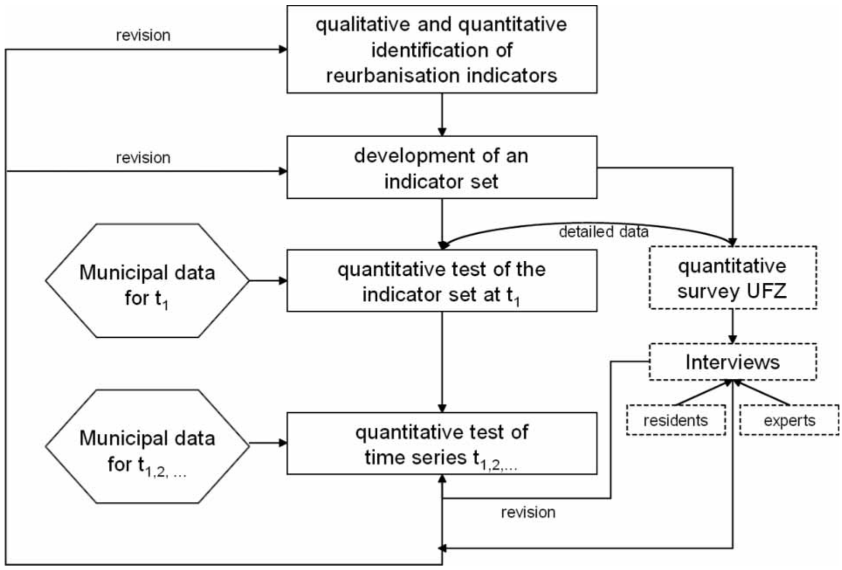

Figure 1. Monitoring reurbanization processes in inner-city areas (t = time step)
Source: author's draft.

hand the initial (more quantitative) recognition of reurbanization, which is in the centre of this paper. A second line of the design follows the investigation of the long-term stability and evidence of change in a more qualitative way using expert knowledge and residents' perceptions (cf. Figure 1 later).

The paper starts off by contextualizing both the urban context (reurbanization) and the methodical approach (urban monitoring). Then, the challenges of measuring evidence and progress of reurbanization are outlined. In a subsequent section, these challenges are transferred into a novel core set of indicators for reurbanization followed by a first proof of the indicators relevance and validity using small-scale statistics for the eastern German city of Leipzig (2004). Finally, some conclusions are made.

Material and Methods Studied: The Context of Reurbanization and Urban Monitoring

Reurbanization

The term reurbanization was already used in 1972 by the German sociologist Pfeil (1972, p. 326) in an incidental way. During the 1980s and early 1990s, it was discussed in relation with the re-discovery of the inner city by non-traditional and city-minded households in Western Europe (Häußermann & Siebel, 1987; Kujath, 1988; Lever, 1993) as well as a trend of recentralization (Berg *et al.*, 1982; Cheshire, 1995). Then, however, reurbanization vanished to return the main attention of urban research again to more established concepts like regeneration or gentrification. Moreover, many scholars continued to express scepticism referring to the existence of reurbanization, at least in a long-term perspective

(Cheshire, 1995, pp. 1058–1059; Champion, 2001, p. 158; Klaassen & Scimeni, 1981; Müller & Siedentop, 2004, p. 25). It is only during recent years that reurbanization was re-set as a top issue on the European urban research agenda. Its application is, however, still mostly based on the quantitative, population-focused model of urban development by van den Berg *et al.* (1982; for an updated version see Lever, 1993, pp. 268–271) that supposes reurbanization to be reached when—after urbanization, suburbanization, dis- or counterurbanization—the share of residents in the inner city is, compared with the whole urban agglomeration, increasing again (cf. Cheshire, 1995: relative reconcentration). Despite this predominance, approaches have also been increasingly used that describe reurbanization in terms of qualitative urban change (such as rejuvenation or diversification of household structures. In doing so, e.g. the rise of one-person households and the emergence of a "distinctive urban demography" in French inner cities was taken as evidence for reurbanization by Ogden and Hall (2000, pp. 372–376). Further connotations are "regaining of attractiveness" or "household diversification" (Kujath, 1988, pp. 27–34; Lever, 1993, pp. 271–274) as well as "reurbanisation as the maintenance or re-gaining of social mix in the inner city" (Burton, 2003, pp. 537–539 and 558–559). Some scholars equated reurbanization with gentrification (Kujath, 1988; Lever, 1993; Gaebe, 2004, pp. 154–161) or with revitalization due to cultural flagship projects (Seo, 2002; for a systematic overview see Haase *et al.*, 2005a, p. 80). Last but not least, reurbanization shows some overlap with the UK regeneration debate (for an overview see Carmon, 1999; Roberts & Sykes, 2000) on the stabilization of neighbourhoods by residentialization and balancing socio-demographic structures, housing, leisure and jobs in the inner city (Bromley *et al.*, 2005, pp. 2407–2408, 2409, 2426) and the understanding of small-scale urban dynamics and social cohesion (Morrison, 2003, p. 117; here apply e.g. works on reurbanization by Lambert & Boddy, 2002; Burton, 2003). The debate on reurbanization represents, however, a distinctly separate discussion since it has focused, to date, less on planning initiatives and more on the observation of emerging trends of inner-city residential change and the return of urban living as a housing preference.

Cross-referencing mainly the qualitative and small-scale approaches to reurbanization, most promising from our point of view is the strong interplay with fundamental demographic processes, especially since non-growth has been becoming the main development trajectory of European cities (Kabisch *et al.*, 2006). To develop the urban space in a more sustainable and resource-sensitive way and to ensure the liveability of the "compact city" (Burton, 2000), households as the key players of mobility, staying and leaving of residential locations come into focus (Buzar *et al.*, 2005; Buzar *et al.*, 2007; Haase *et al.*, 2005a). Generally, the hitherto under-researched dimension of housing demography (Myers, 1990) and the shaping of an "urban demographic landscape" by households (Gober, 1990) are more considered. Changing household structures in line with the Second Demographic Transition (SDT; Kaa, D. van de, 1987, 2004; Lesthaeghe, 1995) brought about by societal processes (individualization and diversification of lifestyles), economic developments (rise of the service sector) and new fertility patterns (decreasing birth rates, postponement or renouncement of the family phase in the life cycle; for more detail see Buzar *et al.*, 2005, pp. 414–422) are assumed to be preconditions of reurbanization. Contemporary households act very situation-sensitive, i.e. their decision holds the capacity (and necessity) to adapt to changing internal and external conditions. Households have become smaller in size and less stable since individuals shift from one living arrangement to another several times during their life course. Non-traditional or non-familiar household types (one-person, cohabiting couples, single parents and young adults sharing a flat) account for a good portion of the pluralized landscape of household types since their number has significantly increased. While the pluralization of living arrangements is to be observed Europe-wide, the concrete forms are dependent upon cultural and societal specifics (Kuijsten, 1996).

The inner city is highly adaptable to the preferences and needs of SDT-sensitive households. It exhibits a range of appropriate characteristics—e.g. closeness to the city centre and to places of work, qualification and leisure, easily accessible by public transport. Their housing structures allow for flexible adaptations to changing personal circumstances and often the dwellings there are for rent, even in societies which are predominantly owner-occupied. Especially among non-traditional/non-familiar households, urban life with its central notions of density and diversity of both people and opportunities possesses a high value (Häußermann & Siebel, 1987, pp. 17–21; Goetzmann *et al.*, 1996). In both cultural and symbolic terms, the inner city is transformed by these selected socio-demographic groups, their habits, interests and behaviour. But also for families, inner-city housing seems to be more attractive and desirable than hitherto assumptions of urban research have presumed (Brühl *et al.*, 2005). To put it differently: Evidence and progress of reurbanization becomes visible by the match of found residential environment and existing housing preferences of those households who carry recent inner-city in-migration and keep these areas alive and liveable (Buzar *et al.*, 2007; Haase *et al.*, 2005a). Due to its complexity described in this section, reurbanization sets new challenges for urban monitoring to observe this process. The following section therefore deals with hitherto approaches and postulates.

The Methodological Approach: Urban Monitoring

Prerequisites. What is urban monitoring? It is the surveillance in state over set periods of time which provides information primarily on both stock and numerical change of the social, economic, built and ecological environment (Hellawell, 1991, for the city of Leipzig; Brandt *et al.*, 2002). Current literature on urban monitoring argues that scientists and practitioners meanwhile agree that a certain compromise always needs to be made between the spatio-temporal grain that can be included and the level of change that can be reliably detected (cf. again Hellawell, 1991). This prerequisite is given when the monitoring is about known processes (e.g. urban growth) and related indicators, but is often difficult to provide when new ones such as reurbanization have to be observed. Owing to the highly spatial and temporal "resolution" of urban processes it is often difficult to indicate changes that are of interest to the scientist and planner. A temporally reasonable resolute recurrence interval of the observations is another prerequisite for successfully monitoring urban change, because then, irrespective of the extent or variability of this change, it is always "real" (Caruso *et al.*, 2005; Hemphill *et al.*, 2004). By contrast, successive random samples drawn from an urban population or the current urban structure at a certain time give initial and innovative ideas of possible processes that have to be followed by regular monitoring and thus verified afterwards. In doing so, both kinds of analyses are of great scientific value for urban monitoring to register long-term developments. Naturally, the degree of variation between samples taken as single case studies has to be recognized and assessed when transferring its results to the city-level or to another site.

Current urban monitoring deals mostly with processes that are known at the theoretical level for being decisive for urban issues such as demographic (population) development, urban growth (or sprawl), economic development and the environmental status (Home, 1984). In particular, the housing segment of a city is observed only in selected urban monitoring systems at a cumulative level.

Existing approaches. Monitoring strategies dedicated to urban processes, their features and components are stressed as an integrative tool of scientific as well as of stakeholders' or practitioners' relevant activities. But in reality, as research of community, urban structure and residential areas, they are often divided into different sectors due to their multi-dimensional character. Thus urban monitoring programmes are also determined by "the sectoral". Some guiding principles for a complex monitoring of urban processes which could also address reurbanization are given by van Herzele and Wiedemann (2003) and are amplified and interpreted for monitoring reurbanization by the authors (based on Bischoff, 2005):

- "Individual-based" monitoring of reurbanization: As residential spaces (housing units, streets, compartments, parks or other green spaces, etc.) are intended to support urban inhabitants' quality of life, they have to be considered in relation to places where people live and in a way that reflects their wants and needs. However, this kind of monitoring is still far from describing complex profiles of actors (e.g. households, single inhabitants) moving on the urban ground.
- "Process-driven" monitoring of reurbanization: Migration, decline and resilience should be evaluated in relation to the relevant functional scales, ranging from house to city or individual to group level in order to support reurbanization.
- "Space-accessibility-safety-driven" monitoring of reurbanization: Here, the residential space in form of distances (proximity, accessibility, ways-to-go, surface, visibility, safety, criminality, etc.) should be considered. If these are not fulfilled, people will not be attracted to these spaces.
- "Environment-based" monitoring of reurbanization: A variety of qualities ensures an array of activities and experiences related to urban green within close proximity to homes and workplaces. Variety is a general issue for total supply at the different functional levels, e.g. people use urban landscapes such as residential areas including parks, playing fields, urban forests or fallow land (brownfields) compared to suburban ones. Urban green spaces are seen hereby in a wide scope and include all the open areas, which can be perceived by citizens as contributors to their quality of life. This should be highly considered when evaluating the meaning of multiple land use pattern for reurbanization.
- "Strategy-driven" monitoring of reurbanization: In contrast to long-time statistical analyses of the major impact of urban developments, these approaches comprise purpose- and normative-oriented, instrumental ingredients.
- "Practically oriented and administratively based" monitoring of reurbanization: Existing, practically oriented systems of urban monitoring as currently used within the administrative urban development of municipalities are mostly reduced to a simple statistical description of single indicators and simple indices and ultimately to a far-reaching static quantification of the changes of major impacts and factors of urban development in, for example, the monitoring report for the city of Leipzig (Stadt Leipzig, 2001–2004). However, these reports should be used as a database for a more differentiated analysis of the quantitative aspects of reurbanization.

After defining the monitoring framework we come to the discussion of setting up appropriate indicators for the used monitoring approach.

Design of indicator sets. According to the design of a relevant core set of indicators for the reurbanization process urban monitoring appropriate indicator development procedures are required that should be based on existing methodological experience. First, numerous existing approaches propose collections of indicators (e.g. United Nations, 1996, OECD, 1988, 1993, 1997a, 1997b, 1997a, 2001). On the one hand, excessive information collection does not provide a clear interpretation of a given urban process: often it goes against the objective of simplification and proving evidence. On the other hand, an over-aggregated indicator set does not adequately represent urban complexity and heterogeneity, especially if it results from aggregating opposite trends or antinomies (Bell & Morse, 2000). A set of indicators should be flexible enough to respond to the different needs of stakeholders and interest groups and management strategies based thereon at the different scales.

Second, indicators are used to evaluate the performance, thresholds and trade-offs (stocks and flows) of the urban system (Haase & Nuissl, 2007). In doing so, standards or target values are required to define the objectives and evaluate policy strategies. The establishment of these standards is either of quantitative nature (Does the indicator fit with the objective function?) or based on expert assumptions, qualitative information and negotiations of competing interests.

Third, in order to follow up on and audit political actions and strategies, monitoring indicators should generally not only describe the current state. On the one hand, it should acknowledge the future development dynamics to know whether the system is going toward or away from the desired progress. On the other hand, the monitoring proves evidence that a policy strategy generates certain effects (Allen, 2001; Harris & Batty, 2001).

To gain a sound understanding of the urban system, exhaustive collection of indicators with a strong statistical connotation are insufficient. The relevance of each indicator has to be considered with regard to the application context (de Montmollin & Altwegg, 2000; Malkina-Pykh, 2002; Gallopin, 1997). For example, the "Sustainable Seattle Initiative" explicitly proposes the concept of complementary indicators where the linkage of each indicator with others is clearly highlighted (http://www.sustainableseattle.org). The Global Urban Observatory initiative from UN-Habitat discusses transversal indices that link indicators and themes with others (UN-Habitat, 2001, 2002). The "Sustainable Cities Initiative" and the "Urban Audit I/II" from the European Commission proposes a structured approach with several major transversal concerns, each indicator relating to one or several concerns (Ambiante Italia, 2003; OOPEC, 2004).

At the international European level the URBAN AUDIT (pilot phase Urban Audit I followed by Urban Audit II) programme has provided reurbanization-relevant data on the regional and city level since 1991 (Table 1). The programme is carried out under the responsibility of the European Union (EU) Regional Policy Department (DG Regio; European comparative study of cities concerning their quality of life) and data is provided by EUROSTAT for a time frame starting 1991 until recently (survey for the years 1996, 1998, 2001, 2003, 2004):

- larger urban zone (LUZ), which is an approximation of the functional urban zone centred around the town/city;
- core city (administrative definition);

Table 1. Resolution and information level of global, European, national and municipal statistics and monitoring programmes on urban land use development

Statistics, Programme	Spatial resolution	Temp. resolution	Indicators, variables, outcomes
Global			
UN-HABITAT	Global, national	Annual	• simple indicators on demography, migration, economy, environment • complex indicator: HDI
OECD	Global, national	Annual	• simple indicators on demography, migration, economics, environment
European, National			
EUROSTAT	National (macro-level)	Annual	[numbers, counts, share of] • demography, migration, economy, environment
Urban Audit (I, II)	Cities (macro-level), EU25: • larger urban zone • core city • sub-city districts	Annual (1991, 1996, 1998, 1996, 2001, 1996, 1998, 1996, 2003, 1996, 1998, 1996, 2001, 1996, 1998, 1996, 2004)	[numbers, counts, share of] • demography, migration, ecomomy, perception
Municipal			
Sustainable Seattle initiative	City, administrative units (district level)	1993, 1995, 1998, 2004	• demography, migration, economy, environment
IGNIS (GIS-based sustainability information system)	City, administrative units (district level)	Planned annually (1999–2003)	• simple indicators on urban development • complex indicators • time series, trends • target functions • simple indicators on urban development
Leipzig Municipal District catalogue	City, administrative units (district level)	Annual	• simple indicators • time series, trends
FKS (Warning and controlling system)	National, city (macro level)	Unclear	
IRB (Inner-city Observation System)	• inner city (core city-outer city) • inner city II (core city-outer city-city edge) • city (core city . . . urban periphery) • urban region (core city . . . urban periphery-commuters zone)	Unclear	issues of planned indicator set: • city • housing • mobility • supply • urban restructuring • . . .

(*Continued*)

Table 1. Continued

Statistics, Programme	Spatial resolution	Temp. resolution	Indicators, variables, outcomes
Municipal Monitoring System Leipzig	• national, regional • city level, district level	2001–2005 (annual)	• demography, migration, economy, environment
Social Atlas Leipzig (Kabisch *et al.*, 1997)	Micro-scale: • reconstruction areas • prefab housing estates • old built-up housing estates	1997 (input data 1991–1996)	• complex indicators • time series 1993–1996 • scientific base

Source: authors' investigation.

- sub-city district (SCD), which is a subdivision of the city according to strict criteria (5000–40,000 inhabitants in each sub-town/city district);
- selected urban areas.

The Urban Audit represents an indicator-based monitoring of (a) primary data in the form of household surveys (perception) and (b) a kind of secondary data analysis. The huge amount of available indicators is dedicated to the following thematic issues (cf. Table 1): demography, social and economic aspects, civic involvement, training and education, information-society, culture and recreation. Compared to other more conventional monitoring programmes it has to be underscored that Urban Audit includes explicit qualitative and perception indicators such as the perception of integration of foreigners, how people evaluate the housing sector of their city, the perception of safety in the city which becomes more and more necessary since it strongly influences the choice of a household to move.

There is, however, still a lot to be done concerning "adjustment" in terms of better interpretation of indicators based on the subjective perception of housing qualities stemming, for example, from survey results in terms of "measurable" quantitative data (numbers, counts, share). Although the Urban Audit provides both a substantial scientific standard of the monitoring indicators and a relatively broad thematic variety which enable the user a systematic review of the current urban development and an intra-urban, at least European comparison based on a score system, it remains difficult to compare and to evaluate urban processes across Europe due to the different area and population (density) of European cities.

Finally, when looking at the dissemination site, the communication of the results of the reurbanization-monitoring has to be done in the form of a graphic and narrative representation of the spatial heterogeneity and variability of territorial phenomena (Haase, 2005). The technical realization sets special requirements because of the heterogeneity of the end-users and the disciplines they come from, the different modes of use (science, planning, citizen and mutual decision support) and, finally, the related uncertainties of data (inconsistence, estimated versus measured data, change over un-observed time, weakness of prognosis models). Thanks to Geographic Information Systems (GISs), which stores basic data and performs spatial analysis, it is possible to construct spatial indicators that are more comprehensible to a large audience (Allen, 2001; Harts *et al.*, 2003; Lautso, 2003). Maps are often more accessible and understandable than tables of data.

Urban monitoring systems primarily are based on statistics, measured data and further on opinion polls. They are related to spatial units such as the whole city, administrative units (local districts) or to the block level. However, GIS- and statistics-based monitoring systems suffer from a lack of qualitative information and data. But, at the same time, narratives and qualitative information gathered from inhabitants and stakeholders bring awareness of initial processes that later find their realization in the spatial structure of the urban area (Caruso *et al.*, 2005). Qualitative data could often be transferred to quantitative indicators only when making considerable concessions. From the quantitative point of view, peoples' wants and needs expressed in a narrative way often seem to be non-transparent, *ad hoc* and hence irreproducible, and these characteristics undermine their scientific credibility.

Summing up, it has to be stated that urban monitoring offers simple and advanced approaches such as data compilation (as a kind of primary analysis) and secondary data analysis and interpretation (Bischoff, 2005). Simple approaches often contain a large variety of indicators and data sets, whereas advanced monitoring systems are problem-oriented and focussed on specific issues. Even when taking into consideration the "problem focussing" in a more strategic monitoring approach (such as the sustainability approach, cf. Hartmuth, 2006) a functional relation between the indicators is seldom given and cannot be taken as a pre-requisite. Moreover, most of the existing monitoring systems also do not contain any form that assigns weights to specific indicators when focussing a strategic objective. The following section shows which specific challenges the observation of evidence and progress of reurbanization processes demands from monitoring methodologies, if reurbanization is understood as a strongly SDT-driven process.

Findings on Reurbanization—Challenges for Monitoring

Our understanding of reurbanization adheres to its qualitative socio-demographic dimension. It is closely linked to the shifting of demographic and household structures in inner-city areas. Within the EU project "Re Urban Mobil", there has been developed a household-based concept that focuses on recently settled households. Out of this sample, the predominant household types were identified. It became obvious that in all case study areas there is a comparable set of households that comprises the driving forces of reurbanization: young one-person households, households with children, young cohabitation households and adults sharing a common flat (flatsharers). These households form the majority of reurbanizers in all areas (66–87%). According to the findings of Re Urban Mobil, one has to focus on the following aspects to be able to observe long-term trends of reurbanization:

- changes in household composition structures, especially of those households that were identified as driving forces for reurbanization;
- development of mobility and migration balance;
- changes of determinants describing the composition of the population and the social milieu (educational and professional structure, unemployment rate, quota of social welfare recipients, expenditure, etc.);

- changes in economic and commercial structures [retail, small and medium-sized enterprise (SME) development etc.]
- development of those aspects of the residential environment that are keys to determine housing needs and wants of reurbanizers (e.g. housing costs, facilities for children and adolescents, accessible greenery, etc.);
- changes in the perception of the areas by both residents and local experts/stakeholders.

As shown in Table 2, similar reurbanization-sensitive patterns of demographic and household characteristics are found in most of the inner-city districts of the city of Leipzig in eastern Germany, the most prominent example of reurbanization in the aforementioned EU-project by comparison with the other cities under investigation: León (Spain), Bologna (Italy) and Ljubljana (Slovenia).

Within the Re Urban Mobil project context, the compilation of suitable indicators and reference items for four European cities to measure these issues revealed several methodical and database-related problems.

At first, there are deficits of data availability: Socio-demographic and migration data are at one's disposal on the city level, while micro-scale data are only partly available. A lack of household-based data in most municipal statistics is the main problem. Especially data on the composition of households are lacking in most monitoring approaches or systems. Since household composition has been identified as the most relevant reference base for reurbanization processes (Buzar *et al.*, 2005, p. 428–429), and as percentage changes in household composition structures (and/or the development of shares of "new" households) form a key indicator for determining reurbanization progresses, there is a mismatch between data needs and supply that should not be ignored at this stage.

Secondly, perception indicators are recently becoming more and more important to measure in terms of evaluating the attractiveness of residential locations. They are included in European-wide monitoring systems such as Urban Audit (OOPEC, 2004). They take evidence from questionnaire surveys among residents or expert panels (e.g. Leipzig municipal surveys being compiled since 1991). To set soft and perception-based data on an equal footing with statistical data would challenge hitherto approaches to defining "measurable" indicators. This would imply a fundamental turn in monitoring conceptions. However, the results of the Re Urban Mobil research project provided considerable evidence for this. It has to be underscored that they are (more than data on unemployment rate, crime or migration, for example) key to an understanding of how much perceived residential qualities and drawbacks impact on household changes in terms of migration decisions.

In terms of qualitative data, their creation and accessibility the authors see a serious problem for applying such complex monitoring designs. Ideal would be a series of expert interviews or panels and another series of face-to-face interviews in order to shed light on the perception side of reurbanizers. In a first and preliminary test carried out in Leipzig, we used the answer spectra of a regular residents' survey (in German: the *Bürgerumfrage*) to operationalize expressions of well-being and confidence in local neighbourhoods. In general, it is possible to carry out an investigation of well-being und confidence in local neighbourhoods within the framework of regular residents' surveys, using time series analysis in order to get a long-term 'picture' of the perceptions of residents. Restrictions on the interpretation of these data are presented due to the fact that conventional residents' surveys are normally not transacted as longitudinal studies using a stable panel of residents.

Table 2. Socio-demographic data for selected inner-city areas in Leipzig for 2003: deviation from the city mean-value and total value/share

District	Mean age	Persons aged <40 years	Youth rate (%)	Elderly rate (%)	Rate of foreigners (%)	Household size	Migration balance
Neustadt-Neuschönefeld	*−5.6*	5755	*+1.6*	*−9.9*	*+9.6*	*−0.2*	233
	37.3	60%	15.2	16.5	14.8	1.7	
Altlindenau	*−5.8*	7927	*+2.8*	*−10.1*	*+2.2*	*−0.2*	564
	37.1	61%	16.4	16.3	7.4	1.7	
Anger-Crottendorf	*−3.7*	5463	*+3.7*	*−4.9*	*+1.0*	*−0.1*	179
	39.2	56%	17.2	21.6	6.3	1.8	
Gohlis-Süd	*−4.3*	8385	*+2.4*	*−8.4*	*+2.9*	*−0.1*	200
	38.6	57%	15.9	18.0	8.1	1.8	
Lindenau	*−5.6*	3605	*+0.1*	*−9.3*	*+4.8*	*−0.3*	229
	37.3	63%	13.7	17.1	10.0	1.6	
Plagwitz	*−2.1*	5862	*−1.7*	*−3.6*	*+1.4*	*−0.3*	633
	40.8	56%	11.9	22.8	6.6	1.6	
Reudnitz-Thonberg	*−4.0*	10543	*+1.1*	*−5.9*	*+2.1*	*−0.2*	269
	38.9	58%	14.7	20.5	7.3	1.7	
Schleußig	*−6.8*	6914	*+4.4*	*−12.8*	*−1.0*	*0*	301
	36.1	64%	18.0	13.6	4.3	1.9	
Südvorstadt	*−4.9*	13233	*−0.3*	*−7.2*	*−0.6*	*−0.2*	573
	38.0	62%	13.2	19.2	4.6	1.7	
Volkmarsdorf	*−4.8*	4686	*+2.6*	*−9.2*	*+8.1*	*−0.2*	227
	38.1	56%	16.1	17.2	13.3	1.7	

Note: Text in italic typeface: deviance in comparison to the mean value of the City of Leipzig.
Source: Haase *et al.* (2005c).

The common prerequisites for an urban monitoring are to define, explicitly: goal, scope, grain, spatial scale and the components of the urban system being monitored. As the paper focuses on the applicability of monitoring approaches for urban processes not only at a general level but also considering a specific development trend, i.e. reurbanization tendencies, the reflections made earlier have to be broken down to. In other words: There is a wide-ranging variety of existing approaches and systems of urban monitoring which have specific methodological profiles and priorities. With respect to the specific content of a qualitative reurbanization, the question arises: In what way and to what extent are these approaches applicable for a reliable monitoring of reurbanization in terms of both its qualitative, demographics-related character and its micro-scale (i.e. district-based) mode of action?

It is first and foremost the following characteristics of reurbanization processes that challenge hitherto existing monitoring approaches:

- its close relation to households since household-based statistical data are insufficiently provided by most municipal statistics;
- its dependence on district characteristics and local institutional and housing market settings (reurbanization occurs in several directions and fields such as changes of function, the physical state, the social, ethnic and demographic composition of inner-city residential areas);
- its connection to housing preferences and mobility decisions of households i.e. residents that are needed to fully understand demographic and social shifting in the areas and which are to be gathered only by surveys or expert panels;
- its application or use as a planning strategy with a normative impetus and thus an object of planners' decision-making processes.

The existing urban monitoring approaches and tools are not sufficient to meet these challenges [cf. also Bischoff (2005) who provides a detailed analysis of the applicability of local monitoring approaches for reurbanization processes in the City of Leipzig in eastern Germany]. Particularly, the following fundamental deficits become obvious: Existing (practically oriented) systems of urban monitoring are mostly reduced to a simple statistical description of single indicators and simple indices and finally to a far-reaching static quantification of the changes in major impacts of urban development. They include neither a deeper explanatory analysis of interdependencies between relevant factors of urban development nor an analysis of the effects of administrative measures upon urban development. However, as the authors will argue later on in more detail, these reports can be used as a data base for a deeper and more differentiated analysis of quantitative aspects of reurbanization processes.

In contrast to simple operational monitoring systems, advanced approaches—developed mostly in scientific contexts—are more theoretically based since they comprise new instrumental ingredients. These are, for example, related on the one hand to administrative measures and actions (operative monitoring) and on the other hand to concrete administrative objectives of urban development (strategic monitoring, cf. Siedentop & Wiechmann, 2004; Ringel *et al.*, 2004). In the aforementioned survey analysis of monitoring concepts, these conceptual approaches were designated as "strategy-driven monitoring concepts". They allow a better understanding and a more effective monitoring of urban development as a complex unit of objective impacts and changes as well as subjective actions and goals. In this way such new and advanced approaches of urban monitoring offer a better starting point for a reliable approach to monitoring reurbanization processes. In comparison to the concept of reurbanization introduced here, it is otherwise clear that these approaches have set other theoretical priorities and assumptions and focussed primarily on interdependencies between structural and functional conditions of housing such as linkages between infrastructures, urban physique, housing market and labour market (cf. Ringel *et al.*, 2004).

By way of conclusion, the question arises—how can complex processes such as evidence and progress of reurbanization be made the subject of a monitoring tool? The following section will on the one hand present and explain the set of core indicators. On the other hand, it discusses on that basis further challenges of improvement of monitoring tools for more complex processes of urban change.

Monitoring, however, is a powerful tool to follow urban development but it is far from being the only way to understand urban processes, dynamics and change. This view would not meet the complexity of the urban context. The suggested monitoring design and the respective indicator set are worthy to serve as a starting point for detecting reurbanization in parts of the city from the demographic point of view. It further will serve in a second phase for proving evidence of a longer stability of once recognized reurbanization trends and facilitate comparison.

Tool Development: An Indicator Set for Reurbanization

Reurbanization Indicators

Due to the temporal complexity of the underlying processes, the design to monitor reurbanization presented here comprises on the one hand the initial and more quantitative step of "recognition of reurbanization", which is in the centre of this paper. On the other hand, the design focuses on the investigation of the long-term stability and (real) evidence of change in a more qualitative way using expert knowledge and residents' perceptions (cf. Figure 1).

Using a broad range of methods, i.e. statistical data analysis, workshops, interviews and a multi-step consultation with experts, a set of core indicators to observe reurbanization had been compiled (cf. initial step of the design in Figure 1). Thus, the current set includes experts' opinions from both scientists and practitioners exemplified in four European cities (Bologna, Leipzig, León, and Ljubljana). The indicator set represents a tool of high applicability in different local and cultural contexts (based on the local settings in four different cities in four countries) and—therefore—of low specification. It goes beyond traditional monitoring tools by considering the reurbanization process as a theoretical foundation and applying selected indicators to that issue. It proposes households (not individuals) as basic agents.

The mentioned core set comprises 20 indicators (Table 3). The first four of them, namely household size, household type, migration (balance) and age structure, represent basic indicators that are indispensable to the identification of evidence and progress of reurbanization. The majority, however, represents indirect indicators that depend in their relevance on the interplay with other indicators. They offer a framework to evaluate the characteristics and specifics of reurbanization processes measured by means of the direct indicators.

Table 3. Core set of indicators of reurbanization

No.	Indicators	Measurement/characterization
1	Households	– Number of households – Size of households – Percentage change of the number of households – Percentage change of the size of households
2	Household types	– Number of one-person households – Percentage change of one-person households
3	Migration (1)	– Migration balance – Rate of immigrants/foreigners
4	Age structure	– Youth, elderly/dependency rate
5	Educational and professional structures (2)	– Percentage change in educational structure – Percentage change in professional structure
6	Employment, unemployment and social welfare	– Change in annual growth rate of employment, unemployment rate and share of social welfare recipients
7	Housing costs (2)	– Price per square metre for owner-occupied housing and rental housing – Ratio between housing costs and income
8	Tenure structure (2)	– Percentage change in share of owner-occupied housing – Percentage change in share of rental housing (or more specific: private rental and municipal rental housing) – Percentage change in share of social housing (depending on national categories) – Percentage change in residential vacancies due to national categories
9	Residential and commercial vacancy (2)	– Percentage change in commercial vacancies using categories like retail vacancies, industrial vacancies, etc.
10	SME (2)	– Annual change of the number of SMEs
11	Schools/kindergartens (3)	– Number of schools and kindergartens per 1000 children ageing from 6–18/0–6 years – Annual percentage change of schools and kindergartens per 1000 children ageing from 6–18/0–6 years
12	Renovated housing, newly built and demolished housing (4)	– Percentage change of the number of dwellings in renovated housing/newly built housing/demolished housing
13	Accessible public greenery (5)	– Area of accessible public greenery per capita in the area (square metre per person) – Indicator defined by time relation – Indicator defined by convenience (not statistically measurable)
14	Travel frequency (6)	– Number of passing cars per 24 hours at the most frequented road in the respective area
15	Air quality and noise pollution (7)	– More relevant would be the "measure" the perception by air quality or noise pollution by the residents
16	Types of land use structure (2)	– Residential use, industrial/commercial use, recreation area/greenery, traffic area, etc.

(*Continued*)

Table 3. Continued

No.	Indicators	Measurement/characterization
17	Income and expenditure structure of households	– Percentage change of mean expenditure per capita – Percentage change in income structure (types, e.g. income from work, social welfare, unemployment benefit, etc.)
18	Municipal budget per capita (8)	– Annual real (inflation adjusted) growth rate of municipal budget per capita – Municipal budget – Limited in time funds
19	Local commitment (9)	– Number of associations and community groups – Percentage change of associations and community groups – Percentage change in numbers of subjects/members
20	Perception of the development of the area by experts and residents (10)	– Respective data of consecutive surveys

Explanations, contingency and dependencies:
(1) Depending on general relevance of immigration in the respective city/neighbourhood
(2) Depending on national categories
(3) Depending on national categories and urban school policies
(4) Depending on national categories and general trends of urban development (growth, shrinkage, stagnation)
(5) Definition "accessible public greenery": The public green area which an inhabitant can reach within 15 minutes walk without facing significant physical barriers. *Explanation*: The examples of above mentioned physical barriers are: roads with heavy traffic, railways, stairs or any other objects which can make the access to the area difficult for all people or for a specific group of inhabitants (children, elderly, disabled). For this reason any considered green area may be accessible for a certain group of inhabitants and simultaneously inaccessible for another group. So the area from which the green area is accessible must be defined individually for the particular green area. As factors for accessibility we can also consider: parks fencing and location of entrances, entry-fees, possibility of entry on the lawn, safety aspects, etc.
(6) Depends on the location of an area to arterial or main roads; relevant only for areas affected by such traffic
(7) Relevance of the indicator depends on the affectedness of an area by air or noise pollution perceptions depend on local situation and impact of environmental attitudes in general
(8) Depending on function of budget in the area
(9) Depending on national/local traditions of civic involvement
(10) Relevant if perception relates to direct reurbanization indicators (see above)

Source: Haase *et al.* (2005b).

In the following, the functioning of the indicators is explained by means of some examples. The first refers to the direct indicators that include (1) number and size of households; (2) percentage change of household types; (3) migration balance; (4) youth *vis-à-vis* elderly, i.e. dependency rate; (5) rate of immigrants or foreigners.

The explanatory framework for these basic indicators underscores the demographic bedding of the reurbanization approach used in this paper: A positive migration balance in the inner city is a sign of reurbanization, especially if the area has suffered from population losses. If the migration balance is still negative, reurbanization might be indicated by a growing number of households above the city-wide average. Other key indicators for occurring reurbanization processes include: higher (or increasing) youth rates and/or lower dependency rates; a rising number of younger and "non-traditional" households (cf. earlier section) which is revealed through data on the household structure (ideally in combination with the age structure of households); an influx/rising share of families with children (as a type of household that is likely to stay in the area for more than a short period of time; an influx of foreign migrants representing mainly young and mid-aged households).

The contingency of relevance of the indirect indicators depends on different constellations. In the following paragraph, some examples are given (cf. Table 3).

- Percentage change in tenure structure (no. 8): This indicator operates in a user-defined test-area, city or regional context, since an absolute measure might reflect different cultures and housing systems. A rise in owner-occupied housing and a reduction in rental housing would usually be associated with improved economic performance. However, at many locations we observe rather a trend towards rental housing in core city areas (from social landlords or private landlords). There, the link between a rise or reduction in different tenure forms and improved/declining economic performance is less clear cut.
- The percentage change in renovated housing, newly built housing or demolished housing (no. 12) in an inner-city area also represents a very sensitive indicator: Renovation of housing stock improves the attractiveness of the residential environment of an urban area. Renovation supports the suitability of an area to become reurbanized (supports the influx of better-off households with higher standards of residential qualities). The same might be true for a high or rising share of newly built housing in cities. In shrinking cities, however, the rising number of demolished (dilapidated) housing stock can also indicate a positive development for the whole area and be favourable for a reshaping of the residential environment. To put it differently: In the case of urban growth, an increase in newly built housing would indicate reurbanization. In shrinking cities, on the contrary, reurbanization could be indicated by either a rise in renovated housing or a more generous shaping of the existing urban fabric (spacious housing).
- Individual traffic is the main environmental stressor in residential areas of inner cities. Therefore, the number of passing cars per 24 hours at the most frequented road in an inner-city area (no. 14) was included in the indicator set. A majority of cities makes repeated censuses of traffic flow in main communications and crossroads. Therefore, the proposed indicator is easily collectable and can be up-dated without major effort. However, its relevance depends on the affectedness of an area/sub-area by traffic and related pollutions. For most residential areas, this indicator operates on a very micro-scale level (streets, blocs, crossings, etc., street side of houses, etc.).
- The perception of the development of the area by experts and residents (no. 20): Perception indicators are acquiring more and more relevance in modern monitoring systems and tools. They report on the subjective attachment of a resident to his/her residential environment. Being closely connected to mobility trends and the demographic and household structure of in- and out-migrants, it reflects on the reasons for moving and provides crucial information regarding the adjustment of urban policies in the respective area. However, this kind of "soft" or "subjectively-based" indicator does not, to date, count in the standard repertoire of available data for monitoring tools. It demands an additional amount of work and manpower for carrying out and processing surveys and expert panels.

The set of reurbanization indicators presented here actually is limited in having proved its validity for whole cities. According to the project design of Re Urban Mobil, the indicator set has being trans-disciplinary created by scientific and practice expert opinions and representative examples of field analysis in four European cities. In order to prove its validity and thus applicability for a whole city, an initial statistical test of the set has been accomplished in the following section for the eastern German city of Leipzig, where reurbanization is obviously occurring.

Reurbanization Indicators—First Statistical Evidence from Leipzig

For the statistical analysis of the reurbanization indicators, a simple approach has been chosen as a kind of "starting point" which is plausible for the authors in the first phase of analysis. Using a data set of the municipal statistics for the city of Leipzig, four of the core indispensable indicators and another additional indicator had been tested concerning their relevance and dependency. The small-scale municipal statistics of the city of Leipzig (in German "*Ortsteilkatalog*") consist of contingent data for all 63 districts of Leipzig dating from 2003 and 2004 (Stadt Leipzig, 2004). Moreover, the case study of Leipzig serves as the most prominent reurbanization case among the investigated cities in the Re Urban Mobil project. The following regression analysis has been done plotting the first of the indispensable indicators, the household size, against other indicators of the set for all 63 districts of Leipzig (cf. Figures 2–6).

Assuming that, in particular, smaller 1–2-person households represent the reurbanizers (mean value for all households in Leipzig is 1.9; Stadt Leipzig, 2004), the following indispensable and additional variables were plotted against youth rate (share of persons

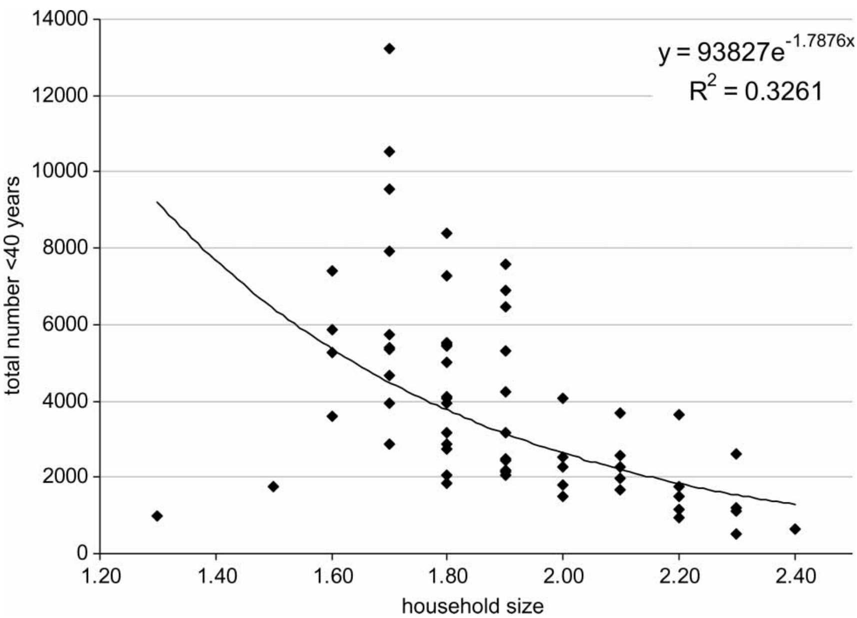

Figure 2. Youth quota (share of persons under 40 years) compared to the household size of the 63 districts of Leipzig (data from 2003/2004; regression analysis)

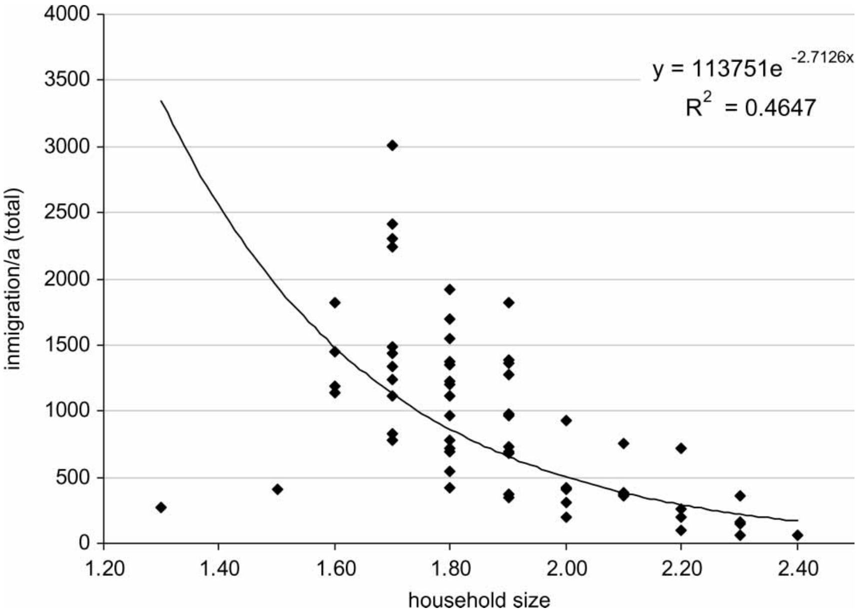

Figure 3. In-migration compared to the household size of the 63 districts of Leipzig (data from 2003/2004; regression analysis)

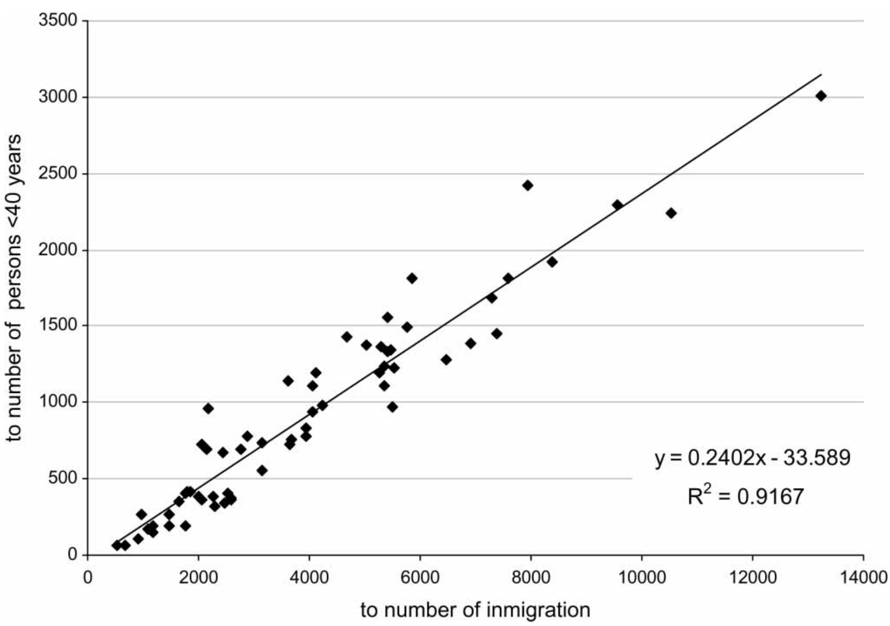

Figure 4. Number of persons younger than 40 years plotted against the annual immigration rate (data from 2003/2004; regression analysis)

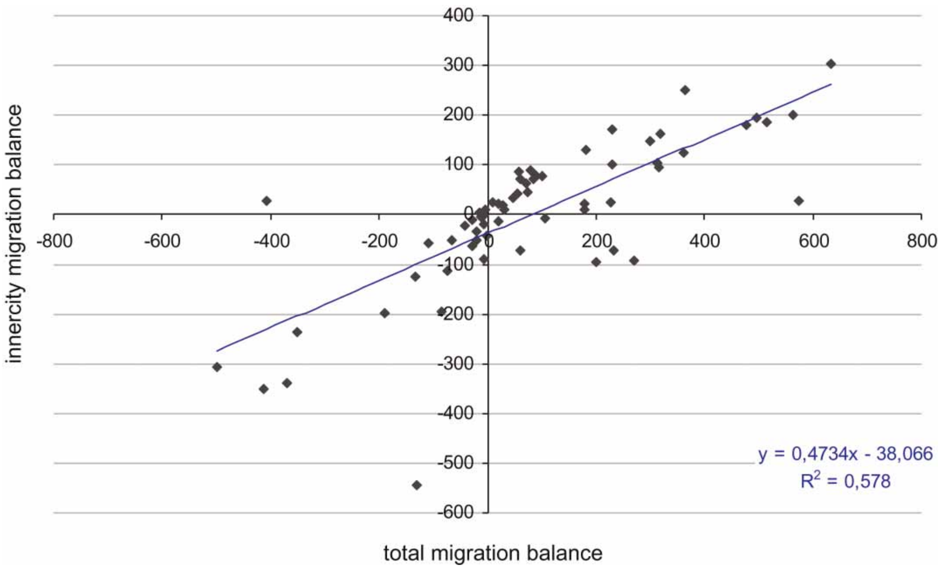

Figure 5. Migration balance Leipzig: People moving within the city borders; high potential of these districts (data from 2003/2004; regression analysis)

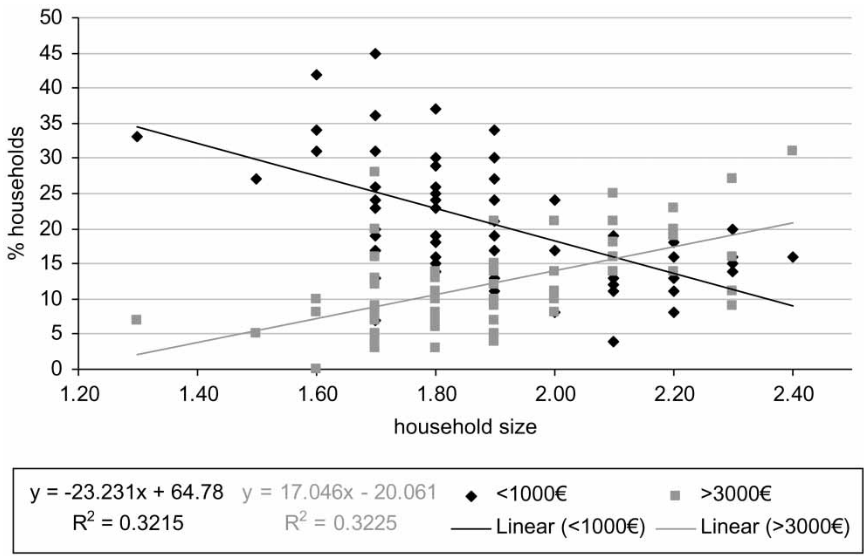

Figure 6. Total income (<1000€; >3000€) compared to the household size of the 63 districts of Leipzig (data from 2003/2004; regression analysis)

younger than 40 years per district; Figure 2), annual in-migration quota (Figures 3 and 4) and the share of households with a total income <1000€ and >3000€ (Figure 6).

Testing at first the relevance of two of the indispensable indicators as dependent variables, youth rate in Figure 2 and in-migration in Figures 3 and 4, we get a clear picture that districts of small households (typical for reurbanizers) belong to the "young" districts in Leipzig with respectively high in-migration rates compared to the districts with bigger households. Reurbanizers are younger households; their mean age is considerably lower compared to the mean age of the population of the city of Leipzig. Respectively, in the case of bigger households we have lower in-migration rates and a comparatively elderly population (Figures 2–4). An extremely close correlation was found between youth quota and immigration with 0.9167 (Figure 4).

Due to the fact that urban migration is always influenced by both city-internal and regional migration Figure 5 gives an idea of the total migration balance of the city of Leipzig. As already identified in Figures 3 and 4, in-migration is an indispensable indicator but, as Figure 5 argues, not specific enough to separate reurbanization from non-reurbanization districts. In the case of reurbanization in Leipzig, in-migration mainly results from migrants from the rest of the city rather than from regional or intra-urban migration (Figure 5). The ratio of total migration per in-migration per district ($mig_{total}/mig_{innercity}$) somehow specifies the indicator "migration" as being relevant as a reurbanization indicator. It should be added to the core set which was presented in an earlier section.

Finally, one of the additional reurbanization indicators, the total income, had been ranked again against the independent indicator of the household size (Figure 6). What we see is that in districts with small household sizes and high in-migration, there is a considerably high share of low-budget households (with an income < 1000€) but at the same time a certain percentage of better-off households (with an income > 3000€, cf. Figure 6). This proves that reurbanization is—according to our presumptions—driven by a socially mixed population. The distribution curves of both higher and lower income groups meet at a household size of 2.0 at the *x*-axis, the already mentioned mean value for Leipzig.

As already mentioned in earlier sections, a second focus of the design follows the investigation of the long-term stability and evidence of change in a qualitative form using expert knowledge and residents' perceptions (cf. again Figure 1). This qualitative analysis will be accompanied by a discussion of statistical times series, a repetition of a detailed household survey and an interview phase. First ideas on stability and long-term meaning of the identified indicators to recognize reurbanization have been gained in the survey 2004: Resident households, among them explicitly reurbanizers and long-established households had been asked concerning their intention to move (or move again). Compared to the long-established households, each third household among the recently in-migrated (young families, single-parent families and young singles) already plans to move. In opposition to this general trend, flat-sharer households have been found to be less mobile with an intention of moving within the near future below average (of the total number of reurbanizers). The authors see reasons therefore in the good accessibility to the city centre, the university and comparatively low rents. In conclusion, old-built up areas, where reurbanization had been investigated in the case of Leipzig, serve as "transitory areas" for relatively mobile, young and low-income households (cf. Haase, A., *et al.*, 2006).

Implications for Monitoring Networks

The first statistical analysis to test the reurbanization indicator set for Leipzig shows a good accordance among the four indispensable demographic indicators of the set. The analysis gives an idea that those indicators could be utilized to identify (potential) reurbanization areas. The outlined ranking according to one of the indispensable indicators (household size) permits one to establish an order of the urban districts and to put the indispensable and additional indicators in direct relationship to one another.

An implication for the amplification and adoption of existing monitoring approaches is that two demographic core indicators, youth rate and in-migration, are in good accordance with the theoretical and empirical pre-assumptions of the indicator set. Moreover, the indicator "income" as a non-indispensable indicator proves that also a non-demographic variable contributes to the more differentiated explanation of reurbanization in terms of where it occurs and who might be able to afford it. Moreover, the statistical analysis gave an idea that the current set of reurbanization indicators, in particular the migration indicator, is still in need of being added and/or specified.

Although the spatial grain of the district scale (where the analysis has been carried out) is compared to the urban heterogeneity relatively rough and mean values often do not reflect the heterogeneity of the districts, the statistical test gave first evidence on the validity of the reurbanization indicators at district level. Here, the municipal statistics could start to redefine their own annual indicator matrix. More inner district heterogeneities which have been proved by Haase, D. *et al.* (2006) afford a more detailed statistical data set to apply the same set of reurbanization indicators at, for example, block or housing estate level.

Conclusion

In this paper, we have analysed the demands and prerequisites for a monitoring of inner-city reurbanization processes. We contrasted the complex reality of reurbanization as a household-related inner-urban change with the body of hitherto existing approaches and ideas of urban monitoring. There is still missing an urban monitoring approach to detect reurbanization in terms of both the qualitative and the quantitative. Starting from a number of new requirements that reurbanization sets up for a long-term observation of inner-city reurbanization, we introduced a set of indicators with demographic focus that were based not only on sizeable but also on qualitative information. We presented a design to study and monitor reurbanization processes in the initial (more quantitative) recognition state, which has been the focus of this paper. There is envisaged a further test and refinement of the indicators and in particular their operationalization. For the city of Leipzig, the evidence of the indicators was tested by means of small-scale municipal data for all urban districts. Cross-referencing our findings, the following conclusions can be made.

First, it became clear through evidence that previous monitoring approaches did not fully apply for reurbanization as a complex development. This complexity is especially evident because of the close interplay of reurbanization with demographic and household shifts and the related altering housing preferences that need to be considered.

Second, according to these aforementioned specifics, the indicator set is based on demographic indicators. It further incorporates additional ones to monitor a more complete picture of what is reurbanization. In particular, the approach presented here meets the specifics of reurbanization in a primarily qualitative demographic understanding.

Third, for the first example of Leipzig, the baseline indicators and the whole set, represented by some examples, passed the test and confirmed the assumptions made previously for reurbanization-sensitiveness of inner-city districts in Leipzig.

Fourth, hitherto results demand further application for other local contexts, a feedback discussion of the indicator set by using newly-gained knowledge from the statistical tests and, in addition, an enlargement of the tests in terms of further indicators, rankings and cross-comparison of dependent indicators.

The monitoring design is predominantly understood to serve as an academic instrument for scientific cooperation. It further supports scientist-stakeholder communication. Observed from a more operational angle, the indicator set can be incorporated into different existing (monitoring) instruments and thus serve as a completion tool for specifically recognizing reurbanization processes. For the case of Leipzig, the monitoring design and indicator set presented here represent, without a doubt, a qualitative enhancement of the existing residents' survey ("*Bürgerumfrage*"), as well as the annual monitoring programmes (Stadt Leipzig, 2003, e.g. for the residential market the questionnaire-based expert-panel "*Wohnungsmarktbarometer*"). For the latter, the new indicator set offers precise characteristics and distribution of residents who relocate. At a more scientific stage, it is planned to include reurbanization into a web-based observation system for urban sustainability (IGNIS; Hartmuth *et al.*, 2006) or into already existing web-presentations of cities (e.g. City of Bologna; http://www.comune.bologna.it/iperbole/piancont/).

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Evolving Reurbanisation? Spatio-temporal Dynamics as Exemplified by the East German City of Leipzig

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Abstract

After a decade of tremendous population loss indicating severe decline, some large east German cities have been displaying signs of reurbanisation since the late 1990s. Using the city of Leipzig as an example, this paper identifies the major characteristics, progress and underlying spatio-temporal dynamics of reurbanisation, and examines whether it is a long-term process of urban living or features only short-term tendencies. Socio-demographic indicators are used to observe the development of inner-city districts. At the spatial scale of municipal districts, time-series data are analysed for the years 1993 to 2005. The paper argues that reurbanisation has occurred primarily in inner-city districts and has progressed considerably since the early 1990s. However, the spatio-temporal distribution of the relevant indicators shows that reurbanisation is far from being a homogeneous process. In light of this, the paper presents a ring of reurbanisation-sensitive municipal districts around the city centre.

1. Introduction

Since the beginning of the post-socialist transition in 1989, east German cities have been affected by dramatic processes of population loss, mainly due to emigration to western Germany, suburbanisation, a fall in birth rates to record low levels (Kohler *et al.*, 2002) and subsequent ageing processes. At the end of the 1990s, almost all cities and towns in east Germany were shrinking: in only 10 years, they experienced a loss of more than 15 per cent of their inhabitants. Larger cities in particular, such as Leipzig, Dresden and Halle, lost 10–20 per cent of their population between 1989 and 1998. At present, east Germany forms a 'pole of shrinkage' together with other post-socialist countries of eastern Europe (Turok and Mykhnenko, 2007, pp. 168–170; D. Haase *et al.*, 2008b, pp. 331–335).

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Since 2000, however, a reversal of trends has been observed. Some cities and bigger towns are no longer experiencing a loss in their population, but are regaining inhabitants. Positive migration balances are mainly based on intraregional in-migration (from east German regions) and a considerable decline in out-migration. People are increasingly opting to stay in the city, while suburbanisation processes, artificially promoted by subsidies during the 1990s, have almost stopped (Herfert, 2007). In this vein, a discourse about a 'comeback' of urban living—i.e. reurbanisation—as a future scenario for a number of major cities in eastern Germany has evolved (Herfert, 2007; A. Haase *et al.*, 2005a, pp. 83–85; D. Haase *et al.*, 2008a; Köppen, 2005).

Reurbanisation is also currently being discussed in the UK and other European countries (Buzar *et al.*, 2007; Colomb, 2007) and in the US (Cheshire, 2006). However, the east German case shows an 'atypical' or somehow 'specific' pattern, insofar as it refers to shrinking cities and, even more, parts of entire landscapes. It has become an issue of scientific and planning debate against the background of the achievement of sustainable urban development with respect to declining population numbers, underuse of urban infrastructure and the endangerment of the functionality and the habitable factor of the cities.

To be able to draw reliable conclusions about both current and future trends of urban stabilisation, reurbanisation needs to be analysed in more detail concerning its major characteristics, progress and resulting socio-spatial dynamics. First and foremost, it has to be determined whether reurbanisation represents a long-term trend of inner-city stabilisation in eastern Germany or features only short-term tendencies.

Objectives and Structure

Using the example of the city of Leipzig, this paper identifies the major characteristics, progress and underlying spatio-temporal dynamics of reurbanisation, and examines whether it is a long-term process of urban living or merely a short-term aspect. The research draws on the statistical findings of a spatio-temporal analysis of municipal time-series data from 1993 to 2005 for Leipzig's 63 municipal districts. As a base, we used a number of socio-demographic indicators chosen from a set assembled for the observation of inner-city reurbanisation processes by an international consortium (see details in D. Haase *et al.*, 2008a). The indicator set was developed by scientists and practitioners within the completed EU Fifth Framework Programme research project "Mobilising reurbanisation under conditions of demographic change" (A. Haase *et al.*, 2005a; www.re-urban.com). With the help of the analysis, we also test the appropriateness of the selected indicators.

The paper is organised as follows. The first of the following parts (sections 2 and 3) expands on some conceptual considerations regarding the reurbanisation debate and recent reurbanisation processes in east German cities. The second part (end of section 3) sets up five hypotheses. The third (section 4) presents the methodological design—i.e. the indicators used and the organisation of the statistical analysis. Section 5 reports the major results from the study, and, in Section 6, there is a comprehensive discussion of the results. In section, 7, finally, conclusions are drawn in terms of summarising and assessing the hypothetical assumptions made at the outset.

2. Theorising Reurbanisation: The Debate and the East German Case

The Debate

The term 'reurbanisation' did not simply materialise within the recent debate on urban resurgence in Europe (see for this debate, *Urban Studies* 43(8); Buzar *et al.*, 2007; A. Haase *et al.*, 2006). It has a more than 30-year history, whereas the discussion on resurgence—other scholars speak about 'urban renaissance' (Helbrecht, 1996), 'rebirth' or a 'comeback' of cities (Storper and Manville, 2006, p. 1247)—is rather a phenomenon from the past decade. Reurbanisation is defined "against a context of previous decline", but at the same time "it is distinguished from simple growth as such" (Cheshire, 2006, p. 1232); moreover, reurbanisation has been used in many contexts and with many different connotations: as recentralisation and (re) concentration (Klaassen and Scimeni, 1981; Berg *et al.*, 1982; Cheshire, 1995; Herfert, 2002 and 2007), a return of the inhabitants from the surrounding areas (Hesse and Schmitz, 1998, p. 436), resettlement of the inner city (Lever, 1993; Ogden and Hall, 2000; Burton, 2003), revitalisation in the cultural sense (Seo, 2002), determined by economic developments (Priemus, 2003; Hutton, 2004) or gentrification (Bromley *et al.*, 2007; Colomb, 2007, pp. 13-17).

Generally, it has been the subject of international discussion since the 1970s (see, for example, comprehensive overviews in Buzar *et al.*, 2007; A. Haase *et al.*, 2006; Lever, 1993; Berg *et al.*, 1982, who introduced a four-stage urban cyclic model of urbanisation, suburbanisation, desurbanisation and reurbanisation). It is closely connected with, but not identical to, other notions of urban change such as regeneration and revitalisation. Despite these theoretical foundations, the reurbanisation debate has been facing a fundamental problem: there is neither a unified nor an undivided understanding of the concept. It has been used in a variety of ways, as already mentioned.

Today, in spite of these conceptual and terminological 'pitfalls', there is an increasing amount of evidence regarding inner-city reurbanisation in Europe (Lever, 1993; Cheshire, 1995; Ogden and Hall, 2000; Seo, 2002), also in terms of comparable and cross-national research (Priemus, 2003; Bromley *et al.*, 2007; Buzar *et al.*, 2007; sceptical: Champion, 2001, p. 154, 158). The focus is increasingly on the interplay of urban and socio-demographic change in the inner city. Such change mainly involves general socioeconomic processes like the development of the service sector, the rise in female employment, the prolongation of the education carriers and labour mobility. These changes are leading to long-term changes in household structure: households are becoming smaller, living arrangements more diverse and less stable and the number of households formed by a person in his/her lifetime is increasing.

The fact that some of the key characteristics of reurbanisation such as 'new residents', 'liveable inner city', 'rising attractiveness' or 'sustainable, socially mixed neighbourhoods' are terms familiar to those dealing with the gentrification and 'urban renaissance' debate (Colomb, 2007, p. 13) has led to some criticism from the perspective of gentrification research. One of the main arguments refers to the deliberate use of the term reurbanisation so as to avoid the term gentrification in order to remove the social or class issue from the urban 'renaissance' discourse (van Criekingen, 2007; Colomb, 2007). The critics further maintain that the reurbanisation approach underlines the demographic character of urban change in order to strip the process of its social or class character. Due to the neo-liberal logic of revitalisation or regeneration policies, displacement is retitled as replacement or (re)population (Slater, 2008, pp. 214–215).

Given this background, we do not share this view. According to our research, we adhere to the opinion that the concepts of reurbanisation and gentrification depict qualitatively distinctive processes. In our understanding, reurbanisation refers to a much wider range of socio-spatial dynamics compared with gentrification, since its main purpose is to capture the rising overall 'habitable factor' and sustainable use of compact inner-city areas by different groups of residents. Its focus is clearly on the household dimension because reurbanisation processes are driven by households representing a variety of social, lifestyle and income groups. In conceptual terms, gentrification is focused on the politics of selective urban upgrading in terms of the physical, social and symbolic residential environment which is driven by selective groups from certain social, professional and income backgrounds and takes into account displacement (Butler *et al.*, 2008; Hamnett, 2003). It should not be equated with the broader, multidirectional process of reurbanisation, which takes place over the entire inner city and is principally indicated by increasing in-migration and/or decreasing out-migration rates after a relatively long phase of decline (Buzar *et al.*, 2007). Indeed, despite many overlaps, the two concepts do not directly compete with each other because of their different subjects of interest.

Focusing on residential changes within the inner city, reurbanisation analyses the nexus between the development of the urban space and its shifting demographics. These interrelations between shifting household patterns, related housing needs and preferences and the change of the inner city have been hitherto underresearched (see Lee *et al.*, 2003; Buzar *et al.*, 2005; A. Haase *et al.*, 2006). In the conceptualisation of reurbanisation in this paper, they represent, however, the crucial factor for understanding urban change. Reurbanisation, in a more detailed way, is defined as follows. At the total city scale (that is not the focus of this paper), it is a process of absolute or relative population gain of the city in comparison with its suburban regions. At the mesoscale or district level (which we are investigating here), we understand it as

> a process of populating and diversifying the inner city with a variety of residential groups of different ages and socioeconomic backgrounds (Buzar *et al.*, 2007, p. 652; see also A. Haase *et al.*, 2006, pp. 169–170).

In this conceptualisation, reurbanisation is closely related to changing patterns of living and housing arrangements. Traditional concepts, like that of the family, decrease in their significance whilst there is, simultaneously, an increase in the diversification of lifestyles and within-household economies (Buzar *et al.*, 2005). Subsequently, the demand side of inner-city living has changed. It is not only the so-called non-traditional household types like singles, cohabiting (childless) couples and flat-sharers who opt to live close to the centre, but also families (Karsten, 2003). Advantages of inner-city areas, like the specific housing available, the good location and diverse amenities, are becoming increasingly attractive for a wide range of population groups, living arrangements and lifestyles.

The East German Case

At this point, the east German case has come into the international debate. Both the post-socialist transition and its German specifics are necessary to understand east German urban development after 1989. To expand on its course, institutional context and consequences are far beyond the scope of this paper. Therefore, the following section attempts to make a long story short (Kabisch *et al.*, 1997; Harth *et al.*, 1998; Herfert, 2002; Häußermann and Neef, 1996). After the phase of restructuring institutional, juridical and financial framework conditions, which were also characterised by fundamental demographic changes (massive population losses and a reduction in fertility), east German development has seen new dynamics since the mid 1990s.

The impact of property change resulting from restitution and an abatement of debts for former GDR housing companies was increasing, but had not yet led to a softening of the housing markets from the demand side. Simultaneously, suburbanisation spread, mainly due to fiscal subsidies, and represented the predominant pattern of east German spatial development from 1993/94 to 1997. The theory of a 'catch-up suburbanisation' has to be clearly rejected for the east German case due to specific starting-point conditions and political frameworks that differ from those in western Europe and western Germany (Ott, 2001). The main reason for suburbanisation was the unattractiveness of the cities (because of dilapidation, lack of amenities, unclear ownership structures, etc.) and not the attractiveness of suburbia. Processes covering those relating to suburbanisation have been summarised under the terms 'urban sprawl' (Nuissl and Rink, 2005) and 'deconcentration' (according to a very similar development of Erfurt, which is the capital of the new federal state of Thuringia; Ott, 2001).

In the cases of Leipzig and other east German cities, the short-term suburbanisation boom soon lost its significance after reaching its peak at the end of 1996 (Herfert, 2002; Nuissl and Rink, 2005; Municipality of Erfurt, 2007).

In the period from 2000 to 2006, the proportion of shrinking municipalities increased, in particular by up to 85 per cent (Herfert, 2007). As a result, most east German cities suffered from a structural housing vacancy at a significant level. The rise of housing costs in the inner city slowed down and this process contributed to a trend reversal that has been observed over recent years. Since 2000, a number of east German cities have been stabilising despite further regional shrinkage. (Re)concentration processes are occurring in the form of both a selective in-migration and a simultaneous decrease in out-migration rather than a return to the core cities of the people who had moved to their suburban fringe. There are signs of spatial polarisation in east Germany: reurbanising cities are forming 'islands of growth' in shrinking landscapes and transitory zones which are showing moderate to smooth shrinkage processes (Herfert, 2007, p. 439).

3. Reurbanisation in the City of Leipzig

Leipzig between Shrinkage and Resurgence

Leipzig is a case that highlights the east German story of shrinkage and urban comeback. Dating back to the late 1960s, the city had experienced a continuous loss of its population, which underwent an acceleration and a structural turnaround with the onset of the post-socialist transition in 1989. Within just a few years (1989–98), the city had lost about 100 000 inhabitants due to out-migration to western Germany and (strongly subsidised and thus 'artificially' enforced) suburbanisation. The population decreased from 530 000 in 1989 to 437 000 in 1998 (see Figure 1). For this reason, Leipzig belongs to the group of larger cities in eastern Germany with some of the highest population losses of all. Simultaneously, the labour force in industry declined from 100 000 in 1989 to 15 000 in late 1994 (Doehler and Rink, 1996, p. 267).

Population losses brought about changes in the residential structure that involved a decrease in birth rates and ageing, and an increase in residential vacancies; this phenomenon was brought into the spotlight as a general east German challenge in the year 2000 when, at that time, there were over 1 million vacant flats. In Leipzig, the maximum vacancy rate was achieved in early 2000 with 62 500 vacant flats (20 per cent of the total stock). In late 2005, vacancies amounted to 45 000 flats (14 per cent of the total stock; Municipality of Leipzig, 2006, pp. 12–13). This decrease was due to demolition (see next section), a further rise in household numbers and a stabilisation of the population. Still, housing vacancies mostly affected the older housing stock (pre-1914 or Wilhelminian style with 18 per cent and 1919–45 housing stock with 19 per cent; Municipality of Leipzig, 2006, p. 13). Compared with the mid

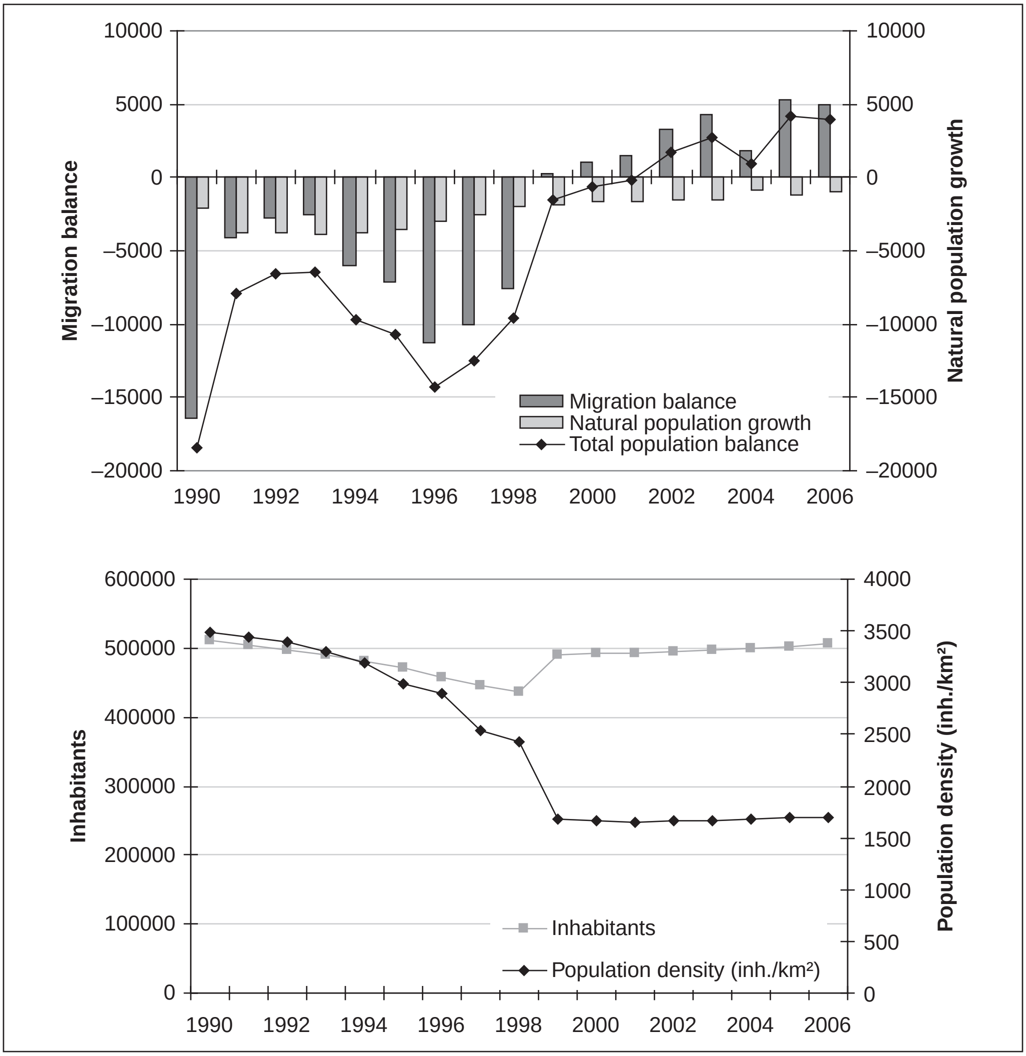

Figure 1. Changes in natural population growth, migration balance and total population balance (above) and population density (below) in Leipzig since 1990.
Source: Municipal agency for statistics and elections.

1990s, however, and due to the clarification of building property rights, the old built-up areas experienced increasing processes of renovation and a new influx of residents after a decade of severe decline (Kabisch *et al.*, 1997; A. Haase *et al.*, 2005b, pp. 83–84). Subsequently, vacancy rates began to decrease while starting to rise in large socialist-era housing estates. The share of such estates in the housing vacancy rates (15 per cent in 2002; 13 per cent in 2005) is only balancing out due to demolition. Thus, vacancies will still be a problem in the future, even if present household numbers continue to rise until 2012 (Municipality of Leipzig, 2007a).

Household numbers are not sufficient to fill the large stock of vacant dwellings. Additionally, the supply of flats is not equal to their demand because of the rising number of one-person households searching for

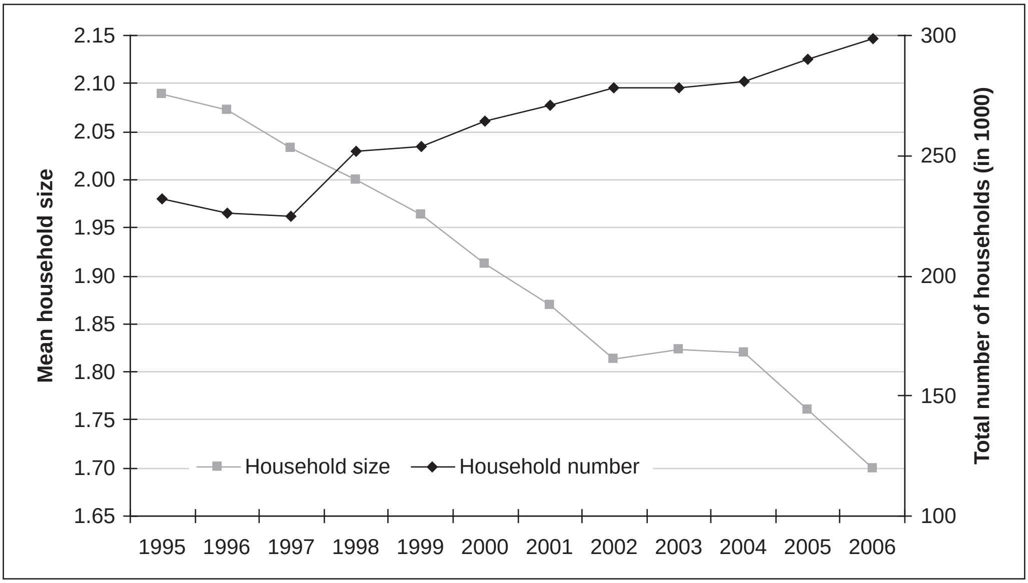

Figure 2. The opposing trends in household size and household numbers in Leipzig since 1995.
Source: Municipal agency for statistics and elections.

smaller flats. One-person households already accounted for more than 50 per cent of all households in Leipzig in 2005. Illustrating this, Figure 2 shows the development of the mean household size and the total number of households in Leipzig since 1995.

In consequence, the further demolition of surplus housing stock is planned. The spatial distribution of vacant housing stock is highly selective and unequal. While some (attractive) residential areas are quite 'filled up', less attractive areas show vacancy rates of 30 per cent and more (Municipality of Leipzig, 2004). Demolition produces new spatial patterns such as urban structures with decreasing house density, demolished sites along the urban periphery, demolition corridors within a city and 'housing islands'. For the latter, the term 'perforation' was introduced by Leipzig urban planners in 2001 (Lütke-Daldrup, 2001) and is still being discussed (D. Haase *et al.*, 2008b, pp. 337–339).

In 1999, administrative reforms 'brought back' a number of the previous suburban out-migrants within the boundaries of the city. Furthermore, and relevant to our topic, in-migration gains from adjacent and other east German regions have led to an increase in the population of 17 046 since 1999. By 2006, Leipzig's number of inhabitants stood at 506 578 (Municipality of Leipzig, 2007b, p. 19) and is expected to grow further to 540 000 inhabitants within the next 20 years (Municipality of Leipzig, 2007b, p.16). In addition, the suburban areas started losing their population (Herfert, 2002). According to the urban cyclical model of Berg *et al.* (1982), Leipzig has entered the phase of reurbanisation. In the inner city, the old built-up areas are most affected thereby, since from 2000 to 2005 88 per cent of all in-migrants have moved to these areas.

At the same time, out-migration from the city has almost stopped: reurbanisation, in this sense, refers also to a rising city-mindedness or willingness of people to stay in the city (A. Haase *et al.*, 2006, pp. 176–177). Reurbanisation is sustained mainly by younger age groups including students, apprentices and young professionals (aged 18–35). This also reflects positive trends in the local labour market where, in 2006, the number of employees liable for social insurance rose for the first time since 1990 (Municipality of Leipzig, 2007b, p. 105). However, the trends of reurbanisation and their long-term stability are yet to be proved. At this particular point, the present paper provides empirical evidence.

It can therefore be said that Leipzig is well suited as a case study for investigating reurbanisation processes because, first, it represents a typical case of a European city faced with an influx of people after a period of strong decline. Secondly, Leipzig's population is large enough that reurbanisation processes can be observed at the municipal-district level. Thirdly, the data availability at the municipal-district level enables us to draw on serial data at a local level for the years 1993 to 2005. Fourthly, there are questionnaire survey data available for selected districts of Leipzig (see A. Haase *et al.*, 2006; Buzar *et al.*, 2007). This survey was conducted by, among others, members of the authors' team and was used for discussing the results of our statistical analysis in the discussion section.

In this paper, we cannot establish whether reurbanisation in Leipzig can be explained best by rent gaps (Smith, 1987, 1996) or shifts in urban social classes or milieus (Hamnett, 1991, 2003; Ley, 1987, 1994) as discussed by gentrification scholars (see earlier). However, we underline that both factors—rent levels and socio-demographic changes—play a role in the Leipzig case in a specific way. Inner-city old built-up areas in the process of renovation and recovering from decline and mass vacancies offer centrally located, acceptable standard housing for moderate rents and a residential environment that is attractive for a diversifying group of users.

Five Hypotheses

In order to analyse the major characteristics, progress and underlying spatio-temporal dynamics of reurbanisation in Leipzig, we set up the following five hypotheses.

***Hypothesis 1*: Reurbanisation is driven by small households of ≤ 2 persons.** As mentioned earlier, households have become smaller and the numbers of small households has been increasing despite falling population sizes. Results of a study conducted by Ogden and Hall (2000, p. 386) underline the fact that reurbanisation is driven by changes to household structures, particularly by an increase in small and the smallest (one-person) households.

***Hypothesis 2*: Recent in-migrants to the inner city are younger than long-term residents.** Younger professionals and students in particular ('starter households') are attracted by relatively low levels of rent, easy accessibility of public transport and commercial and cultural amenities within the inner city. Their priority housing preferences relate to the proximity of their housing location to the city centre as well as to the places of work. Reurbanites prefer appropriate housing at moderate costs (A. Haase *et al.*, 2006, p. 176).

***Hypothesis 3:* Reurbanisation is influenced by the supply and settings of locally available social, economic and educational infrastructure.** Inner-city in-migrants are assumed to be attracted by the quantity and quality of the social and medical infrastructure and the retail trade, supermarkets or other shopping facilities. In this way, the population development, as Beauregard (2004) pointed out, is closely associated with employment change and social conditions such as the quality of schooling. Hence, a growing number of small and medium enterprises (SMEs), and particularly the rise in the number of kindergartens and primary schools, contributes to the stabilisation of areas with family households (A. Haase *et al.*, 2005a, pp. 26–27). Likewise, the proximity to university locations is deemed to be a key factor of student-driven reurbanisation (Buzar *et al.*, 2007, p. 666).

***Hypothesis 4*: Reurbanisation-prone districts exist within the city of Leipzig.** It is postulated that reurbanisation processes can be identified in specific areas within the entire city (63 districts) by applying an interdisciplinary set of indicators (A. Haase *et al.*, 2005a; D. Haase *et al.*, 2008a).

***Hypothesis 5*: Reurbanisation is not only a transitory phenomenon but is a long-term process in a number of inner-city districts.** Reurbanisation patterns can already be traced back for certain districts in Leipzig over a longer period of time, which would allow them to be identified as 'consolidated reurbanisation areas'.

4. Materials and Methods

In order to verify the hypotheses and to identify (potential) reurbanisation processes (A. Haase *et al.*, 2005a), significant indicators were selected out of an interdisciplinary indicator set to observe reurbanisation processes. We used households (size and total number), migration and age structure as direct indicators to present the evidence and progress of reurbanisation (D. Haase *et al.*, 2008a). The indicator of migration is used threefold: first, as a (total) migration balance; secondly, for immigration and the corresponding out-migration, including moves across the city border; and, thirdly, as (inner-urban) in-migration which comprises moves between and within municipal districts. Additionally, the indicator set contains indirect indicators, which describe the framework conditions that are assumed to be favourable to reurbanisation processes. These should be regarded as being in interplay with the direct indicators (A. Haase *et al.*, 2005a, pp. 21–32). From that group, we applied the indirect indicators of (un)employment, SMEs (small and medium enterprises) and schools and kindergartens (D. Haase *et al.*, 2008a).

The indicator set was already tested by D. Haase *et al.* (2008a) for initial statistical evidence and applicability to an entire city: the case study of Leipzig was used since the city counts as a 'prominent reurbanisation case' (D. Haase *et al.*, 2008a). For this purpose, municipal statistics comprising data from the 63 districts of Leipzig dated from 2003 (t_1) were used for a bi-variate regression analysis. The basic indicator household size was plotted against other variables of the set, such as in-migration. The results checked the first evidence of reurbanisation processes according to the indicator set (for example, $R^2 = 0.46$ between household size and in-migration) and confirmed both the applicability and the significance of the indicators.

However, an analysis using data for only one moment in time, t_1 (2003), has to be embedded in a time-series analysis to provide evidence of the stability, dynamics and trends of reurbanisation processes. To bridge that gap, this paper presents a spatio-temporal time-series analysis which uses municipal data from 1993 to 2005. According to our methodological design (see Figure 3), the time-series, with $t_1 = t_n, t_{n+1}, \ldots t_{n+x})$ where x = last time-step, was applied to validate this stability.

Data Compilation

Following our hypotheses, we compiled data from the local municipal statistics of the city of Leipzig. Data were provided by the municipal agency for statistics and elections dating from 1993 to 2005. We developed a consistent database comprising data for each of the 63 districts. As far as the quality of the data is concerned, we do indeed have some data gaps caused by a lack of data available for the time slot 1993–95. In the case of household structures (total number,

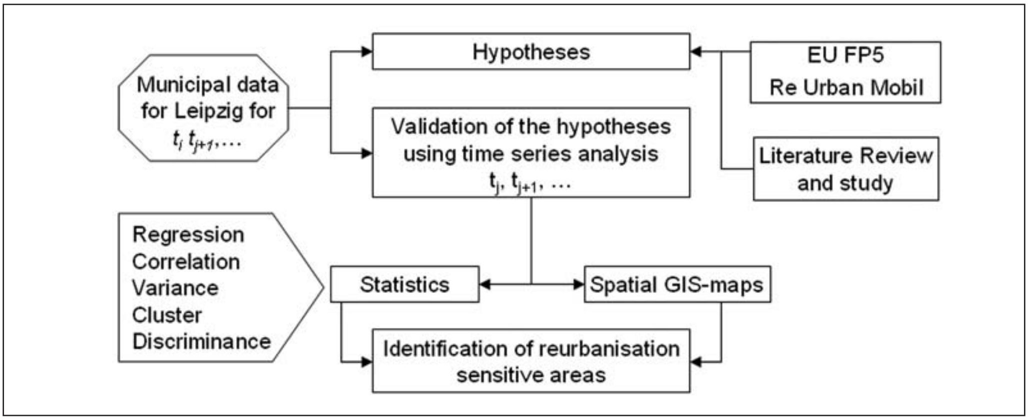

Figure 3. Logic of the approach and methods used.

average size), data are available from 1995 and extrapolated from 2004 based on the Federal Micro-census. Framed by the five hypotheses above and the data availability, the indicator set for this paper is given in Table 1.

Data Processing

Several statistical analyses were applied using the software package SPSS® version 14.

In order to identify relationships between the direct indicators and the indirect indicators for reurbanisation, our analysis starts off by using a bi-variate regression and correlation analysis of the time-series (R^2-series). These statistics were mainly used to test hypotheses 1, 2 and 3. In doing so, significant correlations between the indicators can be identified. Additionally, the analysis gives an idea of its utility for identifying reurbanisation districts according to the value distribution of dependent variables

$$y = ax + b$$

where, Y is the dependent variable; a is the regression coefficient; b is the constant; and x the independent variable.

A regression analysis resulting in R^2-series formulated as

$$R^2_{t_1 \to t_n} = [(y = ax + b_{t1}) + (y = ax + b_{t2}) + (\ldots) + (y = ax + b_{tn})]$$

then reflects the (linear or non-linear) relationship R^2 between the dependent variable of the in-migration a and other reurbanisation-sensitive variables of the set b.

Our database comprises migration data divided into age classes of 10 years. These are presented as: 0–10, 10–20, 20–30, 30–40, 40–50, 50–60, 60–70 and 80 years and older. The span of the age classes was defined as 0–10 meaning 0 to less than 10 years, 10–20, meaning 10 to less than 20 years and so forth. To evaluate which age class counts as the most mobile among the groups, we carried out a ratio analysis (including variance analysis)

$$\mathrm{R} = \frac{(Zi_k + Z_k)_n}{E_k}$$

where, R is the ratio; Zi_k represents in-migration of age class k in district n; Z_k reflects immigration across the city border of the same age class k in district n; and E_k is the inhabitants of age class k of the entire city.

To validate hypotheses 4 and 5, a hierarchical cluster analysis was chosen to identify groups of reurbanisation-sensitive districts and non-affected areas. We used the specific Ward procedure and squared Euclidian distance as the distance measure. The Ward method generally shows a high tendency to build clusters with a similar case occupation. Thus, it is commonly used for spatial

Table 1. Data used for setting the indicator set into operation

Indicator	*Variables*	*Time series*	*Dataset (primary source)*
Households	Household size	1995–2005	Local municipal statistics of the city of Leipzig (for 2004/05 micro census)
	Total number of households	1995–2005	
Migration	Immigration (across the city border)	1993–2005	Municipal agency for statistics and elections
	Out-migration (across the city border)	1993–2005	
	(Inner-urban) in-migration (moves between municipal districts including moves within the district)	1993–2005	
	Total migration balance	1993–2005	
Age structure	Migration according to age structure (10-year age-classes)	1993–2005	Municipal agency for statistics and elections (register of residents)
	Inhabitants according to age structure (10-year age-classes)	1992–2005	
	Mean age	1993–2005	
Foreigners	Percentage of foreigners according to the total number of inhabitants	1995–2005	Local municipal statistics of the city of Leipzig 1997, 2000, 2002, 2004, 2006; statistical year book for Leipzig 1998, 1999, 2000 (register of residents)
Employment	Percentage of unemployment (number unemployed out of 100 employees)	1996–2005	Local municipal statistics of the city of Leipzig 1997, 2000, 2002, 2004, 2006; statistical year book for Leipzig 1998, 1999, 2000 (Federal employment office)
SMEs (small and medium enterprises)	Total number of SMEs	1993–2005	Local municipal statistics of the city of Leipzig 1993, 1995, 1997, 2000, 2002, 2004, 2006; Municipal agency for statistics and elections (Chamber of industry and commerce Leipzig)
Educational infrastructure	Total number of kindergartens	1993–2005	Local municipal statistics of the city of Leipzig 1993–2006; Municipal agency for statistics and elections (Statistical Office of the Free State of Saxony)
	Total number of schools	1993–2005	
Health infrastructure	Total number of doctors	1993–2005	Local municipal statistics of the city of Leipzig 1993–2006; Municipal agency for statistics and elections (Statistical Office of the Free State of Saxony)

socio-demographic and economic data. The analysis was conducted with data from 1999 to 2005 due to the methodological requirement of taking the same number of districts (63) as *n*.[1] Four variables were selected for clustering: migration balance, percentage of foreigners, mean age and percentage of unemployment. The selection of these variables is based on their significance as respective reurbanisation indicators and on a preliminary statistical test of multicollinearity, which could not identify any significant collinearity amongst the variables.

The first three variables—migration balance, percentage of foreigners and mean age—demonstrate demographic changes and simultaneously indicate reurbanisation processes in a direct way. The indirect indicator of the percentage of unemployment was chosen to show characteristics of reurbanisation processes in combination with the direct (but non-correlating) indicators. The Ward-cluster analysis was carried out after a *z*-transformation

$$X(z) = \sum_{n=0}^{\infty} x[n] z^{-n}$$

To evaluate the quality and stability of the Ward clusters obtained, an additional discriminant analysis (including a test of the residual fractions) was conducted based on a discriminant function

$$D = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n,$$

where, D represents the discriminant function; x_n is the attribute variable ($n = 1, 2, \ldots, n$); b_n is the discriminant coefficient for n; and b_0 is a constant.

5. Results

In this section, we present the results which we obtained in the statistical analyses. We used bi-variate regression and correlation analyses to identify significant coherences between the direct indicators and the indirect indicators. The results of the analyses underline the applicability of some of the indicators regarded as basic indicators for measuring the evidence and progress of reurbanisation. The complete list of regression results including the R^2 coefficients and significance levels is given in Table 2.

According to the assumption that reurbanisation is predominantly driven by small households of ≤ 2 persons (Hypothesis 1), the indicator of household size was chosen as the indirect variable and was plotted against the direct indicator of the in-migration. The results showed negative correlation values—i.e. negative exponential coherences—which are significant since 1999 (R^2 increases from 0.01 in 1995 to 0.48^{***} in 2005). The plots underline the fact that districts characterised by high in-migration values simultaneously show small/below-city-average household sizes.

To demonstrate whether those smaller households represent a stabilisation element for inner-city areas, the spatial distribution of the average household size per district is presented in Figure 4 for two time snapshots, 1995 and 2005. In 1995, an average household size of ≥ 2 persons was found in most of the districts. The mean household size was larger in districts located in the peripheral parts of the city than in central ones. While the tendency for household size to increase in peripheral districts persisted in 2005, much smaller households (≤ 1.6) were then typical for inner-city districts around the city core, which underlines the growing tendency to live alone in more central areas.

In accordance with Hypothesis 2, a ratio analysis was used to explore migration to the districts according to their age-class distribution. Simultaneously, we used time-series distributions of the development of the respective 10-year migrating age classes for the districts

Table 2. R^2 coefficients between in-migration and selected variables

	R^2 *between in-migration and*					
	Household size	*Number of inhabitants < 40 years*	*SMEs*	*Kindergartens*	*Schools*	*Doctors*
1993	—	0.93***	0.31***	0.41***	0.52***	0.41***
1994	—	0.79***	0.27***	0.42***	0.46***	0.39***
1995	0.01	0.85***	0.34***	0.48***	0.47***	—
1996	0.04	0.70***	0.33***	0.49***	0.36***	0.57***
1997	0.03	0.77***	0.37***	0.43***	0.39***	—
1998	0.08**	0.76***	0.42***	0.37***	0.36***	0.64***
1999	0.19***	0.81***	0.54***	0.43***	0.44***	0.69***
2000	0.40***	0.86***	0.52***	0.36***	0.29***	0.64***
2001	0.46***	0.89***	0.52***	0.34***	0.31***	0.69***
2002	0.48***	0.91***	0.50***	0.30***	0.34***	0.62***
2003	0.47***	0.93***	0.53***	0.32***	0.34***	0.68***
2004	0.45***	0.94***	0.53***	0.30***	0.38***	0.65***
2005	0.48***	0.95***	0.61***	0.26***	0.32***	0.67***

Notes: *** $p < 0.01$; ** $p < 0.05$;— no data available for the respective year.

of Leipzig from 1993 to 2005 (some of them are shown in Figure 5). Here, we added immigration and in-migration, which are defined in section 4, for a broader view.

Notably, the 20–30s show rising migration numbers and constitute the highest percentage of the entire city since 1996. At the same time, the age class of the 30–40s started to decrease. Further, we identified increasing migration numbers of the 0–10s from 1993 to 1998, since when this age group has remained stable. Evidently, age groups belonging to younger age classes represent the predominant proportion of migrants to inner-city districts.

Even the regression between the entire number of inhabitants and<40 years and in-migration resulted in extremely close relationships for the respective years (Table 2). R^2 coefficients continuously showed highly significant values (1993: 0.93***; 2005: 0.95***).

In terms of Hypothesis 3, reurbanisation is promoted by the local supply and settings of the social, economic and educational infrastructure. Thus, we took the indirect indicators of the total number of doctors (representing the social infrastructure), small and medium enterprises (SMEs, representing economic infrastructure) and the total number of kindergartens and schools (representing educational infrastructure) to investigate Hypothesis 3. Here, we also used the linear bi-variant regression analysis—i.e. R^2 coefficients—by also setting the indicator of in-migration as the direct indicator (Table 2). Regression coefficients for each of the variables are to be found as time-series (1993 to 2005) in Figure 6. The variable 'total number of doctors' was shown to be significantly related to in-migration for the whole period exhibiting increasing R^2 values (1993: 0.41***; 2005: 0.67***).

Similarly, the variable representing the total number of SMEs, indicating the economic infrastructure, appears to show highly significant relationships to in-migration—i.e. positive values that increase from 0.31*** (1993) to 0.61*** (2005). In contrast, we were not able to demonstrate an increase in significant regression coefficients using the total number of

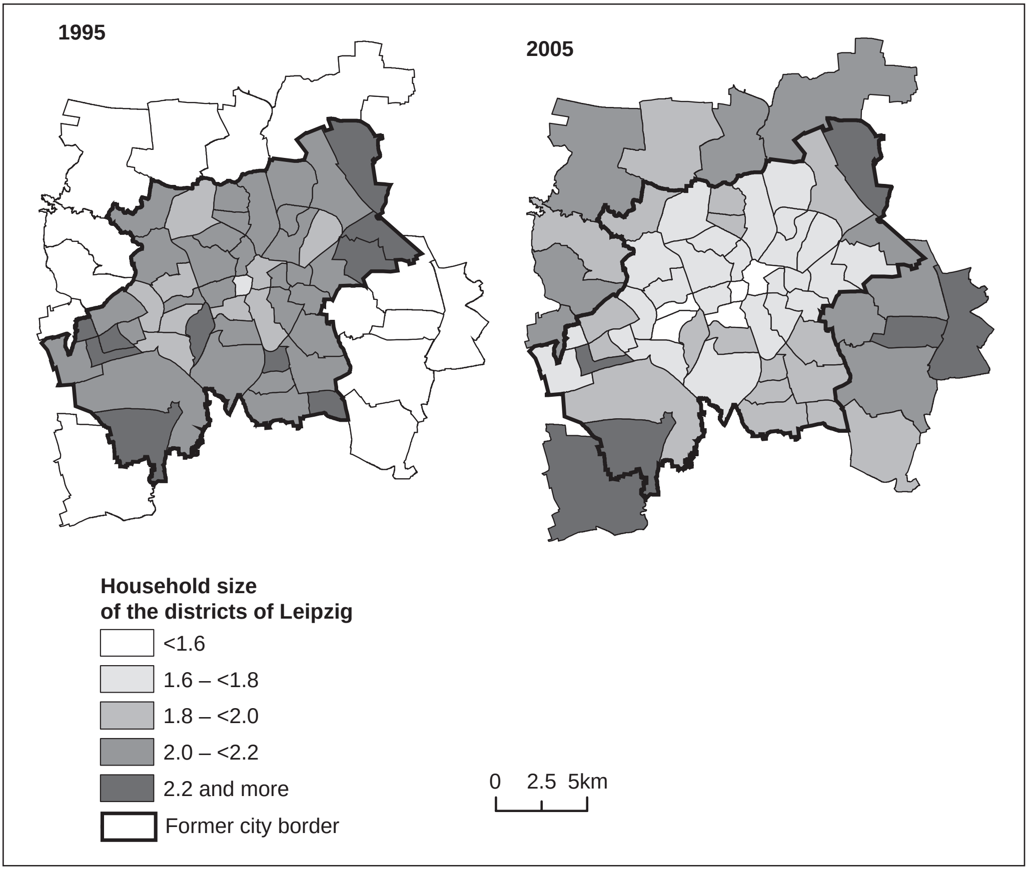

Figure 4. Spatial distribution of households in Leipzig, 1993 and 2005, according to their size (by number of residents) at municipal-district level.
Source: Municipal agency for statistics and elections.

kindergartens or schools; R^2 values decrease from 0.52^{***} (1993) to 0.32^{***} (2005), but are still significant.

Hypotheses 4 and 5 refer to the spatial distribution and the temporal significance of reurbanisation processes. Regarding the latter, we were asking whether there is evidence that reurbanisation is a long-term process or just a short-term development. We expected to find municipal districts that are, due to their local settings, particularly sensitive to reurbanisation (Hypothesis 4).

As a follow-up, we identified four clusters according to the aforementioned variables used for the cluster analysis: migration balance, rate of foreigners, mean age and percentage of unemployment. This grouping was validated by the discriminant analysis that underlines its applicability and identified 90.5–95.5 per cent (depending on the year) of the districts as precisely classified. We named the clusters according to their specific characteristics as follows: Cluster 1—"Centre cluster", Cluster 2—"Shrinking and ageing cluster", Cluster 3—"Young reurban cluster", Cluster 4—"Stable suburban cluster". Table 3 gives an overview of mean parameter values of the four variables forming each cluster. In addition, a comparison of the mean values to the city average is shown. Furthermore, the tendency of the respective variable values within the last two years is presented.

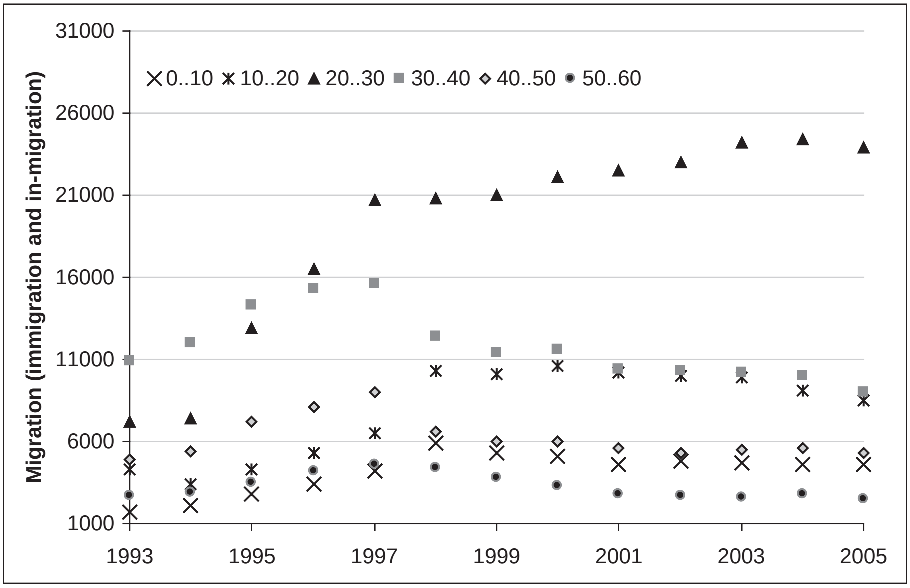

Figure 5. Development of the migrating age classes of the 0–10s, 10–20s, 20–30s, 30–40s, 40–50s and 50–60s for the municipal districts of Leipzig, 1993–2005.
Source: Municipal agency for statistics and elections.

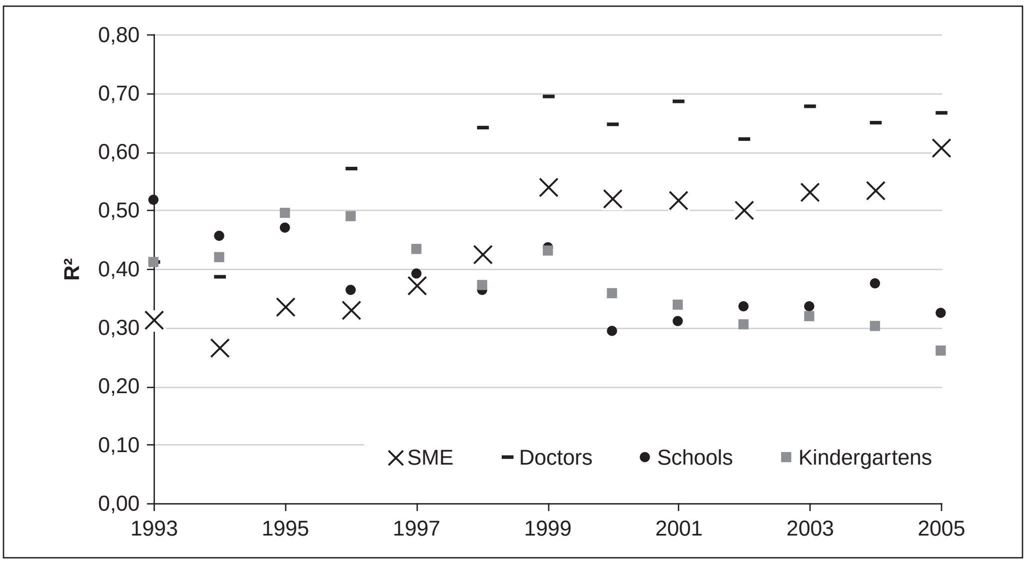

Figure 6. Linear regression coefficient R^2 between in-migration and the following indicators: total number of SMEs, doctors, primary and secondary schools and kindergartens.
Source: Municipal agency for statistics and elections.

Table 3. Clusters of urban socio-demographic development

	Cluster 1 Centre cluster			*Cluster 2 Shrinking and ageing cluster*			*Cluster 3 Young reurban cluster*			*Cluster 4 Stable suburban cluster*			
Variable	*C*	*T*	*V*	*C*	*T*	*V*	*C*	*T*	*V*	*C*	*T*	*V*	*Cluster City average*
Migration balance	+	↑	82	--	↑	−129	++	↓	266	+	↓	86	76
Percentage of foreigners	++	↔	13.1	-	↔	3.2	+	↔	5.8	-	↔	1.4	5.9
Mean age	--	↔	42.4	++	↑	45.7	--	↔	39.8	+	↔	43.4	42.8
Percentage of unemployment	+	↑	12.9	+	↑	14.7	+	↔	13.3	--	↔	7.7	12.1
Number of districts		6			24			17			16		63

C = compared with the mean value of this variable for the whole city.
T = represents the trend of the respective variable values from 2004 to 2005.
V = mean value of the cluster.
++ = far above city average (within interval $\mu + 2\sigma$).
+ = above city average (within interval $\mu + \sigma$).
- = below city average (within interval $\mu - \sigma$).
-- = far below city average (within interval μ - 2σ).
↑ = tendency increasing.
↔ = tendency stable.
↓ = tendency decreasing.

The “Centre cluster” comprises all of the districts in the city centre—i.e. six districts. It shows high values for the percentage of foreigners (13.1), while the city average is 5.9. The “Shrinking and ageing cluster” features a high mean age (45.7 years) as well as a percentage of unemployment which is above city average (14.7). The districts included in Cluster 2 face high numbers of out-migration and thus show a negative migration balance of -129. Cluster 2 comprises 24 districts and therefore appears to be the most grouped cluster. With regard to the “Young reurban cluster” (Cluster 3), we found a positive migration balance (266) and a significant low mean age of <40 years (39.8) to be distinctive characteristics. Overall, 17 districts belong to this cluster. A low percentage of foreigners (1.4) and a positive migration balance (86), with a tendency to decrease over the coming years, feature in Cluster 4, the “Stable suburban cluster”, which comprises 16 districts. This cluster shows the lowest values for variance for the variables according to their parameter-values. Box–Whisker plots report the variance for all of the variables incorporated (Figure 7). Figure 8 shows the spatial distribution of the districts within each of the four clusters.

Looking at the spatial distribution, the districts of Cluster 1, the “Centre cluster”, are predominantly situated in the centre of the city. Cluster 2, the “Shrinking and ageing cluster”, comprises districts that are situated near the former city border and mainly belong to residential areas with predominantly GDR-era prefabricated housing estates. “Young reurban cluster” districts are situated within the inner city, forming a ring of reurbanisation-sensitive districts around the city centre. Most of them are located in the residential area with a predominantly Wilhelminian housing stock. Districts outside belonging to Cluster 4, the “Stable suburban cluster”, are mainly situated outside the former city border in suburbia.

To return to Hypothesis 4, Cluster 3, the “Young reurban cluster”, confirms the presence of reurbanisation-sensitive local districts. With regard to Hypothesis 5, we found seven of the identified districts in Cluster 3 to be stable over the whole time-period from 1999 to 2005, which means that those districts were allocated to Cluster 3 every year.

6. Discussion: Reurbanisation Evidence

Drivers of Reurbanisation

The results of the quantitative study show significant statistical evidence of reurbanisation processes for a definite period of time—i.e. 1993 to 2005. We identified small households of ≤ 2 persons to be closely related to in-migration numbers. According to the municipal statistics, the percentage of those households increased considerably within almost all inner-city districts from 1995 to 2005. Additionally, the results of the ratio analysis clearly show a rising influx of representatives of younger age classes to inner-city districts since 1993, in particular those aged younger than 30 since 1998. With regard to their spatial distribution, it is predominantly to districts close to the city centre that these in-migrants go, resulting in a successive rejuvenation of these areas. These findings correspond very well to those of other European-wide studies. In the cases of Glasgow and Manchester, Seo (2002) identified a large number of young people mainly living in small households within reurbanisation-sensitive areas in the inner city. A comparative study by Buzar *et al.* (2007) analysed recent population trends in inner-city areas in the European cities of Bologna, León, Ljubljana and Leipzig. In all these cities, reurbanisation processes were found. The study concluded that reurbanisation was mainly driven by specific household types such as small households and young people who contributed to the processes of repopulation and rejuvenation of selected inner parts of the cities mentioned. For the purpose of our paper, it can be concluded—supported by

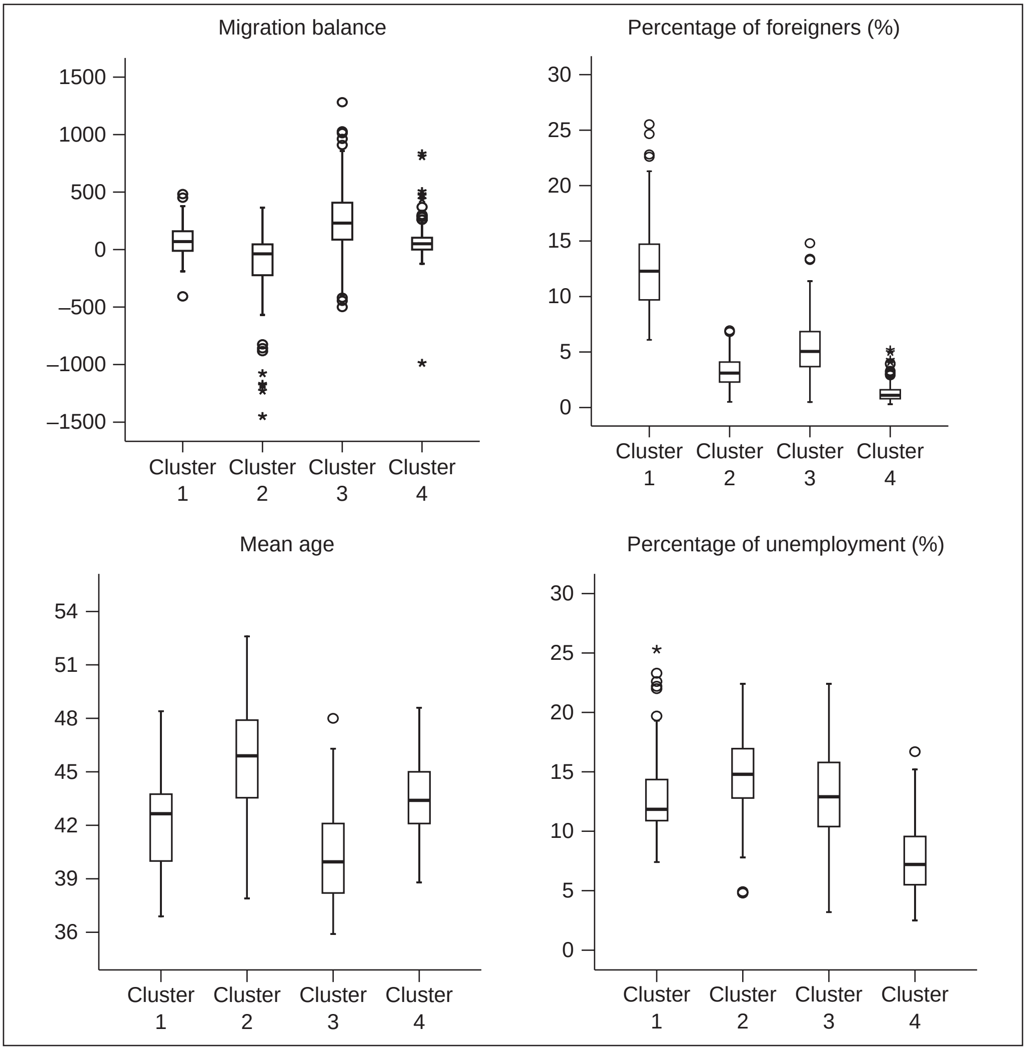

Figure 7. Box-Whisker plots showing the variable variance within the clusters for all 4 variables 1999–2005: mean age, migration balance, percentage of foreigners and unemployment.

findings from other studies mentioned—that it is to a significant degree, although not exclusively, small households represented by young age classes who are driving reurbanisation processes in Leipzig.

As far as the indicators representing the characteristics of social, economic and educational infrastructure are concerned, we found both increasing and decreasing relationships between these indirect indicators and our direct indicator of reurbanisation—i.e. the influx of small and mainly younger households. Positive relations were found in the case of the number of doctors and SMEs, indicating that they could boost the in-migration of specific population groups or age classes to specific districts. In terms of the spatial distribution of their changes in the total number (1993 to 2005), the numbers of doctors as well as SMEs appear to show similarities to the distribution of the household sizes: primarily inner-city districts inhabited by small households appear

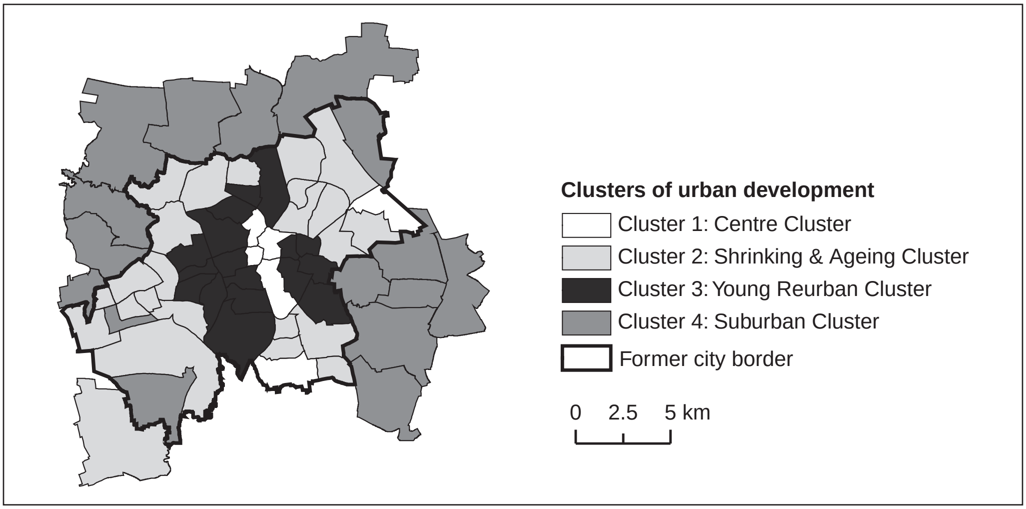

Figure 8. Clusters of socio-demographic urban development at local-district level in Leipzig for the time-span of 1999–2005.
Source: Municipal agency for statistics and elections.

with an increasing numbers of doctors and SMEs. These results fit the findings of a British nation-wide survey on the 'quality of life'. There, it was documented that people prefer to live in places with, amongst others, the best possible health services and good shopping facilities (Findlay *et al.*, 1988).

In terms of the distribution of SMEs, it has to be considered that changes in the total number might also induce labour market transformations. Thus an increasing number of SMEs, often related to rising employment opportunities, is thought to trigger in-migration to the respective inner-city districts.[2] In the case of Leipzig's media cluster (clustering around the regional TV broadcasting service MDR), this had developed to a significant size by the end of the 1990s. At present, it attracts competitors from other regions as well as students from Leipzig's universities (Bathelt, 2005). Obviously

> the city—and more especially the metropolitan core—represents the 'creative habitat' *par excellence* for these new industrial clusters ... offering a critical mass of human capital, amenity attributes, and environmental conditions (Hutton, 2004, p. 1958).

Furthermore, the advantages of location persuaded large firms, such as BMW, Porsche, DHL and Amazon to settle in Leipzig and in the vicinity. Although we cannot infer a direct relationship between the residential shifts in inner-city areas and this type of SME dynamics, there might be an 'interactive' effect that strengthens both trends. Moreover, once settled, the media industry attracts educated (young) professionals who probably consider the residential areas close to their place of work to be appropriate places of residence (Weigel and Heinig, 2007). Previous research on reurbanisation in Leipzig confirms that short distances to work are among the main reasons for reurbanites to move to inner-city districts (A. Haase *et al.*, 2006).

By contrast, the relationship between in-migration and the total number of kindergartens and schools shows a decreasing trend for nearly all districts. It was expected that there would be a significant positive relation between these variables, since other studies present evidence of significant correlations between high-quality schools and residential in-migration (Zhang, 2001). In the case of Leipzig, however, the specific situation of east German cities has to be considered. Leipzig offered a large number of child-care institutions before 1990. However, as a consequence of the fall in birth rates to an all-time low ('lowest-low fertility' with 0.77 children per woman in 1993 and 1994 for east Germany; Kröhnert *et al.*, 2004, p. 46), in some districts almost all kindergartens and schools were closed between 1993 and 2005. Thus, the development of the educational infrastructure rather reflects the decline in demand for schools and kindergartens in many places. Consequently, these two indicators are not considered to be appropriate to indicate reurbanisation at least for the period of analysis. As for the future, however, the expected positive relationship mentioned earlier is expected to resume, most of all for processes of 'family-driven' reurbanisation that, although more modest in numbers, also plays a role in Leipzig.

The "Young Reurban Cluster"

The cluster analysis was conducted to identify groups of districts according to their reurbanisation-relevant characteristics. As a result, we were able to identify four clusters grouping the 63 districts of Leipzig.

An important result derived from the cluster analysis is the identification of the "Young reurban cluster", which shows significant features of reurbanisation processes. Districts in that cluster face an above-average, positive migration balance and a below-average mean age. These districts appear as a kind of rejuvenated reurbanisation-sensitive ring in the inner city of Leipzig and, in addition, some of them appeared stable for the studied time-period (since 1999). Therefore, they were identified as 'consolidated reurbanisation areas'. For further analyses, the identification of this cluster and the cluster approach itself will serve as suitable instruments for a long-term observation of reurbanisation trends as a part of urban monitoring.

Finally, to embed the results for Leipzig into a wider context, we focused on other large and medium-sized east German cities which underwent similar (post-socialist or transitional) developments over recent decades. Cities such as Dresden, Erfurt and Jena show a population turnaround leading to stabilisation and growth tendencies since the end of the 1990s (Herfert, 2002, p. 340). Additionally, the work by Ott (2001) on deconcentration in the city of Erfurt presents patterns of post-socialist suburbanisation until the end of the 1990s. The processes were accompanied by inner city out-migration and the degeneration of large housing estates from the 1960s to 1980s. Thus, this coincides with the development in Leipzig during the 1990s. Since Ott's analysis is limited to data up to the end of the 1990s, it does not report on the population turnaround and inner-city repopulation by younger age classes after 2000 that is also true for Erfurt (Municipality of Erfurt, 2007). Hence, in the east German context, the phenomenon of reurbanisation appears in some of the larger urban centres, first and foremost in university cities with a multifunctional economic and service base—cities that Herfert (2007) referred to as 'islands of growth' in an ocean of shrinkage.

7. Conclusions

In this paper, we have presented quantitative spatio-temporal analyses of reurbanisation based on socio-demographic indicators from an interdisciplinary indicator set for reurbanisation processes. Using the example of the east German city of Leipzig, we proposed five hypotheses to identify the basic characteristics of reurbanisation. We further explored whether reurbanisation is related to certain local settings of spatial, socioeconomic and residential-environment factors. Moreover, we analysed whether reurbanisation shows tendency to be a long-term process instead of being only a temporary phenomenon. In order to test these assumptions, local municipal time-series data for the 63 urban districts from 1993 to 2005 were analysed.

To summarise, we came to the following conclusions. First, we found small (i.e. one- and two-person) households to be the drivers of reurbanisation in Leipzig. Set against the background of the overall trends of the downsizing of households and an increasing importance of living alone, it became clear from the evidence that the current reurbanisation is favoured by these trends.

Secondly, we identified young households, particularly the age class of the 20–30s, as reurbanites who settle in inner-city districts to take advantage of of their central location—i.e. the short distances to work or education as well as easy access to other urban amenities.

Comparing the direct indicators of reurbanisation with some other, seemingly related indicators, we found, thirdly, both increasing as well as decreasing correlations. While the statistical analysis points to a positive relation between reurbanisation and the numbers of doctors and SMEs, no such relation is found for kindergartens and schools. We demonstrated that it is indispensable to look at the processes behind the data to be able to interpret them properly.

By a cluster analysis, we fourthly determined those districts where reurbanisation processes can be observed since the end of the 1990s. A considerable percentage of these districts showed consistent significant characteristics of reurbanisation from 1999 to 2005 and were therefore classified as the "Young reurban cluster" with at least a mid-term perspective.

We conclude that Leipzig is a good city for which to analyse reurbanisation processes that focus on the inner city and younger households and that might even affect outer districts and other residential groups such as families and the elderly in the future. The results underlined that reurbanisation in our conceptualisation best explains the processes of repopulation and socio-demographic shifts that we observe in Leipzig's inner city. For the future, processes of an on-going fragmentation and local gentrification are not excluded and need to be further investigated. Comparison with other east German and even east central European cities (A. Haase *et al.*, 2007) shows that the described trends are of an overarching importance and not locally specific. Whether they are really long term or merely represent a phase of inner-city reconsolidation within a broader cycle of development under the conditions of population decline has to be left for future research.

Notes

1. Due to administrative reforms in 1999, the number of districts increased from 49 (1993) to 63.
2. The opposite effect is also possible: higher in-migration might attract new SMEs to locate in the area.

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Changes to Central European landscapes—Analysing historical maps to approach current environmental issues, examples from Saxony, Central Germany

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Abstract

The issues of historical landscape analysis and the influential driving factors of landscape development provide an essential basis for tackling current environmental questions in spatial planning. Therefore, this paper focuses on the objectives and methods of historical landscape analysis with the example of Saxony, Central Germany.

The different ways in which such investigations can be applied and the results achieved are shown using four case studies. The main objective is to discuss methodological aspects of spatially explicit GIS-based landscape analysis and ways of making full use of the information contained in historical maps. Examples of suitable maps of Saxony dating back to 1780 are presented. In addition to historical land-use information, valuable additional information can also be gained from this kind of data, such as on the historical pattern of landscape functions, potentials and structures. These findings can be used to predict and optimise future landscape development.

The approaches presented here combine methods of classical landscape analysis with modern techniques such as geographic information systems (GIS), the approach of landscape metrics (LSM) or deterministic models (e.g. ABIMO), which can be used to serve spatial analysis, and tools for analysing landscape structure.

Keywords: Landscape changes; GIS; Land use; Historical maps; Landscape structure; Landscape functions

Landscapes—mirror of society

Unlike in previous ages, landscape development in Central Europe is currently characterised by mainly anthropogenic processes affecting almost the entire landscape (cf. e.g. Antrop, 2000; Konold, 1996). Many of these processes are almost imperceptible when viewed over shorter periods and appear to be of little consequence. In the long term, however, they may well lead to changes in the carrying capacity, water balance and usability of the landscape.

Landscapes in this paper are understood as dynamic and open systems where biophysical, social and economic factors mutually interact and are structured in heterogeneous patterns in different space and time frameworks. For the authors, cultural landscapes have a strong historical background to be considered today (Bastian and Steinhardt, 2002).

Changing landscapes, especially changes in the way in which land is used, result in alterations to the landscape structure—and, hence, also to the abiotic and biotic functions and potential of a landscape. The general trend of landscape development in Central Europe is heading towards more monotonous, less diverse landscapes combined with the impairment of landscape functions over large areas (Antrop, 2000). The diverse conditions characterising natural areas are being increasingly narrowed down while the landscape balance is being permanently altered.

In Central Europe, a region dominated by anthropogenic development for housing, trade, industry and

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intensive agriculture, in addition to their natural attributes landscapes are mainly characterised by multiple usage—and, hence, usage conflicts (Antrop and van Eetvelde, 2000). Not just a 20th-century phenomenon, this multiple usage has in fact evolved over a period of centuries—although the period since World War II has been dominated by the human exploitation of natural resources such as soil, water and flora, fauna and space/area itself due to urban expansion on a far greater scale than ever before (Bastian and Schreiber, 1999; Nuissl and Rink, 2005). The expansion of the land used for forestry, water, urban settlement and transport is continuing unabated (Table 1). Moreover, at present the phenomenon of shrinking urban settlements due to population decline (decreasing birth rates, out-migration) and resulting land abandonment and residential vacancy characterises large parts of Central Europe (Haase et al., 2005; Lutz, 2001, 1996). Although population growth, the major driver for land use and landscape change over centuries, has lost its dynamic in Central Europe, increasing migration fluxes at the regional and international level must nevertheless be taken into consideration. Furthermore, open spaces are subject to greater fragmentation by technical infrastructure owing to intensive road construction arising from an increased mobility of our society and related transport infrastructure construction (Jaeger, 2002; Walz, 2005b).

The intensification of farming has resulted in an increase in the average size of individual areas used for agriculture, increasingly attributed to land redistribution and drainage combined with the disappearance of structural elements of the landscape (Dosch and Beckmann, 1999). Especially in the Eastern part of Europe, the socialist planning regime led to extremely large management units. On the other hand, the total amount of land used for agriculture is declining due to economic development and agri-environmental policy of the European Union (BBR, 2002; ESDP, 1999).

In the following, several examples from Central Germany will be in the focus of the discussion. Studying these processes and integrating the findings obtained into relevant instruments of control, e.g. in landscape monitoring and information systems (Walz, 2002) will become one of the main themes of landscape ecology in the coming decades. Besides a sound knowledge of driving forces for land use change, such as the political, social, and economic as well as the institutional framework, investigating the historical development of landscapes serves as an important basis for reducing uncertainty in landscape development.

The objectives of studying landscape change

According to Section 2 of the amended German Conservation Act, "the natural balance…is to be safeguarded in its spatially definable sections such that the biological functions, substance and energy fluxes, and landscape structures characterising an area are maintained, developed or restored." (Bnatschg, 2002). Accordingly, landscape ecology also has to study important factors or 'driving forces' affecting landscape change. They include laws, administrative guidelines and directives, as well as subsidy programmes supporting certain types and intensities of land use. A growing role is being played in this sphere by the frameworks given by the European Union as well as regionally and nationally specified through government and planning administration. Examples include the EU Water Framework Directive (WFD), the European Habitats Directive (Natura2000) and the EU's Common Agricultural Policy, as well as the subsidies granted for building European road networks, and especially, highways.

Detailed knowledge on how fast and exactly where landscapes are changing allows conclusions to be drawn about the effectiveness of socio-political and social driving forces. Moreover, the changes caused to land use provide indications about the resulting state of the landscape. Knowledge of historical landscape development ought therefore to be the starting point for long-term landscape monitoring (cf. Neubert and Walz, 2002). This entails collating information on landscape development from the national down to the local level. In order to evaluate the processes involved, information about the usage of the

Table 1
Land use development in Germany 1950–2003 (%)

	Land use development in Germany (FRG[a]) 1950–1989					GDR[b]	Germany	Germany	Germany
	1950	1960	1970	1981	1989	1989	1989[c]	1997	2003
Settlement	7.1	7.8	9.3	11.1	12.2	9.9	11.5	11.8	12.5
Agriculture	57.3	57.5	55.7	55.2	53.7	57.0	54.7	54.1	53.4
Forest	28.4	28.4	28.9	29.5	29.8	27.5	29.1	29.4	29.5
Waters	1.8	1.7	1.8	1.7	1.8	2.9	2.1	2.2	2.4
Others	5.4	4.3	4.3	2.5	2.5	2.7	2.5	2.5	2.0

Data source:
[a]Federal Republic of Germany.
[b]German Democratic Republic.
[c]Mean value calculated for GDR and FRG in 1989.

(cultural) landscape, its land-use structure and intensity, its natural attributes, and the water and nutrient fluxes are required.

Therefore, investigating landscape change begs the following questions:

- How have land use and the landscape structure changed over historical periods?
- How have these changes to the landscape affected the ecosystem pattern and biophysical processes, especially water and nutrient fluxes as well as biodiversity (as products or services provided by landscapes)?
- What degree of land-use intensity is characterised by what usage patterns?
- Can general trends be concluded regarding future changes to land use and its structuring over the next few decades?
- How can these trends be evaluated in connection with sustainable landscape development?
- What conditions have to be met—and what instruments are required—if the various landscape functions are to continue to be met?

The results of investigating historical landscape development primarily consist of quantitative, statistical information on land use change (i.e. a quantitative analysis of historical states) which can, for instance, be used for the continuous monitoring of comparable metrics and indices in time series. These time series can be used to predict future general trends in the case of assumed constant political and economic frameworks.

Regional and local investigations of landscape changes enable land-use trends and developments to be differentiated by region and hence support analysis of the causes. Spatio-temporal studies also allow conclusions to be drawn about the scale of change to the landscape in historical periods. As far as landscape management is concerned, knowledge of the temporal and spatial variability as well as the dynamics of land-use change is crucial, and can be used to particularise guiding principles and the planning of suitable schemes.

In addition, studying land-use changes by using historical periods (i.e. by quantitatively analysing historical states) can highlight how land use affects the performance of landscape functions (services that are provided by landscapes for society or man e.g. water balance, groundwater recharge, de Groot et al., 2002). The form of landscape functions describes how well or badly a landscape is able to neutralise human usage (both continuous and brief) and regain equilibrium. These values (which can also be described as degrees of fulfilment of landscape functions) provide information about the state and functional capacity of a landscape (Bastian and Schreiber, 1999; Haase, 2003; Antrop, 2004; Walz, 2005a).

Extensive background knowledge is required in order to investigate and correctly assess landscape states in the historical periods concerned. Knowledge of the respective forms of usage connected with specific changes to landscape structures and functions, the respective management systems and usage-related structuring (urban and rural settlement structures, systems of roads and ditches, sizes and shapes of land parcels, Bell and Irwin, 2003) is of fundamental importance. As regards land use, this paper focuses mainly on conflicting uses of landscapes at the regional scale, assuming that e.g. catchments and regions (as typical regional scale landscape units) have to fulfill different functions and provide several services for society at the same time (cf. Chapter 4). Thus, taking history into account, a sound prognosis for future land-use-shaping potential is possible.

Historical maps and other sources

Topographic maps and their predecessors produced in land surveys since the 18th century provide a suitable cartographic base for historical landscape analysis. They have sufficient resolution in terms of geometry and content for medium-scale studies and enable landscape development over the past 200 years to be investigated. Older maps are rarely accurate enough and should, at most, be used as supplementary information.

The following comments describe the data situation of the German federal state of Saxony. There are often similar map series available within Europe, e.g. Austro-Hungarian, Prussian or Swedish military or cadastral surveys, which have an extensive coverage. The specific quality (e.g. geometrical accuracy, information content) as well as suitability for such analysis has to be evaluated in a case-related manner due to the variety of editions. Here, the fact must be added that the study of land use change at the state or national level serves for statistical and comparison purposes and has to be proved by small-scale case studies, because general trends in the development (increase, decline) of land use classes may vary at the regional scale, due to the bio-physical setting of specific sites. Therefore, this paper includes both, state-wide surveys and maps as well as representative case studies.

The Sächsische Meilenblätter ('Saxon mile sheets') were compiled starting in 1780 for the territory of Saxony at that time. The comparatively large survey scale of 1:12,000 chosen was designed to make the maps suitable for the construction of roads and canals, mining and public administration and they feature a commensurate level of detail. The relief is indicated by hatching. This is remarkable because it is an early approach to illustrating relief, but it optically dominates the map.[1] As of 1870, hatching was replaced by contour lines in the 'equidistant maps', which extensively updated the content of the Meilenblätter. Suitable information on land use was subsequently made available in the 'survey maps' (Messtischblätter) as of 1900 and the more recent digital data

[1] 'Hatching' refers to fine lines showing contour gradients. Higher density of lines indicates steeper gradients.

contained in the biotope type and land use maps as well as the current digital data in the Authoritative Topographic-Cartographic Information System (ATKIS) compiled by the regional Department of Surveying and the 1:25,000 topographic map (TK 25N). The ATKIS data are more geometrically accurate than in the other systems and will, moreover, be continuously updated. Furthermore, classified and evaluated remote-sensing data and additional time layers can be shown. For more details about the development and content of historical Saxon maps see Witschas (2002).

When processing and comparing the maps available (Table 2), it must be borne in mind that they vary in terms of survey techniques, given details, accuracy and production depending on when they were made. Moreover, the map content also changed, and old maps often do not include legends or any other form of explanation. The introduction of the Prussian legend in the new edition of the survey maps was the first time that clear, uniform map symbols were used (indeed, a modified form of the same symbols is still employed today). Other difficulties result from the different areas covered owing to the changing borders of Saxony. Any analysis of historical maps must, therefore, start with an examination to determine congruence and comparability between modern and historical maps so that a unified legend can be compiled for evaluation (Neubert and Walz, 2002; Walz et al., 2001).

Studying landscape change in recent centuries is aided by the use of other sources and materials documenting land use and the reasons why it changed. For example, additional useful information is contained in historical landscape descriptions, local chronicles, street maps and land register maps, as well as landscape paintings and special map sections drawn up for legal disputes.

In addition, there is a whole string of geo-morphological and stratigraphic-pedological studies (Bork et al., 1998) which contribute to the analysis and description of previous soil states and hence related structures and processes of land use. Considered in connection with numerous historical sources, these soil studies enable natural and human impact on the landscape to be described and differentiated.

Results of selected research studies[2]

Below, studies into landscape change in various selected areas are presented using four case studies from the Dresden-based Leibniz Institute of Ecological and Regional Development (IOER) and the UFZ-Centre for Environmental Research Leipzig-Halle (Fig. 1). In line with the framework outlined in the introductory sections, the main objectives are as follows:

Table 2
State-wide map series for historical landscape analyses in Saxony

Map series or data	Scale	Time status
Saxon Mile Sheet (*Sächsisches Meilenblatt*)	1:12,000	1780–1809
Equidistant Map (*Äquidistantenkarte*)	1:25,000	1870–1885
Survey Map (*Messtischblatt*)	1:25,000	1900–1924[a]
Biotope type and land use map (digital)	1:10,000	1992/93
Authoritative Topographic-Cartographic Information System (ATKIS, digital) and Topographic Map (TK25)	1:25,000	1993 (up to date)

[a]There are further topographic maps in different time intervals till today.

- a comparative survey and analysis of historical and current land use and its structure,
- an assessment of the landscape change determined and of the effects on the environment and on the landscape's ecological functions,
- the prediction of future land-use trends,
- the formation of indicators and indices for land use or landscape change.

Case study 1: land-use information relevant to nature conservation in rural regions

This IOER study focused primarily on the information content of historical maps relevant to nature conservation.[3] It also set out to ascertain which maps could be integrated into a geographic information systems (GIS) for comparative historical analysis and what methods of geo-referencing and digital evaluation would be required and are the most suitable (Walz and Berger, 2003). Importance was attached to an overall scale analysis, the land-use types to be investigated being geared towards their "discernibility" in historical maps. Another objective of the research work was to optimise the time and resources required.

The historical maps of two test areas—Frauenstein in the eastern Ore Mountains and Riesa-Pausitz in the loess-prevalent agricultural area of the Lommatzscher Pflege (each taken from a 1:25,000 map and measuring about 130 km^2; cf. Fig. 1)—were scanned, geo-referenced and superimposed on the vector data of the current biotope type and land use mapping of Saxony (1:10,000). The map was then subjected to regressive editing, i.e. the current set of data was adapted to the content of the historical map (Neubert and Walz, 2002). This entailed identifying the relevant information on the map, and so an extensive

[2]An overview of studies of landscape change in Saxony is posted at www.ioer.de/nathist. Apart from basic information on historical maps, this German-language website also lists contacts for the numerous projects on landscape change that have since been carried out in diverse regions of Saxony.

[3]Study on behalf of the Saxon Department of Environment and Geology, Dresden (Walz et al., 2001) as well as additional findings from the IOER research programme "Cumulative Environmental Effects of Land-use Changes".

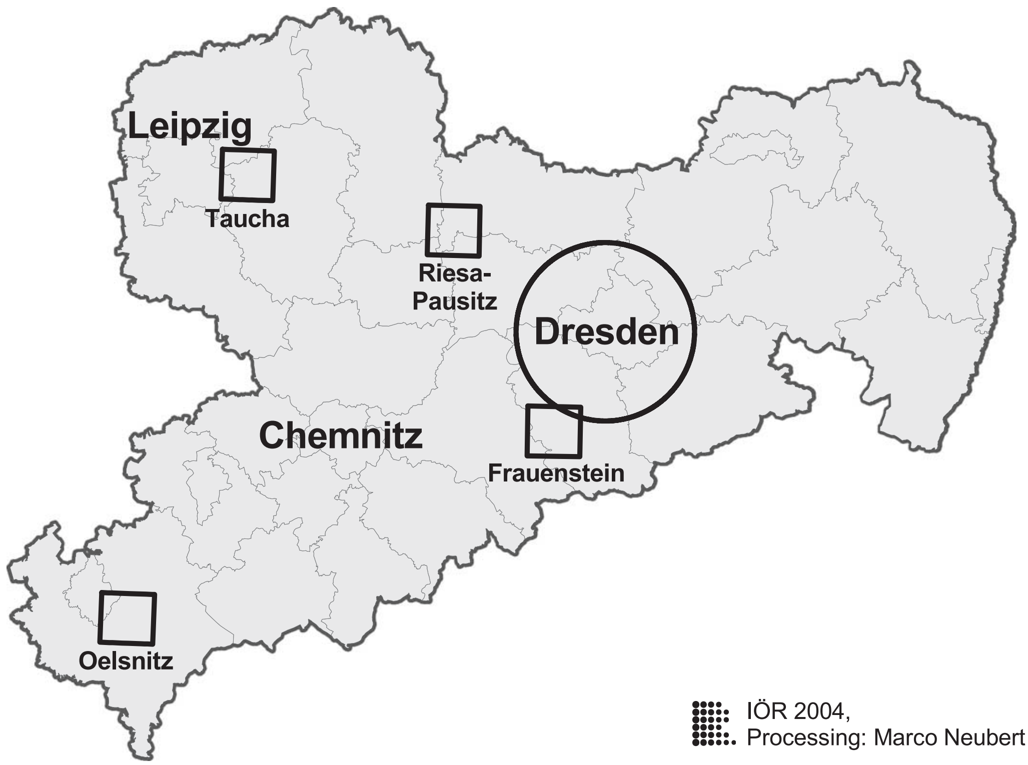

Fig. 1. Study areas of the Saxon case studies presented.

comparison of the map content was carried out beforehand and the usage elements to be mapped were decided.

Four time states were captured: biotope type and land use data was used for 1993, survey maps for 1937, equidistant maps for 1872, and the Saxon mile sheets for 1784/1825. The results comprised areas and linear elements for these time states in the form of digital data layers.

The resulting digital map series enabled comparisons to be made over a period of about 200 years (Fig. 2). Having a uniform legend made visual interpretation and the comparison of the resulting maps much easier. More importantly, however, the digital, geographically referenced processing of the land-use data enabled a series of analyses which would have been next to impossible using analogue methods, such as

- the production of statistics documenting land-use types and linear elements for each time status,
- the quantification of structural changes to the landscape,
- the determination of land use changes to specific areas and, finally,
- studying links between landscape change and landscape functions, e.g. landscape water balance (Walz et al., 2004).

For example, a statistical analysis of the proportions of areas and linear elements revealed a significant reduction of the road system (and hence of valuable boundaries) as well as the decline of small, approximately linear structures (such as hedges and rows of trees). In addition, changing land use due, for example, to the expansion of built-up areas and the expansion of grassland in the Ore Mountains could also be quantified. Being able to pinpoint land use changes threw up indications of old biotopes and ecosystems which could still be useful for nature conservation and, most of all, detailed information where to allocate limited financial resources for landscape development (Haase and Nuissl, 2005).

As well as analysing the proportions of different land uses in the individual time states, being able to take into account structural parameters when assessing changes to land use is also very important. Each landscape has its own characteristic spatial structure resulting from the quantity and arrangement of usage classes and their individual cultivation units. The structural pattern and functions of the landscape balance (e.g. in connection with the water and nutrient fluxes) are closely linked. Changes to landscape structure also affect habitat suitability for certain species of animals (Mathey et al., 1999). Landscape structure can be analysed and described using mathematical indexes covering the size, shape and position of individual cultivation units in relation to each other, for example. Moreover, landscape metrics (LSM) documenting fragmentation, usage diversity or the degree of isolation of individual landscape elements, for instance, can be determined for a landscape or a section thereof (Walz, 2001, 2004; Lausch and Thulke, 2001; Lausch and Herzog, 2002; Forman and Godron, 1986; Gustafson and Parker, 1992). The calculation of comparable indices on land-use structure over a period of time may harbour important conservation information when it comes to assessing the

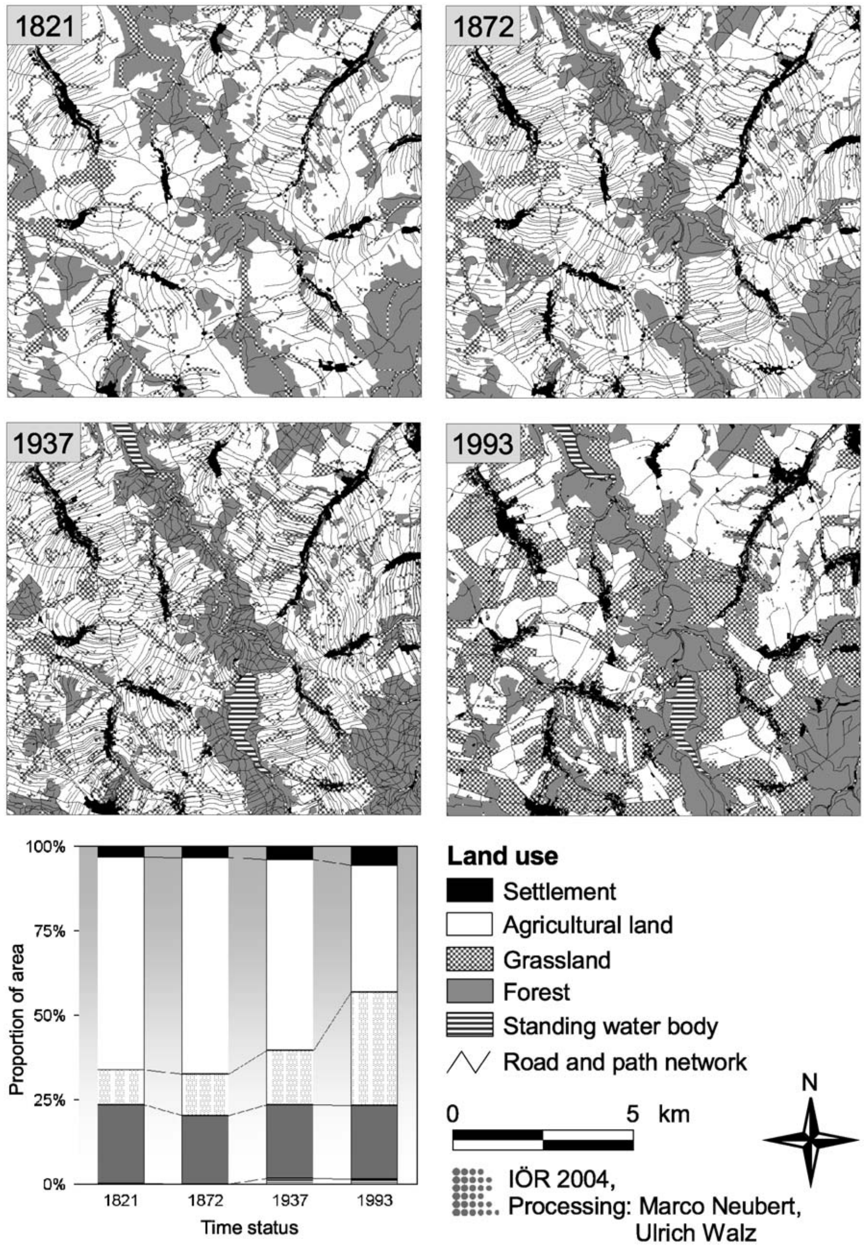

Fig. 2. Landscape development in the Frauenstein study area visualised using data layers and statistical comparisons.

current state of a landscape (cf. Turner, 1990; Neubert and Walz, 2002; Walz and Schumacher, 2003).

If a GIS or suitable geo-statistics software such as FRAGSTATS (McGarigal and Marks, 1994) is used, numerous parameters can be derived to characterise landscape structure (Walz, 2001, 2004; Lausch and Herzog, 2002). Such parameters refer to either an individual object, a land use class or an entire section of landscape. Although natural land units are suitable for differentiation when investigating aspects of the landscape balance, employing administrative and planning units would also be conceivable.

Detailed analyses were carried out using two selected meso-scale landscape units, so called 'micro-geo-chores' (Haase and Mannsfeld, 2002), in the Frauenstein study area: the hilly *Reichstädter Kuppengebiet* and *Hennersdorfer Weisseritz-Talrand* (edge of a valley). Although using natural land units is a favourable choice for landscape issues, employing administrative, socio-economic related or planning units would also be conceivable and often due to data availability.

Land-use balances for both micro-geo-chores show that in 1821 farming accounted for a very much bigger share of the landscape than in 1993 (Fig. 3). By contrast, since then the proportion of grassland has grown. Whereas the share of forest at *Reichstädter Kuppengebiet* has declined, it has risen at *Hennersdorfer Weisseritz-Talrand*. This is probably due to the steep slopes, which nowadays are hardly financially viable for farming. Moreover, when Lehnmühle dam was built, the neighbouring areas were reforested.

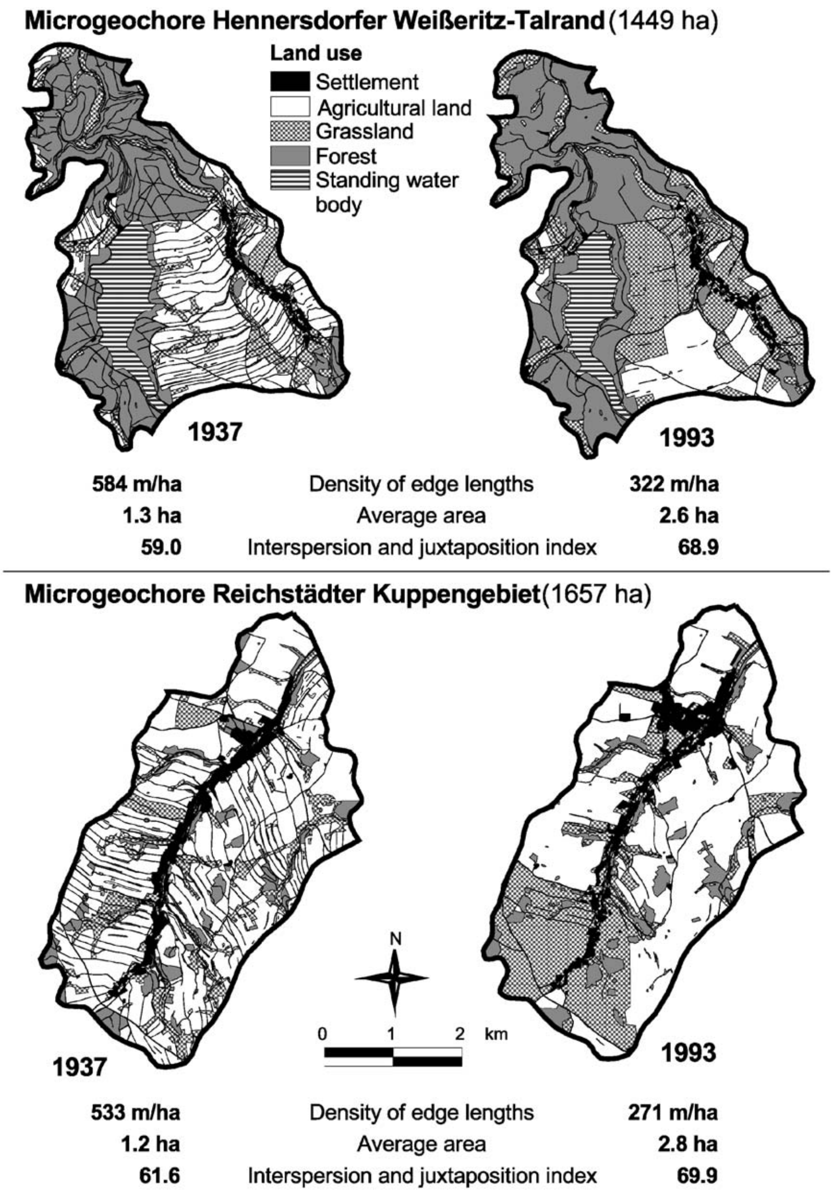

Fig. 3. Quantification of structural changes to the landscape—selected metrics on landscape structure in two micro-geo-chores in the Ore Mountains.

This example shows that statistical consideration must at all costs take into account both natural spatial and social conditions to get a complete picture of the landscape change.

Both areas feature declining structural diversity with a dwindling total length of linear elements, an increase in the average size of the individual cultivation units, and a rising interspersion and juxtaposition index (IJI). The latter indicates that cultivation units are more evenly distributed today than before; meaning the landscape now features more regular structures. In particular, as far as grassland is concerned, between 1937 and 1993 in *Reichstädter Kuppengebiet* for example, the mean size of cultivation units raised from 0.8 to 3.1 ha, while the area of the largest single patch used as grassland increased from 17 to 113 ha. In other words, the tendency towards forms of use becoming the same, and spatial diversity decreasing at the landscape level, is confirmed by the statistics.

In the *Reichstädter Kuppengebiet*, the shape index shows low shape complexity for the 1937 time status (Fig. 4). The reason is the very regular rectangular cultivation units (mainly arable land). Only a few areas, especially forest and grassland, have high shape complexity. In contrast, the 1993 time segment shows at first sight an increase in the average and high values for shape complexity. This is because the elimination of road structures and the merger of cultivation units resulted in new, larger, but also less regular cultivation units. This example also shows that it is not sufficient to merely describe the landscape with one index; instead, a number of indexes have to be used depending on the subject of investigation. In this case, apart from the shape of the cultivation units, the size of the

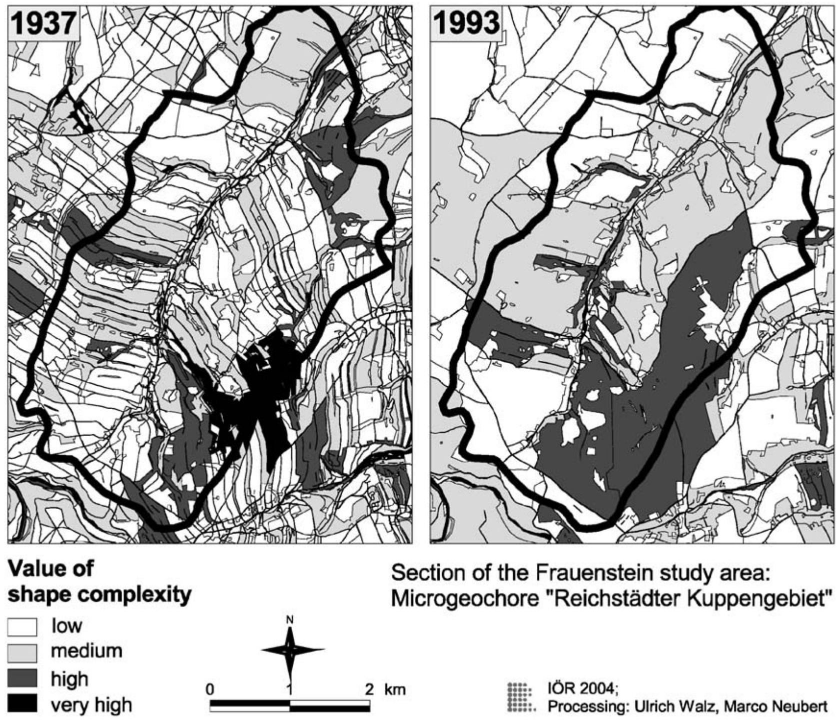

Fig. 4. The changing shape complexity in a section of the Frauenstein study area between 1937 and 1993—an example of the usage of structural metrics for landscape assessment.

area and the density of usage borders (edge lengths) need to be taken into account.

This case study shows that incorporating medium-scale Saxon historical maps into a GIS is both feasible and useful. These maps, especially the Saxon mile sheets as of 1780 and the survey maps as of 1900, contain sufficiently detailed information about uses relevant to nature conservation and landscape ecological issues. Digital processing and geo-referencing provide the basis for a quantitative analysis of land-use development and the superimposition of the data with any other geo-referenced data layers in the same projection. It was also found that suitable structural parameters can serve functionally orientated landscape assessment of rural areas.

Case study 2: the development of urban regions

Under the EU-financed projects MURBANDY and MOLAND,[4] the investigation of the long-term development of urban regions was commenced at IOER together with the Joint Research Centre based in Ispra (Italy). This work is currently being continued as part of a long-term monitoring project in which the development of land use and urban structures in Dresden between 1780 and 1998 is being studied.[5] The project includes designing and carrying out a survey of land-use changes over a long period, analysing the findings and then assessing the cumulative environmental impact. The land-use data compiled will then be used to conclude indicators representing multi-temporal usage and structural changes so that they may be compared. This instrument for the long-term observation of changes to spatial structures is designed to improve the control of measures that change spatial structures in highly dynamic urban and peri-urban areas (Neumann, 2002).

The study area comprises the urban area of Dresden, the capital of Saxony of about 500,000 inhabitants, and its surroundings in the form of a circle with a radius of 20 km (about 1250 km^2). The procedure is based on that of Case study 1, albeit with the inclusion of additional data from remote sensing. The eight time states are based on the following data: 1998—IRS-1C satellite images; 1986—SPOT-PAN satellite images; 1968—CORONA satellite images; 1953—aerial photographs; 1940—survey maps; 1900—survey maps; 1880—equidistant maps; 1780—Saxon mile sheets. Digital processing for the 1998 time segment was based on ATKIS data compiled by the Saxon Regional Department of Surveying and updated using remote sensing data by visual superimposition. The digital data layer resulting was adapted back to the previous time segments by editing. A special MURBANDY-MOLAND mapping key (based on CORINE land cover 1994) ensures that the findings are comparable with the results of other European projects. Owing to the scale used, the minimum size of the objects captured is about 1 ha in urban areas and 3 ha in the surrounding open spaces.

[4]Monitoring Urban Dynamics and Monitoring Land Use Dynamics.

[5]This case study was carried out as part of a diploma thesis (Neumann, 2002).

The extensive findings on land-use development for the urban region of Dresden (Meinel and Neumann, 2003) have been visualised in the form of maps and diagrams. They clearly show the dynamic growth of built-up areas over the past 220 years and depict the processes of growth and suburbanisation taking place, mostly after the political change 1990 because during socialist times Eastern German cities were, for all practical purposes, ignorant of urban sprawl (Haase and Nuissl, 2005; Fig. 5). In addition, spatio-structural indexes denoting the development of built-up areas have been studied and evaluated. It was found that the degree of urbanisation increased from 4% in 1780 to 25% in 1998. In addition, the degrees of jaggedness and compactness were examined (Thinh et al., 2000). The degree of jaggedness describes the external compactness of a patch of built-up land. Although it is calculated in the same way as the shape index, this indicator is related not to individual areas but instead to land patterns. The degree of compactness of a built-up area depends on the ratio between the size of the individual areas and the space between them as well as the resulting spatial interaction between the individual settlement clusters. This revealed that the initially compact settlement developed in an increasingly dispersive fashion owing to decentralised development. This is shown by the rapid decrease in the degree of compactness and the growing fragmentation as the total settlement area increased (Fig. 6). In addition, the structure of new settlement areas at the urban fringe was

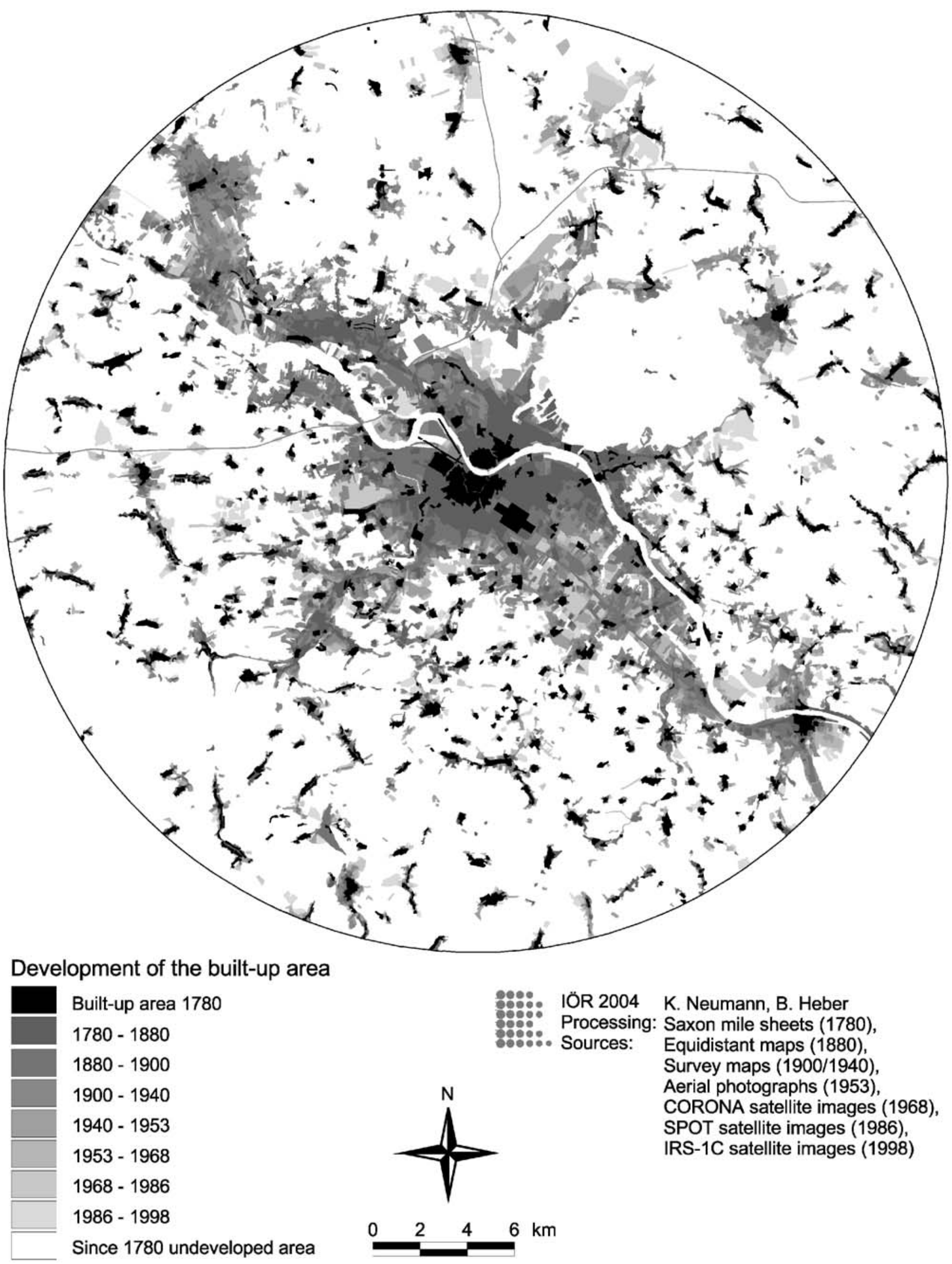

Fig. 5. Development of the built-up area of Dresden and area 1780–1998.

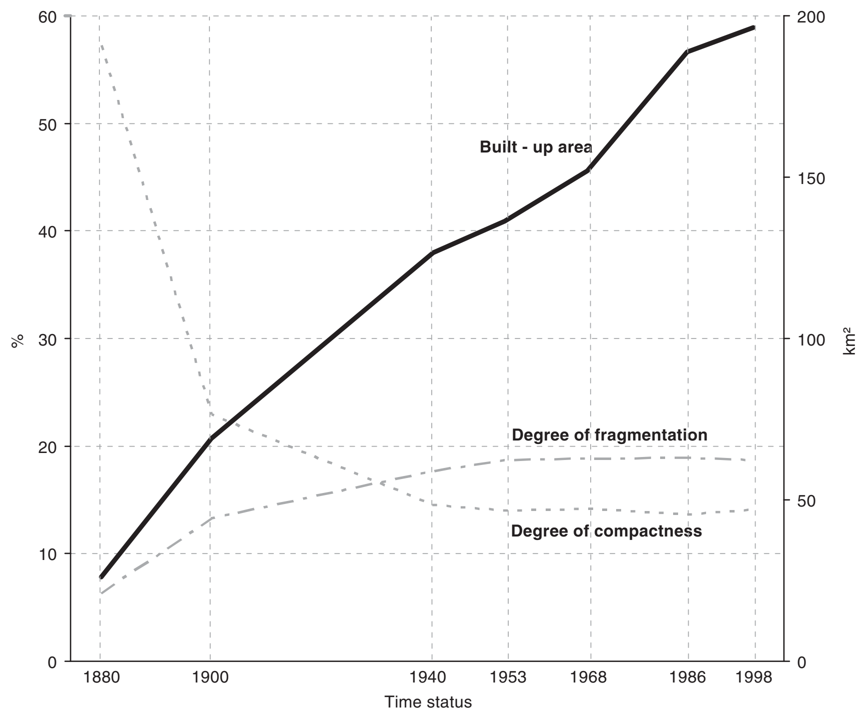

Fig. 6. Development of fragmentation and compactness in the built-up area of Dresden and area 1880–1998.

characterised, with the integration of newly built-up areas into the existing settlement structure being analysed. The information obtained provides qualitative findings on the reshaping of open spaces owing to the growth of settlement areas.

Other analyses tackled the development of roads, the consumption of fertile arable and riparian land by construction, and the link between the development of built-up areas and population development. Distance and accessibility analyses are planned, as is the determination of degrees of land surfacing and densities. All these investigations (which can be carried out relatively simply thanks to the GIS-based processing of the existing digital data layers) enable local historical development to be analysed.

Case study 3: landscape change and functionality on the outskirts of Leipzig—using the example of Taucha

The third case study concerns the dynamics of land-use changes in the catchment area of the River Saale, which has an area of about 23,000 km^2 (Steinhardt and Volk, 2002). Dynamic and less dynamic regions are to be filtered out and the conflict areas resulting are then to be described.[6] For this purpose three test areas (Taucha in the sandy loess area near Leipzig, Querfurter Platte, an area of intensively used agricultural land around Querfurt, and Oelsnitz in the mountainous *Vogtland*; Fig. 1) with different natural characteristics and usage intensity were examined regarding changes to land use. The approach taken by the authors from UFZ's Department of Applied Landscape Ecology involves the parameter 'land use' being included in the modelling of selected landscape functions, which in this manner can also be described for historical periods at different scales (Fig. 7, Bouma et al., 1998).

Land use was digitised on the basis of geo-referenced topographic maps (1879—equidistant map; 1927—survey map; 1997—TK25 N). Once the main usage classes had been decided, the statistical analysis of spatial land-use change was carried out (Fig. 8), the landscape function of groundwater recharge was modelled using ABIMO (Glugla and Fürtig, 1997, Eqs, (1) and (2); Röder, 1992, 1999, Eq. (3); QD = surface run-off).[7]

$$R = \mathrm{Po} - \mathrm{ETa}^{6,7}, \tag{1}$$

$$\frac{\mathrm{dETa}}{\mathrm{dPo}} = 1 - \left(\frac{\mathrm{ETa}}{\mathrm{ETp}}\right)^n, \tag{2}$$

$$\mathrm{QD} = (\mathrm{Po} - \mathrm{ETa}) * p/100. \tag{3}$$

The runoff regulation capacity and resistance to water erosion were determined by empirical estimation models as described by Marks et al. (1992; Fig. 7, Eq. (4))[8].

$$\mathrm{Ao} = \mathrm{f(R,\ S,\ L,\ Su,\ FC)}. \tag{4}$$

[6]Cf. UFZ Joint Research Project 2.1: "Integrated River Management Using the Example of the Saale"—http://www.hdg.ufz.de/saale/.

[7]The water balance model (German: Abflussbildungsmodell) ABIMO is a deterministic model which uses the Bagrov equation to calculate total run-off (R) actual evapo-transpiration ETa depending on precipitation (Po) soil type, land use, and the degree of land surfacing and canalisation.

[8]R = relief index, S = grain size, L = land use, Su = percentage land surfacing, FC = field capacity.

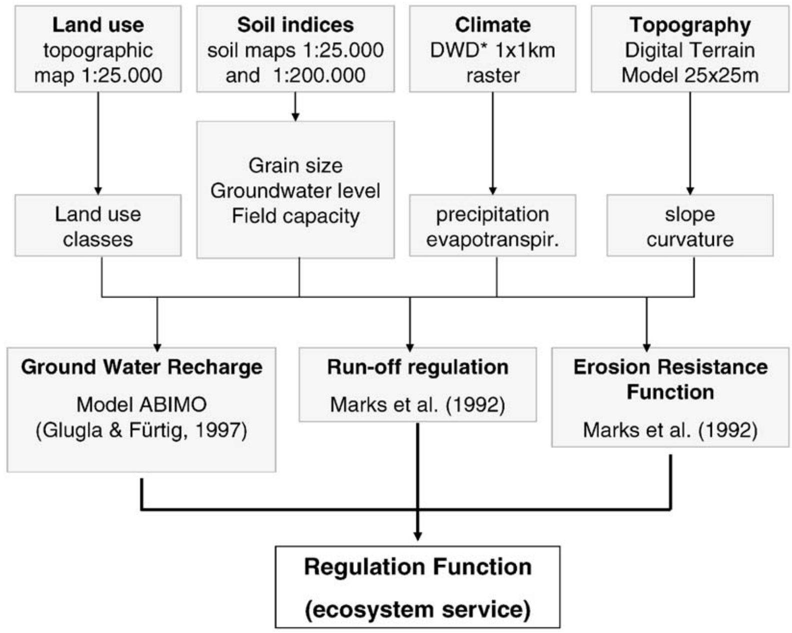

Fig. 7. The links between land use, usage change and agricultural regulatory functions, as well as models for identifying these links.[7]

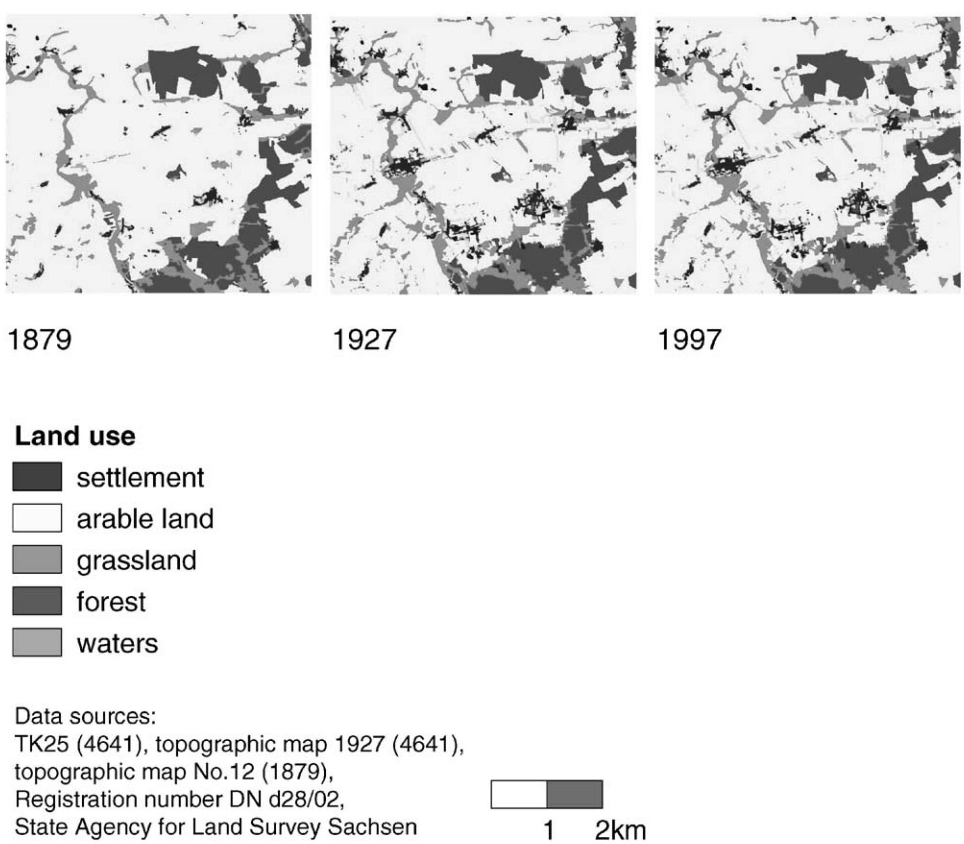

Fig. 8. Spatial distribution of main types of use for the time states 1879, 1927 and 1997 for the Taucha study area (1:25,000).

Below, the findings are shown for the Taucha study area. Taucha has been characterised by residential and commercial suburbanisation since 1990 (owing to its proximity to the city of Leipzig) as well as by intensive agrarian usage for centuries (Fig. 8). The increase in residential and commercial built-up development has resulted in the runoff regulation capacity of the surface becoming extremely limited. The high proportion of surfaced land and low infiltration capacity mean these areas have high surface runoff (A_O). However, the areas of gardening land in residential estates have medium runoff regulation levels, since a smaller proportion of land is paved over (Collin and Melloul, 2003; Haase et al., 2003; Haase and Volk, 2002).

Runoff regulation capacity in open spaces closely depends on the degree of cover, and may be very high under a forest but much lower on grasslands. In areas of open land, soil and relief characteristics determine run-off regulation: loamy areas (such as the Parthe floodplain with a groundwater table < 2 m) have a medium runoff regulation capacity, whereas drainage is much higher outside the floodplain. Around the terminal moraine ridges with sandy soils and a groundwater table of more than 2 m, the runoff regulation is far better.

The runoff regulation capacity calculated for the periods since 1879 indicates that it has been extremely reduced in newly surfaced areas (owing to the expansion of built-up areas). This applies to 14% of the entire area (principally arable land) between 1879 and 1997. Paved areas of high runoff regulation can reduce the infiltration capacity and hence the runoff regulation of the surrounding areas once the soil's saturation level has been exceeded (Mannsfeld and Richter, 1995). A medium to high increase in the runoff regulation capacity is apparent in areas created by mining (including lakes) and in reforestation districts, although they do not reach the same proportion of areas characterised by decreases. Therefore, the runoff regulation capacity in Taucha declined between 1879 and 1997 considerably (Haase et al., 2003).

The recharge of new groundwater resources must be regarded in this connection. In contrast, the proportion of areas with very high groundwater recharge rates increased between 1879 and 1997 in favour of areas of lower recharge rates. For example, the land to the west of Taucha, which is mostly used for agriculture, harbours very high groundwater recharge rates, since the silty, sandy soil where the influence of relief can almost be ruled out (inclination up to 2°) is good for soil infiltration and percolation.

Similar to the runoff regulation capacity, surfacing and the resulting higher surface runoff reduce the quantity of drainage water and hence groundwater recharge (built-up areas: 1–75 mm/a recharge). The calculated increase in surfaced area in the study area indicates an increase in the proportion of land cover with lower groundwater recharge rates (Table 3). If the increase in land surfacing continues in the future, groundwater recharge can be assumed to decrease (Dosch and Beckmann, 1999, p. 302).

An increase in surface runoff in the long-term would mean a shortened water cycle and water retention in the system and thus a general decrease of filter performance. In depressions and floodplains, the increased water surface runoff could contribute to the flood risk in the respective settlement areas in cases of smaller floods up to a recurrence interval of 40 years.

Case study 4: multifunctional areas: how can studying landscape change help solve conflicts?

Owing to the functional overlaps in the landscape, conflicts may arise between individual landscape functions with respect to the optimum performance of these functions (Frede et al., 2002). Instead of being the result of current processes and situations, the thrust of this argument is that they have become exacerbated over the past 100 years.

The discussion below only concerns the landscape functions of runoff regulation (A), groundwater recharge (G), erosion resistance (E) and the buffer capacity of the soil (Haase and Volk, 2002; Walz et al., 2004). Overlaps with other functions such as other pedological and hydrological sub-functions are neglected. Current social-economic requirements and their relevance to the production and recreation function are considered. Land use classes which allow the respective landscape function to act in the best way possible are used to highlight conflicts between landscape regulation functions (Emmerling and Udelhoven, 2002; Fig. 9).

Using the example of the test area of Oelsnitz in the mountainous Vogtland region (uplands, Fig. 1), where soil acidification partially occurs, the multifunctionality of areas is revealed to be another aspect of investigations into historical land-use change. Below, 'multifunctionality' is used to refer to the overlapping and competing of different landscape functions (e.g. production and regulation; Brandt, 2000). Different importance is attached to the functions depending on how relevant they are to society.

Processing the data on historical and current land use and modelling the landscape functions were performed as for Taucha in Case study 3. Groundwater recharge was modelled as described by Dörhöfer and Josopait (1980) (Eq. (5), N = precipitation, ET = evapo-transpiration, A = surface run-off, Au = total run-off). Land use data were taken from 1890, 1943, 1988 and 1996 to examine

Table 3
Calculated groundwater recharge rates (mm) for the Taucha area fort he time segments 1879, 1927 und 1997

Year	Ground water recharge rate (mm)						
	1–25	26–50	51–75	76–100	101–150	151–200	201–250
1879	9	8	18	17	35	13	0
1927	9	9	19	17	31	14	1
1997	10	12	23	21	24	8	0

Source: Haase et al. (2003); Walz et al. (2004).

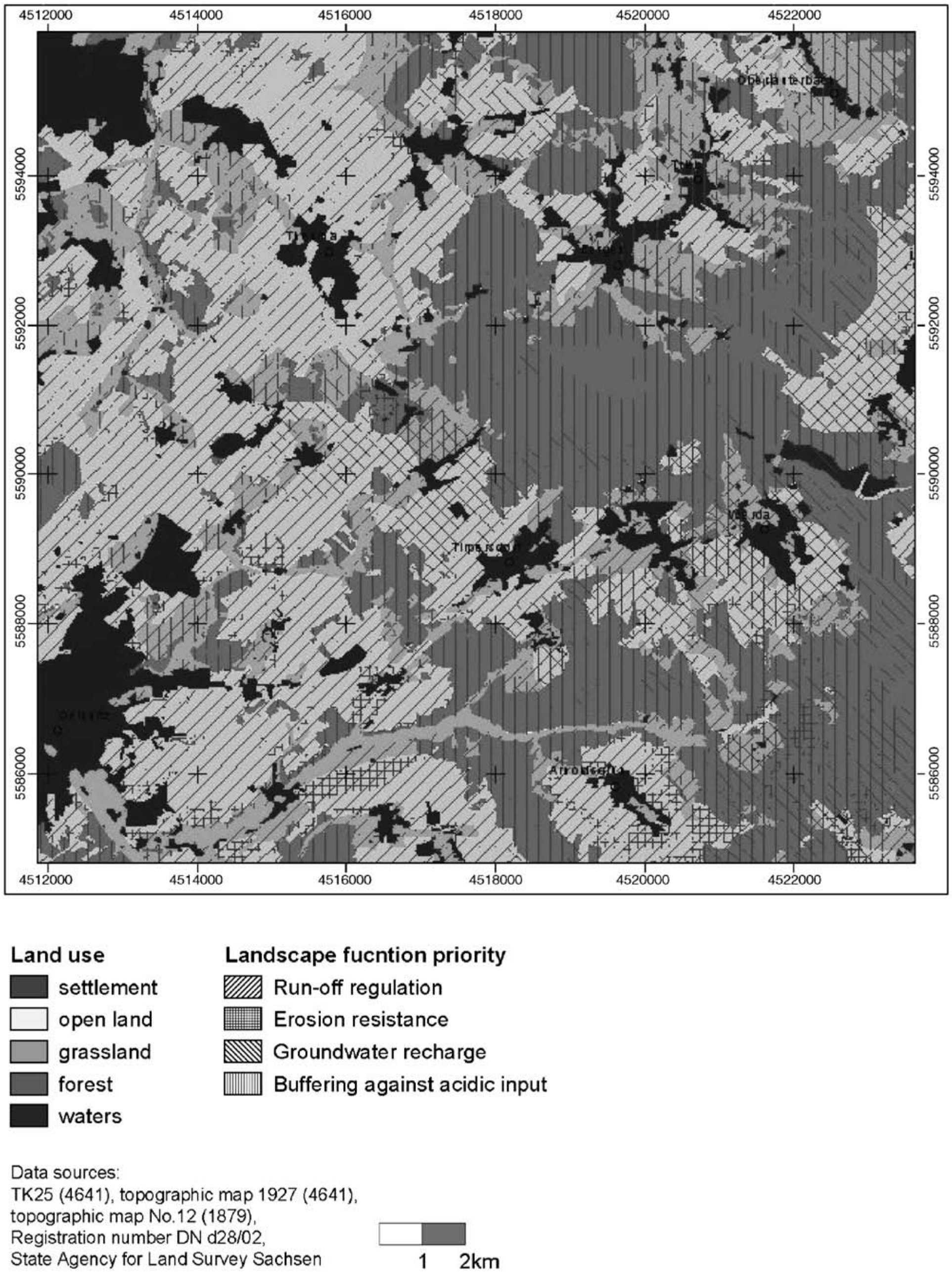

Fig. 9. Spatial specification of proportions of land on which the selected regulatory functions are opposed to each other.

changes over time.

$$1 - \frac{N - 312,5 - (\mathrm{ET} \cdot 25)}{A/\mathrm{Au} \cdot 50}. \tag{5}$$

The results of the interference analysis carried out for the period of current land use and the statistical evaluation of the functional overlaps resulted in a total of 10 different overlaps of between two and four landscape functions (Fig. 9). The performance, interactions and contrariness of individual functions were taken into account.

Overlaps between high performances of the runoff regulation function with resistance to water erosion affected nearly 3% of the land, while overlaps of the runoff regulation and buffer functions affected another 3%. Areas with high groundwater recharge rates overlap with areas of high runoff regulation capacity (604 ha, about 5% of the total area), making up the largest share of the total area, although the scale of interference by the groundwater function with the buffer function is comparable.

The superimposed areas in Fig. 9 are based on analyses of landscape functions (cf. Fig. 7), and recommendations for land-use changes are discussed below. Whenever the performance of runoff regulation is limited in upland areas such as Oelsnitz, improving the regulation of runoff peaks needs to be given top priority. This is clear from the extreme flooding at Zschopau, Striegis, Weisseritz and Müglitz in August 2002 during the Elbe flood. In addition, increased susceptibility to erosion is likely, and so in this conflict the most important issue is clearly to boost runoff regulation (by raising the proportion of drainage).

Conflicts also arise when areas with a high risk of soil erosion and low buffer capacity, partly due to homogeneous coniferous forests, overlap. The areas in the south–east of the study area have mostly been reforested for 100 years. Some of these areas have a soil slope gradient exceeding 7.5°, making any other type of land use unsuitable. When changing the land use would reduce the resistance to erosion, more importance must be attached to the resistance function against water erosion than to other functions, as soil losses are practically irreversible. The performance of the buffer function could be improved by altering the make-up of the forest.

When areas with a limited buffer capacity overlap with land with a high groundwater recharge function, the quality of the groundwater is at risk of being impaired by the input of acids and heavy metals. Acidification alone has already reduced the quality of the drinking water in the study area. Measures such as liming and changing forest make-up by planting deciduous trees could raise the buffer capacity. However, more importantly, measures to prevent or at least reduce emissions of pollutants over a large area should be taken in order to deal with the root of the problem.

On areas with a limited runoff regulation and erosion resistance function, preference should be given to usage types such as grassland and forest. Changes of this type could have a positive impact on runoff events of the type occurring in August 2002. Indeed, back in 1997 Meyer (1997) described a scenario of this type based on the increased precipitation intensity in spring. If the ground is not yet completely covered by vegetation through the cultivation of maize, sunflowers and beets, these events will cause higher soil erosion and surface runoff. The devastating flooding in August 2002 was attributable to similar causes. The expansion of built-up areas and river engineering (e.g. embankment, canalisation) near rivers' sources since 1880 (Walz et al., 2004) meant that natural inundation regions had been sealed, resulting in fewer and fewer areas with a high runoff regulation capacity in the uplands. In regions of low mountains in particular, the valleys are popular settlement areas owing to the natural conditions, and so land surfacing and the canalisation of rivers are especially widespread. Flood protection could be boosted by not building on former retention areas and converting existing arable land into flooding zones and grassland. The designation of new building land in possible retention areas should be critically reviewed, especially from the angle of the water surface run-off.

Discussion and conclusions

The case studies presented here portray the development of land use and how its structure has changed in various types of Central European cultural landscapes such as urban and rural ones, floodplain and mountain situations. The methods developed enabled an extensive database to be created which was then used to analyse how usage has changed and how these changes affect selected structures, functions and potentials of landscapes. Regarding the methodology used in historical landscape analysis, the following conclusions with respect to spatial land use planning can be drawn:

- Historical maps can be integrated into a GIS with sufficient accuracy. As a result, the development of land use can be shown quantitatively over a period of more than 200 years. Statistics can then be compiled on the development of the proportions of linear elements and areas of certain usage types so that the interpretation of landscape development can be quantitatively substantiated.
- The structural changes between landscapes past and present can be quantified by means of indices. This makes a contribution to a functionally orientated assessment of landscape development. By contrast, simple analysis of the proportions of land used for certain purposes sheds light on the possible functional relationships in the abiotic antibiotic landscape balance (Berger and Walz, 2004).
- Taking into account landscape functions in assessment brings home how important it is to consider the 'loss' of not only land in the meaning of total area but also resources and landscape functionality (Krönert et al., 2001; Walz, 2005a).
- Finally, the quantification of long-term land use change and its environmental impact enables us to reduce the existing uncertainty to predict future landscape change in land use change or biophysical models.

Currently, the most serious processes of landscape change with a considerable environmental impact are extensive development caused by processes of urbanisation, especially urban sprawl, the fragmentation of landscapes by infrastructure development which finally leads to a decline of large continuous habitat patches (Kühn et al., 2004), and changes to the structure of farmland. Simultaneously, current land abandonment due to shrinkage will lead to land use changes in the form of extensive development and thus offers new chances for re-naturation or "ecologicalisation". For example, one result of the further liberalisation of farming is that agriculture is withdrawing from areas whose suitability for cultivation is limited (owing to relief, soil and climate conditions as well as farm sizes, etc). On the other hand, the intensity of farming is increasing on land which is more suitable for cultivation (high productive soil regions such as the Loess regions of Europe). However, the authors are aware of the fact that the historical and current development of cultural landscapes described here has a high relevance for many other regions of Europe, but at the same time there exist also contrarian trends that shape landscapes such as field aggregation due to the socialist agricultural policies in Central Eastern Europe.

As far as the development of land for human settlement is concerned, regional decline and shrinkage processes caused by the declining population and the resulting derelict residential and commercial sites contrasts with strong growth and urban expansion in other regions (Stanbeck, 1991; Nuissl and Rink, 2005). These processes will result in sharp changes to the cultural landscape throughout Europe. Sustained usage pressure opens up a whole range of developmental options for the conversion of abandoned sites. Unused land could, for example, be left fallow and left to natural succession of vegetation (''ecologicalisation''), reforested, or used for nature conservation or countryside protection.

Nevertheless, open and unsealed spaces are still in danger of being paved in the near future and the tendency of land use intensification will continue, even in shrinking or declining landscapes. These processes will not be limited to agglomeration areas because land and open space are not unaffordable goods and available for land uses such as housing and industry. But as far as the development of cultural landscapes is concerned, attention must be paid to ensuring that the functionality of landscapes is sustainably maintained and landscape planning has to meet the specific requirements of a multifunctional land use in our cultural landscape. For landscape planners and regional planning authorities, the conclusions presented here should facilitate them to acquire better awareness of the importance of historical knowledge and material available for current and future shaping of the landscape. The paper does not intend to give concrete decision support for planners because of the multitude of pattern and processes and of landscapes in general. However, taking into consideration the history and the changes derived thereby would be a large step forward for landscape planning in many parts of Europe (German Soil and Nature Protection Act 1998, 2002; Kühn et al., 2004).

The intent of this paper has been that, since intensive land utilisation has a long tradition in Central Europe, we must recognise what kind of changes are occurring within recent history and calculate this into the budget of future landscape development.

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Holocene floodplains and their distribution in urban areas—functionality indicators for their retention potentials

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Abstract

Floodplains are among the natural areas in central Europe which—depending on the formative power of flowing water—possess a high natural potential for the regulation of water and matter flows. Many floodplains and urban development share a long common history in central Europe. Numerous, sharply varying historical views exist on how to distinguish European floodplains. Therefore, the aim of this paper is to examine relevant indicators such as floodloam expansion, groundwater table, relief and land use to see how useful they are for characterising current floodplain functionality in urban areas and to 'flesh them out' for a case study.

Keywords: Holocene floodplains; Natural potential; Cohesive soils; Urban floodplains

1. Introduction: urban floodplains—are we left with but the remnants?

Floodplains are among the natural areas in central Europe which—depending on the formative power of flowing water (Galluser and Schenker, 1992)—possess a high natural potential for the regulation of water and matter flows. Owing to their low position and their frequently cohesive soils with a strong filtering effect, floodplains are able to retain sentiments (physically) and pollutants (chemically) (Haase and Schneider, 2001), and to buffer them for long periods of time. In addition, floodplains and in particular floodplain forests are habitats which owing to their nutrient potential and favourable hydrological conditions feature high biodiversity (Wohlgemuth et al., 2002; Büttner, 2000; Berkemeier and Loose, 1997), giving them a high status when it comes to landscape protection and nature conservation (Haase and Neumeister, 2001).

Floodplains and urban development share a long common history in central Europe since many urban settlements were built on large and small receiving streams (Galluser and Schenker, 1992; Deutsch et al., 2000). After the Pleistocene glaciers and deposits, it is above all the 'geological factor' mankind which has decisively shaped the development of central European floodplains over the past 6000 years or so: forest clearance in catchment areas led to large-scale soil erosion as well as a number of cycles of meadow loam sedimentation, sometimes several metres thick (Fuhrmann, 1999; Müller and Zäumer, 1992).

Timber exploitation and fishing were practised in floodplain areas alongside rafting and livestock

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grazing on the moist floodplain meadows. As settlements developed beside rivers and/or their floodplains, important roads were built, such as e.g. the Via Regia and Via Imperii, which crossed in Leipzig. Inexorable urban development led to extensive hydraulic engineering schemes such as dike construction and river regulation, especially in the second half of the 19th century, serving not only water supply and sewage disposal (such as the construction of sewage treatment plants) but also flood protection (StUFA, 2002; Lazowski, 2001). These processes were exacerbated in the 20th century by industrialisation, which was accompanied by the emission of pollutants such as heavy metals and nitrogen oxide and led to acid rain. These developments sharply changed the natural structures and processes in the floodplains (Haase, 1999). Many central European floodplains exposed to urban influence began drying up on a large scale, nullifying their natural retention function and even threatening their vegetation. As a result, only remnants remain of the floodplains' original natural conditions in urban areas (Müller and Zäumer, 1992), and they need to be surveyed, described and protected.

In recent years, floodplains have become increasingly significant for large towns and cities owing to their recreation potential. 'Fear' of unpredictable rivers (Denzer and Haase, 2000, 2001) is giving way to growing interest in quasi-natural living situations, recreation in the 'great outdoors', and a healthy environment in general and in urban areas in particular. At the same time, the retention areas of the floodplains which have remained are threatened by the input of pollutants, land surfacing pressure and the general expansion of the (sub)urban area—perhaps now more than ever before, taking into consideration the disastrous floods in Central Germany in August 2002. There it became clear, that missing retention space for rivers in urban areas can lead in a very short time to enormous material, and mental consequences as well as to an ecological disaster.

2. Problem outline; aims

This all begs the question as to what has become of the natural areas and structures typical of floodplains in urban settings. What sections of river valleys in urban and suburban areas can still be described as 'floodplains'? What criteria can be used to identify floodplains in urban areas and to distinguish them from their surrounding? Is the traditional geo-scientific identification of floodplains using the distribution of floodplain loam or the current depth of the water table still relevant in densely populated spaces? This last question, which also touches on the current management of areas referred to as 'floodplains' or 'floodplain-typical' in (or despite their location in) towns, is especially important.

Numerous, sharply varying historical views exist on how to distinguish European floodplains (Zeese, 1997; Deutsch, 1997; Munzar, 2000). Most of them are geared towards the author's own particular field and the question tackled by him or her, making them difficult to generalise. Indicators such as the water balance of the soil cover (Bock and Gramatte, 2000) or the hydrological conditions do indeed decisively characterise a functioning floodplain (Table 1). Yet little is known about the specifics of these indicators in general and in urban areas in particular, and an assessment of the materials of the German Association of Water Management (DVWK, 1998) in Bock and Gramatte (2000) shows: "... that the current level of knowledge about the water and substance balance of floodplains (above all in urban areas—author's note) still contains large gaps" (p. 40).

Therefore, the aim of this paper is to examine relevant indicators to see how useful they are for characterising floodplain functionality in urban areas and to 'flesh them out' for a case study.

3. Case study: Leipzig's floodplains and their development

For many years the floodplains in Leipzig have been the subject of research of various disciplines in the geosciences. Nevertheless, distinguishing floodplains is an extremely difficult, integrative problem which has so far been solved in many different ways in different publications (e.g. Klimo and Hager, 2000; Hager and Schume, 1998). Floodplain ecosystems in central Europe have been subject to anthropogenic influence for over 1000 years. River engineering works were especially intensive in the area of Leipzig in the 19th and 20th centuries. The objective was usually to 'tame' rivers and to intensify land use in the floodplain flats.

Table 1
Landscape functions south of Leipzig and how they have been changed by intensive opencast mining (Haase, 2001, partly based on a description by Schreiber, 1994)

Landscape function	Prior to urban influence	Current state
Basic function for plant growth and farming (including yield function)	Loess substratum, well buffered soil system with meadow loam on Pleistocene and Holocene gravels/sands in valley floodplains	Soils partly damaged by loam extraction, mining, land surfacing and backfilling; partly still relatively natural state
Physicochemical filtering and regulation function	Functional units of open land and forest with floodplains subject to frequent flooding; high interception by forestland, trees have bioclimatic exchange function, loamy soils have physicochemical sorption function for runoff and pollutants; low soil erosion beneath forestland	Almost complete disappearance of floodplains in part of the city owing to construction; impeded system of running water disconnected from floodplains; low interception due to decimation of floodplain forest in urban and mining areas
Landscape structure barrier function	Partly still functioning running water system comprising flood-plains with slow stretches and hence structural barrier function for particulate and solute transport; forest stands act as another structural component for barrier effects and wind protection	Owing to deforestation and the blockage of the receiving waters White Elster, Luppe, Pleisse and Parthe, these structural barrier functions have been almost completely destroyed in the moraine–floodplain landscape system
Recreation function	Walking and cycling popular in the floodplain landscapes of receiving water; problems due to periodic and episodic flooding, almost no areas suitable for swimming or boating	Walking and cycling in the floodplain landscapes of receiving water; new housing estates near floodplains, boating; the area south of Leipzig is a huge reservoir of potential recreation land with over 70 km^2 of new lakes emerging, space for modern leisure sports and reserves for aquatic flora and fauna; action tourism to industrial monuments and mining history

In addition, lignite mining south of Leipzig destroyed large sections of the floodplains (Fig. 2). The sensitive floodplain ecosystems have hence been increasingly removed from their natural milieu over the past 1000 years. Compared to their surroundings, Leipzig's floodplain forests have a modified climate with an important bioclimatic regulatory function (Fig. 1). The phenomenon of the urban heat island is especially conspicuous. Thermo-isopleth graphs (Richter and Gutte, 2001; Richter et al., 1999) of inner-city areas and the surrounding district show positive anomalies sometimes exceeding 10 K, and which are most

(1)


(2)


Figs. 1 and 2. Two aspects of urban floodplains of the Elster and Pleisse in Leipzig: broad-leaved garlic in the hardwood (*Querco-Carpinetum*) woodlands and the new Lake Cospuden in the middle of the former floodplain of the White Elster and the Batschke.

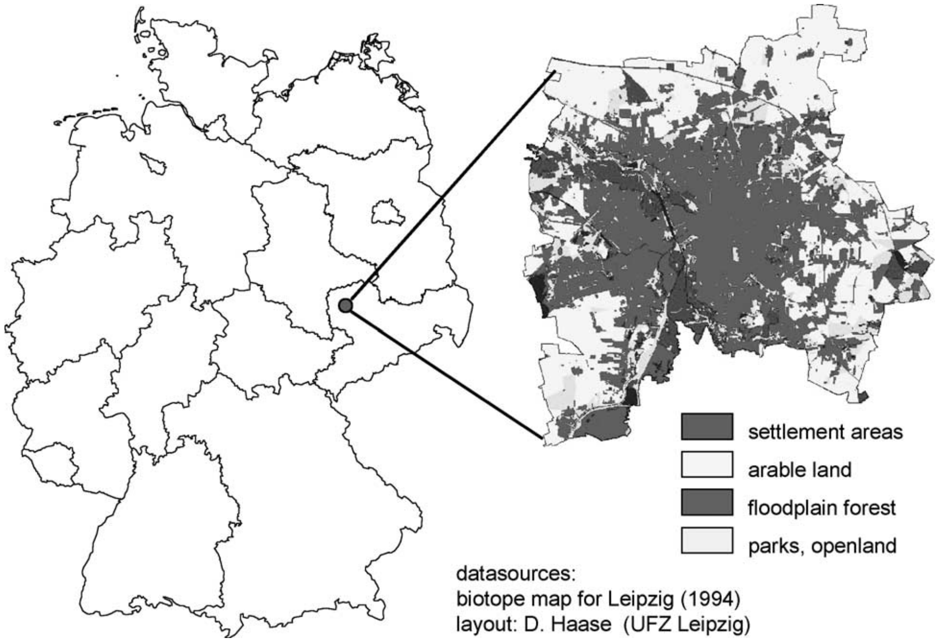

Fig. 3. The position of Leipzig and its floodplains, shown using the 1994 biotope type map for Leipzig.

intensive in the summer months during autochthonous radiant weather. The climatologic normal values feature remarkable gradients between town and the surrounding district in the number of frost days, hot and summer days, which occur much (if not very much) more frequently than in forestland (Figs. 1–3).

4. Methodological approach and databases

The method described here is based on the definitions and typical aspects of 'floodplains' as natural systems. Floodplains are usually identified by the distribution of meadow loam and floodplain sands as well as floodplain gravel, and are defined as flat valley areas, wetlands, floodplain vegetation areas and flood areas. The identification of floodplains depends on the classification used (e.g. according to Leser, 1995; Schenker, 1992); they may be:

- The deepest flat sections of a river valley which is temporarily flooded during high water.
- Valley floors which are subject to floodwater influence and where (assuming the occurrence of loess in the catchment area) fluvial sediment, flood loam and meadow loam are distributed.
- Areas featuring typical vegetation such as softwood and hardwood floodplain forests and wetlands, and whose vegetation is adapted to periodically fluctuating groundwater.
- Areas with a pronounced wet regime (Koch, 2000).

Using various criteria, spatial indicators are to be developed. Afterwards, the areas identified by these criteria as floodplains will be considered in more detail. The digital processing of the individual indicators to create 'data layers' on a geographic information system (Erdas Imagine, Arc-Info, Arc-View) and linking vectors to databases enable the integrative depiction of Holocene floodplain areas and also comparison with current and future aerial and satellite image data (Fig. 4).

Analogous data on the geology, groundwater levels and sediment distribution, and digital data on land cover were scanned, georeferenced or read in and processed to produce combined data layers. The data from the attribute tables and databases were parameterised,

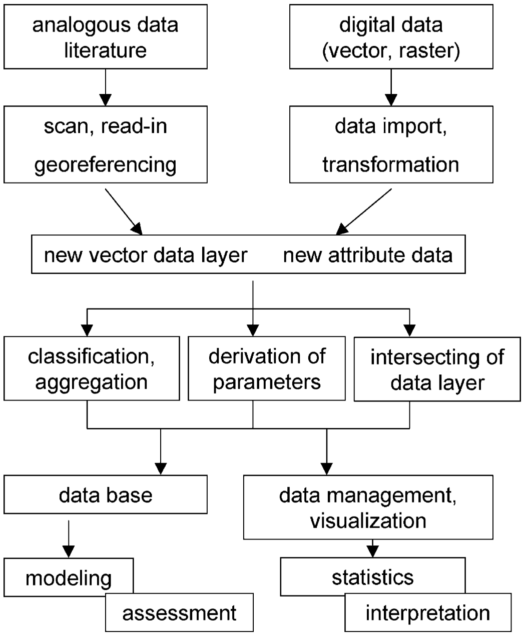

Fig. 4. The methodological approach taken in data processing and the production of difference maps illustrating floodplain spread indicators.

aggregated and classified. The groundwater surface in the floodplain areas in Leipzig was modelled using relief data from topographic maps and analogue point data recording historical and current groundwater levels (Fig. 4).

5. Results

There are many different spatial depictions of Leipzig's floodplains, such as by Neumeister (1964) and others using digital data (Fig. 5). Neumeister (1964) identifies Leipzig's floodplains using the distribution of meadow loam and also describes land usage. However, many of the floodplain areas he mentioned no longer exist as open land with a floodplain character or as retention areas in the functional sense. In addition, changes caused by mining over the past century south of Leipzig require new studies to be carried out of the problems of floodplains and identifying the areas of the floodplains in Leipzig which are still 'active' as such. Even digital soil and relief data as well as land use data (CORINE land cover 1994 and the 1994 urban biotope type map) only give a rough depiction of floodplain spread in connection with sediment and simple surface cover (Fig. 5).

The *distribution of floodloam* as well as of typical river gravel and sand sediment beneath it are the natural historical indicators of floodplains. Meadow loam characterises the maximum extent of flooding and limits the historical area of fluvial influence (Jäger, 1962; Neumeister, 1964). By contrast, Fuhrmann (1999) attributed the emergence of flood loam to climatic fluctuations in the Holocene irrespective of anthropogenic influence: "... the asynchronous nature of flood loam sedimentation phases and phases of increasing agricultural land use means that meadow loam cannot be

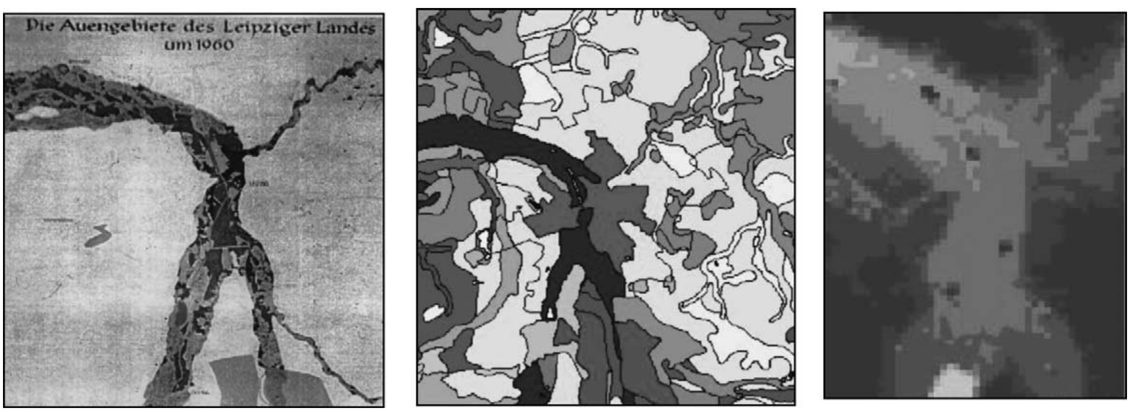

Fig. 5. Depiction of Leipzig's floodplains according to various sources (Neumeister, 1964, 1:200,000 soil survey map, and a 200 m × 200 m terrain model).

a sediment caused by cultivation ...” (p. 35). However, all the authors mentioned refer in connection to the spread of floodplains to the extent of flood loam and meadow loam.

Under natural conditions, the distribution of meadow loam is the best way of distinguishing a Holocene floodplain north of a loessy area and characterising its functionality. The fluvially accumulated sediment describes the maximum area covered by the river during flooding and hence also indicates the area subject to fluvial influence, i.e. the Holocene floodplain. In central Europe, floodplain loam formation mainly occurred in the Atlantic (older floodplain loam) and the Sub-Atlantic (Middle Ages; more recent floodplain loam), and documents the area covered by floodplains at this time (Jäger, 1962).

However, this geological-sedimentological approach established in the geosciences is difficult to follow in the urban agglomerations and urban-suburban areas which increasingly determine major floodplain areas of large rivers in central Europe, including in central Germany (such as the Elbe in Dresden or Magdeburg which have been heavily effected by the disastrous floods in August 2002, the White Elster in Leipzig, and the Oder in Frankfurt which was effected by floods in 1997). Anthropogenic river blockage and damming have been especially responsible for preventing further flooding and hence the sedimentation of new floodplain loam. Similarly, the loamy floodplain soils used by mankind are subject to sharp change, such that “... areas where the water balance has been exposed to considerable intervention (can) no longer (perform) the functions of floodplains within the landscape function ...” (Bock and Gramatte, 2000, p. 40).

The distribution of meadow loam in Leipzig’s floodplains was vectorised using the 1:50,000 geological map (Fig. 6). Meadow loam occurs in large sections of Leipzig, including in areas which have been built over and surfaced such as the historical city centre and inflows of the Elster-Luppe floodplain itself. Boroughs like Schleussig and Leutzsch were almost completely built on meadow loam. In these areas, the high proportion of land surfacing has completely nullified the ecological functions of floodplains such as retention and acting as a pollutant sink. Rain simply flows off the surface and transports pollutants into the receiving water. It is particularly striking that meadow loam is found in the area of small receiving watercourses, indicating that during the Holocene extensive flooding took place. Hence, the meadow loam and the floodplain soils formed from it (fluvisols, gleyic fluvisols) indicate natural and ‘historical’ floodplains in the city, but not anthropogenically influenced Holocene floodplains.

Relief has also been studied as a morphological indicator. The naturally *flat areas* and the *‘5 m above the river level’ isohypse* have been mapped. Under natural conditions, these areas correspond to the meadow loam distribution area (Fig. 7). The spread of floodplain-typical relief in the urban area hardly differs from that of meadow loam. Human intervention has only changed the mesorelief on the edge of floodplains locally. For a long time, urban development took place on the areas of base moraine on the edge of floodplains. Within the floodplains, however, the relief was intensively altered by construction development as of the start of industrialisation, especially above-ground dumps and flood protection dams. The countless embankments and dykes in the floodplain area have not been mapped and so could not be included in the digital relief map.

The floodplains south of Leipzig have been ravaged and in some cases completely destroyed over the past 50 years by lignite mining (Fig. 7). Whereas older descriptions already include large-scale excavation, Figs. 6 and 7 clearly show the interruption of the ‘floodplain’ countryside resulting from the vast expansion of opencast mines.

The *depth of the water table* is an ideal parameter for describing the wetland milieu or hydroregime of fluvial plains. Büttner (2000) modelled this parameter for 1991 and 1995 for the area of the Elster–Luppe floodplain in Leipzig near the city centre. Koch (2000) empirically calculated the criterion for a floodplain milieu to be <2 m.

Natural floodplains are characterised by a small water table depth and a pronounced annual course. Whereas the depth is relatively small (>1 m) in the summer months, especially in hardwood floodplains, in spring the water sometimes rises above the surface and depressions in the floodplain are flooded by infiltration water (Koch, 2000). During this spring flooding phase, vertical and lateral exchange and dilution processes occur in the floodplain soils and sediments which do not take place when floodplains become

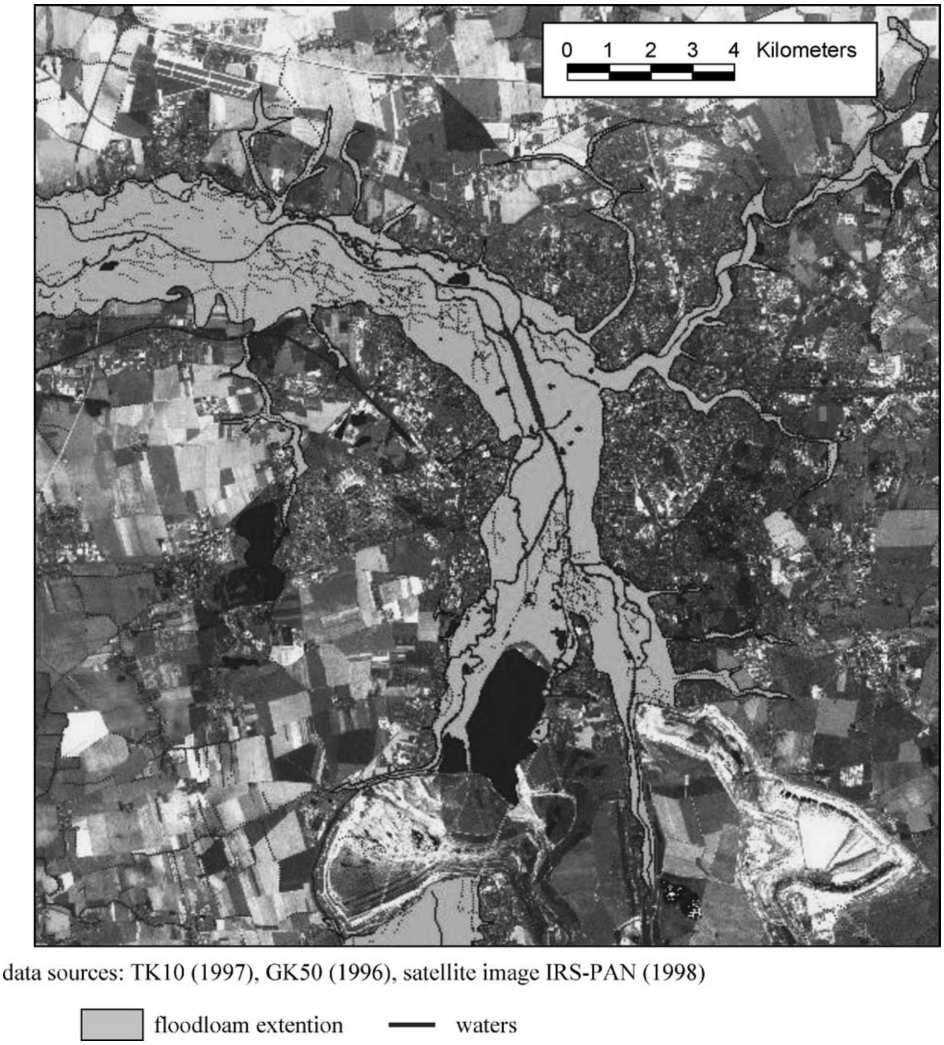

Fig. 6. Demarcation of areas covered by meadow loam (geological indicator) in the urban area of Leipzig (cf. Koch et al., 2001).

dryer. Drainage and the disconnection of small bodies of water from active running water have deprived floodplains of their natural filtering and buffer function (Schreiber, 1994).

Urban development and extensive water engineering schemes as well as lignite mining in more recent times have altered the natural hydrological conditions of Leipzig's floodplains both directly and indirectly. In floodplain landscapes, the water balance is of particular significance since the floodplain forests and also the soil and fauna are closely connected to it. Urban expansion into the floodplain areas, the diversion of entire sections of rivers and lignite mining have all resulted in the water table dropping considerably. The change to the depth of the water table between 1984 and 1995 is shown below using modelling for the floodplain area in Leipzig. Particular attention is attached to data processing in a GIS as well as to the visible rise in the water table just five years following German reunification in 1990 and three years after Cospuden opencast mine was closed down. The surface of the groundwater below sea level was

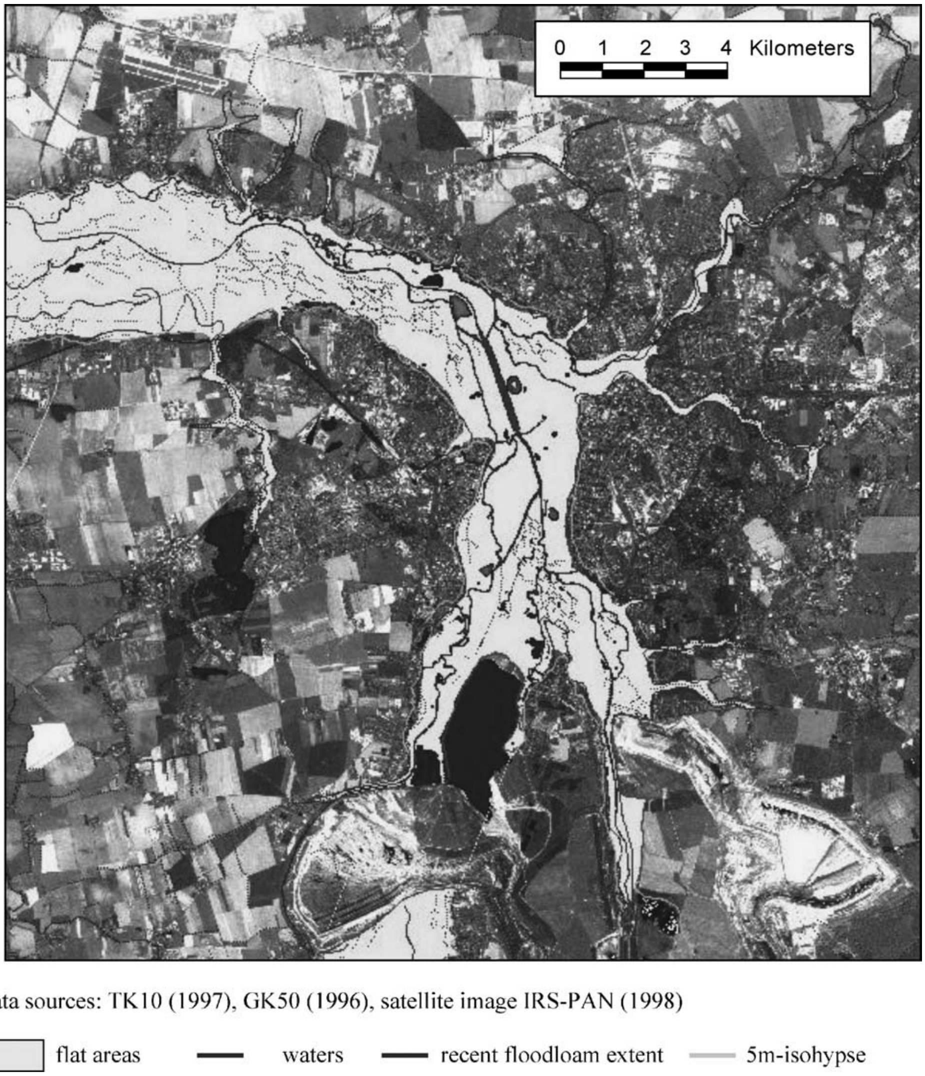

Fig. 7. Demarcation of the low-lying valley areas (morphological indicator; Koch et al., 2001) compared to the situation of the Pleistocene terrace in the urban area of Leipzig.

digitally captured for various times on the basis of hydro-isohypse maps (Governmental Agency for Environment StUFA, Leipzig, 1995). In addition, the relief of the floodplain landscape from the 1:10,000 topographical map was also included in the GIS. A dot matrix (spacing: 100 m) and a TIN model (triangulated irregular network) were drawn up on the basis of the groundwater isopleths. The data from this TIN model were used to generate a surface containing the positional relationships (linear interpolation, 500 dots) stored in the TIN. The resulting LATTICE model (surface model) was in turn used to draw up a coverage which distinguishes intervals of 0.25 m and hence presents output classes for the depth of the water table. The result is an interval map for the groundwater lines in Leipzig. This map was combined with relief data generated from the topographical information to produce a map of the water table depth in the floodplain area of Leipzig (Fig. 8).

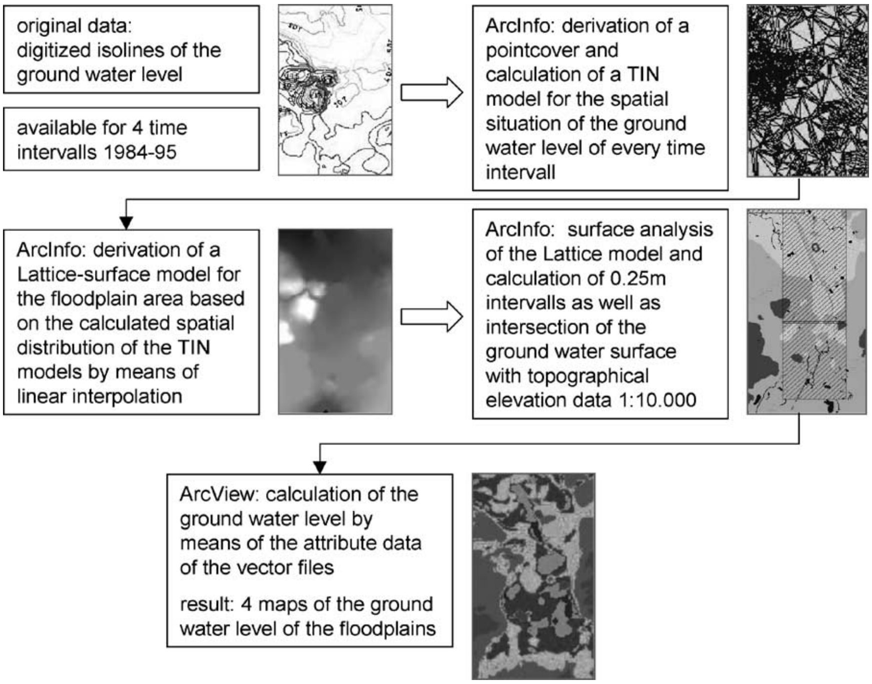

Fig. 8. Procedure for modelling the water table depth at various times in the area of Leipzig's floodplains (Büttner et al., 2001).

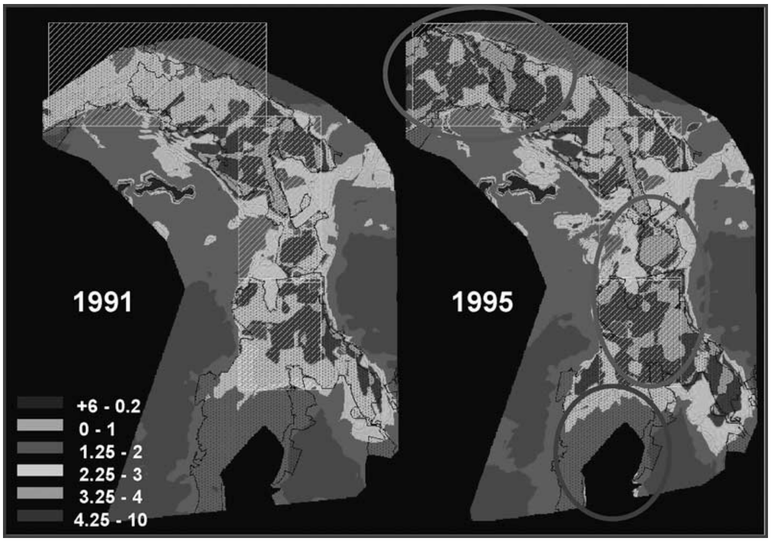

Fig. 9. Results of modelling the water table depth at two different times in the area of Leipzig's floodplains; those areas subject to sharp change are ringed (Büttner et al., 2001).

Far smaller areas are floodplain-typical in the map shown in Fig. 9. The mining-related drops in the water table south of Leipzig and also the increased values in the densely populated city-centre area are especially apparent. In the north-western floodplains of the Elster and the Luppe, the wet regime has been preserved in large areas.

In Fig. 10, the *land use* data layer (biotope types 1994, 1:10,000 topographical map and IRS-1C panchromatic sensor satellite image 1998) are combined with the spread of meadow loam. Land use is classified in five stages rated a priori from 'floodplain-typical' to 'untypical' (Table 2).

The typical vegetation of floodplains is the 'floodplain forest', even if in the case of Leipzig and other urban floodplain woodlands 'floodplain forests' are not natural forms of woodland anymore but actually anthropogenically altered forestland. Wetlands are

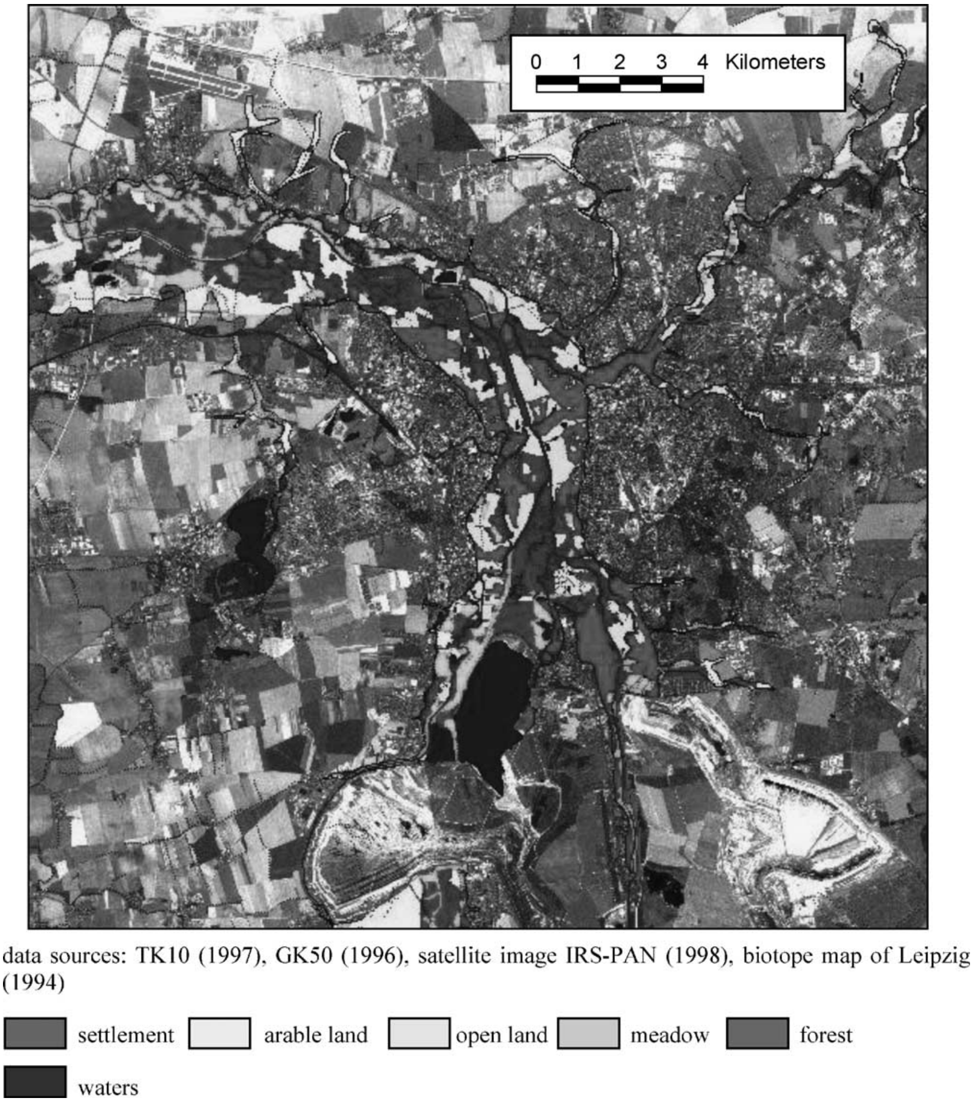

Fig. 10. Extent of various usages in the area of the Leipzig floodplains and remnants of typical floodplain areas indicated by differential analysis of the four indicators selected (Koch et al., 2001).

Table 2
Classification of land usage shown in the biotope type map based on ‘floodplain typicality’

Classification	Categories of biotope type mapping in Leipzig
Floodplain-typical	Floodplain forest, wetlands
Relatively typical	Urban green spaces, parks, sports ground, cemeteries
Relatively untypical	Allotments, farmland, wasteland, other ruderal and succession areas
Untypical	Built-up areas (housing, transport, trade and industry)

another quasi-natural form of usage occurring in floodplains. Amidst the urban sprawl, green spaces, parks, cemeteries and sports grounds are also included in the category of relatively floodplain-typical vegetation since they are often historical amenities which (a) were laid out in the area of floodplains, and (b) still feature relicts of the original floodplain woodlands. By contrast, highly over-fertilised allotments are defined as untypical (despite their location in the vicinity of floodplains), as are farmland and built-up areas.

In the core area of Leipzig, urban areas stretch far into the floodplains (Fig. 10). The central Leipzig floodplain can no longer be identified using its soil cover and vegetation or the amount of open space since the proportion of partly and totally surfaced areas is too large. The north-western floodplains tend to be used in a semi-natural manner, although to the south they are dominated by lignite mining.

The ‘*integrative’ depiction* of Leipzig’s floodplains comprises four individual maps in which all the aspects presented are digitally combined. The spread of meadow loam provides the basis for calculations. Relief, water table depth and vegetation are all combined with the geological indicator.

The extent of the indicator ‘relief’ is cartographically similar in the Leipzig area to the extent of meadow loam. Only backfilling with a height exceeding 5 m and a number of areas on the edge of the floodplains were no longer included in the map after it had been developed (Fig. 11).

For the ‘vegetation’ indicator in the flood loam distribution area shown in five classes in the thematic map in Fig. 10 (Table 2), the classes of floodplain-typical uses were included in the calculations. Forests, meadows and urban green spaces (owing to the variety in the core area of the city) were taken into account as recent floodplain-typical. The water table depth was only calculated by Büttner (2000) in the immediate urban area (yellow marking), and so only this area was included in analysis. The north-western areas on the edge of the floodplains almost all have values less than 2 m. Connecting (not calculated) areas are therefore correctly shown as ‘floodplain-typical’. Solely in the south near Zwenkau oak woods is the low water table depth somewhat doubtful owing to the drop in the groundwater caused by opencast mining (Fig. 9).

6. Discussion

As can be seen in the difference maps from the superimposition of the four indicator maps in Fig. 11, current land use and cover considerably impede the functionality of those areas which in terms of geology and relief can be described as floodplains. Important regulating processes (filtration, delayed surface runoff, water storage, etc.) can no longer take place on surfaced floodplain areas.

Hydraulic engineering measures mean that spring floods are restricted to areas between dykes and flood retention basins. In the city centre and the lignite-mining district south of Leipzig (Zwenkau–Knauthain) the floodplains along with their woodlands and open wetlands are no longer discernible. Discussion of the study results raises the following questions:

- Will naturally functioning floodplains eventually disappear in urban areas?
- Can fluvial plains which have only been flooded a few times over the past century still be called ‘floodplains’?
- How floodplains in urban areas can be considered as retention areas for floods?

The temporary flooding of floodplains is a generic criterion. The numerous flood protection schemes confine this natural process to small dammed in areas near the main flow path, so that in recent times large areas of the floodplains have only been flooded during extreme flooding. This lack of flooding reduces the currently active floodplain areas in this respect to a minimum. Therefore, it makes little sense to integrate this criterion when the areas are combined, although this problem must definitely be involved

data sources: TK10 (1997), GK50 (1996), satellite image IRS-PAN (1998)

current extent of the floodplains as a functional unit based of flood loam distribution, flat land, groundwater level and land use

Fig. 11. Extent of various usages in the area of the Leipzig floodplains and remnants of typical floodplain areas indicated by differential analysis of the four indicators selected (Koch et al., 2001).

in the discussion about the floodplains. In addition, relictic floodplain soil characteristics and meadow loam distribution indicate earlier water tables which could serve as a guide for the water tables and water levels of rivers and lakes current desirable when drawing up development and restoration goals for urban floodplains (Bock and Gramatte, 2000).

Judging by the criteria meadow loam, relief, vegetation and water table depth, the floodplains account for large areas of the Leipzig district. The north-west of the city can for example be described as relatively natural. In the core areas, the floodplains have been ravaged but are still to be seen. The urban green spaces are important here since they augment and in some cases replace the natural vegetation. Things are more difficult regarding the natural soil functions of the floodplain soils, which have not been restored following backfilling, excavation and surfacing. In many areas south of Leipzig, the floodplains have been completely destroyed by lignite mining, and hardly any of the valleys of receiving watercourses like the Parthe and the Zschampert can now be described as floodplain-typical ecosystems.

Concerning flood retention areas there have to be re-discussed river embankment and renaturation measures for the City of Leipzig, although there exist in form of the new lakes in the former mining area big retention areas collecting floods from the mountains, etc.

7. Outlook

Floodplains and floodplain forests in urban areas have been made scarce by centuries of human influence. Their natural functionality as retention areas and pollutant sinks has in many cases completely disappeared which could have disastrous consequences such as in Central Germany in August 2002 (http://www.dfd.dlr.de/images_hochwasser/index.html). When the geochemical milieu conditions change and the soils' cohesive and buffer capacity is reduced, floodplains can quickly become sources of pollution (Haase, 1999). On the other hand, floodplains and relicts of floodplain forests have become important places of recreation and nature perception for many European cities (Ward Thompson, 2002; Daniel, 2001).

The recreation function has replaced the production function of floodplains and floodplain forests in the Elster–Pleiße–Parthe floodplains in Leipzig discussed here. "... The floodplain forest is a green swathe cutting through the city of Leipzig and the surrounding rural district. Its countenance has been shaped by many generations, who have turned this original forest and marsh landscape into a much-visited green belt ..." (Müller and Zäumer, 1992, p. 55).

Yet the analysis contained here shows that these green swathes (also sometimes referred to as 'green lungs') in towns and cities are not adequately protected against land surfacing, blockage and contamination. The usage pressure exerted by inner-city areas repeatedly prompts discussion over open spaces (Haase, 2001). Regarding the problem of the development of land use by towns and cities, Lichtenberger (1993) states that for economic reasons the rising density of built-up areas is regarded as positively as the increasing usage of undeveloped open spaces since they are cheap. And this could well prove to be a vicious circle for relict urban floodplains.

Floodplains and floodplain forests should of course serve as multifunctional areas: recreation areas for the urban population as well as a source of information on relicts of the flora, fauna and morphology of the natural fluvial landscapes of central Germany (such as in the case of Leipzig) and central Europe. But they must not be allowed to deteriorate "... into a fairground" (Müller and Zäumer, 1992, p. 56).

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Determinants of floodplain forest development illustrated by the example of the floodplain forest in the District of Leipzig

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ABSTRACT

This paper discusses determinants of the historical and current spatial extent of the floodplain forest in Leipzig as well as its tree species composition using a GIS-data based delineation model and historical forest inventories for the floodplain forest in the district of Leipzig in Germany from the 19th to the 20th century. We found that the spatial extent of the floodplain forest remained considerably stable in spite of an overall decline in the entire floodplain area from the period where the city first experienced industrialisation in the 19th century to now. However, with river regulations and the alteration of forest management from coppice-with-standards forest to high forest in the 19th century, major changes can be found in the tree species composition of the floodplain forest. Comparing these findings with references from other European floodplain forests we discuss the impact of historical and current forest management as well as the city location's influence on the extent and tree species composition of urban floodplain forests. For urban forest management in particular there is a great need to integrate biophysical, historical and forestry knowledge when predicting future developmental trends.

1. Introduction

Given the complexity of today's cultural landscapes and their interactions with local ecosystems, subsequent difficulties arise in finding the appropriate indicators to assess their functionality. Floodplain and riparian forests are of major importance for urban biodiversity in European cities due to the fact that cities have been located in particular along rivers (Galluser and Schenker, 1992).

Floodplain forests possess the highest species richness and productivity and have the most complex horizontal and vertical structures among temperate forest ecosystems (Bravard et al., 1986). Furthermore, floodplain forests contribute to flood protection in the form of retention areas (Sendzimir et al., 1999). During frequent flooding, water bearing sediments rich in organic matter and nutrients are deposited in the floodplains. The duration and depth of flooding (Day et al., 1988; Leyer, 2004) and the groundwater regimes (Mountford and Chapman, 1993) are important parameters influencing the species composition in floodplain forests.

As settlements developed adjacent to rivers and their floodplains, important transport links were built which consequently led to an increase in urbanisation with land being taken along the banks and even within the floodplains. This was followed by a respective decrease in the natural and open floodplain space (Haase, 2003). For example in Europe, the floodplains of the river Rhine were reduced from primeval 1822 to 353 km^2 from 1842 to 1924 (Schnitzler, 1994). The same trend can be observed in the US where 53% of all wetlands have been lost since the 1780s (Kauffman et al., 1997). In order to save the growing number of urban habitats from floods, extensive hydraulic engineering schemes such as dike construction and river regulations were put in place, especially in the second half of the 19th century (Kasperidus et al., 2001; Schanze, 2006). Additionally, many floodplains were faced with air and water pollution due to the industrial developments of the 20th century (Haase and Neumeister, 2001) as well as the local excavation of the fertile flood loam for pottery and construction purposes. From the 20th century onwards many floodplain forests in vicinity to cities more and more served as recreation area for the urban residents. Today, this recreation function is of overall importance (a.o. Klimo and Hager, 2000; Haase, 2003).

Hence, it is now very difficult to estimate the extent of the original floodplain area. Per definition, floodplains are defined as

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flat valley or depression areas that are situated considerably deeper than their surroundings (Klimo and Hager, 2000). They are further identified by an accumulation of alluvial sediments such as floodplain gravel, fluvial sand or flood loam. Flood loam or fluvial loam is understood here as an allochtonely accumulated and in situ modified sandy to silty material resulting from erosion processes in the up-stream catchment areas. Floodplains possess high groundwater levels (during long periods of the year) and are inhabited by wetland and wet-forest plant and fauna communities (Haase, 2003).

All the urbanisation, human-driven measurements mentioned above sharply changed the natural structures and processes in the floodplains exposed to urban influence in such a way that they began drying up on a large scale. Further they lost their fertile flood loam substrates through excavations. A lack of floods reduced their filtering potential and almost nullified their natural retention function due to a lack of the accumulation of fresh flood loam. This threatens the very characterisation of the specific form of the hardwood floodplain forests (Sendzimir et al., 1999; Haase et al., 2007; Glaeser and Schmidt, 2007).

Alterations to river courses as well as forest management are assumed to be key factors for the changes to the compositions of tree species (Johnson et al., 1976; Tremolieres et al., 1998; Hughes et al., 2001) and the herbaceous layer (Schnitzler et al., 1991; Glaeser and Wulf, 2008). As floods disappear due to river regulations, most of the floodplain forests are subjected to seepage water. Consequently, new species colonised the forests. In the long term, the species composition changed due to the immigration of non-alluvial species such as *Acer platanoides* both in Europe (Tremolieres et al., 1998; Deiller et al., 2001; Glaeser, 2005) as well as in the US (Gergel et al., 2002). Furthermore, in the 19th century, the forest management was altered from coppice-with-standards forest to high forest in most German (Glaeser and Volk, in press) and European floodplain forests (Ellenberg, 1996). This is associated with an increase in canopy density. The interruptions of flooding and the modification of the management system have been found to support an increase in the density of *Fraxinus excelsior* in Europe (Tremolieres et al., 1998; Glaeser and Schmidt, 2007). Together with the Dutch Elm Disease, which led to a decrease in the cover of *Ulmus* spec. (Deiller et al., 2001), the tree species composition in floodplain forests altered dramatically during the 19th century.

In order to analyse the determinants of the historical and current floodplain forest development, we chose the floodplain forest in the district of Leipzig as an example. This study area is characterised by alterations to the spatial extent of the floodplains (Müller, 1995). Furthermore, changes to the tree species composition over recent centuries are well documented (Glaeser, 2005, 2008; Glaeser and Schmidt, 2007). To analyse changes in the spatial extent we used a biophysical GIS-data-model whereas to identify the alterations to the tree species composition archival sources were used. In order to classify the floodplain forest development from industrialisation in the 19th century to now, both methods were combined for the first time.

In particular, the study aims to answer the following research questions:

1. How do changing biophysical determinants (i.e. groundwater, topography, inundation frequency, impervious cover) shape the extent of the floodplain forest?
2. How do flood risk management and floodplain forestry impact the composition of tree species?
3. Are there determinants for floodplain forest development emerging from the proximity to an urban area?

2. Study area

Our study area is situated along the rivers Weiße Elster, Pleiße, Luppe and Parthe in the district of Leipzig, a city in the north-western part of Saxony in Germany. The floodplain forest covers an area of about 1860 ha, whereas the whole floodplain area extends to 5900 ha. The region has a continental climate with an average annual precipitation of 530 mm and an average annual temperature of 8.8 °C (DWD, 2007, 2008).

For a period of more than 600 years, the town of Leipzig has had the ownership of the floodplain forest. From the 14th to the 16th centuries, parts of the floodplain forest were acquired by the town council of Leipzig (Kasperidus et al., 2001). By the end of 1552, a forest administration was established for a part of the floodplain forest (Kasperidus et al., 2001) and since 1553 a "Waldordnung" (forest guideline) has regulated the usage of forest resources (Lange, 1959; Glaeser, 2005).

The floodplains in the district of Leipzig were faced with regular flood events during the winter and early springtime, even though very few regulations of the rivers and their tributaries have been put into effect since 930 (Lange, 1959). By comparison, due to radical regulations of the rivers during the 19th and 20th centuries, flood events have been prevented entirely since 1954. Despite a lack of flooding, the floodplain forest in the district of Leipzig belongs to the community of Querco-Ulmetum minoris (Müller, 1995) with *Acer* spec., *F. excelsior* and *Quercus robur* as the dominant tree species. Extremely wet sites on bolson, backwater and oxbow channels are characterised by Pado-Fraxinetum (Müller, 1995), whereas the morphological top positions in the floodplains are covered by Galio-Carpinetum stachyetosum (Gutte and Sickert, 1998).

3. Methods

3.1. Biophysical determinants for urban floodplain development using a GIS-data model

In order to identify the current boundaries and the spatial extent of the urban floodplains and to determine the biophysical prerequisites of floodplain forest development a conceptual model in the form of a 'GIS floodplain' was developed (Schenker, 1992; Klimo and Hager, 2000; summarised in Haase, 2003). Table 1 defines the criteria or functional indicators set up to identify the occurrence and natural extent of floodplains as well as the respective threshold values for the conceptual model of floodplains:

- flood sediment (clayey loam for the example of Leipzig),
- topography,
- groundwater level,
- land use and
- naturalness of surface (e.g. degree of imperviousness).

The floodplain area F is defined as

$$F = f(S, T, \mathrm{GW}, \mathrm{LU}) \quad (1)$$

where S is the holocene flood loam sediment, T the topography, GW the groundwater level and LU the land use including the degree of imperviousness. More specifically floodplains are those areas defined by the above listed criteria which fulfil Eq. (2):

$$F = S - (T_{>1^{\circ}} + \mathrm{GW}_{>2m} + \mathrm{LU}_{ut}) \quad (2)$$

where ut is defined as "untypical" land use or land cover due to a high degree of imperviousness and canalisation (cf. Table 1).

The outcome from processing the individual indicators in a Geographic Information System (Erdas Imagine, ArcView, ArcGIS)

Table 1
Criteria for floodplain delineation.

	Flood sediment	Topography	Groundwater level	Land use	Naturalness
Inclusion criterion (threshold)	Occurrence	No relief energy, difference to the surrounding terraces	<2.0 m (Vega/Gley soils)	Floodplain forest, wetlands, urban green spaces, parks, sports and leisure grounds, cemeteries	Typical and relatively typical; low degree of imperviousness
Exclusion criterion (threshold)	no occurrence	relief energy > 5%	>2.0 m	allotments, farmland, wasteland, other ruderal and succession areas, built-up areas (housing, transport, trade and industry)	relatively untypical and untypical; high degree of imperviousness
Range	0–1	0–5%	0–2.0		

as shown in Fig. 1 creates an integrative spatial explicit data layer which provides a multi-criteria depiction of those areas that can be defined as floodplains according to Table 1. Using this set of criteria the extent of the floodplain can be modelled for any time slots where the respective data is available enabling a comparison with historical and future maps as well as air-borne land cover data (Fig. 1).

In order to establish the GIS-model, both analogous and digital data on the geology (litho-facies data), groundwater levels (a point data set for the entire area of the city), sediment distribution (soil maps) and land cover (including imperviousness and canalisation) were processed in a GIS to produce intersected and merged vector data layers. The attribute data of each vector or grid were parameterised accordingly as given in Table 1, aggregated and classified. For the case of Leipzig, the distribution of the holocene flood loam was vectorised using the 1:50,000 litho-facies map. The groundwater surface in the floodplain areas was modelled using both relief data from topographic maps and analogue point data recording historical and current groundwater levels. A difference-surface model ($H_{\mathrm{relief}} - H_{\mathrm{GWlevel}}$) enabled the average groundwater level for the entire area to be estimated.

Historical and current land use data (historical maps dating from 1870, 1940, 1985 and 2006; biotope map 1994, topographic map 1:10,000) were intersected with the spread of flood loam. In addition to this, land use was classified into four levels ranked *a priori* from "typical" to "untypical" according to its degree of imperviousness and canalisation (cf. Haase, 2003; Haase and Nuissl, 2007; cf. again Table 2). Thus, a "history" of the extent of the

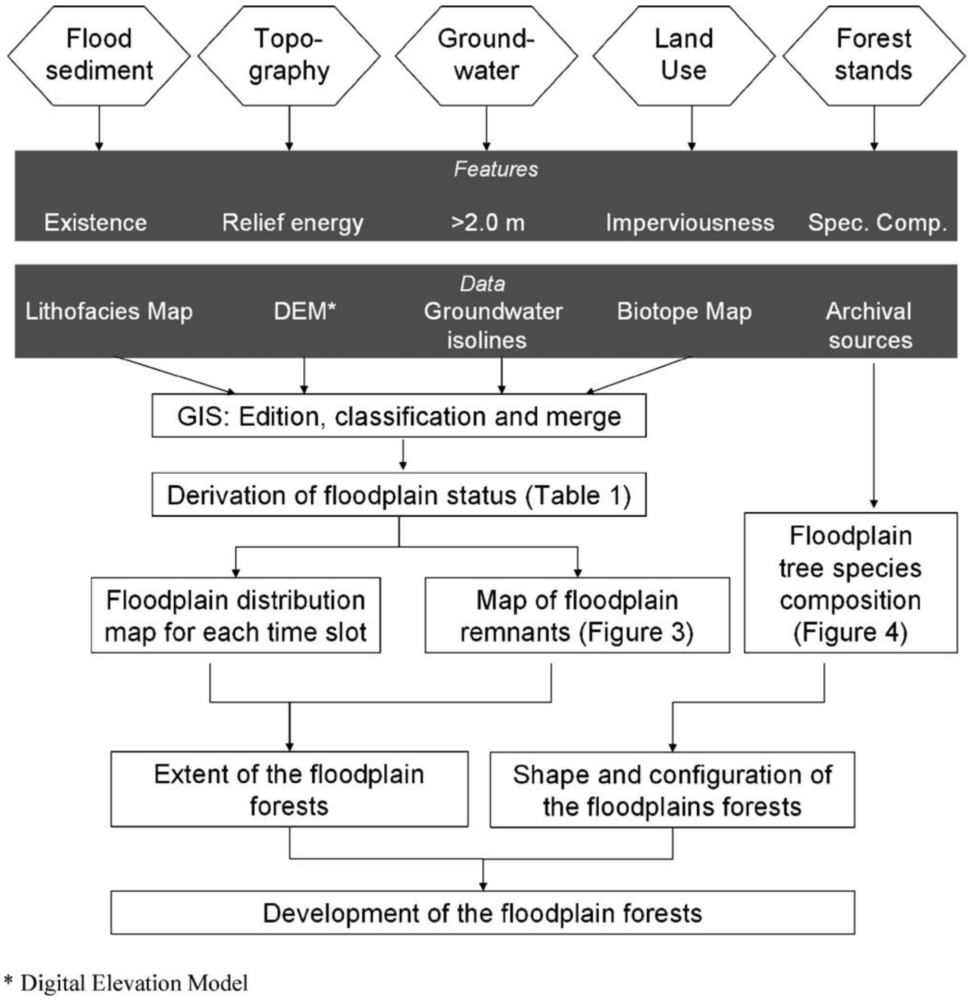

Fig. 1. Scheme of data and model integration for determining floodplain forest functionality indicators (adopted from Haase, 2003; modified).

Table 2
Development of land cover classes in Leipzig from 1870 to 2003.

	1870	1940	1985	2006
Land use type (%)				
Forest	6.4	6.4	6.4	6.3
Meadows, grassland	8.9	6.7	3.1	4.1
Parks, gardens	0.4	1.7	1.4	2.3
Sport, Leisure	0.5	0.5	0.5	1.0
Allotments	1.6	6.3	6.6	5.6
Total urban area (km^2)	50	100	145	298
Population (in 1000)	149	707	581	505
Inhabitants/km^2	8100	4900	3700	1600

floodplain and the floodplain forest cover over the last 150 years could be created.

Normally, the temporary inundation of floodplains is a generic criterion for their delineation. The numerous flood protection schemes confine this natural process to small dammed areas near the main flow path, so that in recent times large areas of the floodplains have only been flooded during periods of extreme flooding (equating to high stream flows and low recurrence intervals). Therefore, it makes little sense to integrate this criterion into the GIS-model applied here although this problem must definitely be included in the investigation of the urban floodplains.

3.2. Archival sources

For the analysis of the historical development and alterations to the plant species composition in the floodplain forest of Leipzig, different archival sources from the State Archives of Saxony in Dresden, the City Archives of Leipzig and the State Archives of Saxony in Leipzig were used (Fig. 1). These historical data sources range from the 17th to the beginning of the 20th century. Historical account books in particular provide important information about tree species and the number of trees cut. However, the absence of tree species in the account book is not equivalent with the absence of them in the floodplain forests. The tree species used as construction timber was nearly exclusively explicitly mentioned in the historical sources whereas data is missing for all other tree species. Hence, a critical interpretation of the archival sources is a prerequisite for any further analysis (Kienitz, 1936).

Besides archival sources, a paper by Müller-Stoll and Süß (1966) was a valuable source of information about the occurrence of tree species for the 17th century. Furthermore, habitat maps by Thomasius (1956) contain relevant information about the management of the floodplain forest in the district of Leipzig after the Second World War.

Additionally, information about the tree species composition in the floodplain forest in the district of Leipzig could be collected from a range of floristic-historical surveys that have been carried out by Wipacher (1726), Klett and Richter (1830), Petermann (1846), Kuntze (1867) as well as other investigations by Müller (1913), Kienitz (1936), Reinhold (1942), Lange (1959), Hempel (1983) and very recently by Glaeser (2001, 2005, 2008), Glaeser and Schmidt (2007) as well as Glaeser and Volk (in press).

4. Results

4.1. Modelling floodplain remnants

Running the GIS-model we found that the spatial extent of the floodplain forest remained considerably stable, even though the entire floodplain area was reduced from the industrialisation of the city (Table 2). Table 2 supports the idea that although the total area of the city increases over time, the proportion of forest area remains stable at 6.3%. Moreover, the proportion of urban green and recreational space such as parks (1870: 0.4%; 2003: 2.3%), sportsgrounds (1870: 0.5%; 2003: 1.0%) or allotments (1870: 1.6%; 2003: 5.6%) particularly increase. The three latter land use types contribute to the share of open space and the per capita recreational space in the city but not to tree species composition or forest biodiversity.

Looking at the results of the GIS-model outlined in Fig. 1, the land use change detection maps given in Fig. 2 and the final difference map from the superimposition of the four floodplain identification indicators in Fig. 3. We can see that current land use

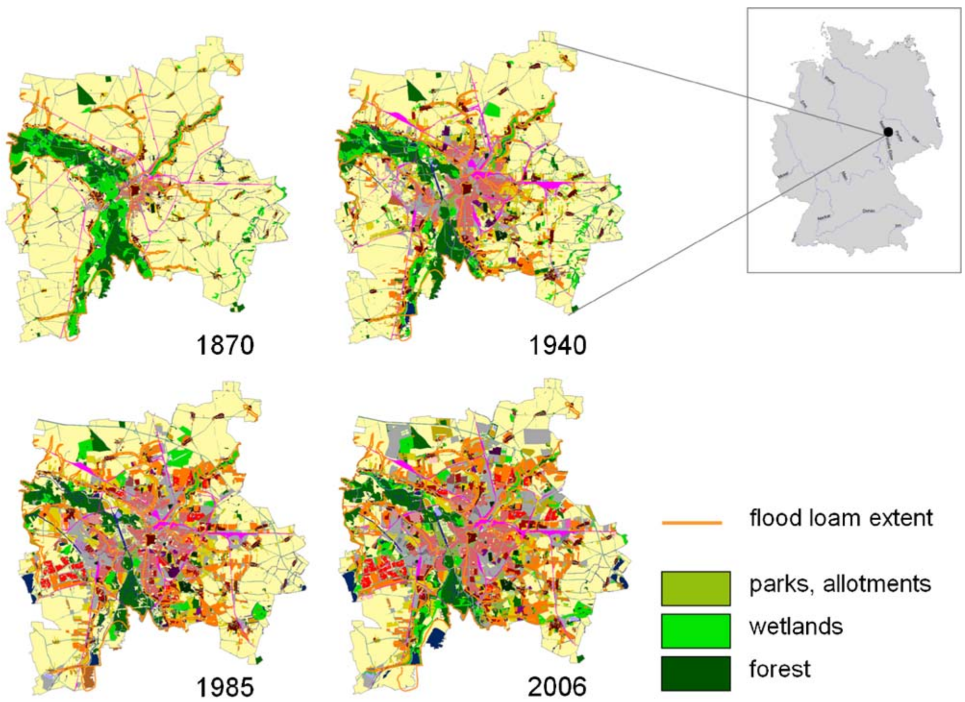

Fig. 2. Floodplain and forest change in Leipzig.

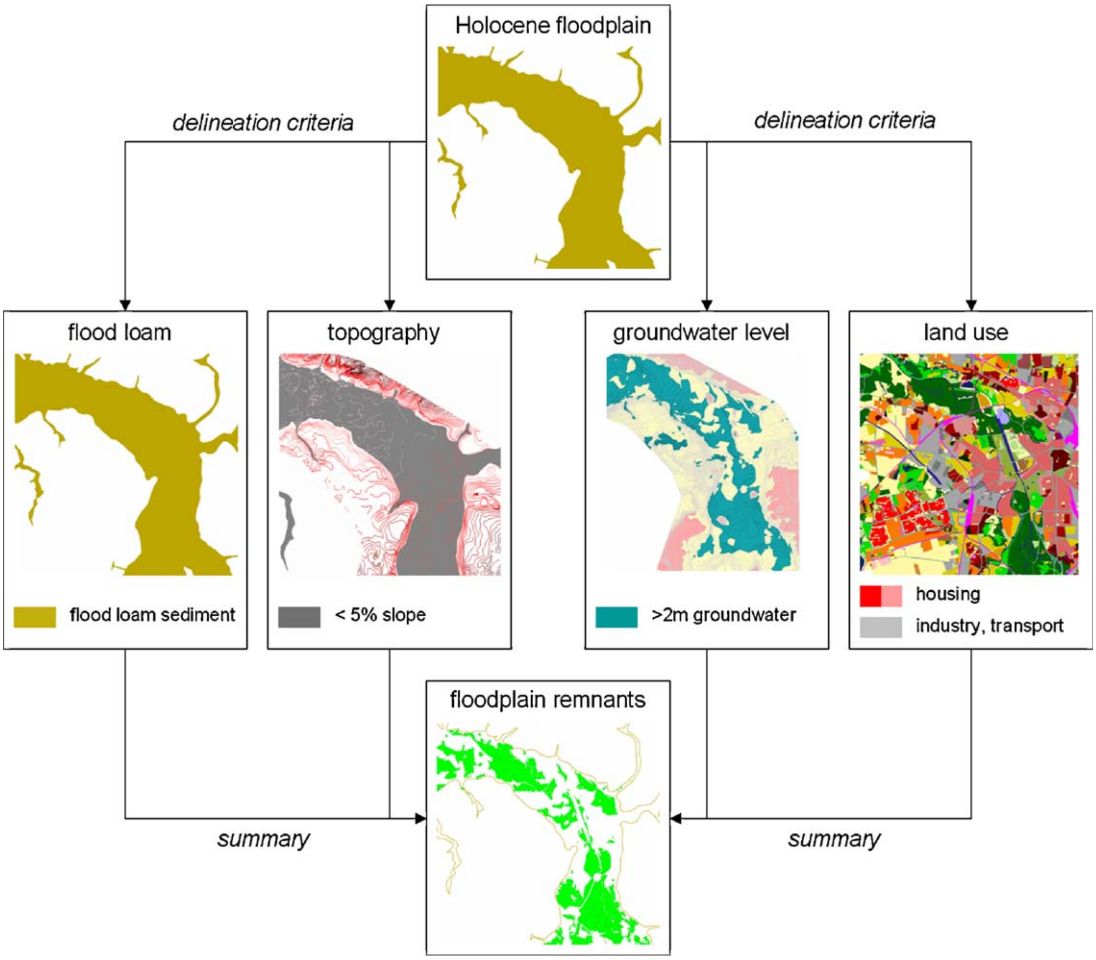

Fig. 3. Remaining open floodplain remnants in Leipzig (adopted from Haase, 2003).

and the respective land cover considerably impede the functionality of those areas which in terms of geology and relief can be described as floodplains (Figs. 2 and 3). Due to the current impervious cover of the floodplains, the fundamental regulating functions (filtration, retention of surface runoff, water storage, etc.) can no longer be fulfilled on surfaced floodplain soils. Situated in the city centre, central parts of the floodplains such as the "Elsterbecken" are there to serve as flood prevention and flood risk reduction. Hydraulic engineering measures mean that spring floods are restricted to areas between dikes and flood water storage basins. In the city centre and the lignite-mining area south of Leipzig, the floodplains along with their forests and open wetlands are no longer discernible.

The reconstruction of the former spatial extent of the floodplain areas was enabled by floodplain soil characteristics and flood loam distribution that indicate historic water tables (Fig. 2). The lack of flooding today (for the last 50 years at least), reduced, in this respect, the currently active floodplain areas to a minimum (Lange, 1959; Haase, 2003). Fig. 3 shows that the holocene floodplain area covers 8830.42 ha compared to floodplain remnants of only 2149.76 ha today. Such data and discussion serves as a target or threshold value for water or flooding levels of rivers that are desirable when drawing up development and restoration goals for urban floodplains in the future.

Based on the criteria of meadow loam, relief, vegetation and water table depth, the floodplains account for large areas in the district of Leipzig. The north-west of the city can, for example, be described as relatively natural. In the core areas, the floodplains have been reduced considerably but are still to be seen in the form of urban green space such as parks, gardens and allotments (cf. again Table 2). The urban green spaces are important here since they augment and in some cases replace the natural vegetation. An assessment is more difficult regarding the natural soil functions of the floodplain soils, which have not been restored following backfilling, excavation and surfacing. In many areas south of Leipzig, the floodplains have been partially destroyed by lignite mining, and hardly any of the small tributaries' valleys can now be described as floodplain-typical ecosystems (cf. again Fig. 3).

4.2. Changes in the composition of tree species in the floodplain forest

From the 16th to the 19th centuries, the composition of tree species in the floodplain forest in the district of Leipzig was relative stable and composed of *Acer campestre*, *Alnus glutinosa*, *Carpinus betulus*, *Corylus avellana*, *Crataegus* spec., *Fagus sylvatica*, *F. excelsior*, *Populus* spec., *Q. robur*, *Rosa* spec., *Salix* spec., *Sambucus* spec., *Tilia cordata* and *Ulmus* spec. (Müller, 1913; Reinhold, 1942; Müller-Stoll and Süß, 1966; Hempel, 1983; Glaeser, 2005, 2008), whereas *Q. robur* was the dominant tree species. *Q. robur* was the most important timber and the basis for tanning agents and pig fatting which led to a selective increase of *Q. robur* far beyond natural conditions (Glaeser and Schmidt, 2007). *C. betulus*, *C. avellana*, *F. sylvatica* and *T. cordata* are tree species with a low tolerance to flooding. Due to the meandering of rivers, a few areas of the floodplain forest were not temporarily flooded. Hence, tree species with a low flood tolerance occurred only rarely and only at morphological top positions of the floodplain forest.

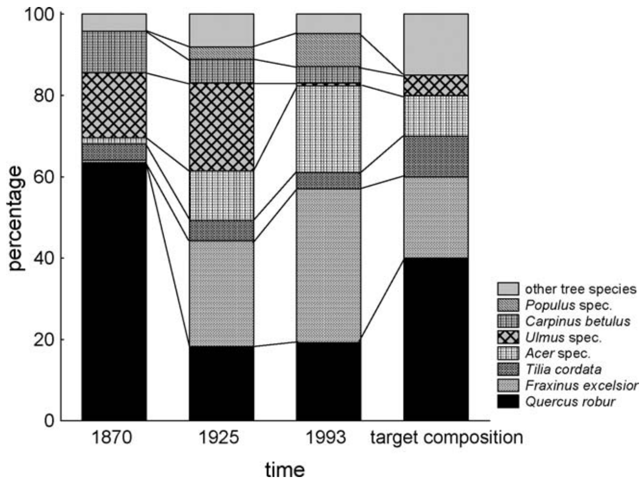

Fig. 4. Proportion of tree species in the floodplain forest in Leipzig from 1870 to 2006 as well as target composition (Lange, 1959; Sickert, 2002). *Acer* spec. is basically made up of *Acer platanoides* and *A. pseudoplatanus*. The main proportion of *Populus* spec. is *Populus* × *canadensis*.

As stated before, during the 19th century the rivers of Leipzig, the Weiße Elster, Pleiße, Luppe and Parthe, were regulated, whereby the number and duration of flood events decreased until they almost disappeared in the 1950s. Furthermore, the forest management changed from coppice-with-standards forest to high forest in 1870 (Thomasius, 1956; Lange, 1959; Glaeser and Schmidt, 2007). From this it follows that the composition of tree species in the floodplain forest remarkably changed up to present (Fig. 4).

From the introduction of high forest management in 1925, the proportions of *Q. robur* and *C. betulus* were dramatically reduced. After 1925, the proportions of both tree species remained constant. Even though *Acer pseudoplatanus* and *F. excelsior* occurred in the floodplain forest in the district of Leipzig in the 19th century (Wipacher, 1726; Klett and Richter, 1830; Petermann, 1846; Kienitz, 1936; Glaeser, 2001), the proportions of *A. pseudoplatanus* and *F. excelsior* on the tree species composition was very low. Due to changes in the hydrology and forest management, the proportions of both tree species increased from 1870 to 1993. Moreover, *A. platanoides*, a new plant species in this floodplain forest, was able to immigrate in the 19th century (Kuntze, 1867).

By the middle of the 20th century, we found a high proportion of *Ulmus* spec. in the floodplain forest (Fig. 4). Due to the Dutch Elm Disease however, most *Ulmus* tree species, especially *Ulmus minor*, were dramatically reduced to nearly 0% at the end of the 20th century (Gutte and Sickert, 1998). In the 20th century, the number of tree species were increased by planting *Acer negundo* (Tit. XVO Nr. 80 B 9[1]), *Carya cordiformis*, *C. ovata*, *Juglans nigra* (Schaarschmidt, 1989; Tit. XVO Nr. 68 B 14[2]), *Picea* spec. (Tit. XVO Nr. 68 B 14) and *Populus* × *canadensis* (Lange, 1959). In according to the target composition (Sickert, 2002), the proportions of *Q. robur* and *T. cordata* in the tree species composition should be increased, whereas the proportions of *Acer* spec. and *F. excelsior* should be decreased in the future (cf. again Fig. 4).

5. Discussion

In this paper we were able to demonstrate that the total floodplain area in the district of Leipzig had been dramatically reduced mainly by flood risk management measures (embankment, dikes, polders) compared to the spatial extent of the forest itself using a set of delineation criteria in a GIS-model. The remnants of the holocene floodplains are decreasingly influenced by floods and high groundwater tables. Instead, they are characterized by a considerable amount of impervious surfaces. However, riparian forests hold an important recreational value, particularly in urban areas. It was this recreational value in particular that already led to the conservation of both the forest in history as reported by archival sources. Compared to the "stability" of the spatial extent of the floodplain forest, the tree species composition changed dramatically due to an alteration to the modification of biophysical conditions (i.e. groundwater, flooding) as well as forest management. Thus, the demand on recreational green space in an urban area does not affect the overall size or extent of the forest area as much as it influences its species composition or forest diversity.

In the light of climate change and an associated increase in flood events (Mudelsee et al., 2003) the renaturation and the restoration of (former) floodplains regains importance and there is a real potential for this. Moreover, newly "designed" floodplain forests could serve in flood regulation, where they will be cultivated in accordance with current scientific and forest management knowledge and respective tree species are planted. When looking at the climate change impacts that are expected to endanger the health and well-being of urban residents this kind of renaturation is an important support (Gill et al., 2007). Consequently, one has to know the potential of floodplains and their forests that are remaining in an area in order to quantify future impacts of, e.g. climate change. Here, the floodplain indication GIS-model presented in this paper provides an innovative and easily applicable tool to identify those areas (remnants) that are still functioning within a former floodplain.

The model exclusively uses analogous and digital data available to the public which reduces the financial and personal requirements for its application to a reasonable amount. Moreover, it produces spatial output maps which enable a visualisation of the results and thus a sound base for discussion between scientists and forest managers. Another advantage of the approach is that most of the data sets that it uses (topography, land use, groundwater level) are part of urban monitoring programmes (ongoing since the 1930s) and so they can be regularly reproduced and time steps can simply be added. Change detection measures can therefore be easily realised.

The data base used for the model provides a range of advantages compared to other existing data which could be used for such a delineation: the unique HYDE land use database (Goldewijk, 2001) delivers land use information for European countries since 1700 but for urban land uses in particular it provides rare information in terms of being up-to-date and accurate. As we are looking for the impacts of urbanisation on floodplains, the topographic map series developed in the early stages of industralisation is suitable as a data source throughout Europe. Although the accuracy of the single data sets used for the delineation model presented here is high, there are still some differences concerning their scales. This difference could be improved using, e.g. a more detailed elevation model as well as a prognostic land use change model that looks into the future of land use development.

Using land cover and land use data for various time slots we were able to answer the question we asked at the beginning of the paper: Did the area of wetlands and respective floodplain forests change over time with respect to the river embankment and regulation measures carried out since 1950? With the help of the GIS-model results we could show that regardless of a decline in the total functional floodplain area, the area of the floodplain forest stand actually remains. We further argue using historical forest archive data that particularly after reformation in the 16th century

[1] Adminstration der Forsten: das Connewitzer Revier betr. Vol III 1874.
[2] Acta, die Administration der Forsten u. w. d. a. betr. Vol XIV 1914.

the city turned from a feudal into a resident's city which aimed to provide production ground and (later on) recreation facilities to their inhabitants. An important argument that supports this is the creation of the first European forest agency in Leipzig in 1524 (Müller, 1913).

The GIS-model was tested for Leipzig. There, river embankment and regulation measures took place after 1850, as stated, but did not influence the distribution of the floodplain forests as much as along the Rhine, for example (Schnitzler, 1994). This shows that the applicability of the indication model has to be proved further using other cases in focus which might confront the model with new settings and local secularities.

Even though the area of floodplain forest remained more or less the same since the 19th century, the regulation of the rivers by embankment and dike construction and the alteration to the floodplain management led to a major change in the composition of tree species. *Q. robur*, *U. minor* and *U. laevis* were discussed as natural tree species in the floodplain forest of Leipzig (Müller-Stoll and Süß, 1966) as well as in other floodplain forests in Germany (Caspers, 1993; Mathews, 1997; Pott and Hüppe, 2001; Lechner, 2005). By the end of the 19th century, *Q. robur* were used as very important building material, for the fattening of pigs and for tanning agents whereby *Q. robur* was planted quite frequently. Hence, in previous centuries, the frequency of *Q. robur* in floodplain forests was mainly determined by anthropogenic influence. Furthermore both the occurrence and composition of tree species strongly depend on the flooding tolerance. Flood tolerant tree species such as *U. minor* frequently dominate areas flooded over longer periods. Conversely, tree species with a low flood tolerance such as *C. betulus* or *T. cordata* occur in infrequently and temporarily flooded areas (Pautou et al., 1992; Tremolieres et al., 1998; Deiller et al., 2001).

In the 19th century, most large Central European rivers were regulated. In addition to this, the overall population of Leipzig has been declining since the middle of the 20th century onwards, which is in accordance with the development in Europe (Lutz, 2001) and agriculture was developed very well. Hence, first and foremost timber production declined in many European floodplain areas and the forest also disappeared as woodland pasture (Ellenberg, 1906). From this it follows that the forest management system changed from coppice-with-standards forest to high-forest in the floodplain forests of Germany (Volk, 2000a; Margraf, 2004; Glaeser and Schmidt, 2007; Glaeser and Volk, in press) and Europe (Mráz and Sika, 1965). As a result of such alterations, the composition of tree species changed so that there was a new opportunity for new tree species to colonise the floodplain forests. Even though *F. excelsior* is a natural tree species in most floodplain forests in Germany (Mathews, 1997; Pott and Hüppe, 2001; Lechner, 2005), its proportion was comparatively low in former centuries. Due to infrequent flood events, the interruption of floods and a high degree of high-forest, the proportion of *F. excelsior* increased through plantations. This can also be stated for most of the floodplain forests in Europe (Mráz and Sika, 1965; Tremolieres et al., 1998; Volk, 2000b; Glaeser and Volk, in press). The same is true for *A. pseudoplatanus* (Glaeser and Volk, in press), whereas the non-alluvial *A. platanoides* was first able to penetrate the floodplain forests in the 19th century (Kuntze, 1867; Tremolieres et al., 1998; Deiller et al., 2001). Nowadays, *A. platanoides*, *A. pseudoplatanus* and *F. excelsior* dominate most of the German lowland floodplain forests along with *Q. robur* (Volk, 2000b; Klausnitzer and Schmidt, 2002; Glaeser and Volk, in press).

Another dramatic change in the tree species composition in the floodplain forests was caused by the Dutch Elm Disease. For the mid-19th century the *Ulmus* spec. dieback especially for *U. minor* was observed in most floodplain forests in Europe (Deiller et al., 2001), even though the Dutch Elm Disease occurred already earlier (Röhrig, 1996). Consequently, *U. minor* occurred exclusively in the shrub layer of the floodplain forests due to root suckers whereas it is missing completely from the tree layer of the floodplain forests.

6. Conclusions

In this paper, we show that regardless of industrialization, the floodplain forests in the district of Leipzig did not disappear but lost their floodplain properties: The determining property of floodplains in general, the flood loam, is still present in most places. Major negative impacts on the functionality of the floodplains, as argued in our paper, are surface sealing, represented by the proxy of the land use type, and the depression of the groundwater table. Both lead to a distinct change of water storage capacity and, subsequently, the species composition. As the paper further showed, forestry and property values kept the medieval forest trees species composition from the 19th century onwards.

When applying the knowledge gained in this study to today's floodplain forest management, we argue to retain the current forest area and to use it as recreation space. In order to positively impact forest biodiversity, the current proportion of *Q. robur* in the floodplain forest in the district of Leipzig has to be extended in the future due to its ecological value and niche function for many organisms. Hence, small parts of the floodplain forest should be used as a coppice-with-standards forest since this management system can be conducive to a higher occurrence of *Q. robur* and, above all, a high biodiversity in the floodplain forests in general. Again, this implies no further reduction of the current floodplain forest extent which still represents major parts of the holocene floodplain remnants.

Further research work will incorporate spatial and structural data for the urban surface (i.e. transport network, housing areas, greenery) as well as distance and connectivity indices to evaluate, in a more quantitative way, the spatio-functional relationships such as accessibility and fragmentation of the urban area, its residents and the remnants of floodplain forests.

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Simulation Models on Human–Nature Interactions in Urban Landscapes: A Review Including Spatial Economics, System Dynamics, Cellular Automata and Agent-based Approaches

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Abstract

Urbanisation belongs to the most complex and dynamic processes of land use and landscape change. At present, we claim “the millennium of the cities,” since more than half of the currently 6.6 billion world population is living in urban areas. Due to the huge impact of urban land consumption on environment and landscape, this paper provides a review of existing urban land use models. The review analyses non-spatially explicit economic and system dynamics models, spatially explicit cellular automata and agent-based model approaches by addressing the respective conceptual approach, model components and causal relationships, including feedbacks. Based upon the review, conclusions are drawn regarding the future development of urban landscape models, as well as on indispensable causal relationships and their representation when modelling urban systems.

Keywords: urban landscape, simulation models, land use change, review, system dynamics, cellular automata, agent-based model, feedback, causalities

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1 Introduction

1.1 Urbanisation of landscapes

Urbanisation is one of the most complex and dynamic processes of landscape change. Although only about 4% of the world's land area is urbanised and densly populated (Ramankutty *et al.*, 2006), we claim "the millennium of the cities," since more than half of the currently 6.6 billion world population is living in urban areas (United Nations, 2008, 2009; PRB, 2007; EEA, 2006; Kasanko *et al.*, 2006). Projections for the future show that urbanisation – in terms of an increasing share of population living in urban areas – is very likely to continue (Batty *et al.*, 2003; EEA, 2006; Lutz *et al.*, 2001). Urbanisation is not only a societal problem, but also an environmental one, because it contradicts a normative ideal of "a natural or un-spoiled landscape" in spatial planning (Nuissl *et al.*, 2008). In a multitude of studies it has been shown that land consumption is usually detrimental to the environment in different regards (e.g., Johnson, 2001; Antrop, 2004). Its impact reduces the ability of landscapes to fulfil human requirements and thus impairs ecosystem services and landscape functions in various ways (de Groot *et al.*, 2002; Millennium Ecosystem Assessment, 2005; Curran and de Sherbinin, 2004). Individual ecosystem services and quality of life aspects that are affected by urbanisation include the production of food, the regulation of energy and matter flows, water supply, the provision of biodiversity and of health and recreation, and the supply of green space and natural aesthetic values (Alberti, 1999). Suburbanisation and urban sprawl were the dominating land consumption processes in North America and Europe after WW II (Batty, 2008). Recently, high growth rates in developing countries have led to enormous environmental loads as discussed above (Heinrichs and Kabisch, 2006). As urban systems are very densely populated and their land use components highly interlinked (Liu *et al.*, 2007), developing views about their future is both a major concern in landscape research and a complex task. Modelling land use relationships helps to understand underlying drivers of land use change, to create future land use scenarios and assess possible environmental impacts (Lambin and Geist, 2006; Ravetz, 2000).

1.2 The "ideal" urban land use model

A variety of land use change models, particularly for urban landscapes, already exist, ranging from specific case studies to generic tools for a variety of urban regions. These models differ largely in terms of their structure, their representation of both space and human decisions, and their methodological implementation. Compared to land use change models in open landscapes, urban areas are shaped particularly by human activities, societal processes and human–nature interactions (Couclelis, 1997). In addition to implemented simulation models, a number of articles and book chapters elaborate on the "ideal" integrated model, theoretically necessary causal feedback loops etc. These "ideal" models shall serve as analytical frameworks to better understand the systems under study. Often, authors use frameworks like the DPSIR-framework (drivers, pressures, state, impact, responses) of the European Environment Agency (EEA) to conceptualise these conceptual models. According to Verburg, "the main drawback of using these analytical frameworks is the assumption of one-directional processes between driving factors and impacts" (Verburg, 2006, p. 1173), because in reality, it is difficult to differentiate between impacts and drivers in a system. Bürgi *et al.* (2004) distinguish five major types of driving forces: socioeconomic, political, technological, natural and cultural. Furthermore, they differentiate between primary, secondary and tertiary driving forces, as well as between intrinsic and extrinsic driving forces (Bürgi *et al.*, 2004). In their introduction to urban simulation, Waddell and Ulfarsson (2004) sketched urban markets and agents, choices and interactions in an "ideal" urban land use model. Timmermans (2006) criticizes that present urban models focus on functional chains like the following: demand causes allocation across space, which in turn causes traffic flows, based upon which a transportation model calculates travel times, which in turn explain residential choice. Timmermans votes to include other aspects of integration in urban land use models, such as task allocation within households, residential choice, job choice, vehicle ownership, scheduling of activities, competition and agglomeration of land uses and actors, co-evolutionary development of demographics, employment sectors, land use and activity profiles and a more thorough treatment of varying time horizons, including anticipatory and reactive behaviour. According to Miller *et al.* (2004), an integrated urban systems model with a focus on transport should include socio-demographic components (evolution of population), demographics (demographic change and migration into and out of a region), decision-making (location choices of households and firms), economic variables (labour market, import/export of goods and services), transportation (activity and travel patterns of population, goods and services, depending upon urban structure and economic interchanges, performance of road and transit systems) and respective effects on land use (evolution of the built environment) and environment (atmospheric emissions generated by transportation and industry; Miller *et al.*, 2004). Moreover, Hunt *et al.* (2005) stated eleven modelling axioms for such an "ideal urban land use model":

- Representation of an urban system should focus on those elements that interact with the transportation system.
- An urban system consists of physical elements, actors and processes.
- A transportation system is multimodal and involves both people and goods.
- Markets are the basic organising principle of an urban system.
- Flows of people, goods, information and money arise out of demand.
- Urban areas do not reach an equilibrium.
- System time must be explicitly dealt with.
- Feedback between short-term and long-term processes has to be integrated (e.g., travel and infrastructure).
- Some factors may be treated as exogenous for modelling purposes.
- Some activities arise in response to external demand.
- A very detailed level of representation for actors and processes is necessary.

1.3 Existing reviews on urban land use models

A variety of reviews including urban land use models already exist: Agarwal *et al.* (2002) as well as Schaldach and Priess (2008) review integrated land use models in general, also including models that deal with non-urban land uses such as forestry, pasture and agriculture. Axhausen (2006) specialises in models on transportation demand and traffic flows. Beckmann (2006) and Iacono *et al.* (2008) focus on interactions between urban land use and transportation. The authors predominantly discuss modelling approaches and does not give details regarding single models. Similar to this, Berling-Wolff and Wu (2004) provide an historical overview of modelling approaches and do not discuss single models. The U.S. EPA (2000) focuses on models of urban growth and sprawl but mainly includes U.S. American approaches and – because of its publication date – does not include recently published models. Geurs and van Wee (2004) and Hunt *et al.* (2005) focus on models which emphasize the interaction between urban land use and the transportation system. Furthermore, Timmermans (2006) gives a historical overview and describes a large number of models but does not give a comparative description of presently developed models. With his review on modelling the urban ecosystem, Alberti (2008) puts less emphasis on urban land use change, but rather focues on the environmental impacts and human-induced environmental stress of the urban system. The review utilises a range of evaluation criteria, of which feedback mechanisms, multiple actors and the inclusion of uncertainy are seen as the most challenging (Alberti, 2008). Finally, Verburg *et al.* (2004) sketch a few exemplary models, but their focus lies on discussing general modelling approaches and not on single causal feedbacks.

1.4 The purpose of this review

Set against the background summarised in Section 1.3, this review analyses economic models, system dynamics approaches, cellular automata and agent-based models developed for urban systems by systematically addressing a range of critieria such as the conceptual approach, model components and included variables. In doing so, it aims at giving an overview on the respective model structures. The main purpose of the review is to derive ideas for causal relationships within land use change in urban systems, with a special emphasis on integrating social and natural science dimensions. The innovative aspect of this review compared to existing reviews is the aim to explicitly analyse causalities and feedbacks in urban land use changes.

As Verburg (2006) points out, an integration of social and biophysical systems could be enhanced by including feedback mechanisms in land use models, e.g., the feedback between driving factors and effects of land use change (here understood as impacts), the feedback between local and regional processes, and the feedback between agents and spatial units (Verburg, 2006). "Less common in land use modelling is the simulation of feedbacks between impacts on socio-economic and environmental conditions and the driving factors of land use change" (Verburg, 2006, p. 1173). Therefore, the review presented here will include a glance at those feedbacks. Since urban land use models deal with spatial entities – that is, among others, the landscape itself – an important aspect of selecting modelling approaches for the review is spatial explicitness in terms of landscape property. In addition, urban landscapes are highly complex, as highlighted in several paragraphs of the introduction part of this paper; therefore, one should focus on comprehensive models that include different relationships, influences and dependencies along with their spatial representation. The paper is organised as follows. Section 2 sets up a set of evaluation criteria for conducting the model review, which follows in Section 3. Section 4 especially focuses on causalities and feedback loops of land use change, before coming to the paper's conclusions (Section 5).

2 Evaluating urban land use simulation models

Compared to natural or agricultural landscapes, urban systems are strongly influenced by both the social and the natural dimension. As mentioned in the introduction, urban landscapes are coupled with human–nature systems (Liu *et al.*, 2007), with many interlinkages between the human sphere – first and foremost demography and economy – land use and the environment. Figure 1 provides a very general but comprehensive overview on the major components of an urban landscape: the major driving force for change is the human sphere, which creates pressures on the state of the land use, which again will have effects on the environment, its natural resources and ecosystems.

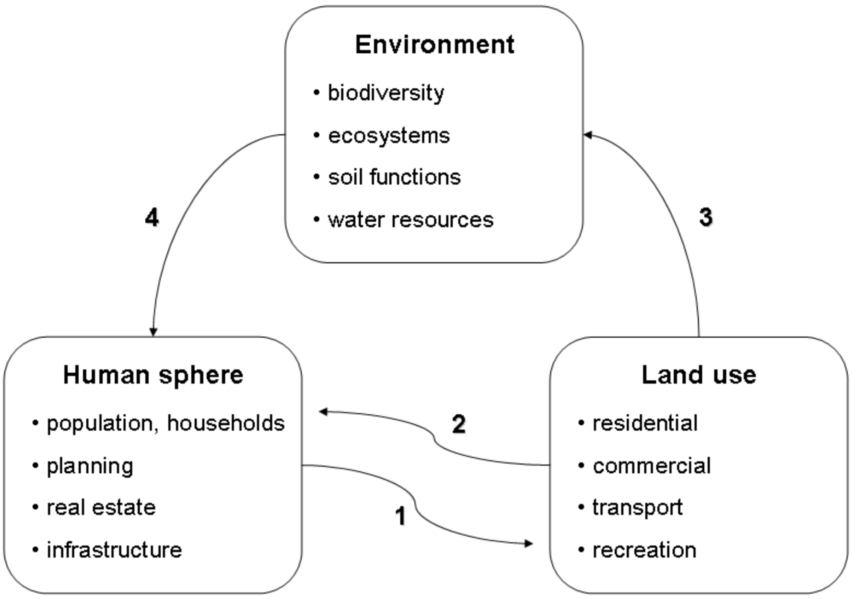

Figure 1: Main components (human sphere, land use, natural resources) and relationships (1 – 4) which describe human–nature interactions in urban regions: (1) Impact of human sphere on land use, (2) feedback of land use on human sphere, (3) impact of land use on environment (including ecosystems) and (4) feedback of environment on human sphere.

The human sphere characterises the socio-economic system of cities: it comprises variables such as population (development), households, spatial planning and governance, the real estate market, commercial activities and infrastructure, including transportation. Specifically, the human sphere includes human decision making and actions upon land use. The land use component itself comprehends all types of typical urban land uses such as residential, industrial, commercial, transport and recreation. The third component contains natural resources, such as ecosystems, biodiversity, soil functions and water resouces (cf. again Figure 1). We set up these feedback loops between the three dimensions/components of the urban system discussed above: (1) the impact of the human sphere on land use, (2) the feedback (= reverse to the impact function) of land use on the human sphere, (3) the impact of land use on the environment and (4) another feedback of the environment on the human sphere. All relationships are labelled in Figure 1, respectively. Furthermore, a short Section (4.4) deals with the scale-specific causal feedbacks between local and regional scale, insofar as they are covered by the models investigated. The evaluation of the feedback loops includes (1) the identification of a respective formal representation of the respective causalities in the model and (2) whether or not they have an impact on other model components again/vice versa. In order to structure the review and to give brief overviews of the models under review, we summarised the findings of the analysis of each of the models in Table 1, which provides comprehensive information about the main purpose and major components classified according to Figure 1.

3 Models under review

With respect to the model evaluation criteria mentioned in previous reviews and for the "ideal urban model" (Sections 1.2 and 1.3), we solely focus on causalities and feedback loops in the models under review, as we believe that alongside a good description of model components (human sphere, land use, environment), representation of the linkages between the components (= impacts and feedback loops) make up the comprehensiveness and the explanatory strength of the models. The models included in this review were selected in order to represent the most influential streams of urban land use change modelling. First, the review includes models well known within the community, such as those which are discussed in the related literature on urban land use change, e.g., by being referenced in other reviews. Second, system and land use approaches which are not discussed at great length in the literature were included, because system dynamics as a method forces modellers to think in a systemic way and easily allows for the inclusion of feedback mechanisms. For system-oriented, causality-driven models on at least one dimension of urban land-use change, a search on the ISI Web of Science was performed. This procedure led to a total of 19 models, which were also included in this review. These models are listed in the form of a comprehensive overview in Table 1. Details are given in the Annex 7.

Roughly four different modelling approaches can be distinguished. Two of the models under review belong to the class of spatial economics/econometric models (SE_1 and SE_2: Nijkamp *et al.*, 1993; Mankiw and Weil, 1989). These models mainly look at demography and household-driven demand-supply relations in urban regions, such as housing market developments. Seven models included in this review (SD_1 to SD_7: Forrester, 1969; Haghani *et al.*, 2003a,b; Eppink *et al.*, 2004; Sanders and Sanders, 2004; Onsted, 2002; Eskinasi and Rouwette, 2004; Raux, 2003) are system dynamics or causality-driven models (Table 1). System dynamics is an approach which models complex systems using stocks and flows and by explicitly including feedback loops in the model (Sterman, 2000). System dynamics models are – in their standard application – not spatially explicit. Rather, the structure of combining stocks, flows and feedback mechanisms leads to a set of differential equations. The outcome of these equations can be simulated, given values for parameters and initial conditions. The classical approach to modelling urban systems using system dynamics is Forrester's book on "Urban Dynamics" (Forrester, 1969): He linked the three subsystems "business," "housing" and "population" to describe and model urban systems in general, subsequently differentiating each of the three subsystems in very detailed sub-models. Five models included in this review (CA_1 to CA_5: Verburg and Overmars, 2007; Landis and Zhang, 1998a,b; Landis *et al.*, 1998; Engelen *et al.*, 2007; Dietzel and Clarke, 2007) use cellular automata as the main modelling technique (Table 1). A cellular automaton consists of an n-dimensional grid of cells. Each cell has a finite number of states. Cells change their state simultaneously according to the same rules coded in the model, and the state of a cell in time t solely depends on the state of neighbouring cells in t_{-1} (cf. Clarke *et al.*, 1997; Landis and Zhang, 1998a,b; Silva and Clarke, 2002). Land use change models use cellular automata with 2-dimensional grids which represent the majority of land use. Each cell symbolises a patch of land, and states of cells are the land use options. Five models in this review (ABM_1 to ABM_5: Strauch *et al.*, 2003; Salvini and Miller, 2005; Ettema *et al.*, 2007; Loibl *et al.*, 2007; Waddell *et al.*, 2003) use agent-based approaches as the main modelling technique (Table 1). Agent-based models consist of autonomous individuals (agents) who perceive their environment and interact with one another (Parker *et al.*, 2003). Applications of agent-based modelling in land use change are usually spatially explicit, and agents represent, for example, households relocating their homes or individuals using transport systems, but also governmental and other institutional bodies.

Table 1: Overview of main purposes and components (according to Figure 1) investigated in reviewed models.

Model	Main purpose	Components	Reference
Spatial Economics / Econometric models			
SE_1	Modelling household life cycles and their impact on residential relocation behaviour and the urban housing market for a European capital city.	Human sphere (population, migration, household, transportation, housing market, prices, dwellings, vacancies)	Nijkamp *et al.* (1993)
SE_2	Simulation of demographic changes (baby boom and baby bust) and its influences on the housing market in the U.S.	Human sphere (population, migration, household, housing market, prices, dwellings, vacancies)	Mankiw and Weil (1989)
System Dynamics			
SD_1	Modelling urban system in general, explicitly including "urban decline." Examples: focus on a specific topic, e.g., rapid population growth, demolition, et cetera and therefore need specific models.	Human sphere (business, housing, population)	Forrester (1969); Alfeld (1995)
SD_2	Integrated land-use and transportation model for estimating scenarios regarding transport policies	Human sphere (population, migration, household, job growth, employment and commercial land development, housing development, travel demand, congestion)	Haghani *et al.* (2003a,b)
SD_3	Assessing the impact of urban sprawl on wetland biodiversity and social welfare	Human sphere (population) Land use (agricultural land, wetlands) Environment (wetlands, nature protection)	Eppink *et al.* (2004)
SD_4	Redefining the model of urban dynamics by Forrester (1969), including: 1. spatial dimension (16 squares) and 2. disaggregation: different types of housing, industry, and people in zones	Human sphere (population, housing availability, houses, land availability, business structures, and job availability, labour market and housing market)	Sanders and Sanders (2004)
SD_5	Simulation model to provide scenarios for future land use in Santa Barbara, e.g., with restrictions to urban growth	Human sphere (housing, population, business) Land use Quality of life	Onsted (2002)
SD_6	Assessing the impact of future policy interventions on the social housing market (specific: rate of building new dwellings)	Human sphere (commercial housing stock, social housing stock, waiting families, supply of available social houses; migration, demolition, construction)	Eskinasi and Rouwette (2004)

Table 1 – *Continued*

Model	Main purpose	Components	Reference
SD_7	Simulating medium- and long-term effects of urban transportation policies with reference to sustainable travel	Human sphere (urbanisation, internal travel demand, car ownership, external travel demand, transportation, socio-economic evaluation) Environment (environmental appraisals)	Raux (2003)
Cellular Automata			
CA_1	Tool for understanding land-use patterns, possible future scenarios for given demand	Human sphere (demand rules) Land use (suitability rules)	Verburg and Overmars (2007)
CA_2	Simulating urban growth, scenarios for future development	Human sphere (population, household, jobs, employment) Land use (single-family residential, multi-family residential, commercial, industrial, transportation, public) Environment (undeveloped land)	Landis and Zhang (1998a,b)
CA_3	Development of policy scenarios of urban growth, impact on habitat change/biodiversity	Human sphere (urban growth, policy simulation and evaluation) Environment (habitat change and habitat fragmentation)	Landis *et al.* (1998)
CA_4	Monitoring developments of urban areas and identifyng trends at the European level, focus is on growth scenarios	Human sphere (population, economy, planning, accessibility via transportation network) Land use (land use functions)	Engelen *et al.* (2007)
CA_5	Modelling urban growth, scenarios for future development of an urban region	Land use (urban or non urban, roads, different land use types) Environment (topography)	Silva and Clarke (2002); Dietzel and Clarke (2007)
Agent-Based Models			
ABM_1	Dynamic simulation model with a focus on urban traffic flows, including activity behaviour, changes in land use, and effects on environment	Human sphere (activity patterns and travel demand, traffic flows, goods transport, accessibility of locations, location decisions of households, firms, developers) Land use (moving households, location of firms, investment of developers, new industrial area) Environment (clean air, traffic noise)	Strauch *et al.* (2003); Moeckel *et al.* (2006)
ABM_2	Evolution of an entire urban region with emphasis on transportation	Human sphere (location choice, activity schedule, activity patterns, automobile ownership, travel demand) Land use (land development, transportation network)	Salvini and Miller (2005); Miller *et al.* (2004)

Table 1 – *Continued*

Model	Main purpose	Components	Reference
ABM_3	Predicting urbanisation with behavioural agents	Human sphere (demographic change, decisions of individuals)	Ettema *et al.* (2007)
ABM_4	Development of built-up area in peri-urban region, driven by households and entrepreneurs; urban growth with different growth rates	Human sphere (households, jobs, numbers of people, households and workplaces at the start of the year, average travel time to district centres and capital city) Land use (urban land, open space, forest area)	Loibl *et al.* (2007)
ABM_5	Link between transport and land use; impact of different planning strategies	Human sphere (population, households, employment, travel demand, accessibility, mobility, real estate, land price) Land use	Waddell (2006); Waddell *et al.* (2003)

4 Representation of urban landscapes

One of the major aspects which urban land use models have to represent are causalities and feedbacks related to human–nature interactions. The main components representing an urban system, according to the models under review, are summarised in Tables 1 and 2. Spatial Economic models are labelled SE, Cellular Automata CA, System Dynamics Models SD, and Agent-Based models ABM.

Table 2: Main components of urban systems – do the models under review include them?

	Human sphere	**Land use**	**Environment**
(Spatial) Economic models			
SE_1	x	x	
SE_2	x	x	
System dynamics			
SD_1	x	x	x
SD_2	x	x	
SD_3		x	x
SD_4	x	x	
SD_5	x		x
SD_6	x	x	
SD_7		x	
Cellular automata			
CA_1	x		
CA_2	x	x	
CA_3	x	x	x
CA_4	x		x
CA_5			x
Agent-based models			
ABM_1	x	x	
ABM_2	x	x	x
ABM_3	x	x	
ABM_4	x	x	
ABM_5	x	x	

Structural relationships between model components and variables are found to be very different in the models (Figures 2 and 3). This is due to the fact that levels of rules for land use change vary largely, depending on the modelling technique used, i.e., (spatial) economics, system dynamics, cellular automata or agent behaviour (Table 2).

The first model group, (spatial) economic or econometric models, sets up a formalised relationship between population and market; in our case these compounds are the housing market and residential land use. Spatial economics models can be dynamic (when model parameters are treated endogeneously) or quasi dynamic (if model parameters are fixed or an exogeneous input during the model runtime). Generally, such models define a demand based on a population/household/cohort, etc., number, but only a limited feedback is generated from the net supply to the original driver (in our case: population). Cellular automata derive probabilities of land use change for a certain cell out of historical land use data (Engelen *et al.*, 2007; Barredo *et al.*, 2003) or by using try-and-error “calibrations” (Hansen, 2007). Therefore, they do not explicitly deal with causal relationships between urban drivers and land use states. Driving forces of the human sphere, such as population dynamics, residential mobility or price elasticise of the real estate market, can be included as scenario assumptions in some of the models in order to define the magnitude of urban sprawl (e.g., CA_2, CA_4). Nevertheless, the decision about which cells change their land use in which way is based upon historical land use change patterns. In contrast, landscape properties like topography, hydrography or morphology are reflected in most of the cellular models (CA_1; CA_3 – CA_5; Table 2). Using a different approach, agent-based models include individual and institutional actors to explicitly simulate processes of land use conversion. The main actors in these models are individuals or households, which choose their residential location according to their preferences, local industries and businesses which choose their location and employ local people, and institutions, which steer land use development by planning, permitting or restricting land use change, et cetera. Therefore, these models explicitly name the decision-making processes relevant for urban land use changes (ABM_1 – ABM_5). System dynamics models lie between these two "extremes": They include the processes, but in an aggregate way without incorporating single actors and their individual goals (Table 2).

In the following, the processes captured in the simulation models are analysed with respect to the feedbacks mentioned in Section 2.

4.1 Spidergrams

For comparison purposes, we set up an assessment matrix, in which the degree of fulfilment of the four relationships (cf. again Figure 1) is assigned to each of the models under review. We used a metric scale from 0 to 2: If the criterion is fulfilled, then the "mark" 2 is given; if only parts of the criterion are fulfilled – e.g., the processes implemented by rudimentary or very simple – the "mark" 1 is given; and if the criterion is not at all fulfilled or not included in the model, the "mark" 0 is given. The results of the model assessment are given in forms of simple multicriteria spidergrams which compare the three types of models (SE, SD, CA and ABM; Figure 2) for all criteria and, in a second range of graphs, all models for each single criterion (Figure 3).

4.2 Relationships between human sphere and land use

Most of the models under review represent the impact of human sphere on land use. Table 1 provides an overview of the model components. Except for three model approaches, each model covers population dynamics and housing or built-up land, which belong to the major variables either for human sphere or land use. The spidergram in Figure 2 clearly shows that causal relationships between human drivers are better captured than the reverse feedback from urban land development to the human drivers. Agent-based approaches mainly cover both loops, since land use variables belong to the neighbourhood of the agents and thus directly influence decision making. In comparison, spatial economics and system dynamics models comprehensively cover loops of type 1 "human sphere to land use," but mostly neglect effects of changing urban land use on population dynamics or economic development. Cellular automata do include some feedbacks from the effects of land use changes on the human sphere.

4.3 Impact of land use on environment

Only very few simulation models close the loop between driving forces and environmental impacts. Cellular automata perform better in capturing the effects of relatively simple rule-based or neighbourhood-statistic driven land use changes on the environment. Since they are often spatially explicit, landscapes can be more easily represented (cf. again Figure 2). For example, in CA_3, the impact of urbanisation on biodiversity is assessed, but no feedback to driving forces is taken into account. In SD_7, the impact of transport on the environment is integrated, but it is not

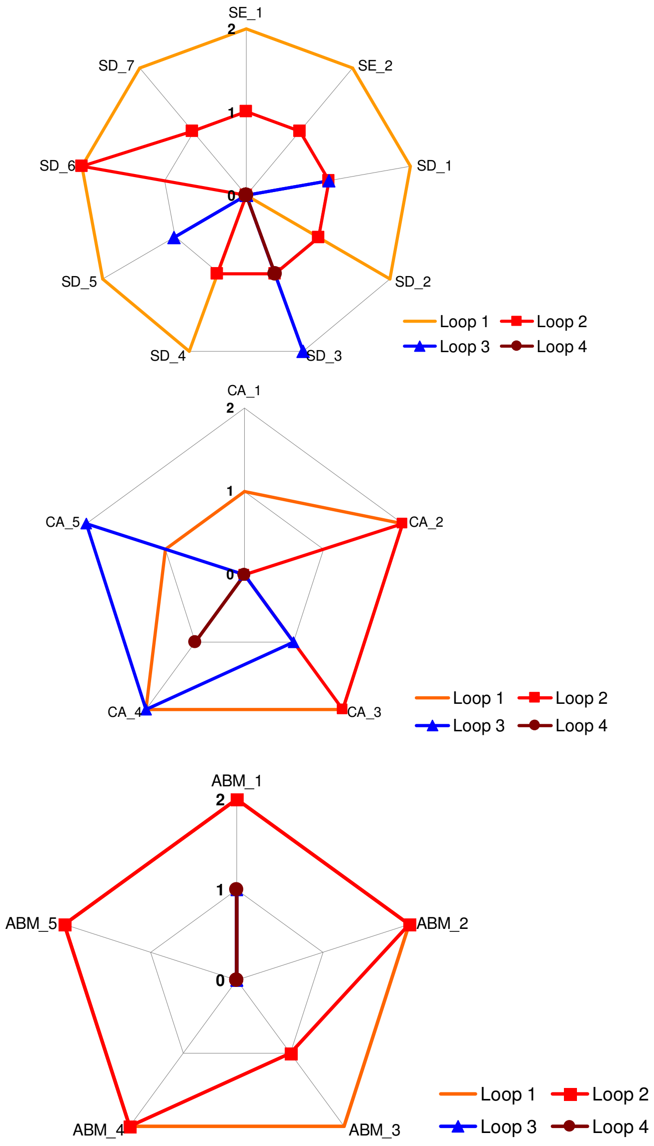

Figure 2: Spidergrams showing how far the reviewed models (according to their model type) incorporate the four relationships set up for model evaluation.

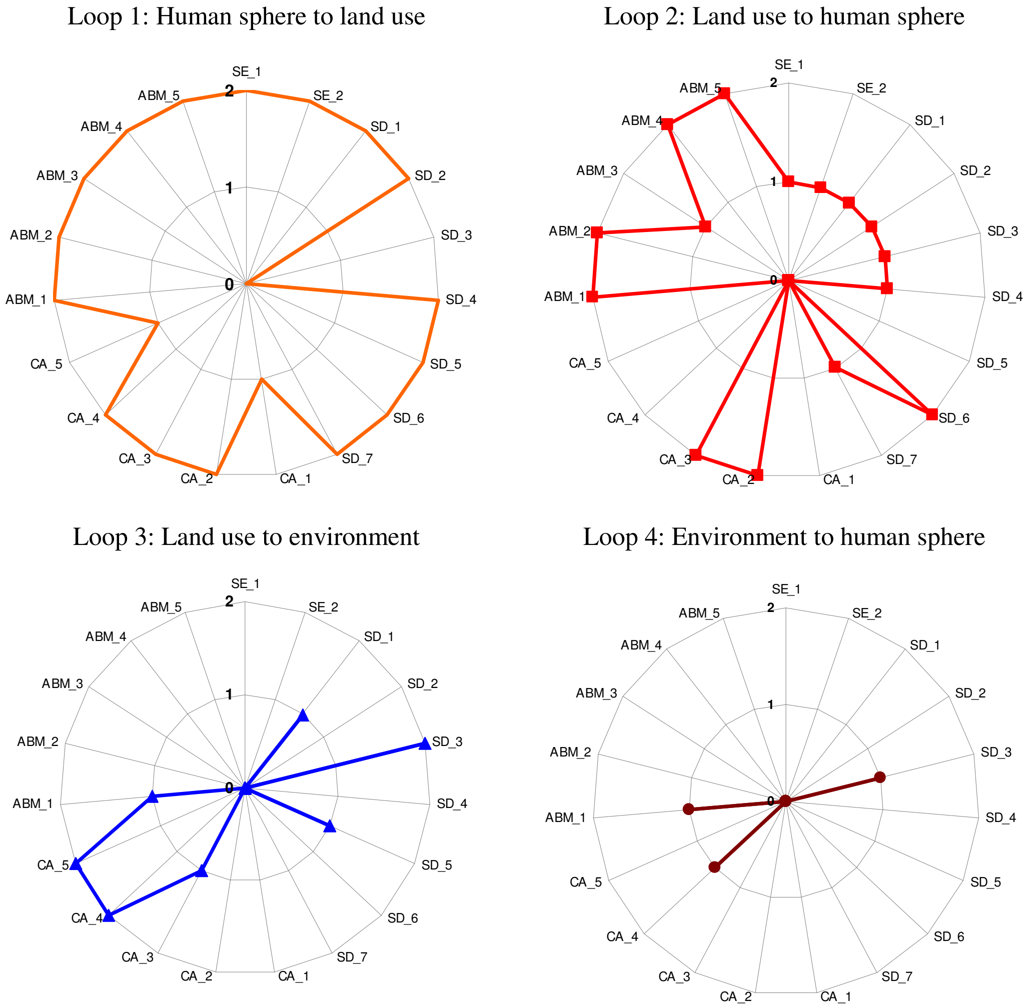

Figure 3: Spidergrams showing to which extent all reviewed models include the four loops.

clear from the available literature if there is a feedback to driving forces (travel and transportation flows). The two economics models under review (SE_1 and SE_2) lack spatial explicitness to be able to capture a more comprehensive land use relation or feedback.

4.4 Feedback from environment to human sphere

Feedbacks from environmental impacts back to the driving forces that cause urban land use change are mostly realised through changing attractiveness of grid cells or regions for household residential location choices. Those were found in ABM_4 (open space, forest area), ABM_1 (traffic noise, air quality), CA_4 (quality and availability of space for activities), and SD_5 (traffic volume produces air pollution and thus affects human quality of life). In SD_3, the decrease of wetland area (and its negative impact on biodiversity) directly influences decisions to buy land for nature protection instead of further urbanisation. These relationships are the only ones that close the loop from households/individuals as drivers of land use change to environmental impacts and back to the original decision algorithm.

4.5 Feedbacks between local and regional scale

Feedbacks between the local and regional scale can be realised in a variety of ways: first, migration of population within single districts can have an influence on the attractiveness of the districts and therefore influence the housing market in the region, which in turn affects migration. Second, planning and governance on the regional scale can influence local land use changes, which in turn can impact regional planning. In several of the models, the housing market (or price development) is captured implicitly or explicitly. For example, in the spatial economics models SE_1 and SE_2, as well as in the system dynamics models SD_2 and SD_4, the housing market and housing development are explicitly included: In the two former cases in the form of real case study examples (Amsterdam and the U.S.), while in SD_2 an artificial market is created between expansionists and conservationists who want to buy open land – either in order to turn it into urban area or to conserve it. In cellular automata, prices for housing are not explicitly included. Probabilities for land use change can be regarded as bids for (re-)development (CA_2). In some of the agent-based models, real estate markets are already included or are planned to be included (e.g., ABM_1, ABM_3, ABM_5). In these models, developers are agents who can influence the market and therefore also the prices. Governmental planning processes are never explicitly represented in a way that governmental agencies are actors within the model. In some models, planning decisions are integrated as a part of the scenario configuration, e.g., by restricting or promoting possible evolution paths for certain grid cells (e.g., MOLAND). In others, construction and demolition are exogeneous variables (Nijkamp *et al.*, 1993). But in these cases, planning decisions or housing market trends are not changed during the simulation, so that no feedbacks are established.

5 Conclusions

The main purpose of this review was to analyse causalities and feedback loops in current urban land use change models. Therefore, we analysed 19 simulation models stemming from four different simulation methodologies: spatial economics, system dynamics, cellular automata, and agent-based modelling. The main conclusion of this review is that there is a range of comprehensive urban land use change models but no unique approach to represent urban landscapes and human–nature interactions. Each author or working group has its own view and focuses on other parts of the urban system and the relationships within that system. Thus, the landscape aspect is of minor importance. Most of the approaches bear the potential to model local and regional urban processes, as they provide a multitude of components and variables. However, currently only a few models integrate direct or indirect feedback loops from environmental and landscape-related impacts of urban land use change on environment to the respective driving forces in the human sphere of the systems. We see the reason for this in the gap between social science methods and findings, and computational models (cf. Geist and Lambin, 2004, 2002). The former comprehensively cover behavioural heuristics on decision making but are often qualitative in nature. The latter need quantitative (sometimes spatially explicit) input data or at least simple rules to be coded and thus incorporated into the models. To bring both approaches together and to better incorporate qualitative, social science data into quantitative models is still one of the major challenges of urban land use and landscape modelling. This is a challenge, not only for modellers, since empirical data for formulating a resilient feedback loop, resulting from environmental impacts on human quality of life and decision making, is rarely available (Haase and Haase, 2008). As urban systems are open systems which do not depend on local or regional natural resources and ecosystem services, neither individual nor policy decisions strongly depend on the availability and state of nature of the surroundings (cf. Haase and Nuissl, 2007). This makes it more difficult to elicit and formalise resilient feedbacks from the environment or landscape back to the driver. Another challenge is to express urban land use relationships, and in particular the aforementioned decision making in a spatially explicit way, as most of the CA models under review do. Finally, relationships between the local and regional scale are realised only with respect to housing markets, as single choices on the local scale are able to influence regional markets and vice versa. None of the models deals with all possible linkages between "the built-up urban" and "the rural" landscape within an urban region, although CA models such as MOLAND cover both types of land use, at least in terms of land use types. Current "hotspots" of the worldwide agri-environmental discussion, such as biofuels and organic farming, should also be partially incorporated into urban models. Here, we see another way to introduce more landscape aspects into urban land use modelling.

6 Acknowledgements

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7 Annex

Within the following tables (describing the models in alphabetical order), empty cells indicate that no information was found in the literature on this issue. "–" in a cell means that this issue is not applicable to the model in question.

Field "Duration of model run:"

- C: Calibration to fit model parameters
- S: Scenarios for projections of future trends
- V: Validation using independent data

Table 3: Household life cycle model for residential relocation behaviour [SE_1]

Name of model	Household life cycle model for residential relocation behaviour			
Sources	Nijkamp *et al.* (1993)			
Technical data				
Application area	Covered area, physical boundaries	Case study: Greater Amsterdam Area	Extent of area	350 square miles / About 800,000 people
	Spatial units	20 zones	Size or grain of grids/zones	–
Time horizon	Time step	1 year	Duration of model run	1971 – 1984
Modelling approach	Simulation technique	Spatial economics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Modelling household life cycles and their impact on residential relocation behaviour and the urban housing market for a European capital city.			
Main variables with relationships	(1) households, (2) migration, (3) occupancy, (4) housing demand, (5) dwelling supply in zones and dwelling types, (6) allocation of households.			
	Domain	Not explicitly	Temporal range	–
Human decision making	Typology (classes) of agents?	Allocation of household	→ if yes: what types?	Households: single, 2-person household, 3-person household, 4+ person household, non-household
	Decision algorithm	Rational choice, maximum utility	Input into decision	Population and household data
Goals	Authors' opinion	Successful runs, validation and scenarios.		
Model development process	Concept	Given	Quantification of relationships	Empirical data

Table 4: Simulation of demographic changes and the housing market [SE_2]

Name of model	Simulation of demographic changes and the housing market			
Sources	Mankiw and Weil (1989)			
Technical data				
Application area	Covered area, physical boundaries	U.S. cities (census)	Extent of area	– / 203,190 people / 74,565 households
	Spatial units	U.S. cities (census)	Size or grain of grids/zones	–
Time horizon	Time step	1 year	Duration of model run	1970 – 2007 or 2020
Modelling approach	Simulation technique	Spatial economics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Simulation of demographic changes (baby boom and baby bust) and its influences on the housing market in the U.S.			
Main variables with relationships	(1) population, (2) households, (3) housing market (demand, prices), (4) economy (GNP)			
Human decision making	Domain	Not explicitly	Temporal range	–
	Typology (classes) of agents?	Allocation of household	→ if yes: what types?	Dummy household
	Decision algorithm	Rational choice, maximum utility	Input into decision	Census data
Goals	Authors' opinion	Successful runs, validation and scenarios.		
Model development process	Concept	Given	Quantification of relationships	Empirical data

Table 5: A System Dynamics Approach to Land Use / Transportation System Performance Modeling [SD_2]

Name of model	A System Dynamics Approach to Land Use / Transportation System Performance Modeling			
Sources	Haghani *et al.* (2003a,b)			
Technical data				
Application area	Covered area, physical boundaries	Varies with application area; Case study: Montgomery County	Extent of area	– / About 800,000 people
	Spatial units	U.S. cities (census)	Size or grain of grids/zones	–
Time horizon	Time step	1 year	Duration of model run	C: 1970 – 1980 V: 1980 – 1990
Modelling approach	Simulation technique	Spatial economics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Integrated land-use and transportation model for estimating scenarios regarding transport policies			
Main variables with relationships	Seven sub-models: (1) population, (2) migration, (3) household, (4) job growth, employment and commercial land development, (5) housing development, (6) travel demand and (7) congestion.			
	Domain	Not explicitly	Temporal range	–
Human decision making	Typology (classes) of agents?	Cohorts within population submodel	→ if yes: what types?	Persons: age 0–17, 18–44, 45–64, 65 male and female / Households: single, married with children, married without children, male or female with children, other
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	First step is achieved, successful validation and scenarios.		
Model development process	Concept	Not stated	Quantification of relationships	Empirical data

Table 6: CLUE-s (Conversion of Land Use and its Effects) [CA_1]

Name of model	CLUE-s (Conversion of Land Use and its Effects)			
Sources	Verburg and Overmars (2007)			
Technical data				
Application area	Covered area, physical boundaries	User-specified / Several examples published	Extent of area	User-specified
	Spatial units	CLUE: soft-classified data (large pixels with fraction of land-uses)	Size or grain of grids/zones	User-specified / CLUE: 7 to 32 km / CLUE-s: 20 to 1,000 m
Time horizon	Time step	Iterative process stops when demand for land-use meets allocated area	Duration of model run	–
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Tool for understanding land-use patterns, possible future scenarios for given demand			
Main variables with relationships	Input: Pre-defined change in demand for land by different sectors for whole simulation area → CLUE-s assigns new land-uses per grid Each cell: most preferred land use based on suitability of location and competitive advantage of different land use types (demand), check: is land use change allowed? If no: next most preferred land use is chosen			
Human decision making	Domain	Not explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Case-study specific		
Model development process	Concept	Not mentioned	Quantification of relationships	User-specified: empirical analysis, expert knowledge, spatial interactions, conversion elasticities

Table 7: CUF-2 (California Urban Futures) [CA_2]

Name of model	CUF 2 (California Urban Futures)			
Sources	Landis and Zhang (1998a,b)			
Technical data				
Application area	Covered area, physical boundaries	San Francisco Bay Area (California)	Extent of area	1.8 million ha
	Spatial units	Grid cells	Size or grain of grids/zones	100 × 100 m
Time horizon	Time step	Econometric: 10 years / Probabilities for land use change: once per simulation	Duration of model run	C: 1985 – 1995 / S: ?
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Simulating urban growth, scenarios for future development			
Main variables with relationships	Top-down approach: future trends of population, household, jobs → are assigned to grid cells Econometric models predict future population, households, employment (10 year intervals) LUC-model: estimates probabilities for land use change out of historical data, and simulation engine assigns probabilities to cells Probability of land use change (multinomial logit models) for a cell from i to j = f (initial site use, site characteristics, site accessibility, community characteristics, policy factors, relationships to neighbouring sites) → probabilities are interpreted as bids for (re-)development → population and jobs are assigned to cells by bids 7 urban land-use categories: undeveloped, single-family residential, multi-family residential, commercial, industrial, transportation, public			
Human decision making	Domain	Not explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Achieved		
Model development process	Concept	Not mentioned	Quantification of relationships	Calibration using maps of land use change

Table 8: CURBA (California Urban and Biodiversity Analysis)(CA_3]

Name of model	CURBA (California Urban and Biodiversity Analysis)			
Sources	Landis *et al.* (1998)			
Technical data				
Application area	Covered area, physical boundaries	San Francisco Bay Area (California)	Extent of area	See CUF-2
	Spatial units	Grid cells	Size or grain of grids/zones	100 × 100 m
Time horizon	Time step		Duration of model run	
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Development of policy scenarios of urban growth, impact on habitat change/biodiversity			
Main variables with relationships	Two components: (1) urban growth model and (2) policy simulation and evaluation model / Urban growth model is based upon CUF-2 Policy simulation and evaluation: several growth scenarios → impact on habitat change and habitat fragmentation			
Human decision making	Domain	No explicit decision making	Temporal range	-
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Achieved		
Model development process	Concept	See CUF-2	Quantification of relationships	See CUF-2

Table 9: ILUMASS (Integrated Land-Use Modelling and Transportation System Simulation) [ABM_1]

Name of model	ILUMASS (Integrated Land-Use Modelling and Transportation System Simulation)			
Sources	Strauch *et al.* (2003); Moeckel *et al.* (2006)			
Technical data				
Application area	Covered area, physical boundaries	Dortmund and its 25 surrounding municipalities	Extent of area	About 2,000 km^2 / 2.6 million people
	Spatial units	Statistical zones (total: 246) and grid cells	Size or grain of grids/zones	Grid cells: 100 × 100 m
Time horizon	Time step	One year	Duration of model run	S: 2000 – 2030
Modelling approach	Simulation technique	Coupled simulation system including agent-based simulations	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Dynamic simulation model with a focus on urban traffic flows, including activity behaviour, changes in land use, and effects on environment			
Main variables with relationships	Five modules (+ integration module): 1. changes in land use, 2. activity patterns and travel demand, 3. traffic flows, 4. goods transport, 5. environmental impacts of transportation and land use Land use → demand for spatial interaction (work, shopping trips, etc.) → traffic → environmental impacts Feedbacks: (a) transport → accessibility of locations → location decisions of households, firms, developers. (b) environmental factors → location decisions (e.g., clean air, traffic noise) Land use module: moving households, location of firms, investment of developers, new industrial area			
Human decision making	Domain	Various, e.g., transport, household location, daily activity plans	Temporal range	Depending upon domain (daily travel behaviour vs. moving)
	Typology (classes) of agents?	Yes	→ if yes: what types?	Not mentioned
	Decision algorithm	Various (Markov, Logit, Monte-Carlo)	Input into decision	Depending upon domain, feedbacks included
Goals	Authors' opinion	Time of report: work in progress, later papers all focus on single modules		
Model development process	Concept	Not mentioned	Quantification of relationships	Not mentioned

Table 10: ILUTE (Integrated Land Use, Transportation, Environment model) [ABM_2]

Name of model	ILUTE (Integrated Land Use, Transportation, Environment model)			
Sources	Salvini and Miller (2005); Miller *et al.* (2004)			
Technical data				
Application area	Covered area, physical boundaries	Tests for Toronto area	Extent of area	5 million people
	Spatial units	Two versions: grids and buildings	Size or grain of grids/zones	2 parallel approaches: Grid: 30 × 30 m / Buildings as objects
Time horizon	Time step	Varying with submodels	Duration of model run	V: 1986 – 2001 / S: 10 – 20 years into future
Modelling approach	Simulation technique	Agent-based simulation	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Evolution of an entire urban region with emphasis on transport			
Main variables with relationships	Land development → location choice → activity schedule → activity patterns → back to land development and all other variables in chain transportation network → automobile ownership → travel demand → network flows → back to transportation network and all other variables in chain influences			
Human decision making	Domain	Activity/travelling scheduling, route choice, real estate market, behaviour of economy, land development, household ownership	Temporal range	Depends upon domain. E.g.: typical travel day is computed once per simulation year per agent type.
	Typology (classes) of agents?	Yes	→ if yes: what types?	For households, individuals, firms
	Decision algorithm	Rule-based: reducing number of choices / logit model for selecting the "best" option	Input into decision	Not mentioned
Goals	Authors' opinion	Work in progress		
Model development process	Concept	Not mentioned	Quantification of relationships	Empirical data

Table 11: Modelling biodiversity and land use [SD_3]

<table>
<tr><td>Name of model</td><td colspan="4">Modelling biodiversity and land use</td></tr>
<tr><td>Sources</td><td colspan="4">Eppink et al. (2004)</td></tr>
<tr><td colspan="5">Technical data</td></tr>
<tr><td>Application area</td><td>Covered area, physical boundaries</td><td>No explicit representation of a specific area. Urban region with surrounding area including wetlands</td><td>Extent of area</td><td>–</td></tr>
<tr><td></td><td>Spatial units</td><td>No spatial resolution</td><td>Size or grain of grids/zones</td><td>–</td></tr>
<tr><td>Time horizon</td><td>Time step</td><td>1 year</td><td>Duration of model run</td><td>S: 100 years</td></tr>
<tr><td>Modelling approach</td><td>Simulation technique</td><td>System dynamics</td><td>Qualitative or quantitative</td><td>Qualitative</td></tr>
<tr><td colspan="5">Contents</td></tr>
<tr><td>Main purpose</td><td colspan="4">Assessing the impact of urban sprawl on wetland biodiversity and social welfare</td></tr>
<tr><td>Main variables with relationships</td><td colspan="4">Population growth within city → higher population density and more need for agricultural land → expansionists attempt to buy surrounding area → change of wetland area to urban area & more agriculture decrease wetland biodiversity → conservationists' valuation of remaining biodiversity increases → conservationists buy wetland area for nature protection</td></tr>
<tr><td></td><td>Domain</td><td>Human decision making is represented within system dynamics equations</td><td>Temporal range</td><td>1 year</td></tr>
<tr><td>Human decision making</td><td>Typology (classes) of agents?</td><td>Yes</td><td>→ if yes: what types?</td><td>Expansionists, conservationists (see above) and owners of land</td></tr>
<tr><td></td><td>Decision algorithm</td><td>Land is sold to the highest bidder</td><td>Input into decision</td><td>Prices offered by conservationists and expansionists.</td></tr>
<tr><td>Goals</td><td>Authors' opinion</td><td colspan="3">First step for improving relationship between economic development and biodiversity</td></tr>
<tr><td>Model development process</td><td>Concept</td><td>Not mentioned</td><td>Quantification of relationships</td><td>Not mentioned</td></tr>
</table>

Table 12: MOLAND [CA_4]

Name of model	MOLAND			
Sources	Engelen *et al.* (2007)			
Technical data				
Application area	Covered area, physical boundaries	Several examples across Europe and elsewhere	Extent of area	User-specified
	Spatial units	global: 1 zone / regional: zones, typically NUTS / local: grid cells	Size or grain of grids/zones	User-specified
Time horizon	Time step	annual	Duration of model run	C: last 40 – 50 years / S: user-specified, normally 30 years
	Simulation technique	Mainly rule-based cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	To monitor developments of urban areas and identify trends at the European level, focus is on growth scenarios			
Main variables with relationships	Growth of economy and population (global level) → growth in competing regions (regional level), sets boundaries for all cells in a region → rules for land use change at the grid level: physical suitability, institutional suitability (e.g., planning documents), accessibility (via transport network), dynamics at the local level (land use functions attracting or repelling each other) Feedback from grid level to regional level: spatial distribution leads to quality and availability of space for different activities, which influences comparative attractiveness of a region			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Achieved		
Model development process	Concept	Not mentioned	Quantification of relationships	Calibration with historical data

Table 13: PUMA (Predicting Urbanisation with Multi-Agents) [ABM_3]

Name of model	PUMA (Predicting Urbanisation with Multi-Agents)			
Sources	Ettema *et al.* (2007)			
Technical data				
Application area	Covered area, physical boundaries	North Dutch Ranstadt (including Amsterdam, Utrecht, Schiphol airport)	Extent of area	3.16 million inhabitants
	Spatial units	Grid cells (and travel zones)	Size or grain of grids/zones	500 × 500 m
Time horizon	Time step	1 year / later: up to daily	Duration of model run	S: 2000 to approx. 2050
Modelling approach	Simulation technique	Agent-based simulation	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Predicting urbanisation using behavioural agents			
Main variables with relationships	Demographic change → decisions of individuals → land use change / Not yet implemented: developers, authorities and firms/institutions (so far exogenous) [impact of household's decisions on land use not described]			
	Domain	1. demographic events (no decisions, just stochastic) 2. residential relocation 3. job changes	Temporal range	Annual [Daily decisions in future work]
Human decision making	Typology (classes) of agents?	Yes	→ if yes: what types?	Households: Number of adults and children; age of household head [dwellings are agents as well]
	Decision algorithm	Rational choice with utility maximisation	Input into decision	Residential relocation: characteristics of dwelling, commuting distance, socio-demographics / Job choice: salary, job type, distance to dwelling, personal preferences...
Goals	Authors' opinion	Promising approach, still work in progress		
Model development process	Concept	Empirical data	Quantification of relationships	Empirical data

Table 14: Rotterdam urban dynamics [SD_4]

Name of model	Rotterdam urban dynamics			
Sources	Sanders and Sanders (2004)			
Technical data				
Application area	Covered area, physical boundaries	Rotterdam	Extent of area	100,000 acres
	Spatial units	16 grid cells called "zones"	Size or grain of grids/zones	Squares with 3,125 miles each side
Time horizon	Time step		Duration of model run	S: 250 years
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Redefining the model of urban dynamics by Forrester (1969), including: 1. spatial dimension (16 squares) and 2. disaggregation: different types of housing, industry, and people in zones			
Main variables with relationships	Bi-directional causal loops between: population, housing availability, houses, land availability, business structures, and job availability (linked with population) / Two markets: labor market and housing market compete for land / (no transportation)			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Case of Rotterdam only as an example for generic results		
Model development process	Concept	Not mentioned	Quantification of relationships	Out of statistical data and expert knowledge

Table 15: SCOPE (South Coast Outlook and Participation Experience) [SD_5]

Name of model	SCOPE (South Coast Outlook and Participation Experience)			
Sources	Onsted (2002)			
Technical data				
Application area	Covered area, physical boundaries	South Coast of Santa Barbara County	Extent of area	137,000 acres / Approx. 200,000 inhabitants
	Spatial units	No spatial resolution	Size or grain of grids/zones	–
Time horizon	Time step		Duration of model run	V: 1960 – 2000 / S: 2000 – 2040
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Simulation model to provide scenarios for future land use in Santa Barbara, e.g., with restrictions to urban growth			
Main variables with relationships	Five sectors: housing, population, business, quality of life, land use			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Achieved, but should still become more differentiated.		
Model development process	Concept	Expert knowledge	Quantification of relationships	Assumptions and statistical data

Table 16: Simulation of polycentric urban growth dynamics through agents [ABM_4]

Name of model	Simulation of polycentric urban growth dynamics through agents			
Sources	Loibl *et al.* (2007)			
Technical data				
Application area	Covered area, physical boundaries	Austrian Rhine valley with medium-sized centres and rural villages	Extent of area	7,330 hectares built-up area / 260,000 inhabitants
	Spatial units	Grid cells	Size or grain of grids/zones	50 × 50 m cells
Time horizon	Time step	Simulation stops when certain household, population and workplace growth numbers are achieved	Duration of model run	V: 1990 – 2000 / S: user-specified
Modelling approach	Simulation technique	Agent-based simulation	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Development of built-up area in peri-urban region, driven by households and entrepreneurs; urban growth with different growth rates			
Main variables with relationships	Initialisation: increase of household and workplace numbers is defined 1. Municipality choice depending on regional attractiveness criteria (numbers of people, households and workplaces in the start of the year, average travel time to district centres and capital city, average share of attractive land-use classes in the municipality (open space, forest area) → household growth and workplace growth per municipality → transformation of absolute values into relative search frequencies → agents choose municipality via discrete choice 2. Local target area search: start with random cell, choosing most attractive cell 3. land use change (new built-up area, higher density) → influencing local attractiveness			
	Domain	Causing the construction of new built-up area or the densification of existing area, no moving as 'exchange' of dwellings	Temporal range	Long-term (moving / start-up of companies)
Human decision making	Typology (classes) of agents?	Yes	→ if yes: what types?	Four household types (1, 2, 3 or 4 persons) and two entrepreneurs (small and large)
	Decision algorithm	Discrete choice	Input into decision	Regional and local attractiveness
Goals	Authors' opinion	Achieved		
Model development process	Concept	Empirical data	Quantification of relationships	Empirical data

Table 17: SLEUTH (Slope, Landuse, Exclusion, Urban Extend, Transportation and Hillshade) [CA_5]

Name of model	SLEUTH (Slope, Landuse, Exclusion, Urban Extend, Transportation and Hillshade)			
Sources	Clarke *et al.* (1997); Silva and Clarke (2002); Dietzel and Clarke (2007)			
Technical data				
Application area	Covered area, physical boundaries	Numerous applications, mostly U.S.	Extent of area	User-specified
	Spatial units	Grid cells	Size or grain of grids/zones	Input for model: 8-bit GIF (100 × 100 m cells can be converted)
Time horizon	Time step	1 year	Duration of model run	C: at least 4 time steps / S: User-specified
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Modelling urban growth, scenarios for future development of an urban region			
Main variables with relationships	Two components (use depends on available data): (1) Urban growth: cells have one of two states: urban or non urban (2) Urban land use change with different land-use types Four types of growth behaviour: spontaneous, diffusive (with new growth centres), organic (into surroundings) and road-influenced Five main coefficients: diffusion, breed, spread, slope, and road coefficient (need to be calibrated for each case study) Self modification rules: e.g., concerning the kind of exponential or S-curve growth; denser road network → road gravity factor increases; land availability decreases → slope resistance factor is decreased (more hilly areas); spread factor increases over time			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Achieved		
Model development process	Concept	Not mentioned	Quantification of relationships	Calibration using historical maps

Table 18: Urban dynamics [SD_1]

Name of model	Urban dynamics			
Sources	Forrester (1969); Alfeld (1995)			
Technical data				
Application area	Covered area, physical boundaries	Either suburban or core area (Forrester 1969: 2) / Examples mentioned in Alfeld, 1995: Lowell, Boston, Concord, Marlborough, Palm Coast	Extent of area	User-specified
	Spatial units	No spatial resolution	Size or grain of grids/zones	–
Time horizon	Time step		Duration of model run	S: Up to 250 years
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Modelling urban system in general, explicitly including "urban decline." Examples: focus on a specific topic, e.g., rapid population growth, demolition, et cetera, and therefore need specific models.			
Main variables with relationships	Original model by Forrester: Three subsystems: business, housing, population			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Achieved		
Model development process	Concept	Expert knowledge	Quantification of relationships	Statistical data and own estimation

Table 19: Urban transformation process in the Haaglanden region [SD_6]

Name of model	Simulating the urban transformation process in the Haaglanden region in the Netherlands			
Sources	Eskinasi and Rouwette (2004)			
Technical data				
Application area	Covered area, physical boundaries	The Haaglanden region, including the Hague and surrounding suburbs	Extent of area	
	Spatial units	No spatial resolution	Size or grain of grids/zones	–
Time horizon	Time step		Duration of model run	S: 1998 – 2010
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Qualitative
Contents				
Main purpose	Assessing the impact of future policy interventions on the social housing market (specific: rate of building new dwellings)			
Main variables with relationships	Four stocks: 1 Commercial housing stock 2 Social housing stock 3 Waiting families 4 Supply of available social houses Processes involved: Migration, demolition, construction			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Model is useful for its goal		
	Validation	No (but impact of process on stakeholders is monitored)	Plausibility analysis	With stakeholders
Model development process	Concept	Participation of stakeholders, narrative approach	Quantification of relationships	Empirical data or expert guesses.

Table 20: Urban travel system [SD_7]

Name of model	A system dynamics model for the urban travel system			
Sources	Raux (2003)			
Technical data				
Application area	Covered area, physical boundaries	Hypothetical city	Extent of area	–
	Spatial units	No spatial resolution	Size or grain of grids/zones	–
Time horizon	Time step		Duration of model run	S: 20 years into the future
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	To simulate medium- and long-term effects of urban transport policies with reference to sustainable travel			
Main variables with relationships	Seven major blocks: urbanisation, internal travel demand (trips within system), car ownership, external travel demand (inflowing, outflowing and through traffic), transportation (comparing supply and demand) and evaluation (socioeconomic and environmental appraisals)			
Human decision making	Domain	No explicit decision making	Temporal range	–
	Typology (classes) of agents?	–	→ if yes: what types?	–
	Decision algorithm	–	Input into decision	–
Goals	Authors' opinion	Work in progress		
Model development process	Concept	Expert knowledge	Quantification of relationships	Expert knowledge and statistical values

Table 21: UrbanSim [ABM_5]

Name of model	UrbanSim			
Sources	Waddell (2006); Waddell *et al.* (2003)			
Technical data				
Application area	Covered area, physical boundaries	Several examples in the U.S., Europe and Asia	Extent of area	User-specified
	Spatial units	Initially: mixture of parcels and zones / later: grid	Size or grain of grids/zones	User-specified / Cell: 150 × 150 m regarded as default
Time horizon	Time step	1 year	Duration of model run	User-specified
Modelling approach	Simulation technique	Coupled simulation models including agent-based simulations	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Link between transportation and land use; impact of different planning strategies			
Main variables with relationships	Exogenous: (1) macroeconomics (population, employment) and (2) travel demand (travel conditions). Six models: 1 Accessibility (output: access to workplaces and shops for each cell) 2 Transition (output: number of new jobs and new households per year) 3 Mobility (output: number of moving (existing) jobs / households) 4 Location (output: location of new or moving jobs / households) 5 Real Estate Development (output: land use change) 6 Land price (output: land prices)			
Human decision making	Domain	Mobility and location	Temporal range	Depends on issues
	Typology (classes) of agents?	Initially households / firms, later persons / jobs	→ if yes: what types?	User-specified
	Decision algorithm	Multinomial logit model	Input into decision	Land-use itself, socio-demographics, dwellings
Goals	Authors' opinion	Achieved		
Model development process	Concept	Not mentioned	Quantification of relationships	Out of empirical data

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Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage

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Abstract. Simulation models on urban land-use change help in understanding urban systems and assist in urban planning. One of the challenges of simulating urban regions in Europe as well as in North America or Japan is urban shrinkage, where deindustrialisation, massive population losses, and ageing cause unforeseen (or unexpected) commercial and housing vacancies in cities. In order to set up a conceptual framework for model improvement to assist such challenges, we review recent urban land-use-change simulation models, using four different modelling approaches: system dynamics, linked transport – urban models, cellular automata, and agent-based modelling. The focus of the review is to assess the causalities and feedback mechanisms that were implemented in these models. The results show that simulation models are very heterogeneous in implemented mechanisms leading to urban land-use dynamics. No single model fulfils all of the criteria required to model urban shrinkage in a spatially explicit way. However, system-dynamic models that are documented in the literature can serve as a good starting point for spatially nonexplicit simulation, and one example was found for linked transport – urban models which encompasses aspects of urban shrinkage. The potential of cellular automata is unclear as spatially explicit data on vacancies to feed this class of models is usually not available. Agent-based models appear to be the most promising approach for spatially explicit modelling of urban shrinkage.

1 Introduction

Urban shrinkage is a phenomenon that has been associated with individual cities for centuries but recently it has been receiving more and more attention for entire urban regions in (central eastern and eastern) Europe (Rieniets, 2006). In industrialised countries in Western Europe, the US, and Japan, urban dynamics have been characterised, over recent decades, by sprawling cities more or less regulated by urban planning. Currently, suburbanisation and the associated conversion of open or arable land to urban areas is often accompanied by shrinking populations in inner cities in those countries due to deindustrialisation and out-migration. Shrinkage is understood in this paper to mean population decline (Oswalt and Rieniets, 2006) caused by predominantly deeconomisation processes. This trend of urban shrinkage is likely to increase in the future due to further economic and demographic decline leading to decreasing population numbers (Couch et al, 2005; Turok and Mykhnenko, 2007); indeed urban shrinkage in terms of population losses in city centres is a worldwide phenomenon (Lutz, 2001; Rieniets, 2006; see figure 1).

The impact of shrinkage on urban land use is not a total decline of the settlement area; it is more a perforation of the settlement area into used and abandoned (vacant) plots often accompanied by further (but in any case abating) suburbanisation (Nuissl and Rink, 2005). A variety of simulation models for urban land-use changes has been developed in order to assist urban planning [see reviews by Berling-Wolff and Wu (2004) and EPA (2000) for a historical overview; Axhausen, (2006), Beckmann (2006), Geurs and van Wee (2006), Hunt et al (2005), Iacano et al (2008), and Timmermans (2003) for urban land-use and transport models; Agarwal et al (2002), Matthews et al (2007), and Verburg et al (2004) for land-use change models in general]

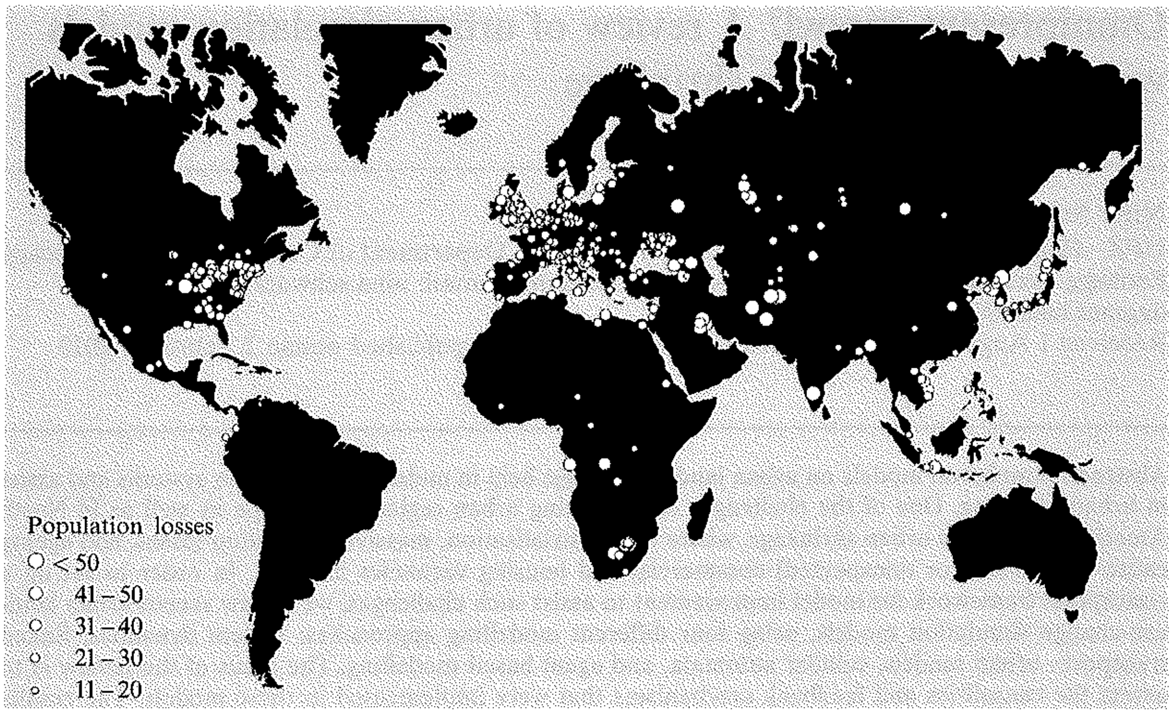

Figure 1. World map of shrinking cities with more than 100 000 inhabitants (source: Office Oswalt; Rieniets, 2006).

Urban land-use-change models range from specific case studies to generic tools for a variety of urban regions. These models differ largely in terms of their structure, their representation of both space and human decisions, and their methodological implementation.

The process or phenomenon of shrinkage poses new challenges for these simulation models because the models were developed mostly for growing cities in industrialised countries. The modelling of land-use change in shrinking urban regions requires not only a detailed implementation of population and economy as driving forces, but must also include deconstruction and further demolition and other forms of dealing with residential and commercial vacancies. Feedback on the demand for and supply of residential and commercial areas, related prices, and vacancies needs to be specified in order to simulate shrinking regions.

It is therefore worth assessing existing models of urban land-use change with respect to the processes included in these models. Hence, the main aim of this study is to review current simulation models of urban land-use change in order to answer the following questions: What are the main variables computed in these models? What causalities are implemented? Is the feedback from the environment and social system, the housing and real estate, included? The latter is actually less common in land-use-change modelling (Verburg, 2006), although it could prove to be essential in modelling shrinkage (with residential mobility probably being determined additionally by neighbourhood and environmental factors due to a surplus of available housing). Answers to these questions can give first indications as to whether existing simulation models are capable of projecting urban shrinkage. As shrinkage is a very complex phenomenon, we focus here exclusively on residential vacancies and their respective demolition or deconstruction, since this belongs to the most visible and land-use-related features.

The paper is organised as follows. Section 2 introduces the phenomenon of urban shrinkage. Section 3 postulates a set of evaluation criteria for conducting the model review that follows in section 4. Section 5 focuses primarily on causalities and feedback loops related to shrinkage before coming to conclusions in section 6.

2 Urban shrinkage as an urban phenomenon

In the course of history phases of urban shrinkage played as great a role in urban development as phases of growth (Rieniets, 2006), but with the collapse of the socialist system and the planned economies in Eastern Europe a new, incomparably fast, form of urban shrinkage emerged. Urban shrinkage in the transformation period since 1990 in particular results, first, from an economic decline in the form of deindustrialisation and deeconomisation in city regions and, second, from resulting population losses (Couch et al, 2005; Rieniets, 2006). In light of the basic knowledge of the correlations between land-development processes and the population (Hall, 1992; Kasanko et al, 2006; Ravetz, 2000), the following considerable spatiotemporal effects of shrinkage will gain even more significance in the near future:

- an increase in spatial separation between growing and shrinking areas next to each other in a city region;
- a small-scale perforation (spatial separation) of the urban population [fragmented housing geography (Buzar et al, 2007)];
- a considerable number of residential vacancies in parts of the urban fabric;
- large-scale urban brownfields in both inner-city and suburban areas;
- out-migration from larger cities and related land-abandonment processes in suburbia that might have been started recently;
- perforation (that is, patchwork settlement structures without a compact core) of urban landscapes in particular and a related creation of low-density counter settlements (with implications for lower ceiling rates, building, and population densities);
- deconstruction and large-scale demolition of parts of the urban housing stock in cities and possibly in suburbia (Haase et al, 2007); and
- modified, rather decreased, demand for technical, transport, and social infrastructure (the demand for schools will decrease compared with an increase in the demand for retirement homes and medical infrastructure).

On the one hand, the preferences of particularly young-family households for residential choice still lead to urban sprawl at the periphery. On the other hand, population losses and migration to the periphery cause housing space in the city core to become vacant. Housing space that is vacant over a long period of time is either demolished or simply decays, which in turn creates both a perforation of the urban fabric with more open or unused space or both, and also problems for infrastructure which relies upon built-up networks [such as for electricity, water supply, and wastewater disposal (see, for example Haase et al, 2007; Koziol, 2004; Westphal, 2007)]. Furthermore, high residential vacancies create an unsaturated housing market with falling prices in some segments, which—together with perforation because of demolition—is assumed to lead to a higher residential mobility of households. As recent observations in shrinking cities show (Fritsche et al, 2007), further residential vacancy is concentrated in single districts of the city core. In determining residential choices, households (not individuals) are the deciding entity that is relevant for analysing urban shrinkage.

It appears to be evident that shrinkage has serious implications for all dimensions of sustainability and quality of life in cities. In consequence, planners and policy makers search for new concepts to deal with it, which requires going into 'uncharted territory'. Shrinkage requires new action schemes such as restructuring, deconstruction, and 'demolition due to receipt' for cases involving extreme vacancies. However, even more sensitive measures such as the innovative reuse of abandoned land and brownfield redevelopment are discussed (Jessen, 2006; Wiechmann, 2003).

3 Evaluation criteria

To analyse the simulation models in terms of their capacity to model shrinkage, a set of evaluation criteria is proposed in this section. Simulating urban shrinkage means, at the very least, that model results will reflect the following pattern of urban development: within the same urban region, both growing and shrinking districts can be detected in close vicinity within the city, while at the periphery the city faces urban sprawl. In contrast to this, the city core of a growing region remains constant or even grows in terms of population numbers. See table 1.

A number of articles and book chapters elaborate on the 'ideal' integrated simulation model and the theoretically required feedback loops. Often, authors use frameworks such as the DPSIR-framework (drivers, pressures, state, impact, responses) from the European Environment Agency to conceptualise the model structure. According to Verburg (2006, page 1173), "the main drawback of using these analytical frameworks is the assumption of one-directional processes between driving factors and impacts" because, in reality, it is difficult to differentiate between impacts and drivers in a system. Bürgi et al (2004) distinguish between five major types of driving force: socioeconomic, political, technological, natural, and cultural. Furthermore, they differentiate between primary, secondary, and tertiary driving forces as well as between intrinsic and extrinsic driving forces. In contrast, Waddell and Ulfarsson (2004) sketched urban markets and agents, choices, and interactions in an 'ideal' urban model in their introduction to urban simulation (see figure 2).

Table 1. Schematic overview of population density in growing and shrinking urban regions.

	Growing urban region	Shrinking urban region
City core	Population density remains constant or even increases	Population density shows great variance characterised by a close vicinity of shrinking and growing districts within the same city
Periurban area	Population density decreases due to urban sprawl	Population density decreases due to urban sprawl

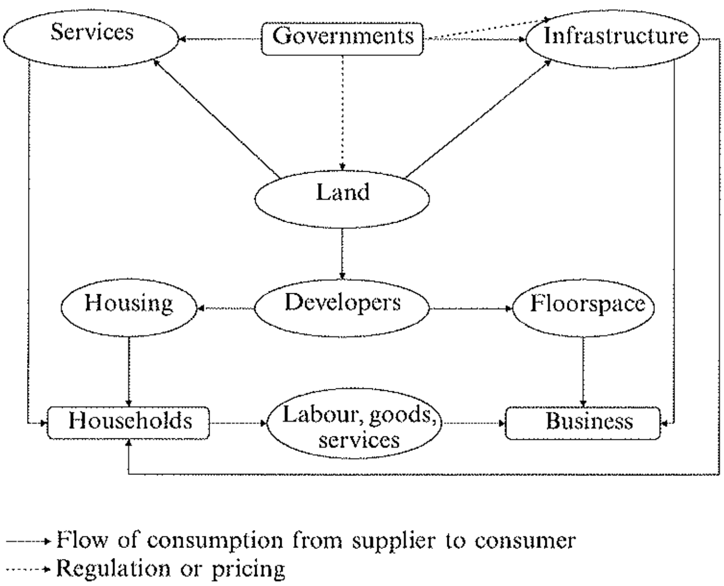

Figure 2. Linked urban markets and agents (after Waddell and Ulfarsson, 2004).

Building on this 'ideal' model, a preliminary causality model for urban shrinkage was designed (see figure 3). This model integrates the basic relationships described in section 2 and is the basis for the following evaluation criteria.

Models need to include residential vacancy as an output variable in order to simulate urban shrinkage (criterion 1). Further, models have to include deconstruction and the demolition of vacant residential fabric (criterion 2). Models should take regard of housing markets which can react to a high number of vacancies by lowering their prices (criterion 3). Models are required to incorporate explicit household location choices which react to prices, perforation, and social neighbourhoods (criterion 4).

Fulfilling these four criteria is a necessary condition for replicating the central process of urban shrinkage. Furthermore, the following criteria are desirable for capturing the dynamics in a more comprehensive way including providing feedbacks.

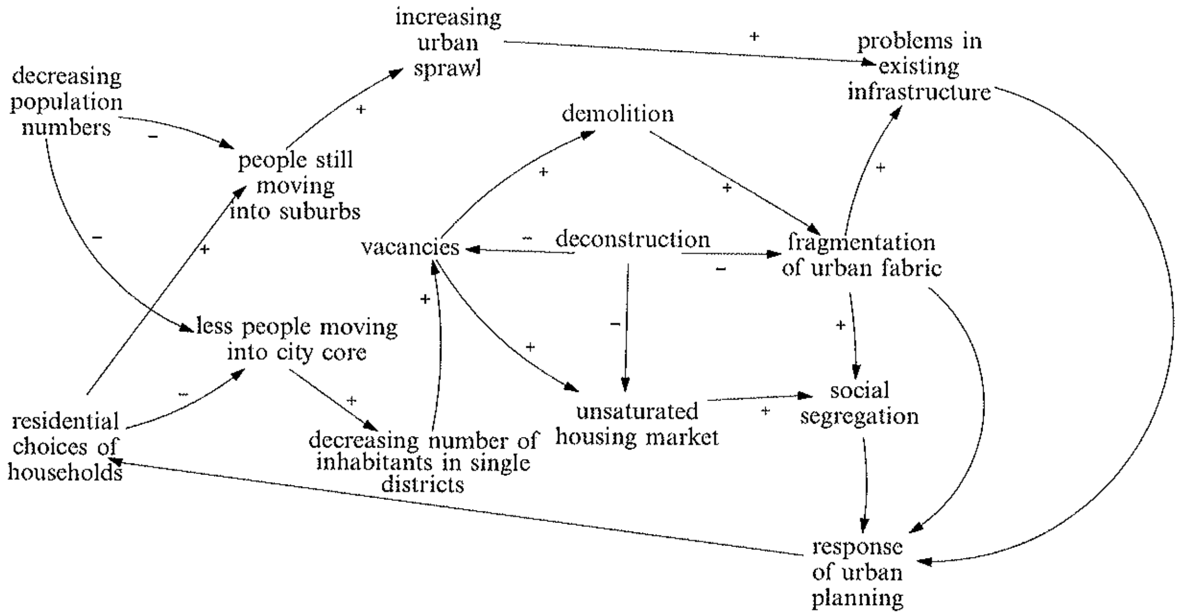

Figure 3. Drivers and feedback loops in shrinking urban regions. The figure follows a system-dynamic approach in depicting positive (+) and negative (−) causal loops between variables. The focus is on population numbers and residential choices, the impacts of industrial decline and commercial activities are included indirectly (see below). Decreasing population numbers due to out-migration and/or lower fertility and changing residential choices both lead to a shift of inhabitants from the city core to the suburbs. Movements to the suburbs increase urban sprawl through the development of new residential settlements on the fringe. Population loss in the core decreases the total number of inhabitants in single districts, which in turn increases vacancies. Vacancy leads to an unsaturated housing market and—if high vacancy rates occur over a longer period of time—to the demolition of surplus housing. Demolition increases the fragmentation of the urban fabric, which together with an unsaturated housing market can foster social segregation. Deconstruction involves, for instance, reducing the levels of a building from a multistorey to one or two storeys. Increasing urban sprawl on the one hand and fragmentation of the central urban fabric on the other hand lead to problems with existing infrastructure, such as the underutilisation of the water supply, sewage, electricity, or transport networks, while an expansion of these infrastructure networks on the fringe might be necessary. Urban planning is influenced by a variety of factors, including problems with infrastructure, social segregation, and the fragmentation of the urban fabric. The response of urban planning can in turn influence residential choices, for instance, by creating green urban areas on former brownfields (increasing the quality of life) or by enforcing zoning so that new residential development is kept to certain areas and therefore choices are restricted. The impacts of decreasing industrial activity and therefore the loss of jobs and inhabitants are captured indirectly through the decreasing number of the population. Residential settlements following commercial areas on the fringe are part of residential choice and therefore are also included indirectly.

Models should reflect reactions of network-dependent infrastructure on the perforation of the urban fabric (criterion 5): infrastructure related to water, sewage, or electricity is usually optimised in a given area for a certain demand structure, which depends on population density and commercial or industrial activity. Urban shrinkage can decrease efficiency and cause problems related to underutilisation. Planners can respond to these problems, for instance, by trying to concentrate demolition in certain areas. Therefore, models should include the reactions of urban planning to infrastructure-related problems (criterion 6). Incorporating planning decisions into the model itself allows for the inclusion of dynamic planning-decision rules instead of static planning policies. This enables a prompt response to new land-use patterns or states produced by the model in the form of 'playing' or 'running through' different decision options using the model, which is not the same as what is possible using static maps.

Perforation of the urban fabric can lead to changing housing prices, faster social segregation, and an increasing attractiveness of areas due to the conversion of brownfields into urban green spaces. Thus models should cover the reaction of household residential choices to perforation of the urban fabric (criterion 7).

4 Models reviewed

The models included in this review were selected in order to represent the most influential streams of urban land-use-change modelling. First, the review includes models that are well known within the planning community. Therefore, models that are discussed in the related literature on urban land-use change, for example, through reference in other reviews, are included. Second, system-dynamic approaches that were not discussed at great length in the literature were included because system dynamics as a method forces modellers to think in a systematic way and enables feedback mechanisms to be implemented easily. To find system-dynamic models on urban land-use change, a search was performed on the ISI Web of Science.(1) This procedure led to a total of twenty-one models which have been included in this review. These models are listed in table 2, which also gives further information on technical aspects such as temporal and spatial scope.

4.1 Modelling approaches

Roughly, four different modelling approaches can be distinguished. Seven models that have been included in this review [SD_1 to SD_7, see Forrester (1969), Haghani et al (2003a; 2003b), Eppink et al (2004), Sanders and Sanders (2004), Onsted (2002), Eskinasi and Rouwette (2004), Raux (2003)] are system-dynamic models (table 2). System dynamics is an approach to modelling complex systems through the use of stocks and flows and by explicitly including feedback loops in the model (Sterman, 2000). System-dynamic models are—in their standard application—not spatially explicit; rather, the structure that emerges from a combination of stocks, flows, and feedback mechanisms leads to a set of differential equations. The outcome of these equations can be simulated, when given values for parameters and initial conditions. The classical approach to modelling urban systems using system dynamics is Forrester's (1969) book on urban dynamics. He linked the three subsystems—business, housing, and population—to describe and model urban systems in general, with each of the three subsystems being subsequently differentiated in very detailed submodels.

Four models in this review [TU_1 to TU_4, see Martinez (1992) and Martinez and Henriquez (2007), Wegener (1982), Abraham and Hunt (1999) and Echenique et al (1990); Johnston and de la Barra (2002)] are models that integrate urban land use

(1) http://thomsonreuters.com/products_services/science/science_products/scholarly_research_analysis/research_disovery/web_of_science

and transportation (table 2). In these models, the interaction between location and transportation choices is simulated using aggregate formulae for the overall behaviour of the system. These relationships usually represent interactions between aggregate, or 'mean', individuals in markets such as labour or housing. These models assume that, in an urban region, location choices are based upon preferences which include the costs of transportation.

Five models included in this review [CA_1 to CA_5, see Verburg and Overmars (2007), Landis and Zhang (1998a; 1998b), Landis et al (no year), Engelen et al (2007), Dietzel and Clarke (2007)] use cellular automata (CAs) as the main modelling technique (table 2). A CA consists of an n-dimensional grid of cells. Each cell has a finite number of states. Cells change their state simultaneously according to the same rules, and the state of a cell in time t depends solely on the state of its neighbouring cells in time $t-1$ (Clarke et al, 1997; Landis and Zhang, 1998a; 1998b; Silva and Clarke, 2002). Land-use-change models use CAs with 2-dimensional grids. Each cell symbolises a patch of land, and the states of the cells are the land-use options.

Five models in this review [ABM_1 to ABM_5, see Strauch et al (2003), Salvini and Miller (2005), Ettema et al (2007), Loibl et al (2007), Waddell et al (2003)] use agent-based modelling as the main modelling technique (table 2). Agent-based models (ABMs) consist of autonomous individuals (agents) who perceive their environment and interact with each other (Parker et al, 2003). Applications of agent-based modelling in land-use change are usually spatially explicit, and agents represent, for example, households that are relocating their homes or individuals using transport systems.

4.2 Applications

Most of the simulation models are applied to cities in the US or Europe (table 2). Only three were applied to areas in Asia, Africa, Australia, or South America: MUSSA (TU_1), CLUE-s (CA_1), and SLEUTH (CA_5). For example, CLUE-s was applied to the Selangor River Basin close to Kuala Lumpur, Malaysia (see *The Clue Group: Study Areas*[(2)]), and SLEUTH was applied for example, to Alexandria, Egypt, Mexico City and Tijuana, Mexico, and Gorgon, Iran (see *SLEUTH's Online Data Repository*[(3)]). MUSSA on the other hand was developed for Santiago de Chile.[(4)]

The main purposes of the models under review (as described by the modellers) are summarised in table 3. We did not find any models that focus explicitly on urban shrinkage. The system-dynamic approaches SD_1 and SD_4 include processes of so-called 'urban decline' in their models of urban dynamics, and in the model on the availability of social housing (SD_6), demolition is also explicitly included. In TU_2, the removal of houses and infrastructure can be included in the submodel for public programmes. However, most of the models focus explicitly, or implicitly, on urban sprawl or urban growth (SD_5, CA_1, CA_2, CA_4, CA_5, ABM_3, and ABM_4), while SD_3 and CA_3 analyse the impact of sprawl on biodiversity. In these models, processes of reconstruction or demolition can hardly be found; the paradigm of modelling urban dynamics is based upon an ever increasing population or the demand for urban land or both. This is also valid for models which integrate land use and transportation (SD_2, SD_7, TU_1, TU_3, TU_4, ABM_1, ABM_2, ABM_5).

(2) http://www.cluemodel.n6/stuarea.html

(3) http://www.ncgia.ucsb.edu/project/gig/v2/About/abAppg.htm

(4) http://www.mussa.cl/E_index.html

Table 2. Overview of technical aspects of reviewed models.

Model	Temporal scope		Spatial scope		Source
	duration	time step	extent	resolution	
System dynamics (SD)					
SD_1 urban dynamics	S: up to 250 years		Examples mentioned in Alfield (1995): Lowell, Boston, Concord, Marlborough, MA; Palm Coast, FL	–	Forrester (1969); Alfield (1995)
SD_2	C: 1970–80 V: 1980–90		Case study: Montgomery County, MD	–	Haghani et al (2003a; 2003b)
SD_3	S: 100 years	1 year	No explicit representation of a specific area. Urban region with surrounding area including wetlands	–	Eppink et al (2004)
SD_4	S: 250 years		Rotterdam (Netherlands)	Squares with sides 3125 miles	Sanders and Sanders (2004)
SD_5 SCOPE	V: 1960–2000 S: 2000–40		South Coast of Santa Barbara County, CA	–	Onsted (2002)
SD_6	S: 1998–2010		Haaglanden region (Netherlands)	–	Eskinasi and Rouwette (2004)
SD_7	S: 20 years		Hypothetical city	–	Raux (2003)
Transport – urban models (TU)					
TU_1 MUSSA		Computation for specific time periods, no time steps	Santiago de Chile	Zones	Martinez (1992); Martinez and Henriquez (2007)
TU_2 IRPUD		Time periods of 1 or more years	Dortmund (Germany)	Zones	Wegener (1982)
TU_3 MEPLAN	C: specific year, user-specified S: user-specified	Computation for specific time periods, no time steps	User-specified Several examples worldwide	Zones	Abraham and Hunt (1999); Echenique et al (1990)
TU_4	C: user-specified S: user-specified	Typically 5 years	User-specified Several examples worldwide	Zones	Johnston and de la Barra (2000)

Cellular automata (CA)					
CA_1 CLUE-s	Iterative process stops when demand for land use meet allocated areas		User-specified Several examples worldwide	User- specified CLUE: 7 to 32 km CLUE-s: 20 to 1000 m	Verburg and Overmars (2007)
CA_2 CUF-2	C: 1985–95 S: ?	Econometric: 10 years Probabilities for land-use change: once per simulation	San Francisco Bay Area, CA	100 m × 100 m	Landis and Zhang (1998a; 1998b)
CA_3 CURBA			San Francisco Bay Area, CA	100 m × 100 m	Landis et al (no year)
CA_4 MOLAND	C: last 40–50 years S: user-specified, normally 30 years	1 year	Several examples across Europe	User-specified	Engelen et al (2007)
CA_5 SLEUTH	C: at least 4 time steps S: User-specified	1 year	Worldwide applications, most in US	Input for model: 8 bit GIF (100 m × 100 m cells can be converted	Silva and Clarke (2002); Dietzel and Clarke (2007)
Agent-based model (ABM)					
ABM_1 ILUMASS	S: 2000–30	1 year	Dortmund and its 25 surrounding municipalities (Germany)	Grid cells 100 m × 100 m	Strauch et al (2003); Moeckel et al (2006)
ABM_2 ILUTE	V: 1986–2001 S: 10–20 years	Varying with sub-models	Tests for Toronto area (Canada)	2 parallel approaches: grid: 30 m × 30 m buildings as objects	Salvini and Miller (2005); Miller et al (2004)
ABM_3 PUMA	S: 2000 to approximately 2050	1 year Later versions: up to daily	North Dutch Ranstadt (including Amsterdam, Utrecht, Schiphol airport) (Netherlands)	500 m × 500 m cells	Ettema et al (2007)
ABM_4	V: 1990–2000 S: user-specified	Simulation stops when certain household, population and workplace growth numbers are achieved	Austrian Rhine valley (Austria)	50 m × 50 m cells	Loibl et al (2007)
ABM_5 UrbanSim	User-specified	1 year	Several examples in the US and Europe	User-specified cell: 150 m × 150 m regarded as default	Waddell (2006); Waddell et al (2003)

Note: C = calibration to fit model parameters; S = scenarios for projections of future trends; V = validation using independent data. Empty cells indicate that no information was found in the literature on this issue; – in a cell means that this issue is not applicable to the model in question. Where authors stated that the spatial resolution of their model is to be specified by the researcher, the phrase 'user-specified' is used in the table. Otherwise the spatial resolution and time steps as described in the respective publication are stated. Regardless of these specifications, it might be possible to specify other time steps or spatial resolutions in a given model.

5 Causalities and feedback related to shrinkage

The main variables and functional relationships in the models under review are summarised in table 3. Structural relationships between variables are found to be very varied in these models. This is due to the fact that the levels of rules for land use vary considerably, depending on the modelling technique used. CAs derive probabilities of land-use change for a certain cell from historical land-use data and therefore do not deal explicitly with causal relationships. Driving forces such as economic development or population dynamics can be included as scenario assumptions in some of the models in order to define the magnitude of urban sprawl (for example, CA_2, CA_4). Nevertheless, the decision about which cells change their land use is on the basis of historical land-use-change patterns. Conversely, ABMs include individual and institutional actors to explicitly simulate processes of land conversion. The main actors are households or individuals choosing their residential location, and local industries and businesses choosing their location and employing local people. Therefore, these models explicitly name the processes relevant for urban land-use changes. System-dynamic models and transport-related models lie between these two extremes: they include the processes, but in an aggregate manner without incorporating single actors and their goals.

5.1 Test of criteria

In the following, the processes captured in the simulation models are tested to see whether or not they match the evaluation criteria postulated in section 2.

5.1.1 *Criteria 1 and 2: residential vacancy, deconstruction, and demolition*

Almost all models reviewed implicitly or explicitly focus on urban growth. Population as well as urban area is supposed to increase in these models, and infrastructure simply follows settlement areas. Only the two system-dynamic approaches, urban dynamics by Forrester (1969) (SD_1/S_4) and the Rotterdam social housing market simulation (SD_6) plus the IRPUD model (TU_1), explicitly include processes of decline and the demolition of houses.

5.1.2 *Criterion 3: housing market*

In several of the models, the housing market or the development of prices is captured implicitly or explicitly. For example, in the system-dynamic models SD_2 and SD_4, housing development is explicitly included, while in SD_2 an artificial market is created between expansionists and conservationists who want to buy open land—either to turn it into urban area or to conserve it. All the transport–urban models include real-estate markets as this is the very basis of the approach (TU_1 to TU_4). In CAs, prices for housing are not included explicitly. Probabilities for land-use change can be regarded as bids for development or redevelopment (CA_2). In some of the ABMs real-estate markets are either already included or planned to be included (for example, ABM_1, ABM_3, ABM_5). In these models, developers are agents who can influence both the market and, consequently, the prices.

5.1.3 *Criterion 4: household location choices*

Explicit residential choices could not be found in the system-dynamics models. In the transport–urban models, aggregated location choices are included in the functions of the housing or real-estate markets or both. Within the CAs one could interpret the variables in multinomial logit function for the attractiveness of cells or regions as residents' preferences (for example, CA_2, CA_4). Explicit household location choices are part of the ABMs described here: households or individuals represented by agents choose either a region or a specific cell according to the respective attractiveness.

5.1.4 *Criterion 5: infrastructure in the perforated urban fabric*
The development of infrastructure is seldom addressed within the simulation models reviewed here. Usually transport-related infrastructure is regarded in the simulation models (for example, in TU_1 to TU_4, SD_2, SD_7, ABM_1, ABM_2). Models compute congestion, the share of transport supply and demand, or traffic flows within a given network. The only exception is TU_1, where infrastructure related to social services, health, and education is also included.

5.1.5 *Criterion 6: response of urban planning*
Governmental planning processes are never explicitly represented in a manner that incorporates governmental agencies as actors within the model. In some models, planning decisions are integrated as a part of the scenario configuration, for example, by restricting possible evolution paths for certain grid cells or the removal or location of infrastructure (TU_1).

5.1.6 *Criterion 7: response of households' residential choice*
None of the simulation models explicitly captures the reactions of households' residential choices on shrinkage. However, there are feedback loops included in some of the models which are worth mentioning because they close the gap between (1) driving forces and environmental impact and (2) environmental impact and household location choice. (1) In CA_3 the impact of urban sprawl on biodiversity is assessed but feedback regarding driving forces is not taken into account. In SD_7 the impact of transport on the environment is integrated, but it is not clear from the available literature whether there is feedback from driving forces. (2) Feedback from the environmental impact of driving forces on urban land-use change are mostly realised through a changing attractiveness of grid cells, or regions, for household location choices: ABM_4 (open space, forest area), ABM_1 (traffic noise, air quality), CA_4 (quality and availability of space for activities), and SD_5 (traffic volume affecting quality of life). In SD_3 the decrease in wetland area (and its negative impact on biodiversity) directly influences decisions to buy an area for nature protection instead of further urban sprawl. These relationships are the only ones closing the loop from households or individuals as drivers of land-use change to impact and back to the decision algorithm.

5.2 Potentials and challenges for modelling urban shrinkage
Modelling urban shrinkage remains a challenge for current simulation models, as most of the models presently focus on urban growth and sprawl. In order to include processes of urban shrinkage in such models, nothing less than a shift in paradigms from ever-growing urban regions to stagnation or even shrinkage is necessary. This assertion is valid not only for the field of urban simulation but also for urban research in general; it is only when processes of urban shrinkage are analysed and quantified empirically that simulation models can be built.

In more detail, several challenges need to be addressed when modelling urban shrinkage:
(1) Incorporating residential vacancies and demolition or deconstruction into non-spatial simulation models is rather easy compared with spatially explicit models for which the question needs to be tackled as to where vacancies or demolition will take place. In order to simulate which areas in a city will stagnate, or even decline, one needs to obtain information on the attractiveness of such areas and any future investments that are planned there and, if applicable, random events that might encourage people to move there.

Table 3. Overview of main purposes and processes investigated in the reviewed models.

Model	Main purpose	Main variables and functional relationships
System dynamics (SD)		
SD_1 urban dynamics	Modelling urban system in general, explicitly including urban decline. Examples focus on a specific topic, for example, rapid population growth, demolition et cetera and therefore require specific models.	Original model by Forrester (1969): three subsystems: business, housing, population.
SD_2	Integrated land-use and transportation model for estimating scenarios regarding transport policies.	Seven sub-models: (1) population, (2) migration, (3) household, (4) job growth, employment and commercial land development, (5) housing development, (6) travel demand, (7) congestion.
SD_3	Assessing the impact of urban sprawl on wetland biodiversity and social welfare.	Population growth within city → higher population density and greater demand for agricultural land → expansionists attempt to buy surrounding area → wetland area changes to urban area and more agriculture decreasing wetland biodiversity → conservationists' valuation of remaining biodiversity increases → conservationists buy wetland area for nature protection.
SD_4	Redefining Forrester's (1969) model of urban dynamics, including: (1) spatial dimension (16 squares) and (2) disaggregation: different types of housing, industry, and people in zones.	Bidirectional causal loops between: population, housing availability, houses, land availability, business structures, and job availability (linked with population). Two markets: labour market and housing market compete for land (no transport).
SD_5 SCOPE	Simulation model to provide scenarios for future land use in Santa Barbara, for example, with restrictions on urban growth.	Five sectors: housing, population, business, quality of life, land use.
SD_6	Assessing the impact of future policy interventions on the social housing market (specific: rate of building new dwellings).	Four stocks: (1) commercial housing stock, (2) social housing stock, (3) waiting families, (4) supply of available social houses, Processes involved: migration, demolition, construction.
SD_7	To simulate medium-term and long-term effects of urban transport policies with reference to sustainable travel.	Seven major blocks: urbanisation, internal travel demand (trips within system), car ownership, external travel demand (in-flowing, out-flowing and through traffic), transportation (comparing supply and demand), and evaluation (socioeconomic and environmental appraisals).

Transport – urban models (TU)		
TU_1 MUSSA	To represent the urban real-estate market and its implications for transport.	Consumers' behaviour within the market, developers, transport system, governmental regulations. Interaction with another transport model is possible.
TU_2 IRPUD	To simulate intraregional location and mobility choices in an urban region.	Submodels: transport, ageing, public programmes, private construction, labour market, housing market. Interaction on five markets: labour, commercial buildings, housing, construction and real estate, transport.
TU_3 MEPLAN	To simulate spatial economies for cities or regions with a focus on interactions between land-use changes and transport.	Two markets interact: land and transport with land prices and transport prices, respectively. Determined by land or floor space plus activity location, mediating variable between markets: accessibility.
TU_4 TRANUS	To evaluate regional transportation and land-use policies using a market-based urban model.	Economic demand → employment in zones of the region → residents follow work. Travel follows from land uses (flows of goods, workers, shoppers) → prices for transportation → rearrangement of employment ... until the equilibrium is reached for both the land and travel market.
Cellular automata (CA)		
CA_1 CLUE-s	Tool for understanding land-use patterns; possible future scenarios for given demand.	Input: predefined change in demand for land by different sectors for whole simulation area → CLUE-s assigns new land uses per grid. Each cell: most preferred land use based on suitability of location and competitive advantage of different land-use types (demand). Check: is land-use change allowed? If no: next most preferred land use is chosen.
CA_2 CUF-2	Simulating urban growth; scenarios for future development.	Top-down approach: future trends of population, households, jobs are assigned to grid cells. Econometric models predict future population, households, employment (at 10-year intervals). LUC-model: estimates probabilities for land-use change from historical data, and simulation engine assigns probabilities to cells. Probability of land-use change (multinomial logit models) for a cell from i to $j = f$ (initial site use, site characteristics, site accessibility, community characteristics, policy factors, relationships to neighbouring sites) → probabilities are interpreted as bids for (re)development → population and jobs are assigned to cells by bids. Seven urban land-use categories: undeveloped, single-family residential, multifamily residential, commercial, industrial, transportation, public.

Table 3 (continued).

Model	Main purpose	Main variables and functional relationships
Cellular automata (CA) (continued)		
CA_3 CURBA (California Urban and Biodiversity Analysis)	Development of policy scenarios of urban growth; impact on habitat change and biodiversity.	Two components: (1) urban growth model and (2) policy simulation and evaluation model. Urban growth model is based upon CUF-2. Policy simulation and evaluation: several growth scenarios → impact on habitat change and habitat fragmentation.
CA_4 MOLAND	To monitor developments of urban areas and identify trends at the European scale; focus is on growth scenarios.	Growth of economy and population (global level) → growth in competing regions (regional level), sets boundaries for all cells in a region → rules for land-use change at the grid level: physical suitability, institutional suitability (for example, planning documents), accessibility (via transport network), dynamics at the local level (land-use functions attracting or repelling each other). Feedback from grid level to regional level: spatial distribution leads to quality and availability of space for different activities, which influences the attractiveness of a region when compared with others.
CA_5 SLEUTH	Modelling urban growth; scenarios for future development of an urban region.	Two components (use depends on available data): (1) urban growth: cells have one of two states: urban or nonurban, (2) urban land-use change with different land-use types. Four types of growth behaviour: spontaneous, diffusive (with new growth centres), organic (into surroundings), and road-influenced. Five main coefficients: diffusion, breed, spread, slope, and road coefficient (need to be calibrated for each case study). Self-modification rules: for example, concerning the kind of exponential of S-curve growth; denser road network → road gravity factor increases; land availability decreases → slope resistance factor is decreased (more hilly areas); spread factor increases over time.

Agent-based model (ABM)		
ABM_1 ILUMASS	Dynamic simulation model with a focus on urban traffic flows, including activity behaviour, changes in land use, and effects on the environment.	Five modules (+ integration module): (1) changes in land use, (2) activity patterns and travel demand, (3) traffic flows, (4) goods transport, (5) environmental impacts of transport and land use. Land use → demand for spatial interaction (work, shopping trips) → traffic → environmental impacts. Feedback: (a) transport → accessibility of locations → location decisions of households, firms, developers; (b) environmental factors → location decision (for example, clean air, traffic noise). Land-use module: moving households, location of firms, investment from developers, new industrial area.
ABM_2 ILUTE	Evolution of an entire urban region with emphasis on transport.	Land development → location choice → activity schedule → activity patterns → back to land development and all other variables in the chain. Transportation network → automobile ownership → travel demand → network flows → back to transportation network and all other variables in the chain. Influences.
ABM_3 PUMA	Predicting urbanisation with behavioural agents.	Demographic change → decisions of individuals → land-use change. Not yet implemented: developers, authorities and firms or institutions (so far exogenous). (Impact of household's decision on land use not described.)
ABM_4	Development of built-up area in periurban region, driven by households and entrepreneurs; urban growth with different growth rates.	Initialisation: increase of household and workplace numbers is defined as: (1) municipality choice depending on regional attractiveness criteria (numbers of people, households, and workplaces in the starting year, average travel time to district centres and capital city, average share of attractive land-use classes in the municipality (open space, forest areas) → households growth and workplace growth per municipality → transformation of absolute values into relative search frequencies → agents choose municipality via discrete choice, (2) local target-area search: start with random cell, choosing most attractive cell, (3) land-use change (new built-up area, higher density) → influencing local attractiveness.
ABM_5 UrbanSim	Link between transport and land use; impact of different planning strategies.	Exogenous: (1) macroeconomics (population, employment) and (2) travel demand (travel conditions). Six models: (1) accessibility (output: access to workplaces and shops for each cell), (2) transition (output: number of new jobs and new households per year), (3) mobility [output: number of moving (existing) jobs or households], (4) location (output: location of new or moving jobs–households), (5) real-estate development (output: land-use change), (6) land price (output: land prices).

(2) Simulating urban shrinkage is a challenge, especially for CA models. Detecting residential vacancies using statistical data, official municipal registration sources, or space or air-borne remote-sensing data is very difficult (see Banzhaf et al, 2007); therefore the data basis for calibrating CA models in shrinking regions needs to be reassessed.

Despite these challenges, current simulation models show a lot of potential for dealing with urban shrinkage. For a start, a few models already incorporate processes of urban shrinkage. Thus, a certain understanding of the processes is already available. In order to model urban shrinkage in a spatially nonexplicit way, existing system-dynamic models can be a good starting point.

To model urban shrinkage in a spatially explicit way, the ABM approach seems very promising. Modelling urban shrinkage requires the incorporation of decision-making processes of households, planners, investors, and the owners of buildings and land since the behaviour and decision making of these actors will change land use. ABMs are—at least theoretically—able to integrate the decisions of various agents and therefore social science knowledge. Accordingly, present ABM approaches could be modified and enlarged to incorporate these decisions and, therefore, to arrive at a basic representation of urban shrinkage.

6 Conclusions

The main purpose of this review was to ascertain the potential and the challenges of future simulation efforts and the applicability of these simulation models to phenomena such as urban shrinkage based on existing model approaches for urban land-use change. Therefore, we analysed twenty-one simulation models originating from four different simulation methodologies: system dynamics, integrated transport – urban models, CAs, and ABMs.

The main conclusion of this review is that there is no unique approach to modelling cities. Every author or working group has their own view and focuses on different parts of, and relationships within, the system. We further conclude that only a few models deal with aspects of urban shrinkage, namely, vacancies and demolition measures. Only a few models integrate environmental factors to determine the attractiveness of cells or regions, which, without a doubt, could be very important for shrinking cities because housing is affordable there. Furthermore, the review shows that:

- feedback loops from the impact of land-use change on the environment to driving forces of land-use change are seldom integrated into simulation models;
- the representation of human decision making focuses mainly on households or individuals (residential location) and local businesses and industries; planning processes are not explicit parts of the models; and
- infrastructure-related problems are not dealt with in these models.

Moreover, a lack of data necessary for calibrating and validating simulation models was identified, especially with respect to decisions made by households rather than individuals. However, system-dynamic models documented in the literature can serve as a good starting point for spatially nonexplicit simulations. For spatially explicit simulations, an ABM approach to planning or steering urban land-use-change processes initiated through shrinkage will be very valuable. This is the only approach which enables researchers to explicitly include household-location choice, housing-market development, and urban planning. These explicit decision rules can circumvent the lack of spatially explicit data on residential vacancy which would be needed for CA models. Instead of calibrating the model for historical data on vacancies, explicit decision rules which determine where vacancies occur and where building stock should be demolished can be incorporated. Furthermore, the ABM approach has the potential to simulate innovative land-use projects as an emerging characteristic of urban communication and governance,

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MONITORING, MAPPING AND MODELLING URBAN DECLINE: A MULTI-SCALE APPROACH FOR LEIPZIG, GERMANY

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ABSTRACT

Urban remote sensing research and approaches to modelling residential mobility focus predominantly on growth patterns. In this paper, the phenomenon of extreme urban decline, named ‘shrinkage’, is scrutinised. The different characteristics of urban decline are illuminated using a multi-scale approach. Selected patterns of the spatial growth and shrinkage are first calculated by means of satellite imagery for the City of Leipzig, Germany. Here, Landsat data for 1994 and 2005 provide information regarding different phases of urban land use dynamics, thereby revealing a pattern of spatial expansion into the peri-urban surroundings. In addition, potential drivers of this detected pattern are investigated through analysis of municipal statistical data, at the local district level, providing evidence that urban growth in general and particularly shrinkage are results of population fluxes and migration. Because urban shrinkage can be found in both the central and peripheral parts of Leipzig City, an even more detailed scale, using a very high resolution (VHR) colour-infrared data set has then been integrated with the local district data, in order to achieve detailed information on intra-urban differentiation of both urban structure and fabric. Finally, using predictor variables such as fertility, life expectancy, migration and residential preferences, a prototype model approach is presented that analyses recent patterns of residential use and the related building vacancies that characterise the housing sector of a shrinking city.

Keywords: Urban remote sensing, urban decline, shrinking city.

INTRODUCTION

The scientific background of urban shrinkage and demographic change in former industrial regions

Tremendously high dynamics of urban change can be observed in the recent development of many Northern American and European cities: here, growth and decline processes occur simultaneously. On the one hand, in this particular case suburbanisation along with an expansion of residential and commercial areas occurs at the urban fringe. On the other hand, it simultaneously interacts with a declining population and a stagnating economy: a consequence of de-industrialisation. In the last 50 years, about 370 cities with more than 100,000 inhabitants have undergone temporary or permanent population losses of more than 10%. In extreme cases, the rate of loss reached peaks of up to 90% (Âbâdân, Iran) (1).

As a particular case, compact cities in Europe are faced with this diverging style development: in their inner parts we find a declining population (density) and, consequently an enormous increase of residential and commercial vacancy. This process stands in a fierce contrast to the continuous land at the periphery that is being built-up. As a result, such ‘shrinking cities’ are sprawling at their fringe and thus represent an urban form that is far from being sustainable. On the contrary, an uncontrolled perforation of the inner urban space can be observed in many recently declining cities (2). Accordingly, neither the paradigm of growth-driven development nor the related well-established planning instruments work here. However, if seen as a kind of ‘counter development’ this decline might be a chance to minimise the amount of future land consumption while restructuring the inner parts of a shrinking city by redeveloping areas of residential vacancy as well as increasing the settlement density and by reusing and recycling urban brownfields. Thus, new and attractive urban spaces could be created (3).

Today, the number of depopulating and shrinking cities is increasing. Moreover, this is expected to be a lasting phenomenon. Between 1950 and 2000, for example, the number of shrinking cities increased by 330 %, whereas, among cities with more than 100,000 residents, there are only 240% more as compared with 1950 (1). Thus, we find that, despite growth being held high on the political agenda, the number of shrinking cities has actually increased faster than the number of boomtowns.

Most cities declining during the last 50 years are located in western industrial countries, particularly in the US (59), the UK (27), Germany (26) and Italy (23) (4). Since 1990, shrinking cities have increasingly been found in the states of the former socialist Eastern Europe such as in Russia (13), the Ukraine (22) and Kazakhstan (13). Between 1950 and 2000, there have also been an above-average number of shrinking cities in South Africa (17) and Japan (12). But ‘hot spots’ of this phenomenon have been in Europe and in the USA. Shrinkage will also emerge in the growing conurbations of the developing world. In 35 years, less than 10% of the world's population will live in Europe or in the USA and some of the southern countries will be facing a general decrease in population, too (1).

Research objectives

The processes and pattern of decline highlighted in the introduction need to be observed and explained in terms of their spatial fingerprint, particularly in built-up structures intended to support sustainable management decisions. A methodological challenge and thus the focus of this paper is to develop an integrated multi-scale monitoring, mapping and modelling system in which remotely sensed land use information and demographic data taken from the municipal statistics (e.g. local neighbourhood, statistical district, city level) explain spatially, correspond scientifically and coincide with the development of a predictive model for the further development of residential mobility and vacancy.

The potential of a combined urban monitoring and modelling approach is analysed. This is realised using (high resolution and VHR) remote sensing data to detect land use change, social statistics, in order to prove that population change and migration have a predictable impact. Finally, an agent-based spatially explicit model is used to figure out the effects of this demographic change for residential use and building vacancy. First, using remote sensing land use information and social science data predictor variables and properties for the agents (urban residents) are identified. Second, they are integrated into a rule-based model programmed in Java. Here, it will be discussed to what extent social science knowledge can be brought together with quantitatively based remote sensing methods, to feed such a model (5). The scales of work range from the total area of the city, to the intermediate unit of the urban local district, down to urban structure types and single buildings.

In terms of the results achieved, the location of the growing and shrinking parts of the city will be shown. Moreover, the analyses presented here give an indication as to why understanding urban shrinkage requires both updated observation instruments / methodologies as well as spatial data integration procedures for model development. The paper draws on empirical evidence from eastern Germany where dramatic shrinkage processes in terms of economic decline and depopulation have been occurring since 1990. As stated before, the model approach concentrates on residential vacancy and shrinkage processes and does not, so far, touch the economic shrinkage and brownfield development.

Case Study: Leipzig, eastern Germany

The City of Leipzig provides the empirical context for our investigation, since it is an illustrative example of a city with negative demographic figures and a decrease in population, accompanied by numerous features of an economic decline. The main processes and patterns of the “shrinking”

Leipzig can be summarised in a dramatic decrease in birth rates that took place after the German reunification in 1990, an extreme loss of residents due to missing labour opportunities and high unemployment rates, and a decline of the inner urban population density due to suburbanisation processes (6).

More than a century ago the city experienced a period of vibrant growth from the 1870s to the 1930s, making it the country's fourth city when it reached its population peak with more than 700,000 inhabitants. An artificial economic push was launched right after the German reunification in 1990 with enormous institutional subsidies intended to attract capital and investments into eastern Germany (7). Combined with high unemployment and out-migration these financial incentives led to substantial misinvestments and had negative spatial development consequences, namely fostering a widespread and unbalanced urban growth or sprawl. As a consequence of expired investment promotions further residential suburbanisation is today also about to decline.

- As a result, apartments and houses fall vacant. Residential vacancy is no longer restricted to uninhabitable and dilapidating housing stocks but also to completely renovated dwellings and building complexes. The supply outweighs the demand even if, at present, household numbers still continue to rise. Some residential districts exhibit vacancy rates higher than 30%, a few even exceed 50% (own investigation).
- This severely negative und unsustainable development of the housing sector has brought up the discussion of demolition of whole housing stocks. As a new strategy, a federal program of urban restructuring and demolition was launched (8). It operates in terms of a guideline to organise and finance both, to demolish overhang of (vacant) housing stock and the revaluation of the remaining residential areas. Furthermore, the analysis of this program represents a scientific challenge, requiring techniques suitable for examining urban monitoring and modelling procedures intended to support the implementation of such a policy.

METHODS

Urban monitoring using remotely-sensed data

Remote sensing plays a valuable role in mapping and characterising urban agglomerations: their growth and decline as well as environmental effects and impacts of urbanisation phenomena (9). In this case study remote sensing is applied on two levels to give insight into the development and the structure of the City. First, Landsat TM data were used to analyse the regional urban system, to give quantitative measures and their local distribution concerning the different land uses identified for Leipzig, and to register the major changes and dynamics of growth and shrinkage patterns. Second, ColorInfraRed (CIR) images were taken because such data facilitate improved discrimination between attributes in the dense and heterogeneous milieu of the old urban cores that are characteristic of European cities. This data set helps to disentangle the urban fabric in these rapidly changing urban spaces (10).

The urban milieu poses far greater problems than the non-urban systems, in that identical spectral reflectance values can correspond to very different land uses and their functions. Hence a direct relationship between the spectral response and land cover (e.g. vegetation, water) is not prominent in this environment (11,12;13). So beyond land cover classes, which can be directly observed, land use classes are defined using expert knowledge. Mappings of land use and its changes were taken from the Landsat satellite series. For 1994 Landsat TM imagery was available (21/07/1994) and for the year 2002 a Landsat ETM scene was used dated from 20/08/2002. For the City of Leipzig these two sets of satellite images were utilised to follow the spatial development over the period of 1994 to 2002 and to observe land use changes within a very dynamic time period of spatial expansion and continuous population loss, as described above. In order to map land use a Maximum-Likelihood classification was carried out for each image. So a quantitative measure was gained for the proportion and distribution of different land use / land cover classes for two time slots. The overall accuracy of this Maximum-Likelihood classification is about 85% for the year 1994 and approximately 82% for 2002 (14).

Table 1 shows the significances of the accuracy of the different land use classes for the two time slots. The major difference between the results achieved for the two acquisition dates is that in 1994 the climate conditions showed a hot and dry summer whereas in 2002 the images were taken only two weeks after a severe inundation of rain in east Germany. So the spectral response of the soil varied immensely. In particular, either parks and grassland or bare soil were wrongly assigned as farmland. The main goal, however, was to distinguish the built-up class from pervious land use and land cover classes, and to gain information on the amount and directions in which the city was growing and shrinking.

Table 1: Accuracy assessment in 1994 and 2002.

Land use	**User's Accuracy**		**Kappa coefficient**	
	1994	2002	1994	2002
Water	98.4	100.0	0.9347	1.0000
Urban Woodland	82.7	75.4	0.8139	0.7104
Parks/ Grassland	88.3	88.5	0.8585	0.8656
Farmland	73.7	69.6	0.6998	0.6796
Impervious Surface	84.1	78.6	0.8087	0.7284
Bare Soil	84.0	80.3	0.7963	0.8004
Overall accuracy	85.2	82.1	0.8186	0.7974

Figure 1 shows the spatial distribution of the most significant changed land uses and assigning *from* and *to* which land use class the changes occur. Change detection highlights suburbanisation processes with inherent growth patterns and the expansion of impervious surface for large and adjacent areas at this spatial scale. Spatially less remarkable land use variations in more central urban districts are characterised by a high building density. Some of these areas are 'shrinking' today. However, it is problematic to detect this using the change detection methodology on the city scale. This process underlies environmental and economic impacts that take place on a larger scale and which have been detected using CIR orthophotos. So, at the city scale, the most significant changes are portrayed in a kind of belt around the central part of the urban area where the city is growing in terms of residential, commercial and transportation land uses. The share of farmland and arable land is decreasing in favour of new impervious surface for urban land.

A range of different change detection procedures comprises multispectral change detection methods, as well as change detection through spatial / textural / numerical analysis (15;16). Some of them, such as the concepts and uses of fractal dimension and spatial autocorrelation indices can be applied to change detection using uninterpreted or unclassified images. In the context of this study the quantified land use portions were of interest for each time slot so each image was classified first and then the post-classification comparison was calculated. The uncertainties of this method are that the accuracy of the change class information depends on the accuracy of the registration of multi-date images as well as on the accuracy of the separate single-date classifications (17). To achieve success two rules are paramount: First, using identical classification procedures for both dates, and second, using the same information classes for both dates (18). The remote sensing monitoring on the overall city scale gives insight regarding growth rate and growth distribution. Then, a further in-depth study is carried out in the second part of the remote sensing research concentrating on the object-oriented CIR classification on a very large scale.

The classification and change detection results were then overlaid over the socio-demographic data (see section "Mapping demographic change and de-concentration" and Figures 3 and 4). The purpose was to determine if the changes in the built-up structure of Leipzig correlated with the social, demographic, or economic indicators. These indicators are mapped on the scale of local districts which correspond well to the derived classifications. This meant that the areas of high dynamics could be discerned. This analysis revealed that growth rates in suburban impervious surface and thus in new buildings and infrastructure go along with an increase in population figures in the very same local districts but that the high inner urban imperviousness and building structure the very same local districts but that the high inner urban imperviousness and building structure did not correlate with population figures and density any more (19).

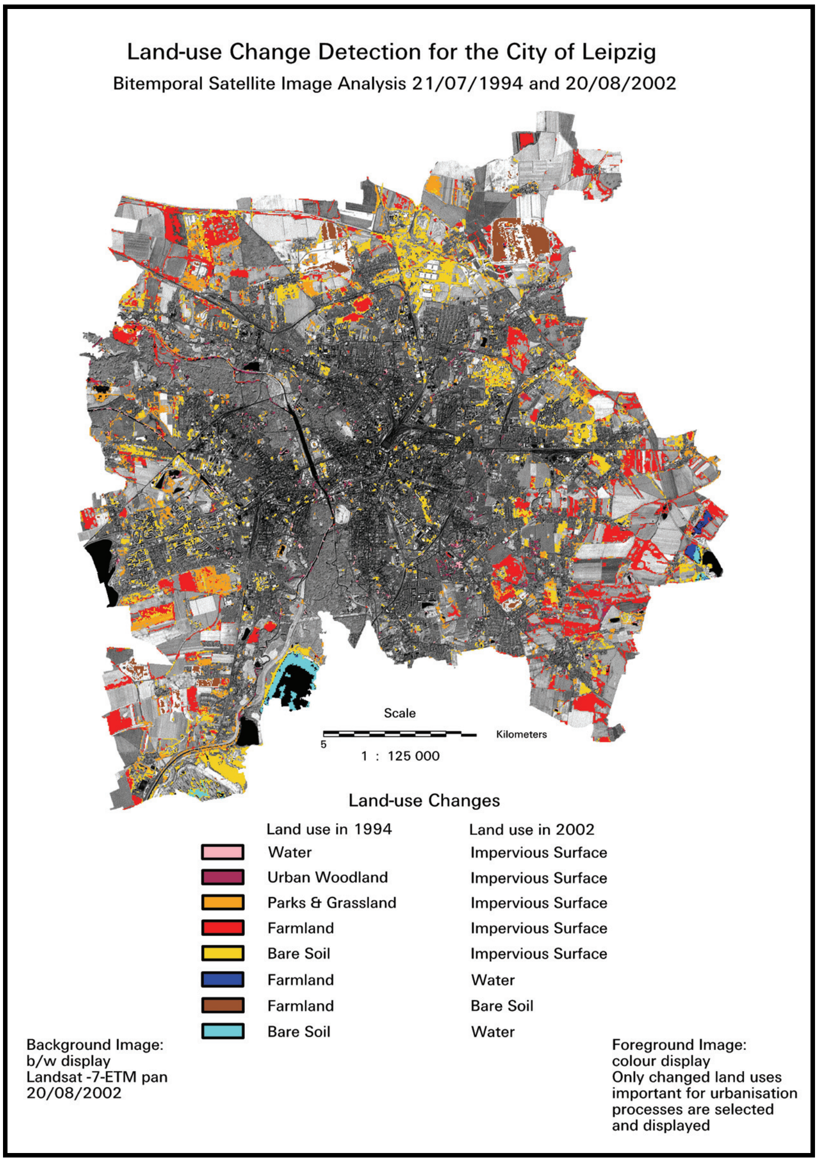


Figure 1: Change detection based on two classifications from Landsat data 21/07/1994 and 20/08/2002.

A more detailed RS data set is needed in order to monitor and analyse the land use information of the sample city, especially the information regarding the urban fabric, at the scale of each individual local district. Therefore, ColorInfraRed (CIR) imagery from the 29/07/2002 is used to calculate the different forms and structures of the built-up and natural land within the city by means of an object-based classification approach (20). The classification shows that single buildings can be extracted and that the type of the building can be assigned. The object identification procedure can also be applied for land cover types such as water bodies, natural vegetation and paved surfaces that do not belong to buildings because the imagery possesses a ground resolution of 40 cm. With variations between the different municipal districts classified, an overall accuracy rate of 82% was achieved. This classification represents the period in time before most of the demolition of vacant housing stocks started (2003/2004) (20).

This object-oriented classification was overlaid with digital ATKIS (Official Topographic-Cartographic Information System of Germany) data, updated in 2006, which served as a base for a ground-truth mapping undertaken in 2005, and was used to check the building inventory, and to quantify and localise the demolition sites for the period 2002 to 2005 (Figure 2 and Table 3).

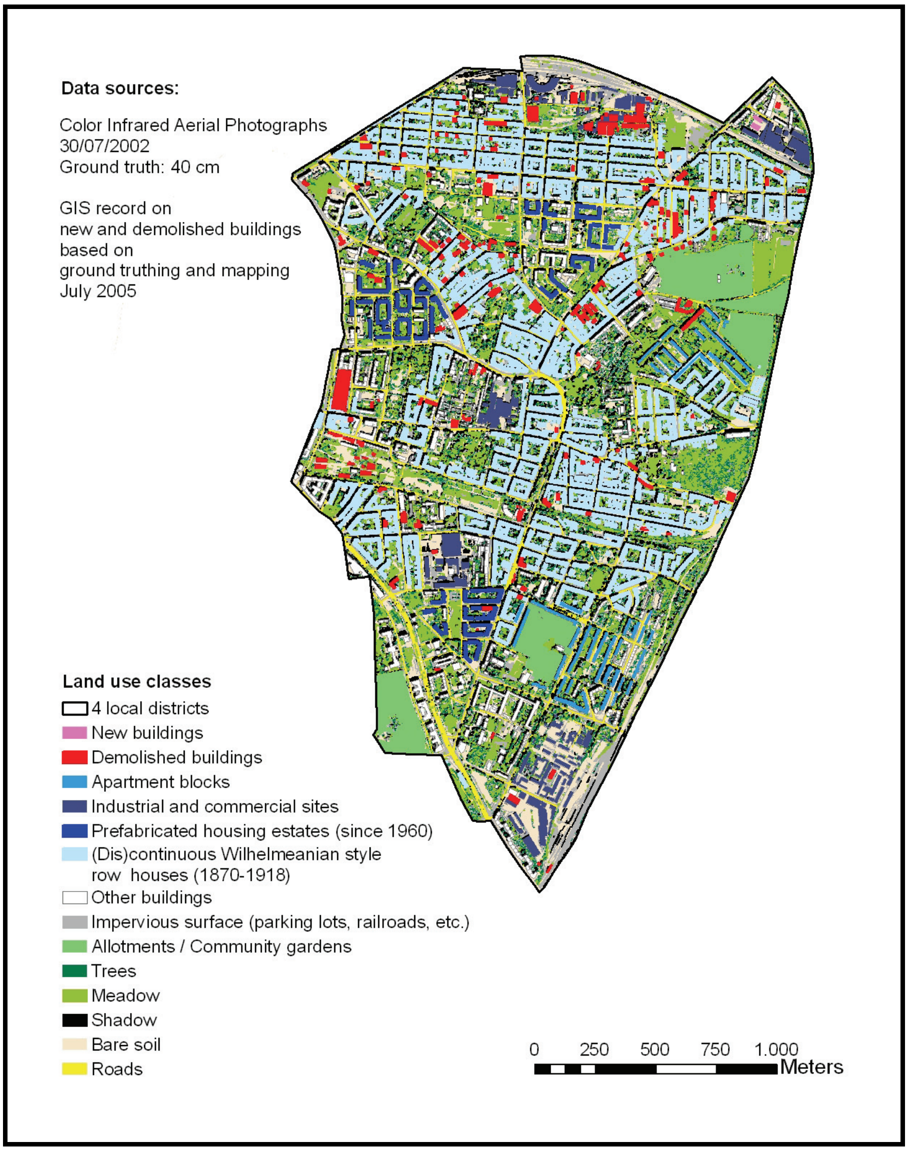


Figure 2: Classification of four local districts in the eastern part of Leipzig using digital CIR photos. Changes in the existence of buildings such as "demolished buildings" and "new buildings" are taken from GIS data sets

Regarding the challenges of urban planning and the goal of a compact urban body, the focus of the statistics is laid over the quantity and urban fabric of demolished houses. The total area of building cover is approximately 112 hectare and makes up about 20% of the total area of the four local districts. The area of impervious surface includes streets, parking lots and other paved facilities that do not belong to buildings. Together with open spaces this area covers the largest part of the test site at approximately 80 % of the total area. The largest proportion of demolished houses is taken by the Wilhelmeanian style row-to-row houses at more than 60% of these demolitions. This is due to the fact that in the eastern part of Leipzig ("east side"), which is the location of the test site, renovation of this type of building happened rather late in comparison with other parts of the city. Statistically, in the category of derelict land, this structure type is followed by industrial and commercial sites, which represent about 28% of all demolished buildings (Table 2) (20). It is hard to make these sites attractive for redevelopment because the city infrastructure now offers better access for commercial sites in suburbia than for those in the more central parts of the city. The overall result of about eight hectare of demolished houses is a high amount of rapidly created open spaces. However, hardly any demand on new buildings and new development of these open spaces has taken place. So there is now a plentiful supply of open spaces for redevelopment and a chance for a difficult area under demolition to change its face (21).

Table 2: Portion of built-up land use in 2002 (derived from CIR imagery)

Land use in 2002	ha	%
Total area of buildings	112.02	20.59
Total area of impervious surface and open spaces	432.25	79.41
Total area of 4 local districts	544.27	100.00

Table 3: Portion and type of demolished buildings between 2002 and 2005

Demolished buildings	ha	%	Portion of total area of buildings in %
(Dis)continuous Wilhelmeanian style row houses (1870-1918)	5.06	62.49	4.53
Prefabricated housing estates (since 1960)	0.06	0.71	0.05
Industrial and commercial sites	2.27	28.06	2.04
Apartment blocks	0.29	3.59	0.26
Other buildings	0.42	5.15	0.35
Total of demolished buildings	8.10	100.00	7.23

Mapping demographic change and de-concentration

When analysing and explaining the detected land use changes (as given in Figure 1) socio-demographic statistical data for the Municipality of Leipzig have been studied for 1994 and 2002. Assuming that, beside the economic variables, demography is the other main driver of urban, particularly urban residential, land use change, including changes in its spatial configuration, the demographic change between 1994 and 2002 were investigated. Based on the statistical data of the Office for Statistics and Elections of the City of Leipzig the population change between 1994 and 2002 was determined for two spatial levels: for the whole city and for each of the 63 local districts. With respect to the most important reasons for population decline, migration is one of the top-most drivers. So, migration, including its dynamics, was analysed for 1994 and 2002. Comparing both changes of population and the balance between in- and out-migration, it was possible to find out the spatial distinctions in the demographic development at the level of local districts and to study their interrelations.

Many eastern German cities have undergone a substantial land use change since 1990. This process corresponds strongly with an extreme demographic change. Based on the total population change and migration time series data provided by the Municipality of Leipzig, the overall demographic development is given in Figures 3 and 4. Having quantified the statistics and overlaid them with these spatial units it becomes obvious that the City of Leipzig is a shrinking city as the combined result of a drop in fertility and a massive out-migration since 1990 (statistically proved since 1994). The decline is accompanied by a smart growth at the urban fringe. This contrasts sharply with the total population figures: 521,539 inhabitants (with primary residence) lived in the 63 local districts in 1994, whereas in 2002 the total population of Leipzig decreased to 481,025 inhabitants. This is an overall decrease of 40,514 residents within less than ten years and corresponds to a population decline of 7.8%. The 37 inner-city districts belong to the most substantially declining districts due to a migration to the other more peripheral 26 local districts (see Figure 3). This reflects the spatial process of suburbanisation found in the change detection analysis of the satellite imagery. Until 1998, out-migration clearly exceeded in-migration.

In 1999, this trend stopped. What is more, since then, Leipzig has turned around to have a (slightly) positive migration balance. In addition to the overall migration balance an internal migration within the city, at district level occurs, and has increasing importance (22). This internal residential mobility is of great interest when explaining and modelling residential patterns and respectively, residential vacancy. Modelling these residential patterns means finding out why certain districts are preferred over others when rental costs are generally at a low level everywhere. As an overall observation suburbs today do not grow as much as in the mid 1990s. Extreme contrasts are observed in the central inner municipal districts, where residential vacancy and subsequent demolition of houses is taking place opposite vital districts undergoing considerable regeneration activity.

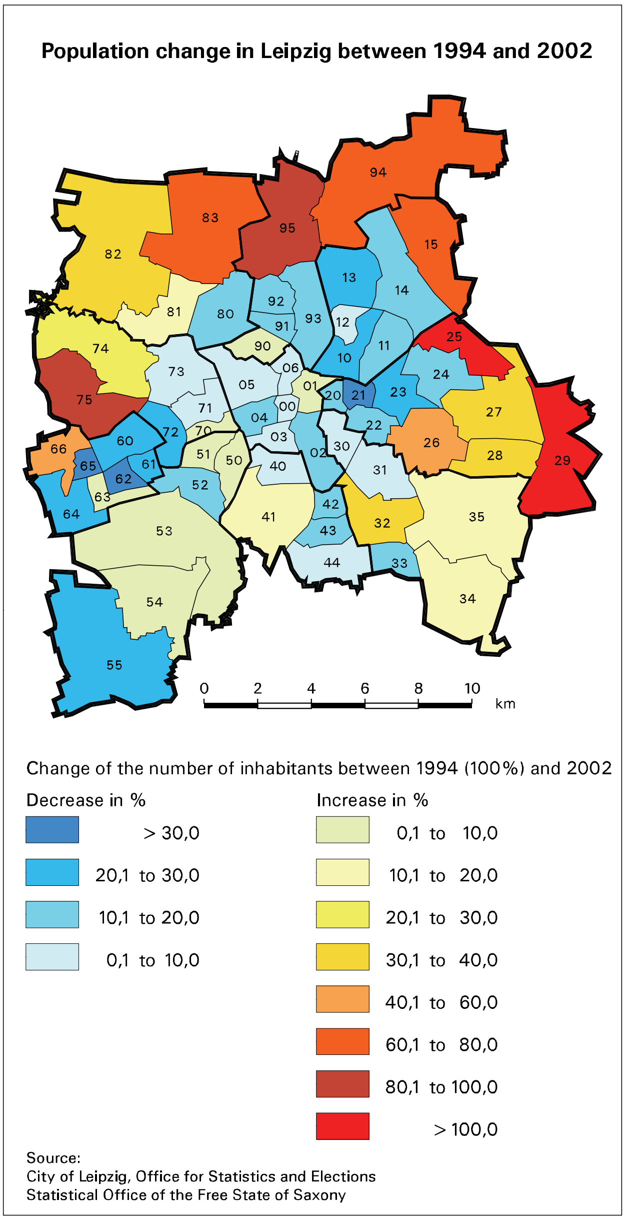


Figure 3: Population change in Leipzig between 1994 and 2002 based on municipal statistics.

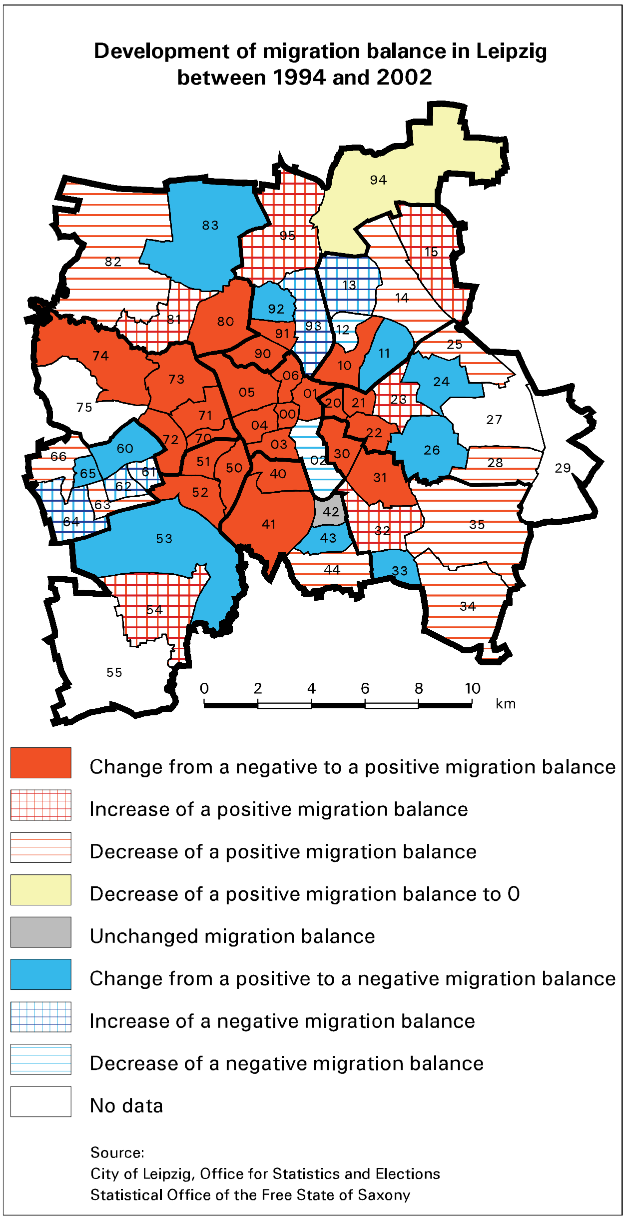


Figure 4: Migration balance in Leipzig between 1994 and 2002 based on municipal statistics.

Modelling residential mobility and residential vacancy under conditions of shrinkage using spatial and socio-demographic predictor variables

In order to analyse land use change and particularly the demolition of the urban fabric in shrinking cities, models can be used as innovative tools to support urban spatial planning, with scenarios being fed from monitoring data, which are thus based on ground truth and empirical evidence (23). Frequently used approaches in urban modelling, which deal with interactions between urban land-use changes and their socio-economic driving forces are, among others, logit models of discrete choice (24), more or less complex cellular automata (CA) models (25,26), and rule or agent-based models (ABM) (27,28,29). Most CA and ABM model-applications, however, deal with urban growth as the predominant form of urban development, whereas the process of urban shrinkage and related residential vacancy still remains outside of the focus (30).

Shrinkage, as an issue for urban modelling, requires additional agent-based, i.e. household-related knowledge and ideas about the spatial effect of migration processes in a depopulating city, if one is to explain the creation of massive stands of residential vacancy. A model approach has to focus on predicator variables and indicators that set the demands of the households into relation with the supply of housing space. Further the model needs to be calibrated with annual municipal data on population growth (fertility – mortality + migration). In doing so, such a model uses evidence provided by quantitative socio-demographic statistics as discussed in the previous section of the paper. The spatial implementation of different housing types in the model, such as apartment blocks or (dis)continous Wilhelmeanian style row houses, is based on data from time series created using the satellite imagery change detection maps presented in section 1 (Figure 2). In order to create knowledge on development and progress of residential vacancy as a function of residential mobility under conditions of excess apartment supply, an innovative ABM framework is formulated working with household types and residential choices. For these model components the above discussed spatio-temporal land use data and socio-demographic analyses are utilised (Figure 5).

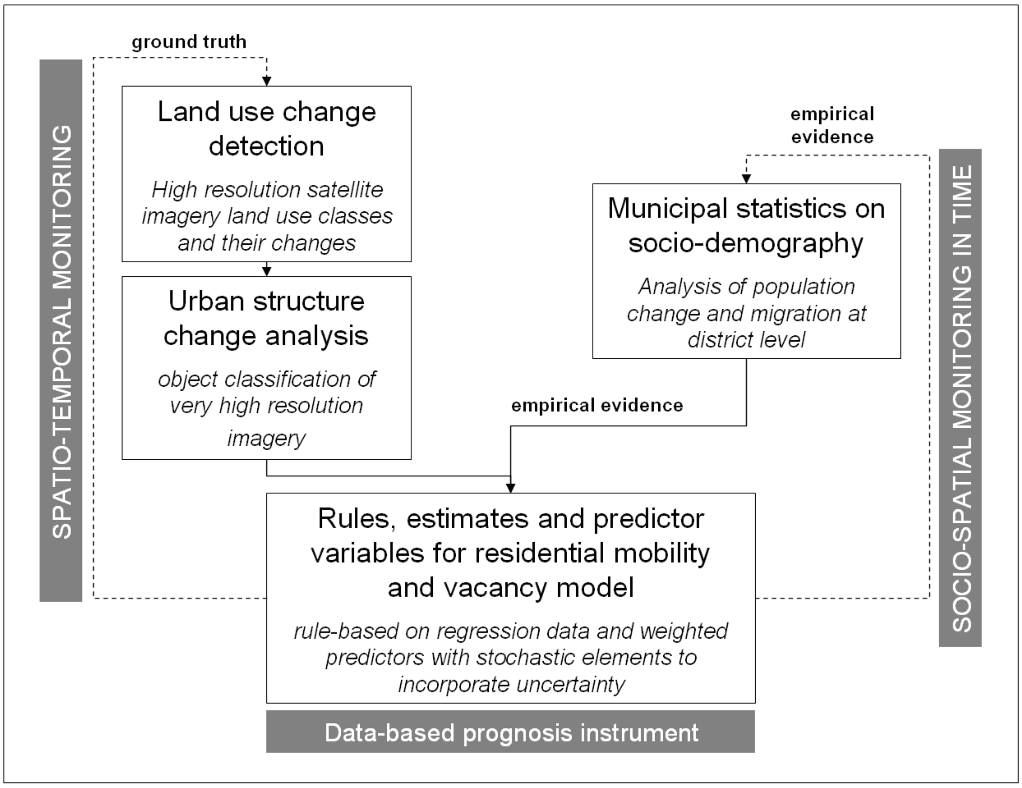


Figure 5: Model concept to operationalise residential mobility.

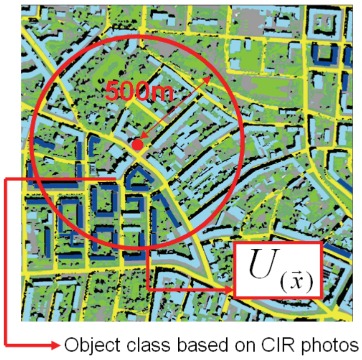
Due to empirical findings of sociological surveys (31) new age groups and household forms have been identified as crucial socio-demographic factors of residential mobility under shrinkage conditions. Furthermore, recent research has brought up the observation that households act as nexus points between changing demographics and residents' housing preferences and thus households are the agents of the housing markets (32). Therefore, they represent the agents in the model.

In a first step, a population model translates cohort-based population development into household types (singles, cohabitation "dinks", patchwork families, single-parent families, elderly cohabitation households, flat-sharers). Here, we achieve a very good accordance with municipal statistical data of Leipzig from 1994 to 2005 (33). An attractiveness indicator matrix on housing preferences for each household (social neighbourhood, housing form, prices, security, transportation, greenery, social infrastructure, shopping facilities etc.) at municipal district and building level is used to formulate a preference-restriction profile for each model agent to simulate their residential mobility (Figure 6). According to the ranking of the variables out of municipal statistics and the questionnaire survey, each indicator has been weighted randomly within a restricted range of values (Figure 6). As the main output of the model we achieve an annual household and cohort distribution for each house for the whole city of Leipzig, which gives us a number of vacant flats and, on that basis we can calculate a demolition rate for each municipal district (cf. again Figure 5).

Attractiveness (A_h) of a residential unit (house) $U_{(\vec{x})}$ for a household h:

$$A_h(\vec{x}_0) = \sum_{k=1,2,..} w_{h,k} I_k \left(U_{\vec{x}_0}(\vec{x})\right)$$

$$\sum_{k=1,2,3,...} w_{h,k} = 1$$



I_1	: social milieu	(w = 0.27 … 0.32)
I_2	: urban structure type	(w = 0.18 … 0.21)
I_3	: social infrastructure (educational, shopping facilities,…)	(w = 0.08 … 0.12)
I_4	: accessibility to urban green (distance to next park,…)	(w = 0.08 … 0.12)
I_5	: security (% of crimes per land parcel)	(w = 0.04 … 0.08)
I_6	: noise, air pollution (mg/kg; dB)	(w = 0.04 … 0.06)
I_7	: travel distance to work (location of working place)	(w = 0.14 … 0.18)
I_8	: travel costs (transport means, infrastructure, …)	(w = 0.18 … 0.22)
I_9	: housing costs (rent, property estate, land market, …)	(w = 0.18 … 0.22)

Figure 6: Example taken from the classification scheme showing the building structure and building classes "apartment blocks", "detached and semi-detached houses", and "discontinuous Wilhelmeanian style multi-storey houses" as well as the vegetation structure ("parks" and "community gardens") - Spatial units of the housing sector serve as prerequisite to which a social science data based preference matrix with the indicators $I_{1...n}$ is applied.

Furthermore, a layer of residential vacancy is part of the output file of the micro-simulation with the same spatio-temporal resolution (Figure 7). It is calculated using the equation

$$M_h(\vec{x},\vec{y}) = \begin{cases} Vac(\vec{y}) & \text{if } A_h(\vec{y}) > A_h(\vec{x}) \\ & \text{and } P_h(t) > P_{\min} \\ 0 & \text{else} \end{cases}$$

where M_h is the migration choice, *Vac* the residential vacancy and $P_{h/min}$ the persistence of a household in a flat. The simulated vacancy has been plotted against expert estimations of current vacancies associated with the municipal districts (as done in Figure 7) and shows a very satisfying accordance. As a next step of the model analysis, the simulated vacancies are set against the classified residential vacancy of the object-oriented classification scheme (as shown in Figure 2).

In the next phase, contextual (policy, legal, planning, conceptual) constraints will be implemented using spatially implicit information such as verbal arguments and guidelines as well as spatially explicit data in form of planning maps. As one pathway of urban shrinkage the following 'compact city concept' is preferred by regional policy makers of Saxony and Leipzig: The centre of the city is foreseen to be preserved as a functional core, to maintain urban quality of life in compact structures and to avoid urban perforation. Demolition activities should be concentrated at the periphery. In fact, in many cases, those concepts of the policy makers are not in line with those of the housing enterprises who take the final decision regarding demolition of their housing stock. Despite being a problem, shrinkage and demolition of vacant housing estates also provide new place for other uses such as spacious living, less density and more greenery in neighbourhoods, which is equal to the typical suburban housing advantages.

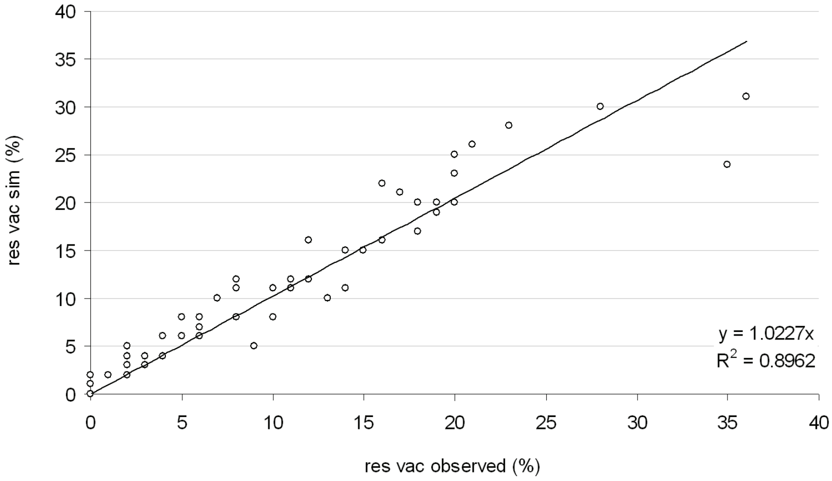
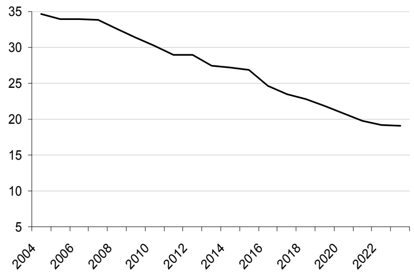
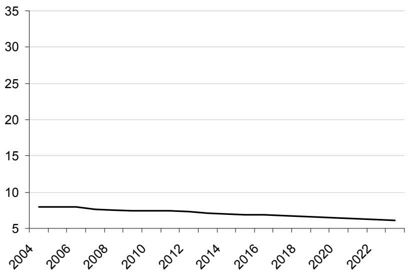


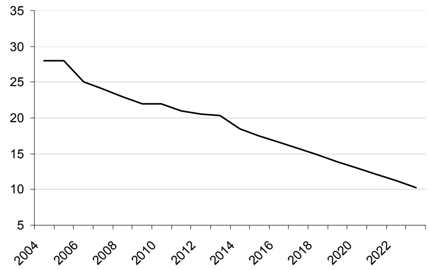
Figure 7: Simulated versus 'measured' residential vacancy in Leipzig for 2004: The first model runs show that the share of residential vacancy of the municipal districts of Leipzig (n=63) is well predicted with the model that bases on both the classes of urban land (use) structures derived from VHR imagery and the respective changes as well as on socio-demographic predictor variables derived from time series. The results are plotted for 2004, the most recent reliable estimation of residential vacancy for the city by local authorities and the Office for Statistics and Elections.



District of Neustadt-Neuschönefeld (Wilhelmeanian estates; negative image)



District of Südvorstadt (Wilhelmeanian estates; positive image)



District of Grünau-Nord (GDR-time prefabricated estates)

Figure 8: Predicted residential vacancy (%) for different old and new built-up residential housing types for Leipzig until 2025.

RESULTS & DISCUSSION

The presented study comprises monitoring of land use changes and mapping of socio-demographic dynamics right after the political transition in eastern Germany, combined with modelling of residential mobility. After having identified spatial suburbanisation processes, which were accompanied by urban growth at the urban fringe and urban shrinkage in the central part of the city, a new focus in urban land use monitoring activities was taken, deriving urban structure types from very high resolution (VHR) data. With respect to remote sensing methods two different data sets and approaches were applied: the multispectral classification and post classification comparison of TM imageries supported the monitoring of urban growth and shrinking processes in this very dynamic region. The object-oriented fuzzy classification of a VHR data set is compared with ATKIS (official topographic-cartographic information system of Germany) data in order to produce a change detection for the process of demolition of houses, which is a special feature of the massive residential vacancy typical for shrinking cities.

The assignment of demolished houses to specific urban structure types is another special contribution arising from the application of the approach presented here. Beside their obvious dependence upon economic variables, urban land use changes are mainly related to the demographic development of a city. In the integrated monitoring and model approach presented above, we assume that there is a causal relation between the built-up environment (housing and infrastructure), the configuration of urban open spaces and demographic processes (first of all migration). Initial results of this model of residential mobility in Leipzig and a respective picture of residential vacancy support the presumption that different household types prefer different housing environments and structures, and that, under a typical pattern of residential behaviour, residential vacancies are created. To validate the model results and to set a relationship between residential vacancy and demolition processes there is the need to create valid data of urban land use change at building level. This brings the model and the paper back to the VHR based object-oriented classification where next steps in the research will be focused on investigating how data sets on urban structure types can be reliably reproduced so that demolition and, respectively, new built-up areas can be monitored regularly on a local scale.

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Chapter 19

BEYOND GROWTH? DECLINE OF THE URBAN FABRIC IN EASTERN GERMANY

A spatially explicit modelling approach to predict residential vacancy and demolition priorities

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Abstract: Urban growth has been replaced by decline of the urban fabric in many parts of Europe. Reasons for this shrinkage are to be found in processes of demographic change and migration in city regions. This chapter presents relevant indicators and a rule-based modelling approach to residential change and building demolition in Eastern Germany. The first part will focus on the research objectives and briefly discusses the urban decline phenomenon and the need for a new modelling approach in order to understand the current shifts in urban development. Besides this, relevant predictor variables for identifying spatial shrinkage and residential vacancy are discussed. Finally, their integration into a GIS-based spatially explicit model completes the chapter.

Key words: Urban shrinkage; demographic change; residential vacancy; demolition; rule-based cellular model.

1. INTRODUCTION

Within the last ten years, a shift in land-use development due to a rapid demographic change has become more and more obvious in many European countries (CEC, 1997; Cloet, 2003; Lutz, 2001). In recent studies of population development, an average population decrease of 11% within the EU-15 countries by 2050 is predicted, with extreme values of decline in Italy (25%), Spain, Switzerland and Austria (20%). For the enlarged EU-25, the average estimated decrease is 18% (Kröhnert *et al.*, 2004). This general

E. Koomen et al. (eds.), Modelling Land-Use Change, 339–353.

trend is highly correlated with continuously decreasing birth rates (currently 1.4 children/woman) and significant changes in the age distribution of populations. In city regions in particular, internal urban migration has taken place towards the urban periphery (residential suburbanisation) while simultaneously, inner city areas have become subject to processes of (partly extreme) abandonment (e.g. Heilig, 2002).

At the moment, we observe diverging processes of growth and decline in many Central and Eastern European city regions. Whereas in the 1980s and 1990s urban growth and suburban development occurred in these cities, partly accelerated by the demise of the socialist system, today they are faced with a general decline of population as well as an increase in life expectancy due to 'ageing' (Antrop, 2004; Cloet, 2003; Lutz, 2001). Thus, population re- and de-concentration processes and related pressures on the current land-use pattern determine the state of the environment and drive future land-use development strategies in particular in urban areas (Deutsch *et al.*, 2003; Ekins *et al.*, 2003; Haase and Nuissl, 2005). Figure 19-1 (Plate 23) exemplifies this with a projection of these diverging trends for Germany in 2020. The red areas will have further population growth; blue areas will have population decline.

Figure 19-1. Spatial re-concentration (blue) and de-concentration (red) trends up to 2020 in German regions. (See also Plate 23 in the Colour Plate Section)

Urban shrinkage, characterized by phenomena such as reconstruction, deconstruction or even demolition, is a process of marginalization of urban areas (cities and regions), where selective upgrading of the fabric and the infrastructure interact with de-industrialisation, massive out-migration, ageing of the population and decreasing birth rates (Cloet, 2003; Lutz, 2001). These processes are very relevant for spatial modelling because they may lead to high inner city discrepancies between growing and shrinking residential areas (with a strong gradient from peri-urban to inner city areas) with very different population densities.

In order to analyse land conversion and decline of the urban fabric in cities caused by the processes described above, models can be used as innovative tools to support spatial urban planning for sustainable development. Frequently used approaches in urban modelling are agent-based models (Miller *et al.*, 2004; Waddell, 2002), logit models of discrete choice (Landis and Zhang, 1998a; 1998b) and complex cellular automata models (Silva and Clarke, 2002; Clarke *et al.*, 1997; White *et al.*, 1997; Wu and Webster, 1998; Wu, 1998). Urban models that deal with interactions between urban land-use change and its socioeconomic driving forces are mainly implemented as agent-based models. These models often incorporate discrete choice theory (Ben-Akiva and Lerman, 1985; Horowitz *et al.*, 1986). Most model applications however deal with urban growth due to its present topicality, whereas the process of urban shrinkage is of growing importance in urban Europe today (Haase and Steinführer, 2005).

This chapter discusses a conceptual framework that analyses the spatial phenomenon of urban shrinkage and subsequently focuses on the related demolition of parts of the urban fabric. A set of predictor variables (social and spatial indices) is selected and incorporated into a rule-based modelling approach to model demolition priorities in a socialist prefabricated housing estate in Leipzig-Grünau, Germany. The findings of the model are then compared with an existing overall planning concept of the 'compact city' in the study area.

2. URBAN SHRINKAGE

To improve the knowledge of current urban shrinkage processes and to support urban spatial planning, the allocation of probable shrinkage and vacancy needs to be investigated. The phenomenon of shrinkage in residential areas in European cities is far from new: it has been noticed and already described (even if mostly theoretically) since the 1950s and 1960s (Couch *et al.*, 2005; van den Berg, 1982). In some European cities – former 'boomtowns' – that are now in decline, research on urban shrinkage has begun to take place. In most cases, this research focuses on population decline and a decrease of total population density in the central parts of the city based on socio-economic statistics. In most of the cases, references are made to urban structures (structural types) such as single family houses, prefabricated housing estates, historical districts, commercial sites as well as (old) industrial sites.

Couch *et al.* (2005) compare Liverpool in Great Britain, and Leipzig in Germany, as two cities undergoing a profound functional transformation from former industrial metropolitan agglomerations to service economy-based cities. Another study of Ivanovo in Russia examines a city in post-socialist economic transition in the aftermath of 'Perestroika' (Sitar and Sverdlov, 2004). Booza *et al.* (2004) focus on Detroit as an American metropolis now experiencing shrinkage. Dura-Guimera (2003) investigates the processes of urban deconcentration and, simultaneously, the dynamics of urban sprawl, including social processes in the 'Barcelona Metropolitan Area' in Catalonia. From recent statistics on population development, in- and out-migration with respect to the urban development of Mediterranean cities in Europe, Dura-Guimera describes population decline in the central urban area (city centre), population increase in the urban periphery and population expansion of the dispersed city. The process is described as the phenomenon of urban 'perforation' in Germany.

Until recently, shrinkage was tackled specifically as a problem of restructuring the old-industrialised areas, neighbourhoods and boroughs of a city in the sense of being part of regeneration processes. On the contrary, today, we find accelerating residential vacancies in housing estates in inner city areas and in (socialist) prefabricated housing estates. In spite of the urgency to tackle this problem and to improve spatial planning policies towards acknowledging non-growth and shrinkage as current urban phenomena in many parts of Europe, the paradigm of growth is still on the agenda (Müller and Siedentop, 2004). Urban modelling is also very restricted to growth and has not embraced the shift in core areas of urban dynamic development (Antrop, 2004; Haase and Magnucki, 2004). However, the effects of shrinkage will have an enormous influence on the development of cities in the near future. As mentioned above, population decline will lead to decreasing demand in the residential market. Related economic shrinkage processes due to declining purchasing power and low investment rates in urban regions will have enormous consequences on the attractiveness of places for new economic investments as well as for in-migration. A comparison of the regional distribution and the variance of the social variables such as population growth rate, net migration and fertility for all German cities with more than 200,000 inhabitants, learns that high residential vacancy rates are found in Eastern Germany (Halle, Chemnitz, Leipzig) and the old-industrialised Ruhr area (Gelsenkirchen, Krefeld, Dortmund). These cities are characterized by a population decline, caused by strong out-migration (5-25% per year). The fertility rates are approximately the same for all big German cities (around 1%).

For German cities, the current situation seems to be rather paradoxical: on the one hand, available data indicates dynamic suburban land-use growth (in single and semi-detached house settlements, new 'housing parks') with adjacent construction activities (trade and industry) in the urban fringe although population declines. On the other hand, there is an increasing process of shrinkage and perforation in the form of residential vacancies in the inner city areas although re-population seems to be a new trend (Figure 19-2). Here, mainly the old industrialised areas and the urban centres are affected. Previous study (Haase and Magnucki, 2004) has shown that the shrinkage phenomenon in the form of residential vacancies is strongly related to socio-demographic variables such as high unemployment rates or reduced (low) household income leading to a total net out-migration, especially in the inner city.

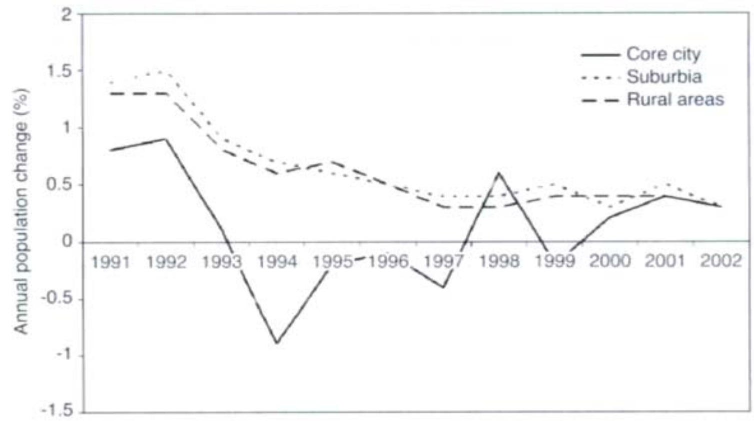

Figure 19-2. Average population change along the rural-urban gradient in German cities with more than 200,000 inhabitants, 1995-2000.
Source: Modified after Müller and Siedentop (2004); INKAR (2003)

3. MODEL DEVELOPMENT

The model for predicting residential vacancies and related demolition priorities is based on a selected set of variables that have been incorporated into a raster-based modelling approach. It is specifically developed to model the urban development of the Leipzig-Grünau region. This section starts with a description of the demographic developments in this region. We then discuss the selection of relevant predictor variables and describe the model concept and implementation.

3.1 Study area

At present, there are over 55,000 empty flats in the administrative area of Leipzig. The area of Leipzig-Grünau, one of the largest prefabricated socialist residential areas of the former GDR, is heavily affected by urban shrinkage and population decline (Figure 19-3). Moreover, Grünau belongs to those areas in Leipzig where strategic demolition programmes have been carried out and others are planned. The district mainly consists of prefabricated housing estates, two single and semi-detached housing estates, recreational and trade areas (Haase and Nuissl, 2006). The prefabricated housing estates (or Wohn-Komplexen, WK, in German) can be divided into large polygonal blocks in the heart and at the periphery of Leipzig-Grünau (WK 4, 5.2, 7 and 8). Other housing estates (WK 1, 2, 5.1) are dominated by the so-called 'point' skyscrapers with 18 floors and a quadratic ground plan. The size of the housing estates ranges from 1,300 to 9,200 building units (apartments).

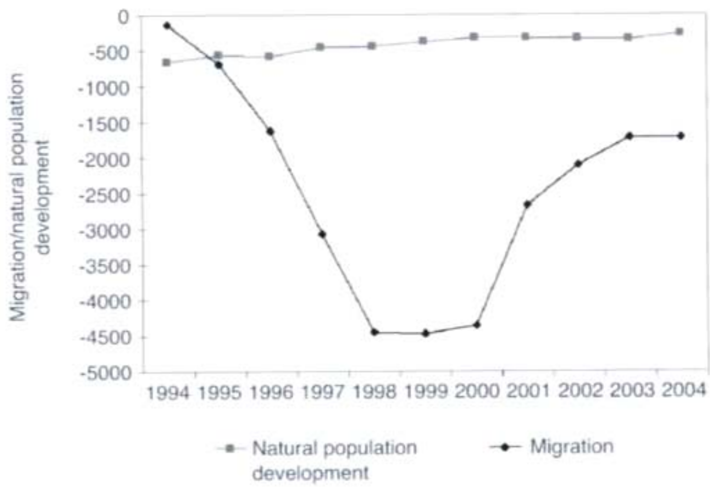

Figure 19-3. Demography of Leipzig-Grünau, 1994-2004.
Source: City of Leipzig (2004a; 2004b)

After German re-unification, Leipzig-Grünau suffered from an extreme population decline due to a negative natural population balance and most of all, an enormous out-migration in the late 1990s. This led to a high residential vacancy share and net out-migration concentrated in the peripheral and central parts (WK 4, 5.2, 7 and 8). This extreme decline process only stagnated in the last 2-3 years. It is still unclear in what direction the large residential area of Leipzig-Grünau will further develop. However, demolition and de-construction will characterise the face of this part of the city for the coming decades. Grünau serves as a study area for micro-level investigations of urban housing and restructuring by many institutions and spatially explicit social data are therefore expected to become available for calibrating the chosen variables utilised in the model.

3.2 Selection of predictor variables

Based on a broad literature review, social and spatial predictor variables for vacancy and urban shrinkage were selected and discussed with social scientists from the Centre for Environmental Research carrying out social empirical work in Leipzig-Grünau (Kabisch, 2005; Kabisch *et al.*, 2004). Strategic planning of demolition in Eastern German cities is mostly based on socioeconomic indices which result from the long-term monitoring systems of each city. In Dresden, the capital of Saxony, for example, the need for action in the form of demolition is assessed by using variables such as residential vacancy, structure type, share of unemployed people, share of welfare recipients and share of inhabitants older than 60 years (City of Dresden, 2003). Following this input from the discussions, the variables listed in Table 19-1 were considered as predictor variables.

Correlations between the selected variables and share of residential vacancy and correlations among variables were tested to select the set of statistically significant variables for the model. The correlation coefficients in Table 19-1 give an idea of how well vacancy and shrinkage can be explained by social features. Based on these outcomes, the variables 'out-migration' and 'share of population above 65 years' were selected, as they have the strongest correlations with vacancy and are not correlated to each other. Unemployment data as well as data on social welfare recipients are seen as relevant, but are not included as the basic idea of the model approach is to reduce the total number of predictor variables to about five.

Based on expert knowledge three additional variables were selected. These include the two spatial variables 'distance to urban sub-centre' and 'adjacent open areas' to represent the hypothesis that proximity to local facilities and green spaces is preferred. Furthermore the variable 'urban structure type' was included, following expert interviews that stated the importance of incorporating housing preferences and property rights. The complete set of selected variables thus consists of: out-migration (%), share of people above 65 years (%), distance to urban sub-centers (metres), adjacent open areas (%) and urban structural type.

Data for these variables are available on different spatial scales. Urban land-use data, including 30 categories, was derived from a land-use map 1:25,000 (Haase and Magnucki, 2004) with a resolution of five metres. This map was produced for the planning authority and provides detailed information about the urban structural pattern. Social data (e.g. migration, age groups) were derived from the social report (City of Leipzig, 2003) and were only available for each borough.

For the variable 'distance to urban sub-cêntre', the mean distance to the nearest sub-centre with an administrative function (municipal offices, post-office, shopping malls) is calculated for each grid cell five. The variable 'proportion of grid cell edges not adjacent to open area' is calculated by dividing the number of cell edges that are not adjacent to an open area by four, the total number of cell edges. Both variables are normalized to a range of values between 0 and 100. The 'structure type' variable is based on the urban land-use map where each residential land use was assigned a value between 0 and 100 according to its popularity and property status, where: '0' means no demolition possible due to private property; '50' means demolition not preferred because of good quality of houses and preferred flat properties; '100' means demolition possible in case of vacancy. Reconstructed old built-up areas and villas are supposed to have a better image than GDR-time prefabricated housing estates. It is assumed that residential types with higher values are less preferred than those with lower values.

Table 19-1. Correlations between vacancy and potential social predictor variables

Variable	R^2 to vacancy
Out-migration	0.7*
Foreigners	0.4
% married people	- 0.6
Unemployment	0.6*
% car owner	- 0.6*
Age group >65	0.8**
Age group <15	0.1
Social welfare recipients	0.6*

** *1% significance level % * 5% significance level (Pearson's r^2)*

3.3 Model concept and implementation

The *Spatially Explicit Landscape Event Simulator (SELES)* modelling environment (Fall, 2000) was used to build our urban development model. The study area is defined in the model as a regular grid of 5x5 metre cells consisting of 1,500 rows and 3,000 columns. The model is based on the rasterised land-use map of the study area of which seven residential land-use types are selected for the simulation of demolition priority. Each residential grid cell is identified by a unique ID and holds information on its land use and on the local predictor variables. In the static expert-based and rule-based modelling approach, demolition priorities are given to these cells, based on the weighted sum of all the normalized predictor variables (see Eq. 1). Thus, we assume a linear relationship between predictor variables and the demolition probability. Figure 19-4 presents an overview of the model concept.

$$D(z)=\sum_{k=1}^{5} w_k \cdot I_k(z) \quad \text{with} \quad \sum_{k=1}^{5} w_k = 1 \tag{1}$$

where:

$D(z)$ is the demolition priority of gridcell z;
w_k is the weight for predictor variable k;
$I_k(z)$ is predictor variable k at location z;
$I_{[k=1]}$ is out-migration;
$I_{[k=2]}$ is the share of population above 65 years (%);
$I_{[k=3]}$ is the mean distance to urban sub-centre (m);
$I_{[k=4]}$ is the share of grid cell adjacent to open area (%); and
$I_{[k=5]}$ is the urban structural type.

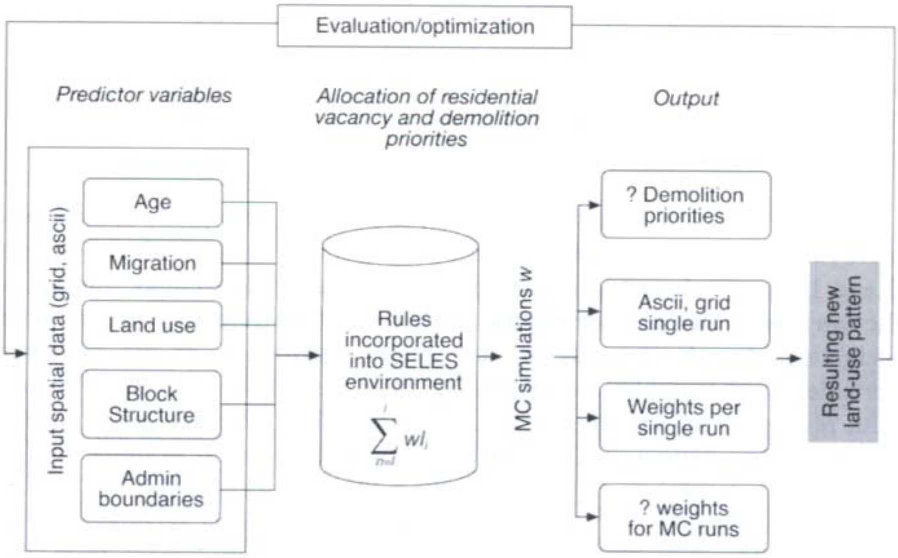

Figure 19-4. Model concept.

Demolition is allocated to the grid cells with the highest priorities for demolition until a given proportion of residential area (D_{max} %) is reached.

Here, we follow the overall concepts of the municipality of Leipzig (agencies for spatial urban planning and domestic construction) and the Federal State of Saxony, where a final demolition rate of D_{max} = 10% (until 2005) and D_{max} = 30% (until 2009) is planned based on a recent demographic and migration prognosis.

4. RESULTS

The spatially explicit model was implemented first to test the applicability of verbally formulated reference scenarios stated by the Department of Urban Planning in Leipzig. Urban scenarios are often based on urban planning related storylines (or narrative descriptions) of a range of plausible, alternative future options within an exploratory framework (Alcamo, 2001). As one alternative pathway of urban development a reference scenario of urban shrinkage and demolition, called 'Maintenance of the urban city centre', was formulated. In this conceptual model of the compact city, the centre of the city will be preserved as an urban core to maintain urban life in compact structures. Demolition is supposed to be concentrated at the periphery. A scenario is built based on Eq. (2).

$$D = D_{CC} \tag{2}$$

where:

D is the demolition priority; and

D_{CC} is the mean distance to city centre.

As part of a sensitivity analysis, 1,000 Monte Carlo (MC) simulations were run with randomly varying variable weightings. Integer values between 0 and 10 were selected as reasonable and differentiable weights, similar to the way an urban planner would value them. The effect of the variable weightings largely depends on the spatial distribution of the predictor variables. If all variables are equally weighted, demolition sites are allocated with respect to all variables in equal measure. The effects of all predictor variables are additive. The 1,000 MC runs were used to examine if and under which conditions (described through variable weightings) the overall concept 'maintenance of urban city centre' can be realized according to the local situation. Therefore, the mean distances to city centre from the demolished grid cells were listed for each MC run. The distributions of these values in each run were then compared to the distribution of values derived from the reference scenario of the 'compact city'.

The first results of the 1,000 Monte Carlo runs show that none of the runs produces a demolition pattern similar to the reference scenario of the 'compact city'. Compared to the reference scenario, the distances to the city centre from the demolished grid cells are considerably lower for all 1,000 runs (Figure 19-5). The median of all 1,000 mean distances from the demolished grid cells to the city centre is 7.7 kilometres as compared to 8.4 kilometres for the reference scenario. Each dot in Figure 19-5 on the right represents a single grid cell that is supposedly demolished, the dot on the left indicates the reference scenario of the alternative pathway described in Eq. (2). The main differences in variable weightings between those runs lie in the weights for out-migration, distance to sub-centres and urban structure type. In general, all runs are quite similar and demolition is mostly allocated in the central and the north-western part of Leipzig-Grünau (Figure 19-6 at right), where both 'share of inhabitants above 65 years' and the 'out-migration potential' are high.

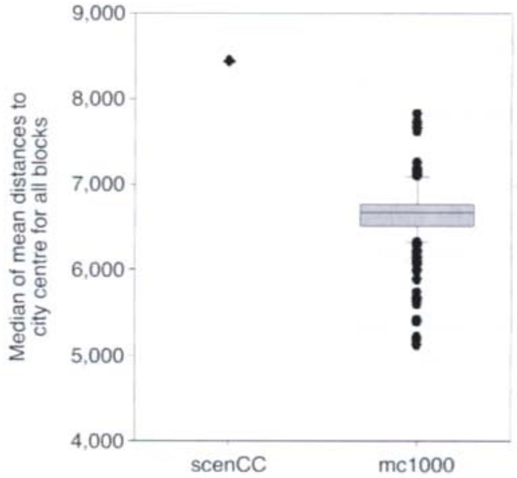

Figure 19-5. Median of mean distances to the city centre from all demolished grid cells of 1,000 MC runs (right) compared to the 'Maintenance of the city centre' scenario (left).

To indicate the validity of the simulation results we calculated a high demolition priority probability per housing estate (WK) for which we divided the number of locations where more than half of the 1000 MC runs allocated demolition by the total number of housing units per WK. This probability was then compared with the observed residential vacancy rate in 2003 and the share of individual building units that were actually demolished in 2004 or planned to be demolished in 2005 (recordings according to the Department of Urban Planning of Leipzig). Figure 19-7 shows that the WK's with a relatively high demolition priority coincide partly with high observed vacancy rates and share of demolished units. This correlation is also indicated by the correlation coefficients of the high demolition priority probability with existing residential vacancy in 2003 (R^2 = 0.39) as well as the share of actually demolished housing units (R^2 = 0.54).

Figure 19-6 Land use 2003 (A) and spatial distribution of demolition priorities within 1,000 MC runs (B). (See also Plate 24 in the Colour Plate Section)

The analysis proves that residential vacancy and demolition in large cities cannot be seen as a single spatial problem of the urban prefabricated periphery (mainly consisting of housing estates of the socialist period). In Leipzig-Grünau, mainly central parts of the residential area are concerned. Thus it can be concluded, that the overall concept of the 'compact city' covers only some specific sides of the reality of vacancy in the investigation area of Leipzig. The low variations of the median distance values of the demolished grid cells with regard to the variable weightings could be explained by the low spatial resolution of the social predictor variables the model is based on. A higher variability of the social data due to an enlarged investigation area or more detailed information on out-migration and share of age-groups in Leipzig-Grünau would, most likely, lead to more differentiated simulation results.

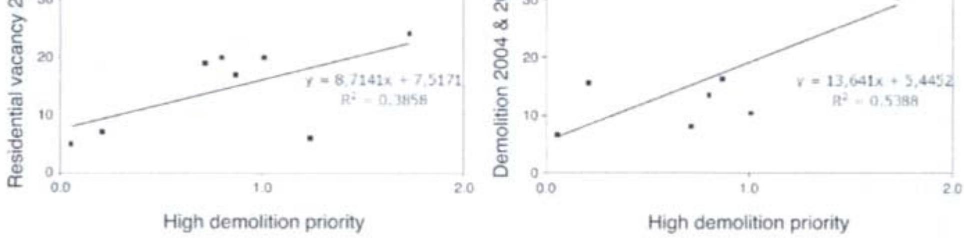

Figure 19-7. High demolition priority probability per housing estate (WK1 – WK8) compared to (A) residential vacancy rate in 2003 (%) and (B) share of actual (2004) and planned (2005) demolished building units (%).

5. CONCLUSION

The first model results of simulated demolition priorities indicate that the overall concept of 'maintenance of city centre' is far from becoming reality in the chosen study area. None of the combinations of the identified predictor variables result in the envisaged compact city pattern. This conclusion is supported by observed and planned demolition in the study site. On the other hand, the apparent correlations of the MC analysis give an idea of how Grünau could develop in the next 5-10 years, as these correspond with the planned demolition within the housing complexes at the central and (north) western part of the city. Another general aspect which arose in the analysis is that deriving general conclusions for the whole city is not feasible, probably because the selected study area of Leipzig-Grünau was too small and the applied social statistical data were not detailed enough.

To improve the promising model results for Leipzig-Grünau, information from a housing estate specific social survey will be included to allow for a spatially more differentiated description of residential vacancy. The assumption of linear relationships between the predictor variables and demolition priority can be altered, as it is possible that there are important interactions between the variables. Furthermore, interactions and feedback need to be incorporated into the model. Dynamics can be incorporated by making demolition priorities depend spatial configuration of housing in the previous time step. Underlying population dynamics and the household pattern and behaviour (housing preferences, migration) can then be considered as dynamic input variables that change over time. The model can also be improved by incorporating more detailed social and demographic data at district level. For the 'city level' ($n_{district} = 63$), the annual statistical reports of Leipzig are supposed to be a sufficient database. Thus, it is proposed to apply the model to the whole city of Leipzig including the old, prefabricated and the new built-up housing estates. In addition, model transferability to other cities dealing with similar phenomena will also be tested.

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BEYOND GROWTH – URBAN DEVELOPMENT IN SHRINKING CITIES AS A CHALLENGE FOR MODELING APPROACHES

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Abstract
Urban growth has been replaced by stagnation and shrinkage processes at many places in Europe during the last decades. Demographic changes and out-migration because of lack of jobs belong to the main impact factors. Urban planners are challenged by this new and dramatic development that impacts on housing markets, the utilization of infrastructure, local labor markets and the whole viability of urban structures. Urban Research is requested to elaborate new concepts and strategies for cities loosing population, facing a big amount of vacant building stock and a large-area re-use of brown-fields.
The purpose of this paper is to analyze the chances and limits of urban modeling to explain and assess urban shrinkage processes in their quantitative and qualitative dimension. First, expertise of new shrinkage processes is investigated in order to explain the need for urban modeling concepts. Second, it is discussed to what extend often misrepresented 'fuzzy' social science knowledge about urban shrinkage can be brought methodically together with 'sizable'-data-based urban models. Third, variables and a prototype model structure are presented to approach to an urban shrinkage model. Finally, novel scientific questions and recommendations for further cooperation of social science and urban modeling are presented.

Keywords
Shrinkage, demographic change, European cities, quantitative and qualitative research, urban modeling

1. Introduction

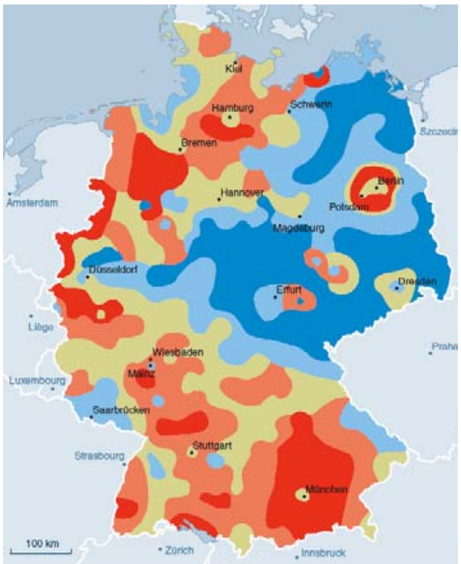
1.1. The context of urban shrinkage and demographic change in Europe

Urban shrinkage is not a new phenomenon. Historically seen, urban populations were decimated by warfare, natural hazards and epidemic plagues. A recent phase of shrinkage began after 1945. Since then, urban growth has been replaced by stagnation and shrinkage processes in many countries. Having started in Europe's old industrial regions like Northern England, the Scottish Clyde side or Lorraine, and the "rust belt" in Northern America, these processes affect today city regions throughout Europe and world-wide. Recent shrinkage processes affect more and more Eastern European, Japanese and South African cities (Rieniets, 2004). Although if not whole urban Europe is affected by shrinkage and there are yet growing cities like most of the capitals, our paper presents empirical evidence from Eastern Germany as an especially striking example of city shrinking that is related to dramatic socio-economic changes after the reunification in 1989. We focus on this extreme example since it shows how shrinkage unhinges hitherto concepts of urban development.

Shrinkage processes unveil that we have to deal in the future with urban regions beyond growth: with cities loosing inhabitants, housing stock falling vacant, residential and commercial areas remain empty and un-used and infrastructures getting under-used. It is mainly demographic change including decreasing birth rates, ageing, and postponement of marriage and childbearing that brings about such developments on the one hand (Haase et al., 2005). On the other hand, many young and well-trained people are forced to out-migrate because of closure of companies and unemployment. As a consequence, the socio-spatial imbalances within a city corpus are rising. Deprived areas losing residents are to be found in close neighborhood with upgrading districts. Disproportions between supply and demand of housing and urban services are rising. At most places, shrinkage processes in the core city coincide with further urban sprawl and land consumption (Couch et al., 2005; Nuissl & Rink, 2005). The intra-urban differentiation is accompanied by regional differentiation. Within the country, economically sound and growing regions exist in an ocean of decline and downgrading (Fig.1).

Urban policy makers are challenged by this new and very complex development – the paradigm of growth has to be replaced also in practice-related thinking and in developing new strategic goals for urban futures, treating shrinkage not only as a menace but also as a chance for reshaping urban spaces (Hannemann, 2000).

During the last years, research discovered shrinkage as a blind spot that urged to be lightened. A body of inter- and transdisciplinary expertise on shrinkage has developed. Whilst studies on Eastern Germany where urban shrinkage appears in its most dramatic form occupy a kind of 'forerunner' role (Kabisch, 2006), the comparative view on shrinking European cityscapes suffers still from a lack of empirical evidence except from rare examples (Bernt & Kabisch, 2003). Knowledge on shrinkage processes, their origins and consequences for urban systems gains more importance in particular for modeling since modelers are challenged to develop new approaches, indicator sets and rule systems (Haase et al., 2006).



Legend: dark blue = strong decrease, light blue = smooth decrease, beige = stable, light red = smooth growth, dark red = strong growth.

Figure 1: "Islands of growth in shrinking landscapes" – spatial simulation of population development in Germany until 2020, BBR-prognosis (BBR 2005).

1.2. Research objectives

Set against this background, this paper analyses the chances and limits of urban modeling to develop an approach to explain and assess urban shrinkage processes in their quantitative and qualitative dimension. After having identified predictor variables for the new 'process quality'of shrinkage in the areas of population, housing, urban pattern, land use and response from urban planning, it discusses to what extend social science knowledge can be brought together with quantitatively based urban model concepts. Methodically, the paper figures out

(1) in what way shrinkage processes challenge hitherto existing urban modeling approaches,

(2) why this shrinkage phenomenon demands both, updated prognostic and observation instruments as well as procedures,

(3) what kind of methodical implications for the development of an urban model that includes shrinkage as a accepted urban development strategy are required.

To allow for a more detailed picture, the paper draws on empirical evidence from Eastern Germany where dramatic shrinkage processes pre-dominate the urban presence and future alike.

1.3. Case study: Eastern Germany

The recent development in Eastern Germany is a case in point to show an 'advanced' or even 'extreme' stage of shrinkage and its impact on urban development, housing markets and usage of infrastructures. Shrinkage is pushed by three reasons: Firstly by a sharp decrease in birth rates after the political change in 1990 that brought Eastern Germany lowest-low birth rates in Europe (0.77 children per woman in 1995; INKAR, 2003). Secondly, most of Eastern German cities have been facing dramatic losses of inhabitants due to job-driven out-migration to the western part of the country. And a third reason is the wide-spread suburbanization during the 1990s (Haase & Nuissl, 2006; Couch et al., 2005).

Eastern Germany was faced with loss of population after 1989 of about 1.2 million people (8% of whole stock). Most cities lost between 10 and 20% of their residents (mean for big cities 1990-1999 16%). Extreme cases such as Weißwasser, Hoyerswerda and Wolfen lost between 30-40% of their inhabitants. Such type of city was mostly dominated by one major enterprise or administrative authority which was closed down after 1990. As result, economic base and local identity of these places eroded dramatically.

In consequence, flats and houses are falling vacant. Vacancy is no more restricted to uninhabitable housing but also to completely renovated building stock. The supply outweighs the demand even if at present household numbers still continue to rise. Whole residential districts exhibit vacancy rates higher than 30 or even 50%.

In this vein, demolition came into serious discussion. As a new strategy, a federal program of urban restructuring (BMVBW, 2003) operates in terms of a guideline to organize and finance the demolition of overhang of housing stock and revaluation of the remaining residential areas. It further represents a scientific approach to deal with urban development under the conditions of non-growth and shrinkage.

The dramatic appearance of shrinkage in Eastern Germany produced a flurry of scholarly activities in different social sciences. Conceptual frameworks such as gentrification or regeneration are about to be modified and adapted to local settings, rarely used approaches like reurbanisation are suggested as explanatory frames and strategies to counteract inner-urban shrinkage. In case of cities that are loosing considerable parts of their housing stock and inhabitants, brand-new ideas like the one of 'temporary residential areas' that still exist but will see a complete demolition in a foreseeable future have entered the scientific debate.

2. Shrinkage processes and pattern as a challenge for urban modeling

2.1 Urban modeling: debate and approaches

In order to analyze land conversion and decline of the urban fabric in cities caused by the processes described above, models can be used as innovative tools to support spatial urban planning. Frequently used approaches in urban modeling are agent-based models (Miller et al., 2004; Waddell, 2002), logit models of discrete choice (Landis & Zhang, 1998a; 1998b) and complex cellular automata (CA) models (Silva & Clarke, 2002; Clarke et al., 1997; White et al., 1997; Wu & Webster, 1998).

Urban models that deal with interactions between urban land-use change and its socioeconomic driving forces are mainly implemented as agent-based models (ABM). These models often incorporate discrete choice theory (Ben-Akiva & Lerman, 1985). The application of agent-based models is reshaping agents' activities from immobile decision to mobile action within a virtual space (Loibl & Tötzer, 2003). Most CA and ABM model-applications however deal with urban growth as the predominant form of urban development whereas the process of urban shrinkage remains still out of focus (Haase, 2006).

The determining factors of shrinkage and the agents of this change, e.g. new household compositions, are only partly sizable as 'quantifiable items'. Urban modeling faces the necessity to find new approaches that anticipate future development trends on condition of simultaneous processes of growth and shrinkage.

2.2 Pre-requisites to model urban shrinkage

In order to approach to an urban shrinkage model the following aspects have to be considered:

(1) Shrinkage as an urban phenomenon seeks for additional experience-based and agent-, i.e. household-related, knowledge to explain the process.
(2) A model approach has to focus on the development of predicator variables and indicators for shrinkage.
(3) The model concept needs to use evidence provided by quantitative social surveys and statistics.
(4) The model has to incorporate variables that are not simply sizable or to draw them from statistics in form of proxy, fuzzy or probability data (e.g. household structures, mobility behavior, decisions by housing market players, interview panel data).
(5) In doing so, social scientists have to accept that dependent (=specific) data are taken as 'pattern' for a development to be simulated as an 'ordinary or standard case' (e.g. household structure per 'urban fabric type' or 'typical mobility behavior per household type').
(6) Social scientists are requested to provide modelers with quantitative and qualitative proxy-data that could by classified, (dis)aggregated or translated into model rules. Our experience with self-administered, household based questionnaire surveys shows that it is indispensable to base models not only on proxy-data. If models intend to reflect household behaviour, households have to be the subjects of a prerequisite empirical database.

Reasonable results for all social scientists, modellers and practitioners are only to be expected when the procedure and the model concept are very clear in terms of objective of the modeling, set of predictor variables and their interplay as well as probable directions and dimension of changes.

Due to the newness of the shrinkage process, (semi-) quantification at local urban level interdisciplinary modeling approaches offer a promising way to improve our knowledge and to illustrate different scenarios for the 'future with shrinkage'. Especially there, where complex processes are about to pass, a view on both imaginable and desirable scenarios is important to shape future policies and its instruments (Caruso et al., 2005).

3. Model approach

3.1 Predictor variables for shrinkage

Population and households

Urban shrinkage is driven by demographic changes including new household types and decreasing birth rates as well as out-migration as the Eastern German example explicitly shows. Changes related to the concept of the Second Demographic Transition (SDT; van de Kaa, 1987, 2004) imply a coincidence of (i) sharp decrease in birth rates, (ii) ageing (Fig.2), (iii) smaller and less stable households (Fig.4) and (iv) societal changes in terms of a diversification of lifestyles.

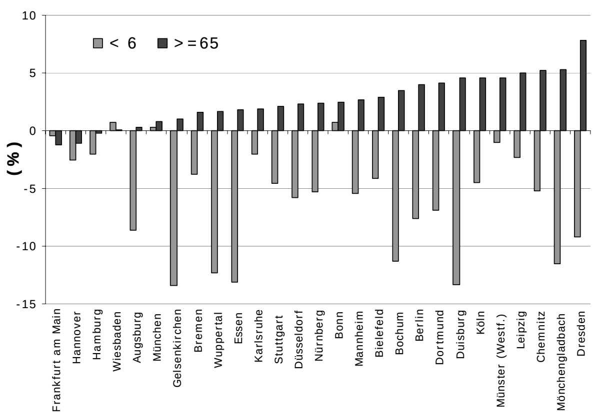
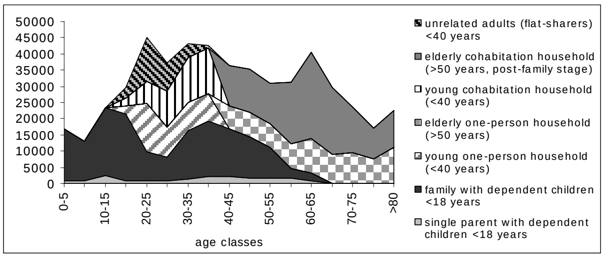


Figure 2: Demographic change in German Cities 1995-2003: age classes <6 and >65 years (INKAR, 2003).

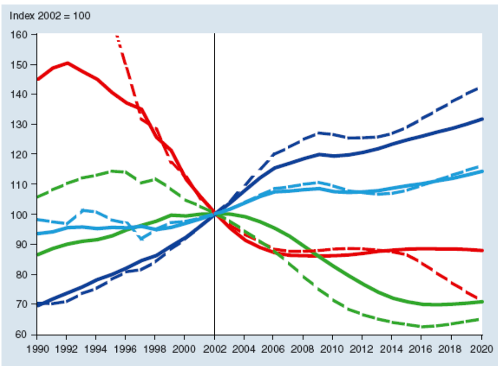
Recent research brought up that households act as nexus between changing demographics and residents' housing preferences and thus households are the 'subjects' and 'agents' of housing markets (Buzar et al., 2005). Figure 3 gives an idea on the social-science based household type classification of Leipzig distributed over cohorts.



**choice of household types context-related, the age group 40-50 was therefore not included*

Figure 3*:* Household types* and their age-class distribution of Leipzig, 2003 (Haase et al., 2005; Stadt Leipzig, 2004a)

A simulation of the household development in Germany until 2020 (BBR, 2005) suggests that in particular elderly one- and two-person households (pensioner couples, widows) will increase (Fig.4). Further, diverse multi-person households such as cohabitation households, patchwork families and flat-sharers will get more importance for the housing market of a city. Subsequently, as Fig.5 implies, a considerable turn of the overall household development in Germany has started to pass recently (2002).



Legend: dark blue = pensioner couples, light blue = widows, green = families, red = young families.

Figure 4: Household development in Germany 1990-2020, BBR-prognosis (BBR 2005).

Correlations between selected variables and share of residential vacancy and correlations among variables were tested to select statistically significant socio-demographic variables that are listed in the municipal statistics and are related to the above discussed household types. Here, e.g. the variable "age group >65" represents elderly one- and two-person households and the variable "% married people" represents families and single parent households. Unemployment rates were not included into the first model prototype even if showing a significant correlation to vacancy. They will, however, impact more on residential mobility in future because recent reforms of the social welfare system in Germany will force affected households to seek for smaller flats. Due to the fact that statistical data on household structures are not sufficiently recorded, such proxy variables with representative character are used to calibrate the shrinkage model.
The correlation coefficients in Table 1 give an idea of how housing vacancy can be interpreted by social features. Based on these outcomes, the variables 'out-migration' and 'share of population above 65 years' were identified as crucial for the model, as they have the strongest correlations with vacancy and are not correlated to each other.

Table 1*:* Correlations between residential vacancy and social predictor variables for the city of Leipzig

Variable	R^2 to vacancy
Out-migration (no)	0.7*
Foreigners (%)	0.4
Married people (%)	- 0.6*
Unemployment (%)	0.6*
Car owner (%)	- 0.6*
Age group >65 years (%)	0.8**
Age group <15 years (%)	0.1*
Social welfare recipients (%)	0.6*

*** 1% ; * 5% significance level (Pearson's r^2)*

Housing vacancy and demolition

Residential vacancies of 1.3 million flats (15% of whole housing stock; Bernt, 2004) in Eastern Germany prove that an extreme supply outweighs demand significantly in the long run. In the city of Leipzig, approximately 50.000 apartments are empty, 16% of the whole housing stock.

Prefabricated blocks on the outskirts predominantly demolished due to big amount of apartments owned by one housing enterprise. For Leipzig-Grünau, one of the biggest prefab estates in Eastern Germany, population decreased from 85,000 to 49,000 from 1989 to 2004. From the former 35.000 apartments 2,700 already demolished and further 2.700 are foreseen for demolition until 2007 (Stadt Leipzig, 2004b).

Demolition of the urban fabric produces new spatial pattern such as perforated structures with decreasing house density, demolition along the urban periphery, demolition corridors within a city or, respectively, 'housing islands'. For the model approach, variables such as land parcel, housing unit and flat for the residential sector are decisive. Threshold values such as demand-supply-relations for different housing estates at the residential market and house density values could serve as decision rules for construction and demolition in the model.

Urban planning and policies as constraints

Administrative urban planning was focused up to present on growth. Today, urban shrinkage presents a new challenge forcing hitherto developed strategies and policies to be adapted. First empirical studies on social consequences of shrinkage in medium-sized cities came up with recommendations highlighting interests and opinions of involved actors (Kabisch et al., 2004). Diverse patterns of owner structures in both old built-up areas and prefab estates make planning processes complicated and less transparent. Here, in particular, social science-based empirical knowledge is indispensable for modeling tools which seek to support planning.

Urban policy delivers contextual constraints for the model approach which could be spatially implicit such as verbal arguments and guidelines (e.g. shrinkage starting from the urban periphery to the core city) as well as spatially explicit in form of planning maps. As one pathway of urban shrinkage the following ‘compact city concept’ is preferred by regional policy makers: The centre of the city is foreseen to be preserved as functional core to maintain urban quality of life in compact structures and to avoid perforation. Demolition activities should be concentrated at the periphery. In fact, not in all cases, the concepts of the policy makers are in line with those of the housing enterprises who take the final decision regarding demolition of their housing stock. But nevertheless, the mentioned scenario could be coded in the model by setting demolition priority D equal to distance to city centre $D = I_{cc}$ with $I(z)$ is the predictor variable at location z. Municipal strategies to counteract shrinkage are to be incorporated more explicitly into the compiled model.

Shrinkage and demolition of housing estates provide new place for other uses such as spacious living, less density and more greenery in the neighborhoods which is equal to typical suburban advantages of housing. Thus, the city administration of Leipzig plans single family housing in the inner city. Based on policy expert knowledge the following additional variables and rules could be selected. These include the two spatial variables ‘distance to urban sub-centre’, ‘distance to main roads’ and ‘adjacent open areas’ to represent the hypothesis that proximity to local facilities and green spaces is preferred. Furthermore, the variable ‘urban structure type’ was included following expert interviews that stated the importance of incorporating housing preferences and ownership issues (Tab.2).

Table 2: Spatial predictor variables and model rules

Variable I	Rule and calculation proposal
Mean distance to sub-centre (providing ad-min. functionality)	Maintenance of urban cores. $D = I_{cc}$ where D is the demolition rate.
Mean share of urban green in the direct neighborhood (UG_{grenz})	Demolition occurs adjacent to already existing green. $$UG_{grenz} = \sum_{n=1}^{n} wBUG_n$$ where UG is urban greenery cells and B the weighted bordering cells/polygons.
Mean distance to main roads (dr)	No demolition along main roads. $$D = f\left(dr = \frac{\left(\frac{\sum_{i=0}^{n} (d_{\min,i} \cdot c_i)}{\sum_{i=0}^{n} c_i} \right)}{R} \right)$$ where D is demolition rate and dr is the mean distance to a main road (R).
Urban structure type (UST)	Old-built up housing estates are more valuable than prefab houses. $$St_{grenz} = \sum_{n=1}^{n} wBSt_n$$ where St is the urban structure type and B the weighted bordering cells/polygons.

3.2 Model structure and example equations

A concept model for setting up spatio-temporal and thematic causal-feedback-loops had been formulated in order to draw a first sketch of the complex housing sector under conditions of shrinkage based on household types (Fig.6).

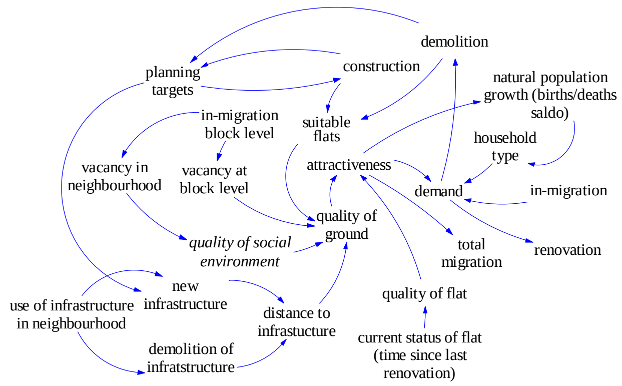


Figure 6: Concept model of residential preferences, related construction, residential vacancy and demolition

In the first prototype of the shrinkage model a population growth approach works in line with a Leslie population model to simulate population dynamics (cohorts; for the city of Leipzig Fig.7; Sharov, 1996). Based on a set of weightings (w) the residents are assigned to the household types relevant for the SDT given in Figure 3 for the example of Leipzig.

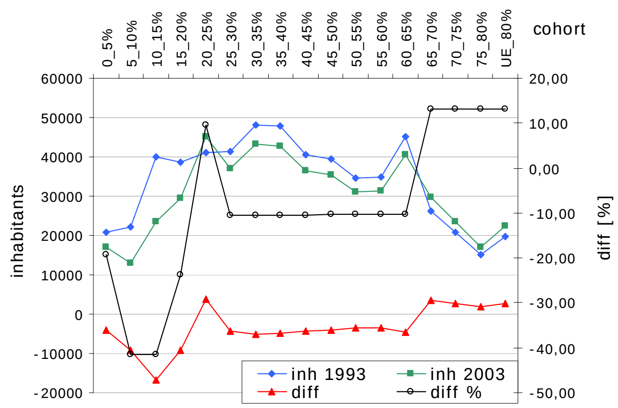


Figure 7: Simulation results for the age cohorts 1993 and 2003 related to the differences (diff no, %) to real numbers of Leipzig.

In the model, households act as agents. They are derived from recent socio-demographic findings (Fig.3). Each household type holds a residential mobility M_h that is related to the preferred surrounding social structure St_h (at the moment in the first prototype restricted to the household type structure; marked in *italics* in Figure 6), the urban land use type and facilities such as green space or transport infrastructure accessibility. Eqs. 1 and 2 show first examples of the calculation of the social structure variable (variable from the concept model in Fig.6, respectively).

$$M_h(i,j) = f(St_h(i,U(j,k))) \quad (1)$$

U is the variable expression for the surrounding social structure St_h for a household h at locations i and j. The weighted (w) social milieu for every location i and household type is calculated as follows:

$$St_h(i,U)0\frac{1}{\sum_{h=0}^{n} n(h,U)}\sum_{h=0}^{n}(wSt_{h_{i,h}} \cdot n(h,U)) \quad (2)$$

Migration occurs between land parcels that contain housing estates and flats. For every urban land use type, a mean housing stock density and a mean total number of flats had been derived. Further, to every household type had been assigned a land use type in terms of moving preferences (Preference h i for UST j = 0.01 and 1.0). Currently, all relationships of Figure 6 are translated into similar equations.

4. Conclusions

To conclude from this study, shrinkage, population losses and vacancies unhinge the balance of existing urban structures, and produce new patterns of cityscapes. An innovative model approach that takes into consideration the consequences of demographic change needs to be developed to come to a better understanding of the complex interactions of the included variables. The model structure and the relationships base on relevant predictor variables as well as urban policy contextual constraints. To allow for a more comprehensive look at shrinkage, weightings of model variables as well as proxy-data for 'not-sizable' variables have to be integrated. For a start, the model to be finally developed should be able to give an idea to scientists what kinds of future scenarios are imaginable, how desirable ones can be reached or supported respective inconvenient trends being omitted. With this approach, new insides and knowledge could be generated which needs further accompanying empirical research which mirrors the model results. Discussing the strengths and weaknesses of such a combined research strategy and find a common language for modelling shrinkage is an exciting challenge.

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Modeling and simulating residential mobility in a shrinking city using an agent-based approach

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A B S T R A C T

Shrinking cities are characterized by a huge oversupply of dwellings and resulting residential vacancies. Discussions among urban planners and policymakers in Europe have focused on the consequences of urban shrinkage following demographic transition, fertility decline and individualization. In this study, the shrinking city of Leipzig in Eastern Germany is singled out as a case basis for the study of residential mobility and land use change using agent-based modeling techniques, in which social scientists developed a concept of household types based on empirical data that form a unique base; these techniques were used to construct a data-driven, agent-based model. The spatially explicit simulation model RESMOB*city* presented here 'translates' these empirical data via behavioral rules of households. It computes spatially explicit household patterns, housing demands and residential vacancies. Based on three scenarios, population growth, stagnation and shrinkage, we show that population might stabilize within the coming years. The number of households is expected to further increase. We demonstrate that a selective demolition of vacant housing stock can counteract the enormous oversupply of dwellings and better balance housing demand and the number of available flats. Scenario simulation shows that the model can reproduce observed patterns of population, inner-urban migration and residential vacancy in a spatially explicit manner and thus can be applied to the analysis of scenarios of demographic change in urban regions. The presented model acts as a tool supporting the testing of hypotheses in social science research and allowing the quantification of land-use scenarios in urban regions based on household choices.

Software availability

Name of the software: RESMOB*city*
Availability: http://www.transfer.ufz.de/index.cgi?dir=%2Fwww%2Fhttp_data%2Ftransfer%2Falok%2Fhaase%2FRESMOBcity (login: alok, password: 06alok05;/haase/RESMOBcity/)
Developer: Dagmar Haase
Year first available: 2009
Software required: Sun Java (JRE/JDK version 1.6 and higher)
Operation systems: Windows
Programming language: Java
License: Sun Microsystems, Inc. Binary Code License Agreement for the JAVA SE RUNTIME ENVIRONMENT (JRE) VERSION 6 and JAVAFX RUNTIME VERSION 1

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1. Introduction

1.1. The research challenge

Residential mobility is one of the major drivers of urban land-use change. Numerous studies of residential mobility in continental Europe, the UK and the US have been carried out in attempts to explain mobility patterns based on housing choices and spatial segregation of the urban population (e.g., Börsch-Supan and Pitkin, 1988; Börsch-Supan et al., 2001; Lindberg et al., 1992). For a number of decades, developments such as urban growth and sprawling settlements dominated housing markets and residential mobility (Antrop, 2004; Kazepov, 2005; Loibl and Tötzer, 2003). Because it is increasingly occurring worldwide, urban shrinkage is currently a hot topic among urban planners (Rieniets, 2006, 2009). Shrinking cities hold huge oversupplies of dwellings and resulting vacancies (Haase et al., 2007; Jessen, 2006).

Urban shrinkage is a complex phenomenon resulting from processes of de-industrialization and out-migration and resulting population decline (Rieniets, 2009). In European cities, shrinkage also occurs due to processes of demographic change such as aging and a decrease in fertility (Kaa, 2004). An increase in the number of one and two-person households, as well as a shift in age-spectra and new forms of patchwork families, are also occurring (Lesthaeghe and Neels, 2002; Ogden and Hall, 2000). Such demographic features considerably affect residential location choices and land use within a city (Torrens, 2002) regardless of whether a city is growing or shrinking.

The eastern German city of Leipzig provides a perfect case for the study of demographic change and shrinkage and for the modeling of residential mobility and the creation of housing vacancies because it is representative of these general patterns worldwide. Because social scientists have developed a concept of household typology under demographic change (Buzar et al., 2005, 2007), such a case study offers a unique database for testing hypotheses on the behavior of urban residents with respect to residential decision-making. As argued by Haase and Haase (2007), this empirical database offers a unique base for construction of a data-based, agent-based model (ABM).

1.2. Objectives

The major objective of this paper is to simulate processes and patterns of residential mobility in a shrinking city using principles grounded in the social science concept of household types and using empirical data related to this concept. We aim to foster ABM development that covers human decision-making tested on independent data. By developing and applying a spatially explicit ABM named RESMOB*city*, we derive scenarios of diverging population and household trajectories and analyze the resulting residential land-use patterns. With the model RESMOB*city*, we present the first complex model

- that describes household agents developed based on a social science concept that reflects demographic transition and
- that is able to simulate urban population growth and shrinkage processes.

Because it is grounded in new and broad empirical data and concepts, we believe that the model provides an innovative contribution to the application of modeling techniques to challenging questions of social and land use science.

2. System analysis: given knowledge of processes, data and modeling concepts

2.1. A case in point for urban-shrinkage modeling: Leipzig

After the German reunification in 1990, most eastern German cities faced dramatic losses of inhabitants due to declining birth rates, job-driven out-migration to the western part of the country and a widespread catch-up suburbanization (Couch et al., 2005; Nuissl and Rink, 2005). From 1990 onwards, eastern Germany faced a loss of about 1.2 million people (8% of the entire stock; Kabisch et al., 2006). Most eastern German cities, among them Leipzig, lost between 10 and 25% of their residents in a short period of time (the mean value for large cities from 1990 to 1999 is about 16%). Accordingly, the population density of Leipzig dramatically decreased from 3.5 inh./m^2 in 1990 to 1.6 inh./m^2 in 2008. Economic resurgence of the city after 1998 and a new wave of reurbanization allowed net migration to increase and turned the balance of population to slightly positive. During the two most recent decades, the number of households have increased by 30%, and a simultaneous decline in the average household size, from >2.3 in 1989 to 1.8 in 2008, has occurred (Haase and Haase, 2007; Kabisch et al., 2009). Such processes of urban shrinkage are not limited to eastern Germany but are now faced by about 20% of the European city regions, predominantly in eastern Europe (e.g., Silesian cities and Romanian and Czech cities) but also in Central France, Napoli and Genova (cf. Kabisch and Haase, in press).

As a consequence of the demographic and economic decline, flats and housing stock have been falling vacant to an increasing degree despite the increasing number of households. Residential vacancy is no longer restricted to uninhabitable housing as it was during GDR times but also affects completely renovated building stock (Kabisch et al., 2006). Based on the present rate of increase in number of households we expect that supply will continue to exceed demand, even if present household numbers continue to increase until about 2017. Entire residential districts, parts of which have been demolished, exhibit vacancy rates >30 or even up to 50% (Jessen, 2006). Demolition produces new spatial patterns such as perforated structures with decreasing house density, demolished sites along the urban periphery, demolition corridors within a city and housing islands.[1]

2.2. New processes: second demographic transition and urban shrinkage

The demographic and shrinkage processes described above are not implemented in most recent land-use change simulation models (e.g., MedAction, Geonamica, UrbansSim, Sleuth, and GLUE-S). We thus offer a concept for translation of the above-described patterns that allows them to be used to identify distinguishable processes that can be coded in a dynamic model. This model is supported by references to social science concepts that aim to explain residential decision-making processes and respective household distribution patterns. By incorporating these concept patterns into the model, we can separate demographics from land use-related processes. Both processes are ultimately linked through the decision-making of people in urban regions, which affects their residential mobility.

The major demographic change occurring at present is described as the Second Demographic Transition (SDT) Lutz, 2001; this transition summarizes the current change and diversity of living arrangements other than marriage, the disconnection between marriage and procreation and the lack of a constant population. Additionally, urban populations face decline in many European countries (Kabisch and Haase, in press), though this decline is frequently neutralized by immigration. Extra gains in longevity in tandem with sustained sub-replacement fertility will produce a major additional aging effect as well (Cloet, 2003; Lesthaeghe and Neels, 2002).

The spatial differentiation of urban neighborhoods along different paths such as development, renewal, and decline, as well as large-scale demolition of entire housing estates, are not explainable by time series of demographic and economic variables obtained from local district statistics (Wegener and Spiekerman, 1996; Haase and Haase, 2007). Particularly in cities with declining populations, residential mobility is of major importance in determining the shape of residential land use. The total population and number of households are less important than general patterns and housing preferences when characterizing specific urban geodemographics (Gober, 1990; Kemper, 2001).

[1] As a new intervention strategy, a federal program of urban restructuring (titled in German ‘Stadtumbau Ost’) operates in terms of a guideline to organize and finance the demolition of overhanging housing stock (350,000 flats) and revaluation of the remaining residential areas.

Residential mobility thus belongs to a set of crucial processes that determine whether parts of a city are developed (built-up) or faced with vacancy and demolition (Torrens, 2002; Rees et al., 1996). At present, both increasing household diversification and declining population force cities into competition to attract new inhabitants or at least to motivate their residents to remain (Kabisch, 2005). Thus, a more fragmented residential land use emerges in which stable neighborhoods occur in the vicinity of those falling vacant; furthermore, the fact that some neighborhoods remain locked in the poverty trap is seen as a danger for the future of cities. Finally, by 'shrinkage' we denote a land use pattern in urban regions that is characterized by a high and increasing vacancy rate, demolition of buildings without rebuilding and an increase in open space and urban brownfield sites (Rieniets, 2009; Banzhaf et al., 2007). In shrinking cities, residential facilities show a surplus of vacant dwellings and an open residential market with a large number of affordable flats spread over the entire urban area (Jessen, 2006).

2.3. Methods of simulating residential mobility

Urban land use change, the development of built-up areas and the creation of residential vacancies result from actions by urban agents, e.g., people living in the urban region. This idea differs from concepts of land use change modeling that rely on statistical evidence of land use transitions (Silva and Clarke, 2002; Torrens, 2007; White et al., 1997; Wu and Webster, 1998; Wu, 1998). Agent-based models posit autonomous individuals (agents) who perceive their environment and interact with each other (Parker et al., 2003). Applications of agent-based modeling in land use change are usually spatially explicit, and agents represent, for example, households that are relocating their homes (Loibl and Töetzer, 2003; Waddell et al., 2003) or individuals using transport systems (Miller et al., 2004). Agent-based systems have recently gained popularity in migration and residential mobility research and in land use change modeling; in such modeling, individual agents interact with one another and with larger housing markets while also creating synthetic submarkets (Matthews et al., 2007; Evans and Manson, 2007). Agent-based approaches allow modeled representations of a range of different individual agents that act on the system under consideration, which in this case is the housing sector of a shrinking city, Batty, 2001). Such an ABM is based on the preference-driven decision-making of agents (residents) regarding their mobility and location (Earnhart, 2002; Loibl and Tötzer, 2003; Caruso et al., 2005). The preference profiles of the respective agents and their responses to contextual and environmental constraints represent are the major structural determinants of an ABM (Janssen and Ostrom, 2006; Garía and Hernández, 2007; Castle, 2006; Deadman, 1999; Wegener and Spiekerman, 1996).

Some of the recent applications of ABMs include the reproduction of demographic features as a means of understanding the evolution of society and the evaluation of economic systems (Gilbert and Doran, 1994; Kohler and Gumerman, 2000; Fontaine and Rounsevell, 2009). Some of these models seek to link human and natural systems at different spatio-temporal scales to understand changes in land use (Torrens, 2002; Parker et al., 2003). There are further decision-making-oriented models of the urban housing market (Eskinasi and Rouwette, 2004) and of segregation at the local district level (Pancs and Vriend, 2003). With some exceptions (e.g., Fontaine and Rounsevell, 2009), these models have no spatial representation.

In contrast to many of the urban models that are based on the urban growth paradigm of the 1980s/1990s (Schwarz et al., in press), it is still a challenge to model residential mobility in a shrinking city. Another problem of most existing ABMs is their limited empirical foundation and the resulting difficulties that occur in attempts to validate them (Evans and Manson, 2007). Recent studies have made greater efforts to validate ABMs than was the case during the inception of ABM applications (Janssen and Ostrom, 2006). Particularly in terms of land use change ABMs, a quality assessment can be performed either by matching the land use patterns produced by the

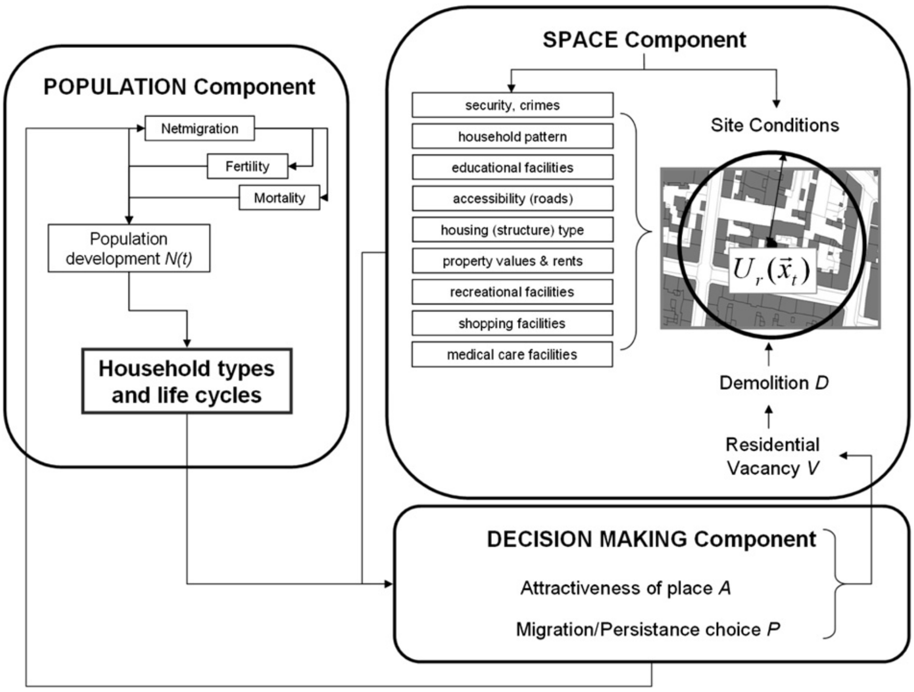


Fig. 1. RESMOB*city* concept —components, information flows and predictor variables. The agent-based model is a spatially explicit model and considers three main components: the population and household component, the spatial site component (where the population lives) and the decision-making component of the households. The households are mobile agents who can decide to change location at certain points in time, which are defined according to their life cycles (given in Table 1) according to specific rules that depend on their assigned attributes (site conditions $U_r(\vec{x})$).

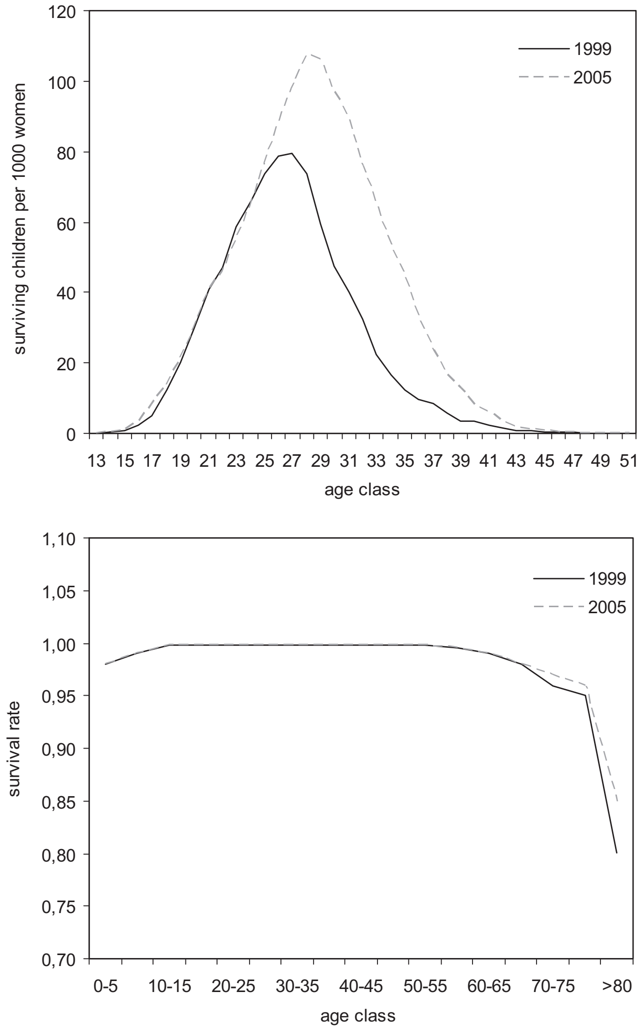


Fig. 2. Fertility and mortality curves are used to setup the population model. The data have been adopted from federal census data of Saxony dating for the two time slots that were used to define the three scenarios, 1999 and 2005.

model to observed data using error matricés (Pontius and Petrova, 2010; Pontius and Spencer, 2005), as with the use of a cellular automaton. Alternatively, attention can be focused on evaluating the spatial interactions inherent in the model by identifying spatial patterns that occur in a system as the result of spatial interactions (Evans and Manson, 2007). In this paper, each of these methods of model quality assessment was used to evaluate the specific output of our model.

3. Methods

3.1. Concept

The ABM RESMOB*city* is a spatially explicit model that includes three major components: (1) the population and household component, (2) the component of spatial locale of housing and (3) the decision-making component of the households. Fig. 1 illustrates these components and shows their interactions. The household decisions relate to the location of living, which depends on the recent life cycle of the agents as well as on the environmental and socioeconomic constraints of their environment, such as the price of a flat or house, accessibility of transport, and the social and recreational infrastructure forming the logic behind the decision-making.

3.2. Population

The process of population dynamics in RESMOB*city* is coded similarly to a Leslie-model and computes the population development using the parameters of fertility, mortality and net migration (Fig. 2). Parameters were derived from long-term census data of the Federal State of Saxony and the city of Leipzig (1993–2008).

In the model, individuals may enter the population of the city either by birth or by in-migration. Exchange of persons between age classes are unidirectional from younger to older, reflecting the aging process. Leaving an age class can occur by aging, out-migration or dying. (Eq. (1)): Let $\vec{N}$ be a vector of n age classes of the population at time t_i, and S be the transition matrix for each age class:

$$\vec{N}(t_{i+1}) = S\cdot\vec{N}(t_i) + \vec{M}(t_i) = \begin{pmatrix} n_1 & \cdots & n_n \\ s_1 & \ddots & \vdots \\ \vdots & \ddots & 0 \\ 0 & \cdots & s_{n-1} \end{pmatrix} \cdot \vec{N}(t_i) + \vec{M}(t_i) \tag{1}$$

where $N_i(t)$ $(i = 1,\ldots n)$ is the number of persons in age class i at time t and s_i is the survival probability of the age classes $1,\ldots,n$, e.g., $1-s_1$ denotes the infant mortality. Without loss of generality, we use time intervals of five years for the age classes. M denotes the net migration, which can be assumed to be a time-dependent driving force. The number of women in childbearing age classes, as well as the total fertility rate (TFR), which represents the number of (living) children per woman, constitute important factors. Based on the known parameters, the remaining unknown coefficients of the Leslie-model were identified by calibrating the population dynamics with the current demographic change, fertility and mortality census data of Saxony. The fertility peak is located in the age classes of 25–35. Due to a drop in fertility after 1990 (Council of Europe, 2004), we generally assume a low TFR of $\leq$1.1 children per woman. Conversely, mortality is assumed to increase in the future and to comprise values of 0.8 in the age class >80 (Fig. 2).

3.3. Households

Households were chosen to represent the agents. We distinguish the derivation of the agents from the population dynamics related to decision-making in the next section. By so doing, a link between the process of population dynamics and the socioeconomic processes of household decision-making is created. The core idea is to aggregate individuals of the population into households based on the modeled age structure. Empirical research has shown that household characteristics are a reliable proxy for residential decision-making at the person level (Buzar et al., 2007; Haase and Haase, 2007).

Household configurations change over time by birth, marriage, death and divorce. There is an existing overlay of dynamics of household development and demography (Leslie-model). We apply a concept of household types based on findings of social science regarding demographic transitions (Buzar et al., 2005, 2007); in such transitions, households become smaller and change more quickly, and living arrangements are adapted to individual life scripts (van de Kaa, 2004; Ogden and Hall, 2000). In RESMOB*city,* we define household types in accordance to Buzar et al. (2007), including more traditional

- family households with dependent children,
- elderly one-person households and

Table 1
Household types (H) and their demographic properties, the number of persons per H and average survival time T_j (years; according to Buzar et al., 2005) of staying in one place (in one flat) and share of age classes N_i per household type H_i.[a]

H	Age classes involved	Number of persons	Survival time T_j (years)
Young single (YS)	18–<45	1	5
Young cohabitation (YC)	18–<45	2	5
Elderly single (ES)	>45	1	20
Elderly cohabitation (EC)	>45	2	30
Family with dependent children (F)	18–<45; <18	3–5	18
Single parent family with dependent children (SPF)	18–<45; <18	1–3	12
Unrelated flatshares (FS)	18–<45	2–4	5

N_i

H_j	$N_{i\ 1\ldots4}$	$N_{i\ \ldots-6}$	$N_{i\ 7\ldots8}$	$N_{i\ 9\ldots10}$	$N_{i\ 11\ldots12}$	$N_{i\ 13..14}$	$N_{i\ 15\ldots16}$	$N_{i\ 17}$
YS	0	0.22	0.24	0.22	0	0	0	0
YC	0	0	0	0	0.21	0.23	0.29	0.4
ES	0	0.11	0.18	0.27	0	0	0	0
EC	0	0	0	0	0.34	0.64	0.61	0.3
F	0.7	0.3	0.28	0.35	0.35	0.09	0	0
SP	0.3	0.13	0.12	0.11	0.1	0.04	0	0
FS	0	0.24	0.18	0.05	0	0	0.1	0.3

[a] The results of questionnaire surveys conducted in several districts of Leipzig were used to determine the age class proportions for each of the household types. In doing so, the proportions found in the questionnaire sample were transferred to the total population of the city in 1990 as the starting year of the simulation.

Table 2
Weights w_{ij} of the attractiveness A of a location $\vec{x}$ for the household types $1 \ldots m$ using the descriptors $I_{1 \ldots k}$.

Descriptor $I_{1 \ldots k}$	Young single	Young cohab.	Elderly single	Elderly cohab.	Families	Single-parent families	Flat-sharer
Young single	0.053	0.048	0.011	0.010	0.018	0.028	0.052
Young cohabitation	0.018	0.018	0.068	0.062	0.018	0.018	0.013
Elderly single	0.048	0.060	0.023	0.021	0.018	0.018	0.039
Elderly cohabitation	0.018	0.018	0.068	0.062	0.018	0.018	0.013
Families	0.024	0.024	0.023	0.021	0.018	0.046	0.064
Single-parent families	0.024	0.036	0.023	0.021	0.036	0.046	0.026
flat-sharer	0.036	0.036	0.023	0.021	0.018	0.018	0.077
City center	0.031	0.033	0.032	0.016	0.015	0.022	0.021
Multi-story 1960s	0.033	0.033	0.032	0.016	0.015	0.022	0.021
Prefab estates GDR	0.045	0.023	0.034	0.016	0.013	0.013	0.003
Residential park 1990s	0.000	0.031	0.005	0.027	0.036	0.037	0.015
Single house area	0.000	0.014	0.027	0.033	0.026	0.017	0.013
Tenement blocks 1870s	0.059	0.026	0.027	0.012	0.016	0.015	0.064
Villas	0.000	0.002	0.020	0.043	0.026	0.013	0.046
Multi-story suburbia 1990s	0.026	0.026	0.023	0.023	0.024	0.020	0.018
Sport, leisure	0.036	0.048	0.011	0.010	0.036	0.037	0.039
Parks,	0.024	0.024	0.045	0.041	0.027	0.028	0.026
Allotments	0.012	0.024	0.056	0.051	0.036	0.018	0.013
Cemetery	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Open land, farmland	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pastures, grassland	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Forest	0.024	0.036	0.045	0.041	0.027	0.028	0.013
Brownfields	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rivers	0.048	0.040	0.023	0.041	0.018	0.018	0.013
Lakes	0.024	0.024	0.023	0.041	0.046	0.037	0.013
Crime rate > mean	0.060	0.038	0.023	0.021	0.009	0.009	0.064
Crime rate < mean	0.012	0.024	0.045	0.041	0.036	0.037	0.013
School <250 m	0.012	0.024	0.011	0.010	0.055	0.074	0.013
School <500 m	0.012	0.024	0.011	0.010	0.055	0.074	0.013
School >500 m	0.012	0.002	0.011	0.010	0.055	0.074	0.013
Shop <250 m	0.012	0.012	0.056	0.051	0.036	0.028	0.013
Shop <500 m	0.024	0.024	0.045	0.041	0.027	0.028	0.026
Shop >500 m	0.060	0.048	0.011	0.010	0.018	0.018	0.064
Maximum flat/land price (€)	0.060	0.039	0.034	0.062	0.091	0.046	0.026
Rent <5€/m^2	0.024	0.042	0.045	0.041	0.018	0.028	0.052
Rent >5€/m^2	0.048	0.030	0.011	0.021	0.046	0.018	0.013
Public transport <500 m	0.024	0.024	0.045	0.041	0.027	0.028	0.026
Public transport >500 m	0.060	0.046	0.011	0.010	0.018	0.018	0.064

- elderly couples (mostly married) as well
  as a group of new or non-traditional household types, such as
- young one-person households,
- young unmarried couples or cohabitation households,
- single parents and
- unrelated adults sharing a common flat.[2]

Table 1 lists the households and their decision-making parameters[3] related to choice of housing location.

The functional relationship between the age structure of a population and the distribution of its households is defined by a matrix, Φ, which maps the total population N with n age classes to m household types in the form (see Table 2):

$$H_j(t) = \sum_{i=1}^{n} \Phi_{i,j} N_i(t), \text{ with } \sum_{i=1}^{n} \Phi_i \leq 1 \tag{2}$$

where H_j is the number of households of type j and Φ is the distribution of n age classes of a population N at time t. Questionnaire surveys conducted in Leipzig in several municipal local districts (Kabisch, 2005) were used to determine the age class proportions for each of the household types. In so doing, the proportions found in the questionnaire sample were extrapolated to the total population of the city in 1990 as the starting year of the simulation. Similarly, the total population number and age class distribution can be derived from the household pattern at a time t to check the plausibility of the household formation algorithm. In the dynamic simulation, households can be tracked throughout all life stages. The basic characteristics of households are given in Table 1. Young singles, young cohabitation and flat-sharer households have a higher flexibility in their residential choice than elderly single and cohabitation households or families. The household transition dynamics from one type to another functions according to a transition and persistence restriction matrix.

In RESMOB*city*, household agents are assumed to be autonomous and goal-directed objects that are part of and respond to their environment, are economically independent and occupy one flat (Buzar et al., 2005; Haase et al., 2005). Given the real population of Leipzig (approx. 510,000 in 2008), the model consists initially of approx. 250,000 agents. Households interact through their preference-driven choices of housing locations and influence residential land use accordingly.

3.4. Decision-making of the household agents

Housing choices are determined by variables including social environment (social class, lifestyle, household type), income, financial budget and the accessibility of public infrastructure. Because a shrinking city with an unsaturated housing market provides an oversupply of affordable flats (Jessen, 2006), more variables regarding housing choice than simply affordability must be taken into account. Thus, in the model, households' preferences are driven by the multifactorial indicator matrix A denoting the attractiveness of a potential housing unit or location.

Indicators that are used to estimate household preferences are aggregated in an attractiveness matrix summarizing a set of descriptors $I_{1 \ldots k}$ (Table 2). These indicators result from the findings of household-based questionnaire surveys conducted in Leipzig and other European cities (Buzar et al., 2007; Steinführer, 2005;

[2] Within the Second Demographic Transition, worldwide households change considerably in size and form (Buzar et al., 2005, 2007). Households become smaller and less stable and are defined as more subject-oriented, and living arrangements are adapted to individual life scripts (Kaa, 2004; Ogden and Hall, 2000). Within the FR5 EU Project Re Urban Mobil (www.re-urban.com), households in selected districts in four European cities were classified according to their types. The resulting clusters of classic household types (i.e., family, elderly one-person households and couples) and those designated "new" or non-traditional household types (i.e., young one-person households, young couples, single parents, unrelated adults sharing a common flat) provide a highly innovative conceptual model of the residential agents living in a city region. In this paper, we dropped this aspect of "new household types" and simply explain the need of households for an aggregated description of activities in the urban area. For further information on the household type concept, please refer to the literature discussed above.

[3] Derived according to the empirical results of the FR5 EU Project Re Urban Mobil (www.re-urban.com).

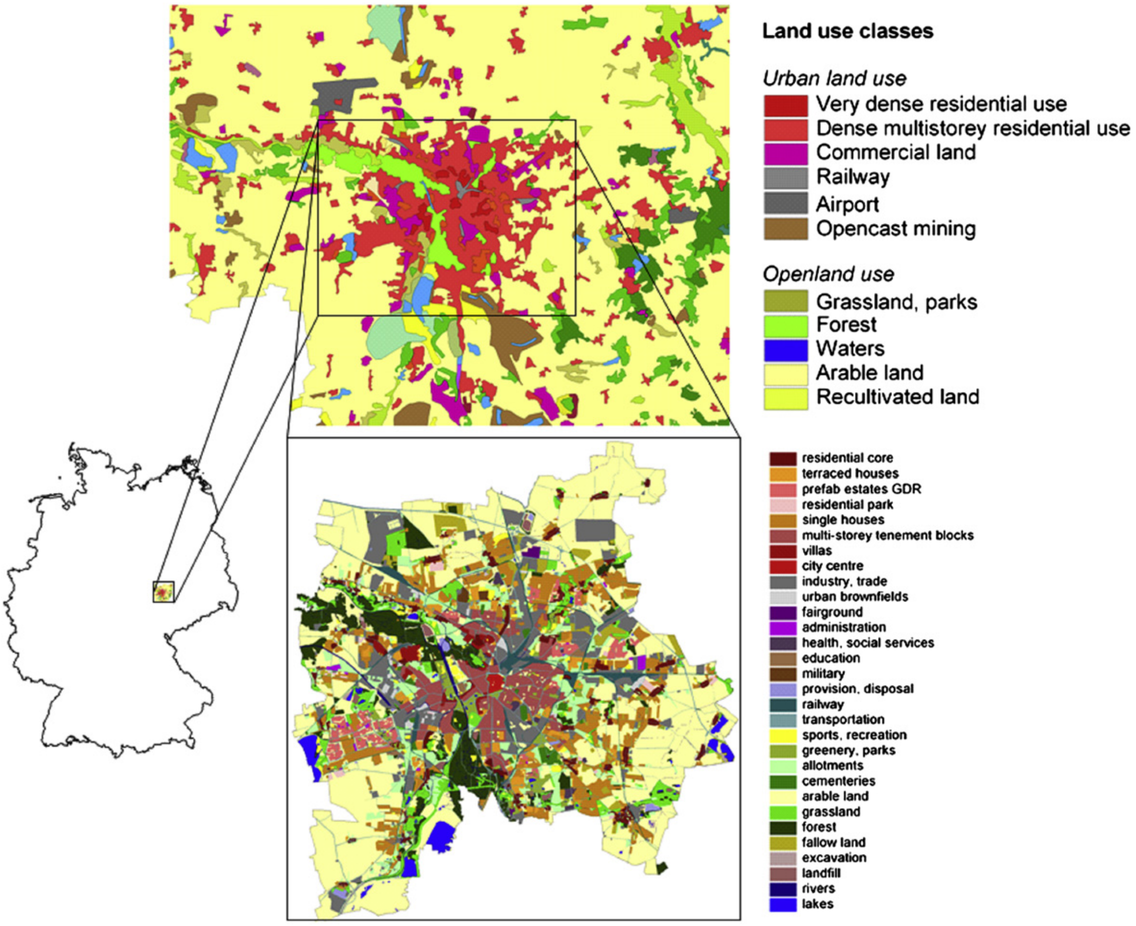


Fig. 3. Land use (upper map) and residential pattern (lower map) in the region and city of Leipzig (data sources: Corine Land Cover, 2000, EEA; own data).

Steinführer et al., in press) in the form of systematic variable rankings, proportions, and choices. The weights *w* are derived using the ordination (ranking) of individual systematic variables obtained in the surveys. Quantitative rankings or proportions given as answers in the questionnaires were translated to preference probabilities/weights between 0 and 1 for each indicator; qualitative valuations given in Likert scales were similarly standardized between 0 and 1. Answers in form of Boolean values (yes/no) were coded as 1 and 0. In addition to descriptors obtained from the questionnaire, descriptors used in preference profiles developed by other ABM (Clark and Huang, 2003) are also considered. The preference descriptors $I_{1...k}$ represent the socio-demographic (household patterns in the neighborhood), economic (costs, flat and house prices), spatial (accessibility, distances) and recreational (greenery, waters) environment of the households expressed in a mean attractiveness $A_j(\vec{x})$ of a household type *j* and a residential location $\vec{x}$ (flat, tenement block) and its surroundings denoted by $U_r(\vec{x})$. *U* specifies the surrounding of a location $\vec{x}$ with radius $r = 500$ m in the RESMOB*city* (see Fig. 3).

The spatial configuration and representation of the urban residential and open land use are defined by a regular lattice with cells and their location $\vec{x}$ with a grid cell size of 10 m. The attractiveness *A* of a place $\vec{x}$ for a household H_j to live is formally

$$A_j(\vec{x}) = \sum_{k=1}^{l} w_{j,k} I_k(U_r(\vec{x})), \text{ with } \sum_{i=1}^{n} w_{j,k} \le 1 \tag{3}$$

where A_j is the attractiveness between 0 and 1 (1 most attractive) of a location $\vec{x}$ for a household H_j, *w* is the weight of the preference descriptor *I*, and $I_{1...k}$ are the preference descriptors. For the model, it is crucial to create differentiated and, at best, "realistic" behavioral agent profiles for the household types.

Decision rules for residential migration are based on simple additive weighting of the type that is used by the most popular decision-making methods. This type of weighting ranks the included variables (controlled by expressing the indicator's importance) according to their estimated importance. Additive weighting assumes additive aggregation of the normalized descriptor values, which converts the multidimensional values of the attractiveness matrix into non-dimensional values ranging between 0 and 1.

Households migrate if a location $\vec{y}$ is more attractive than a location $\vec{x}$ and, further, if a household-specific time (designated by T_j) has passed since the household's last change of location. Thus, if time since last movement of a household *j* exceeds T_j years (Table 1; cf. Buzar et al., 2005), a list of locations that are more attractive than the recent location is generated.

$$M_j(\vec{x}) = \{\vec{y}_i,\ i = 1,2,...|\ A(\vec{y}_i) > A(\vec{x}),\ A(\vec{y}_i) > A(\vec{y}_{i+1}),\ i = 1,2,..\} \tag{4}$$

Note that the list of locations for movement *M* are sorted by its attractiveness.

Table 3
Data used to run and test the RESMOB*city* model. The census data of the municipal statistics were used to calibrate the model; the independent micro census data of Saxony were used to validate the population model (cf. Fig. 7).

Variable	Data set; reference
Calibration	
Population	Micro-census of Saxony
Households	Micro-census of Saxony; Empirical survey UFZ 2003–2004
Rents, (Land) Prices	Information from local financial institutes; Municipality of Leipzig
Land Use	German topographic information system (ATKIS) 2006; Haase and Nuissl, 2007
Infrastructure (education, medical care)	ATKIS 2006; Haase and Nuissl, 2007; Municipal statistics
Transport	ATKIS 2006
Crimes	Municipal statistics
Residential vacancy	Municipal statistics
Shopping facilities	Municipal statistics; Internet survey of the shopping enterprises
Urban greenery	ATKIS 2006; Haase and Nuissl, 2007; Municipal Agency for Environmental Planning
Plausibility test	
Population	Municipal census data
Households	Municipal statistics

Table 4
The three scenarios used to test the model.

	Fertility	Net migration	No. of households
Scenario *Stagnation*	linear extrapolation of trend 1999–2005	linear extrapolation of trend 1999–2005	300,000
Scenario *Growth*	2× linear extrapolation of trend 1999–2005	2× linear extrapolation of trend 1999–2005	320,000
Scenario *Shrinkage*	−2× linear extrapolation of trend 1999–2005	−2× linear extrapolation of trend 1999–2005	240,000

Thus, movement of households can easily be computed by moving through the list top-down seeking for matching free living space within the map of vacancies.

3.5. Residential land use, vacancy and demolition

In case of non-satisfaction with the residential location and after a series of attempts to find a new suitable flat, out-migration can increase. Simultaneously, the share of residential vacancy increases in those parts of the city that do not or only partially fulfill the housing preferences of the households. Residential vacancy is formally expressed as follows:

$$V(\vec{x},t) = F(\vec{x},t) - \sum_{j=1}^{m} H_j(\vec{x},t) \quad (5)$$

where V is the residential vacancy in percent and F the number of available flats at a land parcel $\vec{x}$ and time t. Note that because new houses might be built up or demolished, F can vary in time. Demolition occurs when a households more than 90% vacancies over a time span of 5 years. Vacancy occurs at the level of single dwellings within a house; it can also increase to completely vacant housing estates (100% vacancy). We further assume that a house becomes unlivable after being vacant for over 5 years; at that time, its maintenance and reconstruction costs exceed by far the rental income that would be obtained through new residents. The resulting demolition rate, D_F, of flats is coded accordingly in the model.

4. Implementation

4.1. Model setup and iterations

The spatial discretization of the simulation model refers to a classification of the city area into local districts and detailed land parcels. These result from an intersection of the vector-based municipal local districts and the land use map. This procedure creates the spatial model units and the number of houses and flats in each. The initial values for the first model iteration are taken from either empirical or census data and from municipal statistics provided on raster maps, using the above-mentioned information and data from Table 3. After each run, a range of output files is created that contains all output variables including age classes, household type numbers, number of (filled and vacant) flats and demolished houses. The simulation is based on iteration, assuming one year in reality for each time step.

A simulation is initiated by the determination of an initial distribution of households in the region, based on the real household distributions (Buzar et al., 2007). It is followed by the determination of attractiveness of a site $(\vec{x})$ for each household type H_j according to Eq. (3). The difference in attractiveness for a given pair of locations $(\vec{x};\vec{y})$ for all households H is then calculated. For each household, the individual preference to stay or to move to a more preferred location is calculated; from this, the number of all households H that intend to move can be determined using Eq. (4). Migration of all households is then instantiated as far as new housing space is available or can be built up. In one iteration step, the spatial distribution of households changes as new vacancies are created or houses are demolished, which may impact the suitability of housing for the next time step.

4.2. The test site-specific implementation

Leipzig is characterized by an urban core of old, built-up tenement blocks with patches of 1920s–1930s buildings (local municipal districts of Südvorstadt, Neustadt-Neuschönefeld and Alt-Lindenau), multi-story houses and comfortable villas. During the GDR era, these housing estates were occupied by better-off families with above-average educations. In the eastern and western parts of the city, we find mixed-area residential and 19th century industrial areas. Adjacent to the old town center and to large GDR-era prefabricated estates such as Grünau in the west, Lößnig in the southeast and Paunsdorf in the east, a peri-urban ring of single and semi-detached houses such as Meusdorf is present (see Fig. 3). Residential vacancies are primarily concentrated in the old built-up areas (up to 50%; average ≈25%) and, secondarily, in the prefabricated newly built-up areas (≈20%).

A land use vector map (Haase and Nuissl, 2007) and the city's cadastral database are used to define residential land use and urban

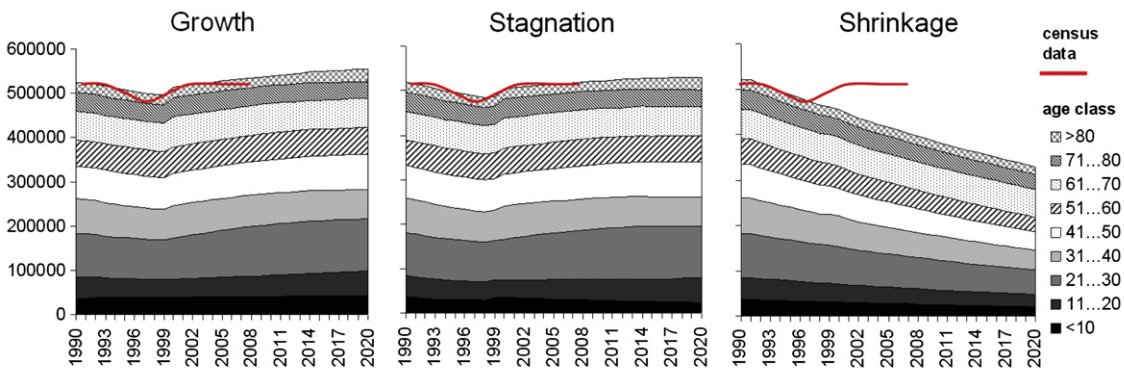


Fig. 4. Simulated total population and age class (<10 … >80 years) development for 1990–2020 for the *stagnation*, the *growth* and the *shrinkage* scenarios. In both the *stagnation* and the *growth* scenarios, in-migration leads to an increase of the young adults, whereas the number of children remains low in all three scenarios, particularly for *shrinkage*. Aging – that is, the relative increase of the elderly population – can be found in all three scenarios. For comparison, the population development in Leipzig from 1990 to 2008 is shown in red (data: Census by Municipal Agency for Statistics and Elections). The census data show the decrease of the total population after the German reunification, the increase in 1999 due to the enlargement of the admisitrative area of Leipzig and the slow but steady increase of the total population after 2000 (which could be replicated in the simulation results of the *stagnation* and *growth* scenarios). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

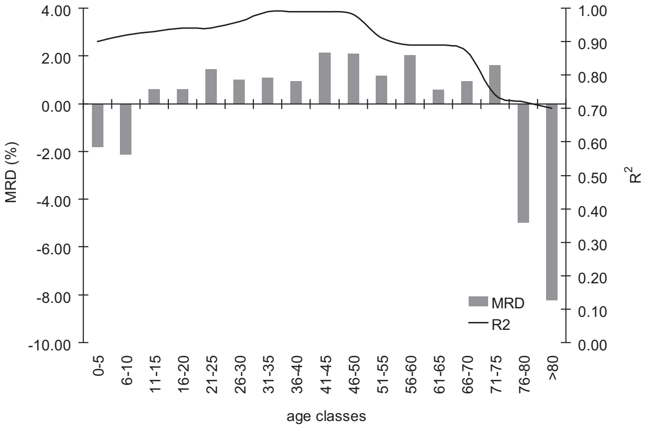


Fig. 5. Assessment of the simulated age class values versus the observed values provided by municipal census data for 1990–2005 using a bivariate regression (R^2) and the MRD (%). The very young age classes (0…5, 6…10), as well as the old age classes (76…80, >80), are underestimated in total numbers by the model, whereas all other age classes are slightly overestimated.

green spaces. The latter is then incorporated into the model for use in determining the overall accessibility (distance in meters) of urban greenery (parks, sportsgrounds, forest, etc.) for any given location. Distance functions calculating the accessibility to transport, shopping and educational infrastructure are derived using vector data of road networks and the locations of schools and supermarkets.

4.3. Empirical database and derivation of preference descriptor weights

The model is based on a large set of quantitative empirical data stemming from several questionnaire surveys on housing preferences conducted in Leipzig as well as in other European cities of comparable size and structure (Buzar et al., 2005, 2007; Kabisch, 2005). The data are available as an SPSS database. Overall, only attributes ranking higher than rank 20 in the importance scale of the questionnaire surveys were used to derive values for the model. To derive preference weights for the different housing attractiveness descriptors, respective data attributes were dedicated to the descriptor (e.g., the answers given to the question "How important is surrounding green space for you?"). A qualitative Likert-scale was used to determine the weights for the descriptors parks, open land and cemeteries.

4.4. Scenarios for model analysis

Three scenarios are used to analyze the model. In these scenarios, agents and their behaviors (e.g., household distribution and decision-making) remain constant; only population dynamics and migration pattern are varied. In this way, we are able to assess the impact of agent-based decision-making on the land use change pattern of the study region. Additionally, these scenario assumptions are of interest to decision makers such as local planners. Table 4 summarizes the scenarios and respective parameter assumptions, which can be described as follows:

1. The current situation of population development in Leipzig is represented in the *stagnation* scenario: fertility and in/out-migration as in 1999–2005,
2. the *growth* case assumes a positive fertility and stronger in-migration and
3. the *shrinkage* scenario considers a demographic decline with negative trends in both fertility and net migration.

5. Results

5.1. Population dynamics

The model outputs show three different paths leading to future population development in Leipzig. The real population growth between 1990 and 2008 (from 450,000 in the mid 1990s to about 510,000 in 2008; red graph in Fig. 4) is replicated by the model under the *growth* and the *stagnation* scenarios. In the *stagnation* scenario, we find almost no future population growth; the *growth* scenario shows a moderate population growth such that the total population is about 540,000 in 2020 (Fig. 4). In comparison, the *shrinkage* scenario projects a steady population decline from >500,000 inhabitants in 1990 to <400,000 in 2020.

Age structure in both the *stagnation* and *shrinkage* scenarios shows a decrease in newly- born children due to the low TFR. Under all three scenarios, the model computes a smooth decrease in the teenage population (11–20 years) from 1990 to 2000, following which this age class again increases under the *growth* and *stagnation* scenarios. Due to an increase in (an assumed) influx of students, the model predicts an increase in the young age classes (ages 20–30) for both the *growth* and the *stagnation* scenarios. All three scenarios result in a moderate increase in the elderly classes aged >60 years, which means that the population of Leipzig is aging regardless of its actual growth or shrinkage.

An assessment of the population model quality can be performed using the municipal census data available for 1990–2005.

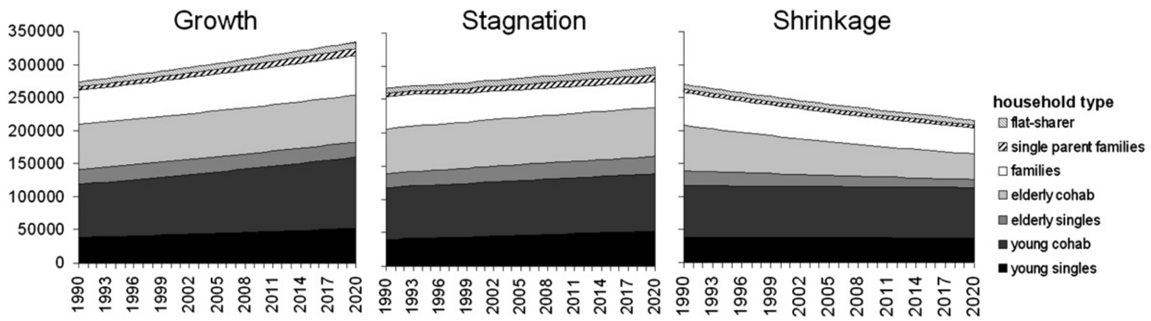
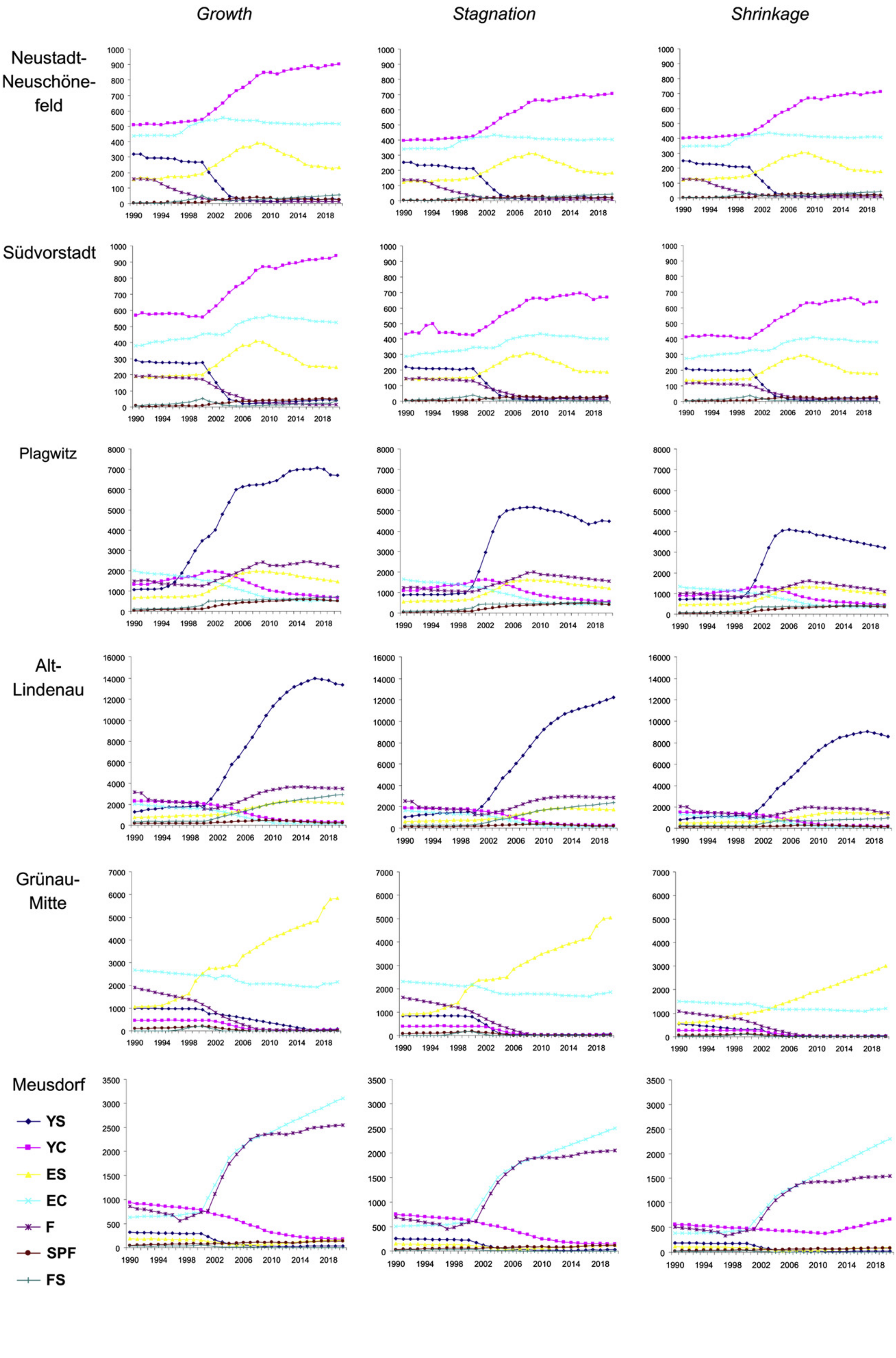


Fig. 6. Simulated number of the seven different household types used in RESMOB*city* for the *growth*, *stagnation* and *shrinkage* scenarios for 1990–2020. In each of the scenarios, we find an increase in young households, both single and cohabitation. In accordance with this finding, we find in the *growth* and *stagnation* scenarios a non-growth of the family households, while in the *shrinkage* scenario, the number of family households considerably decreases. By comparison, the number of single parent families increases regardless of the growth or decline of the total population.

Fig. 7. Probability values of the spatial distribution of young single households, elderly cohabitation households and family households in Leipzig for the three time steps of 1990, 2000 and 2020 (*stagnation* scenario). We find an increasing concentration of young singles in the inner part of the city; this reflects their preference for being highly mobile and well-connected to the public transport, as well as the positive image of the old built-up type of residential housing located there. Elderly couples, by comparison, are preferentially located in the outer parts of the old and pre-WW II built-up part of the town, which is cheaper but has longer travel distances to the city center. Families tend to move to the peri-urban parts of the town, where mostly single house areas are situated.

In performing this assessment, we applied a bivariate regression for analyzing the relationship between the dependent variable (simulated) and the independent (observed) variable; we also used the mean relative deviation (MRD in %) to show how close the simulation results are to the independent census data by predicted-observed plots (Fig. 5). The latter method expresses accuracy as a percentage but not in absolute terms, which is suitable for our purpose because we want to show and discuss the polarization of the errors. We assume the population model results are plausible if $R^2 \geq 0.75$ (25 percentile; Fox, 1997) and the MRD equals $|\leq 10\%|$ (Wackernagel, 1998). Plotting the model age classes of the *stagnation* scenario against independent statistical data, we achieve R^2 greater than 0.75 for all age classes except the >70 year-old class. Using the MRD, we see that the model


Growth
Stagnation
Shrinkage
Neustadt-Neuschöne-feld
Südvorstadt
Plagwitz
Alt-Lindenau
Grünau-Mitte
Meusdorf
YS
YC
ES
EC
F
SPF
FS

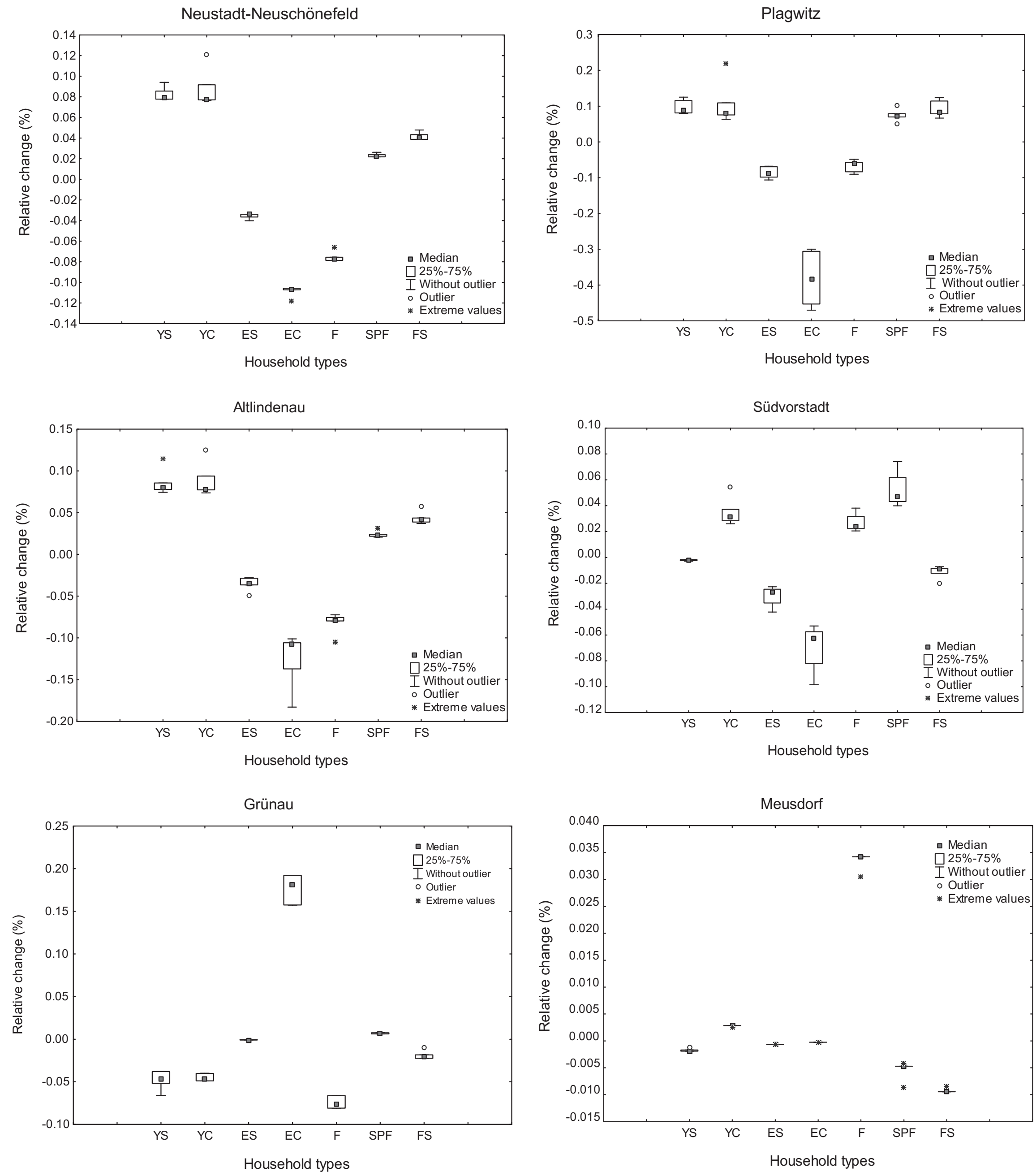


Fig. 9. Relative change rates across all three scenarios 1990–2020 of household types *1…m.* where YS is a young single household, YC a young cohabitation household, ES an elderly single household, EC an elderly cohabitation household, F a family household, SPF a single parent family household and FS a flat-sharer household (see Table 1) in 6 selected municipal local districts of Leipzig: the old built-up "low-image" district of Neustadt-Neuschönefeld, the old built-up "high-image" district of Südvorstadt and the socialist pre-fabricated housing estates of Leipzig-Grünau. The size of the boxes reflect parts of the uncertainties of the age/class simulation, particularly in the family and elderly single and cohabitation households.

systematically underestimates both the very young age classes (0…5, 6…10) and the old age classes (76…80, >80) by a small amount compared to the census data. All other age classes are slightly overestimated (Fig. 5). The reason for the underestimation of the very young and the old age classes might be that we assume average fertility and mortality rates for all residents regardless of their gender or ethnicity and regardless of the effects of these factors on longevity. Because we do not feed a specific share of gender and ethnicity within the annual in-migration into the model but instead use average data here, we underestimate particularly the aged. Despite these minor deviations from the census data, the population model results meet the quality criteria defined above.

Fig. 8. Scenarios of household pattern (distribution of household types *1 … m* where YS is a young single household, YC a young cohabitation household, ES an elderly single household, EC an elderly cohabitation household, F a family household, SPF a single parent family household and FS a flat-sharer household, see Table 1), aggregated age class distribution (children, working age, pensioners) and trend of the average age of selected local municipal districts of Leipzig 1990–2020. The districts include the old built-up districts of Neustadt-Neuschönefeld, Südvorstadt, Plagwitz and Alt-Lindenau, the GDR-era prefabricated multi-story district of Grünau and the peri-urban single house area of Meusdorf in the peri-urban part of the city.

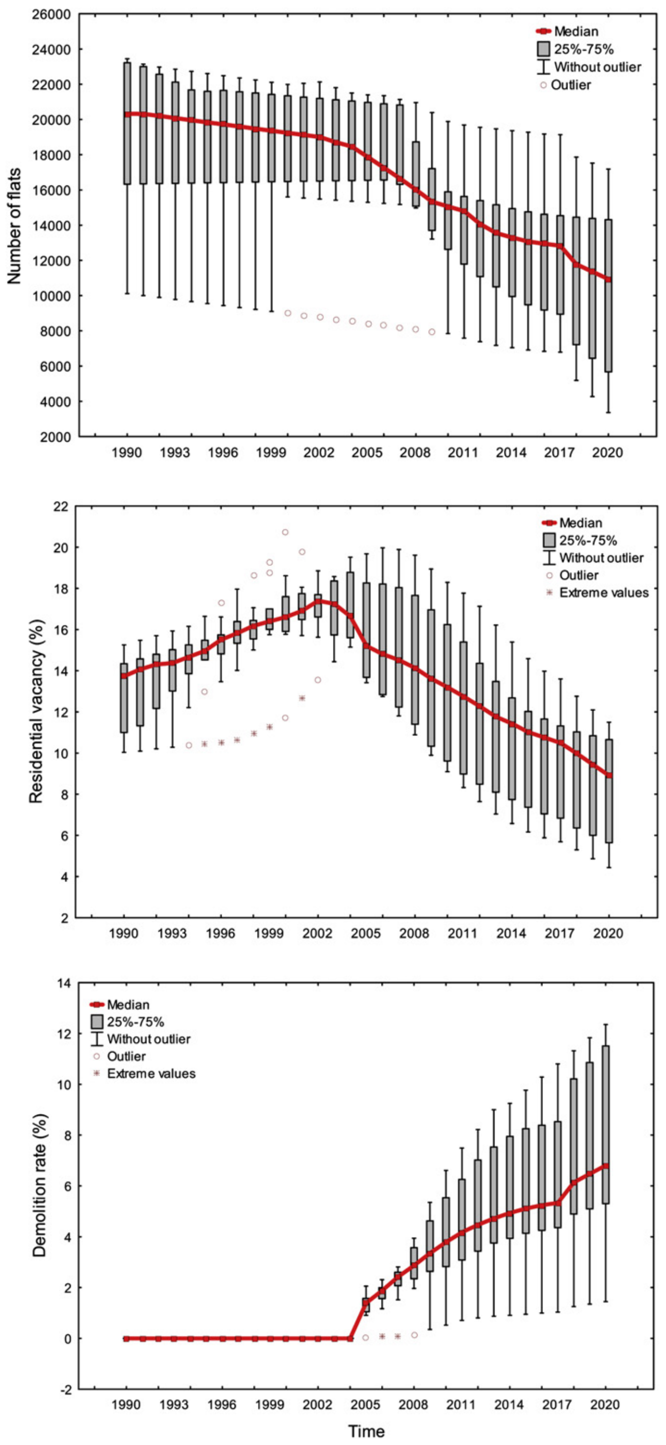


Fig. 10. Simulation of the past and future development of the residential land use of the city of Leipzig across all three scenarios using the model variables of the number of flats, the share of residential vacancy and the related demolition rate at the municipal district level for the period 1990–2020.

5.2. Household dynamics

The household simulation results show that the number of non-traditional young and elderly single households, as well as the number of young cohabitation and flat-sharer households, increases regardless of population growth or shrinkage (Fig. 6). The model well reflects theoretical considerations of an increasing individualization formulated by Giddens and the SDT or a regaining

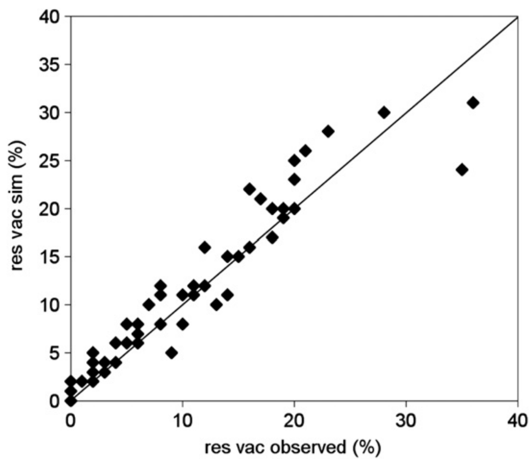


Fig. 11. Simulated residential vacancy (%) versus measured residential vacancy (%) for all 63 municipal districts of Leipzig for 2004 for the *stagnation* scenario (the only reliable available estimation of existing housing vacancy).

of attractiveness of the inner city (Burton, 2000, 2003) for young professionals. The results of the household simulations are also in accord with empirical findings on other European cities such as Paris, Bologna and León (cf. data published in Buzar et al., 2007; Ogden and Hall, 2000). 'Accord' means here that both development trend (positive, negative) and share (relative percentage of the total population) of the respective household types are similar to survey and literature findings. Next to young households, elderly ones contribute most to the increase in single and cohabitation households in the inner city; they rise in terms of their total numbers and particularly their share per local municipal district. Conversely, the number of families, which still represents the highest number of residents due to its household size of 3–5 persons, decreases, at least in the *stagnation* and *shrinkage* scenarios (Fig. 6). Single parent families, by contrast, increase.

The spatial household patterns simulated by RESMOB*city* are, in part, the result of spatial interactions between the agents ("like my neighbor") but may also be the result of relatively simple factors such as distance or accessibility to social or transport infrastructure. The relative importance of these factors cannot so far be explained by the model. Because no observed spatial data for household distribution in Leipzig are available, a map comparison, as suggested for assessing spatially explicit land use change models (Pontius and Petrova, 2010), is not feasible.

Fig. 7 gives an idea of the spatial change in probability of the concentration of young singles, elderly cohabitations and family households in Leipzig from 1990 to 2020 using a range of values from 0…1. Compared to a more equal spread in 1990, in 2020 young singles will primarily reside in old 19th century built-up districts of the inner city, along with a simultaneous decrease in their residence in the 1920s to 1930s, 1960s and GDR-era prefabricated housing estates. The model thus predicts a concentration of young people in the inner city, likely because it is close to the city center and provides better access to public transport facilities, labor and other socio-cultural facilities. This mode behavior is supported by recent empirical research on inner city reurbanization processes in Leipzig, in which an increasing influx of young (<45 years old) and mobile households to the inner city since 1995 was found (Kabisch et al., 2009).

By comparison, elderly cohabitation households assemble in either the 1920s to 1930s, the 1960s or the GDR-era prefabricated housing estates because, for them, lower rents and housing costs are more important than high accessibility values. The families meanwhile concentrate in the single house areas in both the inner and outer parts of the city. Overall, RESMOB*city* simulates an

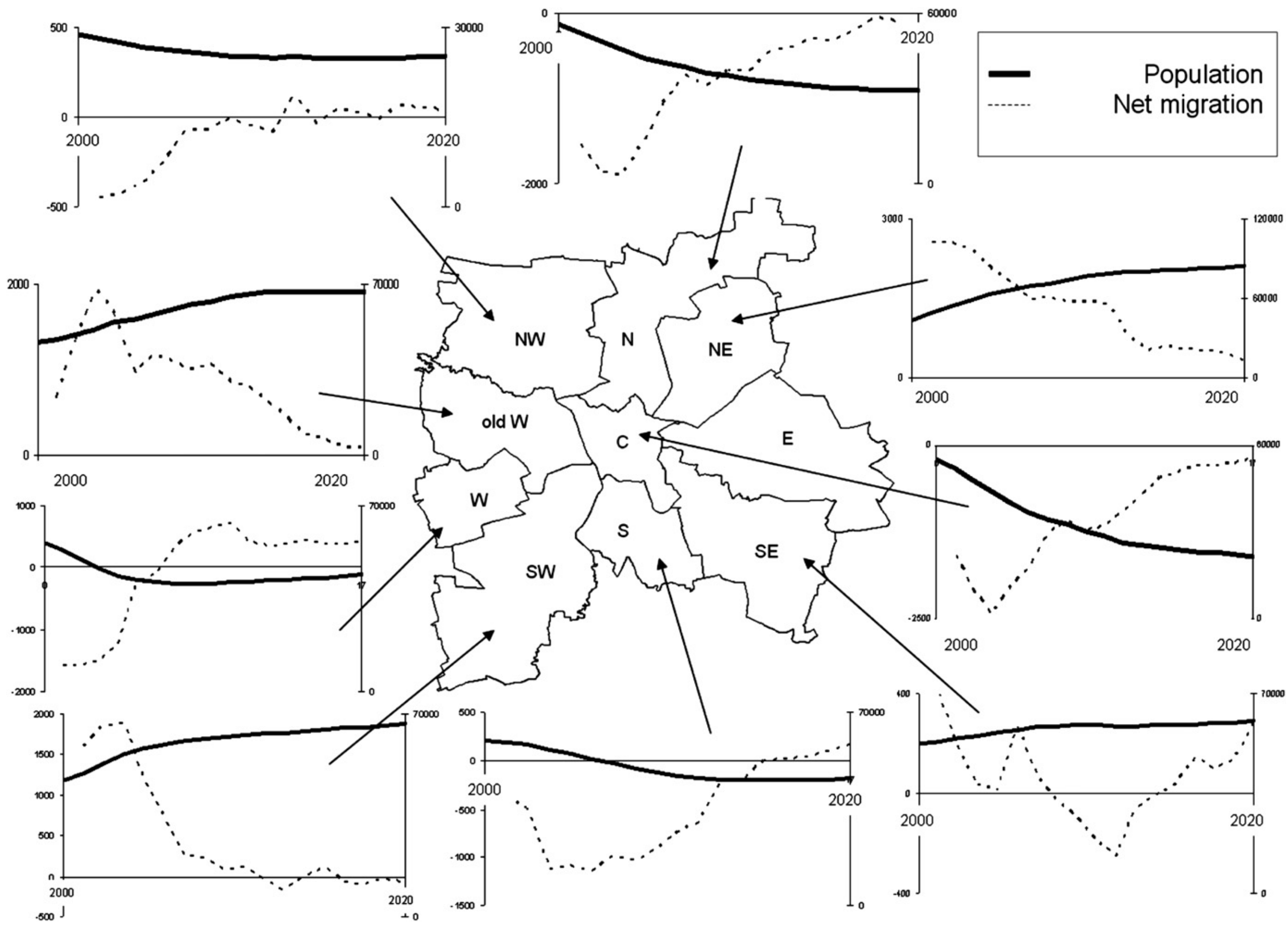


Fig. 12. Summary of trajectories of population growth and net migration at the municipal district level of the entire study area of Leipzig for 2000–2025 for the *stagnation* scenario (based on the smaller local municipal districts; the larger municipal districts are summarized and labeled by cardinal points here. C denotes the Central district).

increasing segregation of the different household types in Leipzig. Based on these findings, we hypothesize that after a phase of relative mixture during socialist times, the reverse process of increasing social segregation carries more and more significance.

Spatial segregation patterns of both household types and age classes offer novel and challenging insights into a future spatial housing geography of European (shrinking) cities (Figs. 8 and 9). In the old built-up local municipal districts such as Südvorstadt, where urban sociologists assume that something like gentrification is occurring, an increase in and relative gain of young single, but first and foremost, young cohabitation households is simulated. Inner city residential areas of this type, which have a positive image as well as proximity to green and other kinds of urban infrastructure, are preferred for long-term residency and during the family formation phase. We find a lower number of flat-sharers here.

In 2020, the district seems to be saturated, which explains the lowering of the influx projected at that time. By comparison, at that time other old 19th century built-up districts evidence high vacancy rates, suggesting an image of a place for the deprived class such as Plagwitz or Altlindenau. In these areas, the model simulates a high influx of mostly young single households and flat-sharers (Fig. 8), which means that shorter persistence (living-in) times dominate within one flat, resulting in a higher through-flux of households within this structure. Remaining young cohabitation (dinks[4]) and elderly households either profit from short distances and good access to social and transport services or do not want to leave their areas. In summary, we find positive relative changes of young households in these deprived old built-up districts, along with positive relative changes in the number of single parent families, whereas families leave these districts (Fig. 9).

These results are comparable to those observed in local municipal districts such as Neustadt-Neuschönefeld and Alt-Lindenau that have been found to be typical reurbanization districts; thus, data of the model prove this (Haase et al., 2008; Kabisch et al., 2009). The town center, however, faces an extreme loss of population due to a decrease in residential land use (expressed in the number of flats per land parcel) in the town center through replacement by commercial and cultural land uses.

In contrast to the old built-up areas, the local municipal district of Grünau, one of the prefabricated GDR-era housing areas, is faced with an extremely diverging household development. According to the model, elderly (single and couple) households remain or even increase, whereas young households continuously leave the district in all three scenarios. According to the shrinkage scenario, in 2020 we find nearly exclusively elderly singles and couples in Grünau, which leads us to speculate whether such districts will die out (Fig. 8). Current municipal statistics report a positive net migration of low-income single parent households to Grünau (City of Leipzig, 2006a, b, 2007), but this is not reflected in the model outputs.

[4] Short for "Double income no kids" households.

Finally, we look at the typical peri-urban single and semi-detached house areas such as Meusdorf; here, we find a concentration of young cohabitation households (before the parental phase), families and elderly cohabitation households (after the parental phase). Does this represent a future group-wise segregation pattern? The concentration of families at the periphery shows that these areas are still attractive to younger households, which supports the idea of the shrinking city with islands of inner city and suburban growth.

At present, the model does not reflect ethnic questions in the migration data. In Leipzig, we have only a limited number of foreigners from other countries, and there is only a very limited amount and quality of reliable input data related to the ethnicity of residents of the city. However, this point should be kept in mind with respect to later amplification of the model because it might be useful in another case study where ethnic issues are of more importance.

5.3. *Dynamics of residential land use*

In terms of the future housing structure and available dwellings, the following model output variables are of interest:

- the number of dwellings,
- the residential vacancy and
- derived demolition of houses (clearance of housing areas).

Fig. 10 illustrates that the number of flats remains stable until 2005; a decrease in this number is simulated between 2005 and 2008 due to high vacancy rates and related demolition measures. In the model, the latter processes depend on each other and emerge from the net migration of the household agents.

According to our model, the rate of demolition of vacant houses (or housing estates) begins to increase by 2004. This can also be deduced in reality based on the demolition rate in Leipzig East and Grünau (Schetke and Haase, 2008). Hereinafter, starting in 2008, we will find about 10% of the vacant dwellings demolished, by 2015 about 50% and by 2020 >50%. After 2010, the demolition curve slowly flattens out; it approximates 0 in 2015 due to the fact that the equilibrium is reached between houses being demolished and remaining vacant.

Residential vacancy appears more or less the same in terms of its share until 2005 (Fig. 11; it comprises also in reality 15–25%). For 2004, we plotted simulated versus observed data and compared those values with the MRD (Fig. 11; percentage values of the local statistics for 2004 represent the most recent reliable estimate of residential vacancy for the city by local authorities and the Agency for Statistics and Census; Banzhaf et al., 2007). Although the MRD is comparatively low ($\leq$|10%|), the model systematically produces values that are too large by a small amount in cases where the share of vacancy is $\leq$30%, but underestimates higher shares of vacancy.

The start of demolition generated a decrease in the highest shares of residential vacancy to an average value of 20% in 2007–2008. Development since 2008 decreases residential vacancy to 15%, which fits into the long-term (until 2050) vision for Saxony that predicts 10–15% residential vacancy (Börsch-Supan et al., 2001).

6. Discussion

The RESMOB*city* simulations computed for the 30-year period 1990–2020 show that non-traditional household types such as young singles, young cohabitation households and flat-sharers will be the primary occupants of the old and densely built-up districts with above-average (district of the Südvorstadt) and below-average (district of Neustadt-Neuschönefeld) flat costs or rents. Conversely, in the GDR-era prefabricated districts such as Grünau, the future proportion of financially deprived and medium-level income elderly couples will dramatically increase to up to 20%.

The model results for the three scenarios suggest locations in which future hot spots for urban planners might encounter recent negative developments. A cross-comparison of the findings for all local districts supports the idea of the shrinking city with islands of urban and suburban growth (Fig. 12).

The predicted increase in spatial segregation of households within the entire city also means a change of residents' demand concentration, which has further implications for the consumption of land, environmental resources and local ecosystems. A clear advantage of the model is that the household and vacancy patterns it produces are very detailed compared to the more general findings (maps, data) obtained by household and housing market prognosis for Germany (BBSR, 2009) and Europe (Council of Europe, 2004).

To test the plausibility of the presented RESMOB*city* model results, we have chosen a twofold approach in agreement with Jakeman et al. (2006) and Evans and Manson (2007). As assessment criteria for the quality of the model, we first used statistical fitness as far as independent data was available. Subsequently, we presented the simulated housing patterns to experts in the field of housing mobility and requested that they evaluate the results. In terms of the statistical evidence, the model simulates the population development in such a way that the measured R^2 between simulation and observed (=census) data are 0.70–0.99 and the MRD |$\leq$10%|; it further simulates proportions of migration flows, required flats and resulting residential vacancy along an $x = y$ line that differ at most |$\leq$10%| from the statistical data provided by the city. Particularly, future flows of net migration give an idea of the segregation and clustering processes in a city that holds massive residential vacancies and a rental market of low pressure and huge oversupply.

Another factor relevant to comprehensive quality assessment of our residential mobility and vacancy model is the relatively short time span since the German reunification in 1990. Following Pontius and Spencer (2005), we see a plausibility analysis as presented as the currently most effective and realizable form of model test. An interdisciplinary causal interpretation of both the temporal and the spatial model results creates credibility in both model concept and output data. In developing such an interpretation, an intensive discussion of the model results with social scientists and experts of the city planning department of Leipzig positively evaluated the model outcomes. These scientists and experts can serve as a communication platform during decision-making processes in town planning, the more so because their involvement has already been achieved when presenting the model.

Model rules are transferable to other European cities by incorporating respective local data in addition to available European data sets (Haase and Haase, 2007). Thus, RESMOB*city* can act as a tool for quantification of residential land-use scenarios of the future of both growing and shrinking cities. We further argue that, compared to simply demographically-driven, quantitative approaches, a qualitative household-choice-based ABM approach is more productive with respect to explaining the nexus between spatially selective growth, perforation and shrinkage processes, the occurrence and amount of residential vacancy, and demolition processes at both the city region and small-scale level (e.g., local municipal districts). The ABM approach enables us to shed light on the household-type-based perspective of urban dwellers concerning their housing choices and, furthermore, to gain knowledge about potential variables that influence residential and mobility behavior.

Our model does not explicitly capture the decision-making process itself, as a behavioral agent-based approach would (as stated in Parker et al., 2003). It does not explain the individual reasons for alternative choices of residential mobility; rather, it investigates the relationship between the existing housing supply and the specific demands of the agents to explain mobility decision-making and household patterns.

7. Conclusions

Using the example of the eastern German city of Leipzig, the specific local conditions (population decline over decades, high vacancy rates, and tenants' market) were set in relation to the residential preferences of empirically-based household types. The findings of our model, in the form of household patterns and trends of residential vacancy created by the model, were in plausible agreement with both measured municipal data and estimates by local experts. We were able to show that an increase in the total number of households reduces residential vacancy only in the event of a simultaneous demolition and sanitation of the housing market.

Assuming that today's residential behavior is valid for the near future, we have to expect an increase in the spatial segregation of households in the city, with youngsters and the very old concentrating in the center, whereas families still direct outward. Residential vacancy will decrease and level out at a 10% rate in 2020. It will move from the old built-up estates of the inner city to the 1920s to 1940s and 1960s housing estates, which will lose attractiveness for most of the household types.

The concept of RESMOB*city*, we believe, is a useful one in terms of evaluating demographic scenarios and their impacts on residential land use in urban regions. The model is applicable to ongoing processes in many cities in Europe. Thus, its development can be used as a tool for further analysis in other comparable regions. We were able to demonstrate how and where potential re- or de-densification of urban housing structures will most probably occur up to the year 2020. The same is true for the future allocation and concentration, or even the disappearance, of residential vacancy. We have further shown both difficulties and options related to assessment of the quality of such an ABM using empirical data, as well as in cases in which no validation is possible due to missing independent data.

Future work will focus on the incorporation of additional economic variables that consider the economic constraints of individual households and their choices concerning transport modes and travel distances, as well as scenarios of decreased or modified infrastructure supply due to shrinkage. Additional improvements will include a more detailed incorporation of the local housing market as well as contextual constraints for land use policy and planning in the form of scenario alternatives.

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DO EUROPEAN SOCIAL SCIENCE DATA SERVE TO FEED AGENT-BASED SIMULATION MODELS ON RESIDENTIAL MOBILITY IN SHRINKING CITIES?

Dagmar Haase and Annegret Haase

Abstract

In this paper, we analyse the potential of European social and economic data sets and regionalised panel data for their suitability for a micro-simulation model on residential mobility at the city region level. The micro-simulation approach refers to the social unit of the household which is assumed to be decisive for residential migration and the housing sector, respectively. Social science data are required firstly for the individual profile of the model agents and secondly for the parameterisation of the urban environment where the agents move. In particular, the challenge of transferring socio-economic variables into the space, represented through a GIS, is discussed. The city region of Leipzig, East Germany, being faced with shrinkage and large scale housing vacancies provides both an illustrative example and a real world challenge of how an innovative micro-simulation approach could profit from European survey and panel data.

1 Introduction

Migration and residential mobility in city regions belong to the crucial processes of urbanisation and determine whether a city further grows or is faced by non-growth and shrinkage (summary in Kazepov, 2005; Rees et al., 1996). At present, both the increasing differentiation and diversification of city regions throughout Europe and the reality of shrinking population numbers that in our days affect most of the

European cities and urban regions, force cities into a competition in order to attract new inhabitants, or at least to make their residents stay. Subsequently, a more fragmented urban space where stabilising neighbourhoods are to be found close to those falling vacant and kept locked in the poverty trap is the most likely future of European cityscape. A double challenge arises from these processes: On the one hand, scientists are required to give evidence and explanation of the processes behind such patterns. On the other hand, policy makers and planners are required to counteract negative consequences of both, urban growth and shrinkage (Kabisch et al., 2006; Haase et al., 2006a).

Besides the temporal analysis of population dynamics, residential and migration pattern of a city region and relationships derived there from, correlations and heuristic-explanation micro-simulation models are of growing importance to shed light on the impact of individual decision-making by the residents that when summarised produces the mentioned pattern (cf. Wegener & Spiekerman, 1997). In particular, the spatial differentiation of neighbourhoods that follow diverging development paths – e.g. areas characterised by regeneration and stabilising population numbers or areas seeing the large-scale demolition of whole housing estates – are not explainable by simply using time series of demographic and economic variables gained from local district statistics.

In this vein, the housing sector is of major importance in shrinking cities with declining population and high rates of out-migration. It is the residents who represent the demand side here. They can be defined as the consumers of residential facilities in city regions with an overhang of vacant dwellings and an open residential market with a large amount of affordable flats. Evidently, the total number of potential in-migrants is less important than their household structure, related housing preferences and lifestyles. Here the household as an urban unit, economically independent and occupying one flat, comes into the play as the agent of residential mobility decisions (Buzar et al., 2005; Haase et al., 2005). Households are supposed to move or migrate according to a typical preference profile, thus producing a specific "urban demographic landscape" (Gober, 1990; cf. Kabisch et al., 2006; Kemper, 2001).

We argue further that compared to simply demography-driven, quantitative approaches a household-preference-based micro-simulation model approach is more productive when explaining the nexus between spatially selective growth, perforation and shrinkage processes, the occurrence and amount of residential vacancy, and demolition processes at city region and at small-scale level (e.g. local districts). Micro-simulation enables us to shed light on the household based perspective of urban dwellers concerning their housing choice and, what is more, to gain knowledge about potential variables that influence residential and mobility behaviour. The micro-simulation approach does not go into the depth of decision making processes itself such as a behavioural agent-based approach would (cf. Parker et al., 2003). It does not aim at explaining the single reasons for alternative choices of residential mobility. It investigates the relationship between the existing housing supply and the specific wants and needs of the agents (= households) in order to explain mobility decisions as well as simulating potential processes of in- and out-moving for urban residential areas.

For the use of an agent-based simulation approach, it is crucial to create differentiated and, at best, "real" agent profiles for the household types as model units. Furthermore, the urban space where the households move has to be described in a spatially explicit way. Therefore, high resolution and spatially explicit social-science and land use data is required. The paper evaluates the potential of European social and economic data sets and regionalised panel data to serve as data pools for household based micro-simulation models. It further investigates the challenge of allocating such social data into space to get the 2-dimensional view of urban mobility and migration pattern at the city (region) level.

The paper starts with an overview of the strength of micro-simulation agent-based model approaches with respect to urban shrinkage processes. In a next section, it exemplifies the specifics of urban shrinkage taking the East German Leipzig as an example. The paper then briefly expands upon the data dimensions to compile the model agents. In a fourth section it provides a systematic overview on data sets from European surveys and panel data and discusses their suitability to be fed into the agent profiles and the spatial representation of the model, an urban GIS (Geographical Information System). Finally, some conclusions are made.

2 Agent-based models to simulate processes in city regions

Household based decision making is behind all mobility processes and resulting residential pattern. Due to the lack of these behavioural data, policy to steer migration often fails or is afflicted with major uncertainties. Micro-simulation or agent systems have recently gained popularity in migration and (residential) mobility research. The application of micro-simulation (Wegener & Spiekerman, 1996) and agent-based models (ABM) in spatial sciences started in the mid-1990s (e.g. Batty et al., 2003; Loibl & Tötzer, 2003; Caruso et al., 2005). Agent-based approaches allow for modelled representations of a range of different agents that act on the system under consideration, in the following the housing market of a city region. This includes the preference-driven action of both agents who make direct decisions about their residential mobility and location as well as planners and institutions seeking to encourage or constrain certain types of land use and housing sector development. The profiles of the respective agents and the defined response to certain contextual and environmental constraints represent the heart of a micro-simulation or ABM.

Some of the recent applications of agent-based modelling include the reproduction of spatial and demographic features to understand the evolution of society and the evaluation of economic systems (e.g. Gilbert & Doran, 1994; Kohler & Gumerman, 2000; Axtell et al., 2002) or the linking of human and natural systems at different spatio-temporal scales to understand changes in land cover and land use changes (e.g., Parker et al., 2003). There are further specific micro-simulation models of urban systems, such as system dynamics models on urban dwelling supply (Eskinasi & Rouwette, 2004) or segregation processes at local district level (Pancs & Vriend, 2003). These models have, for the most part, no spatial representation.

In contrast to the mostly cell- and rule-based urban growth models grounded at the urban-growth theory and respective empiric findings of land use development in the 80s and 90s worldwide, it is still a challenge to model processes such as land use perforation, urban shrinkage, dilapidation in direct neighbourhood to new construction or renewal sites (Haase et al., 2006a). Here, besides spatial neighbourhood relations and population dynamics, concepts of individualisation and the break-up of traditional class society due to modernisation (Beck, 1983; Beck & Beck-Gernsheim, 2002; Giddens, 1984), second demographic transition (van de Kaa, 1987; 2004), household structures and stability (Buzar et al., 2005 and 2007), and lifestyles (Schulze, 1992; Dangschat & Blasius, 1994; Schneider & Spellerberg, 1999; Richter, 2005) have to be considered and, what is more, "translated" and transferred into quantitative data for latter use in the profiling of agents in micro-simulation model approaches.

3 Beyond growth – shrinkage in East German urban regions: the case of Leipzig

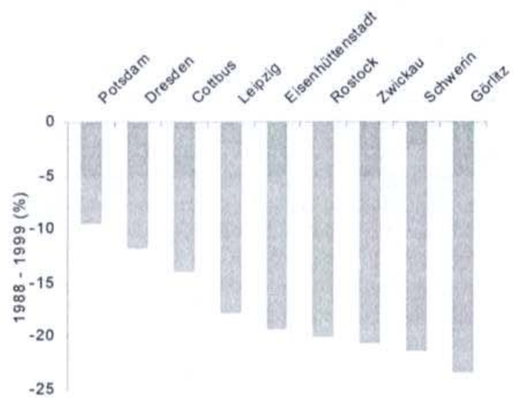
The city region of Leipzig serves as an example for applying the micro-simulation model approach. Situated in Eastern Germany, the city experienced a period of vibrant growth approximately between 1870 and 1930, reaching its historical maximum at a population of more than 700,000 in the early 1930s which then made it Germany's fourth-largest and one of the most densely populated cities. This development was accompanied by the urbanisation and incorporation of what were then the city's rural surroundings. The onset of post-socialist transformation beginning in 1989 ushered in a period of heavy urban sprawl. Countless shopping malls, enterprise zones and residential "parks" were spreading – in that order – into the city's outskirts and into the suburban townships. At the same time, industrial decline and the social consequences of societal transition lead to an on-going out-migration to Western Germany and a sharp fall in fertility, i.e. lowest low birth rates (0.77 children per woman in 1995; INKAR, 2003). Subsequently, more and more

housing stock fell vacant, and the suburban investments even aggravated the mismatch between oversupply and sinking demand. This is true not only for housing, it also affects the under-use of urban infrastructure, amenities, office space and developed land in general. Since the late 1990s urban sprawl around Leipzig has abated considerably, suburban areas have started to lose inhabitants (Nuissl & Rink, 2005). Simultaneously, migration balances of the city itself turned from negative to stable, especially inner-city old built-up districts have been regaining new residents during recent years, which urban researchers call either reurbanisation or the "return of urban living" (Haase et al., 2005). As many old industrialised cities in the West have to deal with similar problems, Leipzig is also a general example of old-industrialised cities in Europe that entered the stage of "non-growth" or even shrinkage. Apart from the inner city which consists of a solid, dense structure of 19th and 20th century tenement blocks, the city's territory contains large areas of the "typically suburban" mixture of land uses, including agricultural open land, forests and restoration areas (Haase & Nuissl, 2006).

3.1 Causes of shrinkage – focusing on demographic transitions

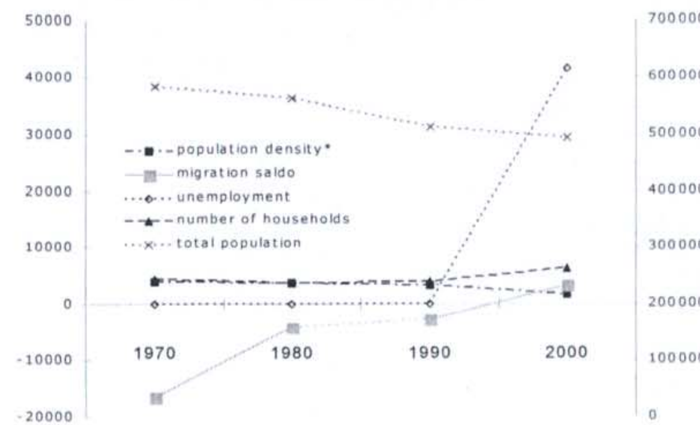
Demographic change is considered one the major forces remodelling European land use, settlement and housing development in city regions, alongside globalization and technological change. Demographic trends underlie many socio-economic processes; thus they often have an ineluctable force and end up changing the whole social and economic system (Wilson, 2006). At present, large parts of Europe undergo considerable demographic changes (Antrop, 2004; Cloet, 2003; Lutz, 2001). Related processes such as a decline in fertility and a rising life expectancy (which results altogether in ageing), the postponement of childbearing, changes in age group spectra, and size, structure and stability of household patterns (van de Kaa, 1987; Ogden & Hall, 2000; Haase et al., 2005; Bösch-Supan et al., 2005) impact enormously on affiliations and motivations of residential mobility that – again – challenge current land use patterns, housing markets and the development of urban space (Deutsch et al., 2003; Ekins et al., 2003). A major challenge is to find scientifically-based methods and empirical grounds for predicting trends in the components such as fertility, mortality or migration as well as consequences of demographic change for the urban space. As it is particularly true for migration and residential mobility, agent-based (here: household-related) decision making goes beyond what can be revealed by statistics. What is more, the lack of these behavioural data often causes planning endeavours to steer migration to fail or at least to be afflicted with major uncertainties.

Figure 3.1: Loss of inhabitants in East German Cities 1988-1999 (Banse & Effenberger, 2006)



Most East German cities have been facing dramatic losses of inhabitants due to declining birth rates, but it is predominantly due to job-driven out-migration to the Western part of the country and the afore-mentioned wide-spread suburbanization during the 1990s (Haase & Nuissl, 2006; Couch et al., 2005; Nuissl & Rink, 2005). After 1989, East Germany was faced with loss of population of about 1.2 million people (8% of whole stock). Most cities lost between 10 and 20% of their residents in a short period of time, among them Leipzig (mean value for big cities from 1990-1999 is about 16%; cf. Figure 3.1). Figure 3.2 sheds light on the temporal dynamics of other variables that determine urban land use and residential development in Leipzig. Illustrated are the migration balance, unemployment rate and, what is of particular interest for the housing sector, population density and number of households. The latter has increased during recent decades (today approx. 260,000 households) accompanied by a simultaneous decline in the mean size of the households (from >2.3 in 1989 to 1.9 in 2003; Haase et al., 2006c).

Figure 3.2: Demographic and economic development of the city region of Leipzig since 1970 covering the socialist and post-socialist phase

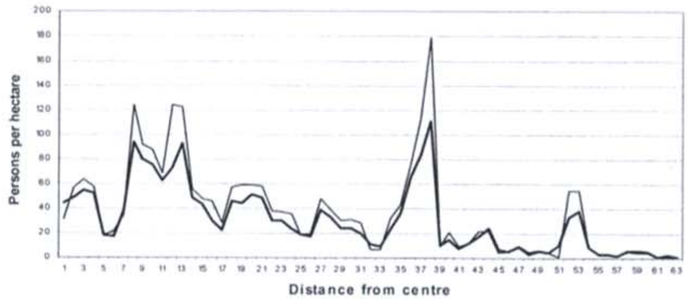


Source: Haase et al., 2006a; right axis: total population, number of households

3.2 Challenge of the housing sector: residential vacancy and demolition

In consequence of the demographic changes described above, flats and housing stock are falling vacant to an increasing degree although the number of households increases. Residential vacancy is no more restricted to uninhabitable housing but also affects completely renovated building stock. The supply outweighs the demand even if at present household numbers still continue to rise up to 2015. Whole residential districts exhibit vacancy rates higher than 30 or even 50 per cent (Stadt Leipzig, 2005; Kabisch et al., 2006). In this vein, demolition came under serious discussion. Demolition produces new spatial pattern such as perforated structures with decreasing house density, demolished sites along the urban periphery, demolition corridors within a city or, respectively, "housing islands". As a new strategy, a federal program of urban restructuring (titled "Stadtumbau Ost", cf. BMVBW, 2003) operates in terms of a guideline to organize and finance the demolition of overhanging housing stock (350,000 flats) and revaluation of the remaining residential areas (Kabisch et al., 2006).

Figure 3.3: Change of the population density 1991-2000 (bold line) along the rural-urban gradient in the Leipzig region



Source: Couch et al., 2005; modified

Coming back to the case study, Leipzig's land development today provides a paradoxical situation: On the one hand, monitoring-data implicate a continuous dynamic of suburban growth on a very low level (single and semi-detached houses, new "housing parks") with adjacent partly over-dimensional commercial centres at the urban fringe. Simultaneously, Leipzig's suburban hinterland is faced, these days, with a rising loss of population and vacant ("unsaleable") housing stock. On the other hand, the core city shows stabilisation and positive migration balances since the late 1990s after a decade of population loss, rising vacancies and structural decline (Nuissl, Rink, 2005; Haase & Nuissl, 2006; see Figure 3.3). Whereas the city lost about 100,000 inhabitants from 1989-98, household numbers have been continuously growing due to downsizing. Independent of the small-scale mosaic of shrinkage and stabilisation in Leipzig's urban space and society, existing residential vacancies (55,000 vacant flats in 2005, Stadt Leipzig, 2005: 14) are strongly related to socio-demographic processes (cf. section 3.1) and socio-economic realities such as low investment rates, high unemployment, reduced family income or jobless economic growth. First results of a study on predictor variables that create or determine residential vacancy (i.e. bivariate correlation analysis of interval and ordinal scaled variables) provide statistical evidence that vacancy under conditions of urban shrinkage is more or less tidily related to demographic and socio-economic parameters such as migration balance, household income, age class composition and social milieu (cf. Table 3.1). Districts with high vacancy rates are on the one hand characterised by high rates of unemployment ($R^2 = 0.82$) and an above-average share of households with lower income (<1000€; $R^2 = 0.67$).

The above-mentioned development of the inner city is mirrored by the interplay of three variables: high residential vacancies, positive migration balances ($R^2 = 0.47$), and an influx of small one- and two-person households ($R^2 = -0.59$; cf. Table 3.1).

Table 3.1: Regression (Pearson's R) between socio-demographic variables and residential vacancy for the city region of Leipzig; the sample consists of all local districts n=63 (2003).

variables	house-hold size	age 18-25 years (%)	age < 40 years (%)	immi-gration (from hinter-land)	in-mi-gration (inner city)	residen-tial vacancy (%)
persons 18-25 years (%)	-0.48		0.79	0.77	0.59	0.41
persons < 40 years (%)	-0.33	0.79		0.73	0.63	0.33
immigration (from hinterland)	-0.61	0.77	0.73		0.86	0.30
in-migration (inner city)	-0.57	0.59	0.63	0.86		0.47
household income <1000€	-0.57	0.53	0.31	0.39	0.40	0.67
household income >3000€	0.57	-0.25	0.07	-0.18	-0.27	-0.66
rate of foreigners (%)	-0.74	0.61	0.46	0.57	0.33	0.44
graduates (%)	0.00	-0.03	0.13	0.10	-0.05	-0.40
employment rate (%)	0.71	-0.46	-0.38	-0.42	-0.32	-0.47
unemployment rate (%)	-0.42	0.32	0.15	0.23	0.38	0.82
residential vacancy (%)	-0.59	0.41	0.53	0.30	0.47	
criminal offences	-0.78	0.50	0.42	0.62	0.56	0.34
companies	-0.66	0.46	0.56	0.73	0.73	0.14
schools of primary education	-0.42	0.27	0.13	0.49	0.58	0.38
kindergartens	-0.43	0.27	0.14	0.50	0.64	0.36
physicians (all)	-0.62	0.53	0.51	0.77	0.82	0.36
urban greenery (%)	0.62	-0.42	-0.18	-0.45	-0.41	-0.38
perception of quiet location (%)	0.55	-0.63	-0.52	-0.66	-0.47	-0.20

In order to compile the profiles of household-agents in the micro-simulation model to simulate residential mobility that finally leads to the spatial shape of inhabited and vacant housing within the urban space (also revealing where these patterns occur and why), district-related data gained from a European household questionnaire survey in which Leipzig took part had been utilised (Haase et al., 2005; FR5 EU Project Re Urban Mobil 2002-2005; further case studies had been Bologna, Ljubljana and Leon).

4 Dimensions of micro-simulation models for a European city region

4.1. Model agents: households

For the micro-simulation model on residential mobility, households have been chosen to represent the model agents. As given in the literature as well as in Figure 3.2 and Table 3.1 for the sample city region of Leipzig, households vary considerably in form and size. This variety even increases within the context of demographic change: households get smaller and less stable, are defined more subject-oriented, and living arrangements are adapted to individual life scripts (Buzar et al., 2005; van de Kaa, 2004; Ogden & Hall, 2000). Within the FR5 EU Project Re Urban Mobil (www.re-urben.com), households had been classified according to their type for selected districts in four European cities (cf. Table 4.1). The resulting clusters of classic household types (i.e. family, elderly one-person households and couples) and those called "new" or non-traditional household types (i.e. young one-person households, young couples, single-parents, unrelated adults sharing a common flat) provide a highly innovative conceptual model of the residential agents living in a city region.

The results of a population-dynamics model including fertility, mortality, life expectancy and migration variables are transferred into household agents with the properties given in Table 4.1. Starting from an initial classification and spatial distribution (over the whole number of dwellings in Leipzig) the households go through a whole-life cycle according to their basic characteristics (cf. Table 4.1). The household transition dynamics from one type to another works according to a transition-probability matrix and a persistence restriction for each household type (persistence = 15 means that this type will live in the respective form about 15 years). Due to the newness of the household type concept and the new household forms such as single-parent and patchwork families or flat-sharers (Haase et al., 2005), there is still a considerable degree of uncertainty in the agent profile, not in terms of quantitative properties such as given in Table 4.1, but in terms of their properties and persistence of living together as one household (Lesthaeghe & Surkyn, 2002).

Table 4.1: Household types used for the micro-simulation approach and their main properties

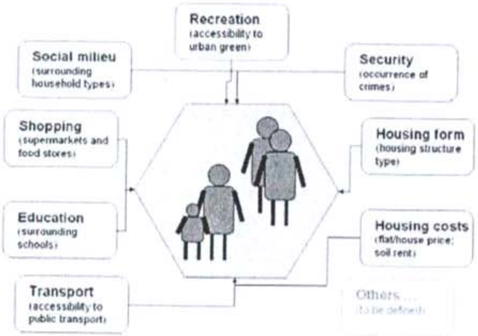
Household type (HHT)	Age classes involved	Number of persons	Persistence of HHT status (years)
(1) Young one-person	18 - <45	1	5
(2) Young cohabitation	18 - <45	2	5
(3) Elderly one-person	>45	1	20
(4) Elderly cohabitation	>45	2	30
(5) Family	18 - <45; <18	3 – 5	18
(6) Single parent family	18 - <45; <18	1 – 3	12
(7) Young flat-sharer	18 - <45	2 – 4	5

4.2. Preference matrix

Given that households move to their preferred residential location when there are only a few financial restrictions of the city's housing market because of the extreme vacancy rates (= oversupply of dwellings), the model is structured not only by variables concerning the household dynamics but also by a preference matrix for the single agents containing a specific profile for each household type. The preference variables result from the findings of the aforementioned household-based questionnaire survey of the Re Urban Mobil research project for Leipzig and other European cities. Furthermore, it considers additionally preference profiles developed by other agent-based models (cf. Parker et al., 2003, Wegener & Spiekerman, 1997).

The agent profile used in the micro-simulation approach contains variables of the socio-demographic (milieu), economic (costs, prices), spatial (accessibility, distances) and ecological (greenery) environment of the respective household expressed in a probable attractiveness A_h of a residential location (flat, tenement block) $U_{\vec{x}_0}(\vec{x})$ with U = surroundings of vector x (500m; cf. Figure 4.1).

Figure 4.1: Preference profile for attractiveness of a place A_h for 2 urban household types: cohabitation and single-parent



The spatial configuration and representation of the urban built and natural environment is defined by a regular lattice z_{ij} $i=1,..,M;$ $j=1,...,N$ (with z = 10m) similar to a cellular automaton approach (see Clarke et al., 1997). The movement of the household from one flat to another is simulated using eq.1:

$$A_h(\vec{x}_0) = \sum_{k=1,2,..} w_{h,k} I_k\left(U_{\vec{x}_0}(\vec{x})\right) \text{ with } \sum_{k=1,2,3,...} w_{h,k} = 1 \qquad (1)$$

where

A_h : attractiveness of a place for a household h
w : weight of preference vector I
$I1$: social milieu in surrounding U of h
$I2$: urban structure type and housing form
$I3$: social infrastructure (educational, shopping facilities in a defined accessibility radius)
$I4$: accessibility to urban green (e.g. distance to all parks in a defined accessibility radius)
$I5$: security (% of crimes per land parcel)
$I6$: noise, air pollution (mg/kg; dB)
$I7$: transport infrastructure (roads, public transport in a defined accessibility radius)
$I8$: housing costs (rent, costs to buy a house, land area rent)

As illustrated in Figure 4.1, a range of input data enters both the preference matrix and the spatial representation of the city in the background (in form of a GIS). The *social milieu* hereby is represented by number and structure of *households* and the *number of committed crimes* in the 500m surroundings of the respective residential location. In form of distance functions the accessibility to *transport, shopping* and *educational infrastructure* is incorporated into the model using vector data of road network and *xy*-representations of school and supermarket locations. A land use vector data set based on topographic and planning map information (Haase & Nuissl, 2007) as well as the city's cadastral database are use to define *type of housing stock*, urban *structure type* and places of urban *greenery*. The latter is than incorporated as the overall accessibility (= total distance) to all types of urban greenery (park, leisure ground, cemetery, forest, waters).

4.3 Spatial realisation using GIS

In order to identify the spatial heterogeneities of residential patterns and migration processes, a space-explicit *xy*-approach is indispensable. This section illustrates in short the potentials as well as the difficulties of putting micro-simulation into space (cf. Loibl & Tötzer, 2003). Starting with the potentials, a GIS-database behind a model provides the user with spatial reference data of all processes and patterns of the simulation. Thus, 2d-views of the scenarios and simulation results can be easily realised for different scales and grain depending on the data available (Mihelič et al., 2005). Due to the multitude of data to be fed into the preference matrix (cf. again Figure 5.1), many different data layers are required for spatial model realisation. In particular land use, transport and infrastructure data are mostly available in digital vector or raster form such as cadastral data (broken down to the single building), ATKIS[1] basic topographic data for Germany, or biotope maps for the ecological dimension of the land use. Using the building or block layer of the cadastral maps for the *xy*-approach, also socio-demographic municipal data given at the district level need to be quantitatively distributed to the building level. In doing so, a certain age class distribution is dedicated to a tenement block or house using the following eq.2:

[1] Amtliches Topographisches Informationssystem

$$n_{AC_i}(x) = \frac{n_{AC_i}(d)}{n_f(d) \cdot p_{AC_i}} \qquad (2)$$

where

n : number
p : probability of occurrence of an age class
AC : age class
f : number of flats
d : local district

However, particularly for perception related parameters such as residential attractiveness, the geometric resolution and the available GIS-vector or raster database are not sufficient. Often, it is not clear to which spatial unit qualitative perceptions are related and what reference framework they refer to. Is, for example, the perception of "feeling comfortable somewhere" or "I would recommend that a good friend move to this district" bond to a district, street or block borderline? What is the best quantitative translation for "to have a park in the very near surroundings of my home" or simply "accessible greenery"? The micro-simulation model is faced with this challenge since it has not yet been solved.

Re Urban Mobil and other project related small-scale survey data sets are unique and not regularly executed; thus, they do not reflect a longer period of time. They are useful and – as was shown here – indispensable to establish the methodical approach and body of variables of the model but do not present a long-term or panel database. Subsequently, model input data as well as observation data to test the plausibility of the micro-simulation model results have to be generally taken from public available survey or panel data for several city regions in Europe for a longer period of time. Supported by the research funding of the EU during the last decade, a noteworthy variety of European-wide data sets on socio-economic issues had been developed and, moreover, is currently under ongoing development (cf. www.eds-destatis.de). In the following section their suitability to be used in micro-simulation models for residential mobility will be analysed.

5 European social science data sets – treasure troves for micro-simulation models?

5.1. Survey and panel data

Most of these data sets refer to the European statistical planning units of NUTS0-3 (national to regional level). Only partially are they available at the smaller LAU1-2, i.e. municipality level. Person- or people-related data are given either at the individual or household level. It respectively depends on each of these data sets or panels to which time interval they refer:

1. The main and most continuous data set on spatial development is the EUROSTAT national and European harmonised data base on the main issues of spatial development such as demography, migration, labour market, business data, education, transport and energy, health, tourism, agriculture, environment, research and development (www.eds-destatis.de). Data are given for most issues at NUTS 3-level; population data are provided with higher grain at LAU-level which makes the data panel more sensitive to local demographic dynamics and distribution processes. For Europe, where over 80% of all citizens live in cities, Urban Audit (http://www.urbanaudit.org/) is an essential data base: 258 cities are involved in the 333-variables programme on predominantly demography, social aspects, economy, civil involvement, training and education, land use, travel and transport, information society, culture and recreation. In terms of spatial dimensions for the data set, information for the following spatial units is available: larger urban zone, core city, sub-city or municipal districts. Such kinds of data are in good accordance with processes and pattern that are typical for the whole city and at the municipal-district-level of the city. Urban Audit allows a cross-comparison between cities (or a ranking), too. But, when working on the context of urban shrinkage and respective residential vacancies, the data set does not offer any data.

2. To shed light on the more qualitative side of socio-demography the European Social Survey (ESS; 3 rounds available starting from 2001) provides information socio-political orientation, trust in policy, and governance issues at a national level. More detailed information is given by the ESS regarding socio-demographic composition, households as well as socio-political values and well-being. The users of the data set could get access to large samples of, at minimum, 1,500 interviewed individuals (response rate ≈70%). The 3 time steps (2001, 2004, 2006) carried out so far already prove evidence of the data and their significance in terms of time (http://naticent02.uuhost.uk.uu.net/).

3. The European Community Household Panel (ECHP) is a survey based on a standardised questionnaire that involves annual interviewing of a representative

panel of households in European countries (national level) covering a wide range of topics: income, health, education, housing, demographics and employment features. The total duration of the ECHP covers 8 years (1994-2001). Two major areas investigated in considerable detail concern the economic activity and personal income of the individuals concerned. The ECHP panel provides comparable and interrelated information on e.g. earnings and social protection benefits, employment and working conditions, housing and family structures, social relations and attitudes. Information on some of these topics may be less detailed or less precise than that in single-topic sources, but in ECHP it forms a part of a single micro-data source on the basis of which interrelationships between the relevance of specific factors for individual living conditions can be analysed (http://forum.europa.eu.int/irc/dsis/echpanel/info/data/information.html).

4. The European Value Study (EVS; http://www.europeanvalues.nl), carried out at the national level, presents European ideas and beliefs in the form graphs, charts and maps. Values such as democracy, freedom, equality, human dignity and solidarity are held by almost all Europeans, but the survey points to differing views about marriage, religion, work and such topics as euthanasia, happiness, sexuality and death. It works exclusively at the national level and provides the user with a single time step.
5. The Labour Force Survey, carried out in 2005, covers mainly information on private and collective households. It is done annually and does not provide information on household types. In Germany, it forms part of the micro-census. From a spatial point of view it does not allow one to make any rural-urban and regional differentiations although it is very detailed. For a city region model the data seem to be less applicable (http://forum.europa.eu.int/irc/dsis/employment/info/data/eu_lfs/index.htm).
6. GfK-Europe-Report (2005; Germany, EU25, EFTA, 10 accession countries) contains very specific information on socio-demography (population, population density, age, gender, migration and private households), purchasing power (index for EU25 and EFTA), traffic, industry (density and employed staff), employment (according to sectoral branches, salaries, unemployment), retail trade, housing and construction sector and GDP. The report supplies a generous grain size and enables differentiated analysis, but is not open to public use. The spatial grain of the GfK-data differs considerably and depends on the requirements of the clients (http://www.gfk.com/group/index.de.html).
7. SHARE (Survey of Health, Age and Retirement, http://www.share-project.org/) provides a unique multidisciplinary and cross-national data base of micro-data on health, socio-economic status and social and family networks of individuals aged 50 or over. It is mainly funded by the EC 5[th] FP. 11 European countries provided data for the baseline study in 2004. For Israel, Poland and Czech Rep. data have been collected from 2005-2007). Compared to other ageing-related surveys such as HRS and ELSA, SHARE has the advantage of encompassing cross-national variation of public policies, cultures and histories in a variety of European countries. SHARE is designed to shed light on the different dimensions of ageing processes in Europe such as income security and personal wealth, kinship and social networks, living arrangements, physical and mental health, disability, mortality. It is a multidisciplinary study created as a cross-fertilisation study of former non-linked disciplines. Data are gathered by questionnaire surveys and qualitative interviews with selected respondents or family members.

8. The European Spatial Planning Observation Network (ESPON) is set up to support policy development and to build a European scientific community in the field of territorial development. The main aim is to increase the general body of knowledge concerning territorial structures, trends and policy impacts in an enlarged European Union. Applied research and studies on territorial development and spatial planning are viewed from a European perspective in support of policy development. National, regional and local knowledge is partly already existing and available, although only covering smaller parts of the European territory (http://www.espon.eu/).
9. The GEO Data Portal is the authoritative source for data sets used by UNEP and its partners in the Global Environment Outlook (GEO) report and other integrated assessments of environment. Its online database holds more than 450 different variables in the form of national, sub-regional, regional and global statistics or as geospatial data sets (maps), covering themes such as Freshwater, Population, Forests, Emissions, Climate, Disasters, Health and GDP. Display them as maps, graphs, data tables or download the data in different formats (http://geodata.grid.unep.ch/).
10. The objective of the European project CORINE Land Cover (CLC) is the provision of a unique and comparable data set of land cover for Europe. It is part of the European Union programme CORINE (Coordination of Information on the Environment). The mapping of the land cover and land use was performed on the basis of satellite remote sensing images on a scale of 1:100,000. The first data base is CLC1990- consistently provided land use information comprising 44 classes. In the project CORINE Land Cover 2000 (CLC, 2000) an update of the database and a mapping of changes have been accomplished using the year 2000 as reference. With CLC2000 a reliable, objective and comparable data base for the description of the current land use situation and the

analysis of changes during the decade between 1990 and 2000 is available (http://dataservice.eea.europa.eu/).

Do these data bases and surveys deserve to be implemented in the model approach discussed above?

5.2. Criteria for applying the European data sets to hypothesis-driven models

Coming back to the micro-simulation approach and in particular to the preference matrix, it is of interest to what extent the above analysed European social science data sets fit into scale and purpose of the households' preference profile. Figure 5.1 provides an overview of which of the data sets analysed provides relevant information for all of the preference vectors, regardless of the grain and scale of the data behind it. At a first look, for each parameter there are data on European scale as well as some finer scales such as city and local district level available. Looking, however, more comprehensively at the existing sources, it becomes clear that although data is available,

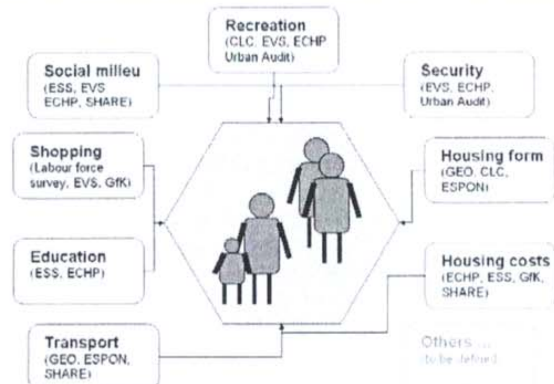
a. often grain and scale do not permit a direct dedication to a specific household type. Since the household is the model agent and therefore seen as decisive for residential mobility decisions, we need additional data sets such as expert panels or, as mentioned above, individual project-bond surveys. The city of Leipzig serves here as an excellent example providing a semi-quantitative 4-annual survey on households' perception at local district level (started 2003). Furthermore, an annual monitoring "barometer" report and data set for the residential market is available.

b. there is no common and Europe wide accepted household term available, which hampers a transfer of a household based micro-simulation model philosophy to a considerable degree (cf. European Housing Statistics gives a definition of "what is a household" for each national context).

c. panel data often cover a national sample and may considerably differ between single regional and even local contexts. Therefore, without context knowledge it is hardly possible to interpret data from European social science data sets for a specific city (region). For example, the ESS provides an agent-profile with useful information on individual perception of the local neighbourhood (= demand side). For our purpose, however, this profile would have to be confronted with the either growth or shrinkage driven pressure on the housing market (= supply side) to determine the scope of residential location choice and, in consequence, the weight w of the variable "perception" of neighbourhood.

For the variable "recreational value" the EVS and the ECHP could be utilised for the formulation of general recreation needs (= demand side) in terms of accessibility and form for different age classes or, respectively, household types. Data from Urban Audit provide some information on regional differences in green requirements of urban dwellers throughout Europe at the city level. Finally, CLC provides spatially explicit data to allocate available green spaces in relation to flats or tenement blocks and thus allows one to determine their overall accessibility (= supply side). The explanatory value of the micro-simulation model considerably decreases when neglecting such specifics and when simply feeding the model, regardless of any regional adaptation.

Figure 5.1: Data sources for implementing the preference profile



6 Conclusions and outlook for future work

In this paper we discussed to what extent European social science data sets can serve as a database to feed agent-based micro-simulation models of residential mobility in cities with particular respect to the context of non-growth or shrinkage. Using the example of the East German city of Leipzig, the specific local conditions – high vacancy rates, "tenants' market" – were set in relation to the residential preferences of household types who form the agents of our model. The needed range, scale and quality of agent-related data was identified by means of municipal statistics and a household-based questionnaire survey based on an SDT-driven concept of demographic change and its implications for housing. By comparison with available European social science data it became obvious that a) data sets do not always meet the needs of scale and grain, b) do not provide a clear definition of households, c) suffer from a lack of contextual information in terms of defining the impact of shrinkage and oversupply of housing stock, amenities and urban infrastructure, d) do not always allow for local differentiation in terms of urban small-scale areas (sub-city level). Up to the present, this missing information can only be acquired by using survey data or expert panels that exist for single cases, and merely for more than just a limited period of time, as the Leipzig example shows.

Therefore, we see a need to improve European social science databases in the following manner: a) add variables for the context of local non-growth or shrinkage processes, b) try to define a common household term, c) plead for bringing in survey and expert panel information on a more regular base, d) provide information on the transferability of the data to either another spatial grain or national/cultural context.

Since urban development beyond growth and respective residential mobility behaviour are likely to determine urban futures in Europe, it is crucial to think about an improvement of European regionalised data to provide a more promising database for this new challenge. As a pre-condition, it is, however, indispensable to identify the required contexts, variables, terms and inter-linkages for a case in point, as it was presented here for the city of Leipzig.

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THE CHANGING FACE OF THE LANDSCAPE

Dagmar Haase and Matthias Rosenberg

One of the factors which has the most lasting impact on the condition and function of the landscape is land use. The land around us was and still is intensively used in many places, yet all too often this clashes with the aim of protecting the biotic and abiotic resources mankind needs. Central Germany is doubtless an extreme case given the extensive ravaging of the landscape by lignite mining and the subsequent complete reshaping of the areas concerned. But all over the world, the question of how far mankind can go before nature's regulatory mechanisms finally collapse has become highly relevant. Landscape ecologists are using cutting-edge technology to tackle this issue internationally. One of their key findings is that a landscape's history also needs to be taken into account.

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Figures 1, 2, 3: Three pictures of the same landscape segment. The Elster floodplain on the southern edge of Leipzig near Cospuden opencast mine. 1880: floodplain landscape. 1998: the recultivation of Cospuden mine is in full swing. 2002: the mine pit has been transformed into a lake popular among Leipzig residents for swimming and other recreational activities.

1880: A river winds its way through the base moraine of the Leipzig district, flooding the slight surrounding depression. Farmland and small villages lie a few metres above the floodplain on the edge of the base moraine plates. The sections of the floodplain not containing woodland are marshy. Leipzig's city limits are still several kilometres away.

1980: Lignite mining has eaten its way to the very edge of Leipzig and extensive deposits of lignite have been found beneath the city itself. Large areas of floodplains and farmland have disappeared, as have the villages they once contained, to be replaced by industry and mining as far as the eye can see.

2002: Within the space of just ten years, an old opencast mine has been transformed into Lake Cospuden, complete with a sandy beach and a yachting harbour. Measuring 4.3 sq km, such large areas of water do not occur naturally in the old moraine of the Leipzig lowland indentation. Other lakes are currently emerging with beaches and woodlands on the shore.

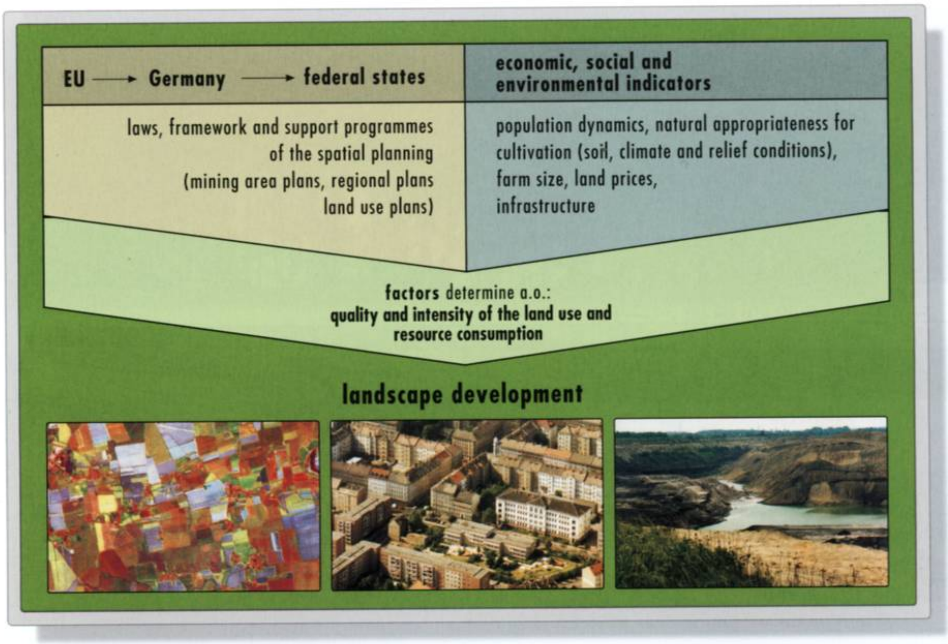


Figure 4: Factors which determine the change of landscapes.

The conflict

Mankind has always used – and hence altered – the surrounding landscape and its components such as soil, raw materials, water and biological resources. In addition, the landscape is exposed to natural processes of change which are virtually impossible for mankind to influence. The last major example of this in central Europe was the ice age about 22,000 years ago. By the time the land was finally free of ice about 10,000 years later, the landscape had been drastically reshaped. The history of anthropogenic landscape changes hence started all over again, the difference being that this time they were increasingly more frequent, more intensive and shorter than before. It was inevitable that usage and preservation would eventually clash. But what exactly do we mean nowadays by the preservation of nature and the landscape? According to the German Conservation Act, nature and landscapes:

»*... are to be preserved, nurtured, developed and if necessary restored in both populated and non-populated areas in order to lastingly safeguard:*

1. The function and efficiency of the balance of nature;

2. The regeneration and sustainable exploitability of nature's resources;

3. Fauna and flora along with their habitats;

4. The variety, particularity and beauty of nature and landscapes.« (Section 1, para.1 German Conservation Act 2002)

This conflict has been studied by scientists from almost all continents of the world for about 30 years. One important forum they use is the IALE (International Association of Landscape Ecology), under whose auspices over 1,000 landscape ecologists, geographers, biologists and agricultural scientists are involved in all sorts of projects. Examples of the questions they are trying to answer include: Have we reached a threshold at which nature's natural retention and regulatory mechanisms are increasingly failing and the overexploitation of the landscape can no longer be stopped? Have we perhaps already reached the end of an era of highly intensive agricultural land use, the expansion of built-up areas and biotope fragmentation which will abate over the next few decades? How long does it take to drastically change the landscape – and how intensive is this process?

UFZ's landscape ecologists are also involved in this discussion. One of their main objects of study is central Germany. This region is ideal for investigating land-use change and landscape structures, and how they affect the »productivity« of the natural balance and biodiversity. As well as studying historical states of the landscape, they also analyse what drives these developments and future trends of landscape development.

Starting from trend analysis of future land use based on economic, social and scientific indicators, and taking into account European Union funding policy and overall spatial planning in Germany, scenarios on the type and intensity of landscape changes are compiled. One of the results to emerge is that in central Europe agriculture is being increasingly restricted to just a few fertile areas and many areas previously used for farming have since been abandoned.

These descriptions of past and future landscape transformation provide a basis for models which are used to estimate how land-use changes will affect the water and substance regime. Management plans can then be drawn up as specified by for instance the EU's Water Framework Directive to ensure that surface water is ecologically and chemically sound and to safeguard the availability of groundwater (Figure 4). These general aspects are illustrated below with two examples.

The urban sprawl

Between 1997 and 2010 the amount of land used for building development and transport in Germany as a whole is expected to grow by 530,000 hectares. This means an increase of 112 hectares – the size of four football pitches – every day. But what's the situation in central Germany?

UFZ researchers have been testing ways of determining the growth of towns and cities as well as other land-use changes over a long period of time, including historical states of landscapes and their ecological functionality, by using the example of the region around Taucha, a small town north-east of Leipzig.

First of all, they digitised historical maps using geographic information systems. Reading and interpreting old maps is an important skill among landscape ecologists (albeit not one they need every day) which calls for a great deal of experience in dealing with cartographic material. Having been computerised, these digital data were juxtaposed and compared with modern-day maps and aerial and satellite photographs in a geographic information system, enabling exact statistical analyses of zoning development and for example the expansion of paved land. In addition, the GIS's databases allow the effect of land-use changes on certain landscape functions to be determined, such as the impact of suburbanisation on the runoff behaviour and natural groundwater recharge. Both these aspects are important factors in an intact landscape, as shown to dramatic effect by

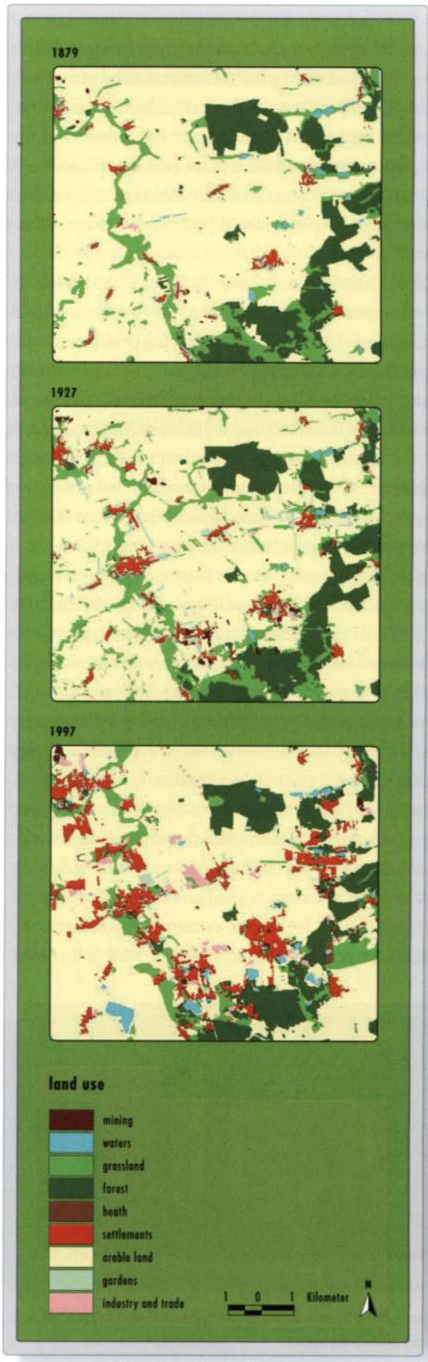


***Figure 5:** The increasing urban sprawl of the landscape around Taucha and above all the floodplains is clearly apparent from the three time segments. (Content, cartography and GIS: D. Thormann; data: Saxon Surveying Office)*

the flood disasters which hit the Elbe and the Mulde in August 2002. Runoff behaviour characterises the ability of a landscape (chiefly the soil) to absorb and regulate the surface runoff of rainwater depending on the use to which the land has been put and hence minimise the danger of flooding. Natural groundwater recharge is a process which contributes to the renewal of water resources in a region. The two processes are directly interlinked: areas with high surface runoff have lower natural groundwater recharge, and vice versa.

Figure 5 shows the zoning changes in 1879, 1927 and 1997 in the Taucha region. They were treated as a basis for modelling runoff regulation. It can be easily seen that building development – and hence the proportion of built-up and paved land – on the north-eastern edge of Leipzig sharply increased, especially after the political changes in 1989/90, making floodplains and open spaces around the town increasingly rare. In other words, these changes sharply reduced local recreation opportunities for the residents of Leipzig. In addition, the River Parthe lost its function as a flood retention area. This was because the green band of floodplains so important as a retention area for water and sentiments from the Parthe catchment and which in 1879 was clearly identifiable had by 1997 been interrupted and hence fragmented at many points by built-up areas and farmland. This in turn meant it was no longer able to promote the migration and spread of many species of flora and fauna, and for instance yellow irises (*Iris pseudacorus*) and the hairy star of Bethlehem (*Gagea arvensis*), both once common here, are now no longer found.

There is every reason to assume that these processes of urban sprawl will continue in the countryside around Leipzig, turning open spaces into a very rare commodity in the coming decades. Extrapolating the increase in paved land around Taucha between 1879 and 1997 of 1,181 hectares and taking into account current construction projects such as BMW's new car plant on the Parthe

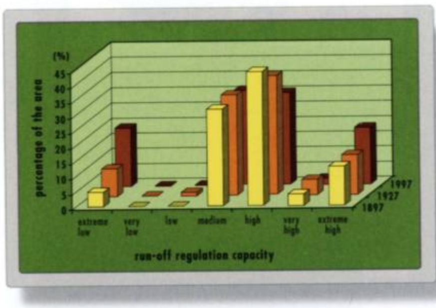


Figure 6: Paving the soil is drastically reducing the runoff regulatory potential of the earth's surface in this region.

Figures 7 and 8: So close and yet so different – views from the Parthe catchment today: relatively natural river sections adjacent to newly built commercial estates with high rates of paving.

floodplain along with other sites earmarked for housing development, it seems that despite the falling population of Leipzig and other regions in central Germany, some natural retention and regulatory mechanisms are increasingly failing – as demonstrated by the floods in 2002.

Nevertheless, UFZ's landscape ecologists believe that despite the huge amount of land affected by altered use since 1990, the overusage of the landscape can still be stopped. In order to hone and underpin the current political and legal instruments available, landscape analyses of this type will become indispensable for many regions in Europe.

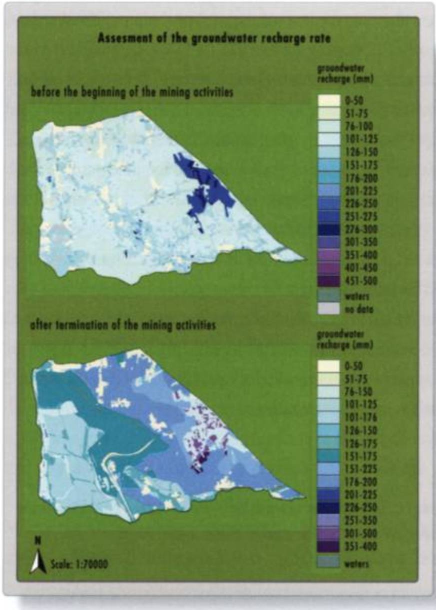


Figure 9: The area of the former Espenhain mine before the start of mining and nowadays shortly before the pit was flooded. Mining and the expansion of built-up areas drastically changed the spatial distribution of the natural groundwater recharge rate. (Content and cartographic processing: Yvonne Voigtmann)

Mines into lakes

After decades of devastation of arable land, woodlands, villages and floodplains and the diversion of rivers, by around 2050 the region south of Leipzig will have developed into a lake district with a total surface area of some 79 sq km of water with plenty of scope for a variety of usage and development. Nowadays less and less farmland is needed, and so disused mining pits are being ecologically landscaped to provide areas for tourism and recreation. This may mean leaving dumps as they are with as little remediation as possible (as called for by nature conservation), or alternatively afforestation, as is practised for example in large expanses south of Leipzig, an area which is low in woodlands. Over 570 million tonnes of lignite were mined here between 1937 and 1994 at Espenhain mine. The mine destroyed areas like the Gösel floodplain, which was an important regulation area for water and substance cycles in the Leipzig district. By the year 2020, a network of lakes including Lake Störmthal (6.9 sq km) and Lake Markkleeberg (2.5 sq km) will account for large parts of what used to be the Gösel floodplain before it was turned into an opencast mine and its surroundings. Scientific analysis of landscape functionality south of Leipzig was carried out by researchers from various institutions in a pilot regional landscape monitoring scheme. It enables an integrated, ecological view of all the components of a landscape such as the soil, relief, climate, water balance, flora and fauna as well as changes to the landscape over time. The landscape monitoring concept used and tested in this particular case is designed to work out methods and parameters which are suitable for large areas. The aim is to enable an ecological analysis and assessment of very different natural areas in Saxony – and in the next stage in Germany. Since mining and post-mining landscapes are among the most dynamic areas in central Germany in terms of landscape change, alterations to the water and substance regime for example which can be attributed to this change of usage can be modelled and impressively visualised (Figure 9). The changes which took place in the Gösel floodplain agrarian district between 1944 and 1996 can be characterised as follows:

- Extensive change to the relief and the emergence of hollow and solid structures (mining pits, dumps, slagheaps);
- Changes to the substrate deposition conditions, with extensive mixing and restratification of soil and sediments;
- The destruction of natural soil, especially the Gösel floodplains important for the landscape balance, and the emergence of heterogeneous dump soils which need a few decades to undergo initial soil development;
- The regulation and canalisation of the main outlet (the Gösel), including the complete destruction of natural retention areas and wetland habitats in the floodplain.

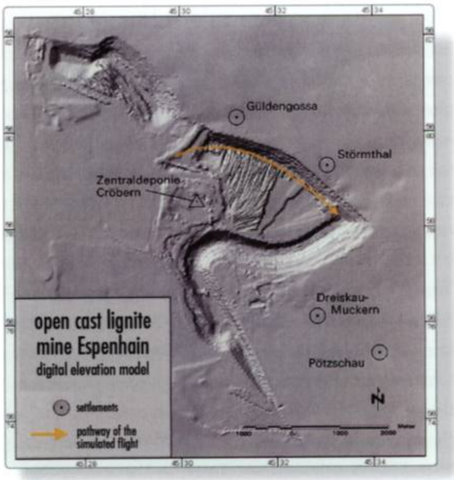
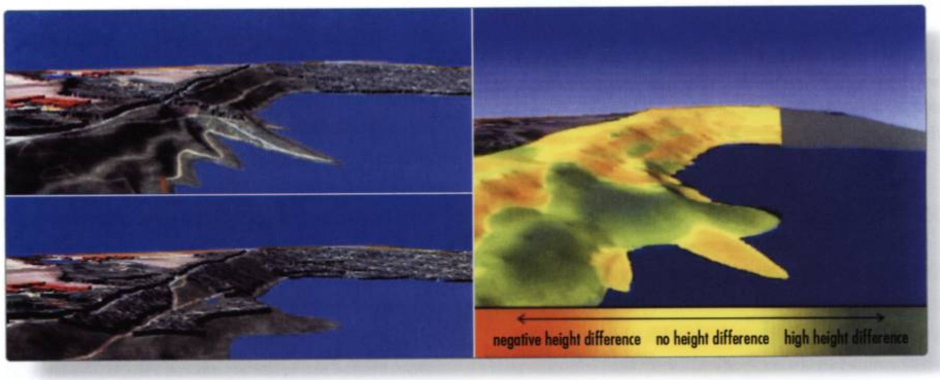


Figure 10: One major source of data for studies of landscape change is high-resolution digital terrain models – in this case one of Espenhain mine in 1998 (based on underground survey data from LMBV).

When planning the landscaping of Espenhain mine, researchers from the UFZ working together with the LMBV (Lusatian and central German mining administration company) developed a method which enables actual landscapes and the changes taking place in them to be depicted by using visual 3D simulation based on a GIS. This technique gives landscape planners a spatial impression of landscape changes. Moreover, it provides an important aid for visual communication and decision support in the planning process and in the development of planning alternatives – including with the local population.

Four visual dynamic simulations were developed for the future Lake Störmthal. They were produced by juxtaposing zoning data (planning documents, aerial and satellite images) and a digital elevation model obtained from survey data.

Figure 11: »Lake Störmthal mining district« – the 3D visualisation of two different planning options which differ above all in terms of bank heights.



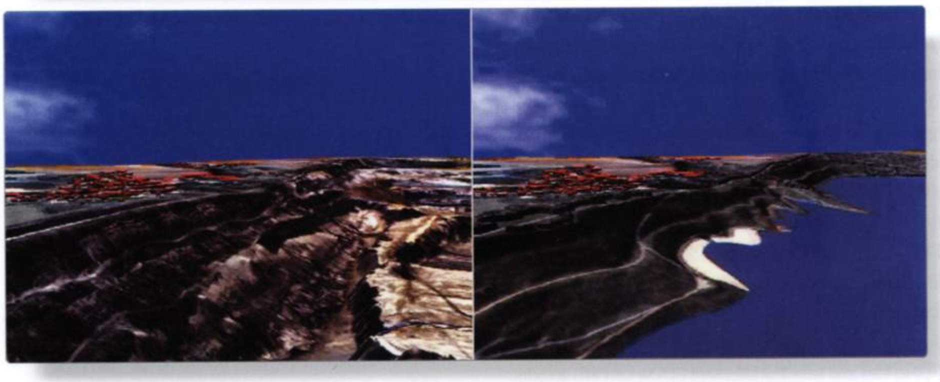


Figure 12: »Lake Störmthal mining district« – the 3D visualisation of the initial situation in 1998 as a mining pit and a planning variant for future landscaping.

Summary

The scientific work on the transformation of the usage and structure of a landscape as well as its influence on the productivity of the natural balance provides an important basis for landscape and regional planning and serves as decision-support instruments for regional and local planning agencies. In the case of the UFZ these include the Saxony Department of the Environment and Geology, the state environmental departments in Leipzig and Chemnitz, and the regional administration offices of the various districts in the Saale River basin. They are also important for a broad section of the local population as well as researchers from the State Department of Construction and Environmental Planning dealing with the long-term trends of spatial development in Germany since they show how the surrounding landscape changes and how planners' ideas will actually appear in the landscape.

So how far can mankind go before the natural regulatory mechanisms collapse? The investigations carried out by UFZ's landscape ecologists to date back up the opinion that a whole range of natural regulatory mechanisms in the landscape such as runoff and flood retention can only function to a limited extent and in some cases fail locally owing to the continuing consumption of floodplains and open spaces for construction.

In future the researchers will undertake additional specific investigations into trends of zoning development and their influence on natural landscape functions. This can be regarded as a module to help achieve genuinely sustainable »co-operation« between mankind and nature in the multifunctional central European cultural landscape.

Haase, G., Haase, D., 2002. Approaches and methods of landscape diagnosis. In: Bastian, O., Steinhardt, U. & Z. Naveh (eds). Development and Perspectives of Landscape Ecology, Kluwer, pp.113-122.

Chapter 3

Landscape analysis, synthesis, and diagnosis

O. Bastian, R. Glawion, D. Haase & G. Haase, H.-J. Klink, U. Steinhardt,
M. Volk

3.1 Approaches and methods of landscape diagnosis

3.1.1 Introduction

The current land use processes and land use changes in the last centuries make it necessary for all natural, socio-economic and cultural conditions to be carefully considered in the socio-economically dominated processes of landscape management and planning. The socially necessary benefit-cost ratio of securing natural processes of regulation in physical regions, especially for both simple and extended reproduction of natural conditions, is increasingly becoming a driving force in the determination of the economic and social effectiveness of land use.

Extensive and intensive use of processes, functions and characteristics of the physical or natural resources can be accomplished without major disturbances only if the utilization requirements and the existing natural equipment develop proportionally to each other. These proportions are results of, on the one hand, active technical and natural principles (properties of natural-technical geo-ecosystems) and on the other hand, the socio-economic conditions and requirements under which the activities of society are taking place in landscapes, respectively (including urbanized areas).

3.1.2 The social requirements of landscape utilization

A major obstacle to interpreting the results of landscape inventory with respect to utilization requirements is an inadequate theoretical and methodological basis. Neef (1969) referred to the combination of scientific exploration results and measurements with technical and economic parameters. He proposed the transformation of geo-synergetic and ecological parameters into economic and social indices. Hence he introduced the term **transformation problem** (see Chapter 5.3, Figure 3.1-1).

Figure 3.1-1: The transformation of ecological parameters into economic and social indices is one of the central problems in the field of landscape research: Cultural landscape in the temperate tropics – Viñales (Cuba) (Photo: O. Bastian 1993)

A prerequisite for a socially (and economically) precise formulation of landscape management requirements is a multi-part logical chain of relations between landscape inventory and the application of its results to natural resources-oriented planning. According to Graf (1984) the following factors will serve as links:

– criteria for landscape utilization, that have to be fixed by planning authorities and law enforcement agencies (local/regional/national authorities and stakeholders) and that can be measured with respect to social effectiveness and/or economy-related efficiencies (costs),
– criteria-related interpretation of exploration results by means of landscape inventory and (digital) landscape mapping.

The relations between landscape exploration and evaluation and the decisions concerning their utilization have been superposed or even interrupted by other decision criteria. These are the utilization of areas in connection with a further division of labor and with a combination of the social reproduction process as well as financial considerations dictated by the economic utilization of fixed assets funds. Sometimes, this is connected with political transitions as well (e.g. Eastern and Central East Europe after 1990).

Hence it is obvious that the social and/or economic requirements of a diagnostic and prognostic landscape evaluation have to be derived from

- normative target formulations for effectiveness of the specific utilization form, especially for mesoscale analysis (chorological dimension),
- the respective regional utilization structure (represented in land use scenarios, Meyer et al. 2000), and
- the landscape capacities and potentials themselves (Figures 3.1-2 and 3.1-3, see Chapter 5.2).

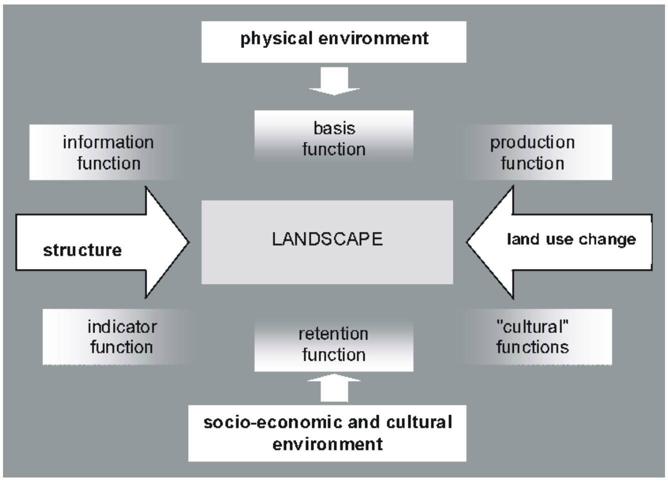


Figure 3.1-2: Landscape functions representing the satisfaction of socio-economic benefits by the natural environment

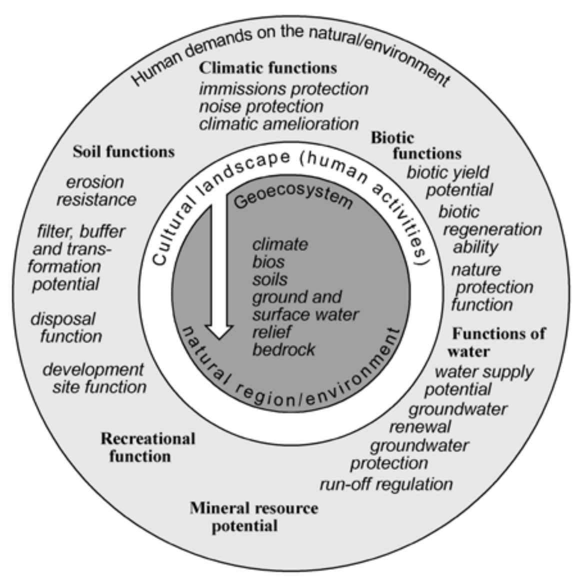


Figure 3.1-3: Functions and potentials of the natural environment together determining the carrying capacity of the landscape (after Zepp 1994 (Klink after Zepp 1994)

The land use efficiency expressing the totality of regional correlation between nature and society is governed, at least theoretically, by the whole amount of socio-economic needs that can be satisfied with the aid of the considered area and its natural potential. This whole amount of social needs and functions is, however, extremely difficult to ascertain. The various needs cannot be determined directly or compared by a uniform measure. The degree of multiple utilization with all its secondary, cumulative, and side effects is hard to determine. Moreover, the different social costs corresponding to the particular efficiency and to local relations of individual land use units have to be allocated or apportioned for the various forms of land use and, finally, for the different scales (Steinhardt and Volk 1999). Therefore it is evident that economic criteria have to be supplemented by social as well as ecological evaluation measures. This way of landscape diagnosis leads to **multifunctional approaches** (Brandt et al. 2000).

Thus it is necessary to consider the following relationship in detail: Landscape is not improved or changed as a whole, but primarily through the utilization of individual parts (e.g. field plots, landscape elements or compartments) or functions (e.g. production, retention, information) demarcated by different users. Consequently, all criteria required for maintaining multifunctionality of a landscape have to be taken into consideration. Any intervention in the overall natural and land use structure has to consider **landscape as an entity** (see Chapter 1.3). At the same time a historical perspective of the landscape marked by major shifts in the time and/or space is necessary.

Geo-scientists and experts of related disciplines attempted to explain and illustrate some approaches to determine the social functions guided by **normative regulations**. It is pertinent to mention some literature published in the former German Democratic Republic (Haase et al. 1991):

– methodological fundamentals of the structural, functional, and interference analysis of landscape as well as the multiple-step analysis of the economic and non-economic evaluation of interactions between society and nature,
– characterization of the development stages of a region due to the social utilization of nature and its consequences (see Chapter 4.1),
– derivation and interpretation of the natural potential as a basis for an assessment of the resources' structure in a region (see Chapter 5.2),
– determination of the stability, resilience, and carrying capacity as parts of an intensively used landscape (see Chapter 5.1),
– methods of transferring landscape inventory and survey results into landscape planning and control of economic branches using the landscape (agriculture, forestry, water resources management, sewage and refuse disposal services, building industry) (see Chapter 7.3),

– methods of the multi-functional assessment of landscape benefits, suitability, and resilience by an optimization approach (see Chapter 5.4).

Based on these facts it is obvious to start a **landscape analysis** from one of the following two premises:

1. Dealing with problems associated with resources available to society a **landscape approach** is essential. The major focus has to be on the landscape capacity and its limiting conditions and risk factors.
2. Dealing with problems associated with resources available to society a **reproduction-area approach** is essential. It has to start from the actual land use and has to include the potential abilities and incompatibilities.

A detailed description of the landscape's functions in the process of social reproduction is a prerequisite to any attempt including the actual state of landscape. Literature offers several approaches, some of which should be mentioned as typical examples (see Chapter 5.2):

– It is in the sense of a landscape approach that Preobraženskij (1980, 1981) proceeds from the natural functions of a landscape, determining their importance for the process of social reproduction. Haber (1979b) applies the results of bio-ecological research to discriminate between productive and protective ecosystems corresponding to two different behavior patterns of society, referred as "strategy of utilization".
– Using the reproduction-region approach, Niemann (1977) characterizes the social functions of landscape elements and units starting from four functional groups (production functions, environmental functions, human-ecological functions, ethic and aesthetic functions).
– A similar breakdown of the social functions and, consequently, of the social requirements of landscapes is presented by van der Maarel and Dauvellier (1978) in the well-known "Globaal Ekologisch Model" of the Netherlands. Like Niemann (1977) the authors further subdivide the mentioned functional groups to visualize relations between social requirements, landscape structure or natural conditions (see Chapter 5.2).
– Another approach was chosen by Grabaum et al. (1999) using a multicriteria optimization considering compromises between the different land uses and landscape functions (Meyer et al. 2000, see Chapter 5.4).

3.1.3 Principles of landscape diagnosis on the basis of ecological data

Over the last few years, landscape research resulted in the development of an essentially coherent, highly consistent concept of landscape analysis, diagnosis and management (Haase 1991, 1999, Figure 3.1-4).

Landscape analysis can be classified as the first step in this scheme. It results in a scientific landscape inventory with respect to its natural, use-related, and dynamic characteristics. Based upon these results, landscape diagnosis has to determine the "capability" or "capacity" of a landscape to meet various social and economic requirements and to define limiting or standard values. **Landscape diagnosis** lays the foundations for measures taken to improve, to change, and protect landscapes as a whole or some of their components. Depending upon particular social objectives to be achieved, four fields of activity can be distinguished:

– **landscape planning** (preparation and territorial integration as well as securing of suitable measures, see Chapter 7.3),
– **landscape preservation** (conservation and stabilization of natural conditions, structures and species, see Chapter 7.7),
– **landscape control/monitoring** (socially necessary or desirable control of landscape processes, Brandt 2000b, Haase 2000, see Chapter 4.2), and
– **landscape management** (land use strategies).

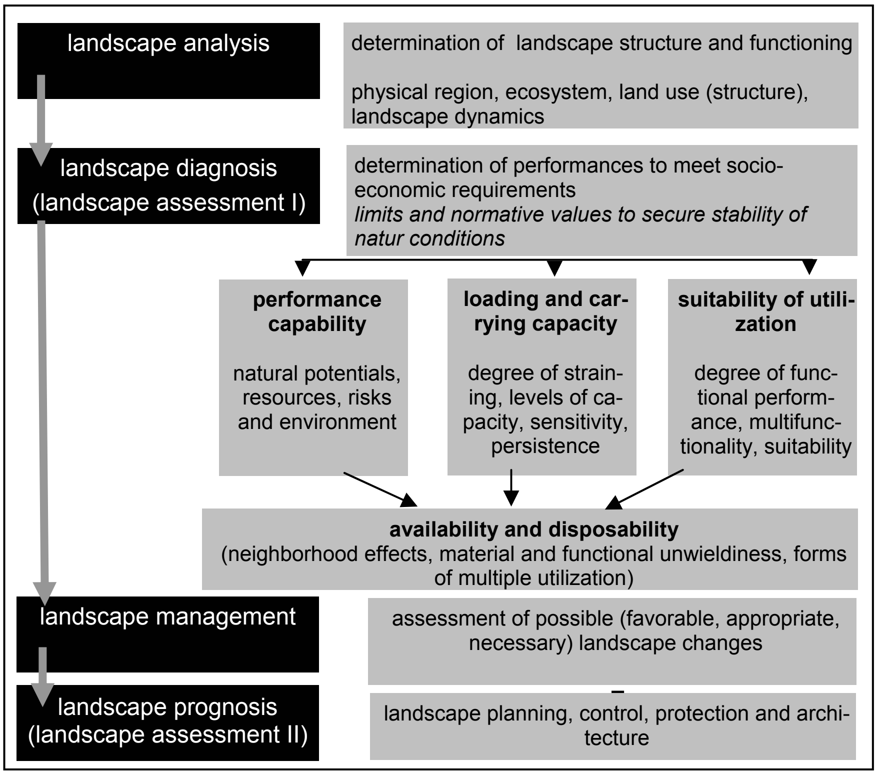


Figure 3.1-4: Interrelations and connections between landscape analysis, diagnosis and landscape management (Haase 1991)

The following four-phase approach based on a detailed landscape analysis is the methodological base of landscape diagnosis:

1. **Analysis of the social functions** of landscape considering also future land use types.
2. **Evaluation of geo- and bio-ecological landscape characteristics** (determined by laws of nature) with respect to socio-economic requirements and functions.
3. **Analysis of landscape interactions** including secondary and remote effects as well as limitations triggered by past, present and proposed land use forms.
4. **Social evaluation** of present and proposed land use forms referring to land use conflicts and preparing solution strategies.

This multi-phase approach can be considered as a general model for landscape diagnosis and derivation of prognostic data (Figure 3.1-5). The first phase of landscape diagnosis has already been discussed at the beginning of this chapter and will be explained in Chapter 5.2 more comprehensively. The second phase is based upon a scientific analysis of the spatial structures and the temporal behavior of landscape objects. The third phase requires a connection of scientific information with statements about current and future social utilization. Referring to these criteria as structural diversity, duration and temporal sequence or succession of land use, social expenditures for the reproduction of natural systems, and substitution of substances and processes in the framework of social reproduction can be used.

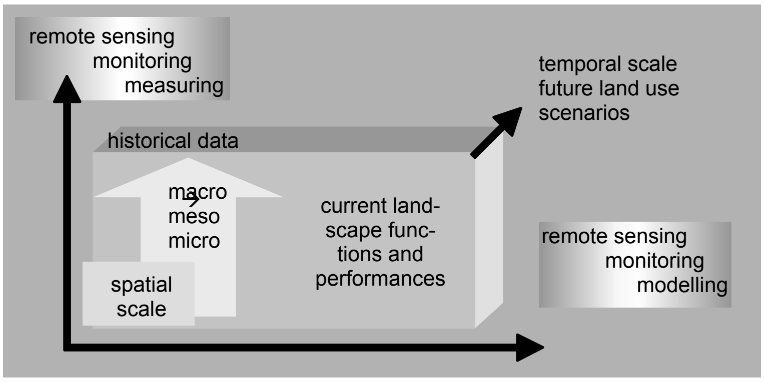


Figure 3.1- 5: Scales and methods for landscape diagnosis

Difficulties are frequently encountered in this particular step: Natural scientists fear of a loss of accuracy and quantitative details. The transformation of geo- and bio-ecological data does not naturally result in scientific accuracy. The connection of these parameters with those of socially determined processes enables information obtained at a more complex level of reality. The more complex and complicated the subject being dealt with, the larger the number of generalized "macro-parameters", transformation functions, tolerance ranges, probabilities, etc. to be used for the resolution. Up to now this problem has not been solved successfully with the exception of some pedotransfer functions with respect to the scale problem (Steinhardt and Volk 1999).

The **comparison of scientific data with** socially determined **standard values** connects causal-analytic and functional-analytic data obtained from the two previously discussed phases of landscape diagnosis with the fourth phase of landscape diagnosis.

There is the demand to translate the scientific data and content in the language of stakeholders and policy goals. At the moment landscape models in form of DPSIR (Driving forces – Pressures – State – Impact – Response) are discussed (Brandt 2000b).

The multistage character of landscape diagnosis can be summarized:

1. Scientific and technological characterization of landscape objects and processes (**scientific and technological stage** of landscape diagnosis).
2. Arrangement of landscape objects and processes into the fulfillment of social functions (**social and function stage** at the regional level).
3. Formulation or verification of standards and norms for use of information in the management and planning of the national or regional economy (**normative stage**).

3.1.4 Aspects of landscape diagnosis and methodological approaches

In determining landscape capacities with respect to social requirements, landscape diagnosis relies on a relatively wide spectrum of cause-effect relations between the natural system and its forms of social utilization (Figure 3.1-1).

With respect to the use of natural resources two aspects which are frequently compared with each other in an opposite relationship have to be emphasized: the resources-related approach to the **efficiency** of the natural conditions as well as the matter and energetic approach to the **resilience and carrying capacity** of natural conditions under certain forms of utilization (see Chapter 5.1). An approach is needed that unifies these two aspects.

Each of the aspects of landscape diagnosis can be described by specific properties that can be determined by a number of proven methods and attributes:

1. Characterizing the **efficiency of natural conditions** through

- determination of properties of the partial potentials and of the natural resources for landscape objects,
- properties of the natural "milieu", especially with respect to the values of human-ecological environment and recreation capability of landscape objects, and
- determination of natural risks (hazards, disturbance factors) in certain forms of utilization for landscape objects and natural processes.

2. Characterizing the **loading and carrying capacities** through
   - degrees of stress and levels of loading capacity, retention time intervals relative to certain forms of utilization, for landscape objects and natural processes,
   - carrying capacity (e.g. acid neutralization capacity (ANC), water carrying capacity, soil density) and limits of carrying capacity, relative to certain land use forms, for landscape objects and natural processes, and
   - characteristics of persistence and sensitivity of landscape objects and natural processes toward certain forms of utilization (modified carrying capacities).
3. Characterizing the **utilization suitability** (Figure 3.1-6) through
   - degrees of functional efficiency and performance of landscape objects,
   - multiple functions of landscape objects (scales of functions, combinations of characteristic features in a multidimensional space),
   - suitability preferences of landscape objects for different social and economic functions, and
   - connection with the history of human activities in a region to determine the development of the cultural landscape and to widen the knowledge about the time-relationship of landscapes processes.
4. Characterization of **availability** (**spatial disposability**) through
   - features of neighborhood effects of pairs and patterns of landscape objects,
   - forms of multiple utilization and their functional modes for landscape objects,
   - gradations of difficulty in the manageability of land use forms in respect of spatial effects of natural processes and neighborhood effects of particular forms of utilization of land.

An expansion of the conventional scientific approach to parameter and attribute transformation is associated with the interpretation of the results of inventory and survey of physical regions and landscape analysis. This is based on the proposed objectives to be tuned to the decision process on usually highly complex subjects, which are intended to be included.

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Environmental impact assessment of urban land use transitions—A context-sensitive approach

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ABSTRACT

Land consumption due to residential development, economic growth and transportation belongs to the most serious environmental pressures on landscapes worldwide, in particular in urbanised areas. Accordingly, the aim of containing the development of land is rated increasingly high on the agenda of environmental policy, at least in densely populated countries such as Germany, Belgium, the Netherlands or the UK. As a result, different strategies and instruments to prevent excessive land consumption are being discussed. However, many of these strategies and instruments adopt a rather general approach, while it seems more effective to define the particular areas where the goal of reducing land consumption is to be pursued. Such an approach must draw on information about how detrimental specific land use transitions are with regard to, for instance, the functionality of soils, water balance or habitat quality at specific locations. This paper introduces a conceptual framework for the impact assessment of land use transition in urban areas which highlights how such information can be acquired. This framework includes the differentiation of two levels of impact assessment: the level of the single land unit and the context level which takes into account regional and aggregated impacts of land use transition bound to the spatial context. The conceptual framework provides a basis to disaggregate (supra-)national policy targets regarding land use, to scale them down to the regional level, and thus to clarify the spatially explicit implications of land use policies.

Introduction: The quest for a methodology of integrated impact assessment of land use transition

The problem of land use transition

The transformation of natural, open or agricultural land into urban land is one of the major environmental impacts in most urbanized countries and regions (OECD, 1997). Moreover, along the urban rural gradient this land consumption is often characterised by dispersed developments, mono-functional and low-density land uses and reliance on private car ownership—thus displaying the typical features of veritable urban sprawl (Squires, 2002; Torrens and Alberti, 2000; Couch et al., 2005). This is also true for Europe, although European cities and towns have traditionally been rather compact (Kasanko et al., 2006). In Germany for instance, between 1993 and 2004 daily land consumption has amounted to 80–130 ha (BBR, 2007). Accordingly, the share of urban land (settlement and transportation) of the total territory of Germany in 2007 is some 12.8% compared to 7.1% in 1950—a ratio which is only exceeded by smaller and more densely populated states such as the Netherlands (18%) or Belgium (14%; EEA, 2006) (Fig. 1).

Land consumption is not only a problem because it contradicts a normative ideal of spatial planning. In a multitude of studies it has been shown that land consumption is usually detrimental to the environment in different regards (e.g. Johnson, 2001). Its impact reduces the ability of nature to fulfil human requirements and thus impairs ecosystem services in various ways (De Groot et al., 2002; MEA, 2005; Curran and Sherbinin, 2004). Individual ecosystem services that are affected by land use transition include the production of food, regulation of energy and matter flows, water supply, supply of recreational space, biodiversity or natural aesthetic values.

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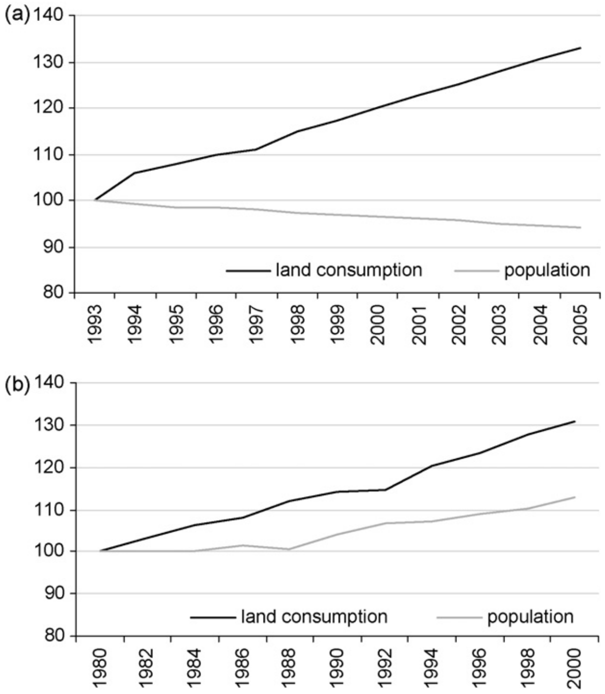


Fig. 1. (a) Land consumption (settlement and transport) compared to the population and employee development 1993–2005 for the shrinking greater metropolitan area of Leipzig (in German: Regierungsbezirk Westsachsen), eastern Germany (1993 = 100). (b) Land consumption (settlement and transport) compared to the population and employee development 1980–2000 for a growing Bavaria, western Germany (1980 = 100).

Current land use policy approaches

It is widely accepted in the field of land use policy that the incessant consumption of open land demands intervention and regulation. At EU level, documents such as the European Landscape Convention (CoE, 2000; CEC, 2001, 2004, 2005), the European Spatial Development Plan (1999), or the guidelines for the funding schemes of the common structural and agricultural policies call for the reduction of land development. While these documents are not legally binding for the member states, the EU further requires the introduction of an environmental impact assessment for spatial plans. This latter instrument has the potential to considerably reduce the negative impact of urban development and land use transitions, provided there is a sound methodology of impact assessment at hand that can be applied in practice.

At the national level an array of different policies for addressing the challenge of land consumption are being discussed in the different EU member states. In Germany, the Netherlands or the UK, for instance, the discussion on strategies and instruments to inhibit the further growth of settlement and transport areas is a high priority on the agenda of environmental politics. Besides the regulatory means of both the planning system and environmental policy, this discussion also highlights more informal instruments – such as spatial development concepts, municipal resource management schemes aiming at the reuse of brownfield land, and inter-regional cooperation initiatives – as well as so called economic instruments – such as changes in land taxation, or the introduction of a scheme of tradable development permits (German Council of Sustainable Development, 2004; Bundesregierung, 2004). Above and beyond these instruments, the Federal Government of Germany has defined the so called "30-hectare-goal" (Bundesregierung, 2004; Dosch, 2001). It thus committed itself to the goal of reducing the daily rate of land consumption from currently around 110 to only 30 ha in 2020. This figure might be seen as a political manifestation rather than a strict quantification of a land use policy goal, but it clearly provides political guidance towards the goal of mitigation of land consumption. However, the "30-hectare-goal" is abstracted from the context-sensitivity of land use transition impact, such as deterioration of water balance, soil functions or habitat quality, which differ tremendously depending on where the 'consumed' land is located. This leads to the question whether such general goals can be specified and differentiated in terms of *where* the incremental development that is still deemed acceptable should take place (EEA, 2006)—i.e. how the 'remaining' development can be steered to the most desirable locations.

Generally speaking, the different policy approaches and instruments on the containment of land consumption aim at two interrelated but distinguishable goals (Schröter-Schlaack and Ring, 2006): firstly a reduction of the (aggregated) amount of land development; secondly, an improvement of (particular) land use and development patterns, i.e. the achievement of a development pattern that is least detrimental in terms of deterioration of ecosystem services. In practice however, only if it succeeds in pursuing both goals at the same time can land use policy successfully mitigate the environmental impact of land consumption. In other words, a quantitative reduction in land consumption will only substantially contribute to the preservation of ecosystem services if supplemented by efforts to break it down to the regional and local level. Such efforts should be substantiated by scientific knowledge of the impact – or at least on the methodology of assessing the impact – of land use transition. Compared to more complex and innovation-related definitions (cf. Elzen et al., 2004; Wiek et al., 2006) the term 'transition' in this paper is understood as the change of one type of land use to another.

Studies on the impact of land use transition

The assessment and evaluation of the impact of land use transition, including both land consumption and land abandonment, is a major task of landscape research in general (Wu and Hobbs, 2002; Naveh, 2001). Accordingly, there is affluent expertise on the effects of land use transition on ecosystem services concerning, for instance, landscape clustering and fragmentation (Ewing, 1997; Pauleit et al., 2005), disturbances in the water balance (Samaniego and Barossy, 2006), soil compaction (EEA, 2006), air pollution and noise (cf. indicator set by Wiek and Binder, 2005), or increased risk of flooding (Bertoni, 2006). However, as a rule these studies are highly sophisticated contributions to the research on individual aspects of land use transition and employ a scientific methodology which could hardly be copied in practical spatial planning.

On the other hand, we find integrated assessment schemes for whole city regions, drawing on a multitude of disciplines and taking account of interlinked urban dynamics, such as suggested by Ravetz (2000), Hasse and Lathrop (2003) or, in a more participatory form, Wiek and Binder (2005). However, the primary focus of these studies is not the problem of land use transition but rather the conceptualization and evaluation of urban development processes in general. Hence, a systematic, scale-spanning and practically applicable approach to the integrative assessment of the impact of (urban) land use transition is still missing. In particular, the various forms of land use transition in the housing sector need a more detailed analysis so as to enable an assessment of its impact at the relevant spatial scales.

Objectives and structure of the paper

In this paper we deal with the question of how environmental science can support land use policy and planning in making quantitative goals of land use policy spatially explicit. We shall outline an approach to the integrated assessment of the impact of land use transition which is easily comprehensible and works on a comparatively small data base (as otherwise it would be hardly applicable in practice, since land use policy and planning usually have only limited resources at their disposal). This approach can in principle be applied to all patterns of land use and land development.

The paper consists of five sections. Section 2 explains our conceptual framework for the comprehensive environmental evaluation of land use transition. Section 3 introduces the distinction between two scales of impact evaluation of land use transition—unit and pattern or context level. It illustrates these scales, which are essential to our evaluation approach, by means of a couple of examples. Section 4 provides some remarks about the application of the conceptual framework in practical land use management and spatial planning. Section 5 provides a brief conclusion.

Conceptualising land use transition

Scientific support to land use policy must be based on some general idea about how the use of land develops so as to acknowledge the respective 'point of scientific intervention'. Fig. 2 presents a heuristic flowchart that illustrates the basic dynamics of land use transition. This flowchart builds upon the model of "Driving Forces, Pressure, State, Impact and Response" (DPSIR-model) which is widely used in interdisciplinary environmental research as well as in policy documents. Basically, it conceptualises human–environment interactions as the (more or less permanent) exertion of pressure, caused by societal driving forces, on the environmental media, leading to a certain state of the environment that exerts particular impact. It is then essential to the DPSIR-model that this impact possibly has a feedback effect on the driving forces (cf. Brandt, 2000; Ravetz, 2000). (The five key notions of the DPSIR-model are indicated at the respective places in Fig. 2; the arrows in the graph reflect the chain of causation assumed by the model.)

Our conceptual flowchart makes two important additions to the original DPSIR-model. Firstly, it explicitly mentions the actual process of land use transformation (see box at the top of Fig. 2). It is through this process that the demand for a certain land use (pressure) brings about a certain land use pattern (state). We therefore deem it necessary to deal with this very process. Secondly, the notion of governance is introduced in the flowchart because, although public concern about the impact of urban sprawl is increasing (Bengston et al., 2005), there is little evidence of

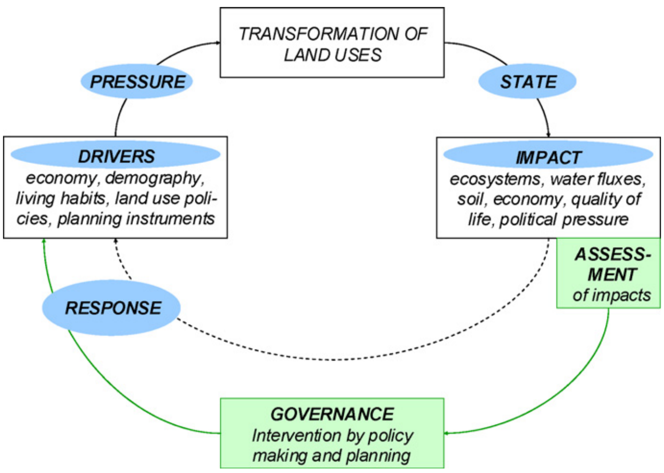


Fig. 2. Conceptualisation of land use transition, inspired by the DPSIR framework.

the impact of land consumption having direct feedback on its causes—by, e.g., prompting households, enterprises or decision makers to change their behavioural patterns regarding land use (Haase and Nuissl, 2007; see broken line at the bottom of Fig. 2). Instead, it is mainly the purposeful intervention by land use policy and urban planning that has the potential to create such feedback (see line and box at the bottom of Fig. 2).

We think that the conceptualisation of land use transition presented in Fig. 2 clearly illustrates some aspects that must be considered by any scientific effort to support land use policy. First of all, its circular structure demonstrates that, unless policy strategies and planning instruments attempt to address the problem of land use transition as an ongoing process (rather than defining fixed land use patterns as their ultimate goal), they will neglect possible feedback dynamics and thus can hardly be successful. The flowchart also shows that information on the impact of land use transition does not in itself lead to an improved land use policy—rather, such information can only provide the grounds for advising policy makers and planners regarding the potential consequences of their decisions and actions so that they are prompted to influence and change the societal drivers of land use transition, in particular existing institutional structures and governance strategies. Moreover, the flowchart can provide an orientation for researchers from different disciplines (e.g., sociologists, landscape ecologists and political scientists) on how their particular disciplinary contributions are interrelated (or should be related to each other) as well as an inspiration for decision makers to seek more detailed information on how land use transformation actually "works".

More specifically, Fig. 2 demonstrates what is needed to accomplish a sound impact assessment of land use transition. As the point of reference is the actual dynamic of land use change, it is quite clear that such an assessment must draw on reliable land use data. Such data can be either derived from existing maps, observed in the present, or obtained from land use scenarios (Patel et al., 2007; Wiek et al., 2006) concerning future developments. The practical use of an assessment of land use transition increases, if it provides policy makers with a better understanding of the consequences of specific types of land use transition in a specific location. In order to acquire such an understanding it is necessary to apply existing theoretical wisdom to the particular case under scrutiny. This can be done by means of some form of algorithm or formula which allows one to attribute certain observations in the natural and/or social world to the land use transition that has occurred. Here, the discussion on ecosystem services has contributed considerably to the formulation of the required algorithms and formulas (Finco and Nijkamp, 2001). In addition to the information on land use change, further data may be required for the calculation of the impact; however, the methodology of calculation should generally be kept as simple as possible and as sophisticated as necessary so as to make it applicable in practical land use planning and policy. Finally, for an impact assessment to become practically relevant goals are needed against which the results of the assessment can be evaluated. However, goal setting, i.e. the definition of target values, is certainly a challenge that cannot be dealt with only on scientific grounds. As a fair and credible goal setting requires the knowledge of all relevant actors, i.e. stakeholders, it should be carried out through a participatory process (cf. Wiek and Binder, 2005)[4]. Although we are fully aware that the mere definition of categories and criteria along which any assessment procedure is to be pursued entails a strong normative element, we contend that the results of an impact assessment along the lines we specify in the next section can con-

[4] We owe this argument to one of the anonymous reviewers.

siderably facilitate the formulation of site-specific goals of land use policy and spatial planning.

Environmental impact assessment of land use transition

Methodological considerations

From what has been said regarding the conceptualisation of land use transition, it becomes clear that an empirical impact assessment of land use transition has two essential preconditions: (a) a concise monitoring of actual land use transitions and (b) a set of algorithms or equations for the impact assessment that can be applied to the land use transition data resulting from the monitoring.

Monitoring of land use transitions

Empirical data on actual land use transitions must build on information concerning the features of single land units of (more or less) homogeneous use – such as *one* field of arable land, *one* cadastral unit, or *one* suburban retail complex – and their transformation over time. There are quite a few methodological problems linked to the collection of such data. These concern mainly the problems of delineating homogenous land use units, defining appropriate land use classes, and introducing monitoring routines so as to survey the ongoing transformation of these patterns. Generally, it is hardly avoidable that the land units on which the data collection draws may differ in size and land cover, and may, to a certain extent, also display internal heterogeneity; but they should be small enough to allow an unambiguous definition of their predominant use and characteristics, e.g. their sealing rate; and if they are changed, this change should usually affect the whole unit. Fig. 3 gives an example of what such land use units may look like.

Together the defined land use types build a typology on the basis of which the actual land use transitions in a particular study region can be systematized and, consequently, the impact assessment can be carried out. To this purpose we propose the construction of a matrix that consists of the empirically significant forms of land use transition along the rural–urban gradient (rows) and a set of impacts, i.e. impact dimensions, that are deemed most relevant (columns) (see Table 1).

The land use transition types defined in the rows of the matrix put the process of transformation of land uses in concrete terms. They may thus also be seen as a differentiation of 'pressure' within our conceptual framework. As there is in principle a vast abundance of potential types of land use transition, it is very important to adapt the typology that is actually to be used to the respective study case. As an example, Table 1 defines those types of land use transition that are relevant to city regions in eastern Germany that experience urban decline and urban sprawl at the same time (e.g. Nuissl and Rink, 2005). These land use transition types have been found from an evaluation of both historical and current digital land use transition data sets of the eastern German city regions of Leipzig, Halle, Dresden, and Berlin (Haase et al., 2007; Walz et al., 2004). At the same time they have been adjusted to categories used in regional, national, and EU statistics (at the NUTS[5] and LAU[6] level) in order to ensure a certain degree of comparability.

Assessing the impact of land use transition on ecosystem services

The empirical assessment of various land use transition impacts in a specific study region can draw on ample scientific expertise. In various disciplines different formula, estimates, models, or more qualitative cause-effect-theorems have been defined that could be applied to land use (transition) data so as to derive conclusions regarding the various (i.e. sectoral) consequences of the observed land use transition. Some of these algorithms may aim at/provide only a relatively simple verbal assessment, resulting in statements like 'land use A impacts more on landscape function x than land use B' (cf. Ravetz, 2000); others may perform a precise quantification of ecosystem services (e.g. Glugla and Fürtig, 1997; Mehnert et al., 2005; Rounsevell et al., 2006; Alcamo et al., 2005). However in many cases, in order to incorporate existing knowledge and procedures, these have to be adjusted to the context/issue of land use change. For instance, there are various approaches and models that aim at deriving traffic flows from spatial configurations but these have to be modified so as to be applicable to the problem of land use change. Moreover, it will usually be recommendable to gear such approaches and models towards the specific situation under scrutiny.

Levels of impact-assessment

Concern about the ongoing land consumption is usually expressed in very general (spatial) terms. The German Federal Government's "30-hectare-goal" which was mentioned in the introduction is but one example for this trend. However, research on the effects of urban development and urban sprawl has proven how difficult it is to achieve an overall assessment of all land use transitions that occur in a particular area over a particular period of time (Ravetz, 2000). Since the processes by which land use transformation creates various specific effects are rather different, we propose to distinguish between two analytical "levels" on which these effects can be established (Fig. 4; Table 2). Note that the notion of "level" does not signify a geographical scale but reflects a particular analytical perspective.

On the one hand, the change of land use on a particular plot of land may affect ecosystem functions that are related to this very plot. For instance, the development of formerly agricultural land goes along with – partly or even entirely – sealing the respective site's surface. This results in an increase in surface run-off and a reduction in the filtering capacity of soils for pollutants. Such consequences of land use transition occur directly on, i.e. below, above, or in direct physical connection to the plot of land which is subject to a transformation of its use and are an immediate result of the change of this plot's properties. Therefore, we allocate these consequences at the *land unit level* of land use transition.

On the other hand, the impact of land use transition may depend on the characteristics of the (broader) area in which it is taking place. This is the case, for example, if the construction of an industrial estate or the building of a new road cuts an existing habitat in two or if the establishment of a new large-scale out of town retail facility attracts consumers from far away and, thus, increases the car traffic in its surrounding areas. It is obvious that these phenomena cannot be captured by only analysing what is happening on a particular piece of land, nor do they occur on the very piece of land the use of which has been transformed. Instead, they are determined by the context in which the transformation of land use is taking place – in the examples mentioned this context is defined, among others, by the quality of habitats in the area and the average distance from the resident's homes to the new retail facility, respectively. Therefore, these examples represent what we call the *context level* of land use transition.

Environmental impact of land use transition at the unit level

The unit level refers to the single land units of a – more or less – homogeneous use that form the basis of the land use transition

[5] NUTS = Nomenclature des unités territoriales spatiales.

[6] LAU = Local Administrative Unit.

Table 1
Impact assessment matrix

Land use transitions	Impact (effects) on												
	Surface run-off (mm)	Groundwater recharge (mm)	Evapotranspiration (mm)	Filter capacity (mg)	Edaphon (no. of species)	Biodiversity (no. of species)	Habitat integrity	Global warming, (CO_2, UV)	Noise (dB)	Municipal taxes (€)	Maintenance costs (€)	Usability	Soil rent (€)
Agricultural (fallow) land													
Changes in single house area													
Changes in compact housing estate													
Changes in commercial area													
Changes in roads, traffic area													
Changes in fallow land													
Changes in forest													
Grassland and meadows													
Changes in single house area													
Changes in compact housing estate													
Changes in commercial area													
Changes in roads, traffic area													
Changes in fallow land													
Wetlands													
Changes in single house area													
Changes in compact housing estate													
Railway													
Changes in compact housing estate													
Changes in commercial area													
Changes in roads, traffic area													
Changes in railway fallow land													
Prefab large housing estate													
Changes in single house area													
Changes in shopping centre													
Changes in urban fallow land													
Changes in forest													
Compact housing estate													
Changes in urban fallow land													
Urban brown-fields													
Changes in single house area													
Changes in compact housing estate													
Changes in fallow land													
Changes in forest													
Succession land													
Changes in single house area													
Changes in compact housing estate													
Changes in shopping centre													
Forest													
Changes in single house area													
Mining area													
Changes in waters													
Changes in fallow land													
Changes in forest													
Military ground													
Changes in fallow land													
Changes in forest													

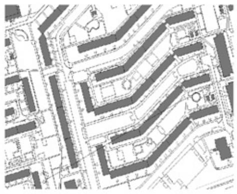
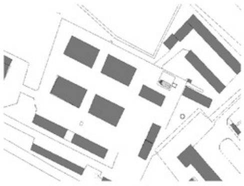
Type of land cover	Example	Structure Pattern (floor and site space)	Mean degree of sealing (%)
Compact multi-storey housing stock			60-80
Single and semidetached housing estate			60-80
Prefabricated large scale housing estate			40-60
Transportation (roads and railway)			railway 20-40 roads 80-100
Commercial and industrial site			80-100

Fig. 3. Characteristic features of three selected types of urban land use transition (according to and modified after Haase and Nuissl, 2007).

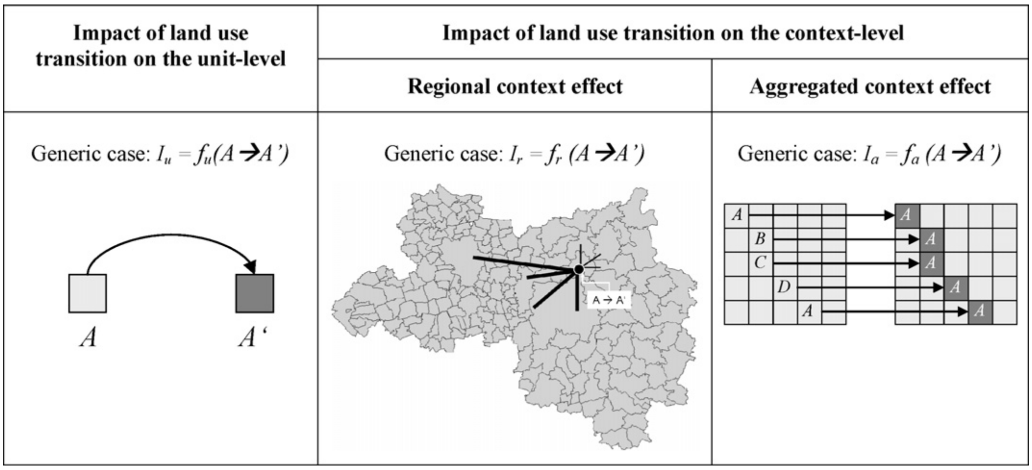


Fig. 4. Spatial schemes of the "2-level approach": land use transition from A to A′.

Table 2
Levels of impact assessment ecosystem services and goods for ensuring the quality of life affected by land use transition

Environmental impact of land use change (impact dimension)	Unit level	Context level			Remarks
		Regional effect		Aggregated effects	
Surface run-off	x		x		
Groundwater recharge	x		x		
Evapotranspiration	x		x		Effect depends very much on local circumstances
Filter capacity (of soils)	x		x		
Soil organisms	x			x	
Biodiversity (occurrence/abundance of endangered species)	x	x (frag-mentation)	x		Through more important added/aggregated land use changes in a region
Habitat integrity		x	x		
Loss of arable land	x			x	
Traffic (increase)[a]			x		
Generation of (municipal) tax[b]	x			x	
Maintenance costs[b]	x			x	
Land values; rents[b]	x				

[a] Does not belong to the ecosystem service concept in a narrow sense but has – amongst others – considerable environmental impact.
[b] Does not belong to the ecosystem service concept in a narrow sense but defines important aspects of the human quality of life.

matrix introduced above (see Table 1). Impact of land use change that occurs at the unit level can in principle be derived directly from how this land use transition has modified the features of the respective plot of land. This impact can be formalized as follows:

$I_u = f_u(A \rightarrow A')$, with I_u being the unit-level impact, A the original land use, A' the subsequent land use.

The following example highlights in more detail how the assessment of unit-level impact of land use transition can be carried out. It also illustrates that such impact assessment will usually require some additional data (in addition to the data on land use transformation), because the occurrence and/or the intensity of impact normally depends on certain framework conditions.

Example 1: Impact assessment at the unit level—water balance as a result of surfacing

Several studies have shown that sealing open land, in particular in connection with the compaction and degradation of the soil's drainage network, results in higher and accelerated surface run-off and thus negatively affects the water regulation in the area (Collin and Melloul, 2003). An increase in surface run-off and the respective decrease in percolation water leads to, firstly, a drop in groundwater recharge rates (affecting water supply for vegetation and groundwater flow in the adjacent area), secondly, a reduction in evapotranspiration (diminishing water content in the urban atmosphere), and thirdly, a decline in the water filtering capacity of soils and open surfaces for pollutants. Fourthly, in the event of heavy precipitation the sewer systems and wastewater treatment plants are often not capable of collecting the total amount of surface run-off resulting in an increased flood risk (Emmerling and Udelhoven, 2002; Deal and Schunk, 2004).

Considering these findings, the water balance model ABIMO (Glugla and Fürtig, 1997) was applied to the territory of the city of Leipzig in order to quantify the long term urban water balance changes resulting from land use transition (Haase and Nuissl, 2007). A sub-model that computes the water surface run-off in urban areas was developed by adapting the long-term water balance to the conditions in highly urbanised areas (Messer, 1997): the latter model calculates direct run-off rates for land units from the soil slope gradient, soil type, groundwater level (the greater the water table depth, the lower the direct run-off), land use, and the degree of surfacing and canalisation.

The modelling results for Leipzig proved that already a moderate increase of newly surfaced land (10–20%) in loess regions leads to an obviously problematic increase in surface run-off (200–400%), as there remains less bare (and sorptive) soil for infiltration and percolation processes. The increase in surface run-off is above all accompanied by a non-linear decline in actual evapotranspiration (Haase and Nuissl, 2007).

The example shows that the detrimental effects of land consumption on an urban region's water balance and flood risk can be derived at the unit level, since the change rates for all water cycle components are calculated for, and thus can be assigned to, individual land units, i.e. polygons, regardless of their respective neighbourhoods. Other environmental impact of land use transition at the unit level – such as, e.g., deterioration of soil functionality or loss in agricultural productivity – can be established in a likewise manner.[7]

Environmental impact of land use transition at the context level

In order to assess the "context level impact" of land use transition it is not sufficient to look at an individual plot of land undergoing land use change. Rather it is necessary to take into account additional information regarding the – spatial – context in which this plot of land is situated. Basically, this context can become relevant in two different ways. We therefore distinguish two types of context level impact which require different analytical approaches.

The first type of context level impact of land use transition is dependent on regional framework conditions. We therefore call it the *regional effect*:

$I_r = f_r(A \rightarrow A')$ with r being the properties of the regional setting.

For example, the development of a large-scale leisure and shopping facility in a specific area certainly affects traffic flow in the broader region (and beyond), and thus also has an effect on environmental conditions. The actual impact however will largely depend on the general characteristics of the region, such as population density, degree of dispersion of settlements, supply of other shopping facilities or number of cars.

While regional context effects could be assigned to the transformation of one single land unit, another kind of context level effect occurs only if a simultaneous change in the use of various

[7] Many social and economic impacts can be assessed with a corresponding approach. However, the assessment of impacts of this kind usually relies on rather different context data; e.g. data on land prices or social structure in a particular area rather than data on slope gradients, ground water levels or precipitation rates.

land units takes place. A prominent example is the fragmentation of habitats by the construction of new roads. While there are various direct effects of road construction on the affected land units, the fragmentation of habitats results from the fact that land use transition occurs in a linear way and involves a continuous row of neighbouring parcels. We call this an *aggregated effect* (which is a kind of 'aggregated unit level effect' that only occurs if the use of several land units is changed simultaneously):

$I_a = f_a(A \rightarrow A')$ with a being the properties of the aggregated effect.

Aggregated effects of land use transition may vary depending on its exact form. In the literature on urban sprawl we find the distinction between, e.g., compact, scattered, strip, poly-nucleated, or leapfrogging development (e.g. Galster et al., 2001).

Example 2: Impact assessment at the context level—increase in traffic as a regional effect

The increase in traffic due to (sub-)urbanisation certainly cannot be understood by merely looking at single land units that are modified in terms of land use. Rather, it also depends on the functional distribution of adjacent land uses and the availability of transport networks (roads, public transport, cycling lanes and footpaths) in the respective region (e.g. Cervero, 1998). Vice versa, the creation of large housing or commercial sites often has considerable impact on the entire urban region in terms of transportation area and traffic flows, and, indirectly, air pollution and noise (e.g. Breuste et al., 1998; Muniz and Galindo, 2005; Ravetz, 2000; Wiek and Binder, 2005; Camagni et al., 2002).

In order to conceptualise and quantify the relationship between land use transition and traffic we can distinguish between urban areas that are either the origin or destination of, or altogether irrelevant for traffic flows. However, land use transitions may not only alter the origin-destination-relation between areas – for example when a recreational site becomes a residential area and thus an area of origin rather than destination of traffic – but also the total amount of traffic: the construction of new suburban houses reduces population densities in existing residential areas and increases average travel distances for shopping, commuting or recreational activities. These effects however will largely depend on the distribution of workplaces and other facilities in the broader region (cf. Ewing, 1994, 1997), and are therefore assigned to the context level in this paper. If the same amount of houses is being built on urban brownfield land, the generation of additional motorised traffic may be comparatively low because of good coverage of most inner urban areas by public transport. Even if new inhabitants there do not change their habit regarding car use, the average distances travelled are significantly shorter in inner urban areas than in suburbia (e.g. Siedentop et al., 2006).

For an assessment of the impact of (different kinds of) land use transition on traffic amount and flows there are several evaluation procedures available: qualitative schemes and estimates for traffic flows (e.g. VISUM), gravity functions based on gravity accessibility between origin and destination (e.g. Torrens and Alberti, 2000; Geurs and van Wee, 2004), and comparatively sophisticated integrated land-use-transportation models such as ILUTM, IRPUD (Moeckel et al., 2003), IMREL (Anderstig and Mattsson, 1999) or MUSSA (Martínez and Donoso, 1995). The decision regarding which of these assessment schemes should finally be applied depends on a range of factors such as data availability, acceptance by local decision makers and suitability for the respective area. Simple estimation procedures or rule-based models can be used if no neighbourhood relationships have to be considered – thus handling the impact of land use transition on traffic as a specific kind of 'unit-level problem'. If this impact is dealt with at the context level, however, more integrated land-use-transport models should be consulted that account for spatial interrelations between transport axis and the neighbouring landscape. Moreover, such integrated models often also look at the socio-economic setting of a whole region.

Example 3: Impact assessment at the context level—endangering of habitats as a regional effect

With respect to most species the habitat suitability of a certain urban area depends on variables such as mean patch size, edge density of (urban) forests or distance between built-up structures. Therefore, the impact of land use transition on habitat suitability usually can only be assessed at an 'area scale', i.e. for an area of a couple of hectares of even square km. To give an example: habitat suitability analysis using both the niche factor analysis methodology (cf. Hirzel et al., 2002) and the *Biomapper* modelling environment (Hirzel et al., 2001) have been carried out in order to measure the impact of land use (transition) on two target species (Mehnert et al., 2005): green woodpecker (*Picus viridus*) and whitethroat (*Sylvia communis*).

For the green woodpecker, a high edge density in woody dwelling related green spaces is most important, as he avoids large, flat open sites. The habitat suitability analysis also revealed that the variables mean patch size of natural forests and frequency of loamy soils explain a good deal of the variation in habitat suitability between different urban areas. Accordingly, habitat suitability for the green woodpecker is surprisingly high in old densely built-up areas in decline that start to 'perforate'.

For the whitethroat, the decisive variables of habitat suitability are the distance between built-up areas. The larger this distance is, the better a site is suited as breeding habitat. Furthermore, short distances between farms, wood-dominated fallow land or ruderal spaces offer favourable breeding conditions. In the event of high frequency of broadleaf forests, a high habitat quality can be predicted, whereas a high edge density of public parks is detrimental to the breeding of whitethroat.

What do these results mean with respect to the assessment of land use transition impact? First of all they show that an analysis of habitat suitability can shed light on whether a land use transition has a detrimental – or sometimes even a positive – effect on species, i.e. on biodiversity, in a certain area. They also underline that the extent to which regional impact of land use transition occurs is often dependent on the precise land use pattern that results. Moreover, they illustrate the kind of data needed for the assessment of regional effects such as habitat fragmentation, increase in the risk of flooding by the encroachment of retention areas, or change in microclimatic conditions. Regional effects can be quantified using weighted summation ($w\Sigma$) of unit-level land transitions, weighted shares ($w\%$), or indices quantifying the density or dispersion of land uses, or the distance between functionally linked land use types (e.g. origin—destination), respectively (Batty et al., 2003). Finally, landscape metrics (adopted from landscape ecology) seem to provide a suitable set of measures to highlight "configuration and pattern effects" (Forman and Godron, 1986; Turner et al., 2001; McGarigal and Marks, 1995; Weng, 2007) as a complex form of regional effects.

Discussion

The conceptual and methodological considerations made in this paper provide a heuristic basis for evaluating the extent to which actual land use transitions jeopardize ecosystem services. In this regard, they can generally inform the debates on land consumption and land use policy. Whereas land use policies often call for regulative as well as economic instruments suited to hamper land consumption in 'a lump sum manner', our approach introduces a more differentiated perspective. Above and beyond this theoretical aspect, the actual application of our approach in empirical studies can contribute to improving regional and local land use and planning policies in several respects.

Firstly, the conceptual framework can be used for an empirical assessment and comparison of land use transition impacts that are to be expected from alternative land use transition scenarios (cf. Patel et al., 2007) in a particular region.

Secondly, the empirical application of our conceptual framework can shed light on the – different ecological – shadow costs of different forms of land use transition that may become actual (economic) costs (when it becomes necessary to replace lost ecosystem services, e.g. by technical infrastructure).

Thirdly, the impact assessment of alternative future land use scenarios (cf. Wiek et al., 2006) can facilitate the definition of target values or thresholds in land use policy and planning at a regional or even local level. (The definition of minimum requirements for habitat suitability provides a good example here; see example 3 above.)

Fourthly, the assessment of impact at the scale of the urban region also takes into account the aggregated – i.e. scalar – effects that result from both the aggregation of unit-level effects as well as the context level effects. Likewise, it acknowledges that the impact of all land use transitions together that occur in a respective urban region is more than the sum of the individual "land unit related" transitions and their effects. This does not become visible in studies that focus on particular sites only.

All in all, an empirical assessment according to the presented conceptual framework of how land use transition – i.e. how alternative land use patterns that may emerge in the future – will affect ecosystem services at a regional scale could provide a basis for well informed decision making – i.e. for the selection of the most desirable land use pattern. For instance, it will enable experts from different disciplines to argue in favour or against new strategies for "space-efficient housing", in particular inner city (re)densification policies (Weber et al., 2006) or brownfield recycling-schemes (Ganser and Williams, 2007). In this vein, our approach supports local and in particular regional (i.e. "inter-municipal") planning authorities who are the ones that must filter down aggregate targets of land use policy, such as the German "30-hectare-goal", to the realities of urban development.

First experiences with this kind of impact assessment scheme were acquired in the context of decision support with stakeholders and practitioners in the urban regions of Leipzig and Dresden (Saxony). The city of Leipzig is applying parts of the impact assessment procedure, namely the derivation of sealing rates for land use transition in the area of landscape planning and environmental protection. With the help of the impact assessment the rainfall regulation and filter potential of soils and open land within the city can be more effectively detected (cf. Haase and Nuissl, 2007). First results from our impact assessment scheme were included in the new landscape plan of Leipzig. In order to assess the environmental effects of the demolition of housing estates in a shrinking city region socio-environmental indicators as presented in Tables 1 and 3 had been applied within a multi-criteria decision support approach (Schetke and Haase, 2008).

Moreover, both its regional focus and its consideration of various forms of land use transition (not only the development of previously green or agricultural land) should make our approach particularly valuable in urban regions that undergo a process of profound population decline and urban restructuring (cf. Fig. 1b). On the one hand, these regions provide a large potential to stop or even "reverse" land consumption by turning formerly urbanised area into green area. On the other hand, the problem of underused (and thus overly expensive) infrastructure occurs in these regions, thus putting the problem of increasing costs for infrastructure provision at the top of the agenda when it comes to an evaluation of land use transformations. It is against the background of these two aspects that the recent efforts in the UK to promote brownfield reuse have been undertaken. But the discussion and decision about how derelict areas (especially in declining urban regions) should be used – or left unused – will certainly become more significant than today, in other European countries as well.

Conclusions

The paper presented a conceptual framework for an integrated assessment of the impact of land use transition in urban regions. This framework provides a basis for an empirical quantification and evaluation of such impact in concrete study regions. It introduces a few new features to the discussion of land use transition and the assessment of its impact:

- the distinction between two levels of impact-assessment of land use transition,
- the classification of land uses in a land use typology (allowing a detailed distinction of different possible transitions),
- the derivation of regional impact of land use transition from aggregate statistical figures, and
- the consideration of a variety of potential impacts. At present our approach accounts for several disciplines – such as hydrology, soil science, landscape ecology, biology, transport geography, and economics – but it is also open for the inclusion of additional fields that have so far not been included.

The integrative character of our approach brings added value into a discussion which is very much focussed on 'space' and 'hectare-figures'. More specifically it can support regional and local decision makers in their attempt to not only gear land use management and planning to the normative idea of sustainability but also to make a qualified contribution to the achievement of 'global' (i.e. national) targets regarding the reduction of land consumption. In other words: Since an assessment of land use transition impact draws the attention to the consequences of alternative land use management and planning decisions, it has the potential to orient urban development to the 'right' places. This will become increasingly important in the near future as we face a simultaneity of growth and decline in many European regions that opens up the chance for new land development strategies. However, in particular under the condition of decline, the evaluation of land use transition should also include socio-economic aspects, such as infrastructure costs or socio-spatial segregation. In this regard, at least in the medium run, the presented conceptual framework should be expanded to further 'impact dimensions'.

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Effects of urbanisation on the water balance – A long-term trajectory

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ABSTRACT

The amount of land consumption required for housing and transport severely conflicts with both the necessity and the legal obligation to maintain the ecological potential afforded by open spaces to meet the needs of current and future generations with regards to the protection of resources and climate change. Owing to an increasing intensity of soil use, soil conditions appear to have deteriorated in most city regions around the world, namely their filter and runoff regulating functions are impaired by land surfacing. As such soil functions depend on the soil's biophysical properties and the degree of imperviousness, the impact on the water balance caused by urban growth varies considerably. In response to the demand for sustainably secure urban water resources, it needs to be assessed exactly how land surfacing affects the functions concerned. Analysing and evaluating urban land use change on the long-term water balance should improve our understanding of the impact of urbanisation on the water household. Therefore, this paper analyses the impact of urban land use change and land surfacing on the long-term urban water balance over a 130-year trajectory by using simple model approaches that are based on data available to the public. The test site is the city of Leipzig. In particular, attention is to be paid to estimating changes of evapotranspiration, direct runoff and groundwater recharge.

1. Introduction

Over recent decades extensive urbanisation and land consumption processes have become an increasingly prominent but contentious issue in both public and academic discussions on land use change (Antrop, 2004). Although worldwide impervious land makes up 0.43% of the total land area (Elvidge et al., in press), in many European countries we find >10% urbanised and commercial land (Nuissl et al., 2008). Forward-looking studies imply that these dynamics will not subside (Antrop, 2004; Kasanko et al., 2006).

Among the most important modifications that affect the urban water balance is the increase in the impervious cover (Grimm et al., 2008; Elvidge et al., in press). Many authors claim that urban sprawl and the growth of the amount of built-up land have considerable negative impacts, such as social segregation and environmental degradation (Squires, 2002; Burchell et al., 2002; Kasanko et al., 2006; Batty et al., 1999; Johnson, 2001). At the same time, there is also strong support for the opinion that the problems of urban sprawl are by far outweighed by its benefits such as that it enables a growing number of people to live according to their desires (Johnson, 1997; Gordon and Richardson, 2001; Alberti and Marzluff, 2004; Alberti, 2000). Inspired however, by the growing concern about sustainability,[1] many academics are calling to effectively contain urban land consumption (Ewing, 1997; Galster et al., 2001).

There have been numerous case studies on the spatio-temporal and functional effects of urban growth on ecosystems (Breuste, 1996). These studies demonstrated that urban land consumption affects the environment in terms of biodiversity (e.g. Löfvenhaft et al., 2002), habitat suitability (e.g. Hirzel et al., 2002), water balance and water regulation (e.g. the storm runoff by Whitford et al., 2001 and Coldewey et al., 2001; water balance more generally by Wessolek, 1988; Interlandi and Crockett, 2003), microclimate (e.g. Pauleit et al., 2005), or photosynthesis (e.g. Imhoff et al., 2000). Considering a more long-term impact however requires a comparison of different time slots. There have only been very few studies which have provided empirical evidence as to the extent that urban growth processes from the beginning of industrialisation onwards have had an impact on the natural environment in the form of landscape functions (Haase and Nuissl, 2007; Haase et al., 2007).

Therefore, this paper focuses on the impact of urban growth on the long-term urban water balance. Based on a long-term trajectory of land use change over a period of more than a century, namely from 1870 to 2003, it presents a case study, the city of Leipzig, that provides empirical evidence of the effects that urban growth and land consumption have on the water balance using simple models, which are based on publicly available data. The analysis focuses in particular on the parameters of evapotranspiration, precipitation, and water regulation represented by direct runoff and the groundwater recharge rate.

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[1] Here sustainability means the balanced development of maintenance, use and abuse of open land resources and the preservation of unsurfaced land.

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Table 1
Classification of GIS-database land use types into categories of impervious land[a] (according to Haase and Nuissl, 2007).

Categories of impervious land	Land use types
0%	Agriculture/forestry, raw materials extraction, areas of water
>0–20%	Green spaces, parks, gardens, cemeteries
>20–40%	Railway tracks, sports facilities, health/social services
>40–60%	Large housing estates (flats and houses), utilities/waste disposal, military
>60–80%	Older villages, 1990s housing estates, education/research
>80–100%	Centre, commercial space, the service sector, trade show venues, roads

It is a summary of the more detailed land use list in Table 2 but more comparable in this form to municipal and regional land use statistics.
[a] The classification of imperviousness follows measurements from field surveys carried out in various German cities based on the same concept of urban structure types. This reduces the uncertainty of estimations of the total amount of impervious land (cf. Haase and Nuissl, 2007).

For two reasons the study is restricted to a comparative model application without using reference measurement data: Firstly, the earliest land use data originate from 1870 where no stream-flow measurement data are available. Secondly, none of the outflow gauges of the city of Leipzig reflect a holistic picture of the runoff generated in the city area that was modelled since they represent larger sub-basins. The major point that this paper intends to illustrate is to provide estimates for the long-term environmental impact of urban land uptake for a specific case study as well as the comparison between four respective time steps.

2. Methods

Section 2 discusses the case study (Section 2.1), the data available and the methods applied to study the effects of urban growth on the water balance. As well as detecting land use change over time (Section 2.2.), first and foremost the methodology covers the modelling of the water balance. Here, the ABMIO model (Glugla and Fürtig, 1997) and an approach by Messer (1997) were used (Section 2.3).

2.1. The case study

2.1.1. Land use history

The case study site, Leipzig, founded in the 11th century, has a long history as an important urban centre and currently has around half a million inhabitants. Situated in the eastern part of Germany, the former socialist German Democratic Republic, it experienced very little urban sprawl in the post-World War II period until 1989. Before, during and after the socialist era, however, an increase in the amount of built-up land was quite common in and around Leipzig (e.g. from allotment gardens, villas and prefabricated high-rise buildings).

Leipzig underwent a period of vibrant growth between 1870 and 1930, reaching its historical maximum with a population of more than 700,000 in the early 1930s, which then made it Germany's fourth-largest city. This development was accompanied by the urbanisation of the city's surrounding environment at that time. After 1989, post-socialist transformation again ushered a period of heavy urban sprawl, with several shopping malls, commercial parks and residential neighbourhoods spreading, in this order, into the city's suburban periphery. Industrial decline, low birth rates and out-migration, however, contradicted the expectations linked to these investments and led to a surplus of housing, office space and developed land.

Since the late 1990s urban sprawl around Leipzig has subsided considerably. Following the incorporation of several suburban townships in recent years, the administrative territory of Leipzig today covers almost 30,000 ha (298 km^2) and has a population of around 505,000 (Haase and Nuissl, 2007).

In terms of the urbanisation process over this long-term trajectory, from 1870 to 1940, urbanisation predominantly meant the growth of new impervious land and built-up areas around the urban periphery. After 1990, there was an excessive sprawl. Urban densification has been observed since 2004 but such inner-urban small-scale changes are not always detectable at this scale of analysis, 1:25,000.

Leipzig is well suited as a case study for modelling the effects of long-term land use change on the water balance for a variety of reasons. Firstly, facing simultaneous processes of societal and economic transition and demographic change, the case of Leipzig is fairly typical of the development of non-capital cities in the former socialist parts of Central Europe (Schetke and Haase, 2008). As many old industrialised cities in the West have to deal with similar problems, Leipzig is also a general example of the medium-sized city that has ceased from growing in the developed world (Banzhaf et al., 2007). Second, Leipzig is large and diverse enough to allow an overall assessment of the impact of urban growth on a regional scale. Apart from the inner city, which consists of a solid, dense structure of 19th and 20th century Wilhelminian-style tenement blocks, the city's territory contains large areas of the typically suburban mixture of land uses (Sieverts, 2003), including agricultural land and floodplain forests. And third, the availability of spatial data, a prerequisite for any kind of spatial modelling, is very good (Haase and Nuissl, 2007).

2.1.2. Biophysical conditions

Leipzig is situated in a lowland position on loess soils in Central Germany along the rivers of the *Weiße Elster* and the *Pleiße*. The city developed along the banks of these small rivers using the natural resources that the region provided in the form of highly diverse floodplain forests and nutrient-rich, binding flood loam soils. The region has a medium-continental climate with an average annual precipitation of 560–580 mm and an average annual temperature of 8.8 °C (Haase, 2003).

2.2. Detecting land use and cover change

Monitoring of the long-term land use change in the study area was related to different data sources. Firstly, topographic maps and the digital land use information system for Germany (ATKIS) from 1870, 1940, 1985, 1997, and 2003, and moreover planning maps and documents for areas designated for land development after 1990 until 2003, were used to create a digital land use data base. Secondly, field surveys were carried out

Table 2
Classification of imperviousness cover and drainage system (in the form of a percentage land parcel connected to the subterrain channel network) for different urban land use types based on field measurements as required input data for the ABIMO model.

Land use type	Degree of imperviousness (%)	Percentage of land parcel drained (%)
Old rural settlement core	65	80
Multi-storey terraced	40	50
Prefabricated multi-storey houses	60	15
Detached housing estates	70	85
Detached houses	50	35
Wilhelminian style tenement	80	85
Villas	50	50
City centre	95	60
Commercial area	90	95
Trade area	85	85
Service sector	85	75
Hospitals	40	65
Education	75	65
Military ground	55	75
Water supply and waste water	50	90
Roads	30	20
Railway	85	90
Sports ground	40	20
Park	20	20
Allotment gardens	20	20
Cemetery	15	20

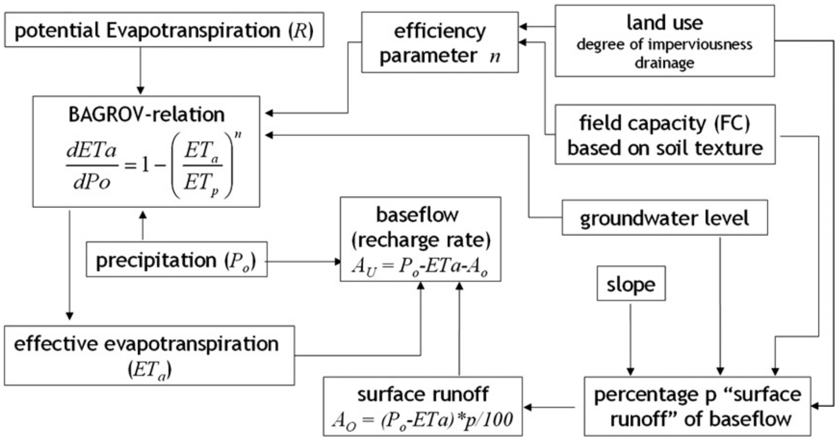

Fig. 1. Logic of the ABIMO and Messer models to calculate the urban water balance: The vertical water flow is determined by precipitation P_o, potential (R) and real evapotranspiration (ET_a). ET_a is a product of R and drainage-sensitive properties of the land parcel such as the degree of imperviousness, ground water level and soil field capacity (FC). In order to determine the horizontal water flow the groundwater recharge (A_u) is reduced by the surface runoff (A_o) using the slope-factor additionally.

in order to obtain the missing (detailed) information on land use (not land cover) in particular areas (cf. Gill et al., 2008, on the differentiation of land use and land cover). From these sources, GIS-based vector files containing land-use nomenclature and derived sealing rates were established. And thirdly, existing studies on the historic and current development of Leipzig and its region were analysed so as to comprehend the respective context of land conversion (Haase et al., 2007). The resulting series of land use (change) maps is given in Fig. 2 and discussed in Sections 3.1.

Based on methodological findings by Steinhardt and Volk (2002) and Frede et al. (2002) and drawing on reference data from other studies on Leipzig (Wickop et al., 1998; Münchow, 1999) as well as field experiments, it was possible to assign a percentage of average impervious cover to each of the urban land use classes identified at a scale of 1:25,000 (Tables 1 and 2). Thus, a set of urban land use types, characterised in terms of built-up form, surfacing and drainage, could be discerned. When different information concerning the degree of surfacing in a particular structural type was found in the afore-mentioned references, the mean value was used for modelling.

Thus, a scale-specific and -spanning[2] classification of impervious cover (Tables 1 and 2) for the entire study region was obtained, providing the data input for both water balance models ABIMO and Messer (cf. Fig. 1 in Section 2.4).

2.3. Input data

In addition to this land use data compiled by the author, regional climate data available to the public (mean 1961–1990 for precipitation and evaporation) provided as 1000 × 1000 m raster data provided by the Federal Meteorological Survey were used for determining the mean long-term precipitation and evaporation values for the city area. Moreover, different 1:25,000- and 1:50,000-scale digital soil maps provided by the Saxon Environmental Agency containing information on soil grain size and field capacity for each land parcel were used. A 20 × 20 m digital terrain model was used to derive the slope parameter.

2.4. Water balance model

Deal and Schunk (2004) argue that surfacing open land, especially in connection with the density and intensification of the soil-borne drainage network, results in higher and accelerated direct runoff flows which first of all provoke a fall in the groundwater recharge rates and subsequently also in the low-water flow of receiving water. Secondly, land-sealing brings about a reduction in water content in the urban atmosphere. Thirdly, it leads to a decline in the water retention and filtering capacity of soils and surfaces for pollutants (Collin and Melloul, 2003; Emmerling and Udelhoven, 2002). Fourthly, in the event of heavy rainfall the sewer systems and wastewater treatment plants are assumed to be not capable of collecting the total amount of direct runoff resulting in an increased flood risk.

To assess the effects of a long-term land use change on such functionalities the water balance model ABIMO (Glugla and Fürtig, 1997; Fig. 1) was applied to quantify the major variables of the long-term water balance for a city, namely for the time period from 1870–2003. ABIMO was designed by the German Federal Institute of Hydrology for modelling the water balance in the quaternary area of Central Germany (Pleistocene and Holocene sediments and substrates with vertical seeping behaviour of the soils) and later modified for urban areas. ABIMO determines the base flow A_u (in mm) of an area from the mean potential (R) and actual evapotranspiration ET_a (in mm) and the long-term mean precipitation rate P_o (in mm). ABIMO uses the BAGROV-relation (Rachimow, 1996) to determine the actual evapotranspiration ET_a of an area (Eqs. (1) and (2)):

$$R = P_o - ET_a \qquad (1)$$

$$\frac{dET_a}{dP_o} = 1 - \left(\frac{ET_a}{ET_p}\right)^n \qquad (2)$$

The BAGROV-relation is based on the evaluation of long-term percolation field studies. It describes the non-linear relation between precipitation and evaporation depending on soil grain size, field capacity, land use and respective drainage properties. With knowledge of the precipitation rate P_o, and potential evaporation ET_p, and the efficiency parameter n, the BAGROV relation determines the real evaporation R for areas without groundwater influence (used as a proxy for vertical flow without any lateral influence; Haase and Nuissl, 2007). With increasing precipitation P_o, real evaporation R approaches potential evaporation ET_p, or the quotient R/ET_p approaches a value of 1.[3] With decreasing precipitation P_o, the real evaporation R approaches precipitation P_o. The efficiency parameter n takes into

[2] Scale-specific in this case means that empirical data elaborated during field work by the studies by Münchow (1999) and Wickop et al. (1998) were aggregated to land use types that work at a scale of 1:25,000. Scale-spanning means that all land use types and land use changes respectively that are detectable at this specific scale of 1:25,000 are incorporated into the analysis.

[3] R is the long-term mean of evaporation (1961–1990) which results from regional measurements (which not only cover urban but also agricultural and forest areas). ETa is the site- or plot-specific evaporation which includes reduction due to sealing and canalisation.

Table 3
Proportion p of baseflow A_u.

Slope	0–2%					
Soil	Sand			Loam		
Depth to water table	<1 m	1–2 m	>2 m	<1 m	1–2 m	>2 m
Land use						
Farmland/grassland	50	0	0	50	20	20
Mixed woodland	20	0	0	30	5	0
Surfacing 1–20%	38	8	8	42	20	20
Surfacing 21–40%	58	43	28	61	51	42
Surfacing 41–60%	73	62	52	74	67	60
Surfacing 61–80%	86	79	73	86	82	79
Surfacing 81–100%	92	89	87	92	91	90
Water	0	0	0	0	0	0

Surface runoff A_o is A_u multiplied by p divided by 100 (modified according to Messer, 1997).

account the modification of the water storage capacity of the evaporative zone due to land use, degree of imperviousness and soil properties of each site (Glugla and Fürtig, 1997). The function of the sewer system (that accelerates the drainage of the land parcels by collecting precipitation and runoff water directly in the river) is estimated according to the land use classes and included in the ABIMO model via the parameter degree of canalisation (%; cf. Table 2): the higher the drainage proportion the lower the groundwater recharge rate which equals A_u.

A second model to calculate the water direct runoff in urban areas was developed by adapting a runoff-model by Schroeder and Wyrwich (1990) to the conditions in the highly urbanised Ruhr-area in Germany (Messer, 1997). Based on the ABIMO base flow (A_u) data, Messer's model calculates direct runoff rates in an area from the soil slope gradient, the soil type, its grain size, the ground water level (the deeper the water table, the lower the direct runoff), land use, and the degree of imperviousness (cf. Fig. 1). The direct runoff A_o equals the proportion p of excess water (difference between precipitation and evapotranspiration; Eq. (3)) out of 100:

$$A_o = \frac{(P_o - ET_a) \cdot p}{100} \quad (3)$$

The factor p is much higher in the case of cohesive soils (silt, clay) compared to grainy or porous ones (sand). With regards to land use p decreases in the following order: farmland, grassland, forest. In the case of surfaced areas, the proportion p rises with the degree of impervious cover (Messer, 1997; Table 3).

3. Results

3.1. Urban growth and land sealing

In 1870, the city of Leipzig had largely preserved its mediaeval character and huge parts of the current city (89%) were covered by arable land and forest (Fig. 2). It was primarily the Wilhelminian-style tenement development and the increase in industrial land that contributed to the subsequent growth of the city. Contrary to the assumption among local and regional representatives of nature conservation, the size of the forested area in Leipzig (around 20 km^2) has not changed much since 1870 (~10% = 30 km^2). On the other hand, the decrease in alluvial and riparian wetlands and grassland has been considerable (−6.8 km^2). Leipzig's development into a compact industrial city between 1870 and 1940 was accompanied by the embankment and canalisation of its rivers, causing the floodplains in the inner city to almost entirely disappear. Concurrently, large allotment garden sites (14 km^2) emerged and on the former outskirts of the city, the number of detached and semi-detached houses increased considerably in the 1920s and 1930s (cf. again Fig. 2).

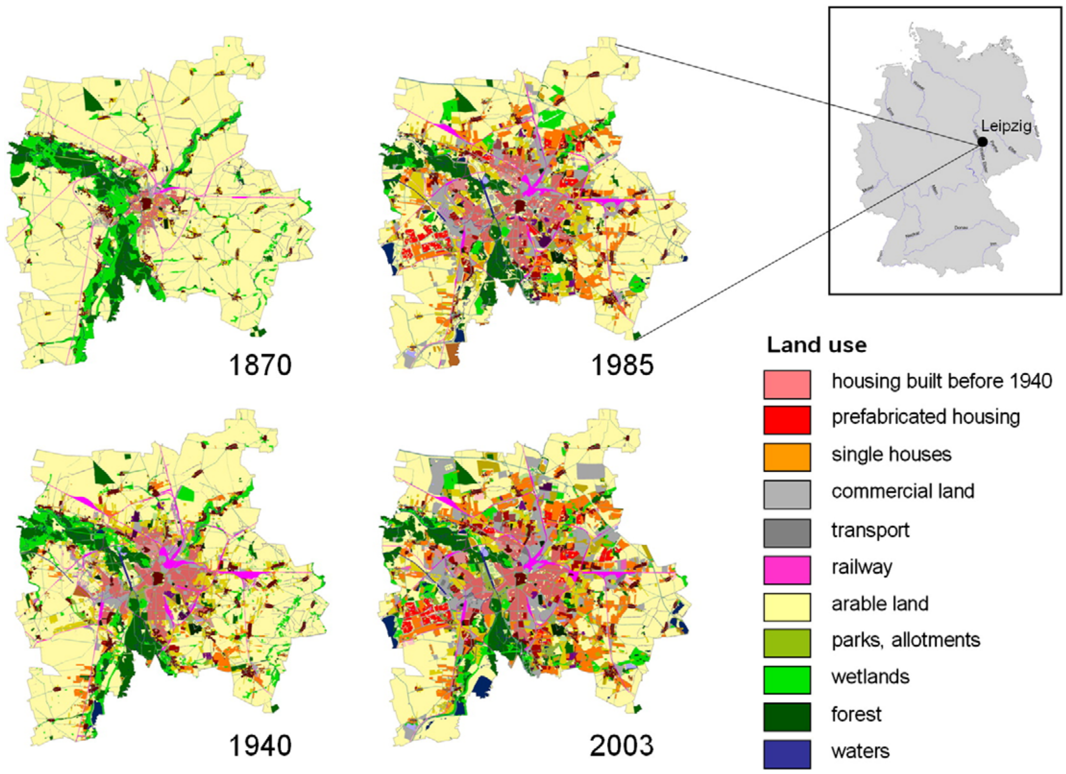

Fig. 2. Land use change in the city of Leipzig between 1870 and 2003. The first phase of growth occurred after 1870 representing the industrialisation and transport development until World War II. Even though up until now Leipzig is a compact city, particularly after German reunification in 1990 we can prove a kind of urban sprawl into the rural hinterland which is connected with land surfacing and an increase of impervious land. First and foremost the north-eastern part of the city experienced a dramatic increase of built-up land after 1990.

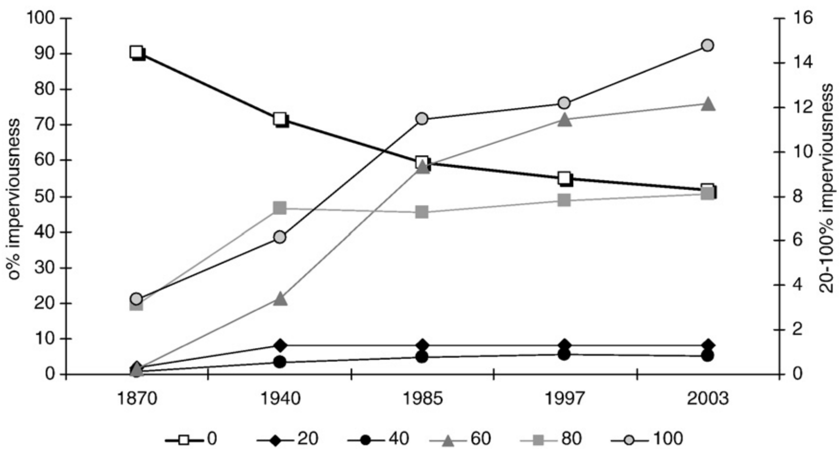

Fig. 3. Development of the degree of imperviousness in Leipzig from 1870 to 2003. In order to include all classes of impervious cover into the graph, the left-hand *y*-axis only shows the 0%-class whereas the right-hand *y*-axis is used for all classes 20–100%. Whereas the proportion of none or low impervious land dramatically decreases, the classes representing high degrees of imperviousness in particular – 60–100% – increase from 1940 onwards.

During the socialist period (1945–1989) continuous urban land take mainly occurred along the transport axes. Apart from a further decrease in arable and open land due to this moderate axial development along the main roads, land-use change also occurred due to reconstruction work in the inner city areas, where vacant lots and brownfields resulting from the destruction of World War II were partially redeveloped. The most striking change in land use over this period was the establishment of an enormous housing estate for 100,000 inhabitants on the city's western fringe between 1976 and 1989. Likewise, other, though much smaller, housing estates were built on Leipzig's periphery (Fig. 2). Processes of urban sprawl after the German reunification in 1990 meant a further decrease in the proportion of arable and open land (−45%). In total, land use change in the 1990s brought about an increase in surfaced land[4] of about 10 km^2 (Couch et al., 2005; Nuissl and Rink, 2005).

Between 1945 and 2003, the surfaced areas in Leipzig increased by 48.7 km^2 (19%). In both absolute and proportional terms, Leipzig has more impervious land compared to other Eastern Central European cities of similar size, such as Dresden (Germany), Brno (Czech Republic), or Bratislava (Slovak Republic). The reason for this can be found in the traditional compact and densely-built urban structures which largely survived World War II. Whereas, during socialist times, mainly new industrial and large housing estates contributed to land-sealing, these days the largest proportion of newly surfaced areas is accounted for by residential land with a medium proportion of impervious land (>40–60%, see Table 1). Highly surfaced areas (>80–100%), such as industrial and commercial land, also account for a large part of the land newly developed after 1990.

By comparison, areas with a limited proportion of impervious surface (>0–20%) such as public parks and gardens but also private allotments, make up for about 18% of land that has been urbanised since 1940 (Fig. 3; Haase and Nuissl, 2007; Banzhaf et al., 2007).

3.2. Water balance change

3.2.1. Direct runoff

In the study area, unsurfaced land mainly features direct runoff rates of 25–l50 mm, as the loess soils in the Leipzig region have high field capacities and are therefore able to take up and store notable quantities of precipitation water. Due to land-sealing after 1870, and particularly after 1990, the study area's high overall run-off control functionality has been severely decreasing (Fig. 4). In areas with a limited amount of impervious land the amount of direct run-off is increasing: the runoff control starts to deteriorate as a share of impervious land of >20% where the direct runoff values start to double. Where the degree of imperviousness amounts to >40–60%, respectively, direct run-off increases by 200 mm/a (e.g. in prefabricated housing estates). Once the share of impervious land exceeds 60%, runoff control drops annually by >200 mm and wherever it is >80%, run-off control drops by more than 300 mm (Fig. 4).

With an average annual precipitation of 570 mm (mean value for 1961–90), an increase in direct runoff of up to 450 mm/a (which is >75% of the total annual precipitation) has been modelled in those areas that have been almost entirely surfaced (>80–100%) in the northern part of the city mostly in the form of commercial land, the new airport and transport ways. The surfaces that were the most sealed were found particularly for commercial land and residential parks built after 1990. The lower the amount of impervious surface cover in built-up areas, the lower the increase in direct runoff is, as there are still sufficient un-built surfaces in which the precipitation water could percolate and infiltrate. Direct runoff also increases less severely where the soil had a poor infiltration capacity before it was surfaced. This particularly holds for loamy soils.

3.2.2. Evapotranspiration

The increase in direct runoff is above all accompanied by a decline in the actual evapotranspiration rates. In areas with a proportion of impervious land of >20–40%, evapotranspiration declines by 100–150 mm/a; in areas where this proportion is very high (>80–100%), it goes down by 450 mm/a. Overall, this means that the water regime is shifting towards a direct run-off throughout the study area (Fig. 5).

3.2.3. Groundwater recharge

Due to changes in land use, the groundwater recharge rates on agricultural land are about 125–175 mm from East to West of the study region, which is in line with the distribution of precipitation. The amount of percolation in areas where surfacing is up to 60% could be as much as 100 mm/a. In areas where surfacing is >60%, percolation has declined by up to 150 mm/a (Fig. 6).

Looking at the overall changes of the urban water balance caused by urban growth and land surfacing we find a considerable decrease in evapotranspiration fluxes of up to 25% (compared to 1870 which serves as a baseline). Compared to this baseline, the direct runoff rates dramatically increased from 1870 onwards to 282% in 2003.

The groundwater recharge rate has only decreased slightly so that we can conclude that water cycling in Leipzig has accelerated through urban growth. The water holding capacity has dropped in

[4] Surfaced land is calculated using the total area of specific land use types multiplied by their use-specific proportion of sealed surface given in Table 2.

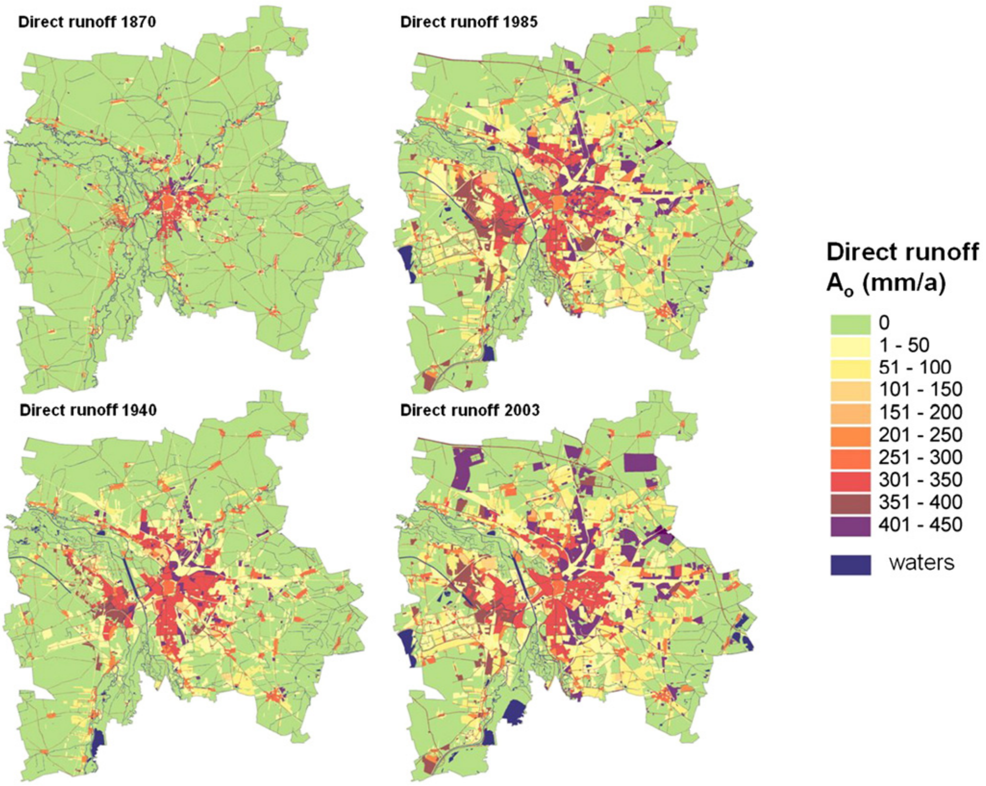

Fig. 4. Mean annual direct runoff rates for the 4 time slots 1870, 1940, 1985 and 2003.

favour of an increasing direct runoff. This leads to the need for an underground drainage system network as well as wastewater treatment. In the case of a continuous increase in direct runoff, a flooding of low-lying areas (e.g. roads, adjacent residential areas, allotments and green spaces) after heavy rainfalls, which already occurs from time to time now, must be assumed to happen more frequently when considering the model results that are presented (Table 4).

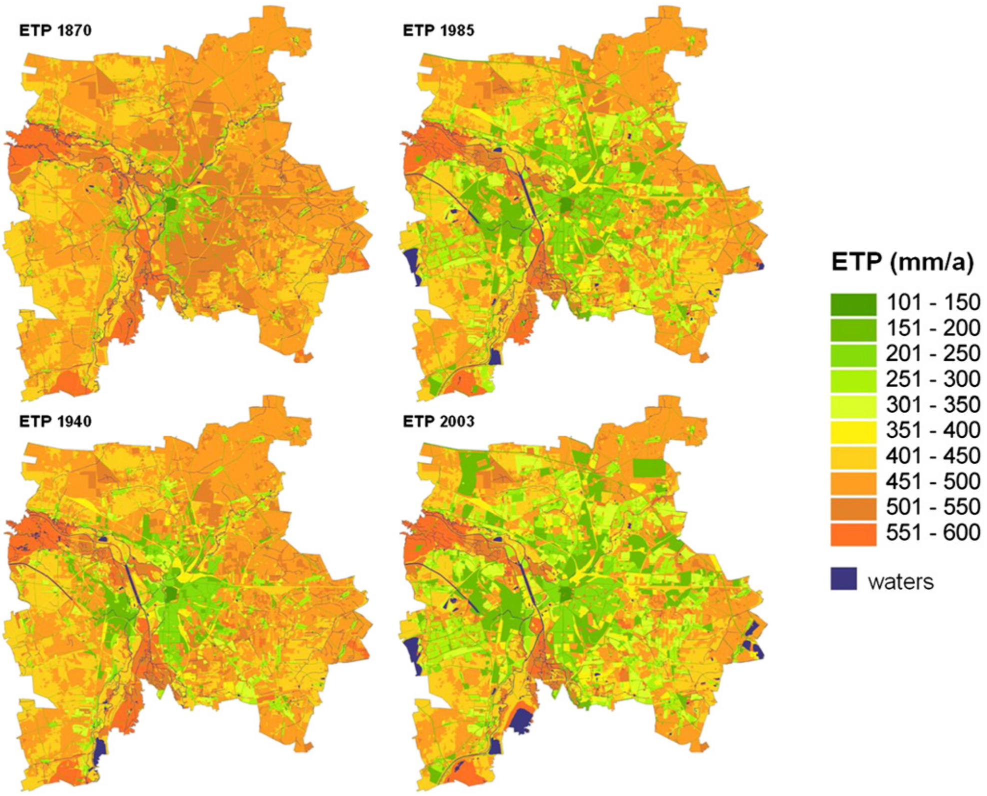

Fig. 5. Mean annual evapotranspiration for the 4 time slots 1870, 1940, 1985 and 2003.

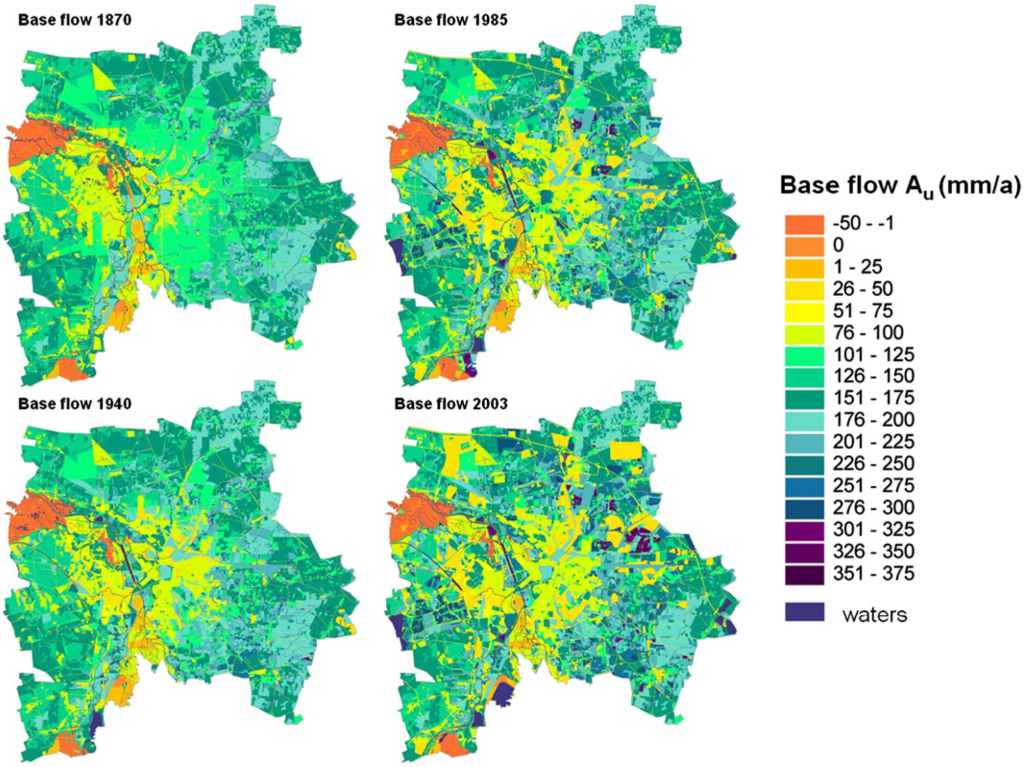

Fig. 6. Mean annual base flow A_u (representing the groundwater recharge rates) for the 4 time slots 1870, 1940, 1985 and 2003.

3.3. Parameter sensitivity

In order to test the parameter sensitivity of ABIMO and in doing so determine any uncertainties of the modelling approach presented here a number of simulations have been carried out using a range of different input values for the most sensitive[5] model parameters such as the real evapotranspiration (ET_a) in relation to the percentage impervious cover and soil field capacity (FC), and base-flow (A_u) in relation to percentage impervious cover and FC. For most of these parameters it is difficult to determine "the one" valid value of a land parcel since they are all derived from soil, land use or hydrological maps (GIS and partially analogue) using rule-based assignment procedures. Here mis-assignments or misinterpretation of the basic (analogue or field) data could occur in the way that imperviousness and the drainage system are over- or underestimated for specific land use types or that soil texture is hard to determine for heterogeneous urban substrates.

In this context, Fig. 7 shows that evapotranspiration (ET_a) increases with a decreasing degree of soil imperviousness. For the model parameter derivation this means that ABIMO overestimates ET_a in the case where the assigned imperviousness values are too high which is often the case in urban areas when the percentage of open land or green space of commercial or residential areas is neglected in the input data. Thus, base flow and/or surface runoff are overestimated. Other model parameters (precipitation, grain size, the drainage system and groundwater level) are left constant.

Furthermore it shows that, assuming precipitation, grain size, the drainage system and groundwater level are constant, the base flow (A_u) depends on the correct estimation of the degree of imperviousness as the graph shows. Particularly for the land use types of omnipresent villas, detached houses and residential parks that vary according to their degree of imperviousness from 50–70%, it is crucial to define them correctly instead of subsume them all under the class of detached houses. If this were the case, one would underestimate A_u up to 30 mm. For impervious rates <30% no considerable changes for A_u have been calculated.

The calculation of ET_a depends on the correct derivation of the soil field capacity which was derived from the soil texture given in the GIS-maps. As Fig. 7c shows, ET_a is underestimated when the loam/clay content of the soil is overestimated, which could occur since GIS-based soil maps generally assume higher clay contents for urban soils as a consequence of densification. The dependency curve of A_u on the soil field capacity is contrary to ET_a: sandy soils with a high porosity contribute comparatively more to the generation of A_u than clayey and silty soils. The poorer the share of medium and coarse pores, the lower is A_u. ABIMO underestimates the base flow by up to 50% in the case where the sand content of the soils, particularly the upper soils, is neglected or inaccurately stated (cf. again Fig. 7).

[5] The assumption about the model parameter sensitivity originate from the literature and from other studies that the author carried out using ABIMO.

4. Discussion and conclusions

The long-term observation of urban growth and sprawling land consumption has proven that it is the cumulative impact of land use change and surface sealing, rather than short-term consequences that is likely to impair the urban water balance. It highlights the problems that can arise in the long run due to this cumulative impact of land use

Table 4
Changes in the long-term water balance (proportions of ET_a, Q_D and A_u) in Leipzig taking the earliest time step from 1870 as 100%.

Year	Evapotranspiration (ET_a)	Direct runoff (Q_D) %	Groundwater recharge (A_u)
1870	100	100	100
1940	90	174	103
1985	81	196	105
2007	75	282	96
Δ 1870–2003	−25	182	−4

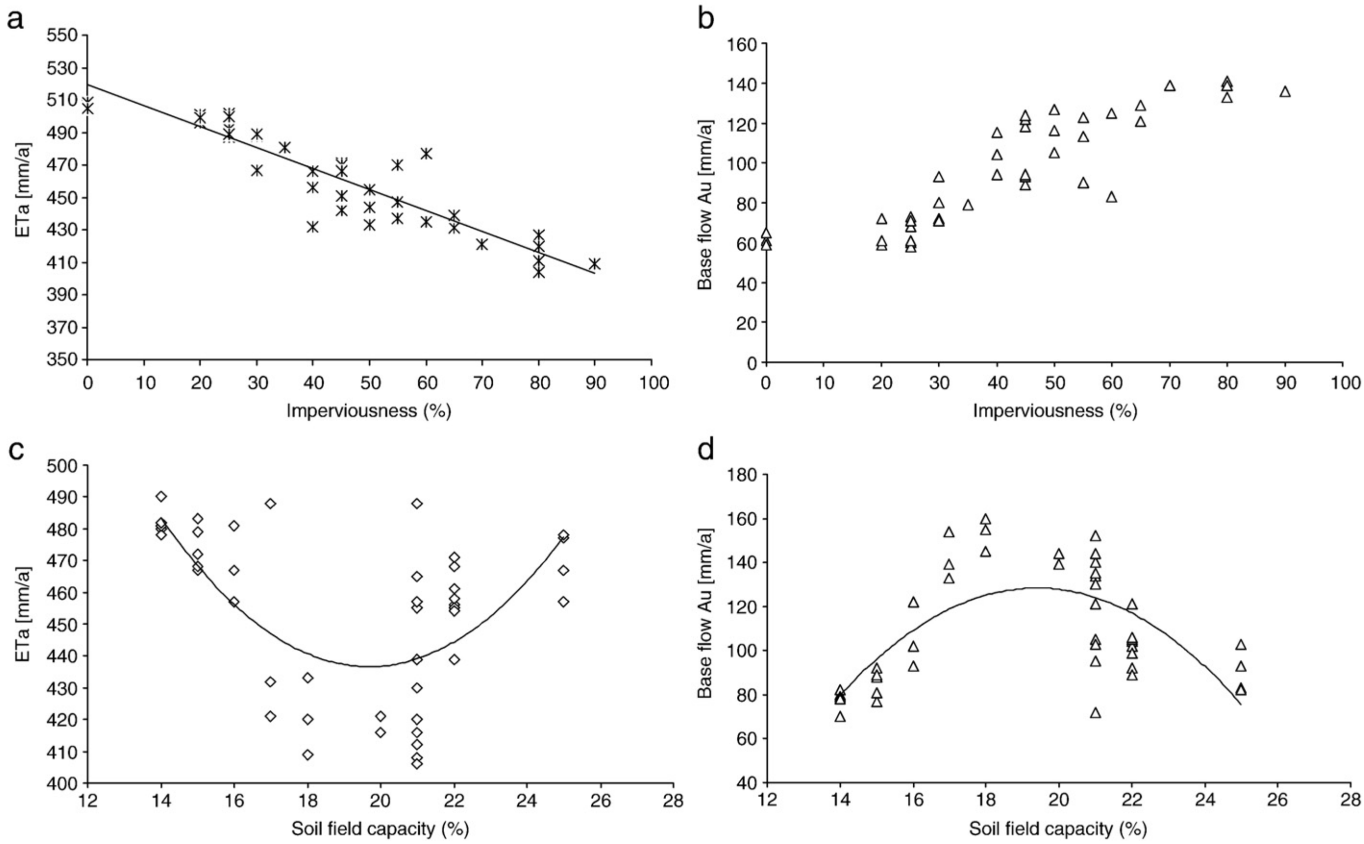

Fig. 7. Parameter sensitivity of ABIMO model results. a) Evapotranspiration (ET_a) increases with a decreasing degree of soil imperviousness. For the model parameter derivation this means that ABIMO overestimates ET_a when the assigned imperviousness values are too high, which is often the case in urban areas when the percentage of open land or green space of commercial or residential areas is neglected in the input data. Thus, base flow and/or surface runoff are overestimated. Other model parameters (precipitation, grain size, canalisation, groundwater level) are left constant. b) Base flow (A_u) depends on the correct estimation of the degree of imperviousness as the graph shows. Particularly for the land use types of omnipresent villas, detached houses and residential parks, which vary from 50–70% according to their degree of imperviousness. It is crucial to define them correctly instead of subsuming them all under the class of detached houses. Then, one would underestimate A_u up to 30 mm. For impervious rates <30% no considerable changes for A_u have been calculated. Other model parameters (precipitation, grain size, canalisation, groundwater level) are left constant. c) ET_a depends on the correct derivation of the soil field capacity (= content of soil water) which is related to the soil grain size. Clay and loam possess low field capacities (<17) due to their low porosity – they hardly release any water with sandy material showing medium field capacities (17–20) and silt showing the highest field capacity (>21) since it has the best ratio of fine, medium and coarse porosity. The soils formed by the latter gradually emit their water back to the atmosphere. ET_a is underestimated when the loam/clay content of a soil is assumed to be higher than in reality, which could occur since many soil maps generally assume higher clay contents for urban soils. Other model parameters (precipitation, degree of imperviousness, canalisation, groundwater level) are left constant. d) Contrary to ET_a is the dependency curve of A_u on the soil field capacity: sandy soils with high porosity contribute comparatively more to the generation of A_u than clayey and silty soils. The poorer the share of medium and coarse pores is the lower A_u. ABIMO underestimates the base flow by up to 50%, in the case of the sand content of the soils, particularly the upper soils, is neglected or inaccurately stated. Other model parameters (precipitation, degree of imperviousness, canalisation, groundwater level) are left constant.

change over time on the city or regional scale and thus gives an example of how severely urban growth on a city's fringes can affect environmental processes such as the water balance in quantitative terms (Gainsborough, 2002).

Urban sprawl potentially leads to an increased flood risk produced by increasing direct runoff and a resulting higher release of water out of the urban system. This could restrict a city's chances for future development in that technical precautions necessary to mitigate these problems may become extremely expensive. However, it is fairly clear that the long-term effects of urban land uptake on the environment in general, and water balance in particular, not only depend on the amount but also the distribution of the land to be developed, or the spatial pattern of land conversion, as well as the previous quality of this land (Newman, 2000; Burchell and Mukherji, 2003; Nuissl et al., 2008).

From an environmental point of view, the compact city generally seems to be the most desirable form because it allows a preservation of the largest possible patches of 'natural' landscape. On the other hand, intensification and an increase of impervious surfaces in existing urban areas tends to be accompanied by a considerable decline in environmental quality. This was recently shown with regard to urban microclimates by Pauleit et al. (2005) and has been illustrated for water balance in this paper. To illustrate this with the results obtained from this paper: a fall in the sensitive ET_a flow increases the vulnerability of the cities' residents to increasing summer temperatures that are assumed to occur due to climate change as the evaporative process supports cool urban areas (Gill et al., 2007).

Further research concerning the effect of a decrease in soil water on the temperature of urban sealed and constructed land surfaces and air temperature is required in order to provide scientific support for spatial planning and intelligent land development options in times of climate change.

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Auswirkungen urbaner Siedlungsflächenentwicklung auf den Wasserhaushalt – das Beispiel der Stadt Leipzig 1870–2003[1]

Summary

The level of land consumption for building work and transport contrasts sharply with both the necessity and the legal obligation to maintain the ecological potential afforded by open spaces to meet the needs of current and future generations. Owing to the increasing intensity of soil usage, in many urban landscapes the condition of the soil has deteriorated. Soil's natural filter and run-off regulating functions are impaired or even stopped altogether by land surfacing, curbing the natural balance. Since such soil functions closely depend on the soil's physicochemical properties, the decline of water household functionality caused by land surfacing varies.

In response to the demand to sustainably secure or restore water household-relevant soil functions, it needs to be assessed exactly how land surfacing affects the functions concerned. Analyzing and evaluating the change of land usage and related changes to land surfacing intensity taking into account interaction between land use structures and water house hold functions ought to improve our understanding of the changes currently taking place in land usage and their consequences.

Therefore, the aim of this paper is to assess the decline of soil functionality regarding water household functions caused by construction and other forms of land surfacing in urban districts over the last 130 years. In particular, attention is to be paid to land-use changes, the land surfacing they involve, and how this affects relevant parameters that describe water fluxes in an urban area.

1 Einleitung und Zielstellung

Umweltbedingungen und Lebensgewohnheiten unterliegen einem permanenten Wandel, der weltweit durch zunehmende Urbanisierung gekenn-

[1] Für die Kooperation und fachlichen Hinweise sowie auch für die kritische Durchsicht des Manuskripts sei Kollegen Dr. Gerd Schmidt herzlich gedankt.

zeichnet ist. In Europa leben derzeit ca. 75% der Bevölkerung in Städten (HALL und PFEIFER 2000). Zwar liegt der Anteil der Siedlungs- und Verkehrsfläche an der Gesamtfläche Deutschlands mit 12,3% (STATISTISCHES BUNDESAMT 2002) im Vergleich mit anderen europäischen Staaten wie der Schweiz mit 6,8% (BUNDESAMT FÜR STATISTIK 2001), Österreich mit 5% (UMWELTBUNDESAMT 2004), oder England mit ca. 20% (DOSCH 2004) in einem mittleren Bereich, aber infolge steigender Ansprüche an Wohnfläche sowie zunehmender Arbeits- und jüngst auch Freizeitmobilität wächst seit Jahrzehnten die Fläche für Wohnen, Verkehr, Freizeit und Arbeiten. Insbesondere nach 1945 sowie nach der politischen Wende 1990 erhöhte sich das Siedlungswachstum und damit der Anteil an versiegelter Fläche in den neuen deutschen Bundesländern beträchtlich (Tab.1, STAT. BUNDESAMT 2004).

Landnutzungsklassen in der									
	Bundesrepublik Deutschland (alt)					DDR	Bundesrepublik Deutschland (neu)		
Jahr	1950	1960	1970	1981	1989	1989	1989	1997	2003
Siedlung	7,1	7,8	9,3	11,1	12,2	9,9	11,5	11,8	12,5
Landwirtschaft	57,3	57,5	55,7	55,2	53,7	57,0	54,7	54,1	53,4
Forst	28,4	28,4	28,9	29,5	29,8	27,5	29,1	29,4	29,5
Gewässer	1,8	1,7	1,8	1,7	1,8	2,9	2,1	2,2	2,4
Sonstige	5,4	4,3	4,3	2,5	2,5	2,7	2,5	2,5	2,0

Tab. 1: Entwicklung der Flächennutzung in Deutschland seit 1950
(Angaben in %), Quelle: Statistisches Bundesamt Wiesbaden 2004

Die Siedlungsflächenzunahme ist dabei heute eng mit dem gewachsenen materiellen Wohlstand verknüpft. Die tägliche Flächeninanspruchnahme für Siedlungs- und Verkehrszwecke ist in Deutschland insgesamt bis heute auf etwa 129 ha pro Tag gestiegen (STATISTISCHES BUNDESAMT 2002), wobei sich die Zunahme der Siedlungsflächen seit dem Beginn der Industriellen Revolution relativ konstant entwickelt hat (DOSCH und BECKMANN 1999a). Im Zuge der Wiedervereinigung nach 1990 bestand gerade im Osten Deutschlands ein deutlicher Nachholbedarf im Verkehrswege- und Wohnungsbau. Der Flächenverbrauch erreicht dabei mit einem täglichen Siedlungsflächenzuwachs von 40 ha (Durchschnitt 1997–2003) einen momentanen Höchststand, wobei vor allem Flächen für Wohnen, öffentliche Verwendung, Handel- und Dienstleistungen überdurchschnittlich und zu Ungunsten von Acker- und Freiflächen zunahmen (DOSCH und BECKMANN 1999b).

Die zunehmende Bodenversiegelung wirkt sich entsprechend des Versiegelungsgrades auf die Erfüllung natürlicher Bodenfunktionen extrem negativ aus – Wasser- und Stoffflüsse werden unterbunden bzw. die natürliche Filter- bzw. Senkenfunktion des Bodens für Schadstoffe geht verloren. Die mit der Zunahme der versiegelten Flächen verbundenen Wirkungen auf den regionalen bzw. lokalen Wasserhaushalt, der im Focus dieses Aufsatzes steht, in einer urbanen Region können allgemein wie folgt beschrieben werden (WESSOLEK 1988; STEINHARDT und VOLK 2002):

- Abnahme der realen Evapotranspiration (ETP) durch Umwandlung natürlicher Vegetationsflächen und Verringerung der Oberflächenrauhigkeit durch künstliche Oberflächen,
- Minderung der effektiven Sickerwasserrate sowie daraus folgend Sickerwasserrate mit zunehmendem Versiegelungsgrad,
- Zunahme des (schnellen) Oberflächenabflusses (Ao) mit Zunahme des Anteils an versiegelter Fläche sowie zunehmendem Versiegelungsgrad.

Um natürliche (landschaftliche) Ressourcen vor allem auch in urbanen und suburbanen Räumen besser schützen zu können und die Effekte von Versiegelung bzw. Siedlungserweiterung auf den Landschaftshaushalt abzuschätzen, ist die flächendifferenzierte Kenntnis von Sickerwasser- und Verdunstungsraten notwendig. Die Analyse des (historischen) Flächennutzungswandels und der Veränderungen in der Versiegelungsintensität unter Berücksichtigung der Wechselwirkungen zwischen Flächennutzungsstrukturen und Wasserhaushalt gestatten dabei ein besseres Verständnis der gegenwärtigen sowie zukünftigen Veränderungen in der Flächennutzung und deren Folgen.

Der vorliegende Beitrag beschreibt die Landnutzungsänderungen und die damit verbundenen Folgen für den lokalen Wasserhaushalt im Gebiet der Großstadt Leipzig seit 1870, die GIS- bzw. modellbasiert bilanziert wurden. Folgende Punkte werden im Weiteren thematisiert:

- die Erfassung des Flächennutzungswandels und der Neuversiegelung im Maßstab 1:25.000 anhand analoger und digitaler topographischer Informationen für die Zeitschnitte 1870, 1940, 1985 und 2003,
- die Ableitung von Modellgrößen aus analog und digital vorliegenden öffentlich verfügbaren Datensätzen,
- die Berechnung bzw. Bewertung relevanter Wasserhaushaltsgrößen auf Basis der Daten sowie
- die anschließende Diskussion der Veränderungen.

2 Methoden

Methodisch stellen die oben genannten Ziele die Bearbeiter vor die Situation, nicht nur die Flächennutzungsentwicklung innerhalb der Stadt zu erfassen, sondern auch Parameter zu den Komponenten Boden, Klima, Relief und Grundwasserflurabstand für ein gesamtes Stadtgebiet in vergleichbaren

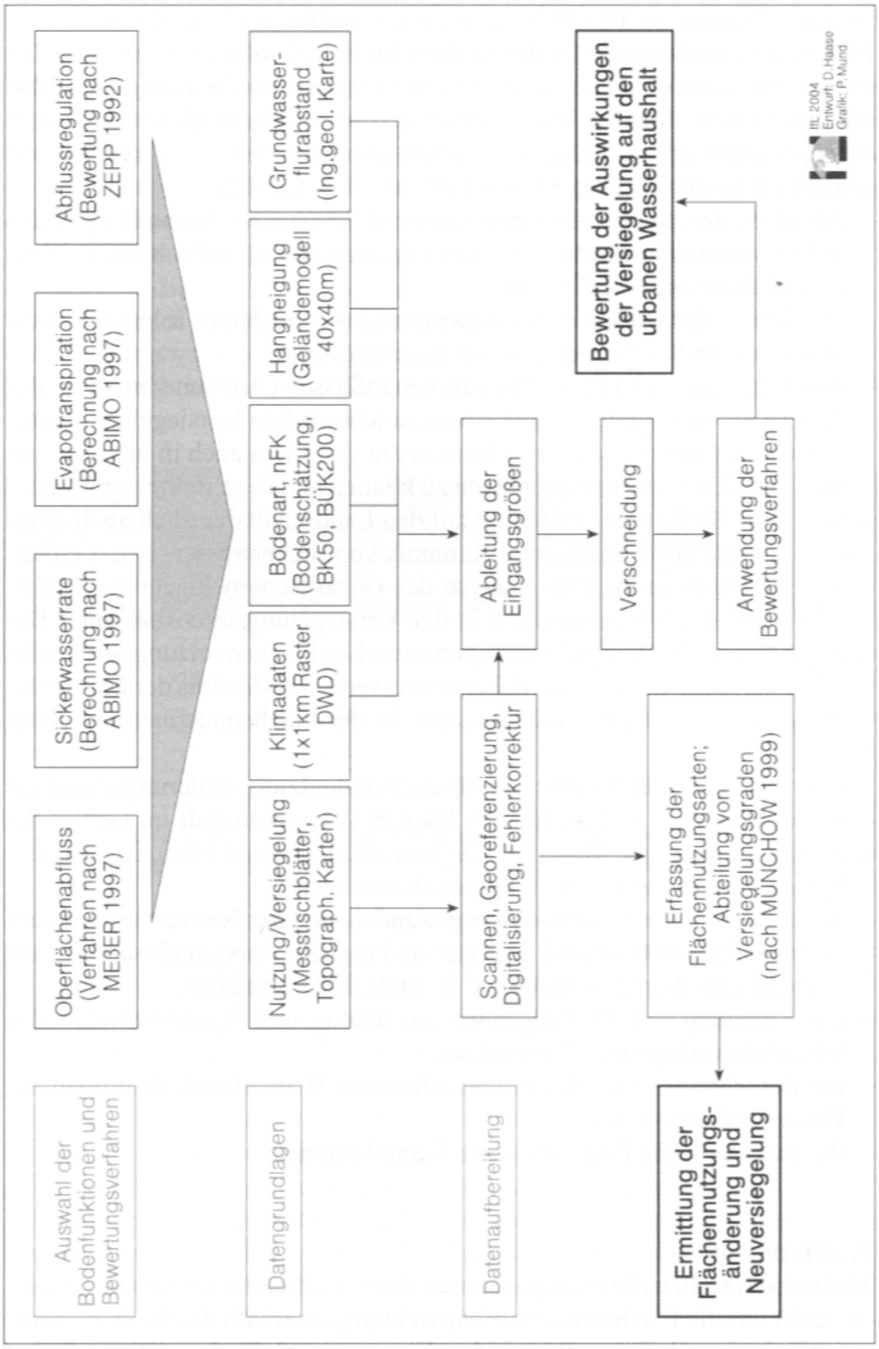

Abb. 1: Schematische Darstellung des Arbeitsansatzes

Maßstäben zur Verfügung zu haben, um vergleichende Aussagen machen zu können. Dabei muss im Wesentlichen auf öffentlich verfügbare, flächendeckende Daten zurückgegriffen werden. Einen Überblick über den methodischen Ansatz gibt Abbildung 1.

2.1 Erfassung der Flächennutzungsarten und Versiegelungsgrade

Für die Aufnahme der Landnutzung wurden topographische Karten/Informationen (Äquidistantenkarten 1870, Messtischblätter 1940, Topographische Karten (AS) 1985 sowie aktuelle topographische Daten von 1997) eingesetzt und diese für den aktuellen Zeitschnitt 2003 mit einem Datensatz einer Kartierung der aktuellen Flächennutzung auf den Planungs- und Erweiterungsflächen der Stadt Leipzig (STADT LEIPZIG 2002, 2003) ergänzt. Aus diesen Nutzungsdaten wurden dann der Anteil an versiegelter Fläche bzw. die verschiedenen Versiegelungsgrade abgeleitet (MAGNUCKI 2003; MAGNUCKI et al. 2004).

Die Flächenutzung wurde nach der Georeferenzierung der topographischen Karten in einem Geographischen Informationssystem (GIS) digital erfasst. Insgesamt wurden 25 Flächennutzungs- bzw. Bebauungstypen unterschieden, die sich an bestehenden Stadtstrukturtypengliederungen orientieren (BREUSTE 1994; ZIERDT und DIPPMANN 1994; HEBER und LEHMANN 1996; MÜNCHOW 1999). Als Ergebnis liegt ein digitaler Datensatz zur Flächennutzung der Stadt Leipzig von 1870 bis heute im Maßstab 1:25.000 für 5 Zeitschnitte (1870, 1940, 1985, 1997, 2003) vor, welcher zum einen die Entwicklung und das enorme Wachstum der Stadt in die Fläche seit 125 Jahren dokumentiert und zum anderen die Dynamik bzw. den Rückgang bestimmter Nutzungstypen bzw. -strukturen in diesem Zeitraum quantifizierbar macht (MAGNUCKI 2003; MAGNUCKI et al. 2004).

Die ausgegrenzten Nutzungseinheiten ermöglichen aufgrund ihrer einheitlichen strukturellen Ausstattung die Ableitung von Aussagen zur Versiegelungsintensität (BERLEKAMP und PRANZAS 1992). Die Ableitung der entsprechenden Versiegelungsgrade für diese Analyse resultiert aus einer Versiegelungskartierung von MÜNCHOW (1999) in der Stadt Leipzig. Durch MÜNCHOW (1999) wurden dabei in verschiedenen Stadtstrukturtypen die Nutzungs-, Belags- und Entwässerungsarten von Flächen aufgenommen, sowie die Versickerungsleistung verschiedener Belagsarten mittels Beregnungsversuchen bestimmt. Der aus der Kartierung hervorgehende Versiegelungsgrad für die einzelnen Stadtstrukturtypen wurde von den Autoren auf die 25 ausgewiesenen Flächennutzungsklassen übertragen. Wenn es für einzelne Strukturtypen mehrere Angaben zum Versiegelungsgrad gab, wurde aus diesen Werten ein Mittelwert gebildet. Für diejenigen Flächennutzungsarten, für die bei der Kartierung von MÜNCHOW kein Versiegelungsgrad erhoben wurde, wurde der Versiegelungsgrad aus HEBER und

LEHMANN (1996) entnommen. Dieser Wert entspricht den durchschnittlichen Versiegelungsanteilen der Flächennutzungsarten und wurde aus den Versiegelungsangaben verschiedener Städte ermittelt. Da die Versiegelungsgrade erhebliche Schwankungen innerhalb einer Nutzungsklasse aufweisen können (vgl. HEBER und LEHMANN 1996; MOHS und MEINERS 1994), wurden die einzelnen Flächennutzungen in Versiegelungsklassen eingeordnet, die eine Klassenbreite von 20% im Versiegelungsgrad aufweisen. Die Tabelle 2 zeigt die dieser Arbeit zugrunde liegende Einordnung der Nutzungen in die Versiegelungsklassen.

Versiegelungsklassen in %	Flächennutzung
0	Land-/Forstwirtschaft, Freifläche, Rohstoffgewinnung, Wasserflächen
> 0 bis 20	Grün-/Parkanlagen, Gartenanlagen, Friedhöfe
> 20 bis 40	Bahnanlagen, Sportanlagen, Soziales, Zeilenbebauung
> 40 bis 60	Großwohnsiedlung, Eigenheime, Villen, techn. Ver-/Entsorgung, Militär
> 60 bis 80	alter Siedlungskern, Gründerzeitbebauung, Wohnpark, Bildung
>80 bis 100	Gewerbefläche, Dienstleistung, historisches Zentrum, Messegelände, Straßenverkehrslagen

Tab. 2 : Einteilung der Flächennutzungen in Versiegelungsklassen

Die Landnutzung bzw. die aus ihr abgeleiteten Versiegelungsgrade wurden als Input-Parameter für die Modellansätze ABIMO (GLUGLA und FÜRTIG 1997), MEẞER (1997) und die Ermittlung der Abflussregulationsfunktion nach ZEPP (1992) genutzt.

2.2 Verwendete Modellansätze zur Abschätzung der Wasserhaushaltsgrößen

Das einem Gebiet durch Niederschläge zugeführte Wasser wird in Abhängigkeit von den klimatologischen Bedingungen, den Bodeneigenschaften und der Flächennutzung mit unterschiedlichen Anteilen in die Wasserhaushaltsgrößen Verdunstung, oberirdischer Abfluss (Oberflächenabfluss) und unterirdischer Abfluss (Versickerung) aufgeteilt (DYCK 1978).

Ein Verfahren zur Berechnung der *Sickerwasserrate* innerhalb eines Stadtgebietes im Tiefland stellt das Abflussbildungsmodell ABIMO (1997) der Bundesanstalt für Gewässerkunde dar. Das Modell ABIMO wurde für den Lockergesteinsbereich Ostdeutschlands entwickelt und für das Stadtgebiet von Berlin modifiziert. ABIMO hat sich auch für den mitteldeutschen Raum mit seinen relativ trockenen Klimabedingungen bewährt (PETRY 2001). Hauptbestandteil des ABIMO ist die Berechnung des Gesamtabflusses (Q), wobei zunächst die reale Evapotranspiration (ETa) einer Fläche über die Bagrov-Beziehung ermittelt wird (GLUGLA und FÜRTIG 1997). Der

Gesamtabfluss (Q) wird durch die Differenz aus realer Evapotranspiration (ETa) und dem langjährigen Mittel des Niederschlages (N) berechnet. Der Direktabfluss eines Gebietes wird nach diesem Modell nur für die versiegelten Flächen berechnet, da dieser nur über den Versiegelungs- bzw. Kanalisationsgrad einer Fläche ermittelt wird (GLUGLA und FÜRTIG 1997). Bei der Ermittlung des Direktabflusses werden weder die Hangneigung noch die Vegetationsbedeckung eines Standortes (Oberflächenrauhigkeit) berücksichtigt.

Ein weiteres Modell zur Berechnung der Sickerwasserrate in Stadtgebieten stellt das Verfahren von MEẞER (1997) dar. Dieses Verfahren ist eine Modifizierung des Modells von SCHROEDER und WYRWICH (1990) und wurde ursprünglich für das urban-industriell geprägte Ruhrgebiet entwickelt. Das Verfahren nach MEẞER (1997) berücksichtigt den Direktabfluss einer Fläche, der sich über die Faktoren Hangneigung, Bodenart, Grundwasserflurabstand und Flächennutzung ermitteln lässt. Die reale Evapotranspiration wird in diesem Verfahren über empirisch ermittelte Werte ermittelt, die nur für das Ruhrgebiet Gültigkeit besitzen.

In der vorliegenden Arbeit wurde die Sickerwasserrate über die allgemeine Wasserhaushaltsgleichung bestimmt, wobei die reale Evapotranspiration mittels des ABIMO-Modells über die BAGROV-Beziehung berechnet wurde und der Direktabfluss über das Verfahren von MEẞER (1997). Einen schematischen Überblick über die Berechnung der Sickerwasserrate gibt die Abbildung 2.

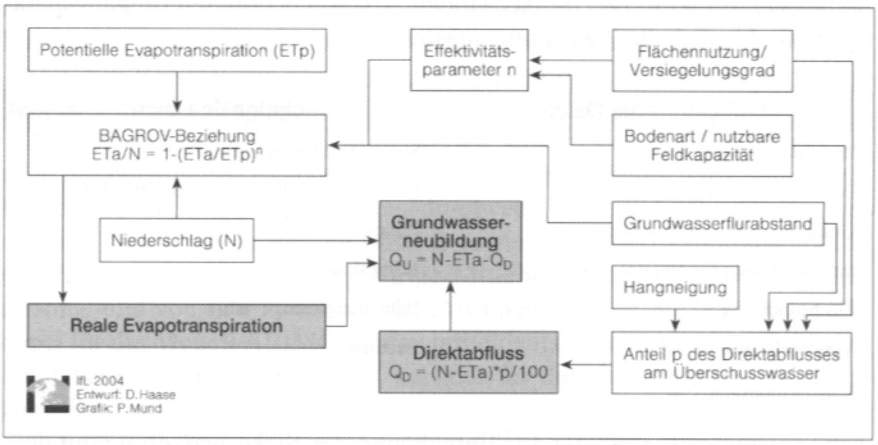

Abb. 2: Schema der Ermittlung der Sickerwasserrate

Das langjährige Mittel der realen Evapotranspiration (ETa) wird mit Hilfe des Abflussbildungsmodells ABIMO über die BAGROV-Beziehung ermittelt.

Die BAGROV-Beziehung beruht auf langjährigen Lysimetermessungen und beschreibt das nichtlineare Verhältnis zwischen Niederschlag und Verdunstung in Abhängigkeit von den Standorteigenschaften (DVWK 1996). Die nachstehende Formel zeigt die BAGROV-Gleichung mit der die reale Evapotranspiration (ETa) ermittelt wird.

$$\frac{ETa}{N} = 1 - \left(\frac{ETa}{ETp}\right)^{n}$$

Mit wachsendem Niederschlag (N) nähert sich die reale Evapotranspiration (ETa) der potentiellen Verdunstung (ETp) an, während sich bei abnehmendem Niederschlag (N) die reale Evapotranspiration (ETa) dem Niederschlag nähert. Die Intensität, mit der diese Randbedingungen erreicht werden, wird durch die Speichereigenschaften der verdunstenden Fläche (Effektivitätsparameter *n*) verändert (DVWK 1996).

Die Speichereigenschaften eines Standortes bzw. einer Flächeneinheit werden vor allem durch die Nutzung (zunehmende Speicherwirksamkeit in der Reihenfolge versiegelte Fläche, vegetationsloser Boden, landwirtschaftliche, gärtnerische, forstwirtschaftliche Nutzung) und die entsprechende Bodenart bestimmt. Das Maß für die Speicherwirksamkeit des unversiegelten Bodens ist die nutzbare Feldkapazität. Je nach den Bodeneigenschaften des Standortes tritt für Gebiete mit flurnahem Grundwasser infolge des Kapillaraufstiegs vom Grundwasser eine gegenüber grundwasserunbeeinflussten Bedingungen erhöhte Verdunstung auf, was im Modell ABIMO berücksichtigt wird. Die für das Modell ABIMO benötigten Eingangsparameter sind in Tabelle 3 zusammengestellt.

Obligatorische Daten	Optionale Daten
Jahresniederschlag [mm]	Sommerniederschlag [mm]
Potentielle Verdunstung [mm]	Potentielle Verdunstung im Sommer [mm]
Grundwasserflurabstandsklasse	Hauptbodenart
nutzbare Feldkapazität [Vol.-%]	Ertragsklasse
Flächennutzung	Beregnungsmenge [mm]
Versiegelungsgrad [%]	Baumart
Kanalisationsgrad [%]	

Tab. 3 : Eingangsparameter zur Berechnung der Sickerwasserrate mit dem Modell ABIMO (nach GLUGLA und FÜRTIG 1997; PETRY 2001)

Die Flächennutzung geht in den Klassen: L (landwirtschaftliche Nutzfläche), W (forstwirtschaftliche Nutzung), K (gärtnerische Nutzung) und D (vegetationslose Fläche) in die Berechnung ein. Zur landwirtschaftlichen Nutzfläche wird zunächst sowohl die Acker-/Freifläche, das Grünland und Grünflächen als auch die Siedlungs- und Industrie-/Gewerbefläche gezählt, da letztere je nach ihrem Versiegelungsgrad auch Freiflächen enthalten. Die Eigenschaften der Siedlungs- und Gewerbeflächen werden dann zusätzlich durch den Versiegelungsgrad (VER) und den Grad der Regenwasserkanalisation (KAN) bestimmt.

Die Gartenanlagen und auch die Einzel- und Doppelhausbebauung werden zur Klasse gärtnerische Nutzung gezählt, da hier eine gärtnerische Nutzung auf den unversiegelten Flächen vorausgesetzt wird. Friedhof wird ebenfalls in die gärtnerische Nutzung eingeordnet, da anzunehmen ist, dass die Ausprägung des Effektivitätsparameter n auf solchen Flächen ähnlich wie bei einer gärtnerischen Nutzung zwischen dem Effektivitätsparameter der landwirtschaftlichen Nutzung und dem des Waldes liegt. Die Flächen der Rohstoffgewinnung werden zur Klasse „vegetationslose Fläche" gezählt. In die Klasse forstliche Nutzung wird die Flächennutzungsart Forst- und Waldfläche eingeordnet.

Die Berechnung des Direktabflusses erfolgt über die Bestimmung des Anteils p am Überschusswasser (Differenz von Niederschlag und Verdunstung). Der Direktabflussanteil p wird über die Eingangsparameter Hangneigung, Bodenart, Grundwasserflurabstand und die Flächennutzung bzw. den Versiegelungsgrad ermittelt. Der Direktabflussanteil p nimmt mit steigendem Grundwasserflurabstand ab. Er ist bei bindigen Böden (ton- und schluffreich) deutlich größer als bei nicht bindigen (v.a. sandigen) und nimmt von Acker über Grünland bis zum Wald hin ab. Bei versiegelten Flächen steigt der Anteil mit zunehmendem Versiegelungsgrad an (MEßER 1997). Ein Beispiel zur Ableitung des Direktabflussanteils p ist in der folgenden Tabelle 4 dargestellt.

Da hier mit langjährigen Mittelwerten sowohl des Niederschlages als auch der potentiellen Evapotranspiration (ETP) gearbeitet wird, werden als Ergebnisse auch nur langjährige Mittelwerte des Wasserhaushaltes berechnet. Die Sickerwasserrate (mm/a) sowie die reale Evapotranspiration (mm/a) müssen dabei als langjährige Mittelwerte angesehen werden, die saisonal und von Jahr zu Jahr stark schwanken können. PETRY (2001) gibt dabei für das Modell ABIMO für den mitteldeutschen Raum einen Fehlertoleranzbereich von ±20 mm/a an, der hier für die nicht bebauten Bereiche zutreffend ist.

Der Oberflächenabfluss wird aufgrund der Datenlage ebenfalls als langjähriges Mittel angegeben. DÖRHÖFER und JOSOPAIT (1980) konnten nachweisen, dass das Verhältnis von Oberflächenabfluss und Gesamtabfluss im langjährigen Mittel dabei konstant und unabhängig von der Niederschlagshöhe ist. Die Abschätzung des Oberflächenabfluss aus den Eingangsdaten

Reliefenergie/Gefälle	0–2%					
Bodenart	Sand/Aufschüttung			Lehm		
Grundwasserflurabstand	< 1m	1–2m	> 2m	< 1m	1–2m	> 2m
Flächennutzung						
Acker/Grünland	50	0	0	50	20	20
Mischwald	20	0	0	30	5*	0
Versieg. 1–20% Mischvegetation	38	8	8	42	20	20
Versieg. 21–40% Mischvegetation	58	43	28	61	51	42
Versieg. 41–60% Mischvegetation	73	62	52	74	67	60
Versieg. 61–80% Mischvegetation	86	79	73	86	82	79
Versieg. 81–100% Mischvegetation	92	89	87	92	91	90
Wasserflächen	0	0	0	0	0	0
Halde (kaum bewachsen)	100	100	100	100	100	100

Tab. 4 : Anteil p am Überschusswasser (nach MEßER 1997, verändert). Der Direktabfluss (Q_D) wird über folgende Formel berechnet: $Q_D = (N\text{-}ETa) * p/100$ (0–2% dienen als Beispiel).

Relief, Bodenart, Grundwasserflurabstand und Nutzungsart bzw. Versiegelungsgrad nach MEßER (1997) ist daher auf den unversiegelten Standorten als plausibel anzusehen.

Auf den versiegelten Standorten wird der Oberflächenabfluss nach MEßER (1997) neben der Berücksichtigung von Relief und Boden hauptsächlich über den Versiegelungsgrad bestimmt. Dabei ist auf versiegelten Flächen für die Bestimmung des Oberflächenabfluss auch der Anschlussgrad der Fläche an die Kanalisation von Bedeutung. So kann bei einem geringen Kanalisationsgrad ein Teil des Oberflächenabflusses an anderer Stelle derselben Fläche versickern, was hier nicht berücksichtigt wird.

Das Modell ABIMO berücksichtigt bei der Berechnung des Oberflächenabfluss zwar den Kanalisationsgrad, nicht jedoch die Bodeneigenschaften der unversiegelten Flächen, so dass hier der Oberflächenabfluss vor allem auf lehmigen Standorten eher unterschätzt wird, was in Abb. 3 deutlich wird. In dieser Arbeit kam deshalb das Verfahren von MEßER (1997) zur Anwendung.

Die ebenfalls zu bewertende *Abflussregulationsfunktion* kennzeichnet das Vermögen des Landschaftshaushaltes, den Oberflächenabfluss zu regulieren, d.h. den Direktabfluss aus der Fläche zu verringern und Abflussspitzen zu vermeiden (BASTIAN und SCHREIBER 1999). Als wichtige Einflussfakto-

Abb. 3: Differenz zwischen den mit ABIMO und dem Verfahren nach MESSER ermittelten langjährigen Werten des Oberflächenabflusses im Untersuchungsgebiet Leipzig

ren auf die Abflussregulationsfunktion spielen neben der Niederschlagsmenge und -intensität vor allem die Bodeneigenschaften, die Flächennutzung, der Versiegelungsgrad und die Hangneigung eine wichtige Rolle.

Die Abflussregulationsfunktion kann mit dem Verfahren von Zepp (in MARKS et al. 1992) bewertet werden. Das Verfahren von ZEPP (1992) ermöglicht flächendifferenzierte Aussagen und ist nicht an ein Einzugsgebiet gebunden (BASTIAN und SCHREIBER 1999). Das Verfahren stellt ein fünfstufiges Punktbewertungsverfahren mit den Eingangsdaten Bedeckungsgrad, Hangneigung, Infiltrationskapazität und nutzbare Feldkapazität dar. Die Infiltrationskapazität wird durch die Ersatzgröße Bodenart des oberen mineralischen Bodenhorizontes repräsentiert (ZEPP 1992). Zur Bewertung der Abflussregulation wird zunächst jeder Faktor einzeln einer Stufe auf der Werteskala zugeordnet, wobei für die günstigste Ausprägung der Faktoreigenschaften die höchste Punktzahl vergeben wird. Bei Böden mit Grundwassereinfluss (Grundwasserflurabstand < 2 m) erfolgt eine Korrektur der Punktzahl der nutzbaren Feldkapazität um einen Punkt, da das kapillare Aufstiegswasser das Wasserspeichervermögen dann herabsetzen kann. Wald- und Wasserflächen werden nach dem Verfahren von ZEPP (1992) immer mit der höchsten Punktzahl bewertet. Versiegelte Flächen werden dagegen immer in die geringste Klasse eingestuft.

Bewertung des Wasserrückhaltes					
Faktoren	sehr gering (1)	gering (2)	mittel (3)	hoch (4)	sehr hoch (5)
Bedeckung	kein Bewuchs	Ackerfläche	Grünland	Mischvegetation	Wald
Hangneigung in Grad	> 35	15–35	7–15	2–7	0–2
Infiltration	Tl	Lt, Lts, Ut,	Lu, Ls, Uls	Sl, Slu, Su	Ss
nFK in Vol.-%	< 6	6–9	9–14	14–20	> 20

Tab. 5 : Bewertung der Einzelfaktoren der Abflussregulationsfunktion nach ZEPP (1992); PETRY (2001), verändert.

Um teilversiegelte Flächen besser bewerten zu können, wird dem Versiegelungsgrad ein Bewertungsfaktor zugeordnet, der die Punktzahl um diesen Faktor mindert. Die Vergabe des Faktors beruht auf der Annahme, dass mit zunehmender Bebauung der schnelle Abfluss und auch die Hochwassergefährdung proportional ansteigen (BASTIAN und SCHREIBER 1999). Mit steigendem Versiegelungsgrad nimmt der Einfluss der übrigen Faktoren auf die Abflussregulation ab.

Bei der Punktzahl für den Bedeckungsgrad werden versiegelte Flächen (Wohnflächen, Industrie-/Gewerbeflächen, Sonderflächen und Freizeit-/Erholungsflächen) in die Kategorie Mischvegetation eingestuft, die im Vegetationsbedeckungsgrad der Kategorie Buschwerk im Bewertungsverfahren von ZEPP (1992) entspricht. Diese Einstufung gilt im Wesentlichen für die unversiegelten Bereiche dieser Flächen. Die versiegelten Anteile werden in dem Bewertungsfaktor (Tab. 6) berücksichtigt.

Versiegelungsklasse	Faktor
0%	1,0
> 0–20%	0,9
> 20–40%	0,7
> 40–60%	0,5
> 60–80%	0,3
> 80–100%	0,1

Tab. 6 : Bewertungsfaktor für teilversiegelte Flächen (MAGNUCKI 2003)

Bergbauflächen werden bei ZEPP (1992) nicht gesondert erwähnt. Da der Bedeckungsgrad von Abbauflächen meist jedoch sehr gering ist (Erfahrungswert), werden diese Flächen deshalb in die Stufe 1 (sehr gering) für den Bedeckungsgrad in der Bewertungsskala eingeordnet. Verkehrsflächen werden im Bedeckungsgrad ebenfalls sehr gering bewertet. Nachdem die Faktoren einzeln bewertet wurden, ergibt sich die Gesamtbewertung dann aus der Summe der Punkte und dem Faktor für die Versiegelung, mit dem die Punktsumme multipliziert wird. Die Gesamtpunktzahl entspricht folgenden Wertstufen:

Bewertung	Punktzahl
sehr hoch	> 18
hoch bis sehr hoch	> 16–18
hoch	> 14–16
mittel-hoch	> 12–14
mittel	> 10–12
mittel-gering	> 8–10
gering	> 6–8
gering bis sehr gering	> 4–6
sehr gering	0–4

Tab. 7 : Einschätzung der Abflussregulationsfunktion nach ZEPP (1992), verändert

2.3 Datenmaterial und Verarbeitung im GIS

Datengrundlage der Berechnungen und Bewertung bildeten überwiegend öffentlich verfügbare digitale Boden-, Relief- und Klimadaten (vgl. Tab. 8), sowie die digitalisierten Flächennutzungsdaten mit den abgeleiteten Versiegelungsgraden.

Datensatz	Stand	Maßstab	Herausgeber/Quelle
Äquidistantenkarten	ab 1870	1:25.000	Stadtarchiv Leipzig
Messtischblätter	1907–44	1:25.000	Landesvermessungsamt Sachsen
Topographische Karten (AS)	1986–87	1:25.000	Landesvermessungsamt Sachsen
Topographische Karten (N)	1997–98	1:25.000	Landesvermessungsamt Sachsen
CIR-Luftbilder	2002	1:6.000	Stadt Leipzig
DGM	1995	20 x 20m²	Landesvermessungsamt Sachsen
Evapotranspiration	1961–90	1 x 1km²	Deutscher Wetterdienst
Niederschlag	1961–90	1 x 1km²	Deutscher Wetterdienst
Ingenieurgeolog. Karte, Hydrolog. Teil	1977	1:10.000	LfUG Sachsen
Karte der Hydroisohypsen, Blatt Leipzig	1984	1:50.000	LfUG Sachsen
Bodenschätzungskarten	ab 1935	1:10.000	Finanzamt Leipzig
Bodenkarte Leipziger Land	1964	1:50.000	RICHTER 1964
Bodenübersichtskarte Blatt CC 4734	1999	1:200.000	BGR Hannover
Auelehmverbreitung	2003	1:50.000	HAASE 2003

Tab. 8 : Verwendete analoge bzw. digitale Datensätze

Für die Anwendung der Verfahren bzw. Modelle wurde es notwendig, die geforderten Eingangswerte aus den digitalen Daten abzuleiten und neue Attributtabellen zu erstellen. So wurde beispielsweise aus dem Geländemodell (DGM) die Hangneigung abgeleitet, aus den Ingenieurgeologischen Karten 1:25.000 die Grundwasserflurabstandsklassen bzw. aus den Bodendaten die nutzbare Feldkapazität (nach KA4, AG BODEN 1994). Da die Bodendaten in den Kartengrundlagen insbesondere für urbane Räume nicht flächendeckend vorhanden sind und so Flächen ohne Informationen vorliegen, wurde eine Synthesekarte aus aktuellen und älteren Bodendaten erstellt: Reichsbodenschätzung, BK50 nach RICHTER (1964), BÜK 200 und der Auelehmverbreitung nach HAASE (2003). Aus dieser Synthesekarte wurden dann die Bodenarten abgeleitet. Im Falle völlig unzureichender Bodeninformationen zu einer Fläche wurde der für die Leipziger Tieflandsbucht typische Sandlöß (Slu) angenommen, für die Auen Auelehm (Ls3). In die Berechnungen gehen die Bodenart und die nutzbare Feldkapazität ein.

Die verwendeten Bodenkarten unterscheiden sich sowohl im Maßstab als auch in ihrem Informationsgehalt. So sind die Bodendaten im Maßstab 1:50.000 bzw. 1:200.000 im Vergleich zu den Daten aus der Reichsbodenschätzung wesentlich weniger detailliert. Die Verwendung der BÜK 200 für

Fehlflächen rechtfertigt sich nur dadurch, dass keine detaillierteren, digitalen Datensätze zur Verfügung standen.

Zur Reduzierung der Unsicherheiten bei der Ableitung der bodenkundlichen Modelleingangsparameter für die Bereiche des Stadtzentrums wurden Informationen einer synthetischen Bodenkonzeptkarte zur Rekonstruktion der natürlichen Bodenverbreitung nach FÖRSTER (2004) und HAASE und SCHMIDT (2004) genutzt. In diese fanden einerseits die Grenze der natürlichen Auelehmverbreitung sowie reliefbedingte Grundwasserflurabstände vor einer urbanen Nutzung v.a. für die Datenbereitstellung zu Zeitschnitt 1870 Eingang.

Nach der Aufbereitung der Eingangsdaten wurden die Datenlayer miteinander verschnitten, nachfolgend bewertet und klassifiziert. Unsicherheiten in der Berechnung können sich dabei vor allem durch die Verwendung von Daten unterschiedlicher Aufnahmezeitpunkte und -ziele sowie unterschiedlicher Aktualität ergeben (MYSIAK et al. 2004).

3 Ergebnisse: Zur Siedlungsentwicklung von 1870 bis 2003 und deren Auswirkungen auf den Wasserhaushalt

3.1 Leipzig um 1870

Das heutige Stadtgebiet von Leipzig (297,6 km², STADT LEIPZIG 2002) wurde vor 130 Jahren überwiegend durch die Land- und Forstwirtschaft bestimmt (89% Flächenanteil). Neben dem Zentrum der Stadt und den alten Ortskernen sind es vor allem die beginnende Blockrandbebauung, Industrie- und Verkehrsflächen um den Hauptbahnhof herum, welche zur Erweiterung der mittelalterlichen Stadt beitragen (siehe Abb. 4a und 4b).

Klimatisch liegt Leipzig im abnehmenden Regenschatteneinflusses des Harzes, so dass die Niederschlagshöhen im Stadtgebiet einen deutlichen Gradienten aufweisen. Die Jahresniederschlagsmenge nimmt von Nordwest nach Südost von 500 mm/a auf mehr als 620 mm/a zu (RICHTER 1995). Die Sickerwasserrate beträgt auf den Ackerflächen im Westen der Stadt zwischen 75 mm/a und 125 mm/a, im Osten des Stadtgebietes kommen Sickerwasserraten von 150 mm/a bis 175 mm/a vor. Relativ hohe Werte (200–225 mm/a) sind auf den Flächen zu finden, die aufgrund der Bodenart eine hohe Infiltrationskapazität und eine niedrige nutzbare Feldkapazität aufweisen (Abb. 7). Diese Versickerungsraten entsprechen nach MARKS et al. (1992) einer „geringen" bis „sehr geringen" Sickerwasserrate.

Die Leipziger Auenbereiche (Elster-Luppe-Pleiße-Aue) sind durch Grundwasserzehrung gekennzeichnet. Hier kann die Vegetation durch die Nachlieferung aus dem Grundwasser mehr Wasser verdunsten als durch die Niederschläge zugeführt wird. Zudem kann in den Auen der Kapillaraufstieg von Grundwasser in die verdunstungsbeeinflusste Bodenzone die Verdunstung erhöhen, obgleich die Leipziger Auen in der Sommerperiode häufig unter Austrocknung leiden.

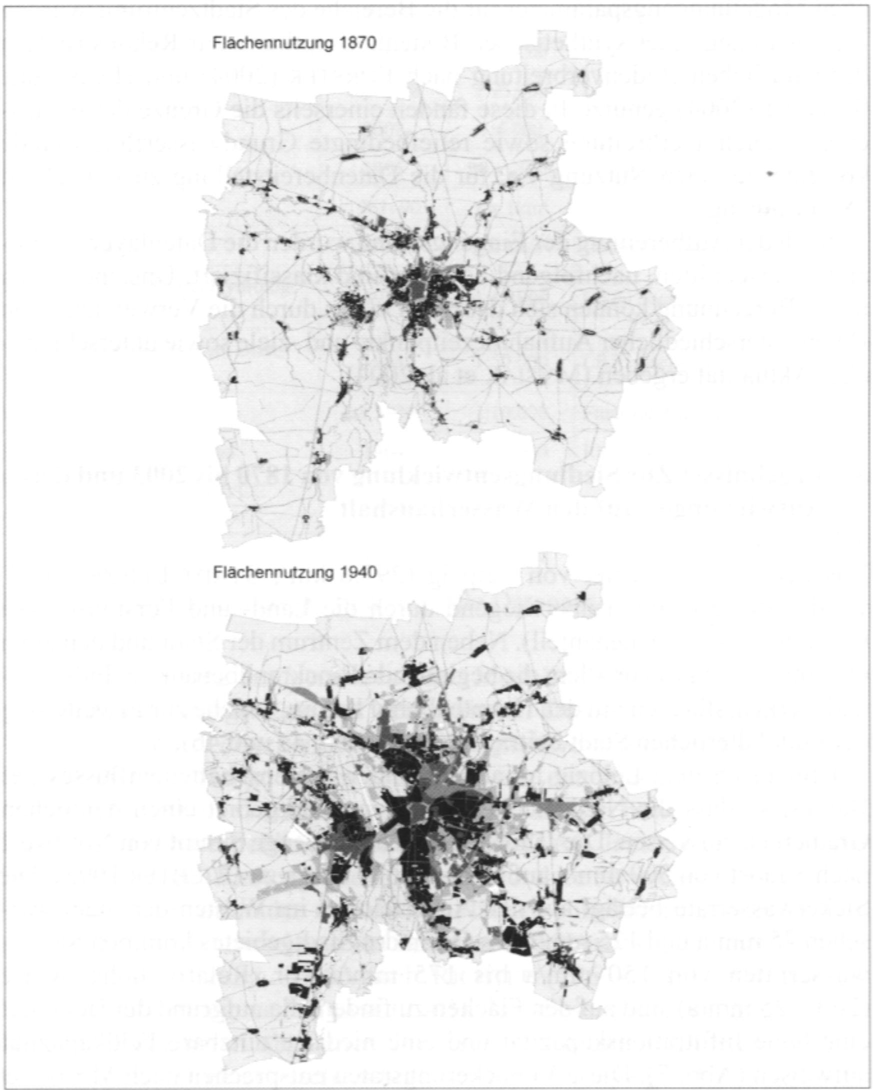

Abb. 4a: Siedlungsflächenentwicklung im Untersuchungsgebiet Leipzig seit 1870

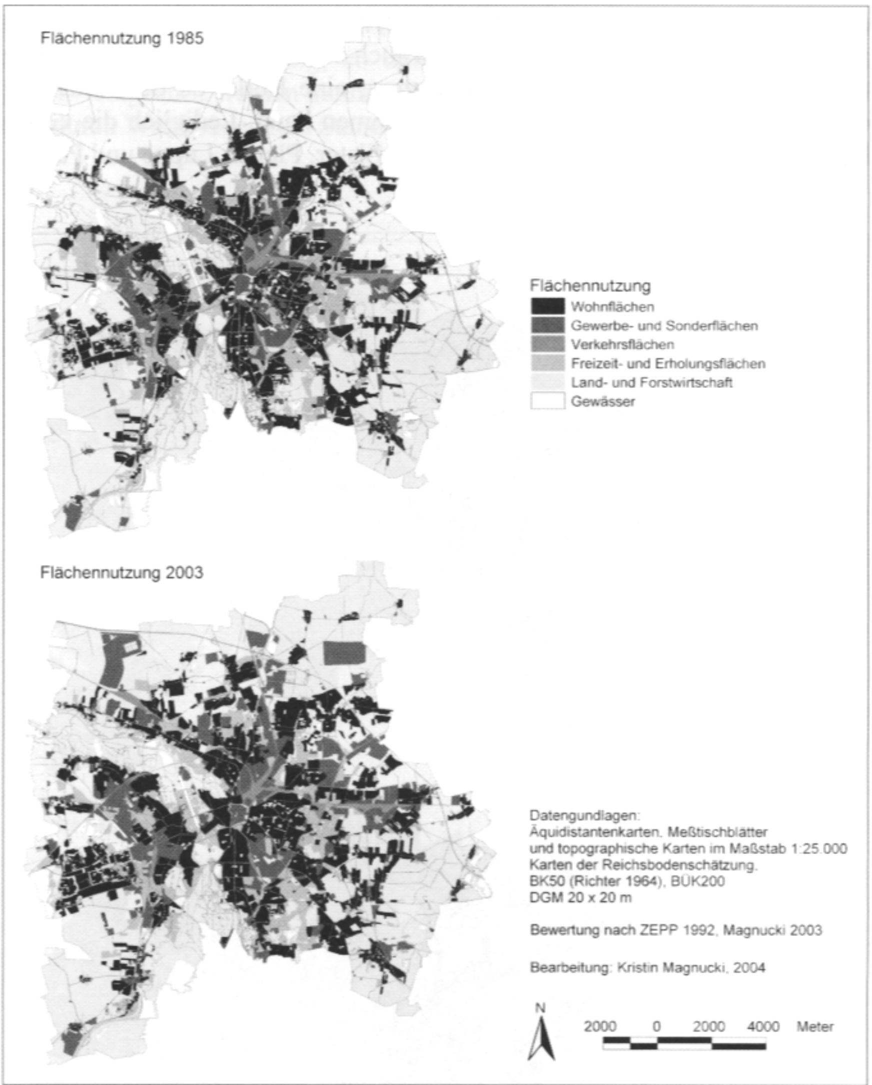

Abb. 4b: Siedlungsflächenentwicklung im Untersuchungsgebiet Leipzig seit 1870

Die landwirtschaftlich genutzten Sandlössgebiete der Stadt weisen überwiegend „hohe" Abflussregulationsleistungen auf (siehe Abb. 5a und 5b), da die Böden meist hohe nutzbare Feldkapazitäten besitzen und so in der Lage sind große Mengen an Wasser aufzunehmen und zu speichern. Die Lössgebiete und die lehmbestimmten Auen weisen dagegen nur eine mittlere Abflussregulationsleistung auf, da hier aufgrund des höheren Lehmanteils die Infiltrationskapazität des Bodens geringer ist. Zudem spielt in den grundwasserbeeinflussten Niederungen auch die häufigere Wassersättigung des Bodens bei der geringeren Bewertung eine Rolle, da der Boden an diesen Standorten weniger Wasser aufnehmen kann. Lediglich die Grünlandflächen in den Flussauen der Weißen Elster, Pleiße, Luppe und Parthe

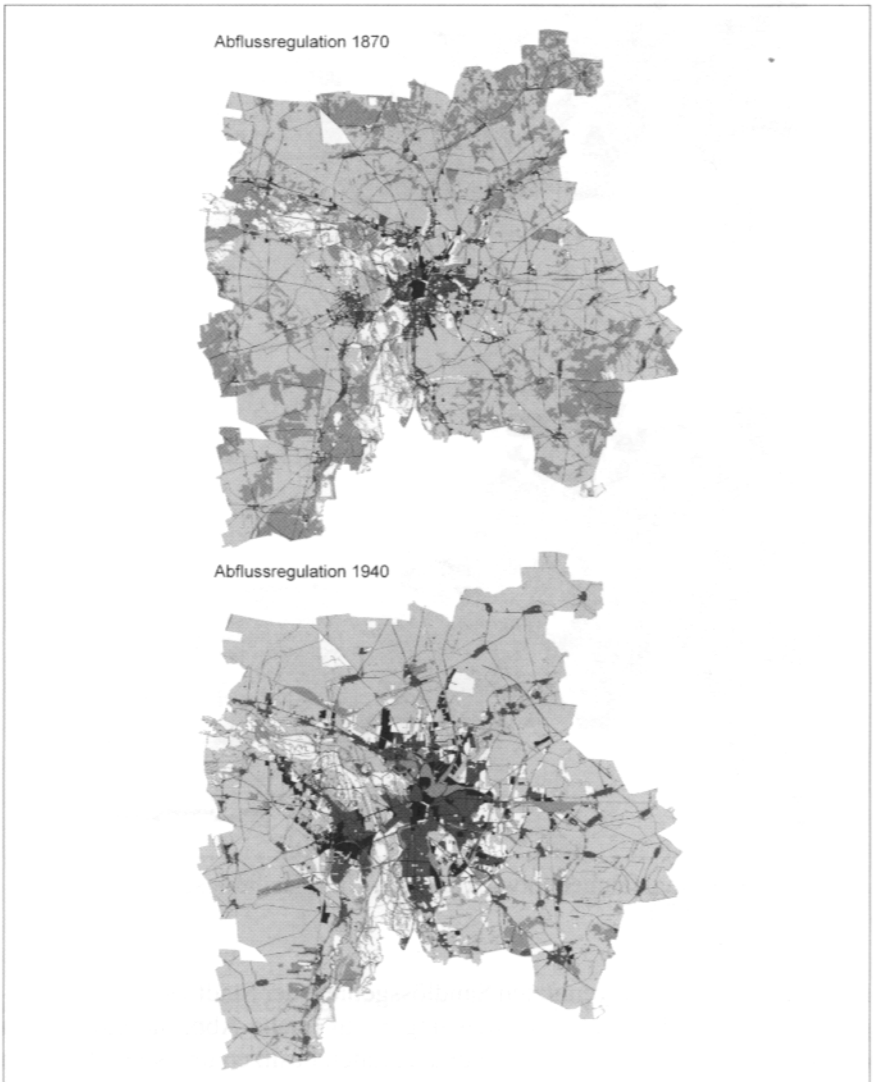

Abb. 5a: Veränderung der Abflussregulationsleistung im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Bewertung nach ZEPP (1992), verändert

besitzen aufgrund der höheren Oberflächenbedeckung eine etwas höhere Abflussregulationsleistung, so dass diese Leistung überwiegend auch „hoch" eingestuft werden kann. Am besten wird die Abflussregulation auf den durch Wald bedeckten Standorten erfüllt.

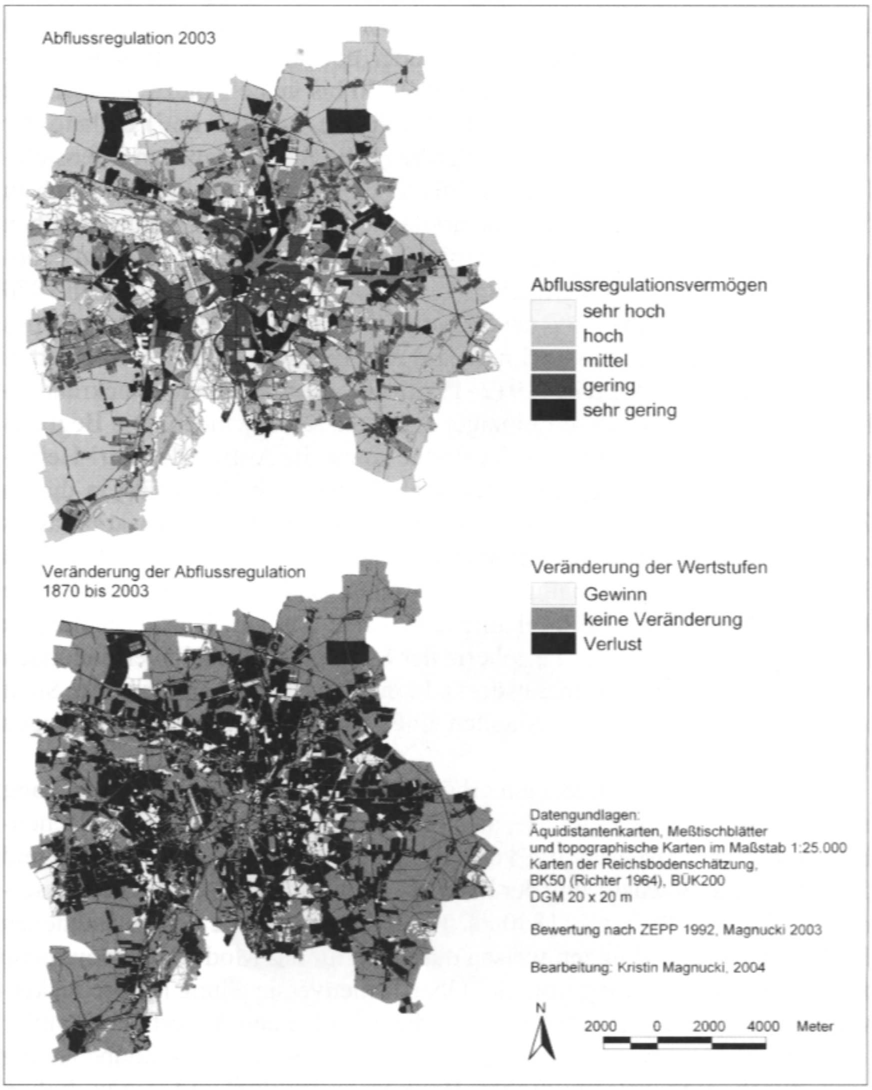

Abb. 5b: Veränderung der Abflussregulationsleistung im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Bewertung nach ZEPP (1992), verändert

Nach der Charakterisierung des Untersuchungsgebietes zum Zeitpunkt 1870 soll nun im Folgenden die Stadtentwicklung bis 2003 bezüglich der Versiegelung und damit verbundener Veränderungen des Wasserhaushaltes diskutiert werden.

3.2 Gründerzeit bis 1945

Durch die industrielle Entwicklung während der Gründerzeit ab 1870 wuchs die Stadt explosionsartig an. Wie jedoch in Abb. 4a und 4b deutlich wird, ist der Waldanteil der Leipziger Auenwälder und übrigen Stadtforsten (insgesamt rund 19 km²) im Zeitraum von 1870 bis heute nahezu unverändert geblieben. Ein Rückgang der Grünlandflächen (um 6,8 km²) entlang der Weißen Elster, Luppe, Pleiße und Parthe nach 1870 ist dagegen offensichtlich. Nach 1870 wurden Acker-, Grünland- und Freiflächen hauptsächlich zu Siedlungs-, Gewerbe- und Verkehrsflächen sowie zu Erholungsflächen umgewidmet (insgesamt etwa 57 km²). Partiell erfolgte auch eine Umwandlung von Grünland in Ackerflächen. Besonders deutlich wird zwischen 1870 und 1940 die Zerschneidung der Leipziger Auen sowie die Entwicklung des Leipziger Westens (Plagwitz, Lindenau) zum Industrie- und Gewerbeviertel. Der Bau des Elsterbeckens (1912–1922) und die anhaltende Blockrandbebauung lassen die Mittlere Leipziger Aue fast verschwinden. Die Begradigung und partielle Verrohrung der Parthe sowie die Anlage des Karl-Heine-Kanals (ab 1856) sowie des Elster-Saale-Kanals (ab 1933) fällt in diesen Zeitraum. Um 1940 kann man Leipzig bereits klar in ein kleines, kompaktes Zentrum, einen Altbauring mit überwiegend Gründerzeit-, Jugendstil- und 1920er/1930er-Jahre-Bebauung sowie einen sich daran anschließenden Industrie- und Gewerbegürtel gliedern. Erste Einfamilienhaussiedlungen (7,6 km²) entstehen in der Peripherie der Stadt (an Eisenbahnverbindungen wie z.B. Knauthain, Hartmannsdorf). In den Übergangsbereichen der Stadt zum agrarischen Umland entstanden eine Vielzahl von Kleingartenanlagen (ca. 14 km²).

In diesen Kleingartenanlagen erhöht sich die Abflussregulationsleistung auf „hohe bis sehr hohe“ Werte, da diese Flächen eine stärkere Oberflächenbedeckung aufweisen als die vorherigen Ackerflächen (vgl. Abb. 5a und 5b). Durch die Bewässerung der Flächen erhöht sich auch die Sickerwasserrate auf bis zu 200 mm/a (1870 ca. 100–125 mm/a). Die neu entstandenen Einfamilienhaussiedlungen weisen durch die für das Modell angenommene zusätzliche Bewässerung trotz der Oberflächenversiegelung höhere Sickerwasserraten (um ca. 25–50 mm/a) als die umgebenden Ackerflächen auf.

Die Gründerzeitviertel in Form von überwiegender Blockrandbebauung sind durch eine relativ dichte Baukörperstruktur und einen hohen Versiegelungs- bzw. Kanalisationsgrad gekennzeichnet. Während die Pflanzen durch ihr Blätterwerk ständig transpirieren, verdunstet von den Gebäuden und versiegelten Flächen nur das wenige Wasser, das auf den Oberflächen nach dem Regen haften geblieben ist. Je höher der Versiegelungsgrad eines Gebietes also ist, desto weniger Niederschlag verdunstet. Die weniger dicht bebauten Bereiche der Stadt, wie Eigenheim- oder Villensiedlungen, weisen Verdunstungshöhen von ca. 300 mm/a auf (Ackerflächen ca. 450–500 mm/a; siehe Abb. 7a und 7b).

Abb. 6a: Veränderung der Sickerwasserrate im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Berechnung mit ABIMO

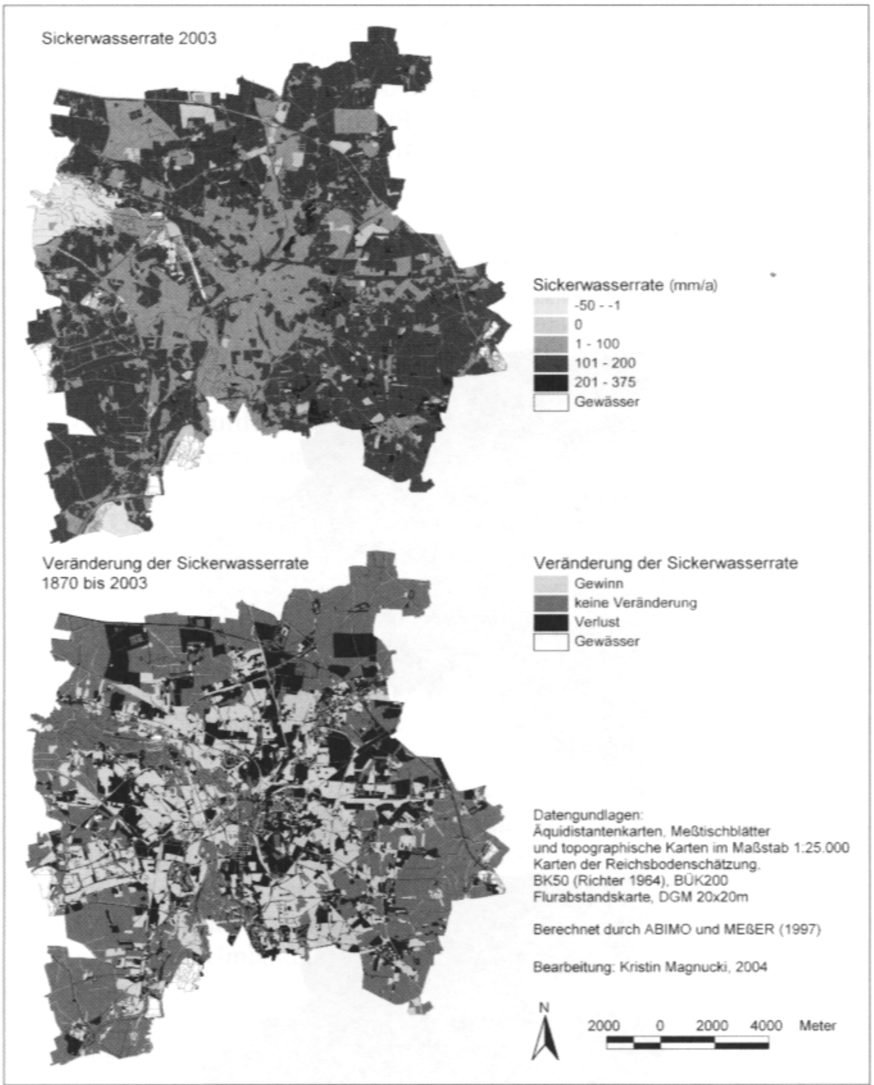

Abb. 6b: Veränderung der Sickerwasserrate im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Berechnung mit ABIMO

In den dicht bebauten Gründerzeitvierteln werden wesentlich geringere Verdunstungshöhen erreicht (um 200 mm/a). Parallel zu der geringeren Verdunstung treten auf den versiegelten Flächen gegenüber den Freiflächen jedoch höhere Oberflächenabflüsse auf (in den Gründerzeitvierteln 300–350 mm/a, siehe Abb. 8a und 8b). Die Sickerwasserrate nimmt in diesen Gebieten entsprechend um ca. 25 mm/a ab. Insgesamt entspricht die

Zunahme des Oberflächenabflusses in etwa der Abnahme der Verdunstung in diesen Gebieten. In den Industriegebieten werden noch höhere Oberflächenabflusswerte (400–450 mm/a) erreicht. Die Sickerwassermenge beträgt nur noch um die 25 mm/a.

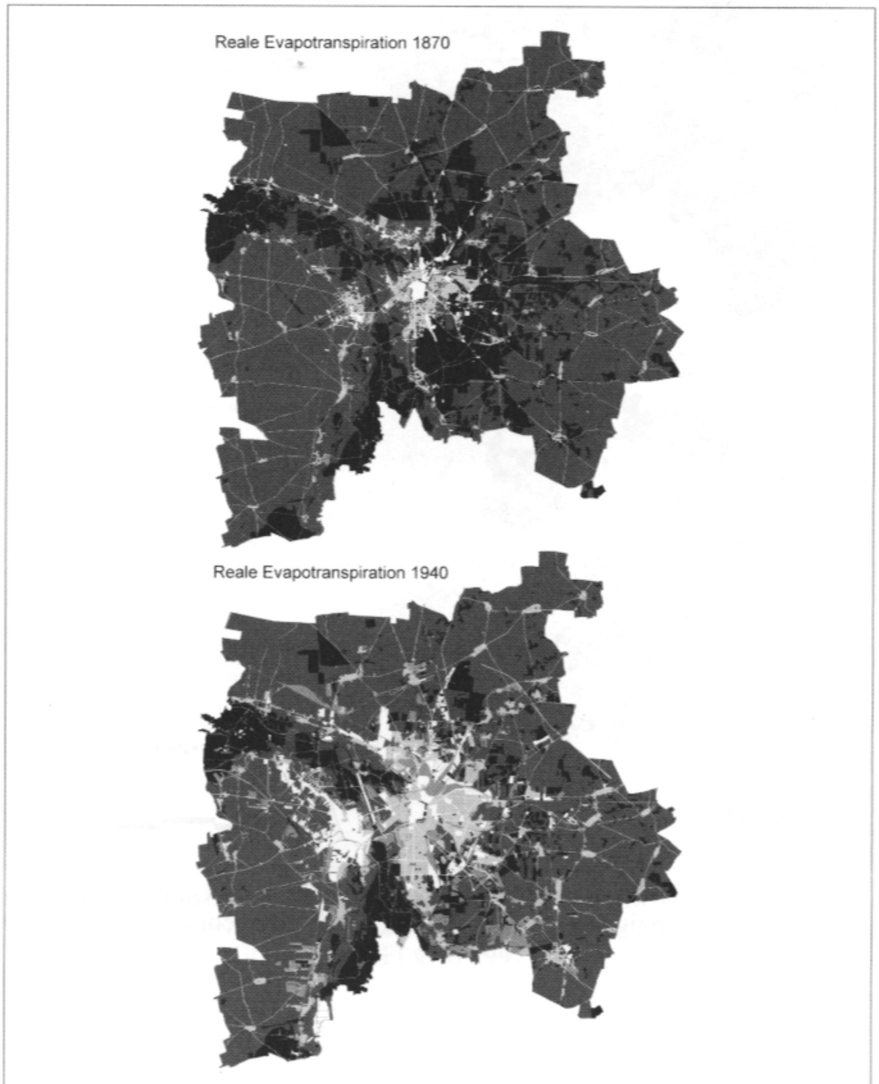

Abb. 7a: Veränderung der realen Evapotranspiration im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Berechnung mit ABIMO

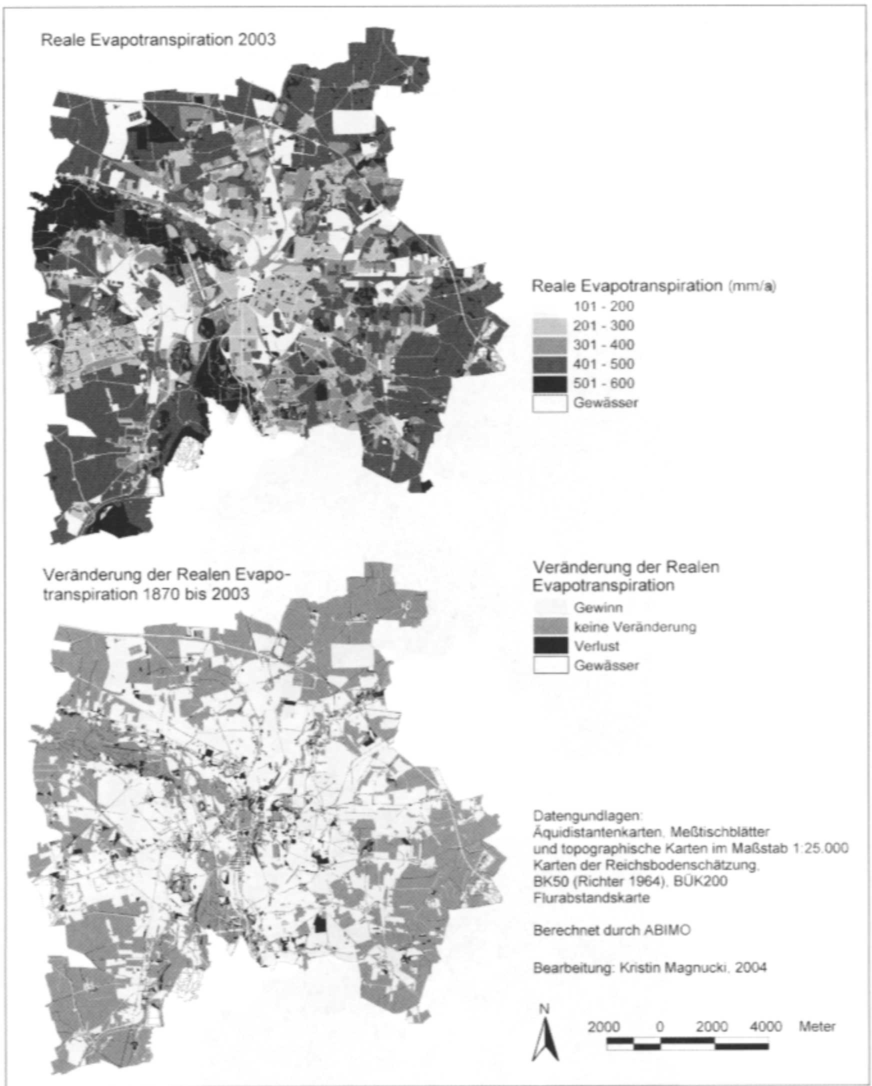

Abb. 7b: Veränderung der realen Evapotranspiration im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Berechnung mit ABIMO

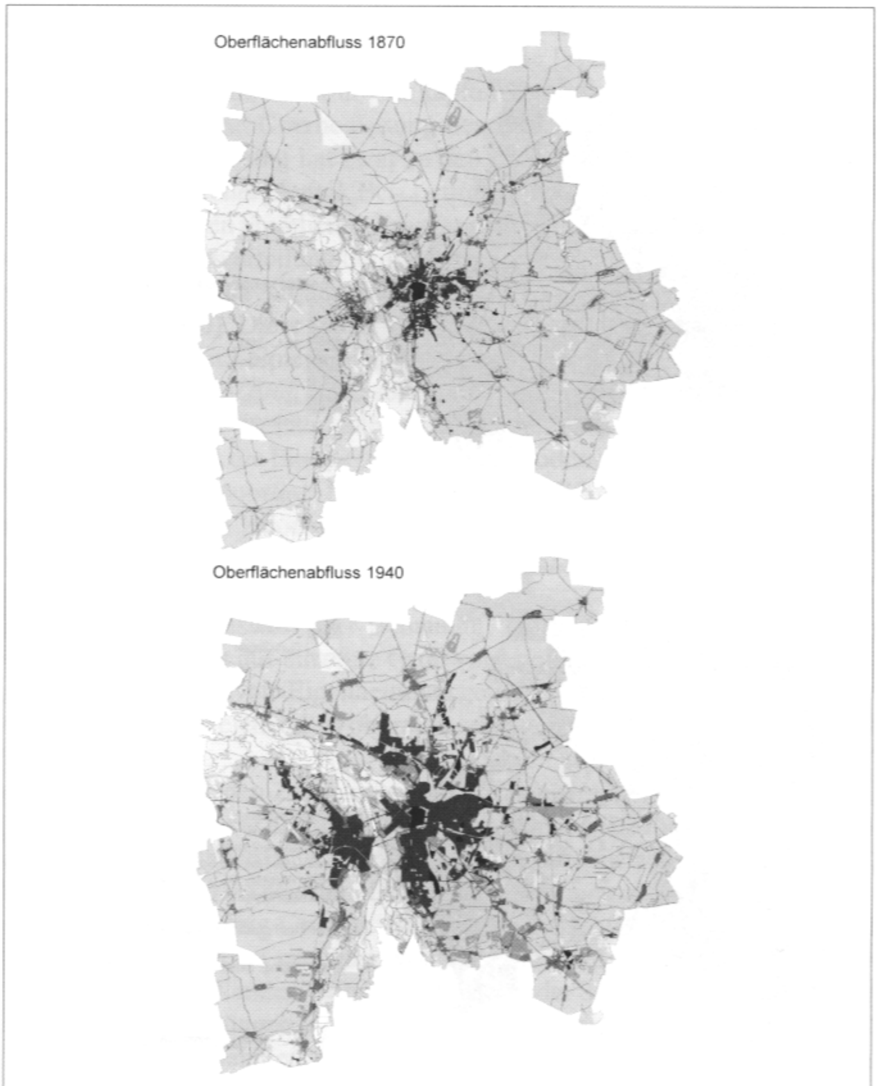

Abb. 8a: Veränderung des Anteils am Oberflächenabfluss im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Berechnung mit ABIMO (GLUGLA und FÜRTIG 1997) sowie einem Verfahren nach MEßER (1997)

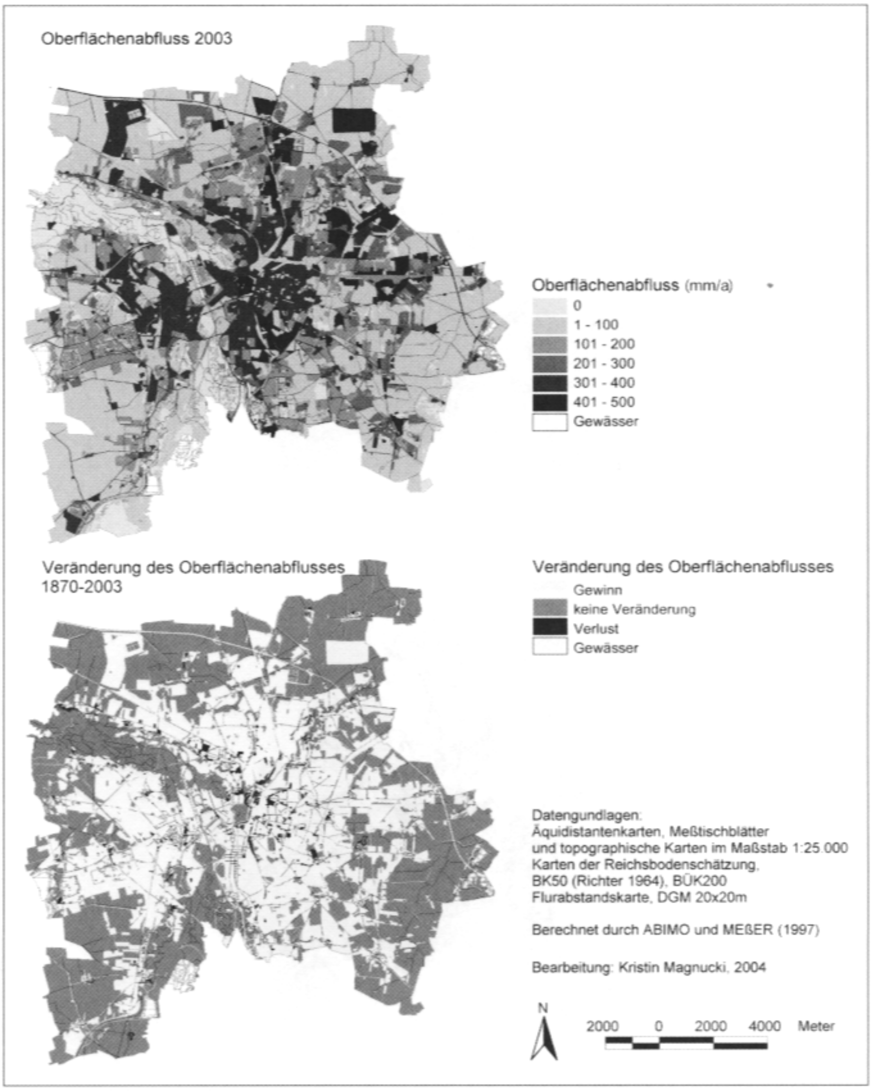

Abb. 8b: Veränderung des Anteils am Oberflächenabfluss im Untersuchungsgebiet Leipzig seit 1870 basierend auf der Berechnung mit ABIMO (GLUGLA und FÜRTIG 1997) sowie einem Verfahren nach MEßER (1997)

3.3 Sozialistische Stadtentwicklung 1945–1990

Nach dem Zweiten Weltkrieg stand die Entwicklung Leipzigs im Zeichen größerer Flächenerweiterungen an den wichtigen Verkehrsachsen. Die Acker- und Grünlandflächen nehmen weiterhin deutlich ab, um insgesamt

39,4 km². Die Stadtentwicklung wurde während der DDR-Zeit durch die Grundeinstellung gekennzeichnet, sich von den Prozessen zu befreien, unter denen sich die Stadtentwicklung in kapitalistischen Gesellschaften vollzog (SAHNER 1996). Die Überbewertung des industriellen Produktionssektors für die Stadtentwicklung hat zwar zu den soziostrukturellen Eigenarten der Städte geführt (hoher Anteil Beschäftigter im sekundären Sektor), nicht jedoch zur massiven räumlichen Erweiterung der Industrie- und Gewerbeflächen. Die Standortverteilung der Industrie wurde weiterhin durch die schon während der Gründerzeit angelegten Industriegebiete bestimmt (LEISTNER und USBECK 1996). Diese Industrieflächen wuchsen entlang der Bahnlinien und Ausfallstraßen Leipzigs bis 1985 um 10,7 km².

Zu Beginn der 1970er Jahre setzte sich die Staatsführung der DDR das ehrgeizige Ziel, die Wohnungsfrage als soziales Problem bis 1990 zu lösen, wobei ursprünglich die Einheit von Neubau, Modernisierung und Werterhaltung der Wohnbausubstanz beschlossen wurde (HUNGER 1994). Die Stadtentwicklung wurde jedoch in zunehmendem Maße durch den randstädtischen industriellen Wohnungsbau bestimmt. So entstanden an der Peripherie der Städte ausgedehnte Wohngebiete mit uniformen Gebäuden und einem hohen Anteil vielgeschossiger Bebauung. Nachdem sich die Ausdehnung der Städte zunächst auf einzelne Großwohnsiedlungen beschränkte, wurde ab 1970 auch der private Eigenheimbau gefördert, da es von staatlicher Seite nicht gelang, ausreichend Wohnraum zur Verfügung zu stellen (OELKE 1997).

In der Karte für den Zeitschnitt von 1985 gegenüber 1940 (Abb. 4a und 4b) wird die Zunahme an Einzel- und Doppelhausbebauung (auf 13,5 km²) am Stadtrand wie auch die Entstehung von Großwohnsiedlungen (insgesamt bis heute auf 5,4 km²) deutlich. Die größte dieser neu entstehen Großwohnsiedlungen ist Leipzig-Grünau. Sie wurde zwischen 1976 und 1988 in industrieller Bauweise errichtet, vor allem um die Bevölkerung aus den immer weiter zerfallenden Gründerzeitvierteln der Stadt Leipzig und den der Braunkohlenförderung zum Opfer gefallen Orten Eythra, Bösdorf und Magdeborn aufzunehmen (BREUSTE 1996). Kleinere Wohnsiedlungen in industrieller Bauweise wurden in den 1970er Jahren im Norden des Stadtgebietes beispielsweise in Mockau und südlich von Thekla errichtet. Im Osten des Untersuchungsgebietes entstanden die Siedlungen Schönefeld, Paunsdorf und Heiterblick. Die reale Evapotranspiration nimmt in diesen Gebieten um etwa 175 mm/a ab, der Oberflächenabfluss um 150 mm/a zu. Die berechnete Sickerwasserrate beträgt in diesem Gebieten etwa 125–150 mm/a, was eine Zunahme gegenüber der früheren Ackerfläche um ca. 25 mm/a bedeutet (Abb. 6a und 6b).

3.4 Nachwendeentwicklung bis 2003 – intensive Bautätigkeit und Suburbanisierung

Bis 2003 nimmt die Bautätigkeit in Leipzig nochmals zu, jetzt entstehen in erster Linie weitere Einfamilien- und Reihenhäuser (6,5 km^2) und sogenannte Wohnparks (1,4 km^2) an der Peripherie der Stadt (Abb. 4a und 4b). Dieser Prozess ist eng verknüpft mit der Entstehung von Wohneigentum nach der Wende. Die Wohnsuburbanisierung erreichte 1996 ihren Höhepunkt (NUISSL und RINK 2003). Auch in der inneren Stadt kommt es zu Lückenbebauungen. Der Anteil an Acker- und Freiflächen dagegen schrumpft weiter (um 26,3 km^2). Die Industrie- und Gewerbefläche nimmt bis 2003 um insgesamt 10 km^2 zu (Abb. 9). Besonders die Gewerbesuburbanisierung im Norden der Stadt durch Unternehmen wie Porsche (2001) und BMW (2002) bindet erhebliche Freiflächen. Zudem steht aktuell aufgrund rückläufiger Bevölkerungszahlen erheblich mehr Fläche pro Einwohner zur Verfügung als noch vor 50 Jahren (HAASE 2004).

Aktuell sind im Stadtgebiet nur noch wenige Flächen für eine Bebauung vorgesehen, sei es als gewerbliche Fläche oder für eine Wohnbebauung. Viele der neu gebauten Wohnungen im Umland stehen leer, insbesondere in den bei der Bevölkerung weniger beliebten Wohnparks. Für die Zukunft ist also vorläufig keine großräumige Ausdehnung der Bebauung innerhalb der administrativen Stadtfläche mehr zu erwarten (NUISSL und RINK 2003). Vergleichbar wird dieses Phänomen für die Leipziger Umlandgemeinden eingeschätzt.

Betreffs des Einflusses der jüngsten Flächennutzungsentwicklung der Stadt auf die diskutierten Wasserhaushaltskomponenten Evapotranspiration, Sickerwasserrate und Oberflächenabfluss sowie die Abflussregulationsfunktion kann folgendes gesagt werden: Ein deutlicher Verlust an oberflächlicher Evapotranspiration (⅓ bis ½ der Gesamtevapotranspiration, Verlust von 200–300 mm/a) auf den neu entstandenen Gewerbeflächen als auch den Siedlungserweiterungen mit Wohnfunktion ist zu verzeichnen (Abb. 7a und 7b). Besonders betroffen ist der Nordbereich der Stadt. Ebenso sind Verluste von >50mm bis 150mm der Sickerwasserrate und daraus folgend potenziellen Sickerwasserrate in den gleichen Gebieten errechnet worden (Abb. 6a und 6b). Durch Natur- und Landschaftsschutz konnten aber seit 1870 bis heute die Flussauen als größtenteils unversiegelt erhalten werden und damit auch ein wichtiger Raum für hohe Verdunstungsraten und vergleichsweise hoher Abflussregulationsfähigkeit (Abb. 5a und 5b). Aufgrund des Abtrages von natürlichen Geschiebelehm (autochton) und der Schüttung eines porösen Sanduntergrundes (allochton) können auf den Neubauflächen der Großwohnsiedlungen aus DDR-Zeit als auch auf nach 1990 bebauten Siedlungsflächen erhöhte Sickerwasserraten auftreten, die jedoch im Modell so nicht abgebildet werden konnten, da keine Bodendaten zu den Auffüllungen existieren.

Die Siedlungsflächenentwicklung und -erweiterung seit 1870 hat erheblich zur Differenzierung der Wasserhaushaltsparameter im Stadtgebiet von Leipzig beigetragen und „verschleiert" zunehmend den West-Ost-Gradienten des Klimas in Bezug auf den Wasserhaushalt.

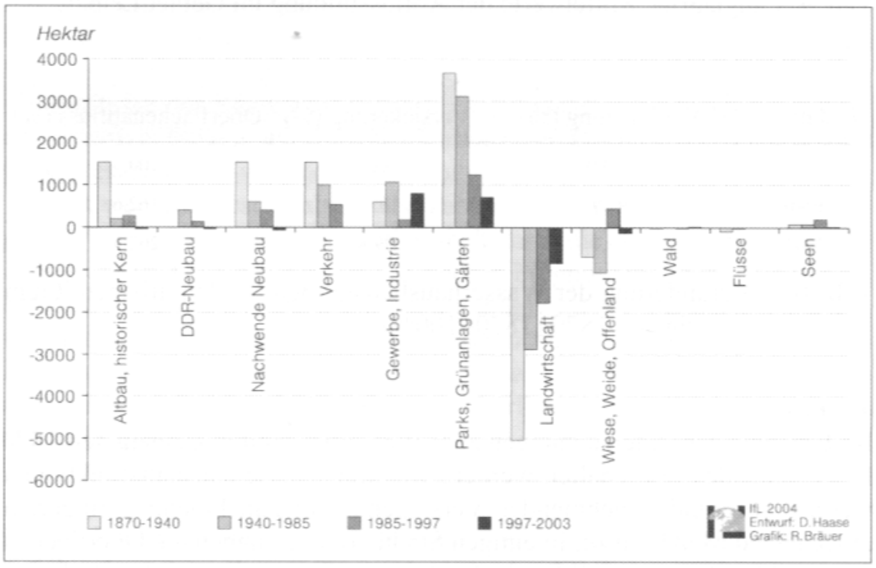

Abb. 9: Flächenveränderung der Hauptnutzungsklassen (in Hektar) in vier Zeitschnitten seit 1870

Insgesamt kam es zu einer Verschiebung des Wasserhaushaltes zugunsten des Oberflächenabflusses. Während der Oberflächenabfluss im Jahr 1870 einen Anteil von 8,1% am Wasserhaushalt des Untersuchungsgebietes ausmacht, sind es im Jahr 2003 schon 21,3% (Tab. 9). Diese starke Zunahme ist auch im Verlust der Abflussregulation zu erkennen (Abb. 5a und 5b).

Die reale Evapotranspiration nimmt aufgrund des zunehmenden Versiegelungsgrades stark ab. Der Anteil der Sickerwassermenge verändert sich dagegen nicht sehr stark und hat im Jahr 2003 den gleichen Anteil am Gesamtwasserhaushalt wie im Jahr 1870.

Bezogen auf das Jahr 1870 erhöht sich der Oberflächenabfluss in Leipzig bis zum Jahr 2003 um 162,5%. Die reale Evapotranspiration beträgt nur noch 83,1% der für das Jahr 1870 ermittelten Verdunstung, die Sickerwassermenge jedoch noch 99,8% (Tab. 10).

Jahr	Verdunstung		Versickerung		Oberflächenabfluss	
	Mio. m³/a	%	Mio. m³/a	%	Mio. m³/a	%
1870	137,6	74,8	31,3	16,9	15,0	8,1
1940	127,8	69,5	32,5	17,6	24,4	13,2
2003	114,3	62,2	31,2	16,9	39,4	21,3

Tab. 9: Langjährige Mittelwerte der Abflussbildung im Gebiet Leipzig

Jahr	Verdunstung (%)	Versickerung (%)	Oberflächenabfluss (%)
1870	100,0	100,0	100,0
1940	92,9	103,8	162,6
2003	83,1	99,8	262,5

Tab. 10: Veränderung der Wasserhaushaltsgrößen für den urbanen Raum Leipzig seit 1870 (1870=100%)

4 Fazit

Im Ergebnis der Untersuchungen zum Wasserhaushalt in Leipzig seit 1870 kann folgendes festgehalten werden: wichtige Wasserhaushaltsfunktionen werden aufgrund zunehmender Versiegelung in zunehmend geringerem ausreichend Maße erfüllt, in einigen Stadtbereichen haben die Oberflächen bzw. Böden keine regulierende Funktion auf den urbanen Landschaftshaushalt mehr.

Klar ist aber ebenso, dass ein urbaner Raum nicht primär zum Erhalt von Bodenfunktionen bzw. der Realisierung wasserhaushaltlicher Funktionen dient, sondern als Aktionsraum des Menschen (HAASE 2001).

Trotz alledem scheint es unter dem Trend einer anhaltenden Bodenversiegelung in Deutschland geboten, Maßnahmen zur Erhaltung der natürlichen Wasserhaushaltsfunktionen sowie im Interesse des Bodenschutzes auch im urbanen Raum zu forcieren. Dies trägt auch der Tatsache Rechnung, dass in Deutschland immer mehr Menschen im urbanen Raum leben werden. Folgende Überlegungen sollten daher in die zukünftige Flächennutzungsplanung bzw. -politik Eingang finden: Eine Verbesserung der Abflussregulationsfähigkeit kann im Falle von Starkniederschlägen (GERSTENGARBE et al. 2003) erreicht werden durch:

- gezielte Entsiegelung überbauter Flächen bei Abriss,
- eine in die Flächenhaushaltspolitik der Stadt integrierte Limitierung der Neuversiegelung im Innen- und Außenbereich,
- die Verwendung durchlässiger Baumaterialien,

- Möglichkeiten der Regenwasserversickerung statt -ableitung in Baugebieten (Neubau und Rekonstruktion, gegebenenfalls Regenwassersammelbecken in den Gründerzeitgebieten) sowie
- gezielte Erhöhung des Waldanteils an den Frei- bzw. Grünflächen.

Insbesondere die Niederschlagsversickerung besitzt den Vorteil der Zwischenspeicherung von Hochwasserabflüssen und gleichzeitig eine Reduzierung von Spitzenwasserabflüssen sowie, v.a. mit dem Blick auf das menschliche Wohlbefinden eine Erhöhung der Verdunstungsraten im urbanen Raum und damit positive Auswirkungen auf das Stadtklima. Jedoch sollten die Einflüsse der Regenwasserversickerung detailliert untersucht werden, um negative Folgen wie die Gefährdung der Grundwasserqualität und Gebäudeschäden zu verhindern (COLDEWEY et al. 2001).

Es ist weiterhin festzuhalten, dass anhand der durchgeführten Bewertungen die Veränderungen im Wasserhaushalt durch die Versiegelung seit 1870 erfasst werden konnten. Bei einer gegebenen Prognose möglicher Siedlungsentwicklung in die Zukunft wird es somit möglich sein, Aussagen zu treffen, wie zukünftige Versiegelungen den Wasserhaushalt beeinträchtigen werden. Zu beachten ist, dass die Ergebnisse entscheidend von den Eingangsdaten abhängig sind. Im Einzelfall sind diese sicherlich zu überprüfen, um genauere Ergebnisse zu erhalten.

5 Ausblick: Die schrumpfende Stadt – eine Chance für partielle Entsiegelung im urbanen Raum von morgen?

Der vorliegende Beitrag befasst sich mit den Auswirkungen von Siedlungswachstum und Suburbanisierung am Beispiel von Leipzig seit 1870 und bezieht sich auf das Phänomen einer wachsenden Stadt. Diese Entwicklung des Stadtwachstums wird sich aufgrund des negativen Bevölkerungswachstums und einer schwierigen ökonomischen Situation (v.a. steigende Arbeitslosigkeit) nicht fortsetzen, auch wenn Prognosen zum gesamtdeutschen Siedlungswachstum es vermuten lassen. Auch bei extrem hohen Zuwanderungsraten wird es nicht möglich sein, die Bevölkerungszahl in der Region Leipzig auf dem heutigen Niveau zu stabilisieren (STADT LEIPZIG 2004).

Daraus folgt u.a. auch, dass zwei für den Bodenschutz und damit mögliche verbundene Entsiegelungsmaßnahmen durchaus wichtige Szenarien bzw. Raummodelle für die weitere Entwicklung Leipzigs zur Disposition stehen könnten:

1. Bei einer anhaltend sinkenden Bevölkerung ist damit zu rechnen, dass sich der aktuelle Wohnungsleerstand von 55.000 leeren Wohnungen im inneren Bereich der Stadt (Blockrand- und Zeilenbebauung v.a. auch aus der Gründerzeit) sowie in den DDR-Neubaugebieten nicht in nächster

Zeit reduzieren lässt und es damit zu flächigem Abriss in diesen Gebieten kommen wird (STADT LEIPZIG 2004). Eine der für Natur- und Umweltfragen positiven Konsequenzen einer perforierten Stadt ist das Entstehen bzw. die Möglichkeit zur Entwicklung innerstädtischer unversiegelter Freiflächen, welche u.a. auch zur Regenwasserversickerung in-situ genutzt werden könnten.

2. Zum anderen kann man aber auch das Leitbild der „kompakten Stadt" zu Grunde legen und versuchen, den Abriss dafür zu nutzen, dass noch bestehende suburbane Potenzial (neue Eigenheime und Wohnparks am Rande der Stadt; Schätzung von ca. 30.000, STADT LEIPZIG 2004) in Form von „Stadtvillen" (mdl. Mitteilung M. DOEHLER-BEHZADI 2004) in die Stadt zurückzuholen und somit freie Flächen am Rande der Stadt entstehen könnten. Diese stünden dann in einem integrativen Landschaftsschutzkonzept partiell auch dem Bodenschutz bzw. der Erfüllung wasserhaushaltlicher Funktionen zur Verfügung.

Weitere methodische Arbeiten zur Bilanzierung von Landschaftsfunktionen sowie der Eingang von Themen zur Stadtlandschaft in Diskussionen/Planungen in Richtung einer nachhaltigen Stadtentwicklung unter Stagnations- und Schrumpfungsbedingungen stellen ein wichtiges zukünftiges Forschungsfeld für Landschaftsökologen und verwandte Disziplinen dar.

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11

Verlust von Bodenfunktionen durch Siedlungserweiterungen und Oberflächenversiegelung in den Stadtgebieten von Halle und Leipzig

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11.1 Einleitung und Zielstellung

Böden besitzen wesentliche Funktionen im Wasser- und Stoffhaushalt der Landschaft. Sie stellen Lebensgrundlage und Lebensraum für Menschen, Tiere, Pflanzen und Bodenorganismen dar. Im Ökosystem wirken sie als Abbau- und Ausgleichsmedium sowie als Quelle stofflicher Einwirkungen (§2 (2) BBodSchG). Aufgrund ihrer Speicher- und Transformationsleistung reagieren Böden oft erst mit großer Verzögerung auf Beeinträchtigungen, wobei die entstandenen Veränderungen dann meist lange erhalten bleiben (Blume 1992).

Neben ihren natürlichen Funktionen haben Böden auch Nutzungsfunktionen als Fläche für Siedlungen und Verkehrswege, der land- und forstwirtschaftlichen Produktion oder für Erholungszwecke (§2 (2) BBodSchG) zu erfüllen. Natürliche und Nutzungsfunktionen des Bodens stehen in starker Konkurrenz zueinander, insbesondere in urbanen Räumen, da hier Freiflächen mit naturnahen Böden meist nur noch sehr begrenzt verfügbar sind.

Urbane Räume stellen heute einen wesentlichen und zunehmend bedeutenden Lebensraum des Menschen dar. Zwar erscheint der Anteil der Siedlungs- und Verkehrsfläche an der Gesamtfläche Deutschlands mit 12,3 % (Statistisches Bundesamt 2002) eher gering, aber infolge steigender Ansprüche an Wohnfläche sowie zunehmender Freizeit- und Konsummobilität wächst seit Jahrzehnten die Fläche für Wohnen, Verkehr, Freizeit und Erwerbsarbeit. Die Siedlungsflächenzunahme ist dabei heute eng mit dem gewachsenen materiellen Wohlstand verknüpft. Die tägliche Flächeninanspruchnahme für Siedlungs- und Verkehrszwecke ist in Deutschland auf etwa 129 ha pro Tag gestiegen (Statistisches Bundesamt 2002), wobei sich die Zunahme der Siedlungsflächen seit dem Beginn der Industriellen Revolution relativ konstant entwickelt hat (Dosch & Beckmann 1999).

Im Zuge der Wiedervereinigung nach 1990 bestand gerade im Osten Deutschlands ein deutlicher Nachholbedarf im Verkehrswege- und Wohnungsbau. Der Flächenverbrauch hat dabei mit einem täglichen Siedlungsflächenzuwachs von 40 ha (Durchschnitt 1997-2001) einen momentanen Höchststand erreicht, wobei vor allem Flächen für Wohnen, öffentliche

Zwecke, Handel- und Dienstleistungen überdurchschnittlich zunahmen (Dosch & Beckmann 1999). Der Flächenverbrauch für Siedlungs- und Verkehrszwecke steht in deutlichem Widerspruch zu der Notwendigkeit und gesetzlichen Verpflichtung, die ökologischen Potenziale der Freiflächen für die Lebensbedürfnisse gegenwärtiger und zukünftiger Generationen zu erhalten. Die flächensparende und bodenschonende Nutzung des Bodens ist im 1998 novellierten Bau- und Raumordnungsgesetz (BauROG) festgeschrieben und von der Bundesregierung 1998 verabschiedeten „Gesetz zum Schutz des Bodens und zur Sanierung von Altlasten" (BBodSchG) bekräftigt. Ziel ist es nach BBodSchG § 1, die Funktionen von Böden nachhaltig zu sichern oder wiederherzustellen.

Durch die steigende Intensität der Bodennutzung hat sich der Zustand des Bodens in der Vergangenheit vielerorts verschlechtert (SRU 2000). Die natürlichen Bodenfunktionen werden durch die Versiegelung stark beeinträchtigt oder ganz unterbunden. Damit wird die Leistungsfähigkeit des gesamten Naturhaushaltes verringert (Bunzel 1992). Entsprechend der Ausprägung der physikalischen und chemischen Bodeneigenschaften kann der Verlust an Bodenfunktionalität durch Versiegelung unterschiedlich groß sein (Mohs & Meiners 1994).

Im Hinblick auf die Forderung einer nachhaltigen Sicherung oder Wiederherstellung von Bodenfunktionen ist es notwendig, die Eingriffswirkungen der Versiegelung auf die betreffenden Funktionen zu beurteilen. Dabei kann die Analyse und Bewertung des Flächennutzungswandels und der Veränderungen in der Versiegelungsintensität unter Berücksichtigung der Wechselwirkungen zwischen Flächennutzungsstrukturen und den Bodenfunktionen zu einem besseren Verständnis der gegenwärtigen Veränderungen in der Flächennutzung und deren Folgen führen.

Ziel des vorliegenden Beitrages ist es daher, den Verlust an Bodenfunktionalität durch die Siedlungserweiterungen und Bodenversiegelungen in den Stadtgebieten der Städte Halle (Saale) und Leipzig im Zeitraum von 1940 bis heute zu bilanzieren. Dabei sollen vor allem die Flächennutzungsänderungen, die damit verbundenen Bodenversiegelungen und deren Einfluss auf die Bodenfunktionen im Mittelpunkt der Betrachtung stehen. Im Beitrag werden folgende Punkte thematisiert:

- die Erfassung des Flächennutzungswandels und der Neuversiegelung in drei Zeitschnitten (1940, 1980er und 1990er Jahre),
- die Bewertung ausgewählter Bodenfunktionen anhand standardisierter Bewertungsverfahren bzw. Modelle raumexplizit mittels eines GIS sowie
- die anschließende Darstellung der Ausprägung der Bodenfunktionen sowie deren Veränderungen in den drei Zeitschnitten.

11.2 Theoretische Vorüberlegungen zur Wirkung von Versiegelungsmaßnahmen auf Bodenfunktionen

Durch die Bodenversiegelung werden die natürlich gewachsenen Böden sehr stark verändert und belastet. Nutzungsspezifisch werden neue Substrate eingebracht bzw. umgelagert, Stoff- und Energiedurchsätze variiert und Bodenentwicklungen gesteuert. Die jeweiligen Bodenmerkmale hängen dabei sehr stark von der Nutzung des jeweiligen Standortes ab. So führt beispielsweise eine gartenbauliche Nutzung durch Anreicherung von Humus zur Entwicklung von Hortisolen. Die Böden in den alten Siedlungskernen sind meist aufgrund von jahrhundertelangen, wiederkehrenden Nutzungseingriffen durch technogene Beimengungen und deutlich erhöhte Humusgehalte geprägt. Die Böden der Innenstädte und Industriegebiete sind überwiegend durch technogenes Substrat wie Bauschutt oder Schlacke gekennzeichnet (Blume 1992; Mohs & Meiners 1994; Burghardt 1996; Stasch & Stahr 1999).

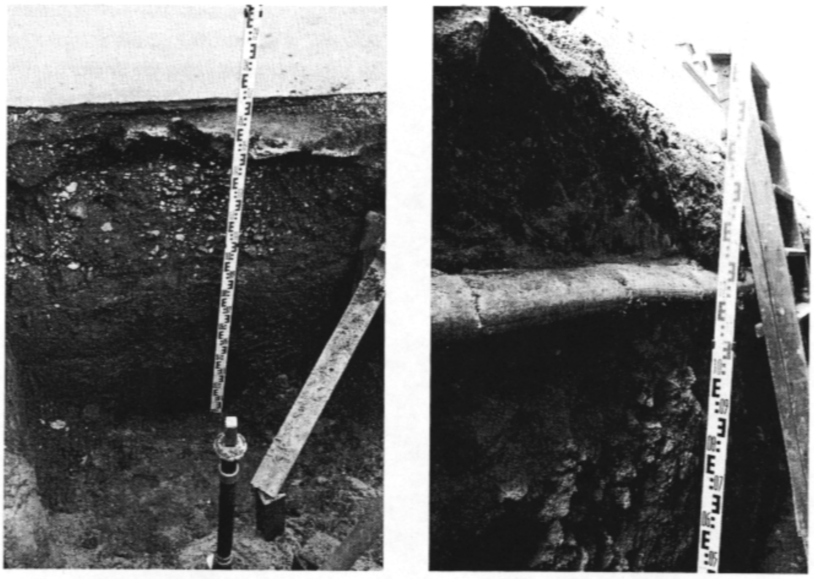
Bei der Bodenversiegelung werden zur Anlage des Versiegelungsprofils die Bodenhorizonte entfernt, die den Anforderungen an die Trag- und Dränfähigkeit bzw. Frostsicherheit nicht gerecht werden. Dabei handelt es sich meist um humose, gering bis nicht verdichtete Bodenhorizonte mit hoher Wasserspeicherkapazität. Zur Erhöhung der Tragfähigkeit wird der danach anstehende Baugrund oft verdichtet. In Abhängigkeit von Nutzungsart und -intensität erfolgt später eine weitere Verdichtung. Bei geringem Grundwasserflurabstand wird der Baugrund durch den Einbau von Trag- und Ausgleichsschichten aufgehöht. Auf den Baugrund werden Trag- und Frostschutzschichten aufgebracht, die die nutzungsbedingten mechanischen Belastungen aufnehmen und eine rasche Ableitung von Wasser sowie eine ausreichende Frostsicherheit gewährleisten. Die Körnung dieser Schichten liegt überwiegend im Bereich der Kies- und Steinfraktion. Der Anteil der Korngrößen der Feinfraktion (nahezu ausschließlich Sandfraktion) liegt meist unter 30 % (Mohs & Meiners 1994).

Durch anthropogene Aufschüttungen wird das Relief eines Standortes nivelliert und die Horizontabfolgen des Bodens werden verändert. Häufig finden sich unter dem Belag (Teer, Pflaster usw.) sehr heterogene Horizontabfolgen (vgl. Abb. 11.1). Demgegenüber sind aber auch natürliche Böden zu finden, die durch das Aufbringen der anthropogenen Deckschichten fossiliert wurden (Sauerwein 1998, 2002; Krug 2002; Burghardt & Kellermann 2002). Stadtböden weisen durch die Beimengung technogener Materialien meist erhöhte Skelett- und Carbonatgehalte auf. Der Einfluss der Skelettgehalte spiegelt sich im Wasserspeichervermögen der Böden wieder. Entsprechend der hohen Skelettgehalte weisen diese Böden meist nur geringe nutzbare Feldkapazitäten und eine hohe Wasserleitfähigkeit auf, was vor allem auf die Filterfunktion der Böden negative Auswirkungen hat, da die Filterleistung dieser Böden aufgrund des großen Porenvolumens und der höheren Infiltrationsrate dann stark herabgesetzt ist (Bädjer & Burghardt 1999).

Die vollständige Versiegelung eines Bodens bewirkt den Verlust der natürlichen Flora und Fauna. Durch die fehlende Vegetationsdecke verringert sich die von ihr ausgehende Verdunstung und die relative Luftfeuchte wird so vermindert, dass in stark bebauten Bereichen Extremwerte auftreten können, die selbst das Wohlbefinden des Menschen erheblich beeinträchtigen. Durch den Verlust von Versickerungsflächen für Niederschläge verändert sich der Wasserhaushalt in den versiegelten Bereichen (Wessolek 1988) aufgrund der:

- Abnahme der Evapotranspiration durch Umwandlung natürlicher Vegetationsflächen,
- Verringerung der Grundwasserneubildung mit zunehmendem Versiegelungsgrad,
- Zunahme des Oberflächenabflusses mit zunehmendem Versiegelungsgrad.

Die Abbildung 11.2 zeigt die deutliche Abnahme der Verdunstung und der Grundwasserneubildung bei gleichzeitiger Zunahme des Oberflächenabfluss mit zunehmendem Versiegelungsgrad. Verworn & Harms (1984) erwähnen, dass die Auswirkungen der Versiegelung ehemals durchlässiger Flächen insbesondere in Verbindung mit der Verdichtung und Verbes-



(a) (b)

Abb. 11.1: Beispiele anthropogen veränderter Böden (Fotos: Burghardt & Kellermann 2002); (a) Teer und Beton über verschiedenen Auffüllungen (mit Bauschutt, Kohle und Glas) in Leipzig-Connewitz; (b) Auffüllungen aus verschiedenen natürlichen und technogenen Substraten und einer Leitungsabdeckung aus Ziegelsteinen in Leipzig-Schleußig

serung des Entwässerungsnetzes zu größeren Direktabflüssen bei gleichzeitiger Beschleunigung des Hochwasserabflusses führt. Der Niedrigwasserabfluss der Vorfluter wird aufgrund der geringeren Grundwasserneubildung in urbanen Gebieten vermindert (Verworn & Harms 1984). Die Verringerung der Grundwasserneubildung in versiegelten Gebieten stellen auch Berlekamp & Pranzas (1992) heraus, wobei in dieser Untersuchung auch betont wird, dass die Höhe der urbanen Versickerung nicht allein durch die Gesamtversiegelungsgrade bestimmt wird, sondern vielmehr auch durch die Materialien der versiegelten Flächen sowie den Umfang der Niederschlagswasserableitung in die Kanalisation.

11.3 Material und Methoden

Im Folgenden werden die verwendeten Methoden und Datengrundlagen der Arbeit vorgestellt. Einen Überblick über den methodischen Ansatz gibt die Abbildung 11.3. Für die Analysen der Bodenfunktionen bezüglich der Zeitschnitte 1940, 1985 und 1997/2001 wurden die entsprechenden Bodendaten der Reichsbodenschätzung (für 1940), der MMK und der Bodenkarte 1:50 000 von Richter (1964) sowie die Bodenkarte 1:50 000 (BK 50) (für 1997/2001)

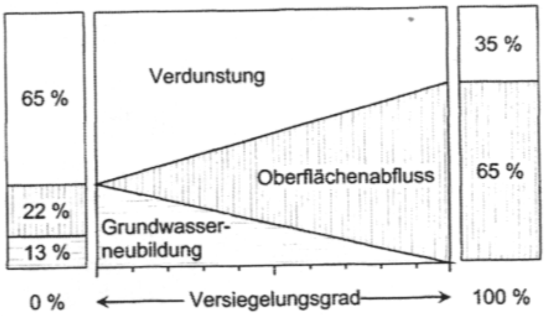


Abb. 11.2: Schematische Wasserbilanz für verschiedene Nutzungsstrukturen (prozentuale Anteile bezogen auf einen mittleren Jahresniederschlag von 600 mm; aus Coldeway et al. 2001)

verwendet. Lücken in den Datensätzen wurden in allen Fällen mit der Bodenübersichtskarte 1:200 000 (BÜK 200) unterlagert, um ein vollständiges Bild zu erhalten und regional stimmige Bodenarten ableiten zu können (Abb. 11.4). Die Modellanwendung bzw. Bodenfunktionsbewertung erfolgte dann auf Basis dieser synthetischen Bodenkarten und den aus der digitalisierten Flächennutzung abgeleiteten Versiegelungsgraden. Unterschiede bei den einzelnen Kartierungen hinsichtlich der Bodenart bei keiner Änderung der Versiegelung wurden bei den Analysen nicht verändert, da es eher um eine methodische Fragestellung für die Gesamtstadt ging. Hier sollte ein systematischer Abgleich dieser Differenzen, welche auf die bodenkundliche Aufnahme zurückzuführen sind, erfolgen.

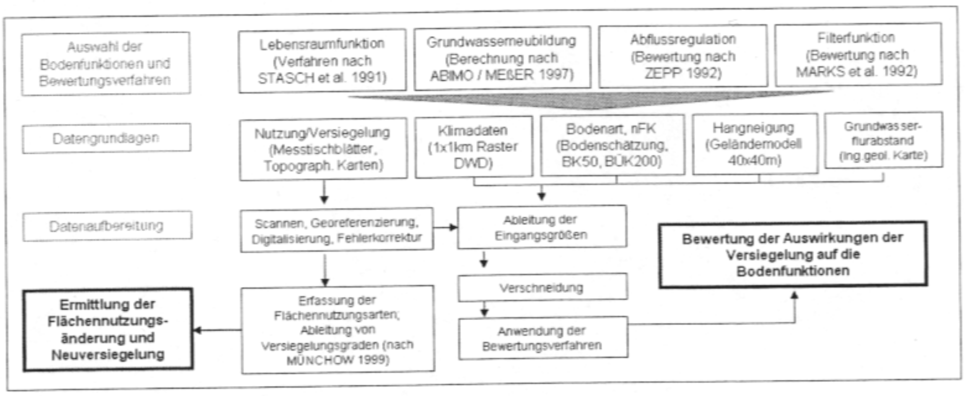


Abb. 11.3: Methodik zur Ermittlung der Veränderung von Bodenfunktionen durch Oberflächenversiegelung

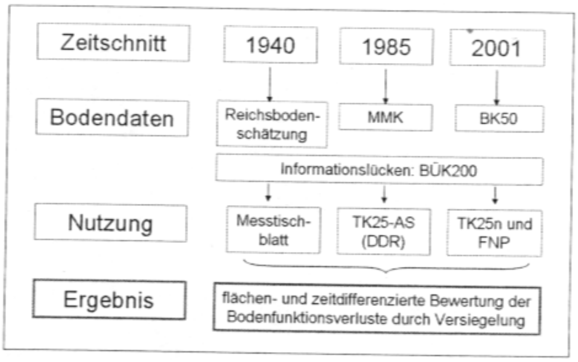


Abb. 11.4: Synthetische Bodeninformationen für die betrachteten Zeitschnitte

11.3.1 Erfassung der Flächennutzungsarten und Versiegelungsgrade

Um den Verlust an Bodenfunktionalität durch die Versiegelung im Zeitraum von 1940 bis heute zu ermitteln, mussten zunächst die Flächennutzungsänderungen und die damit verbundenen Bodenversiegelungen erfasst werden. Zur Ermittlung der Flächennutzungsänderung wurden Flächennutzungstypen aus Messtischblättern und topographischen Karten (1: 25 000) ausgegliedert. Die Abgrenzung der Flächennutzungseinheiten basiert im Wesentlichen auf Unterschieden in der Bebauungsstruktur bzw. der Nutzung der Fläche. Die ausgegrenzten Nutzungseinheiten ermöglichen aufgrund ihrer einheitlichen strukturellen Ausstattung die Ableitung von Aussagen zur Versiegelungsintensität (Berlekamp & Pranzas 1992). Die Zuweisung der entsprechenden Versiegelungsgrade in dieser Arbeit resultierte aus einer Versiegelungskartierung von Münchow (1999) in der Stadt Leipzig, in welcher in verschiedenen Stadtstrukturtypen die Nutzungs-, Belags- und Entwässerungsart von Flächen aufgenommen worden sind. Wenn es für einzelne Strukturtypen mehrere Angaben zum Versiegelungsgrad gab, wurde aus diesen Werten ein Mittelwert gebildet. Für die Flächennutzungsarten, für die bei dieser Kartierung kein Versiegelungsgrad erhoben wurde, wurde der Versiegelungsgrad aus Heber & Lehmann (1996) entnommen. Dieser Wert entspricht den durchschnittlichen Versiegelungsanteilen und wurde aus den Versiegelungsangaben verschiedener Städte ermittelt. Da die Versiegelungsgrade erhebliche Schwankungen innerhalb einer Nutzungsklasse aufweisen können (Heber & Lehmann 1996; Mohs & Meiners 1994) wurden die einzelnen Flächennutzungen in Versiegelungsklassen eingeordnet, die eine Spannbreite von 20 % im Versiegelungsgrad umfassen (Tab. 11.1).

11.3.2 Verwendete Bewertungsverfahren und Modellansätze

Zur Wahl der Bodenfunktionen, die in dieser Arbeit bewertet werden sollten, wurde das Bundesbodenschutzgesetz (BBodSchG) als rechtsverbindliches Instrument herangezogen. Die verwendeten Bewertungsverfahren sollten einerseits für die konkreten Untersuchungsgebiete (Größe ≈ Maßstabsbereich 1:25 000, natürliche Ausstattung) anwendbar sein, andererseits

Tabelle 11.1: Einteilung der Flächennutzungen in die Versiegelungsklassen

Versiegelungs-klassen [%]	Flächennutzung
0	Land-/Forstwirtschaft, Rohstoffgewinnung, Wasserflächen
> 0–20	Grün-/Parkanlagen, Gartenanlagen, Friedhöfe
> 20–40	Bahnanlage, Sport-/Spielanlage, Gesundheit/Soziales, Zeilenbebauung
> 40–60	Großwohnsiedlung, Eigenheime, techn. Ver-/Entsorgung, Militär
> 60–80	alter Siedlungskern, Wohnpark 1990er Jahre, Bildung/Forschung
> 80–100	Gewerbefläche, Dienstleistung, Messegelände, Straßenverkehrsanlage

zwingend den Versiegelungsgrad als Eingangsfaktor berücksichtigen. Die Einschätzung der *Regler- und Speicherfunktion im Wasserhaushalt* erfolgte dabei über die Bewertung der Abflussregulationsleistung nach Zepp (1992), in Anlehnung an Bastian & Schreiber (1999) und über die Berechnung der Wasserhaushaltsgrößen *reale Evapotranspiration*, *Oberflächenabfluss* und *Versickerung* durch das Modell ABIMO (Glugla & Fürtig 1997) in Kombination mit einem Verfahren von Meßer (1997). Bewertet werden sollte, ob die Fähigkeit des Bodens zur Wasseraufnahme aufgrund von Versiegelung soweit eingeschränkt ist, dass gegenüber natürlichen Böden ein verstärkter Oberflächenabfluss und damit eine verminderte Abgabe in Form von Verdunstung oder Versickerung zu erwarten ist.

Die *Lebensraumfunktion für Pflanzen und Tiere* wurde anhand der Hemerobiestufen bewertet (Stasch et al. 1991), da der Boden seine Funktion als Lebensgrundlage am besten erfüllt, wenn er keine Bodenveränderungen (z.B. Schadstoffbelastungen, Aufschüttungen, Versiegelung) erfahren hat (Gröngröft et al. 1999).

Die *Filter- und Pufferfunktion* des Bodens wurde in dieser Arbeit nur über die mechanische Filterfunktion nach einem Verfahren von Marks et al. (1992) bewertet, da sich die Auswahl der Bewertungsverfahren zwar aus den gesetzlichen Rahmenbedingungen ableitet, jedoch bei der Auswahl auch der Maßstabsbereich 1:25 000 und die für die Untersuchungsgebiete vorhandenen Daten berücksichtigt werden müssen. Aufgrund der Datenlage konnten so bei der Bewertung der Lebensraumfunktion und der Filter- und Pufferfunktion des Bodens nur sehr grobe Verfahren angewendet und keine sehr detaillierten Ergebnisse erzielt werden. Im Folgenden werden deshalb im Wesentlichen die Verfahren zur Bewertung der Regler- und Speicherfunktion im Wasserhaushalt vorgestellt.

Ein Verfahren zur Berechnung der Grundwasserneubildung innerhalb eines Stadtgebietes stellt das Abflussbildungsmodell ABIMO der Bundesanstalt für Gewässerkunde dar. Das Modell ABIMO wurde für den Lockergesteinsbereich Ostdeutschlands entwickelt und für das Stadtgebiet von Berlin modifiziert. Das Modell ABIMO hat sich auch für den mitteldeutschen Raum mit seinen relativ trockenen Klimabedingungen bewährt (Petry 2001). Hauptbestandteil des ABIMO ist die Berechnung des Gesamtabflusses (Q), wobei zunächst die reale Evapotranspiration (ETa) einer Fläche über die BAGROV-Beziehung ermittelt wird (Glugla & Fürtig 1997). (Q) wird durch die Differenz aus ETa und dem langjährigen Mittel des Niederschlages (N) berechnet. Der Direktabfluss eines Gebietes wird nach diesem Modell nur für die versiegelten Flächen berechnet, da dieser nur über den Versiegelungs- bzw. Kanalisationsgrad einer Fläche ermittelt wird (Glugla & Fürtig 1997). Bei der Ermittlung des

Direktabflusses werden weder die Hangneigung noch die Vegetationsbedeckung eines Standortes berücksichtigt.

Ein weiteres Modell zur Berechnung der Grundwasserneubildung in Stadtgebieten stellt das Verfahren von Meßer (1997) dar. Dieses Verfahren ist eine Modifizierung des Modells von Schroeder & Wyrwich (1990) und wurde ursprünglich für das Ruhrgebiet entwickelt. Das Verfahren nach Meßer (1997) berücksichtigt den Direktabfluss eines Gebietes, der sich über die Faktoren Hangneigung, Bodenart, Grundwasserflurabstand und Flächennutzung ermitteln lässt. Die reale Evapotranspiration lässt sich nach diesem Verfahren im mitteldeutschen Raum nicht berechnen, da die Verdunstung unabhängig vom Niederschlag des Gebietes ermittelt wird und die vorausgesetzten Niederschlagswerte nur für das Ruhrgebiet Gültigkeit besitzen. In der vorliegenden Arbeit wird die Grundwasserneubildung über die allgemeine Wasserhaushaltsgleichung bestimmt, wobei die reale Evapotranspiration mithilfe von ABIMO über die BAGROV-Beziehung berechnet wird und der Direktabfluss über das Verfahren von Meßer (1997). Einen Überblick über die Ermittlung der Grundwasserneubildung gibt die Abbildung 11.5.

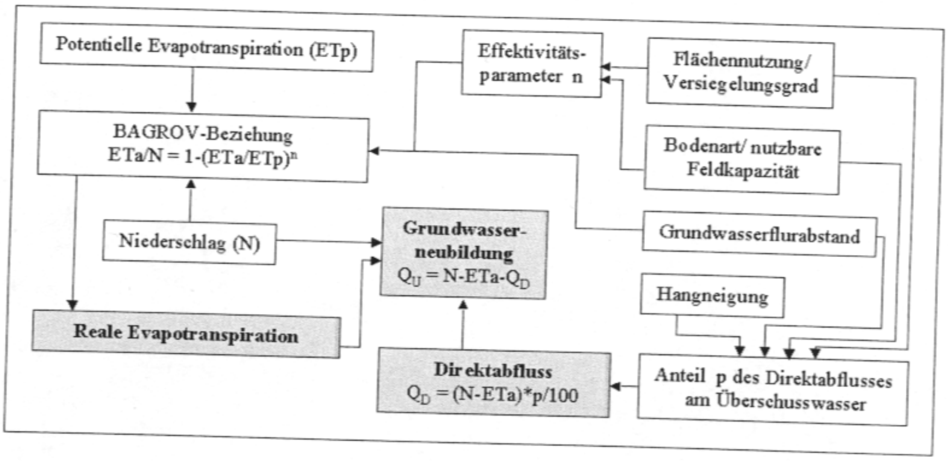


Abb. 11.5: Schema zur Ermittlung der Grundwasserneubildung

Die Berechnung des Direktabflusses erfolgt über die Bestimmung des Anteils *p* am Überschusswasser (Differenz von Niederschlag und Verdunstung). *p* wird über die Eingangsparameter Hangneigung, Bodenart, Grundwasserflurabstand und die Flächennutzung bzw. den Versiegelungsgrad ermittelt. *p* nimmt mit steigendem Grundwasserflurabstand ab. Er ist bei bindigen Böden deutlich größer als bei nicht bindigen und nimmt von Acker über Grünland bis zum Wald hin ab. Bei versiegelten Flächen steigt der Anteil mit zunehmendem Versiegelungsgrad an (Meßer 1997). Ein Beispiel zur *p*-Ableitung ist in der folgenden Tabelle 11.2 dargestellt.

Tabelle 11.2: Anteil p am Überschusswasser (nach Meßer 1997, verändert) bei einem Gefälle von 0–2 % bezogen auf ausgewählte Flächennutzungen und Versiegelungsklassen. Der Direktabfluss (Q_D) wird über folgende Formel berechnet: $Q_D = (N - ETa)(p/100)$.

Boden	Sand/Aufschüttung			Lehm		
Grundwasserflurabstand [m]	< 1	1–2	> 2	< 1	1–2	> 2
Acker/Grünland	50	0	0	50	20	20
Mischwald	20	0	0	30	5	0
Versiegelungsklasse 1–20 [%] Mischvegetation	38	8	8	42	20	20
Versiegelungsklasse 21–40 [%] Mischvegetation	58	43	28	61	51	42
Versiegelungsklasse 41–60 [%] Mischvegetation	73	62	52	74	67	60
Versiegelungsklasse 61–80 [%] Mischvegetation	86	79	73	86	82	79
Versiegelungsklasse 81–100 [%] Mischvegetation	92	89	87	92	91	90
Wasserfläche	0	0	0	0	0	0
Halde (kaum bewachsen)	100	100	100	100	100	100

Die Bewertung der Abflussregulationsfunktion erfolgte nach einem Verfahren von Zepp (1992) (Tab. 11.3), das flächendifferenzierte Aussagen ermöglicht und nicht an ein Einzugsgebiet gebunden ist (Bastian & Schreiber 1999). Das Verfahren stellt ein fünfstufiges Punktbewertungsverfahren mit den Eingangsdaten Bedeckungsgrad, Hangneigung, Infiltrationskapazität und nutzbare Feldkapazität dar. Die Infiltrationskapazität wird durch die Ersatzgröße Bodenart des oberen mineralischen Bodenhorizontes repräsentiert (Zepp 1992). Zur Bewertung der Abflussregulation wird zunächst jeder Faktor einzeln einer Stufe auf der Punkteskala zugeordnet, wobei für die günstigste Ausprägung der Faktoreigenschaften die höchste Punktzahl vergeben wird. Bei Böden mit Grundwassereinfluss (Grundwasserflurabstand < 2 m) erfolgt eine Korrektur der Punktzahl der nutzbaren Feldkapazität um einen Punkt, da das kapillare Aufstiegswasser das Wasserspeichervermögen dann herabsetzen kann. Wald- und Wasserflächen werden nach dem Verfahren von Zepp (1992) immer mit der höchsten Punktzahl bewertet. Versiegelte Flächen werden dagegen immer in die geringste Klasse eingestuft.

Tabelle 11.3: Bewertung der Einzelfaktoren der Abflussregulationsfunktion nach Zepp (1992), verändert

Faktoren	Bewertung des Wasserrückhaltes				
	sehr gering	gering	mittel	hoch	sehr hoch
Bedeckung	kein Bewuchs	Ackerfläche	Grünland	Mischvegetation	Wald
Hangneigung [°]	> 35	15–35	7–15	2–7	0–2
Infiltration	Tl	Lt, Lts, Ut	Lu, Ls, Uls	Sl, Slu, Su	Ss
nFK [Vol.-%]	< 6	6–9	9–14	14–20	> 20

Um teilversiegelte Flächen besser bewerten zu können, wird dem Versiegelungsgrad ein Bewertungsfaktor zugeordnet, der die Punktzahl um diesen Faktor mindert (Tab. 11.4). Die

Vergabe des Faktors beruht auf der Annahme, dass mit zunehmender Bebauung der schnelle Abfluss und auch die Hochwassergefährdung proportional ansteigt (Bastian & Schreiber 1999). Mit steigendem Versiegelungsgrad nimmt der Einfluss der übrigen Faktoren auf die Abflussregulation ab.

Tabelle 11.4: Bewertungsfaktor für teilversiegelte Flächen

Versiegelungsgrad [%]	0	> 0–20	> 20–40	> 40–60	> 60–80	> 80–100
Faktor	1,0	0,9	0,7	0,5	0,3	0,1

11.3.3 Datenmaterial und Verarbeitung im GIS

Datengrundlage der Bewertungen bildeten überwiegend öffentlich verfügbare Boden-, Relief- und Klimadaten (vgl. Tab. 11.5) sowie die digitalisierten Flächennutzungsdaten und die Versiegelungsangaben. Für die Anwendung der Bewertungsverfahren war es notwendig, die geforderten Eingangswerte aus den Flächendaten abzuleiten und neue Attributtabellen zu erstellen. So wurde beispielsweise aus dem digitalen Geländemodell (DGM) die Hangneigung abgeleitet, aus den Ingenieurgeologischen Karten die Grundwasserflurabstandsklassen oder aus den Bodendaten die nutzbare Feldkapazität (nach KA4, AD-HOC AG Boden 1994). Da sich die Bodeneigenschaften bei der Versiegelung meist verändern, weil dann eher sandige Substrate mit einem hohen Skelettgehalt vorherrschen (Burghardt & Kellermann 2002), wurden möglichst für jeden Zeitschnitt Daten der jeweiligen Zeit verwendet, um auch die Eigenschaften der Böden vor der Versiegelung zu berücksichtigen. Da die Bodendaten in den Kartengrundlagen, vor allem im Zeitschnitt 1940, nicht flächendeckend vorhanden sind und so Flächen ohne Informationen vorliegen, wurden für die jeweiligen Zeitschnitte Synthesekarten aus neueren und älteren Bodendaten erstellt. Nach der Aufbereitung der Eingangsdaten wurden die Datenlayer verschnitten, bewertet und klassifiziert. Unsicherheiten in der Bewertung können sich dabei vor allem durch die Verwendung von Daten unterschiedlicher Aufnahmezeitpunkte und -ziele sowie unterschiedlicher Aktualität ergeben.

11.4 Ergebnisse und Diskussion

Die versiegelten Flächen haben im Gebiet Halle von 1940 bis 2001 insgesamt um 18,3 km^2 (15,3 %) zugenommen, im Gebiet Leipzig bis 1997 um 48,7 km^2 (18,8 %). In Leipzig sind sowohl hinsichtlich der Flächengrößen als auch prozentual gesehen mehr Flächen versiegelt als in Halle. Den größten Flächenanteil an den neuversiegelten Flächen nehmen in beiden Gebieten die Flächen der Eigenheime und Großwohnsiedlungen mit einem mittleren Versiegelungsgrad (> 40 bis 60 %) ein. Einen ebenfalls großen Anteil an den neuversiegelten Flächen haben die sehr stark versiegelten Flächen (> 80 bis 100 %), wie z.B. Industrie- und

Tabelle 11.5: Verwendetes Datenmaterial

Datensatz	Stand	Maßstab	Herausgeber/Quelle
Relief			
digitales Geländemodell Halle	1997	40 × 40 m	Landesvermessungsamt Sachsen-Anhalt
digitales Geländemodell Leipzig	1995	20 × 20 m	Landesvermessungsamt Sachsen
Klima			
Evapotranspiration	1961–90	1 × 1 km	Deutscher Wetterdienst
Niederschlag	1961–90	1 × 1 km	Deutscher Wetterdienst
Wasser			
Ingenieurgeologische Karte Halle, Wasserkarte	1967	1:10 000	LAGB Sachsen-Anhalt
Ingenieurgeologische Karte Leipzig, Hydrologische Teilkarte	1977	1:10 000	LfUG Sachsen
Karte der Hydroisohypsen Blatt Leipzig	1984	1:50 000	LfUG Sachsen
Boden			
Bodenschätzungskarten	ab 1935	1:10 000	verschiedene Autoren
Bodenkarte Halle und Umgebung (BK50)	1997	1:50 000	LAGB Sachsen-Anhalt
Bodenkarte Leipziger Land	1964	1:50 000	Richter (1964)
MMK	1970-1980	1:100 000	LfUG Sachsen
Bodenübersichtskarte Blatt CC 4734 (BÜK 200)	1999	1:200 000	BGR

Abb. 11.6: Versiegelungsgrade der neu bebauten Flächen in Halle und Leipzig

Gewerbegebiete. Die sehr gering versiegelten Flächen (> 0 bis 20 %), wie Park- oder Gartenflächen, nehmen in beiden Städten einen Anteil von etwa 18 % an den neuversiegelten Flächen ein (Abb. 11.6).

Die unversiegelten Flächen weisen in beiden Untersuchungsgebieten überwiegend „mittelhohe" und „hohe" **Abflussregulationsleistungen** auf, da die Böden hier meist hohe nutzbare Feldkapazitäten besitzen und so in der Lage sind, große Mengen an Wasser aufzunehmen und zu speichern. Durch die Bodenversiegelungen nehmen die „sehr geringen“ bis „mittelgeringen“ Abflussregulationsleistungen stark zu. Während die Abflussregulationsleistung bei den sehr gering versiegelten Flächen aufgrund der größeren Oberflächenbedeckung dieser Flächen gegenüber Ackerflächen zunimmt, verschlechtert sich die Regulationsleistung ab einem Versiegelungsgrad von 20 %. Bei einem Versiegelungsgrad von > 40 % nimmt die Abflussregulation um drei bis vier Wertstufen ab, bei einem Versiegelungsgrad von > 80 % um fünf bis sechs Stufen. Diese versiegelten Flächen sind also wesentlich schlechter dazu geeignet, Niederschlagswasser zurückzuhalten und den Direktabfluss zu verringern (Abb. 11.7).

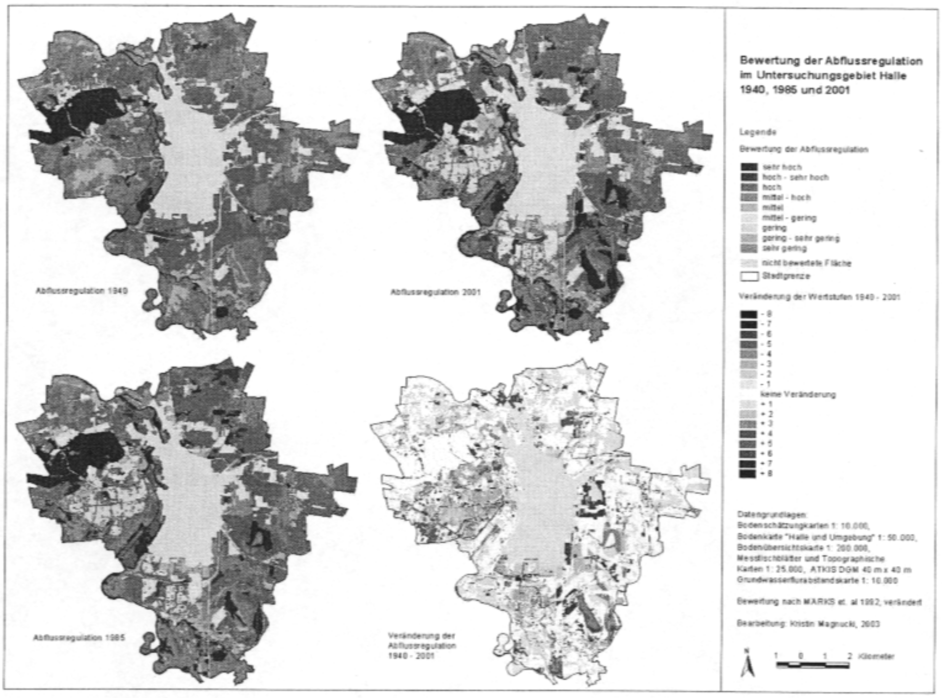


Abb. 11.7: Ergebnisse zur Abflussregulation in Halle 1940, 1985 und 2001

Der **Oberflächenabfluss** weist auf den unversiegelten Flächen im Gebiet Halle überwiegend Werte bis 25 mm/a auf, im Osten bis 50 mm/a. Im Untersuchungsgebiet Leipzig sind es aufgrund der höheren Niederschläge meist 25 bis 50 mm/a. Durch die Bodenversiegelung nimmt der Oberflächenabfluss auf den zu > 40 bis 60 % versiegelten Flächen um bis zu 200 mm/a zu. Im Gebiet Halle nimmt der Oberflächenabfluss auf den gering versiegelten Flächen gegenüber Ackerflächen auf 74 % der Fläche um 1 bis 50 mm/a ab, auf weiteren Flächen sogar um bis zu 250 mm/a. Diese hohen Abnahmen sind vor allem auf solchen gering versiegelten Flächen zu finden (z.B. Gartenland), die auf ehemaligen Bergbauflächen angelegt wurden, wo der Oberflächenabfluss im Jahr 1940 bedeutende Ausmaße erreichte (vgl. Abb. 11.8). Die hohen Abflusswerte auf den Bergbauflächen 1940 ergeben sich aus der Annahme, dass auf solchen Flächen das Sickerwasser in der Regel abgeleitet wird und somit nicht zur Grundwasserneubildung beiträgt (Meßer 1997). Auf den sehr stark versiegelten Flächen (> 80 bis 100 %) wurde im Gebiet Halle eine Zunahme des Oberflächenabflusses von bis zu 350 mm/a ermittelt. Im Gebiet Leipzig nimmt der Oberflächenabfluss auf den sehr stark versiegelten Flächen aufgrund der höheren Niederschlagsmenge sogar um bis zu 400, teilweise 450 mm/a zu. Die Zunahme des Oberflächenabflusses geht hierbei vor allem zu Lasten der realen Evapotranspiration (vgl. Tab. 11.6 und 11.7).

Tabelle 11.6: Langjährige Mittelwerte der Abflussbildung im Untersuchungsgebiet Halle

	Verdunstung		Oberflächenabfluss		Versickerung	
Jahr	Mio. m^3/a	%	Mio. m^3/a	%	Mio. m^3/a	%
1940	46,3	75,5	6,7	10,8	8,4	13,7
1985	44,8	73,7	7,6	12,6	8,3	13,7
2001	44,5	73,6	8,0	13,2	8,0	13,2

Tabelle 11.7: Langjährige Mittelwerte der Abflussbildung im Untersuchungsgebiet Leipzig

	Verdunstung		Oberflächenabfluss		Versickerung	
Jahr	Mio. m^3/a	%	Mio. m^3/a	%	Mio. m^3/a	%
1940	114,3	71,6	14,3	9,0	30,9	19,4
1985	102,9	65,1	22,0	13,9	33,2	21,0
1997	99,9	63,6	24,4	15,5	32,9	20,9

Mit zunehmendem Versiegelungsgrad der Flächen nimmt die **reale Evapotranspiration** immer stärker ab. So sind es bei einem Versiegelungsgrad von > 20 bis 40 % auf einem großen Teil der Flächen ca. 100 bis 150 mm/a. Auf den sehr stark versiegelten Flächen (Versiegelungsgrad > 80 bis 100 %) kann die Verdunstung um bis zu 450 mm/a zurückgehen. Gleichzeitig erhöht sich jedoch der Oberflächenabfluss sehr stark. Auf den geringer versiegelten Flächen nimmt der Oberflächenabfluss entsprechend des Versiegelungsgrades weniger stark zu, da dort mehr Realfläche für den Versickerungsprozess zur Verfügung steht. Der Oberflächenabfluss erhöht sich auch immer dann weniger stark, wenn Böden mit schlechteren Infiltrationskapazitäten versiegelt werden. Das sind vor allem lehmigere Böden, die auch vor der Versiegelung schon einen erhöhten Oberflächenabfluss aufgewiesen haben.

Zusammenfassend kann festgestellt werden, dass die reale Evapotranspiration mit zunehmendem Versiegelungsgrad stark abnimmt, während der Oberflächenabfluss zunimmt. Für das gesamte Untersuchungsgebiet bedeutet dies insgesamt eine Verschiebung des Wasserhaushaltes zugunsten des Oberflächenabflusses.

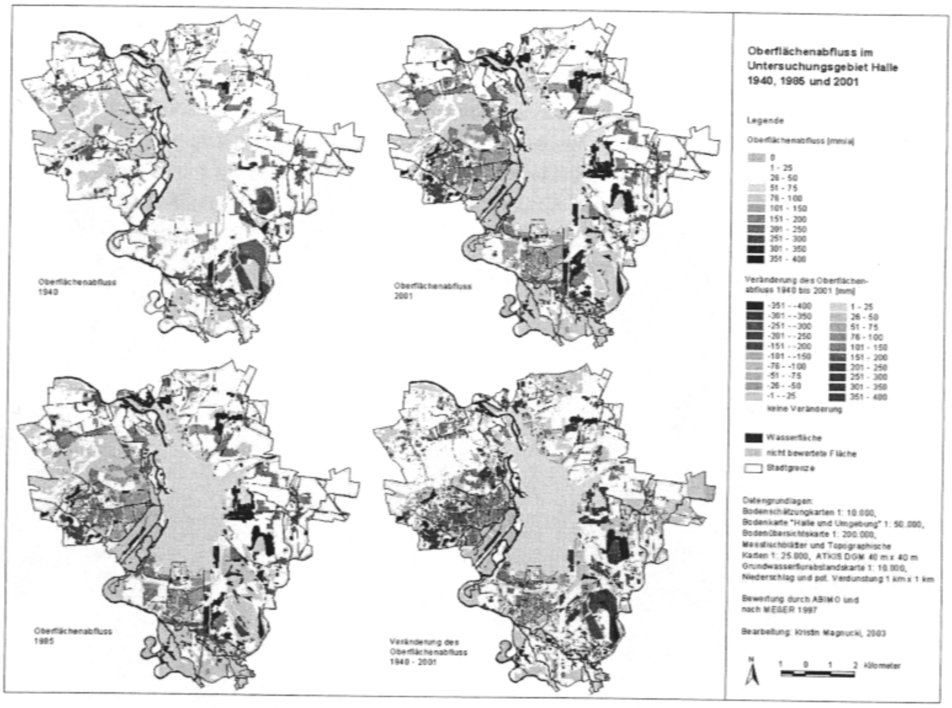


Abb. 11.8: Veränderung des Oberflächenabfluss in Halle 1940, 1985 und 2001, berechnet nach Meßer (1997)

Die **Sickerwasserrate** beträgt im Gebiet Halle auf den Acker- und Freiflächen entsprechend der Niederschlagsverteilung im Westen des Gebietes 50 bis 75 mm/a, im Osten 100 bis 125 mm/a. Im Gebiet Leipzig werden aufgrund der höheren Niederschläge Werte zwischen 125 und 175 mm/a erreicht. Die Sickerwassermenge nimmt durch die Bodenversiegelung bis zu einem Versiegelungsgrad von 60 % sogar teilweise zu. Der erhöhte Oberflächenabfluss in den versiegelten Gebieten wird durch den Effekt der Herabsetzung der Verdunstung auf diesen Flächen zu großen Teilen wieder aufgehoben, sodass die Versickerungsleistung auf den versiegelten Flächen nahezu den natürlichen Verhältnissen entspricht. Im Vergleich zu unversiegelten Fläche sind die Raten teilweise sogar etwas erhöht. Die Zunahmen können dabei bis zu 100 mm/a betragen. Auf den zu über 60 % versiegelten Flächen und den sehr stark versiegelten Flächen nimmt die Sickerwassermenge dagegen um bis zu 150 mm/a ab (Abb. 11.9).

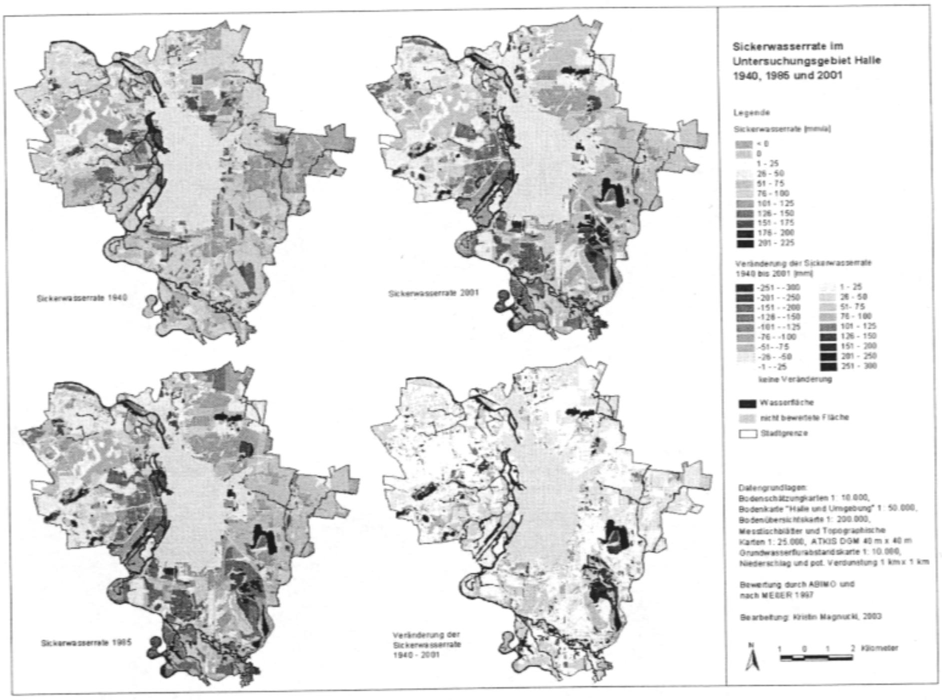


Abb. 11.9: Veränderung der Sickerwasserrate in Halle 1940, 1985 und 2001, modelliert mit ABIMO

11.5 Fazit

Zusammenfassend kann festgestellt werden, dass in beiden Städten die reale Evapotranspiration mit zunehmendem Versiegelungsgrad stark abnimmt, während der Oberflächenabfluss zunimmt. Das bedeutet eine Verschiebung des Wasserhaushaltes zugunsten des Oberflächenabflusses. Bezogen auf das Jahr 1940 erhöhte sich der Oberflächenabfluss in Halle bis zum Jahr 2001 um 20 %. Die reale Evapotranspiration beträgt im Jahr 2001 nur noch 96 % der für das Jahr 1940 ermittelten Verdunstung, die Sickerwassermenge nur noch 95 %. Für das Untersuchungsgebiet Leipzig bedeutet die Versiegelungsentwicklung seit 1940, dass die Verdunstung um 13 % abnahm und der Oberflächenabfluss um 70 % zunahm (Tab. 11.8).

Als Fazit der Arbeit ist festzuhalten, dass anhand der durchgeführten Bewertungen die Veränderungen der Bodenfunktionen durch die Versiegelung seit 1940 erfasst werden konnten. Es ist somit möglich, Aussagen darüber zu treffen, wie zukünftige Versiegelungen die Bodenfunktionen beeinträchtigen werden. Die detailliertesten Aussagen konnten dabei vor allem hinsichtlich des Wasserhaushaltes gemacht werden, während bei der Einschätzung der Filterfunktion und der Hemerobie nur sehr grobe Aussagen getroffen werden können, welche hier nicht vorgestellt wurden. Zu beachten ist, dass die Ergebnisse jedoch sehr stark von den Eingangsdaten abhängig sind. Im Einzelfall sind diese zu überprüfen, um genauere Ergebnisse zu erhalten.

Tabelle 11.8: Veränderung der Wasserhaushaltsgrößen über die Zeitschnitte bezogen auf das Jahr 1940 (1940 = 100 %)

Jahr	Verdunstung [%]	Oberflächenabfluss [%]	Versickerung [%]
Halle			
1940	100	100	100
1985	97	115	99
2001	96	120	95
Leipzig			
1940	100	100	100
1985	90	154	107
1997	87	170	106

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Airborne particle number concentration and acoustic noise in inner city areas

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Abstract

Acoustic noise and ultrafine particle (UFP) emissions are high on the list of environmental health stressors in urban areas as they are considered to belong to the main environmental sources for cardiovascular diseases among urban residents. Often both stressors occur simultaneously because the sources have the same origin, i.e. urban traffic. Particularly little is known about the spatio-temporal distribution of UFP concentrations in residential areas as well as the relation between noise and particle exposure.

To fill these gap, this paper focuses, in the form of a pilot study, on compiling and evaluating data obtained from in-situ measurements in inner urban areas. As for larger particles, also for UFP concentration and noise level a positive relationship has been found, particularly for traffic-prone streets before and after the weekend. The study further shows the potential of in-situ experiments in form of high resolution information directly gathered in the housing area. It underscores that urban traffic results in double exposure to both, UFP and acoustic noise.

Keywords: UFP, acoustic noise, urban area, traffic, human exposure

Summary: In this paper we prove a positive statistical relationship for UFP count and noise level in inner-city residential areas based on in-situ experiments.

1. Introduction

Acoustic noise is one of the most pressing environmental problems for the majority of inhabitants in cities. Traffic is one of the most significant sources of urban noise. In addition, traffic-induced particulate matter contributes to the growing health problems of cities. Recently, especially particles with aerodynamic diameters <100nm, so-called UFP (UFP; also called UFP) and sub-micrometer particles (<1µm) have been regarded as highly significant negative influences for urban health. Both factors together represent a combined risk for human health (among others; Best et al., 2000; Karolinska Institute, 2005). Furthermore, these risk factors may result in similar health impacts, especially with regard to cardiovascular disorders.

In Germany, for example, about 13 million urban inhabitants are persistently affected by (increasing) traffic noise. Recent studies (Babisch, 2004; Babisch, 2006; Best et al., 2000) provide substantiated evidence of a relationship between increasing cardiac infarction rates in residential areas and a high percentage of street traffic noise; this is in contrast to residential areas with a lower percentage of street traffic (Englert, 2004; Franck et al., 2003; Schlink et al., 2006). Gehring et al. (2002) report on traffic-related respiratory health impacts for young children. Epidemiological studies (Franck et al., 2007; Pakkanen et al., 2006; Peters et al., 2001; Wichmann, 2000) assume a health risk for cardiovascular diseases as a result of UFP emissions.

The risk of a cardiac infarction arises at noise levels as low as 65 dB (A), which are assumed to be “normal” along frequently used streets (Peters et al., 2001). At an acoustic noise exposure of ≥90 dB (A) the sympathetic nervous system is stimulated and, consequently, more adrenalin and noradrenalin are discharged from the adrenal marrow. Unfavourable physiological and metabolic changes thereby are induced, such as a rise in blood pressure, elevated blood lipids, an elevation of the blood volume per concentration time and other general stress effects (Stansfeld and Matheson, 2003). At a noise level of 50-60 dB (A) noise effects impact human health such as a decrease in speech intelligibility, accompanied by a higher level of concentration, which – again – causes increased stress effects. In addition to the previously-mentioned effects, the psychic strain, the noradrenalin level and the blood pressure might rise, too (Stansfeld and Matheson, 2003).

Studies with sleeping test subjects prove that a noise level increase of merely 9 to 18 dB (A) caused by open windows in the bedroom leads to a rise in both cortisol levels (30%), and in noradrenalin, especially during sleeping (Ising and Braun, 2000). Thus, particularly, such latent night-time traffic noise is assumed to be the reason for the chronic increase in stress hormones in urban areas. Additionally, outdoor particles may penetrate into the indoor environment even through closed windows (Franck et al., 2006), where exhaust particles can be identified (Franck et al., 2004).

Since the specific characteristics of UFP in interaction with organisms induce disturbances and pathogenesis, they are proposed to lead to diseases occurring in consequence of UFP yielding oxidative stress in human cells. As a consequence, phlogistic reactions occur and thus several respiratory diseases can be boosted or initiated, e.g. pneumonia, bronchitis, asthma, fibrosis and emphysema (Kreyling et al., 2005). The spatial and temporal variation of UFP concentrations in urban areas depends on the urban form and resulting distribution processes. Specific particle sources result in significant differences for different particle sizes. The majority of particles emitted from motor vehicle combustion occur in the UFP size range; thus leading to the inner urban spatial variability (Tuch et al., 2006).

Comparatively little is known about the spatio-temporal heterogeneity of combined noise levels and UFP emissions in residential areas where most people live. Such knowledge would be of particular interest for urban planners who are responsible for developing urban neighbourhoods and traffic-control (Holstein et al. 2002). Therefore, this study focuses on the spatio-temporal distribution of traffic-induced UFP concentration in large cities and, furthermore, attempts to bring it into a context with acoustic noise levels (Diem and Comrie, 2002).

We aim to clarify:

- The differences in acoustic noise levels and UFP concentrations among residential areas with rarely-used, as compared to frequently-used, streets. Serving as essential background for our experiment is the German Environmental Federal Agency (UBA, 2000), which declares "lots of vehicles mean a lot of noise" and "few vehicles mean low noise levels".
- The intensity of diurnal patterns at all sites. Based on a residue analysis, peaks for traffic noise in the diurnal patterns are expected to be identified.
- Coherence between traffic-induced acoustic noise levels and the concentration of UFP in residential areas of cities. Such a co-action would connote a combined health risk (represented by the total impact TI).

In addition to these objectives we test potential and limitations of an in-situ experimental design to measure UFP and noise in residential areas (cf. section 3).

2. Methods

2.1. Test area of Leipzig and sample of test sites

As a consequence of the German reunification in 1990, a structural change in urban land use and built-up structures in most East German cities occurred. Compared to the reduction of industrial emissions due to the close-down of power plants and sites of the chemical industry after 1990, in the 500,000-inhabitant city of Leipzig the number of private and commercial cars more than doubled in the years from 1990 to 1996 (Haase, 1997) and more than tripled in 2006 (Municipal yearbook of statistics, 2007).

The highest degree of density and multiple land use can be allocated to the inner-city area: thus, we can find here the highest concentrations of traffic flow, which are expected to continue to increase (Amt für Verkehrsplanung, 1995). According to local data (LfUG, 2004 and permanently available online data), and in-situ experiments involving air-borne heavy metal concentrations (Haase, 1997), the highest emission loads can be allocated to the inner city, while pollution concentrations decrease with increasing distance from the city centre. In these areas vehicle traffic often emits the majority of particulate matter through dispersion of dust, rubber-tire abrasion and engine-borne emissions. In the city of Leipzig agriculture and domestic fossil-fuel heating are insignificant emission sources (LfUG, 2004). In addition, ~40% of the particle mass concentration within the city results from long-distance transport (Regierungspräsidium Leipzig, 2005). With respect to micro and UFP, urban traffic can be assumed to be the main source.

For the field experiments, conducted in September-October 2007 in the form of consecutive measurement campaigns, 4 sites had been chosen representing the major types of inner-city residential structures with different traffic frequency during the day-time. About 40% of the entire land use of Leipzig belongs to the "residential area" type, with >60% of this being pure residential area use (Haase, 2005; Haase and Nuissl, 2007). The form of the inner-city Wilhelminian housing estates shows a high density including apartment blocks with up to five stories, high-rises and detached houses. Within the inner-urban Wilhelminian apartment-block structure we sampled two very (Herderstraße – "high traffic 1", Waldstraße – "high traffic 2") and two rarely frequented streets (Sigismundstraße – "low traffic 1", Reichpietschstraße – "low traffic 2"; cf. photographs in Figure 1). The weather conditions during the measurement period can be characterised with day temperatures between 12-16ºC and a high-pressure area with very little rainfall.

Figure 1 about here

2.2. Data acquisition through field experiments

The field experiments had been carried out by installing the above described equipment in 4 representative[9] third-story flats, 10 meters above street-level (both sound-level-meter and particle counter were installed in the flat with the detectors placed in the "quasi" closed window; cf. Figure 1 again) at the respective 4 test sites for one week including the weekend (cf. section 2.3).

The noise levels were detected using the mini-sound-level-meter *Boogie* by SINUS Measurement Ltd operating with an embedded A-weighting in accordance with the German Noise Framework for cities. Its results achieve accuracy classes of IEC60651 and IEC60804 (Sinus, 2003). A windscreen on the microphone was used to reduce wind noise. For detection of the particle count we used the Condensation-Particle-Counter 3007 (CPC 3007) by TSI (2006). Both instruments work simultaneously with a time resolution of 1s; the data is recorded in two separate files for further processing. The resulting data sets were split into two time series from 06:00am to 10:00pm and from 10:00pm to 06:00am (according to Federal Emission Legislation § 2 Abs1 16th BImSchV; Strick, 2006).

2.3. Data processing

In order to process the measured data and to determine the empirical distribution of the arithmetic mean, the median and percentile values have been derived. For

[9] Representative here means that the four flats are located in buildings that make up >90% of the Wilhelminian-time building substance of the city. Most houses possess 4-5 stories including the ground floor – thus the third store is existing in all these buildings.

each day the average noise level, the mean value of the UFP concentration, the respective standard deviation, the median and 25- and 75-percentile values were calculated. Being one of the objectives of this study to define a correlation between acoustic noise levels and UFP concentrations, a Pearson linear regression was conducted (Schlittgen, 2001).

3. Results

Whisker box plots illustrate day-time and night-time percentiles for all test sites of the pilot study. The highest values had been measured at day- and at night-time in frequently used streets (sample sites “high traffic 1” and ”high traffic 2”). Significant differences between the two rarely frequented roads (“low traffic 1” and ”low traffic 2”) could not be found. The median values clearly differ between frequently and rarely used streets (Figure 2).

Figure 2 about here

By comparing the noise levels of all test sites in Leipzig with the national target value for day-time noise levels of 59 dB (A) the test site at the Herderstraße (“high traffic 1” appeared to be the most exposed one, since almost 90% of all measured noise levels exceeded the target (cf. again Figure 2). Also the national target value for night-time noise levels of 49 dB (A) was exceeded in the majority of the entire time series in the street “high traffic 1”. The same has been found for the other frequently used street (“high traffic 2” were >50% of all noise levels exceeded the 49 dB (A).

Figure 3 shows the measured particle count of all test sites. The highest standard deviation values of all test sites have been found at the site “high traffic 2” with respective very high particle counts at day-time. Both rarely frequented streets (“low traffic 1” and “low traffic 2”) and the “high traffic 1”- site exhibit a lower particle count. Excluding these values the results are comparable with the other test sites. The lowest data variability during day- and night-time was found at the site Reichpietschstraße (“low traffic 2”) which is characterised by low traffic density.

Figure 3 about here

In Figure 4, the average noise levels and UFP concentrations of all test sites are given. We see similar curve progressions during the day-time and the night-time for both variables. In frequently used streets high noise levels and high concentrations of UFP can be identified, exemplary shown for the Waldstraße. The rarely frequented Reichpietschstraße shows a low noise level and a low average value of UFP concentration at both day- and night time (Figure 4).

Figure 4 about here

The rank correlation relationship between acoustic noise levels and UFP concentrations is provided in Table 1 and Figure 5. The highest correlations between both variables were found in the sites at frequently used streets “high traffic 1”and the “high traffic 2” (r = 0.63), respectively. Correlations are lower at sites with lower traffic densities (r = 0.58 for “low traffic 1”; r < 0.5 for “low traffic 2”). The lowest correlations have been found in the rarely frequented “low traffic 2”.

Table 1 about here

Figure 5 about here

We assume that noise levels and the particle count, consequently also their correlation, are influenced by environmental confounders such as wind and the urban (built-up) structure. At the site “high traffic 1” the measuring instruments were pointed to the west towards a main street, which takes a north-south course. The main wind directions are south and southwest, so a high particle count was measured at the test site “high traffic 1” during the main wind directions. Figure 6 shows the average particle count set against the wind direction. A significant difference (u-test; p = 0.035) was found between luv and lee wind directions.

Figure 6 about here

4. Discussion of the results

4.1. Noise exposure

There are predominantly diurnal temporal variations representing the main traffic times during the day, in which the frequently used streets are clearly distinct from the rarely used ones. The highest noise levels in the frequently used streets were measured in the time interval from 8:00am to 8:00pm when traffic density is also highest. In contrast, the calm streets exhibit the highest acoustic noise between 06:00am and 12:00am during the highest traffic density in the morning. Consequently, the most intense acoustic noise was detected in the morning, in the low-traffic streets earlier than in frequently used ones. Looking at the temporal variation, all test sites reflect heterogeneity in the course of the week, more explicitly in the frequently used streets, which generally show lower noise levels during the weekends.

One reason for differing noise levels in frequently and rarely used streets is clearly the traffic volume with <6,000 vehicles per day for the streets “low traffic 1”- and “low traffic 2” and 15,700 for the street “high traffic 1” and 25,950 for the street “high traffic 2”, respectively (Amt für Verkehrsplanung 2003; Babisch, 2004; UBA, 2000). An additional influencing factor is the continuity of the traffic flow: At the test sites “low traffic 1” and “low traffic 2” there exists a speed limit of 30 km/h and in the streets “high traffic 2” and “high traffic 2” of 50 km/h. Next to traffic flow, traffic volume and urban structure confounders such as wind direction, wind velocity, air pressure and temperature are assumed to influence noise levels and particle count (as reported in Stroh and Gerke, 2003). A significant relationship, however, could not be found.

4.2. Particle count

The highest particle counts during day- and night-time were measured at the sites “high traffic 2” and “low traffic 1”. The frequently used “high traffic 1”exhibits rather low concentrations. At night-time we do not see considerable differences between the sites. There is no simple relation between the traffic flows and traffic volume and particle count; e. g., the rarely-frequented street “low traffic 2” is located near a park area where particle count can spread into the environment. At the site “low traffic 1” a small park with high trees and a church building opposite the test site together hinder fast particle dispersal. Analogous particle dilution behaviour has been found by Bauer et al. (1999). The highest concentrations were detected on workdays at the “high traffic 1” (Wichmann et al., 2000).

The diurnal variations at the test sites showed similar behaviour for each of the measurement days. This study shows the highest particle counts in morning times from 06:00am to 08:00pm with a peak between 07:00am and 12:00am. Wehner et al. (2006) reported similar findings with diurnal variations in traffic density for the city of Leipzig. The variability in UFP measurements among may be also influenced by impacts from the urban buildings and use of vehicles in the area. Urban street canyons lead to more UFP deposition and/or particle agglomeration/coagulation especially at elevated locations such as a third-story flat. Also, if a lot of cars are starting under cold conditions, may lead to elevated UFP concentrations even at low traffic volumes.

4.3. Relationship between acoustic noise and UFP concentration

High noise levels do not necessarily occur simultaneously with the same high particle counts since, besides traffic, also leisure noise in the form of music playing contributes to the overall outside acoustic noise for urban dwellers. The same is true for non-traffic-borne particle matter such as for example emissions due to burning, smoking etc. in residential neighbourhoods. Observed differences in the strength of correlations between acoustic noise and fine particular concentrations are assumed to be caused by local effects in the sites such as available open space or plant cover (Freyer et al., 1996; Kremer et al. 2007). Hence, correlations between noise level and particle count are evidently influenced by confounders such as urban structure, weather conditions (Brüske-Hohlfeld, 2005; Freyer et al., 1996), and absolute traffic volume. Higher rank correlation values are shown in frequently used streets. Moreover, it is assumed that proximity to a park at the site Reichpietschstraße led to lower correlations.

Nevertheless, a correlation was found between acoustic noise level and UFP concentration ($r \leq 0.63$). These values seem to be rather high, taking into account that within this pilot study only a limited number of selected test sites were investigated, that the ratios of emissions of noise and particles from cars strongly depend on such as weather conditions, type of car, driving conditions, building development etc, and that long-distance and regional transport of particles result in a background value which will lower the correlation coefficients.

The influence of meteorological exchange conditions especially on the UFP concentration as reported by Holst et al. (2008) for PM_{10} could not be determined since the measurement period was to short.

5. Conclusions

This study shows that in the residential areas of a city the highest noise exposure can be found along frequently used streets, a lower exposure in rarely used streets. For example, the values detected at the sites “high traffic 1”and “high traffic 2” are assumed to increase the risk of ischemic heart diseases through acoustic noise levels of 65-70 dB (A) (Peters et al., 2001; Leksmono et al., 2006). In addition to this, high day- and night-time particle counts lead to an increase in heart infarction risk for individuals with ischemic heart diseases (Babisch, 2004). This pilot study demonstrates the associations between these two types of human exposure. Based on the results of this study, we propose urban planning to firstly, monitor and, secondly, find ways to reduce car traffic densities in residential areas. Thirdly, it will be very reasonable to prevent “low-traffic” streets from additional cars when generally reducing the car density in residential areas since they represent low-exposure living sites in dense residential areas with a comparatively low health risk to both UFP and noise exposure.

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Table 1 Pearson correlation of the noise level (dB [A]) and average values of the UFP concentration (n/cm³) for a September-week

Test site	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
	Pearson correlation											
Herderstraße				.224	-.153	**.635***	.321	.188	**.637***			
Waldstraße						**.630***	.38	**.549***	**.538***	**.576***	**.508***	.255
Sigismundstraße					.098	**.608***	.052	-.107	.467	.358		
Reichpietschstraße						.294	.248	-.188	.229	.216	**.614***	

* p = 0.0 at a significance level of < 0.05

Site A	Site B
 Herderstraße, Wilhelminian housing stock, 4-5 levels, traffic: high* – 15,700 cars per day**	 Waldstraße, Wilhelminian housing stock, 5 levels, traffic: high – 25,950 cars per day
Site C	**Site D**
 Sigismundstraße, Wilhelminian housing stock, 4 levels, traffic: low – <6,000 cars per day	 Reichpietschstraße, Wilhelminian housing stock, 4 levels, traffic: low – <6,000 cars per day

* These terms are relative values among the sites and for the city of Leipzig. They should be take as such and compared to large Megacities for example.

** There were neither data about the composition of vehicles noise nor on fleet composition and diurnal variation for the routes available.

Figure 1 Location of the field experiment sites: two high and two low affected inner-urban streets according to daily traffic had been chosen. The land use is dominantly residential.

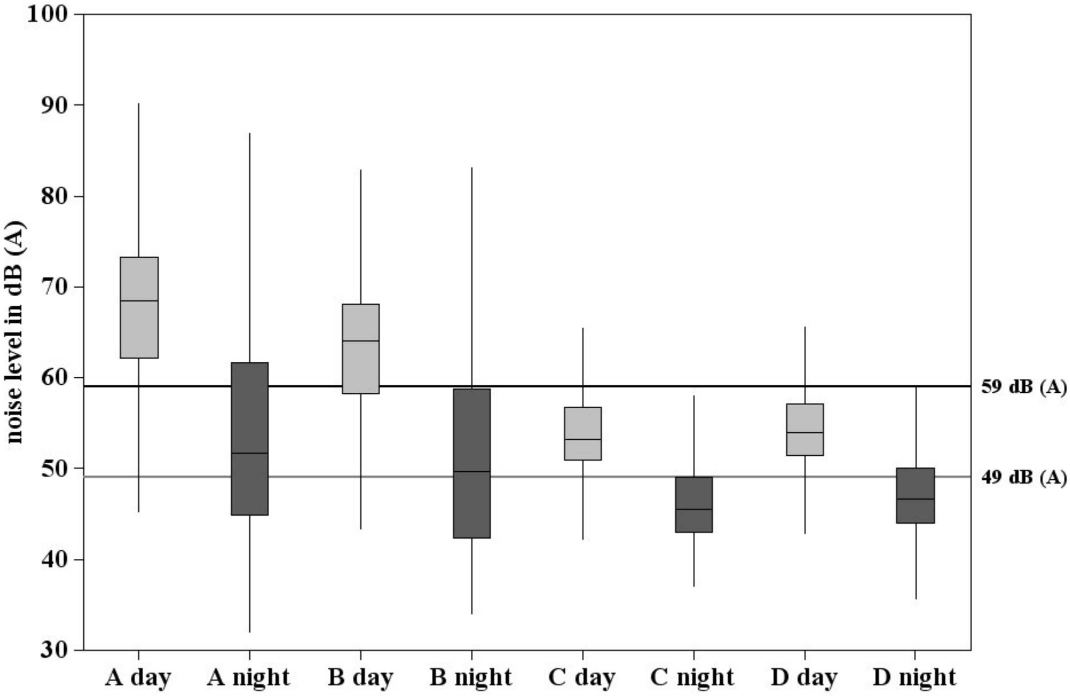

Figure 2 Box plots showing the day-time noise level (light grey) and the night-time noise level (dark grey) for all test sites compared to the German emission guide values for acoustic noise (day-time = black line, night-time = light grey line).
A box plot is a way of graphically depicting groups of numerical data (the smallest observation, lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation). The median (line within the box) separates the higher half of a sample from the lower half. The spacings between the different parts of the box help indicate the degree of dispersion (spread) and skewness in the data, and identify outliers.

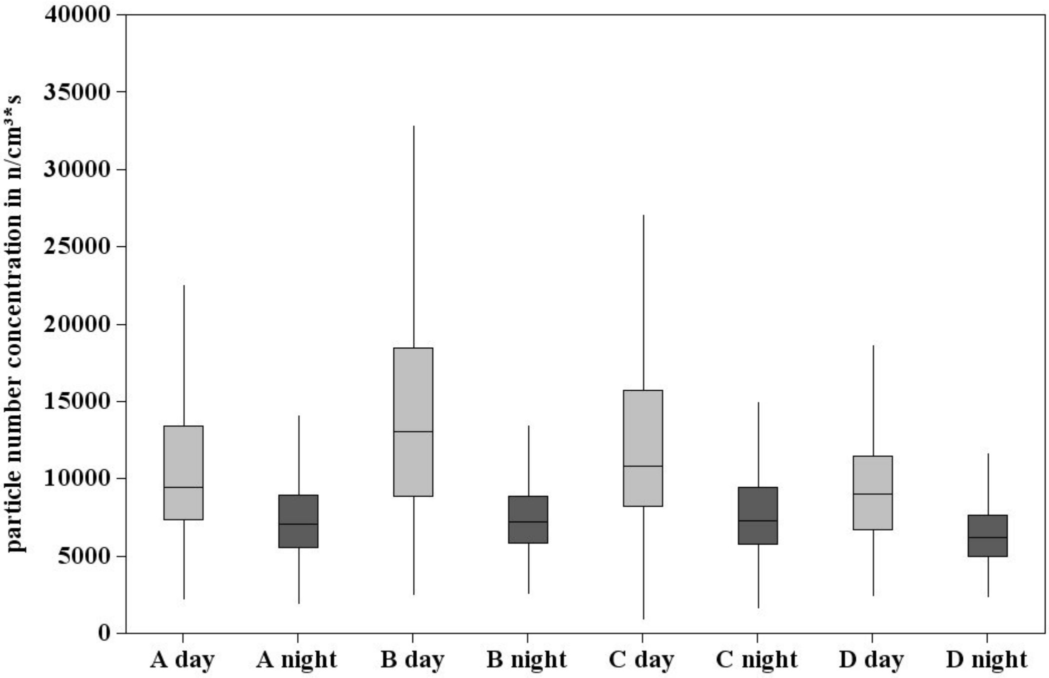

Figure 3 Box plots (explanation cf. Figure 2) of the UFP concentrations at day-time (light grey) and at night-time (dark grey) plotted for all test sites.

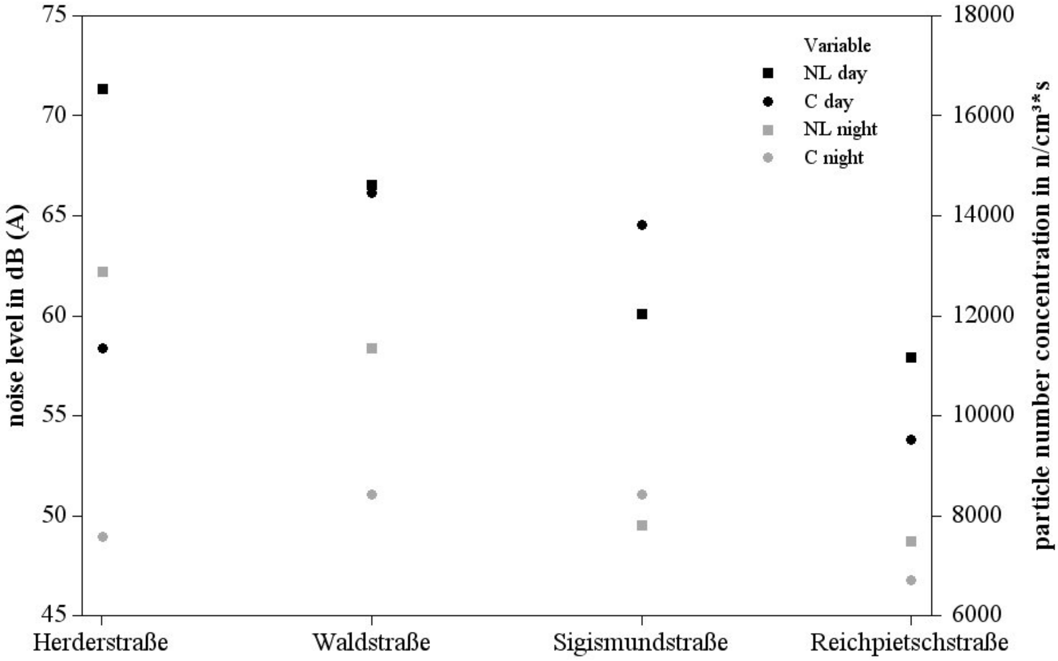

Figure 4 A-weighted noise level (NL) and average UFP number concentration (C) at day-time (light grey) and night-time (dark grey) plotted for all test sites.

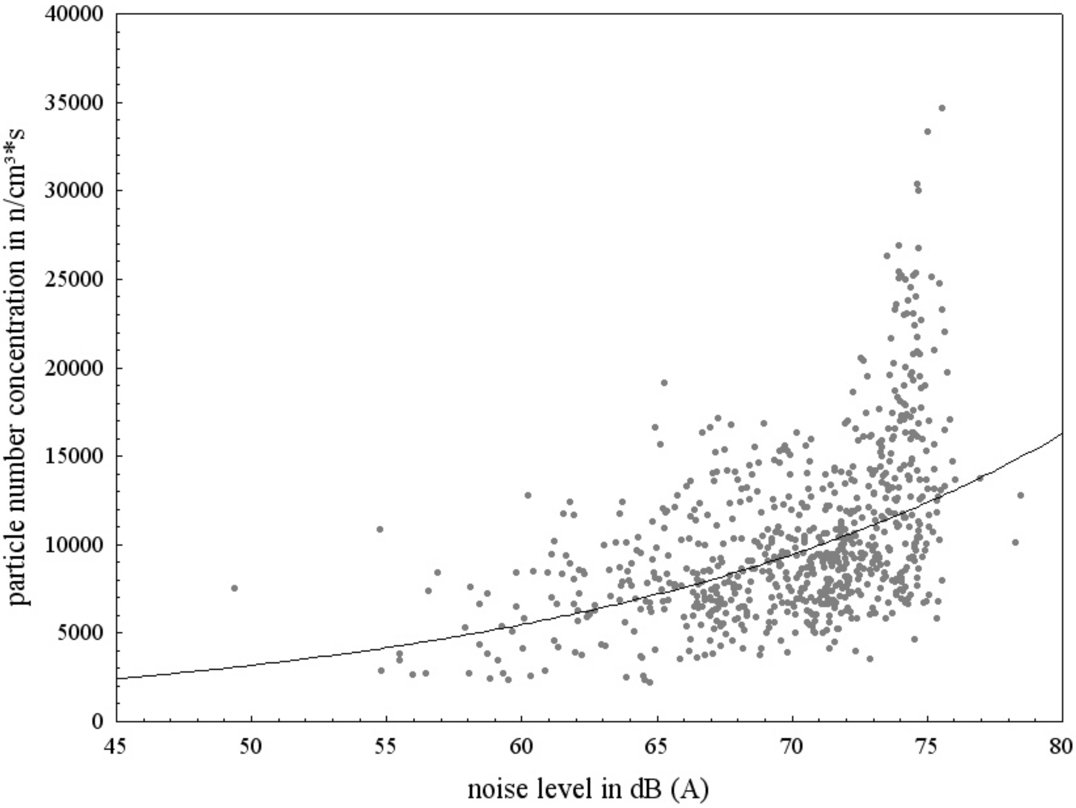

Figure 5 Pearson correlation of the average aggregated noise level (dB [A]) and the particle number concentration (n/cm^{3*s}) at the site "Herderstraße".

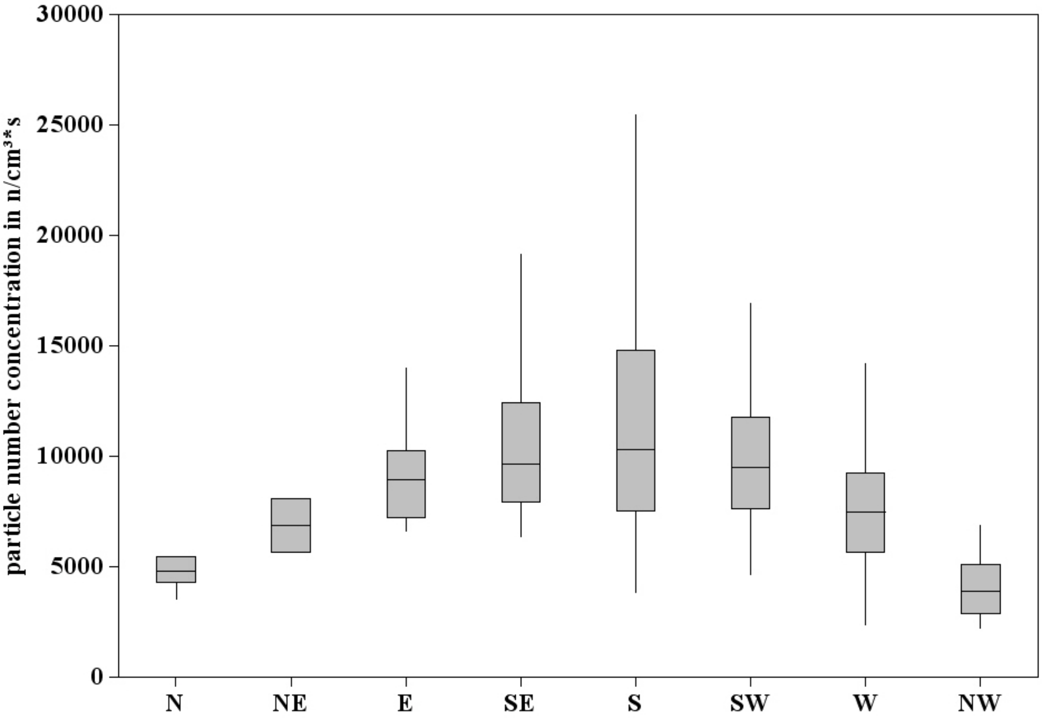

Figure 6 Comparison of the wind directions and the average values of the particle count at the test site of Herderstraße.

Weichel, T., Schulz, K., Haase, D., 2006. Effektive Ansätze zur Beschreibung des Hochwasserrisikos urbaner Bereiche. Forum für Hydrologie und Wasserbewirtschaftung 16.06 (3), 177-180.

Effektive Ansätze zur Beschreibung des Hochwasserrisikos urbaner Räume

Thilo Weichel, Karsten Schulz, Dagmar Haase

Zusammenfassung
Urbane Räume benötigen aufgrund ihrer Werteakkumulation und Schadenspotentiale eine besondere Effektivität und Nachhaltigkeit hinsichtlich des Hochwasserschutzes. Die Autoren beschäftigen dazu mit Fragen der Bewertung der Effektivität hydrodynamisch ausgewiesener Hochwasserrisikoflächen, welche eine wesentliche Basis raumplanerischer Entscheidungen darstellen. Die Ergebnisse sollen als Entscheidungsgrundlage für effektive kommunale Hochwassermanagementstrategien mit dem Ziel der Minderung von Schadenspotentialen exponierter urbaner Strukturen dienen. Methodisch werden dazu die Berücksichtigung und Qualität ausgewählter hydrodynamischer Prozessgrößen sowie deren raum-zeitliche Veränderlichkeit bzw. Unsicherheiten untersucht.

1. Einleitung
Die Entwicklung der Ausweisung von Hochwasserrisikoflächen ist eng an den Bedarf dieser raumplanerischen Basisinformation, als auch an die technische Entwicklung von Verfahren und Modellen gekoppelt. Informationen zu potentiell vom Hochwasser betroffenen Flächen werden dementsprechend vor allem in dynamischen und durch Nutzungskonkurrenzen geprägten urbanen Räumen benötigt (MIGNOT et al. 2006). Die technischen Entwicklungen der Computer- und Fernerkundungstechnologien (BATES et al. 2003, MASON et al. 2003) ermöglichen es zudem, mittels hoch aufgelöster Geländemodelle und mehrdimensionaler hydrodynamischer Modelle zur Hochwassersimulation, detaillierte Aussagen zu diesen erforderlichen Planungsgrundlagen zur Verfügung zu stellen. Inwieweit diese Technologien vor dem Hintergrund der Komplexität der Wassertransportwege urbaner Räume als auch hinsichtlich deren räumlicher und zeitlicher Auflösung hinreichend genaue Aussagen liefern, untersuchen die Autoren am Beispiel der Stadt Dresden im Rahmen des BMBF-Projektes 3ZM-GRIMEX.

2. Projekt 3ZM-GRIMEX
Das BMBF-Projekt „3ZM-GRIMEX - Entwicklung eines 3-Zonen Modells für das Grundwasser- und Infrastrukturmanagement nach extremen Hochwasserereignissen" bildet den derzeitigen Rahmen der Arbeiten. Dazu werden beispielhaft für die Stadt Dresden die komplex ineinander greifenden Wechselwirkungen des Wassertransportes innerhalb urbaner Räume im Hochwasserfall untersucht. Motivation hierzu waren die extremen Folgen des Augusthochwassers 2002, bei dem neben den direkten Überschwemmungen vor allem Überflutungen des Hinterlandes durch die Kanalisationsnetze sowie lang anhaltende Grundwasserhochstände erhebliche Schäden verursachten. Der Schwerpunkt im Gesamtprojekt liegt in der Entwicklung eines Werkzeuges zur gekoppelten modellgestützten Abbildung des Oberflächen-, Kanal- und Grundwasserabflusses. Das hier vorgestellte Teilprojekt beschäftigt sich dazu mit der hydrodynamischen Modellierung des Oberflächenabflussverhaltens.

3. Effektive Ansätze zur Ausweisung von Hochwasserrisikoflächen

Die Ausweisung von Hochwasserrisikoflächen, d.h. Überschwemmungsflächen und überschwemmungsgefährdeten Flächen lt. §31b, §31c Wasserhaushaltsgesetz (WHG 2005), stellen für den Gesetzgeber ein bedeutendes Werkzeug der Raumplanung dar. Dabei erhöhen sich in dicht besiedelten Räumen, u. a. aufgrund der geometrischen Komplexität zu berücksichtigender Strukturen, die Anforderungen an die hydrodynamische Modellierung (MIGNOT et al. 2006). Insbesondere für diese schadenssensiblen Räume ist es von immenser Bedeutung vom Hochwasser betroffene Flächen effektiv und nachhaltig, entsprechend dem Stand der Technik und vor dem Hintergrund der anzustrebenden Zielgrößen zu bestimmen. Anhand nachfolgender Arbeitsansätze soll deren Effektivität, als Maß für die Zielerreichung möglichst genauer Informationen zur Ableitung von Hochwasserrisikoflächen, beschriebenen werden.

3.1. Daten und Skalen

Der Stand der Technik (BATES et al. 2003, MASON et al. 2003) ermöglicht es, räumlich und zeitlich sehr hoch aufgelöste Daten als Grundlage der Modellierung von Überschwemmungsflächen zur Verfügung zu stellen. Diesbezüglich stellt sich u. a. die Frage, welche räumliche Auflösung vor welchem angestrebten Zielmaßstab notwendig ist. Dieser liegt z.B. in Sachsen für die Gefahrenhinweiskarten Hochwasser bei 1:100.000 (LFUG 2005). Um den Einfluss und die Effektivität der Maßstabsabhängigkeit der Modelleingangsparameter auf die Qualität der Vorhersagen möglichst gut beschreiben zu können, werden diese mittels komplexer Sensitivitätsstudien untersucht und an ereignisbezogenen Daten kalibriert.

3.2. Berücksichtigung weiterer Wassertransportpfade

Die Integration der Wassertransportpfade Grundwasser und Kanalisation (SCHMITT et al. 2004) in Hochwassergefahrenkarten stellt insbesondere für urbane Räume eine

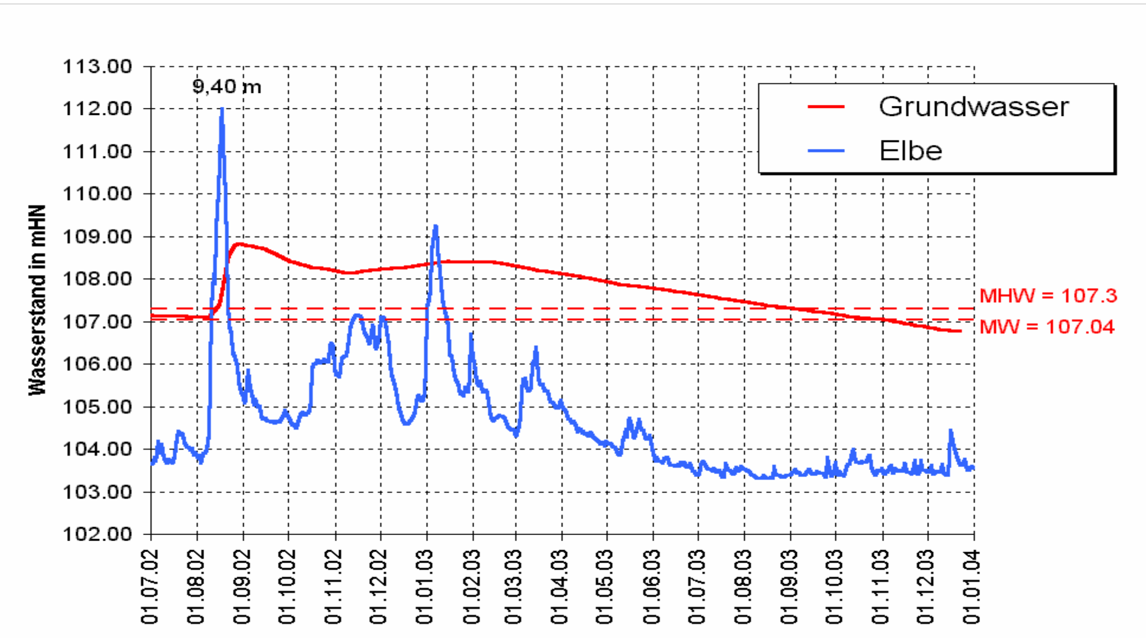

Abb. 1: Verlauf der Hochwasserstände 07/2002 – 01/2004 (DGFZ 2004)

unabdingbare Notwendigkeit dar. Allein für den Talauenbereich der Elbe im Stadtgebiet Dresden kam es infolge des Augusthochwasser 2002 zu Grundwasserhochständen, die bis ca. eineinhalb Jahre nach dem Ereignis anhielten (Abbildung 1). Des Weiteren wurden zahlreiche Flächen in nicht direkt an die Vorflut angeschlossenen Bereichen über Wasseraustritte aus dem Kanalisationsnetz dokumentiert. Um diese Interaktionen mit den direkten Überschwemmungsflächen zu berücksichtigen, werden innerhalb des Projektes 3ZM-GRIMEX die Kopplungen von Modellen zur Abbildung des Oberflächen-, Kanal- und Grundwasser realisiert. Im Ergebnis sollen die bisher allein vom Vorfluter ausgehenden Hochwasserrisikoflächen durch die der genannten Wassertransportpfade ergänzt werden.

3.3. Integration von Flächennutzungsänderungen

Urbane Räume unterliegen aufgrund zahlreicher Interessen und Ansprüche in besonderer Weise einem dynamischen Flächennutzungs- und Flächenwertewandel. Die Entwicklungen der Vergangenheit gingen dabei oftmals zu Lasten der potentiellen Überschwemmungsgebiete (HAASE 2003). Die Ausweisungen von Hochwasserrisikoflächen (WHG 2005) berücksichtigt diese Trends sich verändernder Wertakkumulationen jedoch nicht. Um langfristig angelegte Hochwasserschutzmaßnahmen effizient umzusetzen, könnte die Integration potentieller städtebaulicher Entwicklungstrends, eine sinnvolle Erweiterung des Konzeptes der Hochwasserrisikoflächenausweisung darstellen. Über die Zielgröße Flächennutzung sollen der dynamische Landnutzungs- und Schadenpotentialwandel urbaner Räume in die Modellergebnisse bzw. die Erstellung von Hochwasserrisikokarten integriert werden. Dadurch erhöht sich deren nachhaltige Belastbarkeit. Als Prozessvariablen werden neben dem flächennutzungsabhängigen Rauhigkeitsverhalten (WERNER et al. 2005), Änderungen der Topographie betrachtet und auf ihre Wirksamkeit (ARONICA et al. 1998) in der hydrodynamischen Modellierung hin analysiert. Dazu wird u. a. die Erfassung hydrodynamisch wirksamer Veränderungen mittels flugzeuggetragener Laserscannersysteme (LIDAR) untersucht. Über die bidirektionale Kopplung an ein räumlich explizites Stadtmodell (Abbildung 2) werden die Arbeiten diesbezüglich weitergeführt.

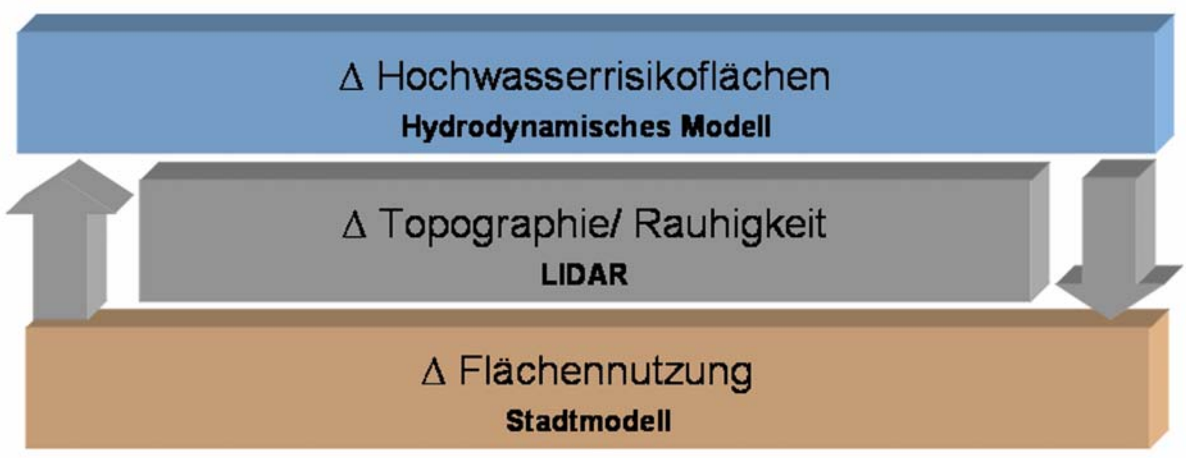

Abb.2: Modellkopplung

4. Hydrodynamisches Modell - TRIMR2D

Die Autoren verwenden zur hydrodynamischen Modellierung des Oberflächenwassers das Programm TRIMR2D (Transient Inundation Model for Rivers-2 Dimensional). TRIMR2D ist ein 2-dimensionales hydrodynamisches Modell, welches ursprünglich als Modell TRIM (CASULLI 1990) für die Modellierung von Küstengewässern entwickelt und später durch den U.S. Geological Survey (WALTERS & DENLINGER 1999) für Fließgewässer weiterentwickelt wurde. Es basiert auf einer semi-impliziten numerischen Umsetzung der Kontinuitäts- und Massenerhaltungsgleichung mittels semi-Lagranian Finite Differenzen Methode. Neben der hohen Stabilität des Modells, auch für große Untersuchungsgebiete, stellte die „open source" Nutzung einen wesentlichen Grund für die Auswahl des Programms hinsichtlich der projektbezogenen Modellkopplung dar. Im Zuge der Modellanwendung und zur Plausibilitätsprüfung der Ergebnisse werden zudem Vergleiche mit weiteren Modellen (TELEMAC-2D, MIKE FLOOD) angestrebt.

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Anthropogenic impact on fluvisols in German Floodplains. Ecological processes in soils and methods of investigation

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A b s t r a c t. The region of the Leipzig floodplain areas (Germany) is one of the most beautiful floodplain forests in Europe with partly degradated soils. The Weisse Elster and Pleisse rivers and their catchments are examples of very strong human impact on the wetland ecosystems in Germany. The open cast lignite coal mining in the south of Leipzig as well as the chemical industries were the source of millions of tons of toxic organic and inorganic contaminants of which some have been accumulated in the floodplains of the Weisse Elster and Pleisse rivers and their floodplains. In recent years, international investigation on the ecological problems of the region has been undertaken.

This paper considers some examples of soil investigation carried out at the Geographical Department of the Leipzig University. First of all, questions related to soil matter flows (mobilization, complexing) of nutrients and harmful substances (e.g., heavy metals) will be discussed here.

K e y w o r d s: Leipzig floodplain, forests, anthropogenic impact on soils

INTRODUCTION

Floodplains and their forests are important retention areas for flora and fauna that are in danger of extinction. Special character of floodplains and floodplain biotops is described by their morphology and vegetation and as well as by the soils of these ecosystems.

The fluvisols of floodplain wetlands are characterised by seasonal hydrological dynamics and strong influence of the tree stand. In the last century, hydrological system of seasonal flooding of flood plains has been influenced intensively by man in the form of riversides regulation utilisation of parts of the floodplain wetlands for agricultural purposes and drying up wetland areas and soils. Most important soils perform an ecological function of accumulating and fixing airborne and fluvially transported nutrients and contaminants.

A geo-ecological team of the Department of Geography of the Leipzig University have been investigating central German floodplain wetlands very intensively for a couple of years. Since soils are good contamination indicators of floodplain ecosystems, they have been the object of research on the soil characteristics and dynamics.

As a consequence of river regulation in the beginning of our century the East-German floodplains of the Weisse Elster and Pleisse (Fig. 1) have been drying up, soils and forests have been changing.

The re-development and closure of large powerplants in the surroundings of Leipzig was followed by decreasing levels of sulphate and calcium in the atmosphere. The acidity of the precipitation was decreasing up untill 1996 [Haase *et al.*, 1998a, b; Kulhavý *et al.*, 1998; Neumeister *et al.*, 1997] to the pH level of 4.6. Nowadays, the pH of the precipitation was found to be 4.8.

Moreover, lignite coal based heating emitted heavy metals into atmosphere which were partly deposited in the fluvisols (which belong mostly to the group of *Umbric Fluvisols*) of the floodplains.

The danger of mobilising heavy metals, considerable damages to the sensetive soil edaphon and the vegetation as well as migration of contaminants into the water saturated zone varies according to the soil conditions but may occur even when the original concentration in the soil was not very high. Increases in the soil acidity will fasten these migration processes.

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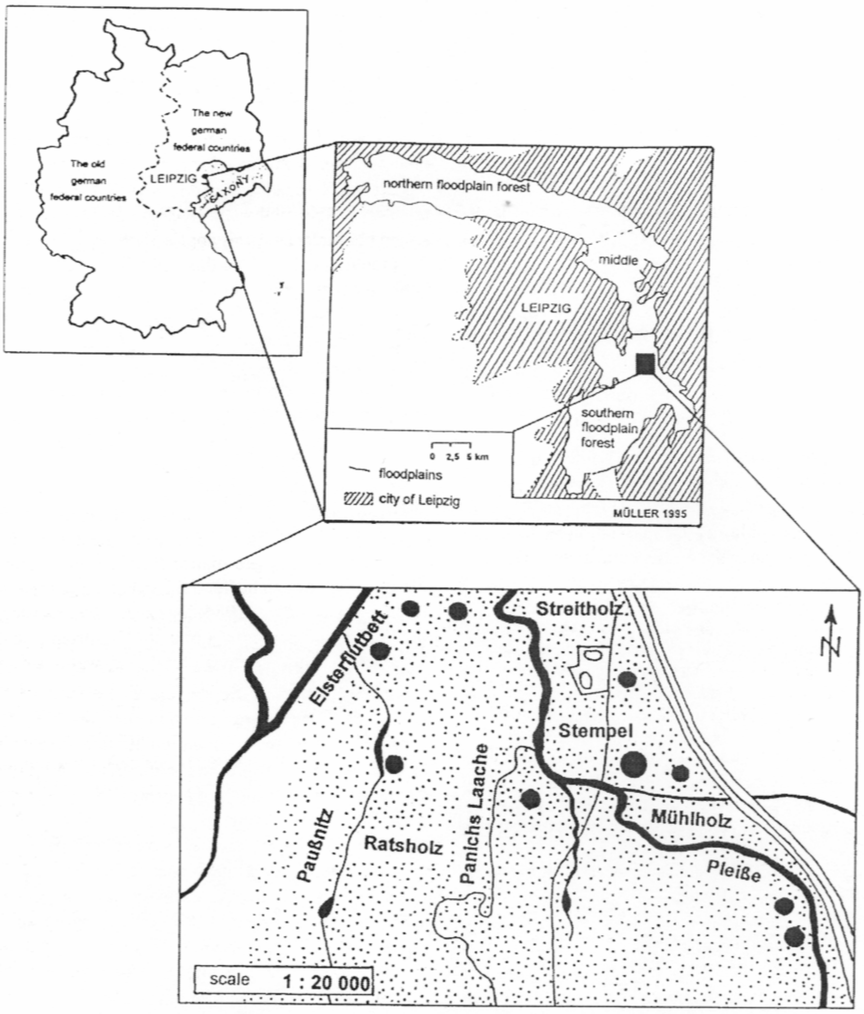

Fig. 1. Situation of the investigation area (• investigation area).

INVESTIGATION PROGRAMME

The main points of the research on the floodplain wetlands concentrate on the contents of toxic contaminants in the water saturated and unsaturated soil zone in general. Simulating of further acidification or alcalination of the precipitation by means of pH-titration experiments [Haase *et al.*, 1998a, b; Krüger *et al.*, 1997; Krüger *et al.*, 1998; Meiwes, 1984; Schneider *et al.*, 1997] gave an idea of possible migration or fixing processes in the humic and mineral soil layers.

Due to the ecological importance of contaminant bonding in the soils sequential leaching procedures [Zeien and Brümmer, 1989] indicated not only the mobility of various elements but also the importance of the DOM and SOM (Dissolved and Soil Organic Matter) for fixing and mobilizing inorganic and organic contaminants. Exchangeable fractions of heavy metals indicate their availibility for plants and soil fauna.

Re-naturation measures, such as artificial flooding of some parts of the wetlands with fresh water, will change geochemistry of the soils as the basis for flora and fauna. Even today, contents of nutrients of the flooded and non-flooded areas differ considerably [Hasse *et al.*, 1998a, b].

The influence of forest vegetation and surface and groundwater in the floodplains has also been investigated because soils and their characteristics can be only understood by comparing them with their surrounding ecosystem compounds. It was proven that mostly airborne contaminants cause chemical enrichment and structural changing before accumulation in the upper soil.

New methological aspects of the in-situ measurement was developed for the spatial pattern of the soil-pH in the wetland floodplain ecosystem [Neumeister *et al.*, 1997]. Special maps show soil reaction, and vegetation with inorganic and organic acids produced in the forest stand.

ISSUES

The main points in the investigation of the fluvisols of the Leipzig floodplains have been:
- developing a measuring system which can show the impact of decreasing pH on the precipitation on the soils;
- role of the wood stand in the nutrient and metal circulation in the soil body;
- finding out posible changes in the buffering system of the soils to answer questions related to mobilization of harmful toxic elements (e.g., heavy metals).

METHODS

The investigation methods included various elements of forest ecosystem research as well as soil investigation methods. To evaluate the processes in the soil as an interactive medium between biosphere, atmosphere and hydrosphere, only a complex compilation of methods can be applied.

Therefore, our plots in the Southern Floodplain Forest of Leipzig (hardwood stands) were chosen according to the layout below (Fig. 2).

One of the aspects was the relation between the soil pH-value and the forest stand. To achieve this we required a reference point for the actual deposition rates. Canopy precipitation, stemflow of various trees and soil solution of the upper soil was investigated over the period of 18 months.

A new field method of investigating acidity of the upper soil in the forest area was applied [Neumeister *et al.*, 1997]. This method is based on the relation between the soil-pH-value on the canopy and stemflow (run-off paths of the trees). The measurement was carried out in-situ (Figs 3-5) and allowed to form an idea of the spatial variation of the actual soil-acidity.

With a carbon-nitrogen-analyser (made by Analytik Jena), contents of dissolved organic carbon and dissolved nitrogen of the stemflow, canopy precipitation and various soil layers have been determined.

Moreover, loamy riverside sediments, non saturated and water saturated soil zones, were analysed with respect to their inorganic compounds (nutrients, heavy metals, proton concentration), organic matter (orgC, DOC, humic acids) and their capacity to buffer acid and alcaline input from the atmosphere [Meiwes, 1984; Haase and Neumeister, 1998].

While studying soil content of nutrients and heavy metals not only the actual total and water soluble contaminant contents were determined. Using the method of sequential leaching procedures ([Zeien and Brümmer, 1989], Table 1), bonds between nutrients and heavy metals were determined to obtain an idea about the bounding mechanisms, reactivity and the resulting mobility of each element.

Mobile fractions of contaminants are able to migrate from the upper soil layers into the water saturated soil zone

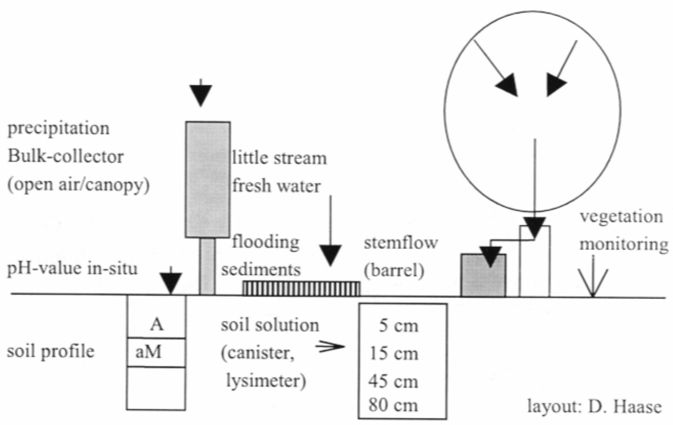

Fig. 2. Station for continiuous measurement in the Southern Leipzig floodplain forest.

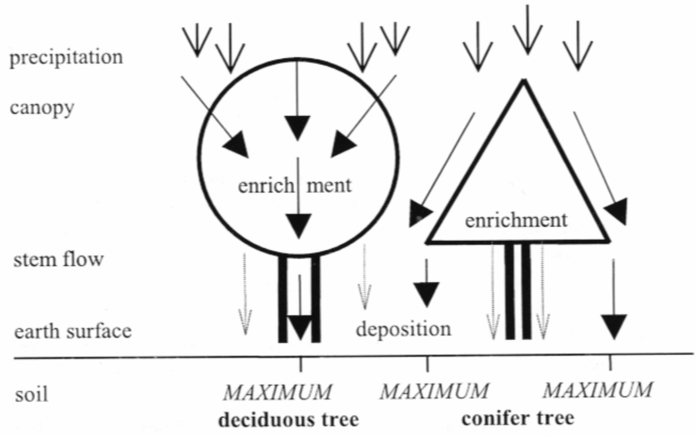

Fig. 3. Run off paths of the precipitation of deciduous and conifer trees [Otto, 1994].

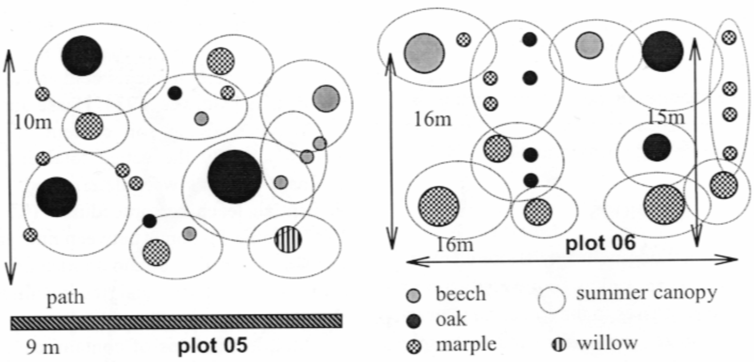

Fig. 4. Examples of 2 plots in the floodplain forests: spatial distribution of trees and determination of the input into the soils.

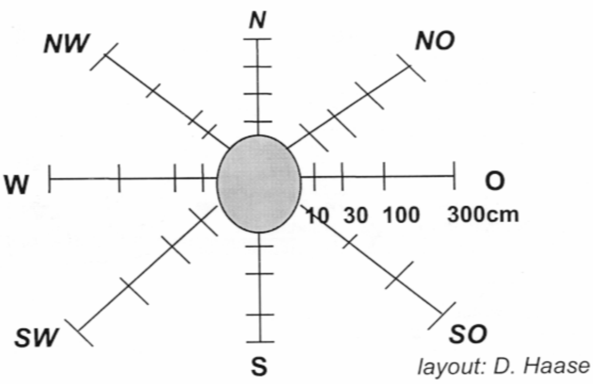

Fig. 5. In-situ-measurement of pH-values of the upper soil layers (0-10 cm) around the trees [after Neumeister *et al.*, 1997].

Table 1. Sequential leaching procedure after Zeien and Brümmer, 1989

Fraction	Extraction reagent	Speciation	Ecological meaning
I	aqua dest.	water soluble fraction	very important, because water is the most frequent solvent
II	1 M NH_4NO_3	mobile fraction, exchangeable bonds	mobilisation is given by acid input
III	1 M NH_4Ac (pH 6)	exchangeable fraction	input of acids and bases; soil-carbonate-buffer (after Ulrich)
IV	0.1M NH_2OH-HCl (pH 6), 1 M NH_4Ac	Mn-oxides fixed fraction	soluble during more acid input (strong acids)
V	0.025 M NH_4-EDTA (pH 4.6)	organic fixed fraction	soluble with solution or precipitation of humic substances
VI	0.2 M NH_4-oxalate (pH 3.25)	poor crystallised Fe-oxides fixed	poor soluble fraction, Al-Fe-soil-buffer (after Ulrich)
VII	0.1 M ascorbic acid in 0.2 M oxalate buffer	crystallised Fe-oxides fixed	
VIII	(HCl, H_2O_2, HNO_3)	residual fraction	not very relevant for natural ecosystems (insoluble fraction)

accelerated by changing of the acidification or alcalination conditions in the soil body.

Therefore, together with sequential leaching procedures, titration experiments were done simulating various conceivable immission or input situations (Fig. 6).

RESULTS

Since 1990 untill 1996, a decreasing pH-value of the precipitation was found [Neumeister *et al.*, 1997]. This resulted in a very acidic stemflows of hardwood forest species like esh or oak (Table 2), in which high contents of sulphate and DOC (dissolved organic carbon) was found.

With the help of High Performance Liquid Chromatography (reversed phase, RP-HPLC; [Krüger *et al.*, 1998; Haase *et al.*, 1998a, b]), organic compounds of the stem flows as well as of the upper soil layers of the fluvisols were determined as humic acids (HA). They showed very similar structures in the chromatograms (Fig. 7). Since the HA contents of the stemflows are higher than in the soil, it can be supposed that parts of the humic acids are produced in the stem and bark. What influence is exerted by these humic acids on further acidification of the soils, cannot as yet be discussed.

The in-situ-measurements of various plots in the floodplain forests show a strong dependency of the upper-soil -pH-value on the trees and their stemflows (Fig. 8). The pH-values between the trees differ up to pH 2.0 in very short distances of less than 2 m. Every rainfall provokes a sudden

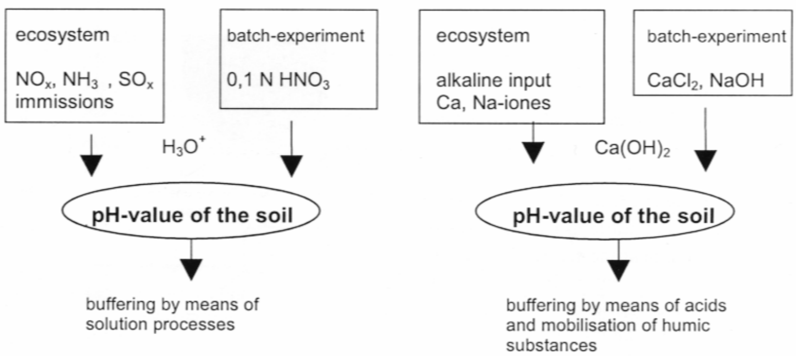

Fig. 6. Experiments on acidification and alkalination by means of atmospheric input after Meiwes, 1984.

T a b l e 2. Acidity and organic carbon content of the stem flows of oak and ash trees

Stemflow	(H^+)	pH-value	DOC
Quercus 1	$10^{-3.3}$	3.30	92.71
Quercus 2	$10^{-3.52}$	3.52	79.77
Quercus 3	$10^{-3.22}$	3.22	206.80
Fraxinus 1	$10^{-3.75}$	3.75	60.88
Fraxinus 2	$10^{-3.94}$	3.94	90.81
Farxinus 3	$10^{-4.09}$	4.09	113.60

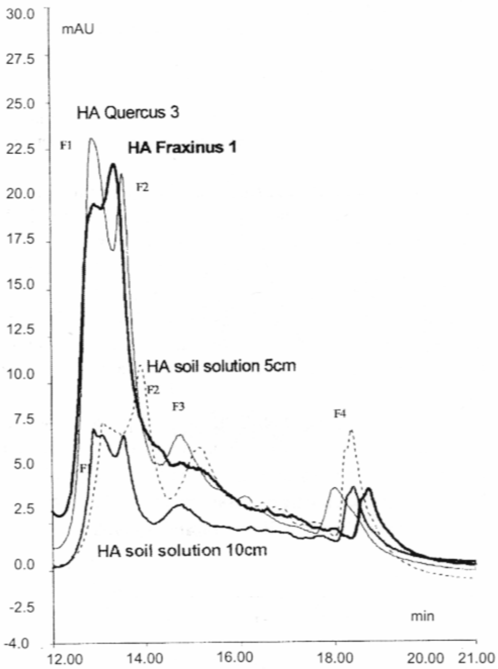

Fig. 7. Humic acids (HA) of stemflow (Fraxinus; Quercus) and soil solution (depth: 5 and 10 cm).

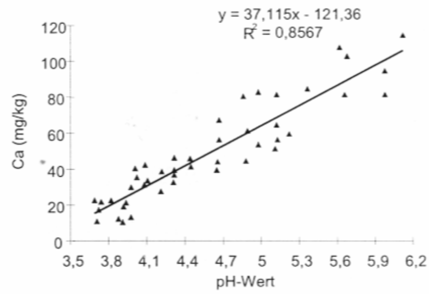

Fig. 8. Regression and correlation between the calcium-content (mg kg^{-1}) and the pH-values of upper soil samples of the Southern Floodplain Forest of Leipzig.

Experiments with the sequential leaching procedures (Fig. 9) and the titration experiments (Fig. 10) show that most of all the positively charged elements, i.e., cadmium (Cd) and zinc (Zn), will be re-soluted from the adsorption surfaces (of the clay minerals). Elements like copper (Cu) or lead (Pb) often form metal-humic-complexes and will be soluted more under increasing alcaline conditions (Fig. 10). This could occur during neutralization measures taken according to the forestry conservation requirement.

The presented results clearly underline, that factors like acidity of the floodplain forest mediums (precipitation, stemflow, soil) and contents of organic matter (dissolved, decrease of the soil-pH and neutralization reactions which lead to the wash-out-processes of nutrients such as calcium (Ca) observed in the upper soil near the stems (Fig. 8).

Furthermore, an input of acids by precipitation, leads not only to a transfer of essential nutrients into the groundwater zone. Harmful effects like the mobilization and migration of mobile and exchangable heavy metals and aluminium (Al) in the fluvisols are also provoked.

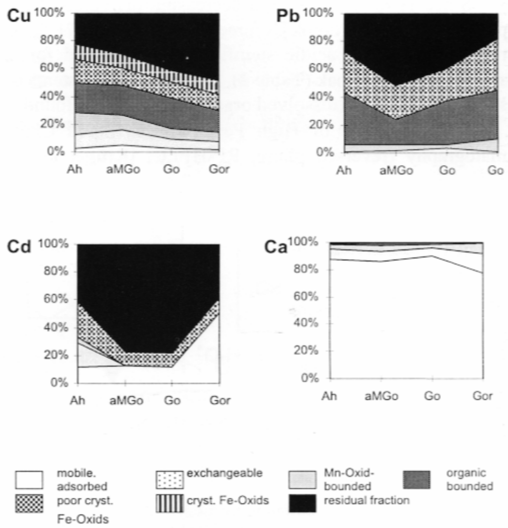

Fig. 9. Bonds of metals in several horizons (Ah, aM, Go and Gor) of the fluvisols in the Leipzig Floodplain Forest.

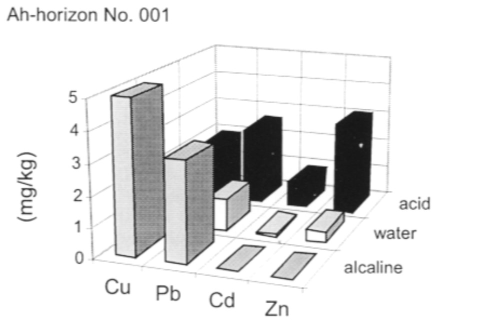

Fig. 10. Mobilization of metals after acid and alcaline input by means of precipitation.

total) must be observed regulary to get an idea of the solution, migration and pollution processes of the soil and groundwater. With the help of fixed plots and a monitoring programme, an efficient support for the landscape and regional planning processes could be achieved.

CONCLUSIONS

Acidity of the upper horizons of the fluvisols in the floodplain forests of Leipzig strongly depend on the spatial distribution of trees. Soil acidity depends also on the season, troughfall and kind of trees. With the tree run-off there occurs also an input of organic humic acids into the upper soil horizons. Within the soil body, the acid inputs lead to element specific mobilization and changing of the bonds.

Not only acid input is followed by the solution of nutrients and metals, but also alcaline deposition provokes leaching of heavy metal-humic-complexes (Cu, Pb).

The results of the investigation show that pH, measured in-situ, as well as the buffering qualities of the soil body can be considered as the main parameters (master variables) to describe the actual processes occuring in fluvisols.

This kind of results is urgently required for the construction of a long-time recording programme monitoring of the positive and harmful effects on soils in floodplain forests (Fig. 11) including both, regional fluctuations and a long time registration.

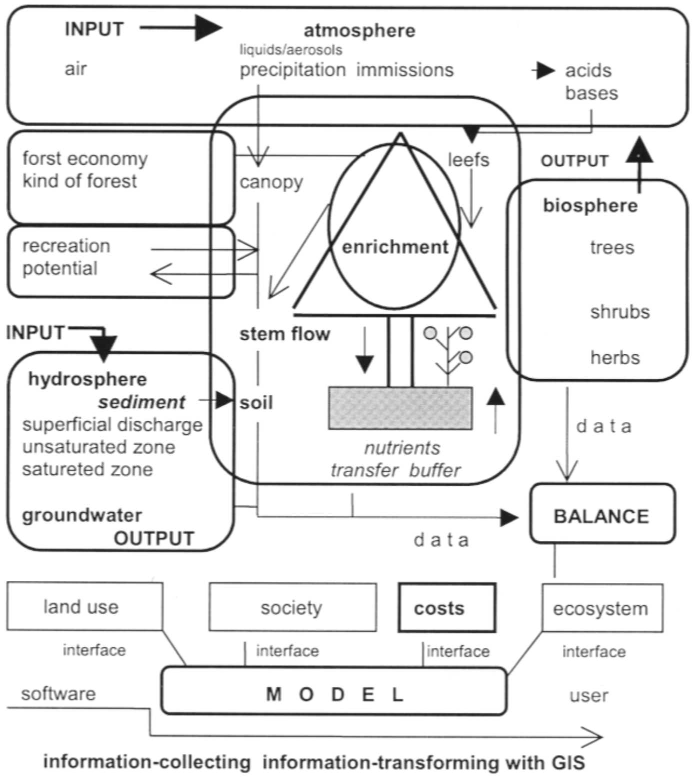

Fig. 11. Model for a computerized forest-monitoring system.

At least a database is needed for forest management and forest economy to build up a soil information system (SIS) of the floodplains, necessary for the decision making, to create or to enlarge environmental protection areas within the floodplain forests.

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Urban Ecology of Shrinking Cities: An Unrecognized Opportunity?

Dagmar Haase

ABSTRACT
Whereas environmental and social impacts of urban sprawl are widely discussed among scholars from both the natural and social sciences, the spatial consequences of urban decline are nearly neglected when discussing the impacts of land transition. Within the last decade, "shrinkage" and "perforation" have arisen as new terms to explain the land use development of urban regions faced with demographic change, particularly decreasing fertility, aging, and out-migration. Although shrinkage is far from being a "desired" scenario for urban policy makers, this paper argues that a perforation of the built-up structure in dense cities might bring up many positive implications.

KEYWORDS
Urban shrinkage, perforation, demolition, green infrastructure, biodiversity, urban wilderness

Environmental and social impacts of urban growth and their immanent land take are widely reflected and discussed among scientists from different disciplines. In contrast, the opposed development of urban decline and, in particular, its spatial effects still lack comprehensive analysis and evaluation. Since the term "decline" has a negative connotation for urban policy makers as well as for urban residents, growth still dominates the political agenda for the majority of European cities (Müller and Siedentop 2004).

Recently, "shrinkage" and "perforation" arose as new terminology to depict the spatial and land use of urban regions faced with depopulation, aging, and out-migration. As Rieniets (2006: 30), for example, argues, phases of shrinkage are as much a part of urban development as are phases of growth. Because of wars, natural catastrophes, epidemics, or even the abandonment of large mines, urban shrinkage is already in evidence between the 1920s and 1940s. English cities also experienced considerable decrease in population due to deindustrialization in the postwar period. The same holds true for industrial agglomerations in the northeastern United States (Rieniets 2006). Although shrinkage,

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after decades of predominant growth, is by no means a "desired" scenario for urban planners and policy makers, this paper argues, from an environmental scientist's perspective, that a perforation of the land use structure in densely built-up cities can have some substantially positive implications. The first of these is the quality of housing and urban green infrastructure supply that serves as a typical and well-established indicator of the quality of life in cities (Santos and Martins 2007). Second, biodiversity benefits from the perforating land use patterns that emerged out of deurbanization, as included in the basic ecosystem services compiled by Costanza et al. (1997). This paper considers the positive impacts that could originate from land use shifts and patterns related to shrinkage and how they affect urban green infrastructure, recreational services, and biodiversity.

As a notably massive form of spatial and functional urban decline, urban shrinkage—the opposite of urban sprawl, which underscores urban dynamics in most of the literature on urban land use change (e.g., Antrop 2004; Kasanko et al. 2006)—increasingly affects urban land use patterns and, consequently, habitats and species distribution. Due to recent demographic changes and economic weakness, every sixth city in the world can be defined as a shrinking city (Rieniets 2006). In such cities, large parts of the inner city are affected by an absolute and relative population loss as well as an industrial blight, both of which produce residential and commercial vacancies, urban brownfields, and abandoned sites.

In eastern Germany, where this phenomenon serves as the empirical background for this paper, shrinkage increasingly affects formerly growing industrial urban regions (Chilla 2007). Currently, there are more than one million vacant flats, excluding 350,000 housing units demolished since the German reunification and transition to a democratic society in 1990. Additionally, the abandonment of commercial land annually comprises ±10 hectares (Jessen 2006). Out-migration and deindustrialization are the main reasons for both types of vacancies. As a result of particularly the large-scale demolition of housing stock, urban land use patterns and the images of residential areas and perceptions of their inhabitants are changing considerably. Moreover, vacancy and demolition modify the biophysical ("natural") environment of a town (see Figure 1).

The experiences from eastern German cities tell us that shrinkage leads to considerable vivid spatial and visual effects: a "perforation" of growing and shrinking urban clusters, patchy patterns of wealth (islands of upgrading), and poverty at the local level (Haase et al. 2007,

Figure 1 ■ A typical feature of urban "shrinkage" in eastern Germany: demolition of prefabricated housing estates to decrease housing surplus and thus "regulate" local markets. (Photo: UFZ)

2008). Furthermore, we find a small-scale fragmentation of the urban population (in the form of a fragmented "housing geography") or splintering of the urban population (Buzar et al. 2007), a high number of residential vacancies in many housing estates, commercial vacancies in inner-city shopping malls, and large-scale brownfields in both the inner city and suburbia. The latter have consequences for the degree of soil imperviousness and building and population densities (Sander 2006; cf. Figure 2).

In terms of biodiversity, Mehnert et al. (2005) found a positive correlation between the total amount of urban green infrastructure (parks, allotments, cemeteries, forest, etc.) and the suitability of habitat for breeding birds (e.g., for the green woodpecker, *Picus viridus*). Strauss and Biedermann (2006) reported on positive reactions of different species to high proportions of inner-city grassy brownfields and negative reactions to the absence of these. Such open or wasteland patches (Figure 3) are niches in which rare species thrive (e.g., Shochart et al.

Figure 2 ■ Large-scale demolition of densely built-up housing structures in inner parts of the Wilhelminian city: new open spaces for experimental design of recreational green infrastructure? (Photo: D. Haase)

Figure 3a. ■ Rare places despite demolition all around—natural secondary succession only occasionally occurs … (Photo: D. Haase)

Figure 3b. ■ … compared to a majority of demolished sites that are prepared for transportation or parking purposes and thus newly contribute to the rate of imperviousness of shrinking cities. (Photo: D. Haase)

2006; Bolund and Hunhammar 1999; Gilbert 1990). This should be particularly true for demolished sites in the core and inner city or dense residential zones, where spots of urban biodiversity benefit from shrinkage and thus can be created at the local level.

At a more aggregated spatial level, both the perforated urban landscape (which is less dense and more heterogeneous in terms of land use) and the mixture of open and impervious land possess a higher share of rural and open land uses than densely built-up inner cities.

Still, there exists no clear idea of what perforation in a final state might look like. Nevertheless, concepts for this "urban type" have already been developed, such as the remaining urban core being divided into equitable subcenters or a polycentric structure with fewer dense or even empty patches. Others foresee the fragmented built-up body as the most probable urban development pathway (Lüdke-Daldrup 2001).

From an ecologist's point of view, one can state that all these forms of urban perforation result in a structural enrichment of urban land use and an increase in edge density. However, generally positive or negative effects of urban perforation as well as urban shrinkage, in a broader sense, upon urban ecosystems and biodiversity have not yet been statistically verified through empirical studies. I argue that residential vacancy, land abandonment, demolition, and perforation are not logically followed by a "resurgence" of nature. Previous land use might have left behind considerable pollution in the soil. Moreover, inappropriate subsequent or interim use of the waste/demolished site, such as leaving the area unused and retaining its impervious surface (Figure 3b), will produce a negative environmental impact: the patch then benefits neither the quality of life (housing) nor the functions of the ecosystem (water regulation, soil biology). An increase in such urban brownfields or abandoned sites, in the aggregate, makes inner-city neighborhoods less attractive and thus supports an ongoing urban sprawl.

Urban shrinkage allows us to contemplate a "resurgence" of nature into inner cities that are densely populated and have been built up "for ages." In this vein, ideas regarding "urban wilderness" for recreational and educational purposes are of concern among urban planners and landscape architects who are confronting this shrinkage (Rink 2005). The eastern German city of Leipzig, a "model city," has made the novel suggestion of creating urban greenery in the form of temporary gardens at core city demolition sites (as a kind of planned alternative) and spontaneous and ruderal nature on former brownfields (as a kind of unplanned alternative). De Sousa (2003) perceives green sites developed from inner-city brownfields as "flagships" or "experimental fields" that serve as models for future greening endeavors to improve both local biodiversity and human livelihoods. Besides total demolition of houses, shrinkage also leads to a deconstruction of multistory housing stock in the form of a transition toward more spacious housing and living conditions in densely urbanized environments: bigger apartments with nonclassical layouts and integrated patios and terraces, as well as higher shares of urban green and "landscape" within the neighborhood.

Doubtless, there is considerable potential for social, residential, and ecological improvement in shrinking cities, which, through exploring opportunities as discussed above, might attract new residents for a longer period of time and keep local dwellers in the city, instead of having them choose the detached-house alternative. This opens a new pathway to counteracting urban sprawl. Such as perspective argues that residential and commercial vacancies and the subsequent demolition represent an opportunity for the enlargement of urban green networks and, to some extent, the ecological restoration of cities.

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Research

Birds and the City: Urban Biodiversity, Land Use, and Socioeconomics

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ABSTRACT. We examined bird diversity in relation to land use and socioeconomic indicators in Leipzig, Germany. We used neighborhood diversity (ND) and bivariate correlation to show that the potential to experience biodiversity in a city is associated with population density, household income, unemployment, and urban green space. People living in urban districts with high socioeconomic status experience the highest species richness around their homes, whereas lower social status increases the chance of living in species-poor neighborhoods. High-status districts are located along forests, parks, and rivers that have a high quantity and quality of green space. However, green space in general does not guarantee high bird diversity. We conclude that bird diversity mirrors land use and socioeconomic patterns within the compact European city of Leipzig. Therefore, urban planning should focus on decreasing these patterns and protecting the remaining species-rich green spaces.

Key Words: *biodiversity; human-environment interaction; neighborhood diversity; urban ecology*

INTRODUCTION

Urban areas cover only 2.7% of the world surface (Center for International Earth Science Information Network 2004) and have been inhabited by the majority of the human population since 2008 (United Nations 2008). Likewise, they are the most domesticated landscapes on earth (Kareiva et al. 2007). The process of urbanization, as this domestication is usually called, generally leads to an environment that is favorable for humans. However, it can lead simultaneously to a host of environmental problems, including the loss of biodiversity (Grimm et al. 2008).

In examining the general role and extent of the impact that urbanization has on biodiversity, no general answer can be found. On a gradient of intensifying urbanization, i.e., the rural-to-urban gradient, the number of species of different taxonomic groups has been shown to peak at different levels. Breeding bird diversity has been found to decrease (Clergeau et al. 1998, 2006, Marzluff 2001) and to be lowest in urban centers (Blair 1999, Tratalos et al. 2007*a*). However, urban structures can provide a wide and heterogeneous range of habitats, depending on the intensity of urbanization (DeGraaf et al. 1991). They often encapsulate remnants of natural or semi-natural ecosystems that are lost elsewhere (Haase 2003, Crane and Kinzig 2005, Millard 2008). The effect on biodiversity also depends on where urbanization occurs. Savard et al. (2000) summarize the effect of urban land conversion on a given landscape as a function of its original composition: Urbanization is most likely to decrease biodiversity when the original landscape is diverse.

Urbanization is not a purely physical process that affects biodiversity. Many authors argue that socioeconomic patterns such as urban structure, population density, neighborhood image, or household income should be taken into account when studying urban ecosystems (Grove and Burch 1997, Dow 2000, Alberti et al. 2003). There is recent evidence that biodiversity mirrors socioeconomic patterns of income, age of development, and ethnicity within North American cities. Findings for Vancouver, Canada, demonstrate that the number of native bird species increases in relation to an increasing socioeconomic status that was measured by mean family income and number of people holding a university degree (Melles 2005). Similar patterns were found by Hope et al. (2003) and Kinzig et al. (2005), who identified substantial neighborhood differences in species richness

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according to the given income status in Phoenix, Arizona, USA. In both cities, neighborhoods with higher social status often have higher species diversity than neighborhoods with lower social status.

In addition to the abovementioned effects, urbanization also changes the way humans experience biodiversity. Turner et al. (2004) calculated the neighborhood diversity (ND) to study the species diversity at people's place of residence. ND indicates the number of species found within a certain radius of a home. Turner et al. (2004) compared the local ND and local human population to the citywide average ND for five cities on three continents. They found that 53 to 82% of the population lives in neighborhoods with below-average ND. They conclude that this might be the case for most urban human populations. This is important for two reasons. First, Miller (2005) and Dunn et al. (2006) argue that the loss of experiencing biodiversity on a daily basis causes an estrangement from nature, which might explain the lack of broad-based support for nature conservation in general. Second, urban green spaces provide important social, psychological (Chiesura 2004), and health (Ulrich 1984) benefits that are not only linked to their quantity, but also their quality (Fuller et al. 2007, Mitchell and Popham 2008). For example, Baines (2000) argues that bird life in urban parks enhances the recreational quality: People who go to parks during the day seek a "wildlife garden" atmosphere that differs from their work neighborhood. In summary, bird diversity is likely to vary across an urban region, and some of this variation is likely to be correlated with demographic and socioeconomic characteristics.

Given this experience, our purpose is to analyze whether this idea holds true for Leipzig, Germany. The city of Leipzig is a compact, central European city that is situated in the former Communist Bloc; the development of the city and its society has been very different compared to most North American cities. We therefore expect different relationships between bird diversity, land use, and socioeconomic patterns. Because we focus on the spatial and social aspects of potential urban human-nature interactions, we take the method developed by Turner et al. (2004) one step further by overlaying patterns of human populations living in neighborhoods of below-average ND with land use and socioeconomic data.

METHODS

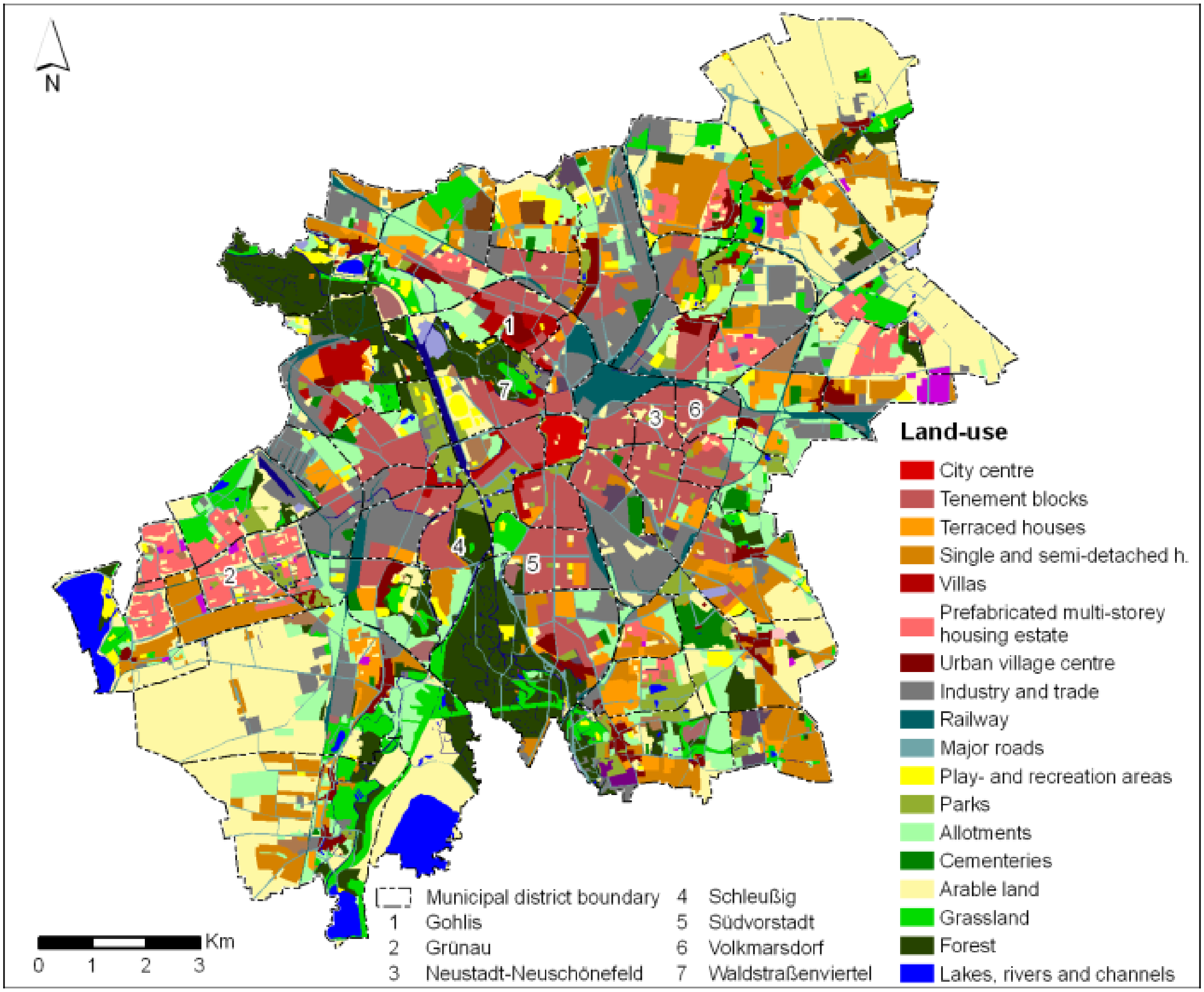
Study area

Leipzig is located in eastern Germany (51°20' N, 12°22' E). The city reached its peak population of more than 700,000 inhabitants in the early 1930s, making it the country's fourth largest city. After WWII, the city entered its socialist period until 1990 and started to lose population. Faced with tremendous societal transition and the withdrawal of investment, the city lost approximately 100,000 inhabitants after the fall of the Berlin wall in 1989, with 530,000 inhabitants in 1989 and 437,000 inhabitants in 1998.

Leipzig consists of a densely developed core with administrative and cultural facilities in the city center. The core is surrounded by a ring of tenement blocks from the Wilhelminian period (1890–1918; Fig. 1). A second residential ring is formed around Leipzig by terraced houses and villas, mainly built between 1900 and 1940, as well as huge socialist-era prefabricated multistory housing estates in the western part of the city. Larger parts of the eastern and western city are covered by manufacturing and commercial land use. Many small and intensively used allotment garden plots are situated along railway tracks and around the city.

There are major differences in population density within the city area. The surrounding ring of terraced and single houses has a low population density of < 1000 inhabitants/km². The southern part and the inner western part of the Wilhelminian block-structures, namely the municipal districts of Südvorstadt, Schleußig, Waldstraßenviertel, and Gohlis, belong to the districts with a population density close to the city's average of 4900 inhabitants/km² (Stadt Leipzig 1995). Inhabitants of higher income groups live in these districts. Districts with a higher population density include the simple or medium-quality Wilhelminian structures of the eastern part of Leipzig such as Volkmarsdorf and Neustadt-Neuschönefeld. These districts suffer from high vacancy accompanied by declining economic activity. In addition, the low quality of public spaces in some of these areas overlaps with social problems and increases the perception of a negative image (Haase et al. 2004). Districts with mainly socialist-era prefabricated multistory housing estates such as Grünau in the outer west had a population density of up to 18,000 inhabitants/km² in 1993. They also suffer from a

Fig. 1. Land-use classification of the study area of Leipzig, Germany, based on a map published in Haase and Nuissl (2007).



negative image because of the low housing quality and the perception that the inhabitants of such high-density districts often belong to lower income and socially deprived groups (Kabisch et al. 2005). These municipal districts are indicated in Fig. 1.

Despite being compact, Leipzig contains a large quantity of green spaces. There are several large parks. The floodplains of the rivers Weiße Elster and Pleiße are covered by old riparian forests belonging to the association *Querco-Ulmetum minoris* Issler 1924 (Müller 1995) and meadows that make up approximately 6.3 and 4.1%, respectively, of the city. Leipzig holds one of the largest and most diverse urban floodplains of Europe (Haase 2003). The floodplain separates the city into western and eastern parts. The soils in the floodplains are mostly loamy Fluvisols, but the major part of the city is covered by Pleistocene sediment-based Luvisols.

In total, 109 breeding bird species were found within the city borders of Leipzig. This diversity is significant; the number of bird species in the entire Federal State of Saxony is 180 (Stefens et al. 1998) and in Germany is 314 (Völkl et al. 2004). *Turdus merula* (blackbird), *Parus major* (great tit) and *Passer domesticus* (house sparrow) have the largest ranges, occupying 93, 84, and 83% of the city, respectively. Diverse areas with rare species such as *Dendrocopos medius* (middle spotted woodpecker) are located along the floodplain, indicating the ecological value of the meadow forests. Only a few species are found in the densely built-up areas and intensively used rural agricultural surroundings. Only a few species are non-native, but those can be considered naturalized, e.g., *Streptopelia decaocto* (Eurasian collared dove).

Indicators

We used three sets of indicators: breeding bird diversity, land use, and socioeconomic indicators. We used breeding birds because they are a very well-studied taxonomic group, providing good data availability. Furthermore, urban bird communities can be independent of bird communities in the rural surroundings at local and regional scales (Clergeau et al. 2001) and have been used to evaluate the ecological quality of urban green space (Sandtröm et al. 2006). Most importantly, birds are probably the most visible and audible taxonomic group for humans in cities. Land use is an indicator that contains information on both habitat quality and residential quality. For socioeconomic indicators, we used variables similar to Hope et al. (2003), Turner et al. (2004), Kinzig et al. (2005), and Melles (2005); we used population density and total number of companies, representing economic density, as indicators of land-use intensity. We used income level and unemployment as indicators of socioeconomic status. Finally, average household size and mean age were used to identify social segregation.

Data

The breeding bird survey of the region of Leipzig was carried out between 1991 and 1993 on a 500 × 500 m sampling raster. In each year, the raster cells were surveyed by volunteer ornithologists at least five times between February and July. Only breeding species were mapped. If a species was found breeding in at least one of the three years, it was marked as present in the respective raster cell of the species atlas (STUFA 1995). The map of Leipzig's land-use structure was compiled by Haase and Nuissl (2007) for 1997 (Fig. 1), which is considered close enough to the survey period of the breeding birds. The information about socioeconomic patterns at the municipal district level (n = 49) was mainly taken from local census data. Data for population density, average household size, mean age, and number of companies per square-kilometer were available for 1994. Data for residential vacancy are from 1995, and those for unemployment rate are from 1996 (Stadt Leipzig 1995, 1997). For the income indicator, there was no information from 1994, 1995, or 1996; data were thus taken from the closest available year: 2003 (Stadt Leipzig 2004). We used the share of households with income < 1000 € and the share of households with income > 3000 €, which were the most detailed indicators available. Although absolute levels of income have changed, the relative spatial differences are expected to be quite stable. See Tables 1 and 2 for lists of all variables used.

Analysis

The spatial data analysis was carried out using ArcGIS version 9.2, with the extensions Spatial Analyst 9.2, ET GeoWizards 9.6.1, and Patch Analyst 0.9.4. The statistical software R 2.7.1 was used for statistical analysis and visualization.

Spatial Analysis

In a first step, each bird survey raster cell with its centroid within the city area was selected and assigned to the municipal district that covered the majority of its area. The angular appearance of the districts is a result of that assignment (Figs. 2 and 3). In a second step, the raster of the breeding bird survey was intersected with the urban land-use map of Leipzig. We then calculated the relative cover of the single land-use classes for each raster cell and for each municipal district. Knowing the housing area and population of the municipal districts, we interpolated the human population of each raster cell using the housing area as a proxy.

We calculated the neighborhood diversity (ND) as a measure of how much bird diversity residents could experience on a daily basis within a certain

Table 1. Spearman rank correlation between land use and the percentage of human population in neighborhoods with below-average neighborhood bird diversity at the municipal district level.

Land use	Correlation (rho)
Urban village center	–0.16
Terraced houses	–0.16
Prefabricated multistory housing estate	0.24°
Single and semi-detached houses	–0.02
Tenement blocks	0.20
Villas	–0.25°
City center	0.23
Industry and trade	0.08
Railway	0.35*
Major roads	0.13
Sports and recreation areas	–0.07
Parks	–0.14
Allotments	–0.09
Cemeteries	0.15
Arable land	–0.03
Grassland	–0.42**
Forest	–0.65***
Rivers and channels	–0.66***
Lakes	–0.51***

°$p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

radius around their home. ND indicates the number of species found within a survey cell and its respective neighbors (nine cells in total), which translates to a radius of 500–1000 m. ND represents the number of species found within that radius for a home within a survey raster cell. This accounts for government recommendations on the availability of natural green space in the proximity of homes in Germany (500 m; Hutter et al. 2004) and England (300 m; Handley et al. 2003). There are no federal recommendations in the United States, but some communities have their own guidelines. Comparing the guidelines of several cities, Harnik and Simms (2004) found that the maximum allowable distance from a park was 890 m on average.

To visualize the relationship between population density and species diversity, we used the two

Table 2. Spearman rank correlation between socioeconomic indicators and the percentage of human population in neighborhoods with below-average neighborhood bird diversity at the municipal district level.

Socioeconomic parameter	Correlation (rho)
Population density (inhabitants/km², 1994)	0.44**
Average household size (1994)	–0.03
Mean age (1994)	–0.02
Companies (number/km², 1994)	0.47***
Residential vacancy (1995)	0
Unemployment (% of employable population, 1996)	0.25*
Share of households with income < 1000 € (2003)	0.36*
Share of population with income > 3000 € (2003)	–0.31*

°$p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

parameters of population and species diversity in one map (Fig. 2). We applied red-grey-blue color coding in which the red channel represents the human population and the blue channel the species diversity. The cell appears red if the human population is high and species diversity is low. In the opposite case, the cell appears blue. The cells are black in the case that both population and species numbers are low. Cells appear white if the population and species diversity are high. All other combinations are represented by shades of gray. This method was adopted from Turner et al. (2004) and implemented with the R 2.71 package Maptools.

Finally, we computed the percentage of human population in neighborhoods with below-average diversity, following Turner et al. (2004). This was done by summing the population of all raster cells with below-average diversity within a certain area and dividing it by the total population of that area. The result is an aggregated value for each municipal district and one for the whole city.

Statistics

A bivariate correlation analysis was conducted to find overlaying patterns at the municipal district level. We correlated the percentage of population living with below-average ND with all land-use and socioeconomic variables. Spearman’s rho was selected as a measure of correlation because not all variables were normally distributed.

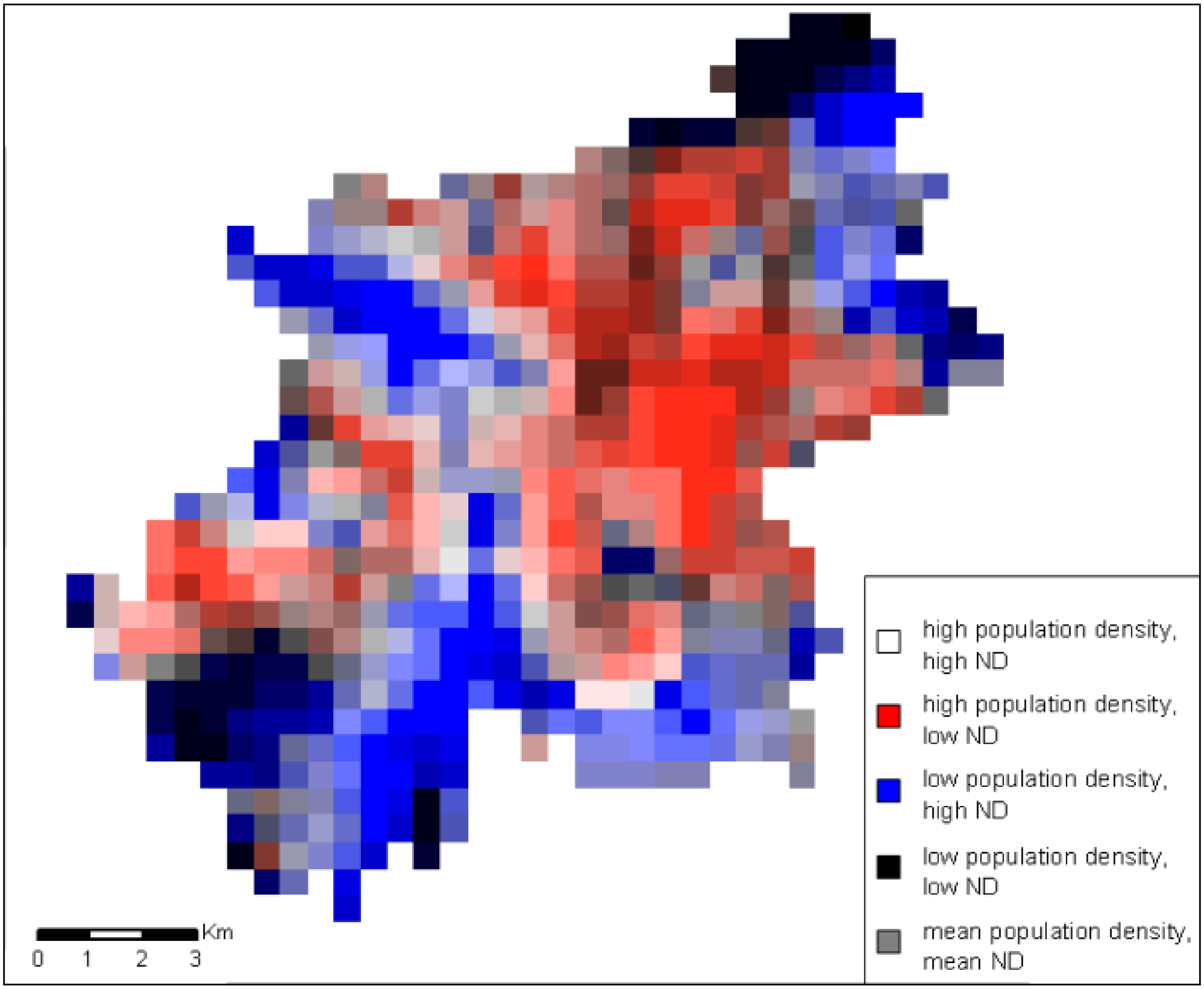
RESULTS

The highest ND is 73, the lowest is 12, and the mean is 47. Areas with high ND and low population density (Fig. 2, blue) are located along the floodplain and the northeast and southeast of Leipzig. The densely populated areas with low ND (Fig. 2, red) are mainly located in the west and in some eastern parts of the city. There is little co-occurrence of high population density and ND (Fig. 2, white).

In 1994, > 66% of the population of Leipzig lived in neighborhoods with below-average bird diversity. The percentage of the population living with below-average ND ranges from 0 to 100% for the municipal districts, indicating great differences among them (Fig. 3).

Districts with a high percentage of population living with below-average ND are situated in the eastern

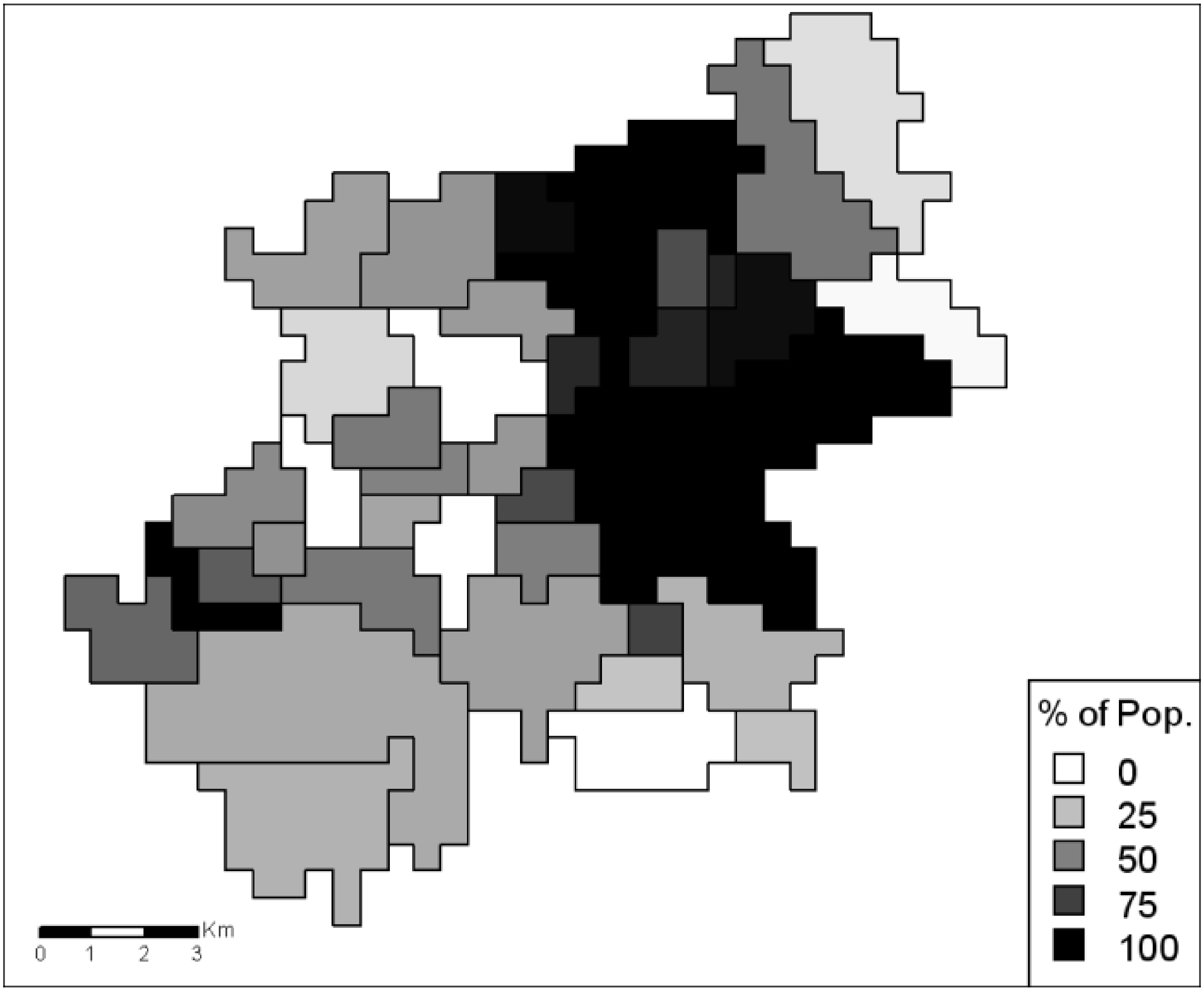
Fig. 2. The distribution of human population and breeding bird diversity in Leipzig, Germany. ND = neighborhood bird diversity.



part of the city, i.e., the low-image districts of Volkmarsdorf and Neustadt-Neuschönefeld, as well as in the prefabricated housing areas of Grünau situated in the west of Leipzig. Areas with a low percentage of population living with below-average ND are located along the floodplains and at the fringe of Leipzig.

We examined the Spearman rank correlation between land use and the percentage of human population in neighborhoods with below-average ND (Table 1). There were negative correlations for land use in either natural or semi-natural habitats such as grassland (–0.42), forest (–0.65), river and channels (–0.66) and lakes (–0.51). There was a weak negative correlation for the residential land-use type of villas (–0.25). A positive but weak relationship emerged for the land-use types of railway (0.35) and prefabricated multistory housing estates (0.24). Other building types, parks, sports

Fig. 3. The percentage of human population in neighborhoods with below-average bird diversity at the municipal district level.



and recreation areas, allotments and cemeteries, industry and trade, major roads, and arable land did not show any significant correlations.

We also examined the Spearman rank correlation between socioeconomic data and the percentage of human population in neighborhoods with below-average ND (Table 2). The two indicators of land-use intensity, i.e., population density and number of companies per square-kilometer, were positively correlated with neighborhoods with below-average ND (0.44 and 0.47, respectively). Unemployment and the share of households with income < 1000 € also showed a weak positive correlation (0.25 and 0.36, respectively). There was a negative correlation with the share of households with income > 3000 € (–0.31), whereas there was no significant correlation with average household size or mean age.

In addition to the percentage of human population in neighborhoods with below-average neighborhood diversity, we also analyzed the Shannon diversity index, a common diversity index that does not require a threshold definition and is not focused on the potential to experience diversity. The results were similar to those above (Appendix 1).

DISCUSSION

The percentage of the population of Leipzig living with below-average ND is similar to that in other cities (Turner et al. 2004; Table 3). On a more detailed scale, we found that this measure differs strongly across Leipzig (Fig. 3), with high percentages of the population living with below-average ND in eastern districts, and low percentages along the floodplain and the fringe. We discuss how this relates to land use and socioeconomic patterns. Many relationships that have been found elsewhere were also demonstrated in Leipzig. In particular, the similarity to North American cities was surprising because there are great differences in lifestyle, urban density, and housing types. The fact that areas with high and low ND appeared both in the city and on its fringe shows that a simple rural-urban gradient does not apply to Leipzig, as it does in the case of Quebec, Canada; Rennes, France (Clergeau et al. 1998); and California, USA (Blair 1999).

Land use

Looking at underlying patterns of land use, there are clear correlations between a low percentage of people living in below-average ND and natural or semi-natural land-use types: forest, grassland, rivers and channels, and lakes. These land-use types were previously shown to be correlated with species richness (Clergeau et al. 1998, Melles et al. 2003, Blair 2004, MacGregor-Fors 2008). Railway areas, which are abundant throughout the city, do not enrich ND. Two housing types had weak correlations: residents of prefabricated multistory housing estates are more likely to experience below-average ND than are residents of villas. Villas are usually situated in districts such as Südvorstadt or Gohlis. They have a much higher quantity and higher quality of urban green. This is because most buildings and related house gardens, street trees, and neighborhood green structures date back more than 50 years. Additionally, they are located close to major park areas of the floodplains. In contrast, prefabricated housing estates were mainly built in the 1970s and 1980s; correspondingly, urban green in such districts is mostly very young and intensively maintained. These results are supported by Gutte and Goldberg (1986), who compared plant species richness of different parts of Leipzig. They found a much lower number of species for a prefabricated housing estate neighborhood (139 species) than for a villa quarter (212 species).

Surprisingly, there were no significant correlations between diversity and the presence of sports and recreation areas, parks, and allotments. This indicates that urban green is no guarantee for high bird diversity. This is supported by a study of bird diversity in allotments in Leipzig, which showed that allotments are structurally homogeneous throughout the city and only host common synanthropic species (Müller 2007).

Socioeconomic indicators

The results derived from socioeconomic data confirm some of the abovementioned findings from other studies and allow additional conclusions. Densely populated areas had low bird diversity, which supports findings by Tratalos et al. (2007*a*) for the United Kingdom and by Turner et al. (2004) for cities in North America, Europe, and Japan. In addition, Hadidian et al. (1997) found the lowest total estimated species richness in commercial areas within Washington, D.C.

Households of higher income groups tend to live within neighborhoods that exhibit higher bird diversity such as the Wilhelminian period districts in the western and southern parts of the city. By comparison, municipal districts with a high share of low-income households and a high percentage of unemployment more often show a high percentage of population living with below-average ND. These findings are in accordance with those of Melles (2005), who found that wealthier neighborhoods in Vancouver, Canada, have more native species. Hope et al. (2003) reports similar results for plant genera, and Kinzig et al. (2005) for birds and plants in Phoenix, Arizona, USA. The income effect, or “luxury effect” (Hope et al. 2003), is most likely a combination of housing choice and design. The wealthiest municipal districts in Leipzig, i.e., Gohlis and Waldstraenviertel, are located along the forests and parks of the floodplain. They have a higher

Table 3. The percentage of human population in neighborhoods with below-average neighborhood bird diversity (ND).

City	Human population in neighborhoods with below-average ND (%)
Western Berlin, Germany†	82
Eastern Berlin, Germany†	65
Chiba City, Japan†	53
Florence, Italy†	77
Tucson, Arizona, USA†	71
Washington, D.C., USA†	56
Leipzig, Germany	66

†Values from Turner et al. (2004).

quality of green, with more, older greenery and gardens compared to the rather low-income districts in the eastern part of Leipzig such as Volkmarsdorf and Neustadt-Neuschönefeld or districts with prefabricated housing estates (Grünau). MacGregor-Fors (2008) also showed significant positive correlations between bird species richness and older garden trees. Grove and Burch (1997), Pauleit et al. (2005), and Tratalos et al. (2007*b*) found more gardens and higher tree and shrub cover in areas with higher socioeconomic status. In the case of Indianapolis, Indiana, USA, Heynen (2003) provided evidence for the unequal distribution of urban trees in relation to income: the upper to middle class are favored, whereas the lower class is environmentally disadvantaged. In the case of Leipzig, it appears that a lower social status increases the chance of living in a neighborhood with below-average ND.

The potential to experience nature on a regular basis is not only determined by social status. A person's lifestyle also plays an important role. Generally speaking, not all inhabitants of a city are restricted to only using natural green space within a radius of 300 to 900 m around the home, a distance that governments and municipalities recommend (Handley et al. 2003, Harnik and Simms 2004, Hutter et al. 2004). However, financial well-being increases lifestyle choices and mobility in general, whereas poverty decreases both (Kinzig et al. 2005). Additionally, children are much less mobile than adults, but the availability of green space is of great importance for them while growing up (Heuser 2007) because attitudes toward nature conservation are often influenced by childhood experiences (e.g., Chawla 1998).

It might be disputed whether something as complex and subjective as the possibility of experiencing nature can be measured. We used the average ND as a threshold. Turner et al. (2004) call ND a conservative baseline, but it is obviously very case sensitive. Comparing the cities studied by Turner et al. (2004), only Florence has a higher average ND (50 species) than Leipzig (47 species). Berlin, a city located very close to Leipzig, has an average ND of approximately 23 species. This means that species-poor neighborhoods in Leipzig could be species-rich neighborhoods in Berlin. However, different ecosystems that are equally natural can have very different numbers of species; this explains the highest average ND for Florence, which is located in the species-rich Mediterranean. In addition, van Kamp et al. (2003:11) examined the literature on environmental quality and human well-being and conclude that the "judgment about environmental quality is always restricted to a geographical area."

However, they also state that the definition of living area is very subjective and dependent on lifestyle and mobility. Hence, people in municipal districts with low ND might not actually feel deprived if they are immobile. In any case, a local definition of diversity is necessary, and a direct comparison to average ND from different cities is problematic.

CONCLUSIONS

Even though Leipzig is a densely built, central European city, the experience of high ND and little domesticated nature is possible. However, the neighborhood diversity indicator showed that there are patterns of inequality. To make nature experiences possible for all residents and to avoid and minimize “environmental injustice” (Low and Gleeson 1998 cited in Heynen 2003), more effort should be made in urban planning to enhance biodiversity, especially in economically poorer areas. These areas often have little and low-quality green space, and most inhabitants likely have fewer resources to spend on travel. ND is therefore a useful indicator for finding areas most in need of enhancement.

In the case of Leipzig, changes in land use caused by urban decline, recent renewal, and restructuring offer the chance to create new habitats and enhance the quality of life of many people by developing green spaces in districts where they were formerly lacking (Stadt Leipzig 2007). Approximately 5–7% of the city is wasteland, holding great potential for the development of green space. However, to gain acceptance from local residents, it would have to be carefully designed (Mathey and Rink 2010). The effectiveness of specific measures already taken in Leipzig is yet to be shown. Great effort should also be placed on preserving existing natural green spaces from development.

These efforts are far altruistic if one considers the benefits that humans receive from green spaces, for example, climate mitigation, attractive scenery, and health benefits (Ulrich 1984). Recently, Mitchell and Popham (2008) showed that exposure to high-quality green space can actually mitigate socioeconomically induced health inequalities. Additionally, people are more likely to take action to conserve biodiversity if they have direct contact with nature. The benefits and the potential to interact should be available for all residents.

Responses to this article can be read online at: http://www.ecologyandsociety.org/vol14/iss2/art31/responses/

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Appendix 1. A correlation analysis between the Shannon Diversity Index and land use as well as socioeconomic parameters for Leipzig, Germany.

Please click here to download file 'appendix1.pdf'.

Mehnert, D., Haase, D., Lausch, A., Auhagen, A., Dormann, C.F., Seppelt, R., 2005. Bewertung der Habitateignung von Stadtstrukturen unter besonderer Berücksichtigung von Grün- und Brachflächen am Beispiel der Stadt Leipzig. Naturschutz und Landschaftsplanung 2, 54-64.

Bewertung der Habitateignung von Stadtstrukturen

Unter besonderer Berücksichtigung von Grün- und Brachflächen am Beispiel der Stadt Leipzig

Von Dorothee Mehnert, Dagmar Haase, Angela Lausch, Axel Auhagen, Carsten F. Dormann und Ralf Seppelt

Zusammenfassung

Die Berücksichtigung von tierökologischen Fragestellungen in der landschaftsplanerischen Praxis ist häufig mit Schwierigkeiten verbunden. Im Rahmen von faunistisch-tierökologischen Beiträgen in der Landschaftsplanung (z.B. Landschaftsplan, Eingriffsregelung) sind oftmals Defizite bezüglich Erfassung sowie Bestandsanalyse und -bewertung erkennbar (vgl. Brinkmann 1998). Habitatmodelle ermöglichen die Formalisierung der Beziehung zwischen Tierarten und ihrer Umwelt. Es existieren zahlreiche Arbeiten zur Modellierung von Habitaten als Grundlage für den Artenschutz in der freien Landschaft, wohingegen wenige Arbeiten diese Thematik im urbanen Raum behandeln.

Die vorliegende Untersuchung zeigt eine Methode zur Bewertung von Stadtstrukturen basierend auf der Habitatmodellierung, welche faunistische Vorkommensdaten sowie allgemein verfügbare abiotische und biotische Daten nutzt. Mit Methoden der Geoinformation und angewandter Statistik (*ENFA – Ecological Niche Factor Analysis*) werden die Stadtstrukturen hinsichtlich der Habitateignung für die zwei ausgewählten Zielarten Grünspecht (*Picus viridis*) und Dorngrasmücke (*Sylvia communis*) bewertet. Die ENFA ermöglicht sowohl die Berechnung der Habitateignung (*HSI – Habitat-Suitabiltiy-Index*) als auch die Erstellung von Habitateignungskarten (*HSI-Karten*). Die ermittelten HSI-Werte dienen als Grundlage für die Bewertung der Stadtstrukturen und unterstützen so städtische Planungsentscheidungen in der Stadtentwicklungs- und Landschaftsplanung.

Summary

Evaluating the Habitat Suitability of Urban Structures – Particular consideration of green-space and fallow areas; the example of the city of Leipzig

The consideration of zoo-ecological questions in practical landscape planning frequently includes difficulties. The establishment of faunistic zoo-ecological contributions to landscape planning (e.g. landscape plan, impact regulation) often reveals deficits regarding inventory as well as analysis and evaluation. Habitat models allow to formalise the relationship between animal species and their environment. There have been numerous studies on habitat modelling as base for species protection in the open landscape, but only few studies have investigated this field in the urban environment.

The study introduces an approach to evaluate urban structures on the basis of habitat modelling, applying data of faunistic surveys as well as generally available abiotic and biotic data. Using methods of geo-information and applied statistics (ENFA – Ecological Niche Factor Analysis) the urban structures are evaluated in terms of their habitat suitability for the two selected target species Green Woodpecker (*Picus viridis*) and Common Whitethroat (*Sylvia communis*). The ENFA allows both the calculation of the habitat suitability (HSI – Habitat-Suitability-Index) and the production of maps of habitat suitability (HSI maps). The identified HSI-values serve as a base for the evaluation of urban structures and hence support local planning decisions in urban and landscape development planning.

1 Einleitung

Entgegen der weit verbreiteten Annahme, dass Städte an sich lebensfeindlich seien und nur einer unterdurchschnittlichen Anzahl von wildlebenden Pflanzen und Tieren Lebensraum böten, ist die Artenzahl in Städten mit mehr als 50 000 Einwohnern größer als im Umland (Haeupler 1974, zitiert nach Sukopp 2003).

Ursachen für die hohen Artenzahlen in Städten sind ökologisch und historisch bedingt (Sukopp 2003). Die starke Heterogenität des Lebensraums Stadt entsteht aus verschiedenen Siedlungsstrukturen sowie einer Vielzahl von Flächennutzungen und Kleinstandorten sowie vielen ökologischen Nischen. Die Verbreitung der Arten und Lebensgemeinschaften in der Stadt wird hauptsächlich durch die zonale Ausbreitung der Flächennutzungen und der Standortfaktoren geprägt (Kowarik 1992). Städte sind ökologisch vielfältig im Vergleich zu dem land- und forstwirtschaftlich geprägten Umland. Beispielsweise sind Brachen im Allgemeinen artenreicher als Biotope der Land- und Forstwirtschaft (Cools 1998, Mathey et al. 2003).

Historisch sind Städte Ausgangspunkt der Ausbreitung von Arten, die nur infolge direkter oder indirekter Mithilfe des Menschen im Laufe der Zeit in die Städte gelangt sind. Biologisch ist das ausschlaggebende Kennzeichen der Stadt der hohe Anteil an nichteinheimischen Arten. Kowarik (1995) geht von einer größeren Invasion und damit Beeinflussung einheimischer Floren bzw. Faunen seit dem Ende des 18. Jahrhunderts aus. Cools (1998) beschreibt in ihrer Arbeit das Problem, dass die Artenvielfalt zunehmend verloren geht und eher die euryöken Arten, mit geringeren Ansprüchen an ihren Lebensraum, eine Überlebenschance in Städten haben.

Im Mittelpunkt städtebaulicher Planung steht die Lebensqualität des Menschen. Zur (Er-)Lebensqualität in der Stadt trägt jedoch auch eine artenreiche Flora und Fauna bei. Natur wird aus diesem und aus vielen anderen guten Gründen (Auhagen & Sukopp 1983) seit Jahrzehnten auch in der Stadt geschützt, gepflegt und entwickelt. Naturschutz und Landschaftspflege sind daher durch das Bundesnaturschutzgesetz und das Baugesetzbuch auch in Städten eine Pflichtaufgabe der Stadtentwicklung geworden.

Eine nachhaltige Stadtentwicklung lässt sich nur durch die Integration des Naturschutzes und der Landschaftspflege umsetzen (Kirsch-Stracke 1990). Dabei ist die Arten- und Biotopvielfalt ein Indikator für den Zustand abiotischer Faktoren und einer ökologisch orientierten Stadtentwicklung zugleich. Aufgrund der Multifunktionalität von Stadtlandschaften ist es notwendig, verschiedene Schutzziele abzuwägen, da hier begrenzte Flächen- und auch finanzielle Ressourcen mannigfaltigen Ansprüchen an Raum und Landschaft gegenüberstehen (Weiland 2002).

Die Zielstellungen des urbanen Naturschutzes unterscheiden sich von denen im ländlichen Raum dadurch, dass nur im ländlichen Raum Arten, die ahemerobe bis oligohemerobe Lebensräume benötigen, erhalten werden können, während in der Stadt eher Arten der meso- bis polyhemeroben Lebensräume im Mittelpunkt des Naturschutz-Interesses stehen. Während im Umland Natur oft vor den Menschen geschützt wird, dient Naturschutz in der Stadt vor allem dazu, den Stadtbewohnern Zugang zu und tägliche Erfahrung mit wildlebenden Arten zu ermöglichen. Dabei sind effektive Lösungen gefragt, die es ermöglichen, Stadtentwicklungsprozesse sowie den Arten- und Biotopschutz adaptiv zu gestalten. Die zu entwickelnden bzw. zu schützenden abiotischen und biotischen Ressourcen müssen auf verschiedenen räumlichen Ebenen (Skalen) einer Stadt bewertet werden.

Die Bewertung von Stadtstrukturen anhand von floristisch-vegetationskundlichen Untersuchungen allein ist nicht zielführend, da Tierarten bzw. -gesellschaften nicht an die gleichen Raumstrukturen gebunden sind (JEDICKE 1996). Tiergesellschaften sind auf unterschiedliche Biotoptypen und Habitatstrukturen in Abhängigkeit von der Jahreszeit und den Entwicklungsphasen angewiesen (JEDICKE 1996). Deshalb sind faunistische Daten in landschaftsökologische Analysen und Bewertungen in jedem Falle einzubeziehen.

Faunistische Daten liegen häufig als Punktdaten bzw. als Rasterkartierungen vor. Auf einer derartigen Grundlage ist es oftmals nur sehr schwer möglich, den Gesamtzusammenhang der Bestandssituation der Arten zu erfassen. Dieses trifft auf einen urbanen Raum ebenso zu wie auf den ländlichen Raum.

Bei der Bewertung von Eingriffen in die Umwelt ist es jedoch wichtig, sowohl das gesamte Stadtgebiet als auch Einzelstrukturen (z.B. Grünflächen, Brachflächen, urbane Forsten) als Lebensraum für charakteristische und/oder gefährdete Tierarten zu berücksichtigen.

In der derzeitigen Planungspraxis werden verschiedene Methoden zur Habitateignungsbewertung angewandt, wie z.B. Entscheidungsbäume, planerisch-argumentative Verfahren (vgl. BASTIAN & SCHREIBER 1999). Mit Hilfe von Habitatmodellen kann jedoch eine komplexere Formalisierung der Beziehung zwischen verschiedenen Umwelteigenschaften und der raumzeitlichen Verteilung von Organismen (SCHRÖDER & REINEKING 2004) erreicht werden. Zahlreiche Arbeiten thematisieren die Modellierung von Habitaten als Grundlage für den Artenschutz in der freien Landschaft (u.a. HIRZEL 2001, REUTTER et al. 2003, SATTLER 2003, SCHRÖDER 2000a). Es gibt jedoch bisher wenige Arbeiten (z.B. WRIGHT & FIELDING 2002), die sich mit dieser Thematik im urbanen Raum auseinandersetzen. Es stellt sich weiterhin die Frage, ob die Kenntnisse der Habitatpräferenzen uneingeschränkt auf in der Stadt vorkommende Arten anzuwenden sind (vgl. WRIGHT & FIELDING 2002).

2 Zielstellung der Untersuchung

Der Fokus der hier vorgestellten Arbeit liegt auf der Erarbeitung einer flächendeckenden Bewertungsmethode, die tierökologisch-faunistische Schutzziele in urbanen Landschaften mittels einer effektiven und planungsrelevanten Methode berücksichtigt. Die Untersuchung zielt auf die Bewertung von Stadtstrukturen unter besonderer Berücksichtigung der städtischen Grün- und Brachflächen hinsichtlich ihrer Eignung als Habitatstrukturen für den Grünspecht (*Picus viridis*) und die Dorngrasmücke (*Sylvia communis*).

Die Bewertungsmethode soll eine übersichtliche und auf allgemein verfügbaren Daten beruhende Vorgehensweise darstellen, welche auch in anderen urbanen Räume nachvollzogen werden kann (MEHNERT 2004). Um eine Bewertung vornehmen zu können, wird eine räumlich explizite Habitatmodellierung für beide Vogelarten unter Verwendung von Geographischen Informationssystemen (GIS) und des statistischen Habitatmodells ENFA (*Ecological Niche Factor Analysis*) im Programm Biomapper 2.0 (HIRZEL et al. 2001) durchgeführt. Die aufgestellten Hypothesen zu den Habitatpräferenzen der Zielarten werden mit der ENFA überprüft und Habitateignungskarten mit den entsprechenden Habitateignungswerten erstellt. Die ermittelten Habitateignungswerte (HSI-Werte, *Habitat Suitability Index*) dienen als Grundlage für die Bewertung der Stadtstrukturen bzw. Stadtstrukturtypen. Darüber hinaus erfolgt eine Auswertung bezüglich der mittleren, flächengewichteten HSI-Werte für alle Stadtstrukturen. Anhand der Grünfläche des Clara-Zetkin-Parks werden verschiedene Methoden der Übertragung des rasterbasierten Datensatzes der Habitateignungskarten auf die Flächen der Stadtstrukturen demonstriert. Die Methode wird hinsichtlich ihrer Validität und Aussagekraft bewertet, und es werden Anwendungsmöglichkeiten in der zukünftigen Praxis der Landschaftsplanung im urbanen Raum aufgezeigt.

Exemplarisch zeigt die Analyse der ermittelten HSI-Werte eine planungsrelevante Anwendung, indem geprüft wird, inwieweit die nach planerisch-argumentativen Ansätzen ermittelten Vorrangflächen für das Projekt „Regionales Handlungskonzept Grüner Ring der Stadt Leipzig" mit der Zielstellung zur Förderung der Habitateignung für die ausgewählten Zielarten übereinstimmt.

3 Das Untersuchungsgebiet – die Stadt Leipzig

Als Untersuchungsgebiet wurde die Großstadt Leipzig in Sachsen ausgewählt. Die Stadt Leipzig umfasst eine Fläche von 298 km^2 und ist mit einer Einwohnerzahl von 494 795 Personen und einer Bevölkerungsdichte von 1663 Einwohnern/km^2 (Stand 31.12.2002) die am dichtesten besiedelte Stadt in den neuen Bundesländern (BREUSTE 1996, Statistisches Landesamt 2003; Gebietsstand 01.01.2003). Leipzig ist eine sehr kompakte Stadt mit einem hohen Anteil an gründerzeitlicher Bausubstanz (Blockbebauung) sowie DDR-typischen Großwohnsiedlungen (HAASE & MAGNUCKI 2004). Demnach ist der Naturraum als stark technisch verändert zu klassifizieren (RICHTER 1995, Stadt Leipzig 2001). Darüber hinaus ist Leipzig Teil des Naturraumes Leipziger Land, im südlichen Bereich der naturräumlich vielgestaltigen Leipziger Tieflandsbucht. Charakteristisch für die Stadt Leipzig ist das geringe Relief der Pleistozänplatte zwischen 90 und 170 m üb. NN, die geringmächtige Sandlössdecke, eine signifikante Zunahme der Niederschläge von Nordwest nach Südost (560 mm auf 620 mm) sowie die Heterogenität der urbanen Bodendecke. Daher ergibt sich eine trotz des geringen Reliefs vorhandene Vielfältigkeit der biotischen Naturausstattung und landschaftliche Differenziertheit (BERNHARDT et al. 1986, BREUSTE 1996).

Die Stadt Leipzig verfügt auf ihrem Territorium neben Flächen mit hohem Versiegelungsgrad auch über durch überwiegend Grün- und Brachflächen geprägte Bereiche in der Stadt. Als Besonderheit der Stadt Leipzig ist die Auenlandschaft (z.B. Leipziger Auenwälder, zählen zu den artenreichsten Europas) der Weißen Elster, Pleiße und Parthe mit einem hohen Artenreichtum zu nennen (StUFA Leipzig 1995, Stadt Leipzig 2001). Sie ist ein Reliktvorkommen eines Auwaldes und damit ein stadt-untypischer Lebensraum. In England werden solche Relikte früher Kultur- und Naturlandschaften in Städten treffend als „*encapsulated countryside*" bezeichnet.

4 Methodischer Ansatz

4.1 Datengrundlagen

Als Datengrundlage für die Habitateignungsbewertung standen sowohl abiotische als auch biotische Geo-Daten sowie die Brutvogelkartierung (Rasterkartierung 500 x 500 m; StUFA Leipzig 1995) der Stadt und des ehemaligen Landkreises Leipzig zur Verfügung. Eine wesentliche Datengrundlage bildete die Stadtbiotopkartierung der Stadt Leipzig (2001), ergänzt durch Daten zum Straßenbaumbestand. Diese wurde durch Daten des Waldalters, des Klimas, der Bodenart sowie der Bodenfeuchte (standortskundliche Feuchtestufe ermittelt aus Bodenart und Grundwasserflurabstand) ergänzt. Neben diesen Informationen kamen Frequenz (in Prozent, wird von einer ausgewählten Biotopklasse, ausgehend von der Mittelzelle, innerhalb des Aktionsradius der zu untersuchenden Zielart berechnet) und Distanz von ausgewählten Biotoptypen sowie ausgewählte Landschaftsstrukturmaße im Modell zur Anwendung. Ebenso wurden die potentiellen Ansitzwarten der Dorngrasmücke (genutzte Daten: Reliefdaten und Stadtbiotopkartierung [Biotophöhen]) als Parameter durch eine Sichtbarkeitsanalyse quantifiziert; dieses ist jedoch nicht Gegenstand der weiteren Diskussion.

4.2 Auswahl relevanter Stadtstrukturen

Warum wurden Stadtstrukturen als zu bewertende Einheiten gewählt? Stadtstrukturen sind abgrenzbare Raumeinheiten urbaner Landschaften mit vergleichbaren Umweltbedingungen und Raummerkmalen (verändert nach BÖHM et al. 2001). Die Zuordnung zu einem Stadtstrukturtyp erfolgte auf der Grundlage der Stadtbiotopkartierung, indem Biotope mit Bedeutung für die Landschaftsplanung zu einem Stadtstrukturtyp zusammengefasst wurden (Abb. 1). Die Auswahl der besonders untersuchten Stadtstrukturen ist abhängig von methodischen und inhaltlichen Gesichtspunkten. Methodisch wurden aufgrund der ungenügenden Datenlage Strukturtypen wie „Wohnbauflächen und gemischte Bauflächen" oder „Industrie- und Gewerbeflächen, Ver- und Entsorgungsanla-

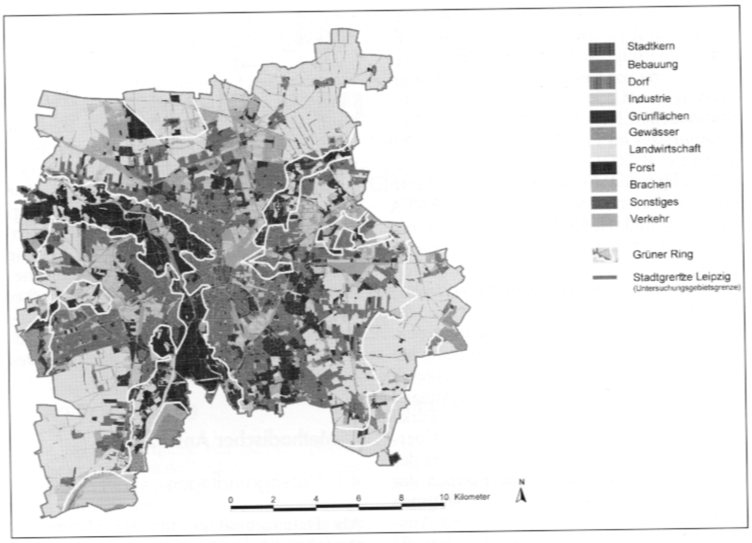

Abb. 1: Flächennutzung und Stadtstruktur in Leipzig sowie die Ausdehnung des Grünen Rings.

gen", die ebenfalls von erheblicher Bedeutung für die Fauna (z.B. Gebäudebrüter) sind, nicht näher untersucht. Die erforderlichen Daten zur Ausstattung und Beschaffenheit von Gebäuden sind nur durch aufwändige Kartierarbeit zu ermitteln.

Inhaltlich ist die Auswahl begründet durch die Orientierung an den Schwerpunkten und Zielen des Naturschutzes und der Landschaftspflege in der Stadt Leipzig. Die ausgewählten Stadtstrukturen Grün- und Brachflächen sind Zentren der Ansiedlung von Tieren (Klausnitzer 1993) und erfüllen sowohl methodisch als auch inhaltlich die Anforderungen der zu untersuchenden Fragestellung.

4.3 Auswahl der Zielarten

Eine vollständige Erfassung der Arten in einem Untersuchungsraum ist nie möglich. Demzufolge wird häufig das Zielartenkonzept angewandt, indem diese Arten eine Stellvertreterposition einnehmen (u.a. Brinkmann 1998, Plachter 1980 und 1991, Vogel et al. 1996). Zielarten dienen der Festsetzung und Kontrolle von Naturschutzzielen (Vogel et al. 1996). Die Bewertung von Landnutzungen ist über die Analyse biotoptypischer Arten möglich. Dabei unterscheidet sich die Herangehensweise des faunistischen Arten- und Biotopschutzes vom floristisch-vegetationskundlichen Naturschutz (Jedicke 1996).

Vögel eignen sich nach Reck (1992) und Jedicke (1996) zur Planungsindikation für mittelgroße bis sehr große Biotoptypen bzw. Funktionseinheiten jeglicher Art sowie Flächen als Einheiten im überregionalen Habitat-/Biotopverbund.

Die Untersuchung wurde in Abstimmung mit dem Landschaftsplan der Stadt Leipzig für den Grünspecht (*Picus viridis*) als Zielart für Grünflächen sowie die Dorngrasmücke (*Sylvia communis*) als Zielart für Brachflächen in der Stadt durchgeführt. Die Auswahl begründet sich folgendermaßen:

► Das erste wichtige Auswahlkriterium stellte die Datengrundlage der Vorkommensdaten für die statistische Untersuchung dar. Mindestens 20 bis 30 Vorkommenspunkte sind für die Berechnung der Habitateignung mit dem Programm Biomapper (Hirzel et al. 2001) notwendig. Die Vorkommenspunkte sollten außerdem weitgehend gleichmäßig in dem Untersuchungsgebiet Stadt Leipzig verteilt sein (keine sporadischen Vorkommen).

► Das zweite wichtige Kriterium betraf die Bindung der Arten an die zu untersuchende Stadtstruktur (Abb. 1) und somit das potentielle Vorkommen der Art.

Die Stenökie der Arten spielt dahingehend eine Rolle, dass die Vorkommensdaten eine gewisse Eignung aufweisen müssen. Viele Vorkommenspunkte bzw. flächendeckende Vorkommen ermöglichen keine Differenzierung der Lebensraumansprüche. Sind allerdings zu wenige Vorkommen vorhanden (z.B. sehr hoch gefährdete Arten), ist die Grundvoraussetzung für die Modellierung mit Biomapper nicht erfüllt, so dass keine aussagekräftigen Ergebnisse erzielt werden können. Die Zielartenwahl war daher primär an die Datenverfügbarkeit (Kartierungsdaten) bzw. statistische Auswertbarkeit gekoppelt („regionale Stenökie"). Dennoch lässt sich eine deutliche (Grünspecht) oder eingeschränkte (Dorngrasmücke) regionale Stenökie (qualitativ) aus den Habitatpräferenzen der Arten im Land Sachsen herleiten (vgl. dazu Steffens et al. 1998). Der Grünspecht gehört zudem zu den „populärsten Arten" in Leipzig, mit dessen Lebensraumverbesserung/-verschlechterung man auch das Interesse der Bevölkerung am städtischen Naturschutz erreichen kann.

Die gewählten Zielarten sind in Beziehung zu den gewählten Strukturen (Grün-, Brachflächen) zu setzen; beide Arten sind nicht wirklich „urban", aber für Großstädte (Leipzig, Berlin, München) typisch.

4.4 Funktionsbezogene Bewertung – Habitatmodellierung mit dem Programm Biomapper

Die Grundlage für die Durchführung der Modellierung von potentiellen Lebensräumen bilden Hypothesen zu den Habitatpräferenzen der Arten. Die Quantifizierung und Umsetzung der Hypothesen zu abiotischen und biotischen Habitatfaktoren in Parameter erfolgte durch die Anwendung Geographischer Informationssysteme (ArcView, Arc Info, Erdas Imagine) sowie dem Raummuster-Analyseprogramm Fragstats 3.3 (McGarigal et al. 2002). Mit Fragstats 3.3 wurden ausgewählter Strukturmaße (z.B. *edge density, proximity index, mean patch size, largest patch index*) aus den Biotoptypen berechnet. Als Datengrundlage standen sowohl raumbezogene als auch Vorkommens- bzw. Präsenzdaten der Art (Hirzel et al. 2001) zur Verfügung. Ein Beispiel für die Ableitung der Parameter aus den Habitatpräferenzen zeigt Tab. 1.

Mit der ENFA werden die ermittelten Parameter auf einen statistischen Zusammenhang zum Vorkommen der Arten untersucht. Aus diesen Ergebnissen werden räumlich explizite Habitateignungskarten erstellt. Zur Berechnung der Habitateignung wurde die ENFA als Analysewerkzeug des Programms Biomapper 2.0 (Hirzel et al. 2001, http://www.unil.ch/Biomapper) verwendet.

Gerade die genaue Charakterisierung des Zusammenhangs von Raumstruktur und Vorkommen ist für die Modellierung von Habitatpräferenzen von großer Bedeutung (Lausch 2004). Daher ist die kartographi-

Tab. 1: Beispiel für die Ableitung der Parameter aus den Habitatpräferenzen.

Landschaftsstruktur (LSM und Distanzmaße)		
Hypothesen	**Parameter**	**Begründung/Erläuterung**
Die Dorngrasmücke bevorzugt Gebiete, deren gehölzbestandenen Flächen nicht weit voneinander entfernt sind. **Biotoptypen:** Feldgehölze, Lineare Gehölzstrukturen, Ruderale Kraut- und Staudenfluren, Gehölzbestimmte Brachen	Proximity-Index [ohne Einheit] Nachbarschaftsmaß/ Klasse	Aufgrund der Bindung an Gehölzbestände ist zu vermuten, dass größere und näher beeinander liegende Patches von Biotopen mit strauchigen Pflanzen und Gebüschen die Chance des Vorkommens der Dorngrasmücke erhöhen.

sche Konkretisierung und Visualisierung bzw. GIS-basierte Umsetzung der Ergebnisse als ein Vorteil der Software gegenüber *non spatial models* (NSM) zu sehen.

Das Hutchinson's Konzept der ökologischen Nische („*ecological niche*") (HUTCHINSON 1957) ist das methodische Grundprinzip der ENFA. Die Verbreitung und Häufigkeit von Organismen ist nicht nur an einen einzelnen Umweltfaktor gebunden, sondern der Organismus besitzt Toleranzen gegenüber einer Vielzahl von Umweltfaktoren. Das Konzept der ökologischen Nische betrachtet diesen Toleranzbereich gegenüber der Vielzahl an Parametern. Der Nischenraum ist ein n-dimensionales Gebilde aus verschiedenen Umweltfaktoren (z.B. Temperatur, Nahrung, Raum, Zeit). HUTCHINSON (1957) unterscheidet zwischen einer „fundamentalen" und einer „realisierten" Nische. Dabei ist die fundamentale Nische jener Bereich, in dem ein Organismus ohne Einwirkung biotischer Faktoren vorkommen würde. Die realisierte Nische beschreibt nur einen Teilbereich davon, der dem Organismus unter Einbeziehung der biotischen Faktoren verbleibt (BEGON et al. 1998, vgl. FISCHER 2003).

Die Grundannahme besteht somit darin, dass das Vorkommen von Arten auf einen Bereich innerhalb eines multidimensionalen Raumes mit spezifischen ökologischen Eigenschaften bzw. Parametern beschränkt ist (HIRZEL et al. 2002). Somit unterscheidet sich die Verteilung der ökologischen Parameter (z.B. Bodenart, Vorkommen von Wald) der Zielart von der Gesamtlandschaft hinsichtlich des Mittelwertes. Ebenso besteht ein Unterschied bezüglich der Standardabweichung.

Die Marginalität (M) gibt an, wie sehr sich das mittlere Habitat der untersuchten Arten von der Gesamtlandschaft (hier: Stadtlandschaft) unterscheidet, und wird definiert als die absolute Differenz zwischen globalem (= gesamträumlichem) Mittelwert und Mittelwert der Zielart geteilt durch 1,96 und die globale Standardabweichung. Die weiteren Faktoren repräsentieren das Maß an Spezialisierung, die als das Verhältnis der Standardabweichung der gesamträumlichen Verteilung zu der der Zielart definiert wird (HIRZEL et al. 2002).

Die Habitateignungskarten werden anhand der voneinander unabhängigen Faktoren berechnet, wobei die Eignung als Wahrscheinlichkeit, dass eine Zelle von einer Art besiedelt ist, definiert werden kann. Der größte Anteil an erklärender Varianz und Information über die Spezialisierung der Art enthalten die ersten Faktoren (Marginalität und erste Spezialisierungsfaktoren). Dabei richtet sich die Auswahl der voneinander unabhängigen Faktoren zur Berechnung der Habitateignungskarten nach der „*MacArthurs's Broken-Stick-Distribution*" (HIRZEL et al. 2002).

4.5 Raumbewertung

Im Gegensatz zu den in der Planungspraxis verbreiteten planerisch-argumentativen Ableitungen des Wertes der Strukturen dienen die ermittelten HSI-Werte als quantitative Grundlage für die Bewertung der Stadtstrukturen und ermöglichen die Herstellung des räumlichen Bezuges. Ein hoher HSI-Wert bedeutet, dass dieses Habitat von der Art präferiert wird. Die Werte werden z.B. durch Mittelwertbildung auf die Geometrien der Stadtbiotopkartierung übertragen.

Das Ergebnis sind Karten mit den entsprechenden klassifizierten HSI-Werten und daraus abgeleiteten verbalen Werten der Habitateignung, bezogen auf die verschiedenen Stadtstrukturen. Dabei kam eine fünfstufige Bewertungsskala zur Anwendung: von HSI = 0 – 20 = sehr geringer Wert bis HSI = 81 – 100 = sehr hoher Wert (MEHNERT 2004).

4.6 Modellvalidierung

Die Validierung der erzielten Ergebnisse erfolgte durch die zehnfache Kreuzvalidierung (*Jack-Knife-Cross-Validation*; FIELDING & BELL 1997). Bei der Analyse werden die Vorkommenspunkte zufällig in sich gegenseitig ausschließende und gleichgroße Teilmengen aufgesplittet. Ein Teil wird benötigt, um das Modell zu kalibrieren, der Rest, um es zu evaluieren. Dieser Prozess wird zehnmal wiederholt und jedes Mal ein anderer Teil ausgelassen. Die Berechnung liefert einen „Pseudowert"; die Mittelung alle Werte ergibt das Jacknife-Resultat. Der AVI (*Absolute Validation Index*) dient zur absoluten Bewertung der Modellqualität. Dieser Index ergibt sich aus dem Anteil der Validierungspunkte, die innerhalb des vorhergesagten Kernhabitats vorkommen, und ist demnach ein Indikator für den Anteil der bewerteten Zellen (in ausgelassenem Teil) mit einem Wert > 50.

Für den Grünspecht wurde ein Anteil von 70,9 % der bewerteten Zellen mit einem Wert von > 50 ermittelt. Für die Dorngrasmücke wurde in 67,6 % der Fälle ein Vorkommen (alle Raster mit HSI-Wert > 50) vorhergesagt. Möglicherweise ist der Grund für dieses Modellergebnis, dass der Grünspecht eher eine stenöke Art ist und somit eine geringere Toleranz zum Optimalhabitat aufweist.

5 Ergebnisse der Habitatmodellierung

5.1 Hypothesen und Habitateignung

Grünspecht (*Picus viridis*)
In das Modell des Grünspechts wurden 44 Parameter integriert, wobei die Anzahl der berechneten Faktoren der Anzahl der Parameter entspricht. Demnach konnten 25 der gestellten Hypothesen angenommen werden, wohingegen 19 abgelehnt wurden.

Als Ergebnisse des Modells erhält man die Korrelationen zwischen Vorkommen und Umweltbedingungen. So wird zwar z.B. eine Korrelation zwischen Niederschlagsverteilung und Vorkommen der Art feststellt, was aber nicht bedeutet, dass dieser Zusammenhang auch mit den ökologischen Bedingungen in Verbindung gesetzt werden kann. Es ist daher notwendig, die kausalen Zusammenhänge zwischen den Schlüsselfaktoren und dem vorhandenen Fachwissen zu den Habitatansprüchen der betrachteten Art zu überprüfen.

Wesentliche das Vorkommen der Art beeinflussende Parameter sind eine hohe Kantendichte von gehölzbestandenen Biotopen, naturnahen Wäldern, Grün- und Parkanlagen mit Baumbestand sowie Gewässern. Ebenso von Bedeutung sind der mittlere Näheindex und die mittlere Patchgröße von naturnahen Wäldern sowie das Vorkommen von lehmigen Böden sowie von Grün- und Parkanlagen mit Baumbestand (korrelierende Parameter – nicht in Tab. 2). Die bevorzugte Nähe von Feuchtgebieten wird deutlich, da die Wahrscheinlichkeit des Brutvorkommens mit einer geringen Distanz zwischen Flüssen und Altwässern steigt. Große, zusammenhängende Ackerflächen (niedriger Wert des größten Patchgröße-Indexes, niedriger Wert der Frequenz und der mittleren Patchgröße von Acker) dagegen werden vom Grünspecht eher gemieden. Möglicherweise im Zusammenhang mit der Nahrungssuche steht die Präferenz für eine hohe Frequenz von Grün- und Parkanlagen ohne Baumbestand. Für das Waldalter konnte in der vorliegenden Untersuchung mit den zur Verfügung stehenden Daten kein signifikanter Zusammenhang zum Brutvorkommen ermittelt werden. Ungleichaltrig gestufte Wälder allerdings korrelieren mit der Kantendichte von naturnahen Wäldern und fördern die Wahrscheinlichkeit des Brutvorkommens.

Grünspechte nutzen in Nordwest-Sachsen überwiegend Weichhölzer als Nistplatz (sonst auch Harthölzer, insbesondere Buche), diese kommen regelmäßig an Gewässern vor: Es besteht also maximal eine sekundäre Verknüpfung zwischen Grünspecht und Gewässer. Man kann somit ggf. den Parameter „Gewässer" als Indiz für Weichhölzer interpretieren, um so dem wesentlichen Kriterium „Habitatrequisite" Rechnung zu tragen.

Dorngrasmücke (*Sylvia communis*)
Von den insgesamt 45 aufgestellten Hypothesen zu den das Vorkommen der Dorngrasmücke beeinflussenden Parametern konnten 32 bestätigt werden, 13 Hypothesen mussten verworfen werden. Das Brutvorkommen der Dorngrasmücke wird maßgeblich durch die Distanz zwischen bebauten Bereichen und Durchgangsstraßen beeinflusst. Je größer diese ausfällt, desto geeigneter als Bruthabitat für die Dorngrasmücke ist die Fläche. Dagegen bieten eine geringe Distanz zwischen Bauern- und Gutshöfen sowie landwirtschaftlichen Großbetrieben ebenso wie ein hoher mittlerer Näheindex von gehölzbestimmten Brachen sowie ruderalen Kraut- und Staudenfluren gute Vorraussetzungen für die Brut. Auch eine hohe Frequenz von Laubholzforsten hat einen positiven Effekt auf das Vorkommen der Dorngrasmücke, wohingegen die Kantendichte von Grün- und Parkanlagen eher gering sein sollte.

Die Stadt Leipzig ist gekennzeichnet durch einen bemerkenswerten Gradienten des Niederschlages, wo sich die Regenschattenlage des Harzes in den Luv des Erzgebirges „verwandelt". Für einige Arten bildet

Tab. 2: Ergebnisse der ENFA-Analyse für den Grünspecht (*Picus viridis*). Die Zahlen geben die Marginalität der Variablen an; ein positiver Wert zeigt eine Bevorzugung eines hohen Wertes des Parameters an, ein negativer das Gegenteil. Die Marginalität (M) des Gesamtmodells beträgt 7 %. Grau unterlegte Parameter sind von signifikanter Wichtigkeit für den Grünspecht. Übereinstimmungen von erwarteten Habitatpräferenzen sind durch ein "ja" in der Hypothesenspalte angezeigt.

Parameter	M (7 %)	Hypothesen
Kantendichte von gehölzbestandenen Biotopen	0,36	ja
Kantendichte von Naturnahen Wäldern	0,28	ja
Frequenz von Grün- und Parkanlagen ohne Baumbestand	0,25	ja
Distanz zwischen Flüssen mit Uferbereich	−0,24	ja
Kantendichte von Grün- und Parkanlagen mit Baumbestand	0,24	ja
Kantendichte von Gewässern	0,24	ja
Distanz zwischen Altwässern	−0,23	ja
mittlere Patchgröße von Acker	−0,22	ja
Frequenz von Acker	−0,22	ja
Altersklasse von Wäldern 3	0,21	nein
größter Patchgröße-Index	−0,20	ja
Diversitätsmaß nach Shannon	0,18	ja
Frequenz von Villen mit parkartigen Gärten	0,18	ja
mittlere Sonnenscheindauer	−0,16	nein
Distanz zwischen Alleen (alt)	−0,14	ja
Distanz zwischen übrigen Straßen und Wegen	−0,14	nein
Distanz zwischen Teichen und Weihern	−0,14	ja
mittlere Jahrestemperatur	0,14	ja
Distanz zwischen Gräben und Bächen	−0,13	ja
Distanz zwischen Baumreihen (neu)	0,12	nein
Kantendichte von Laubholzforsten	0,11	ja
Frequenz von Kleingärten	0,11	ja
mittlerer Jahresniederschlag	−0,10	ja
Frequenz von Friedhöfen	0,10	ja
mittlerer Näheindex zu Feldgehölzen	−0,10	nein
Frequenz von sandigen Böden	0,09	ja
Oberflächentemperatur	−0,09	ja
Frequenz von Feldgehölzen	−0,08	nein
Distanz zwischen Alleen (neu)	−0,08	ja
Frequenz von Wiesen und Weiden	0,08	ja
Kantendichte von offenen Biotopen	−0,07	nein
Frequenz von ruderalen Kraut-und Staudenfluren	−0,07	nein
Frequenz von linearen Gehölzstrukturen (Hecken)	−0,07	nein
Distanz zwischen Baumreihen (alt)	0,06	nein
Distanz zwischen Durchgangsstraßen	−0,06	nein
mittlerer Näheindex zu linearen Gehölzstrukturen (Hecken)	−0,05	nein
standortskundlicher Feuchtegrad	−0,04	nein
Frequenz von Einzelhausbebauung	−0,03	nein
Distanz zwischen Gebäuden	−0,03	ja
Frequenz von Gehölzbestimmten Brachen	0,03	nein
Distanz zwischen Gehölzen (gesamt)	0,03	nein
Frequenz von Streuobstwiesen	−0,02	nein
Distanz zwischen Straßen (Autobahn, Schnellstraße, Bundesstraße)	0,02	nein
Distanz zwischen Nassabgrabungen, Kiesabbauen, gefluteten Tagebauen	−0,01	nein

daher das Stadtgebiet die Verbreitungsgrenze. Daher werden flächenhaft verfügbare Niederschlagsdaten immer mit in die Modellierung einbezogen – auch wenn nicht sicher zu belegen ist, dass die Niederschlagsverteilung im Bereich der Stadt Leipzig das Vorkommen primär beeinflusst. Demzufolge ist dieser Zusammenhang als ein skalenübergreifendes Phänomen zu bezeichnen.

Einige Habitatparameter sind als Stellvertreterparameter zu definieren – z.B. können die Distanzen zwischen bebauten Bereichen und Durchgangsstraßen als direkt wirksame Parameter für Dorngrasmücken gelten (vgl. optisch-akustisches Balzverhalten [Singflug]: Bebauung schränkt die optische, Straßenlärm die akustische Signalwirkung ein, etc.).

5.2 Mittlere, flächengewichtete Habitateignungswerte der Stadtstrukturen

Im Folgenden werden die Ergebnisse der Berechnung der mittleren, flächengewichteten HSI-Werte für die einzelnen Stadtstrukturtypen diskutiert. Die Diagramme in Abb. 3 spiegeln die Habitatpräferenzen der Arten weitestgehend wider. Die höchsten HSI-Werte für den Grünspecht wurden für die Grünflächen (61 %), die Wald-, Forst- und Gehölzstrukturen (58 %) sowie den Stadt- und Ortskernbereich (58 %) ermittelt. Im Gegensatz zur Dorngrasmücke wurden jedoch für Brachen (38 %), dörfliche Strukturen (33 %) sowie landwirtschaftliche genutzte Flächen niedrige (18 %) mittlere HSI-Werte errechnet. Die Berechnungen für die Dorngrasmücke ergaenb hohe bis mittlere HSI-Werte für die landwirtschaftlich genutzten Flächen (73 %), dörflichen Strukturen (67 %) sowie Stadtstrukturen mit Offenlandcharakter (Sonstige – Militär und Baustellen 61 %, Brachflächen 59 %).

Ganz deutlich werden in dieser Auswertung die für das Stadtzentrum typischen Strukturen Stadt- und Ortskernbereich (32 %), Verkehrsanlagen (32 %) sowie Wohnbauflächen und gemischte Bauflächen (29 %) mit einem niedrigen HSI-Wert bewertet. Damit zeigt sich auch in dieser Untersuchung, dass die Lebensräume der Zielarten weitgehend konträr zueinander bestimmt sind. In beiden Untersuchungen sind die ermittelten Standardfehler (zwischen 0,14 % und 1,4 %) und damit die Streuung der HSI-Werte innerhalb der einzelnen Stadtstrukturen gering.

In Abb. 3c und d sind die Analyseergebnisse zu den Grün- und Brachflächen aufgeschlüsselt nach den einzelnen Biotoptypen dargestellt. Die beiden Brachetypen unterscheiden sich nur geringfügig hinsichtlich des mittleren HSI-Wertes (~ 59 %). Ein etwas differenzierteres Bild ergibt sich für die unterschiedlichen Kategorien der Grünflächen. Die Friedhöfe erhalten demnach einen Wert von 78 %, wobei für die Kleingärten der niedrigste mittlere HSI-Wert errechnet wurde. Die Biotoptypen Grün- und Parkanlagen mit und ohne Baumbestand sowie extensiv und intensiv genutzte Sport- und Freizeitanlagen erhielten Werte zwischen 63 und 67 %. Auch bei dieser Berechnung ist der Standardfehler eher gering und reicht von 0,29 und 1,24 % bei den Grünflächen und nimmt Werte von 0,36 sowie 0,49 % bei den Brachflächen an.

5.3 Bewertung der Grün- und Brachflächen

Die Bewertung der Grün- und Brachflächen erfolgte durch die Übertragung der ermittelten HSI-Werte (Abb. 2) als Mittelwerte auf die Geometrien der Stadtbiotopkartierung. Die Stadtstrukturen erhielten dementsprechende Wertstufen. Abb. 4 stellt die Bewertung der einzelnen Grün- und Brachflächen als Habitat für den Grünspecht und die Dorngrasmücke dar. Die HSI-Werte liegen zwischen 2 (negativ) und 100 (positiv).

Dabei konnten die Grünflächen als Strukturtyp anhand der HSI-Werte des Grünspechts mit einer mittleren bzw. hohen bis sehr hohen Wertstufe versehen werden. Als günstige Lebensräume für den Grünspecht wurden vor allem die Flussauen der Weißen Elster, der Parthe und der Pleiße ausgewiesen. Gleichzeitig werden auch die Grünflächen nahe der innerstädtischen Altbauwohngebiete (Gründerzeit-Blockrandbebauung, Zeilenbebauung) sowie die altindustrialisierten, strukturreichen Mischgebiete, die im

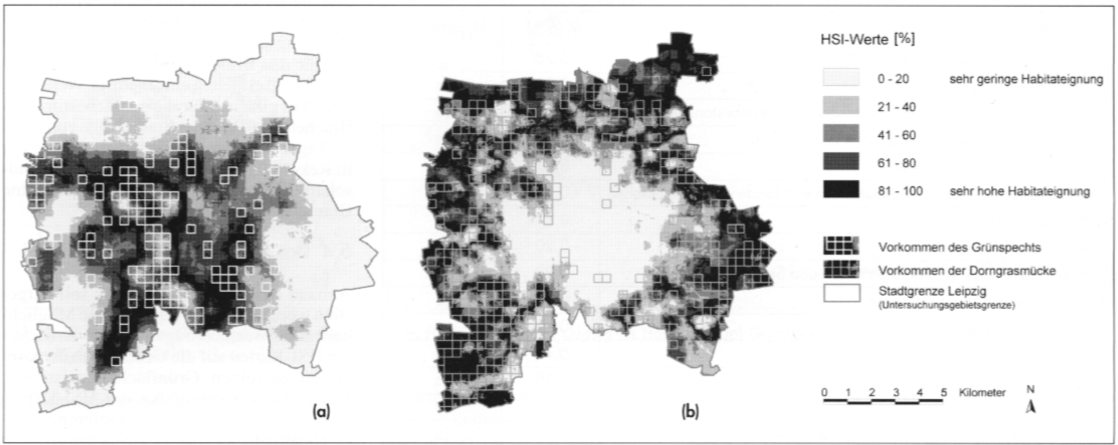

Abb. 2: Berechnete HSI-Werte für (a) Grünspecht (*Picus viridis*) und (b) Dorngrasmücke (*Sylvia communis*).

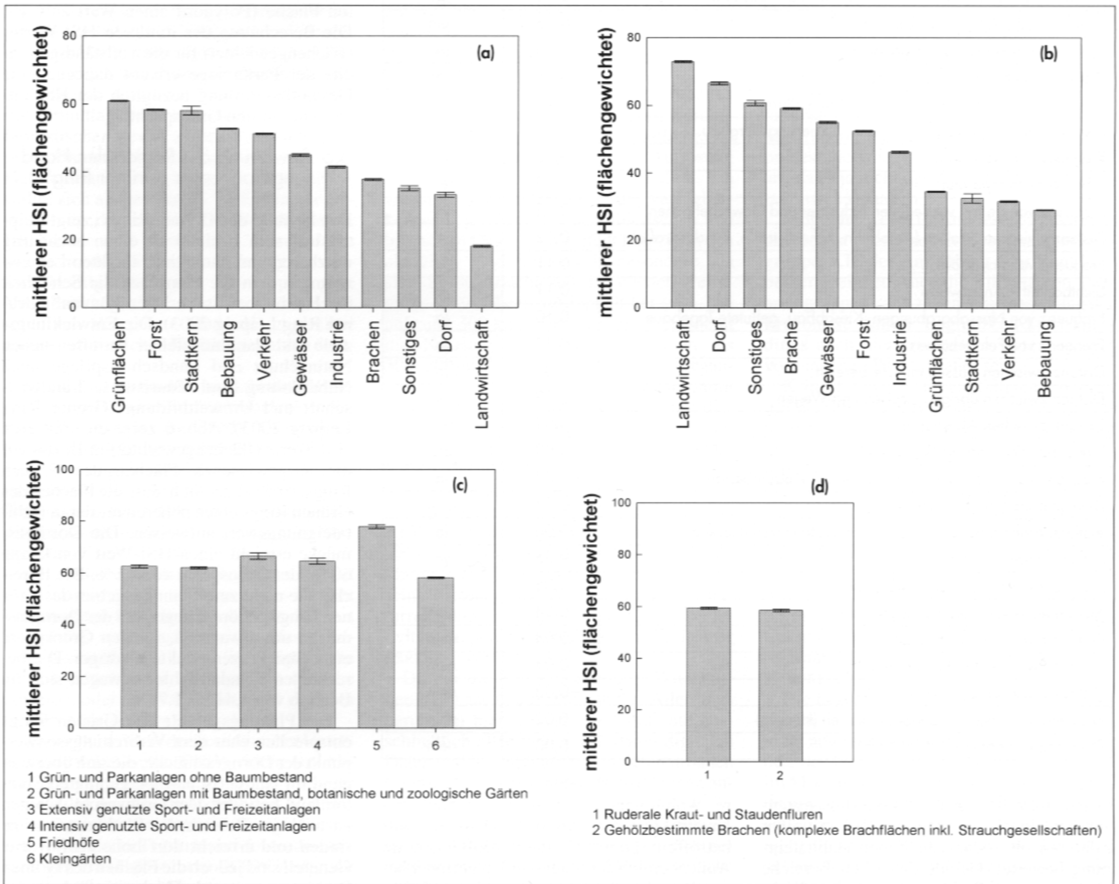

Abb. 3: Mittlerer HSI-Wert der Stadtstrukturen - (a) Grünspecht, (b) Dorngrasmücke, (c) Grünflächen, (d) Brachen.

Tab. 3: Ergebnisse der ENFA-Analyse für die Dorngrasmücke (*Sylvia communis*). Die Zahlen geben die Marginalität der Variablen an; ein positiver Wert zeigt eine Bevorzugung eines hohen Wertes des Parameters an, ein negativer das Gegenteil. Die Marginalität (M) des Gesamtmodells beträgt 6 %. Grau unterlegte Parameter sind von signifikanter Wichtigkeit für die Dorngrasmücke. Übereinstimmungen von erwarteten Habitatpräferenzen sind durch ein "ja" in der Hypothesenspalte angezeigt.

Parameter	M (6 %)	Hypothesen
Distanz zwischen bebauten Bereichen	0,27	ja
Distanz zwischen Durchgangsstraßen	0,26	ja
Kantendichte von Grün- und Parkanlagen mit Baumbestand	−0,24	ja
mittlere Näheindex zu Gehölzbestimmten Brachen	0,22	ja
Frequenz von Laubholzforsten	0,22	nein
Distanz zwischen Bauern- und Gutshöfen und landwirt. Großbetrieben	−0,22	ja
mittlere Sonnenscheindauer	0,21	ja
mittlerer Jahresniederschlag	−0,20	ja
mittlerer Näheindex zu ruderalen Kraut- und Staudenfluren	0,20	ja
Kantendichte von Laubholzforsten	0,19	ja
größter Patchgröße-Index	0,19	nein
standortskundlicher Feuchtegrad	0,19	ja
Frequenz von Wiesen und Weiden	0,18	ja
Frequenz von gehölzbestimmten Brachen	0,18	ja
Distanz zwischen Grün- und Parkanlagen ohne Baumbestand	0,18	ja
Distanz zwischen dörflichen Siedlungsflächen	−0,17	ja
Frequenz von Grün- und Parkanlagen mit Baumbestand	−0,16	ja
mittlere Patchgröße von Acker	0,16	nein
mittlerer Näheindex zu Feldgehölzen	0,16	ja
Distanz zwischen Baumreihen (neu)	−0,16	ja
Frequenz von ruderalen Kraut- und Staudenfluren	0,16	ja
Frequenz von Deponien und Kippen, Sanierungsbergbau	0,14	ja
Frequenz von Acker	0,13	ja
Oberflächentemperatur	0,12	nein
Frequenz von gering versiegelten Industrie- und Gewerbeflächen	0,12	ja
Distanz zwischen Straßen (Autobahn, Schnellstraße, Bundesstraße)	0,12	ja
Frequenz von Friedhöfen	−0,11	ja
Sichtbarkeit – Ansitzwarte	0,11	ja
Frequenz von Nassabgrabungen, Kiesabbau, geflutete Tagebaue	0,10	ja
Frequenz von Feldgehölzen	0,10	ja
Distanz zwischen Flüssen mit Uferbereich	−0,09	ja
Distanz zwischen übrigen Straßen und Wegen	0,09	nein
Distanz zwischen Alleen (alt)	0,09	nein
Frequenz von sandigen Böden	0,08	ja
Frequenz von Grün- und Parkanlagen ohne Baumbestand	−0,07	ja
Diversitätsmaß nach Shannon	−0,07	nein
mittlerer Näheindex zu Linearen Gehölzstrukturen (Hecken)	0,06	ja
mittlere Jahrestemperatur	0,06	ja
Distanz zwischen Gräben und Bächen	−0,05	ja
Kantendichte von naturnahen Wäldern	0,04	nein
Distanz zwischen Alleen (neu)	0,04	nein
Distanz zwischen Bahnanlagen	0,04	nein
Distanz zwischen Baumreihen (alt)	−0,03	nein
Frequenz von linearen Gehölzstrukturen (Hecken)	0,02	nein
Frequenz von naturnahen Wäldern	0,00	nein

Osten und Westen an den Altbauring angrenzen bzw. in diesen integriert sind, mit einer mittleren bis sogar sehr hohen Habitateignung bewertet. Gerade diese Stadtbereiche sind aber vom Problem eines hohen Wohnungsleerstandes (Leipzig 2004: 55 000 leere Wohnungen) und somit nachhaltigen Umstrukturierung in der nahen Zukunft betroffen. Lediglich die Grünflächen im Außenbereich der Stadt wurden geringer bewertet und sind demnach ungeeignet als Habitat für den Grünspecht.

Den Brachflächen im Stadtgebiet, welche erst in größerer Zahl nach der politischen Wende 1990 entstanden (Haase & Magnucki 2004), konnten überwiegend hohe bis sehr hohe Werte zugewiesen werden. Lediglich die Brachen im Innenstadtbereich sind aufgrund der hohen Bebauungs- und Versiegelungsdichte in der Umgebung ungeeignet für das Brutvorkommen der Dorngrasmücke und erhielten eine niedrige Wertstufe. Gleiches gilt auch für die gehölzbestimmten Brachen im Süden der Stadt (Nähe zum neuen Tagebaurestsee Cospuden am Rande der in Rekultivierung begriffenen Tagebaulandschaft Südraum Leipzig) und einzelne Brachflächen im Norden.

5.4 Das Beispiel „Clara-Zetkin-Park"

Anhand des Clara-Zetkin-Parks soll dargestellt werden, welche verschiedene Möglichkeiten der Wertübertragung der rasterbasierten HSI-Karten auf die Geometrien der konkreten einzelnen Grünflächen existieren. Durch die Verschneidung der HSI-Karten mit den Geometrien bleiben Differenzierungen innerhalb der einzelnen Flächen erhalten (Abb. 5) – im Gegensatz zu der Methode der Mittelwertberechnung, die einer abgegrenzten Fläche (Polygon) einen Wert zuweist. Die Berechnung des mittleren HSI-Wertes (flächengewichtet) für die vollständige Fläche der Parkanlage erlaubt dagegen eine Gesamtbeurteilung bezüglich der Habitateignung für den Grünspecht.

5.5 Bewertung des Regionalen Handlungskonzeptes „Grüner Ring"

Das Leitbild des Grünen Rings „zeigt Leipzig und sein Umland als einen nachhaltig nutzbaren und ökologisch intakten Lebensraum, in dem die Menschen die Schönheit der Heimat bewusst erleben können" (Grüner Ring Leipzig 2003). Die Entwicklungsziele und Handlungsfelder betreffen neben Naturschutz und Landschaftspflege auch Naherholung und Tourismus, Landwirtschaft und Umweltbildung (Grüner Ring Leipzig 2003). Abb. 6 zeigt die mittleren HSI-Werte (flächengewichtet) in Bezug auf die ausgewiesenen Flächen des Grünen Rings. Er wird deutlich, dass die Flächen des Grünen Rings einen höheren mittleren Habitateignungswert aufweisen. Die Dorngrasmücke erreicht einen HSI-Wert von knapp 60 %, der Grünspecht von 43 %. Die Bereiche, die nicht zum Planungsgebiet des Grünen Rings gehören, liegen bei der Dorngrasmücke um etwa zehn, für den Grünspecht etwa fünf Prozentpunkte niedriger. Die berechneten Standardfehler bewegen sich im Bereich von 1,44 bis 1,79 %.

Die Planungsgebiete des Grünen Rings entsprechen eher dem Verbreitungsschwerpunkt der Dorngrasmücke, die sich überwiegend im landwirtschaftlich geprägten Stadtumland befindet. Der Grünspecht dagegen ist auch im Bereich des Stadtzentrums zu finden und erreicht dort hohe HSI-Werte. Generell sind jedoch die Flächen des Grünen Rings geeigneter als Flächen außerhalb des Regionalen Handlungskonzeptes.

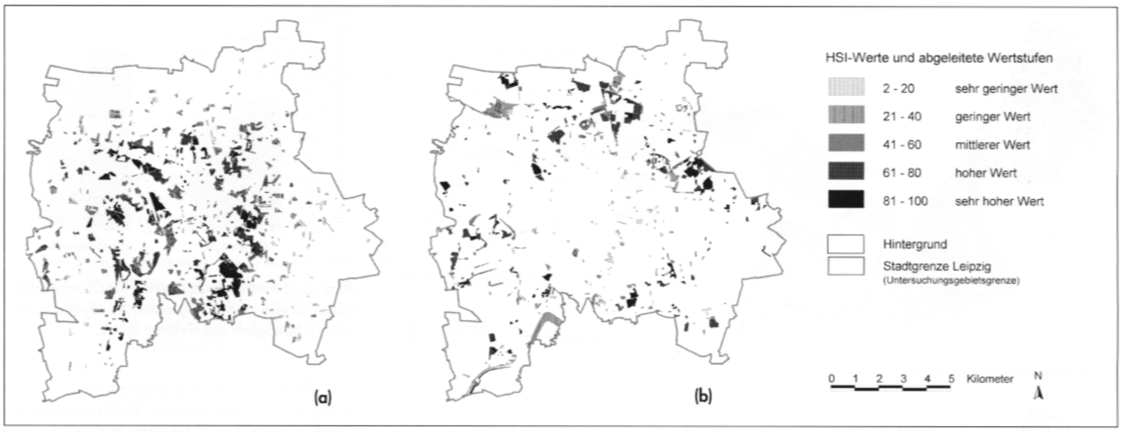

Abb. 4: Bewertung der Grün- und Brachflächen als Stadtstrukturen der Stadt Leipzig als Habitat für (a) Grünspecht (*Picus viridis*) sowie (b) Dorngrasmücke (*Sylvia communis*).

6 Diskussion und Schlussfolgerungen

6.1 Bewertung der Methode und der Ergebnisse

Die Berechnung der Habitateignung mit angewandter Statistik (ENFA) und die Übertragung der Habitateignungswerte auf die Geometrien der Stadtstrukturen erwies sich als zielführende Methode, Stadtstrukturen auf der Grundlage von allgemein verfügbaren faunistischen sowie abiotischen und biotischen Daten flächendeckend hinsichtlich der Habitateignung zu bewerten. Die ENFA stellte sich als geeignetes Verfahren zur Bestimmung der Habitatpräferenzen heraus. Insbesondere die Vorteile (z.B. Präsenzdaten ausreichend, GIS-Implementierung, kostenlose Verfügbarkeit von Biomapper, gute Visualisierung, dokumentierte und wissenschaftlich akzeptierte Methode) gegenüber anderen statistischen Verfahren wurden deutlich.

Klassische Methoden der Habiatmodellierung, wie z.B. Diskrimminanzanalyse, logistische Regression oder GLMs (*Generalized Linear Modells*), sind auf das Vorhandensein von Präsenz-Absenz-Daten angewiesen (Kleyer et al. 1999/2000, Reutter et al. 2003). Die exakte Kartierung von Präsenz-Absenz-Daten ist mit Schwierigkeiten verbunden.

Die Absenz (fehlende Beobachtung) ist nicht immer sicher zu bestimmen. Es gibt verschiedene Ursachen für Absenz: Die Art ist präsent, wurde jedoch nicht erfasst (falsche Absenz), das Habitat ist geeignet, die Art ist jedoch nicht mehr präsent (falsche Absenz), oder das Habitat ist nicht geeignet (wahre Absenz) (Hirzel et al. 2001).

Dagegen ist die in der vorliegenden Untersuchung angewandte ENFA nicht auf Absenz-Daten angewiesen. Damit wird dieser Ansatz den meisten faunistischen Kartierungen (Datenbanken, unzuverlässige Daten) mit vorhandener Präsenz und fehlender Absenz gerecht (Hirzel et al. 2002). Aufgrund der stark limitierten Ressourcen in der Umweltplanung findet man trotz Standardmethoden auch für viele Arten der Stadt Leipzig keine aktuellen flächendeckenden Kartierungen. Bedingt durch die zahlreichen Veränderungen der Stadtgrenze durch Eingemeindungen haben die vorhandenen Daten auch teilweise unterschiedliche Bezugsräume. Die Planungsrelevanz dieser aktuellen Arbeit bezieht sich demzufolge auch auf fehlende Quellen.

Die im Modell verwendeten Daten können als bedingt geeignet angesehen werden. Problematisch erscheinen die inhaltliche und räumliche (mitunter zu geringe) Auflösung (z.B. Klimadaten) sowie die Aktualität. Ein weiteres Problem besteht in der Verfügbarkeit von flächendeckenden abiotischen und biotischen Daten für die Stadt Leipzig in den aktuellen Stadtgrenzen, insbesondere, da sich die Stadtfläche seit der Wiedervereinigung 1989 nahezu verdoppelt hat (von 150 auf rund 300 km^2). Problematisch erscheint die Nutzung der Vorkommensdaten als 500x500-m-Raster. Es wird davon ausgegangen, dass die Art in diesem Raster vorkommt und damit auch der Aktionsradius mit diesem Raum übereinstimmt. Eine andere Herangehensweise ist möglich, wenn Punktdaten zur Verfügung stehen. In diesem Fall wird ein Puffer gebildet, der als Aktionsraum der Art angenommen wird. Für diese Art von Analyse ist allerdings eine Voruntersuchung notwendig, inwieweit dieser Radius adäquat für die Art ist. Im urbanen Raum ist aufgrund seiner Heterogenität und dem großen Strukturreichtum die Frage nach der Repräsentativität von punktuellen Daten noch brisanter (Breuste 2002).

Die für die ENFA notwendige Datenaufbereitung ist relativ aufwändig. Allerdings beruht der hier vorgestellte Ansatz auf ausschließlich allgemein verfügbaren digitalen Daten und ist somit auch in anderen urbanen Räumen für vergleichbare Zielstellungen anwendbar.

Als weitgehend geeignet für die Bewertung der Stadtstrukturen erwiesen sich die ausgewählten Zielarten. Die Dorngrasmücke als Offenlandart meidet eng bebaute Bereiche und kann daher für die Bewertung von innerstädtischen Brachflächen nur bedingt Aussagen treffen. Sie ist eher eine euryöke Art und damit nur eingeschränkt als Zielart geeignet. Es stand jedoch keine andere Art als Zielart für die Brachen zur Verfügung. Alternativ wäre die Haubenlerche denkbar, die jedoch aus Gründen der zu geringen Vorkommen (Anzahl der Vorkommen bzw. der Raster mit brütenden Tieren) nicht in Frage kam. Diese Art siedelt vorwiegend auf vegetationslosen Brachflächen bzw. auf Brachen mit frühen Sukzessionsstadien. Dieser Fakt prädestiniert die Art nicht unbedingt als Zielart, da es ja nicht das Ziel ist, Brachen vegetationslos zu halten.

Möglicherweise ist für diese Zwecke eine andere Art oder eine Art einer anderen Tiergruppe, z.B. der Amphibien oder Reptilien, besser geeignet. Auch die Bildung von Tierartengruppen kann zu einer Verbesserung der Ergebnisse führen. Begrenzend kann allerdings auch hier wieder die Datenlage der vorhandenen Präsenzdaten sein.

Kritisch müssen die vielfältigen Faktoren mit Einfluss auf das Modellergebnis gewertet werden. Dieses betrifft insbesondere die Qualität der Datengrundlage und die Stimmigkeit der Daten in Raum und Zeit. Auch die Auswahl der Parameter und die Quantifizierbarkeit beeinflussten das Ergebnis. Es ist ebenso nicht auszuschließen, dass relevante Parameter nicht betrachtet wurden. Außerdem erscheint es möglich, dass die inhaltliche Auflösung der Stadtbiotopkartierung zu gering ist und somit Habitatstrukturen, die für das Vorkommen der Arten relevant sind, gar nicht erfasst wurden (vgl. Jedicke 1996).

Die Ergebnisse zeigen, dass einige Hypothesen zu den Habitatpräferenzen der Arten nicht angenommen werden konnte. Im Modell der Dorngrasmücke wurden 71 % und im Modell des Grünspechts 57 % der Hypothesen bestätigt. Daraus kann man aber nicht schließen, dass diese Habitatpräferenzen nicht für in der Stadt vorkommende Arten gelten. Die Ablehnung hat andere Gründe, so z.B. die Lage einiger präferierter Stadtstrukturen innerhalb der Stadt (z.B. werden

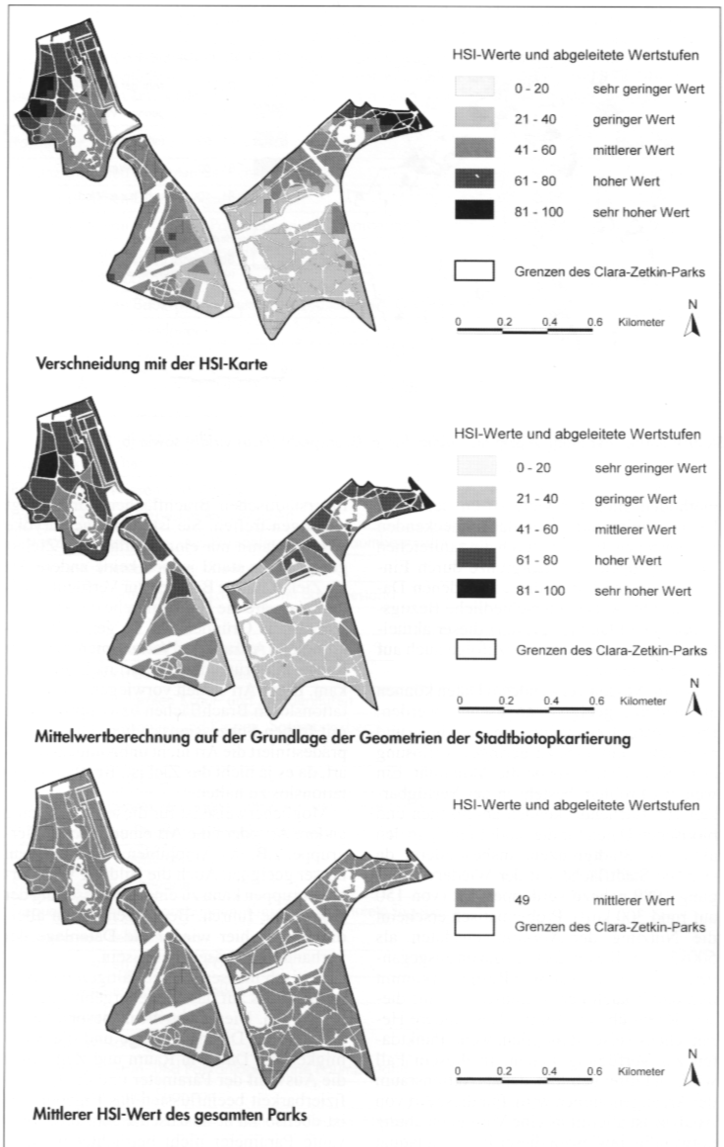

Abb. 5: Übertragung der HSI-Werte auf den Clara-Zetkin-Park in Leipzig.

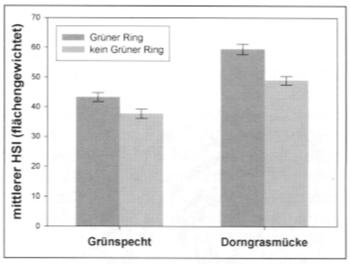

Abb. 6: Habitateignungswerte für Grünspecht (*Picus viridis*) und Dorngrasmücke (*Sylvia communis*) bezüglich des Grünen Rings.

Brachen im Zentrum der Stadt von der Dorngrasmücke eher gemieden). Wichtig ist, dass generelle Vorlieben der Arten für bestimmte Biotope bzw. Stadtstrukturen bestätigt werden konnten und somit möglicherweise mit den Habitatpräferenzen der Arten in der freien Landschaft übereinstimmen. Insbesondere die Brachflächen, die bisher mit einem negativen Image besetzt sind, erhielten hauptsächlich im peripheren Bereich der Stadt hohe Wertstufen. Das gilt ebenso für die Grünflächen, die sich in unmittelbarer Umgebung der Auen (überregionales und national bedeutsames Relikt) befinden.

Für die Wertübertragung der HSI-Werte auf die zu untersuchenden Flächen sind die ersten zwei Methoden (Verschneidung und Mittelwertberechnung) als zielführend einzuschätzen, da eine für die Planung notwendige Differenzierung erhalten bleibt.

Die Analyse zum Grünen Ring zeigte, dass dessen Flächen nur bedingt für den Grünspecht geeignet sind; zu prüfen wäre, ob nicht auch innerstädtische Grünflächen und Stadtstrukturen jeder Größe für den Arten- und Biotopschutz von Bedeutung sind und integriert werden können. Will man Vorhersagekraft erreichen, so ist es notwendig, die erzielten Ergebnisse anhand von Felddaten zu validieren. Ebenso ist die Betrachtung weiterer nicht erfasster Parameter von Bedeutung. Beispielsweise können sich einzelne derzeit unbekannte Habitatparameter auch erst aus der Feldarbeit ergeben, bei der Dorngrasmücke beispielsweise Anforderungen wie Art und Grad der Deckung durch Vegetation am unmittelbaren Neststandort.

6.2 Anwendung der Ergebnisse in der Landschaftsplanung

Der Vorteil der hier angewendeten Methode ist, dass man flächendeckende Datensätze erhält, welche die gesamte Stadt abbilden. Dagegen decken viele Kartierungen nur Teile der Großstadt ab oder werden sporadisch durchgeführt, und die Daten sind demzufolge veraltet. Es sollte die Aufgabe der anwendungsbezogenen Forschung sein, alternative Methoden (selbstverständlich in Kenntnis der Grenzen dieser Methoden) anzubieten. In den hier diskutierten Beispielen können alle Stadtstrukturen und in diesem Anwendungsbeispiel insbesondere die Grünflächen und Brachen der Stadt miteinander verglichen werden. Das ist insbesondere für die kommunenübergreifende Arbeit des „Grünen Ringes" von enormer Bedeutung. Für die Umsetzung des Grünverbundes in der Stadt und den Umlandkommunen werden aussagekräftige Indices benötigt.

Die HSI-Karten des Grünspechtes zeigen deutlich, dass dieser neben den reich strukturierten Auenbereichen (vgl. Kartierung des Stadtforstamtes) auch die Auenrandbereiche und angrenzenden innerstädtischen Flächen präferiert. Das betrifft vor allem die so genannten Altbaugebiete, welche an das kleine, kompakte Zentrum Leipzigs anschließen. In diesem Stadtbereich lassen sich (bedingt durch Schrumpfung) seit ca. 2002 Abrissprozesse beobachten. Diese entsiegelten Flächen bieten eine Chance für den urbanen Naturschutz. Insbesondere die inneren Stadtbereiche der hier besprochenen Gründerzeitwohngebiete (mit einem Leerstand von etwa 55 000 leeren Quartieren) liegen in ehemaligen Auenbereich der Weißen Elster, Pleiße und Parthe (in Abb. 4 als dunkles Band im Nordosten der Stadt).

Im diesem Beitrag soll vor allem gezeigt werden, dass es erstens möglich ist, auf der Basis der in Leipzig verfügbaren Vorkommensdaten die potenzielle Habitateignung für einzelne Arten (z.B. geschützte Arten) für die gesamte Stadtfläche zu modellieren und dem Planer als Grundlage für weiterführende Planungen (Biotopverbundplanung, Eingriffsregelung, Landschaftsplanung usw.) Habitateignungskarten mit einer handhabbaren Skala von fünf HSI-Gruppen in die Hand zu geben.

Diese gesamtstädtische Sicht ist von besonderer Bedeutung, da Leipzig im Augenblick (und das betrifft viele deutsche Städte; siehe Berliner Ausstellung Schrumpfende Städte) einen sehr dynamischen und in diesen Ausmaßen noch nicht gekannten Nutzungswandel (Flächenkonversionen, Abriss) durchmacht. In diesem Zusammenhang stehen in sehr kurzer Zeit zahlreiche (innerstädtische und randstädtische) Flächen einer Nachnutzung zur Verfügung. Die Belange des Natur- und Artenschutzes sind in die Planung dieser Flächenumwidmung und Flächenneuordnung einzubeziehen. Hier besteht großes Interesse von Seiten des städtischen Grünflächenamtes und des Leipziger Stadtplanungsamtes, dessen Mitarbeitern die Aufgabe der Landschafts- und Grünordnungsplanung obliegt.

Als mögliche Planungs-/Praxis-Anwendung der Ergebnisse sind ergänzend zu den bisher besprochenen Ansätzen beispielsweise folgende Einsatzbereiche denkbar:

► Analyse und Benennung limitierender Faktoren (auf Habitatebene – welche Habitatfaktoren sind begünstigend für ein Vorkommen der Art) sowie Planung zur Arrondierung, Verdichtung oder Verbund von Einzelflächen.

► Anwendung bei der Planung des Grünen Rings (z.B. Überprüfung einer Einzelmaßnahme): Es könnten Maßnahmen dahingehend geprüft werden, ob zum Brutvorkommen ein Beitrag geleistet wird oder z.B. die Habitate der Dorngrasmücken/des Grünspechtes beseitigt werden bzw. potentiell bedroht sind. Möglich ist auch ein Vergleich der Situation im Kartierungszeitraum (Gebietszustand) mit der aktuellen: Wie hat sich der Bestand an Brachen (differenziert nach Eignungsklassen) in den letzten acht bis neun Jahren in Leipzig geändert; sind Wirkungen auf den Dorngrasmückenbestand wahrscheinlich und was bedeutet dies für die im neuen Flächennutzungsplan als Bauflächen ausgewiesenen Brachen.

► im Rahmen der Eingriffsregelung: Insbesondere bei dem Aufbau eines Ökokontos/Flächenpools für Leipzig, welches die Stadt führt, können die Ergebnisse wertvolle Anhaltspunkte für die Bewertung von Flächen anhand von faunistischen Kriterien liefern.

6.3 Ausblick

Habitatmodelle dienen der Prognose von Umweltauswirkungen im Rahmen von planungsrelevanten Entscheidungen (z.B. Eingriffe oder Kompensations- und Pflegemaßnahmen), um die Transparenz, Nachvollziehbarkeit und Objektivität in der Planung zu erhöhen (SCHRÖDER 2000b). Dabei erleichtern die ermittelten Ergebnisse die Bewertung und Beurteilung für landschaftsplanerische Fragestellungen. Besonders interessant für urbane Räume wäre die Untersuchung von Arten, die eine hohe Bindung an den urbanen Raum haben, z.B. Gebäudebrüter. Demzufolge wäre es zu prüfen, ob es Möglichkeiten gibt, mit vertretbarem Aufwand relevante Daten zu erheben. Habitatmodelle erklären nur einen Teil des Vorkommens der Arten. Mit Populationsmodellen wären, im Gegensatz zu Habitatmodellen, umfassendere Beurteilungen von Eingriffen in Natur und Landschaft im Rahmen von Eingriffsbewertungen und Umweltverträglichkeitsprüfungen möglich.

Generell ist es das Ziel, die Vorhersagekraft und Güte von Habitatmodellen und somit die Bewertung und Beurteilung im Rahmen von landschaftsplanerischen Fragestellungen zu verbessern. Nach BLASCHKE (2004) werden Modellierungen in den nächsten Jahren im Blickpunkt der Forschung stehen, da flächenhafte Aussagen mit „Mut zur Unschärfe" (BLASCHKE 1997, zitiert nach BLASCHKE 2004: 135) benötigt werden. Modelle sind in jedem Fall Abstraktionen und beinhalten Probleme hinsichtlich Aussagekraft und Gültigkeit.

Zusammenfassend lässt sich jedoch der Aussage von KLEYER et al. (1999/2000: 177) folgen: Habitatmodelle können für die Naturschutzforschung und -praxis wesentlich sein, wenn sie *„predictive power"* besitzen, Potenziale benennen und somit für die Prognose des Vorkommens und der Überlebensfähigkeit von Arten geeignet sind.

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TERMINE

Kommunaler Bodenschutz

„Vollzug des Bodenschutzes – Etablierung des Bodenbewusstseins" ist eine Fachtagung am 11. Februar 2005 in Wuppertal betitelt, die vom Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz Nordrhein-Westfalen gemeinsam mit dem Boden-Bündnis europäischer Städte, Kreise und Gemeinden (ELSA) und der Stadt Wuppertal organisiert wird.

Informationen: Ministerium für Umwelt, Petra Horn, Schwannstraße 3, 40476 Düsseldorf, Telefon (02 11) 45 66-467, E-Mail helmut.ortseifen@munlv.nrw.de.

Wasser und Umwelt

Die Bauhaus-Universität Weimar bietet Fachkräften mit dem Weiterbildenden Studium Wasser und Umwelt ein berufsbegleitendes Fernstudium mit Präsenzphasen an, welches in Kooperation mit der Universität Hannover durchgeführt wird. Anmeldeschluss für das Sommersemester ist der 15. März 2005.

Informationen: Bauhaus-Universität Weimar, AG WBBau, Coudraystraße 7, 99421 Weimar, Telefon (0 36 43) 58 46 27, Fax 58 46 37, E-Mail info@bauing.uni-weimar.de, Internet www.uni-weimar.de/Bauing/wbbau.

Baumkontrolle

15. und 16.03.2005: Verkehrssicherheit und Baumkontrolle (Reinbek)
24.05.2005: Haftung des Baumkontrolleurs/Baumpflegers (Reinbek)
25.05.2005: Pilze bei der Baumkontrolle (Reinbek)

Informationen: Institut für Baumpflege, Brookkehre 60, 21029 Hamburg, Telefon (040) 72 41 31-0, Fax 7 21 21 13, E-Mail info@institut-fuer-baumpflege.de, Internet www.institut-fuer-baumpflege.de.

Naturerlebnis ohne Barrieren

Der Landschaftsverband Rheinland hat seine 16. Fachtagung gemeinsam mit der Natur- und Umweltschutzakademie NRW am 21. und 22. April 2005 in Bad Honnef unter das Thema „Barrierefreies Natur- und Kulturerlebnis" gestellt.

Informationen: LVR, Umweltamt, 50663 Köln, Telefon (02 21) 809-37 80, Fax -24 61, E-Mail daniela.hoenicke@lvr.de.

Artenschutz und FFH

„Die artenschutzrechtlichen Bestimmungen der FFH-Richtlinie" beleuchtet ein eintägiges Seminar, welches das Umweltinstitut Offenbach am 18. März, 04. Juli und 20. Oktober 2005 anbietet. Ein Praxis-Workshop zur FFH-Verträglichkeitsprüfung findet am 23. März 2005 statt.

Informationen: Umweltinstitut Offenbach, Frankfurter Straße 48, 63065 Offenbach, Telefon (069) 81 06 79, Fax 82 34 93, E-Mail mail@umweltinstitut.de, Internet www.umweltinstitut.de.

Difu-Seminare

14. und 15.02.2005: Umsetzung der EU-Wasserrahmenrichtlinie – Konsequenzen für die Kommunen
13. bis 15.06.2005: Veränderte Nutzungszyklen und deren Steuerung – Umnutzung, Zwischennutzung, Nachnutzung

Informationen: Deutsches Institut für Urbanistik (Difu), Ernst-Reuter-Haus, StraOe des 17. Juni 112, 10623 Berlin, Telefon (030) 3 90 01-258 oder -259, Fax -268, E-Mail leute@difu.de, Internet www.difu.de.

Alfred Toepfer Akademie

04. bis 06.04.2005: Naturinterpretation barrierefrei
07.04.2005: Kontrolle von Tiergehegen
11. und 12.04.2005: Die Konvention zum Schutz der biologischen Vielfalt und der Ökosystem-Ansatz in der Naturschutzpraxis
13.04.2005: Natura-2000-Gebiete in Wäldern – Schutz, Bewirtschaftung, Monitoring
14.04.2005: Eichenwälder in Niedersachsen
20. und 21.04.2005: Agenda-21-Workshop für niedersächsische Kommunen
23.04.2005: Natur und Kultur in der Lüneburger Heide
28.04.2005: Ersatzzahlungen und andere Probleme des geltenden Naturschutzrechts (Hannover)

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Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870–2003

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Abstract

Assessment of the environmental impact of urban sprawl being understood here as the conversion of non-urban to urban land is still a subject for debate. Another shortcoming of the current discourse on urban sprawl is that it largely fails to reflect the interconnection of environmental and socio-economic aspects. In presenting a case study on the German city of Leipzig and applying the conceptual framework of driving forces, pressure, state, impact, and response (DPSIR-concept), this paper strives to assess the impact of urban sprawl on water balance and explores the repercussions of this impact upon the causation of and policies on urban sprawl. The study establishes that urban sprawl and related surface sealing have considerable impact on water fluxes and the urban water balance that may become imminent in the longer run. However, the study also shows that societal reactions on urban sprawl, first of all the attempts of both authorities and public initiatives to contain sprawl, are hardly motivated or influenced by concerns about environmental problems in a particular place (affected by urban sprawl). These attempts are mainly carried out on a national and regional level and reflect a general orientation in environmental politics rather than the desire to respond to individual urban developments. The study thus shows that the environmental impact of sprawl elicits only indirect repercussions in society.

Keywords: Urban sprawl; DPSIR-concept; Impervious surfaces; Water balance; Land-use policy

1. Introduction: the problem of urban sprawl

Within the last decades urban sprawl has become an increasingly prominent though contentious theme in both public and academic discussions. Many scholars claim that urban sprawl has considerable negative impacts, such as social segregation and environmental degradation (e.g. Squires, 2002; Burchell et al., 2002, Part II). On the other hand, there is also strong support for the view that the problems of urban sprawl are far outweighed by its benefits in that it enables a growing number of people to live according to their desires (e.g. Gordon and Richardson, 2001; Alberti and Marzluff, 2004). However, inspired by the growing concern about sustainability, many academics are calling for effective containment of urban sprawl (e.g. Ewing, 1997).

One problem with the discussion of urban sprawl is the conceptual vagueness of the term, another its negative connotation. An attempt to give a neutral and concise definition of urban sprawl was made by Galster et al. (2001, p. 685): "sprawl is a pattern of land use in an urbanised area that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity." Endeavouring to cover the variety of aspects discussed under the heading of urban sprawl, this definition is however somewhat all-embracing. Alternative definitions draw solely on a few, sometimes only one, of the dimensions mentioned in the quote. Along with Chin (2002), four basic types of sprawl-definitions can be distinguished. Sprawl can be defined: (1) in terms of urban form (e.g. Song and Knaap, 2004) as opposed to the compact city (cf. Burton, 2002), (2) in terms of density, or density gradients (e.g. Couch et al., 2005), and (3) in terms of changes in land use (e.g. Batty et al., 1999). In addition, various concepts of urban sprawl have been developed which are based on (4) the (presumably negative) impacts of sprawl (e.g. Johnson, 2001) — although it is clear that this creates a tautology when it comes to the discussion of effects of sprawl. It is interesting to note that the latter kind of concepts barely draws on environmental aspects, except for the problem

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of air pollution caused by car traffic. This conforms to the current debate on land consumption where sprawl is usually blamed for its environmental impact, but almost always on a very general level. The attempts to define urban sprawl thus seem to reflect a lack of knowledge of its environmental dimension. More information is needed here in order to substantiate land-use policies (e.g. Stanilov, 2002, p. 171).

There are numerous case studies on local effects of urban developmental activities on natural and semi-natural ecosystems (e.g. Breuste, 1996). These kinds of studies have plainly demonstrated that the development of land for urban use affects the respective site in terms of, say, biodiversity (e.g. Löfvenhaft et al., 2002), habitat suitability (e.g. Hirzel et al., 2002), water balance (e.g. Interlandi and Crockett, 2003), microclimate (e.g. Pauleit et al., 2005), or photosynthesis (e.g. Imhoff et al., 2000). However, scaling up these micro-scale results to a larger spatial scale to assess the accumulated effects of these impacts on a city or regional level, i.e. the medium scale (approx. 5000 to 500,000 ha) is not easy (Verburg et al., 2004). On the other hand, there are also studies which scrutinise environmental effects of urban sprawl on a larger, even global level (Meyer and Turner, 1994; Dolman, 2003). However, the layout of these studies is usually too broad, and the resolution of analysed land-use data too low to allow an inference of results to particular cities or regions. Furthermore, urban sprawl is a human-made process but research on its environmental effects rarely takes its potential feedback on human action into account (Atkinson and Oleson, 1996). More empirical effort seems to be necessary both to evaluate the area-specific environmental impact of urban sprawl on a medium scale and to establish the extent to which this impact is part of, and provides feedback for, the – genuinely societal – process of land-use change (Dwyer and Childs, 2004). Based on a survey of land-use changes over a period of more than a century, this paper presents a case study for the city of Leipzig that undertakes such an empirical effort. It takes water balance as an example for an environmental issue regularly affected by urban sprawl. To obtain a deeper understanding of causes, effects and dynamics concerning the interrelationships between urban sprawl and water balance (with the latter representing the natural environment potentially affected by urban sprawl) the case study employs the concepts of driving forces, pressure, state, impact, and response (see below) to discuss findings from research in social and natural sciences at the same time. In more detail, the principal objectives of this paper are

- an assessment of the effects of urban sprawl on water balance at the medium scale (as opposed to its site-specific impact);
- an analysis (using the example of water balance) of how society responds to the environmental impact of urban sprawl;
- an exploration of the interface and the feedback between the societal and the environmental dimension of urban sprawl;
- a reflection as to whether conceptualising the interrelationships between these two dimensions could help local authorities to both devise and legitimise more appropriate policies on urban sprawl.

This paper adopts a concept of urban sprawl which equates it with the conversion of non-urban (i.e. 'natural' or open) into urban land (comprising buildings, infrastructure, private gardens), and thus corresponds to the third type of sprawl-definition introduced above. (The term land-use change on the other hand refers to any kind of conversion of land uses.) Admittedly, this definition of urban sprawl allows subsumption of any process of physical urban growth. However, it has two important advantages with regard to its application in empirical research (e.g. Lopez and Hynes, 2003): in contrast to definitions based on urban form, it allows one to perceive urban sprawl as a dynamic process and, as opposed to definitions based on density, it also allows one to study urban sprawl by means of GIS data. Some recent case studies that chose a similar approach have proven that the land use-based definition of sprawl is suitable for guiding empirical exploration of environmental effects of urban sprawl (e.g. Hasse and Lathrop, 2003; Robinson et al., 2005).

2. Material and area studied

Leipzig has a long history as an important urban centre and currently has around half a million inhabitants. Situated in the eastern part of Germany, the former German Democratic Republic, it experienced little urban sprawl in the post-World War II period (except for the building of a few big housing estates on the urban fringes). Before and after the socialist era, however, large-scale changes in land use were quite common in and around Leipzig.

Leipzig underwent a period of vibrant growth between around 1870 and 1930, reaching its historical maximum with a population of more than 700,000 in the early 1930s, which then made it Germany's fourth-largest city. This development was accompanied by the urbanisation of what were then the city's surroundings. After 1989, post-socialist transformation again ushered in a period of heavy urban sprawl, with several shopping malls, business parks and residential neighbourhoods spreading, in this order, into the city's outskirts and the suburban towns and villages. Low birth rates, industrial decline, and out-migration, however, contradicted the expectations linked to these investments, which eventually led to a surplus of housing, office space and developed land in general. Since the late 1990s urban sprawl around Leipzig has abated considerably. Following the incorporation of several suburban townships in recent years, the administrative territory of Leipzig today covers almost 30,000 ha (297.5 sq. km) and has a population of around 500,000.

The city of Leipzig is suited as a case study region for the purposes of this paper mainly for three reasons:

- Facing simultaneous processes of societal and economic transition and demographic change, the case of Leipzig is fairly typical of the development of non-capital cities in the former socialist parts of Central Europe. As many old industrialised cities in the West have to deal with similar problems, Leipzig is also a general example of the medium-sized city that has ceased growing (Banzhaf et al., 2005).
- Leipzig is large and diverse enough to allow an overall assessment of the impact of land-use change and urban sprawl on

Table 1
Data used to quantify land-use change and water balance

Data	Stand	Scale	Publisher/source
Relief			
Digital elevation model (DEM): Leipzig	1995	20 m × 20 m	Saxon Land Registry
Land use			
Topographic maps, CIR photographs, planning maps	1870–2003	1:25000–1:5000	Saxon Land Registry, Agency of Spatial Planning of Leipzig, ASW – Office for urban renewal of Leipzig
Climate			
Evapotranspiration	1961–90	1 km × 1 km	German Meteorological Service
Precipitation	1961–90	1 km × 1 km	German Meteorological Service
Water household			
Geological engineering map of Leipzig, hydrological map	1977	1:10000	Saxon State Department of the Environment and Geology
Map of hydro-isohypses for Leipzig	1984	1:50000	Saxon State Department of the Environment and Geology
Vegetation			
Biotope map of Saxony and Leipzig (based on colour infrared photography, CIR)	1994/99	1:10000	Saxon State Department of the Environment and Geology, Environmental Agency of Leipzig
Soil			
Soil fiscal evaluation maps	1935	1:10000	Various authors, Communal financial departments
Soil map of Leipzig and surroundings (scale 1:50000)	1997	1:50000	LAGB – State Department of Geology and Mining of Saxony-Anhalt
Soil map of the rural district of Leipzig	1964	1:50000	Richter (1964)
Medium scale agricultural mapping for Leipzig	1970–80	1:25000	Saxon State Department of the Environment and Geology
Soil survey map Germany No. CC4734 1:200000	1999	1:200000	German Agency for Geology and Natural Resources

a medium scale. Apart from the inner city, which consists of a solid, dense structure of 19th and 20th century tenement blocks, the city's territory contains large areas of the typically suburban mixture of land uses (Sieverts, 2003), including agricultural land and forests.

- The availability of data on urban development in Leipzig is fairly good. Table 1 indicates the spatially explicit data used for a posteriori analysis of the consequences of urban sprawl on water balance.

3. Methods

3.1. The heuristic DPSIR-concept: objectives and requirements

The driving forces–pressure–state–impact–response concept (DPSIR-concept) provides a heuristic framework for the analysis of cause–effect relationships in complex systems, which are subject to human action (Brandt, 2000). It also helps to select the variables and indicators to be monitored and analysed in order to study the environmental dimension of sprawl. The general idea behind this concept is that human activities, i.e. driving forces, exert a certain pressure on a particular part of the natural environment causing a change in the state of the physical media. The consequence of this process is environmental impact, which usually results in certain (political, economic, socio-cultural) responses by society. These responses may or may not modify the nature of the driving forces (thus mitigating or even enhancing the actual pressure) and/or compensate for the impact (which may be mitigated by technical solutions) (http://glossary.eea.eu.int/EEAGlossary/D/DPSIR). In addition, the driving forces may also be altered directly by the impact. Applied to the process of urban sprawl, the DPSIR-concept enables us to conceptualise and observe the underlying dynamics as follows:

- Generally speaking, urban development is induced by societal and economic processes, such as population growth and the accumulation of wealth. In an actor-oriented perspective, however, the driving forces of urban sprawl could be conceptualised more specifically by referring to the 'demand' for urban sprawl. This demand becomes tangible with the activities of the actors who either plan and/or facilitate urban development or enter the real estate and/or housing markets in search of a (new) location. (The term actor is used here in the sociological sense of an agent, individual or collective, capable of undertaking purposeful action.)
- The pressure that is caused by this demand for urban sprawl is defined – and measured – as initially stated: as conversion of non-urban to urban land.
- This pressure results in a certain state of land cover, the indicator for which is the proportion of impervious surfaces.

- Surface sealing has its most obvious and critical impact in the area of water balance. It leads to, and is indicated by a rise in water surface run-off which is tantamount to both a reduction in groundwater recharge and a decline in effective evapotranspiration.
- Many vested interests and actors are affected by, and therefore in some way or other react to, urban sprawl. In order to study the response of society to the impact of sprawl on water balance it therefore seems appropriate to look at how different (collective) agents that become concerned with the issue perform in the public discourse on urban sprawl and try to influence land-use policies.

Fig. 1 sketches the heuristic DPSIR-concept regarding the trade off between urban sprawl and water balance. The arrows represent the cause–effect relationships between the five elements of the concept. The figure illustrates that, in addition to the (potential) feedback from the response, there may also be feedback from the impact on the driving forces (in that environmental degradation can reduce the attractiveness and thus the demand for land). In any case, as a broken arrow indicates a somewhat weak causal relationship, it becomes apparent that the argument below will be that, firstly, the environmental impact of urban sprawl is only of minor importance for societal response to land consumption and, secondly, the feedback loops from this response to the dynamics of sprawl are generally weak.

3.2. *Breaking down and applying the DPSIR-concept to the issue of land-use change*

3.2.1. *Driving forces: demand for urban sprawl*

The demand for urban development, and thus urban sprawl, is largely determined by both the 'hard' facts of demographic and economic dynamics (e.g. Ciscel, 2001) as well as the socio-cultural and institutional context of decisions and activities (of sprawl producing agents) (e.g. Johnson, 1997). This context comprises common beliefs, values, and norms of conduct as well as the organisational and legal setting of a society. Although no empirical data has been researched in these fields for the case study, the review of literature in connection with scholarly reflection allows a general assessment in how far the demand is affected by the impact of sprawl. However, while we address these topics in a general manner here, it remains a goal to also address the driving forces of sprawl empirically.

3.2.2. *Pressure: land-use change*

Monitoring long-term land-use change in the study region resorted to three different data sources. Firstly, topographic maps from 1870, 1940, 1985, 1997, and 2003, as well as planning documents for areas dedicated to urban land use in the future, were used to create a digital land-use data base. Secondly, field surveys were carried out in order to obtain the missing (detailed) information on land use in particular areas (Haase and Magnucki, 2004). From these sources, GIS-based vector files containing land-use nomenclature and derived sealing rates were established. The one-level land-use classification applied here (Table 2) goes beyond the degree of differentiation of most attempts to scrutinise urban sprawl on a regional level (cf. Stanilov, 2002). Thirdly, existing studies on the historic and current development of Leipzig and its region were analysed so as to comprehend the respective framework conditions of land conversion (Haase et al., 2004).

3.2.3. *State: land cover*

Based on methodological findings by Steinhardt and Volk (2002) and Frede et al. (2002) and drawing on reference data from other studies on Leipzig (Wickop et al., 1998; Münchow, 1999) as well as field surveys, it was possible to assign a percentage of average impervious surface to every urban land-use class. Thus, along with Münchow (1999) a set of "structural types" of urban land, characterised in terms of usage, surfacing and drainage, could be discerned. When different information concerning the degree of surfacing in a particular structural type was found, the mean value was calculated. Thus, a scale-specific clas-

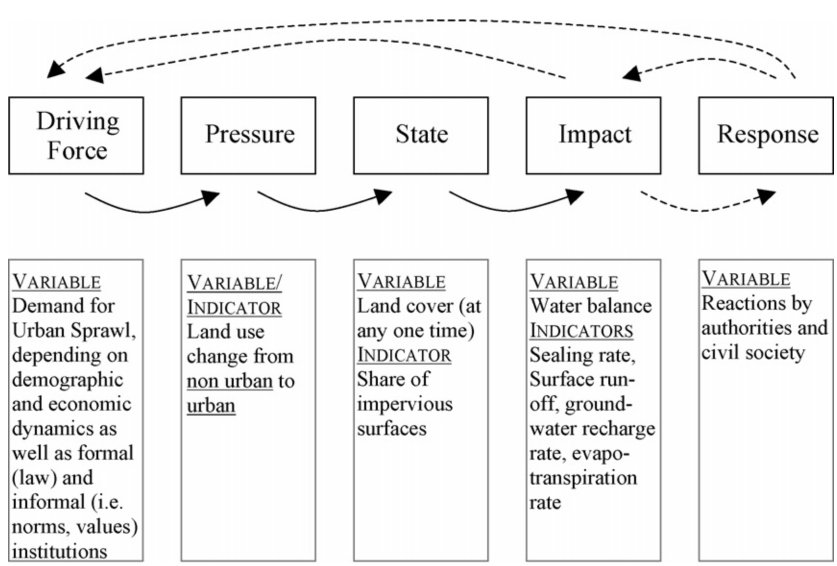

Fig. 1. Application of the DPSIR-concept to the issues of urban sprawl and water balance.

Table 2
Impervious land at the urban fringe 1940–1997 (Haase and Magnucki, 2004)

Urban land-use type	Construction period	Sealing rate (%)	Share of urban area of Leipzig since 1940
Old centres	Medieval times to 1945	63	9.0
Old built-up area	1870–1910	>60	–
New built-up area	1920–1960	32–38	1.7
Modern estate GDR-time	1960–1990 (GDR)	52–63	2.1
Modern estate after 1990	After 1990 (post GDR)	58–68	0.1
Detached houses	Continuously from 1850	49–52	9.0
Parks, garden, cemetery	Medieval times to today	20	9.8
Trade area	Continuously from 1850	>85	5.2
Arable and grass land		–	52.1
Urban forest	Urban forest since 1560	–	7.2

sification of impervious land covering the whole study region was obtained (Table 3; Haase and Schmidt, 2003), providing a sound data base for the water balance models ABIMO and MESSER (see below).

An equal interval classification was used to select the classes of impervious land. The selection of run-off classes was conducted using 25 mm-classes for lower rates (0–100 mm) and 50 mm-classes for higher rates. These thresholds were chosen in order to be consistent with the literature and to obtain data that is comparable to the findings from other studies (cf. Messer, 1997; Münchow, 1999).

3.2.4. Impact: water balance

Deal and Schunk (2004) argue that surfacing open land, especially in connection with the compaction and improvement of the soil-own drainage network, results in higher and accelerated direct surface run-off and thus has some critical consequences (cf. Collin and Melloul, 2003; Emmerling and Udelhoven, 2002): An increase in surface run-off usually leads to, firstly, a drop in groundwater recharge rates and subsequently also in the low-water flow of receiving water, secondly, a reduction in water content in the urban atmosphere, and thirdly, a decline in the water retention and filtering capacity of soils and surfaces for pollutants. Fourthly, in case of heavy precipitation the sewer systems and wastewater treatment plants are not capable of collecting the total amount of surface run-off resulting in an increased flood risk. Considering these findings the water balance model ABIMO (Glugla and Fürtig, 1997; Fig. 2) was applied to the investigation area in order to quantify the long-term urban water balance for the time period from 1870 to 2003.

Table 3
Classification of land uses into categories of impervious land

Categories of impervious land (%)	Land-use categories
0	Agriculture/forestry, raw materials extraction, areas of water
>0–20	Green spaces, parks, gardens, cemeteries
>20–40	Railway tracks, sports facilities, health/social services, ribbon development
>40–60	Large housing estates (flats and houses), utilities/waste disposal, military
>60–80	Older villages, 1990s housing estates, education/research
>80–100	Centre, commercial space, the service sector, trade show venues, roads

The classification of sealing rates follows field surveys carried out in various German cities based on the same concept of urban structure types. This reduces uncertainty of estimations of the total amount of impervious land and is in accordance with meso-scale GIS or model based approaches (Haase and Magnucki, 2004).

ABIMO was designed by the German Federal Institute of Hydrology for analysis in the quaternary area of Central Germany (pleistocene and holocene sediments and substrates with vertical seeping behaviour of the soils) and modified for urban areas. The main element of ABIMO is the calculation of basic run-off R from the mean actual evapotranspiration $\mathrm{ET_a}$ and the long-term mean precipitation rate P_0; ABIMO uses the BAGROV-relation to determine the actual evapotranspiration $\mathrm{ET_a}$ of an area Eqs. (1) and (2):

$$R = P_0 - \mathrm{ET_a} \quad (1)$$

$$\frac{\mathrm{dET_a}}{\mathrm{d}P_0} = 1 - \left(\frac{\mathrm{ET_a}}{\mathrm{ET_p}}\right)^n \quad (2)$$

The BAGROV-relation is based on the evaluation of long-term lysimeter studies. It describes the non-linear relation between precipitation and evaporation in dependence on local soil, land use and drainage properties. With knowledge of precipitation rate P_0, and potential evaporation $\mathrm{ET_P}$, and the efficiency parameter n, the BAGROV-relation can determine the real evaporation R for areas without groundwater influence. With increasing precipitation P_0, real evaporation R approaches potential evaporation $\mathrm{ET_P}$, or the quotient $R/\mathrm{ET_P}$ approaches a value of 1. With decreasing precipitation P_0, real evaporation R approaches precipitation P_0. The efficiency parameter n covers the modification of the water storage properties of the evaporative zone due to land use and soil of every site. The function of the drainage and sewer system is estimated according to the land-use classes and included in the ABIMO model via the parameter degree of canalisation (%).

Another model to calculate water surface run-off in urban areas was developed by adapting the model of Schroeder and Wyrwich (1990) to the conditions in the highly urbanised Ruhr area in Germany (Messer, 1997). Based on the ABIMO results, Messer's model calculates direct run-off rates in an area from the soil slope gradient, soil type, groundwater level (the greater the water table depth, the lower the direct run-off), land use, and

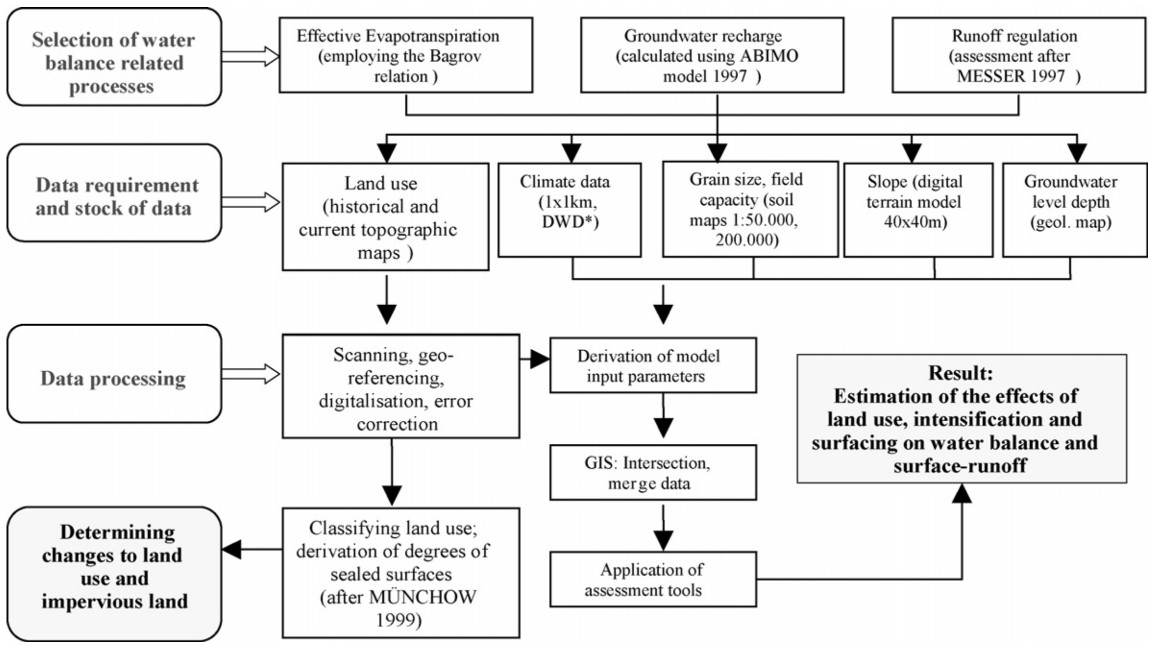

Fig. 2. Scheme of data integration, manipulation and modelling.

the degree of surfacing (Fig. 2). The direct run-off Q_D is calculated by determining the proportion p of excess water (difference between precipitation and evapotranspiration) Eq. (3):

$$Q_D = \frac{(N - ET_a)p}{100} \tag{3}$$

The factor p is much higher in the case of cohesive soils (silt, clay) compared to non-cohesive ones (sand). Concerning land cover p decreases in the following order: farmland, grassland and forest. In the case of surfaced areas, the proportion p rises with the degree of surfacing (Messer, 1997; Table 4).

3.2.5. Response: reactions by authorities and civil society

A sample of around 20 narrative interviews with experts and stakeholders from authorities and research institutes in Leipzig and the Leipzig region provided the empirical basis for the discussion of who (or what agents) responds how to the problem of urban sprawl. These interviews were carried out in the context of recent research projects on urban development in the Leipzig region (Rink et al., 1998; Nuissl et al., 2005). A major task of this research was to identify the perceptions of, and strategies on urban sprawl of various stakeholders from both public authorities and civil society.

4. Results

The case study has yielded insights into the nature of environmental and societal issues of sprawl as well as their interplay. In the following, results concerning the first element of the model, driving forces, will be highlighted at the end in order to relate them to the (potential) feedback

Table 4
Proportion p within excess water (modified according to Messer, 1997)

	Slope (0–2%)					
	Sand/backfilling			Loam		
	Depth to water table (m)					
	<1	1–2	>2	<1	1–2	>2
Land use						
Farmland/grassland	50	0	0	50	20	20
Mixed woodland	20	0	0	30	5	0
Surfacing 1–20% mixed vegetation	38	8	8	42	20	20
Surfacing 21–40% mixed vegetation	58	43	28	61	51	42
Surfacing 41–60% mixed vegetation	73	62	52	74	67	60
Surfacing 61–80% mixed vegetation	86	79	73	86	82	79
Surfacing 81–100% mixed vegetation	92	89	87	92	91	90
Water	0	0	0	0	0	0
Heath land	100	100	100	100	100	100

The direct run-off (Q_D) is calculated using the formula $Q_D = (N - ET_a) \times p/100$.

from the last element, response (compare feedback loops in Fig. 1).

4.1. Land-use change

Around 1870 the city of Leipzig had largely preserved its mediaeval shape and huge parts of the case study region (89%) were covered by arable land and forest (Fig. 3). It was primarily the perimeter block development and the increase in industry that contributed to the subsequent growth of the city. Contrary to popular belief among local and regional representatives of nature conservation, the size of forest area in Leipzig (around 20 km^2) has not changed much since 1870. On the other hand, the decrease in alluvial and riparian wetlands and grassland has been considerable ($-6.8\,km^2$). Leipzig's development into a compact industrial city between 1870 and 1940 was accompanied by the embankment and canalisation of the rivers, causing the floodplains in the heart of the city to almost entirely disappear in this period. Concurrently, large allotment sites (14 km^2) emerged and on the former outskirts, the number of detached and semi-detached houses increased considerably in the 1920s and 1930s (see Fig. 3).

During the socialist period (1945–1989) spatial urban growth mainly took place along the transport axes. Apart from the further decrease in arable and open land due to this moderate strip development, land-use change also occurred because of reconstruction work in the inner city areas, where vacant lots and brownfields resulting from the devastations of World War II were partially redeveloped. The most striking change in land use in this period was the establishment of an enormous housing estate for 100,000 inhabitants on the city's western fringe between 1976 and 1988. Likewise, other, though much smaller, housing estates were built in other places on the city's periphery (Fig. 3). The recent processes of urban sprawl after the German reunification meant a further considerable decrease in the proportion of arable and open land. In total, the changes in land use in the 1990s brought about an increase in surfaced land of about 10 km^2.

4.2. Land cover

Between 1945 and 2003, the surfaced areas in Leipzig increased by 48.7 km^2 (19%). In both absolute and proportional terms, Leipzig has more impervious land compared to other Eastern Central European cities of similar size, such as Dresden, Brno, or Bratislava. The reason for this can be found in the traditional, compact and densly built urban structures, which largely survived World War II. Whereas, during socialist times, it was mainly the erection of industry and large housing estates which contributed to land surfacing, these days the largest share of newly surfaced areas is accounted for by residential estates with a medium proportion of impervious land (>40–60%). Highly

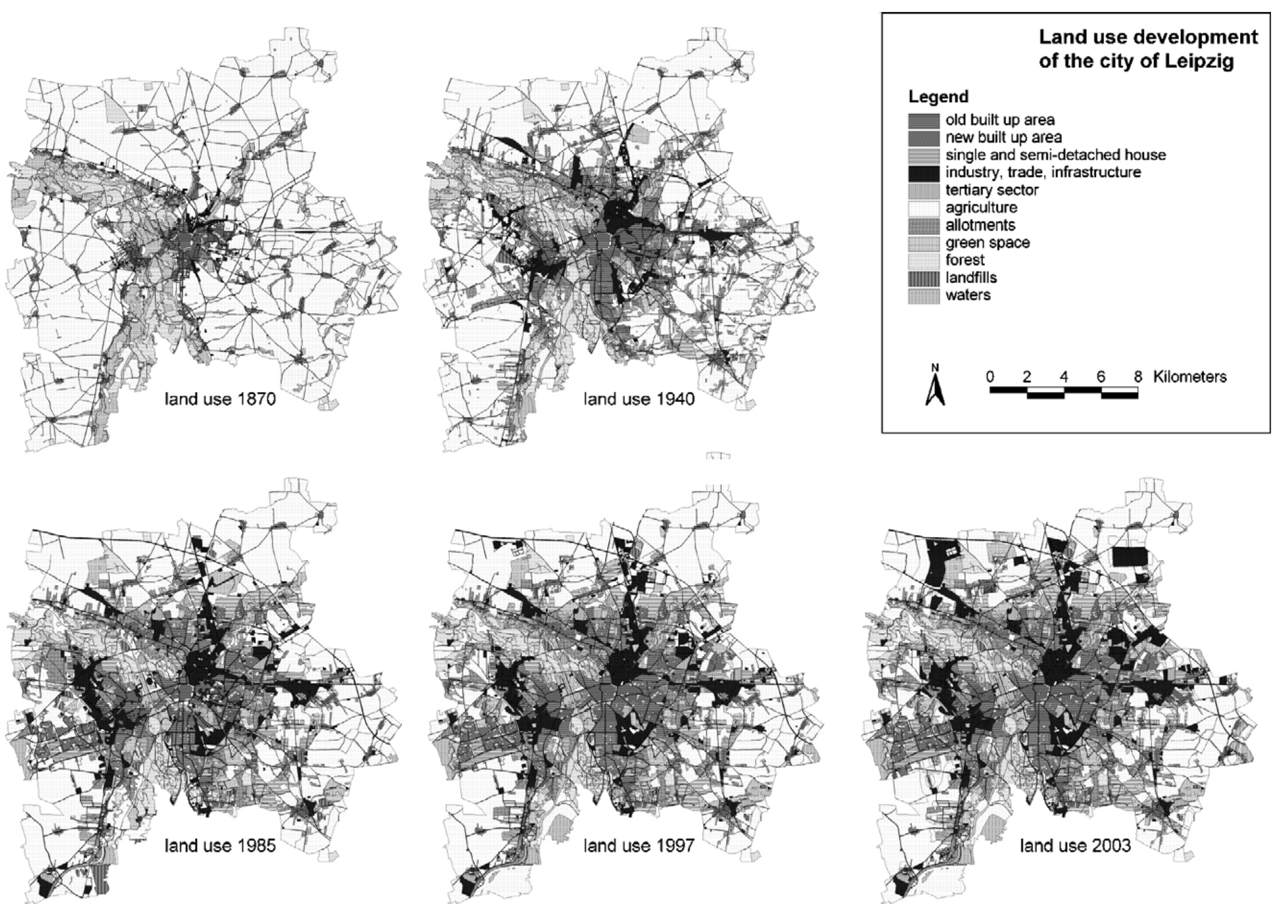

Fig. 3. Spatial growth and land conservation in Leipzig since 1870. The land use change was visualised based on topographic maps. The quality of the maps allows the deduction of land conversion and surface run-off rates as of 1940.

surfaced areas (>80–100%), such as industrial and commercial estates, also account for a large part of the land newly developed after 1990. Areas with a limited proportion of impervious surface (>0–20%) such as parks and gardens, make up for about 18% of land urbanised since 1940 (Fig. 3, cf. Table 2).

4.3. Water balance

In the study area, un-surfaced land mainly features medium to low surface run-off rates (>25–150 mm), as the loess soils here usually have high field capacities and are therefore able to take up and store large quantities of water. Due to land surfacing after 1940, the study area's high overall run-off control factor has been decreasing severely. In areas with a limited amount of impervious land the run-off control factor *p* is increasing: *p* starts to deteriorate as of a share of impervious land of >20%. Where this share amounts to >40–60%, respectively, surface run-off increases by as much as 200 mm/a (in 'prefab' housing estates). Once the share of impervious land exceeds 60%, run-off control drops by 3–4 levels and wherever it is >80%, run-off control drops by 5–6 levels (Fig. 4). With an average annual precipitation of 560–580 mm (mean value 1961–90), an increase in surface run-off of up to 450 mm/a has been determined in those areas that have been almost entirely surfaced (>80–100%) only after 1990. To sum up, the smaller the amount of impervious surface in newly developed areas, the more moderate and less problematic the increase in surface run-off, as there remains enough bare soil in which the precipitation water could percolate and infiltrate (Tables 5 and 6). Surface run-off also increases less severely where the soil had a poor infiltration capacity before it was surfaced. This holds in particular for loamy soils (Fig. 5).

Table 5
Long-term water balance for Leipzig

Year	Evapotranspiration (%)[a]	Surface run-off (%)[a]	Seeping water rate (%)[a]
1940	100	100	100
1985	90	154	107
1997	87	170	106
2003	83	262	99

[a] Referring to 1940 (1940 = 100%).

The increase in surface run-off is above all accompanied by a decline in actual evapotranspiration rates. In areas with a share of impervious land of >20–40%, evapotranspiration declines by 100–150 mm/a; in areas where this share is very high (>80–100%), it goes down by as much as 450 mm/a. Overall, this means that the water regime is shifting towards surface run-off throughout the study area (Tables 5 and 6).

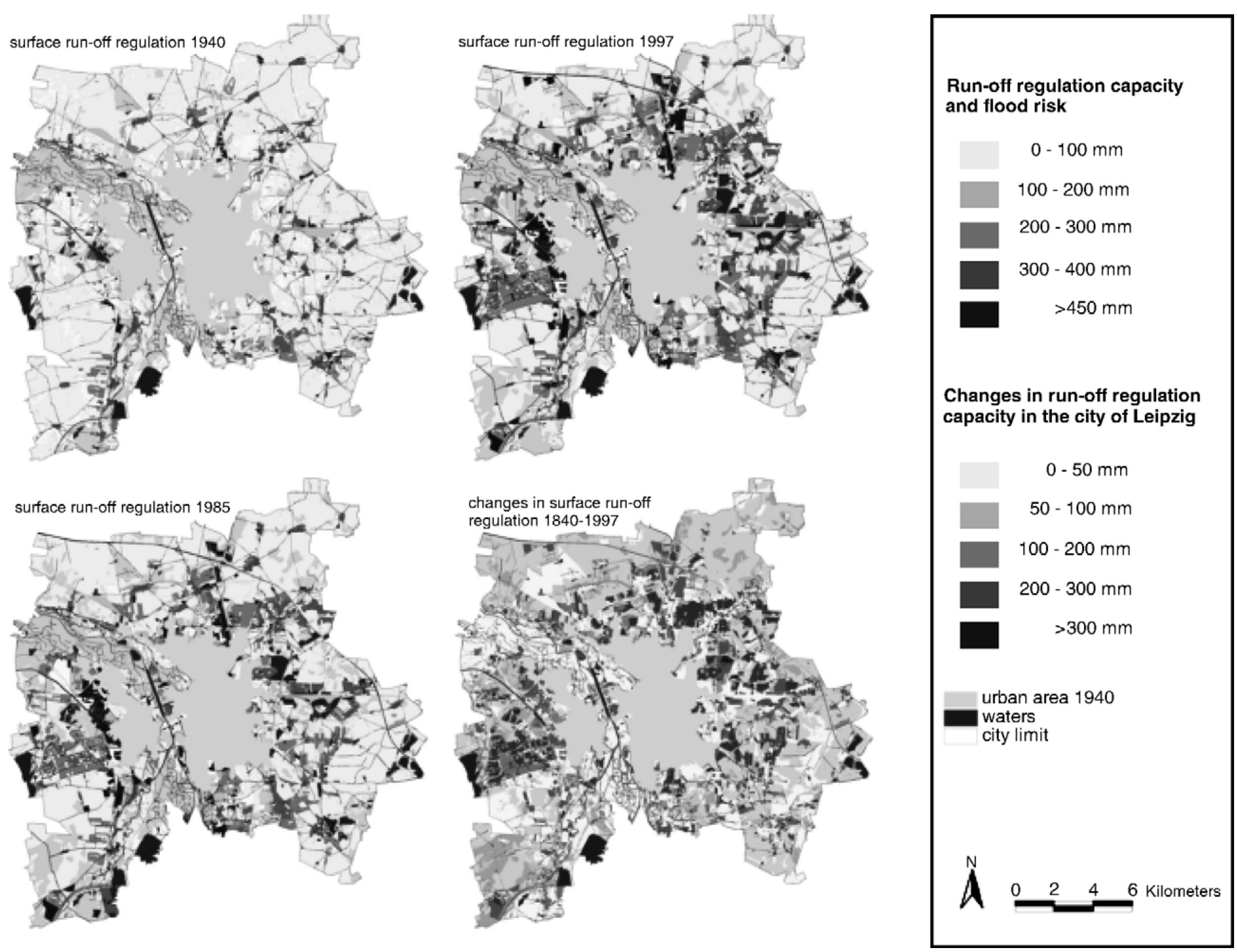

Fig. 4. Surface run-off rates 1940–1997.

Table 6
Water balance of the newly sealed areas in Leipzig since 1940

Proportion of impervious land (%)	Area (ha)	Evapotranspiration (mm/a)	Surface run-off (mm/a)	Seepage water rate (mm/a)
>0–20	1111	351–550	1–150	51–300
>20–40	626	251–450	51–250	51–250
>40–60	2547	201–350	151–300	101–200
>60–80	146	151–300	251–350	51–125
>80–100	1842	151–200	351–450	1–75

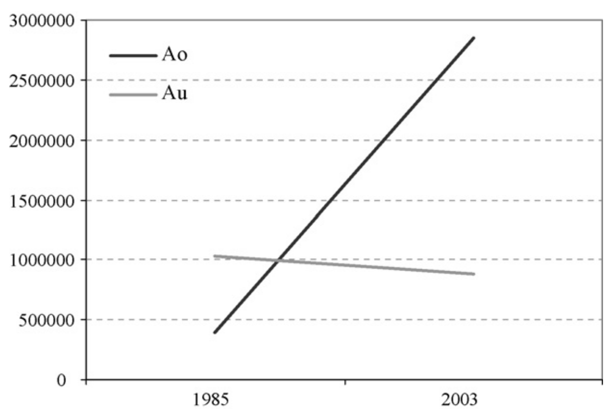

Fig. 5. Total amount of increase and decrease of groundwater recharge (A_u) and surface run-off (A_o) for surfaced land newly sealed since 1985.

Due to changes in land use, the groundwater recharge rates on agricultural land are about 125–175 mm from East to West of the study region, which is in line with the distribution of precipitation. The amount of percolation in areas where surfacing is up to 60% could be as much as 100 mm/a. In areas where surfacing is >60%, percolation has declined by up to 150 mm/a.

4.4. Reactions by authorities and civil society

4.4.1. Federal state authorities

The German federal government has recently developed its interest in tackling urban sprawl. It committed itself to the aim of reducing the rate of conversion of land from natural (or rural) to urban land by around three-quarters, from a nationwide 105 ha per day today to 30 ha per day by 2020 (The federal government of Germany, 2002). Thus the critics of unremitting land-use change and its environmental consequences have eventually also drawn the attention of policy makers — but note that this response is not rooted in the acknowledgement of specific problems in particular areas, but more in the general idea of preserving the environment. Regarding the actual steps taken to support this idea, federal policy is only in the early stages and is meeting strong resistance from lobby groups and parts of the political system (Besecke et al., 2005).

4.4.2. Regional authorities

Authorities at the sub-national or supra-local level, respectively, in charge of ensuring the balanced development of the territory have been attempting to contain sprawl in the study region with increasing success — with regional planning being particularly important (Herfert and Röhl, 2001). They undertake their efforts mainly for two reasons. Firstly, recent urban development has been particularly dispersed and thus – at least from a planner's point of view – calls for intervention. Secondly, it has proved to be a waste of economic resources, leading to an oversupply of developed land and housing because population in Eastern Germany is in decline (Lütke-Daldrup and Döhler-Behzadi, 2004). Both the legally binding regional development plan for Western Saxony (to which Leipzig belongs) and the informal plans and concepts prepared at a regional level address environmental issues. The former for instance defines particular protection areas for the provision of drinking water. But such regulations are mainly due to sectoral concerns – for example in the field of water management – and do not affect developmental activities in the region in general. Vice versa, the attempt of regional planning to contain such activities – i.e. to limit the amount of land for which development plans can be drawn up – is little motivated by concerns about ecological issues, such as water balance.

4.4.3. Local authorities (the city of Leipzig)

The city of Leipzig is struggling in the existing boards of regional policy for a limitation of developments in the surrounding municipalities whilst it has recently developed new residential neighbourhoods and industrial areas on its own periphery. Both these activities are prompted by the (fear of) negative impacts of urban sprawl on the core city in terms of population loss, declining tax base, and withdrawal of consumer purchasing power; they hardly reflect concerns about the environmental effects of urban sprawl. Accordingly, Leipzig's land preservation activities are largely focused on the city's floodplain forests, which contain only a small share of the region's non-urban land. On the other hand, following the United Nations initiative for global sustainability started in Rio de Janeiro in 1992, Leipzig has launched a "local Agenda 21" (UNCED, 1993) in order to gear its local development to the regulative idea of sustainability. The city established an agency which takes care of the city's compliance with this idea. However, this agency has only restricted financial and human resources at its disposal and has no legal and little political power. Moreover, its orientation to the sparing use of land does not tally with the city's decision-makers preoccupation with the promotion of economic development and growth. This creates a latent conflict which most recently became obvious with the establishment of a large car manufacturing plant on a huge greenfield site which should have been preserved according to the regional development plan. On the whole, there is little sign of the local authority responding to the water related impacts of sprawl.

4.4.4. Initiatives and activities by civil society

The most prominent response of civil society on urban sprawl consists in suburban advocacy groups trying to prevent further growth in their locality (Dear, 1992). Notwithstanding that this NIMBY-type of response to sprawl does not occur around Leipzig (so far), it however reflects worries about the social composition of the local population, the preservation of green space nearby and the value of land, rather than concerns about the environmental impact of urban development. What is more, common sense has it that technology has always made it possible to bypass the inevitable interference of urbanisation with the environment. People, therefore, tend to demand a mitigation of the negative consequences of urban sprawl by the authorities rather than call into question the phenomenon of sprawl itself. Accordingly, around Leipzig we find several citizens' initiatives for building new (bypass) roads. On the other hand, several nature preservation associations and environmentalist groups exist in Leipzig which undertake various political and lobbying activities in favour of a limitation of land development. These groups however are to be seen as part of the broader environmentalist movement (Rink, 2002). Their existence can at best be partly attributed to particular environmental disturbances in the region — and the problem of urban sprawl affecting the water balance is not really an issue here. Moreover, when it came to the 'big' decisions, such as the aforementioned establishing of a car manufacturer or the enlargement of the airport, they were largely unable to influence local policy. Yet, their national umbrella organisations have played a major part in prompting the contemporary debate about urban sprawl in Germany, reflecting the recognition of the environmental impacts of sprawl on a broader, i.e. national, scale.

4.5. Demand for urban sprawl

The actual interdependence of the environmental and societal dimensions of urban sprawl hinges on the extent to which the responses discussed above have an impact on the driving forces of sprawl. As regards to the study region, such feedback however proved to be insignificant. Furthermore, no indication could be found that the environmental impact reduces the demand for sprawl. Although some pressure groups were found to be 'responsive' to urban sprawl their activities have not yet led to a general shift in cultural orientations or institutional settings, let alone population dynamics or economic growth — it is in fact difficult to envision how these activities could affect the latter processes. However, if they succeed in implementing new planning and policy strategies, the responses outlined obviously have the potential to alter the framework conditions of decision-making and action in space — even though such alteration has so far barely taken place in the case study region. Additionally, in the longer run they can trigger a change in norms, beliefs, values and preferences concerning the proper use of land which today (not only in Leipzig) largely reflect the idea of a suburban lifestyle (e.g. Kaplan and Austin, 2004).

5. Discussion

5.1. On the assessment of the effects of urban sprawl on water balance

The long-term observation of urban sprawl on the medium scale has proven that it is the accumulation of impact, rather than short-term consequences that is likely to impair a region's water balance. Urban sprawl potentially leads to an increased flood risk produced by increasing surface run-off and a resulting higher release of water out of the urban system. This can restrict a city's chances for future development in that technical precautions necessary to mitigate these problems may become extremely expensive. However, it is fairly clear that the long-term effects of urban sprawl on the environment in general, and water balance in particular depend not only on the amount but also the distribution of the land to be developed, or the spatial pattern of land conversion, as well as the previous quality of this land (e.g. Newman, 2000; Burchell and Mukherji, 2003). In this respect, this paper is incomplete in that it does not account for urban form and handles urban sprawl mainly as a problem of quantity rather than quality. However, this shortcoming reflects the fact that little is known about how to measure environmental consequences of different land-use patterns, as has been shown by Alberti (2000) in a review of recent research work. Hence, it is very difficult to give an account in quantitative terms of the relation between land-use patterns and environmental variables, such as surface run-off or groundwater recharge. From an environmental point of view, the compact city generally seems to be the most desirable form because it is allows the preservation of the largest possible patches of 'natural' landscape. On the other hand however, intensification in existing urban areas tends to be accompanied by a considerable decline in environmental quality there. This was recently shown with regard to the microclimate by Pauleit et al. (2005) and has been illustrated for water balance in this paper. Thus, further research is required in order to provide scientific support for spatial planning.

5.2. On the response of society to the environmental impacts of sprawl

The case of Leipzig demonstrates that it is mainly the upper levels of the administrative system that respond to the impact of urban sprawl on water balance. Overall it is for at least three reasons why other actors seem to be less concerned about this issue:

Firstly, except for the widespread fear of the destruction of landscapes, the environmental impact of urban sprawl generally affects public rather than private interests. It is public bodies that have to deal with a disturbed water balance or an increased flood risk.

Secondly, if the local budget depends on the taxation of local firms and population, local authorities first of all perceive the fiscal consequences of urban sprawl as an urgent problem (Brueckner and Kim, 2003). Its environmental impact, for instance on water balance, seems to be less important from the local point of view, because it accumulates over a long period of time and becomes imminent only at some stage in the future.

Thirdly, on the local level the latent conflict between the orientation towards growth and the desire to protect the environment becomes most obvious. Especially in countries like Germany where local authorities have considerable political and legal power and at the same time largely depend on the local tax base, representatives and stakeholders have almost no alternative but to try to attract investors to their own municipality, thus promoting its (spatial) growth (Gillette, 2001). Their environmental concerns are usually limited to the preservation of green areas valuable for recreation purposes and – of course – the negative impacts of urban sprawl in neighbouring communes.

That the most important responses to the environmental impact of sprawl occur at a national level bears some kind of coherence insofar as it is on this level where policies on urban sprawl can become most effective. Land-use planning on the regional or local level may be able to shape land-use patterns, but has little means to exert influence on the quantity of land-use change (Ackerman, 1999). This requires an attempt to change the driving forces of urban sprawl — in particular the (economic) dis-/incentives for behaviour in space (Pendall, 1999; Gihring, 1999; Anthony, 2004), which are a part of the institutional context. Such dis-/incentives however are primarily set by national (tax) policy on economic development and housing. Accordingly, urban sprawl has frequently proved to be largely a result of the legal framework for urban development. This is true for instance of the massive urban sprawl in the US (Fishman, 1987) and the UK (Harris and Larkham, 1999) in the 1930s and 1940s as well as in Eastern Germany in the 1990s with the federal government largely subsidising any kind of development in the area (Nuissl and Rink, 2005).

5.3. On the interface and feedback between the societal and the environmental dimension of urban sprawl

The study illustrates that the environmental dimension of urban sprawl is connected to the societal sphere. However, when it comes, on the other hand, to the repercussions of the environmental impact of sprawl on the social world, the interrelation between the two spheres seems to be somewhat weaker than initially assumed. There is a response to urban sprawl by several involved parties, but it is rather difficult to define the extent to which this is due to environmental concerns. Moreover, this response does not automatically elicit feedback regarding the urban sprawl process itself (via changing its driving forces). Rather, the occurrence of such feedback will either require direct action from the responding actors or the raising of public awareness of the environmental dimension of sprawl. However, given how society deals with other environmental problems, such as energy consumption, air pollution, and climate change, which are even more pressing than urban sprawl, at least the latter requirement is not very likely to occur short term. The intensity of feedback from the environmental consequences to the causation of urban sprawl will, therefore, mainly depend on the extent to which those organisations that already call for public intervention into the processes of land-use change are able to gain political influence on spatial policy and planning. This however will rely not least on somewhat contingent framework conditions (cf. Gainsborough, 2002), such as the social composition of local population, polls, or unexpected events like the vast flooding in Central Europe in 2002 which helped to sensitize both authorities and the public to the issue of land consumption. Hence, it is difficult to unambiguously define the feedback by societal response on the causation of sprawl in a way that could be included in a general model.

5.4. On the contribution of the DPSIR-concept to the exploration of the impact of urban sprawl

Using the DPSIR-concept as a kind of perception tool that facilitates the interpretation of observations concerning an actual process of urban sprawl has helped to understand this process, its consequences and potential feedback. The DPSIR-concept should thus be able to support stakeholders in monitoring and assessing the dynamics of spatial development in a particular area (Antrop, 2004, p. 21) as well as evaluating the policies enacted to tackle urban sprawl (Lee et al., 1998). This may eventually provide a source of legitimacy for efforts to steer, or contain, urban sprawl and to promote the intensification of urban uses on already developed land. Hence, applied by urban policy makers the heuristic tool of the DPSIR-concept may itself contribute to the strengthening of the feedback between impact and the driving forces of urban sprawl.

6. Conclusions

Drawing on a long-term observation of land-use change in the city of Leipzig this paper proves that urban sprawl has considerable impact on the urban water balance. It highlights the problems that can arise in the long run due to the accumulation of this impact on the city or regional scale and thus gives an example of how severely urban growth on a city's fringes can affect environmental features such as water balance in quantitative terms. The paper further discusses the extent to which the impact of urban sprawl on the water balance has a feedback on how society handles and regulates the use of land. It has been found that, even though several actors do pay attention to the problem of urban sprawl, they are usually not concerned about its impact on the environment in general, or water balance in particular, in a specific region. It is therefore possible to conclude that land-use policy will not adapt automatically to the environmental challenges posed by urban sprawl. Rather it is a question of political argument on all levels of policy making and spatial planning whether these long-term hazardous challenges will be tackled.

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Multi-criteria assessment of socio-environmental aspects in shrinking cities. Experiences from eastern Germany

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Abstract

Demographic change and economic decline produce modified urban land use pattern and densities. Compared to the beginning of the 90s after the German reunification, nowadays massive housing and commercial vacancies followed by demolition and perforation come to pass in many cities of the former GDR. In consequence, a considerable surplus of urban brownfields has been created. Furthermore, the decline in the urban fabric affects social infrastructure and urban greenery of local neighbourhoods. Here, urban planning enters into 'uncharted territory' since it needs to assess the socio-environmental impact of shrinkage.

In order to carry out such an evaluation quantitatively, a multi-criteria assessment scheme (MCA) was developed and applied. Firstly, we identified infrastructure and land use changes related to vacancy and demolition. Secondly, demolition scenarios for the coming 20 years were applied in order to give an idea for a long-term monitoring approach at the local district level. A multi-criteria indicator matrix quantifies the socio-environmental impact on both urban greenery and residents. Using it, we set demolition scenarios against urban 'quality of life' targets. Empirical evidence comes from Leipzig, in eastern Germany, a representative case study for urban shrinkage processes.

The results show that shrinkage implies socio-environmental changes of residential livelihoods, however, does not simply increase or decrease the overall urban quality of life. The integrated assessment of all indicators identifies environmental and social opportunities, as well as the challenges a shrinking city is faced with.

Keywords: Multi-criteria assessment; Shrinking city; Demolition; Urban greenery; Social infrastructure

1. Introduction

Increasingly, cities experience signs of environmental stress, notably in the form of ground surface sealing, heat waves, poor air quality, excessive noise, and traffic congestion. The speed at which land is being consumed by urban development in Europe continues (Kasanko et al., 2006; EEA, 2006). It has often been stated that the enhancement of green areas has the potential to mitigate the adverse effects of urbanisation in a sustainable way, making cities more attractive to live in and reversing urban sprawl. Throughout Europe, there is an increasing requirement for more green space within and around cities (de Ridder, 2003). As urban green and open space plays this important role for the quality of life in cities, it is worth involving both ecological targets and the social criteria for local livelihoods in the assessment and management of urban green spaces (van den Berg, 2004).

But what about those cities that are shrinking and acquiring myriad brownfields and open spaces in the

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inner or peripheral parts of compact residential structures? Here, the story of this paper begins. Current trends in a number of European city regions provide evidence that they are undergoing considerable changes such as demographic ageing and out-migration due to economic decline. Comparable to the urban growth of the early 1990s after the societal transition in the former socialist Europe, today massive shrinkage processes and related vacancies in the housing and commercial sector come to pass (Hannemann, 2004). These processes produce perforated land use patterns, i.e. decreasing housing densities, abandoned sites and urban brownfields (Haase et al., submitted for publication).

Particularly in eastern Germany, urban regions today hold massive residential vacancies in non-renovated as well as renovated housing estates. In response to this, urban renewal programs such as '*Stadtumbau*' (Federal program for urban restructuring and demolition) had been set up on the national agenda to tackle this problem. These funds appear to have demolition as their main program, and urban reconstruction and regeneration support only as their second (Kabisch et al., 2005; Jurczek and Köppen, 2005).

As a consequence of demolition, a considerable surplus of brownfields and open spaces are being created. Moreover, the decline in the urban fabric affects local livelihoods and social infrastructure that are not prepared for shrinkage. In the case of both, urban planning enters 'uncharted territory' in terms of assessing the impact of shrinkage upon urban residents and ecosystems. Does this shrinkage provide the opportunity to make compact cities greener (EEA, 2006; Häußermann and Haila, 2005)? Does it enhance the quantity and quality of urban green spaces? Can prevailing urban structures and networks be maintained, or do we have to navigate into a patchy urban encounter? A review of current literature on shrinking cities reveals a larger degree of lamentation regarding this decline, as opposed to discussions about the positive aspects (Wiechmann, 2003).

Urban planning is challenged by shrinkage processes because it has to assess the social, environmental and spatial effects of demolition on local livelihoods in the form of qualitative and quantitative results. It is clear that shrinkage affects more than one dimension of sustainability. Many components have causal influences: the demolition of houses impacts the openness of land but, simultaneously, the persistence and accessibility of social infrastructure. A surplus of open land influences both quantity and quality of urban green. Moreover, newly emerging open space has to be incorporated into existing housing and green structures as well as transport networks. The design of new urban green corridors or neighbourhood parks is of primary interest in order to avoid a perforation of the urban structure, but consistently benefit from these spatial conditions. Last but not least, it has to be matched to a declining population.

Regarding this complex setting of causal–spatial interaction the paper firstly focuses on the analysis of socio-environmental pattern emerging under the process of urban shrinkage. Generally, in the urban environment green spaces represent a rare good in terms of recreational facilities and biodiversity. Under conditions of shrinkage these aspects have to be rethought in a different way as a considerable supply of brownfields and open space influences not only the amount of green spaces but has different impacts on the structure and quality of urban green and therefore on the urban ecosystem. Beside that, determining factors for the residents' quality of life, such as supply and quality of urban green spaces as recreational areas as well as supply and accessibility of social and transportation infrastructure, are changing.

The second focus of this paper investigates the development of a framework to assess the above discussed impacts of shrinkage upon urban ecosystems and residents. To do this, a multi-criteria indicator matrix using clear quantification rules and a normative set of reference values has been developed for decision support. GIS-based multi-criteria impact matrices (Nijkamp and Ouwersloot, 2003; Perdicoúlis et al., in press; Perdicoúlis and Glasson, 2006; Thérivel, 2004) have already been applied in Environmental Impact Assessment (EIA) for many years now. In addition to these existing studies, the authors tested a multi-criteria assessment (MCA) scheme for a shrinking city. In doing so, infrastructural and housing structure changes induced by vacancy and demolition were detected for a case study, the eastern German city of Leipzig. Additionally, demolition scenarios for the coming 20 years were incorporated into the assessment. The multi-criteria indicator matrix quantifies socio-ecological impacts of shrinkage and sets them against a set of normative reference values.

2. Shrinking cities and their socio-environmental dimension

2.1. Shrinkage[1]

At present, large parts of Europe are undergoing considerable demographic changes (Antrop, 2004; Cloet,

[1] The term 'urban shrinkage' is used to describe the decline, emptying and depopulation processes in eastern German cities since 1990, which have occurred in such a *massive* form that it exceeds normal urban decline rates or even depopulation processes.

2003; Lutz, 2001; van de Kaa, 1987, 2004; Ogden and Hall, 2000). Accordingly, processes of fertility decline, rising life expectancy, ageing, structure and stability changes of households influence residential mobility enormously. The resulting modified housing demands as well as migration flows challenge both the urban housing market and the development of the urban land use. Along with massive out-migration and population loss urban shrinkage started to come into discussion in reference to urban Europe (Wiechmann, 2003; cf. Fig. 1).

Shrinkage in particular results from an economic decline in (most of all central and eastern) European city regions. In addition, industrialized areas are undergoing a demographic change in terms of fertility decrease, child bearing postponement, ageing, individualization of household forms and migration (Haase et al., 2005; Bösch-Supan et al., 2005). Both, the weak economy, low investment rates and labour-driven out-migration are to be seen as consequences of the political transition since 1990.

Pioneers in terms of shrinkage-experience are city regions of eastern Germany: most of them have been facing dramatic losses of inhabitants due to declining birth rates, but predominantly because of job-driven migration either to the western part of the country or to suburbia during the 1990s (Couch et al., 2005; Nuissl and Rink, 2005; Haase and Nuissl, 2007). After 1990, eastern German cities lost some 10 and 20% of their residents in a very short period of almost 10 years, among them Leipzig (mean value for big cities from 1990–1999 is about 16%; cf. again Fig. 1). The phenomena of urban shrinkage concomitant with "de-economisation, depopulation, and desurbanisation" (Hannemann, 2004) and low housing demand (Haase and Haase, submitted for publication) can be vividly exemplified: dilapidated residential buildings and estates, extensive brownfield and derelict commercial sites, streets with many vacant shops, housing, offices, underutilised social and technical infrastructure, and neglected parks and squares (Jessen, 2006).

Only some years ago shrinkage had been handled as a political taboo and was quasi neglected in planning. Conversely, growth was still slated high on the political agenda (Müller and Siedentop, 2004). Today, urban shrinkage has been acknowledged as a process that is going to be occurring more frequently, first and foremost in eastern Germany. Shrinkage, this appears to be evident, has serious implications for all dimensions of sustainability and quality of life in cities. In consequence, planners and policy makers search for new concepts to deal with it (Table 1). Shrinkage requires new action schemes such as restructuring, deconstruction and 'demolition due to receipt' in case of extreme vacancies. But also more sensitive measures such as the innovative reuse of abandoned land and brownfield re-development are discussed to open a sluice for reurbanisers (Wiechmann, 2003; Jurczek and Köppen, 2005).

2.2. Urban renewal in eastern German urban livelihoods

Because of the serious physical decline of many housing estates of the former GDR since the German reunification in 1990, a set of nationally funded urban regeneration programs had been developed and applied: in the early 1990s the 'Federal program of urban renewal' (*Bund-Länder-Programm 'Städtebauliche Erneuerung'*) or '*WENG*' (a program dedicated to enhancing the development of prefab housing estates) has been set up. Both programs primarily focused on the maintenance of the

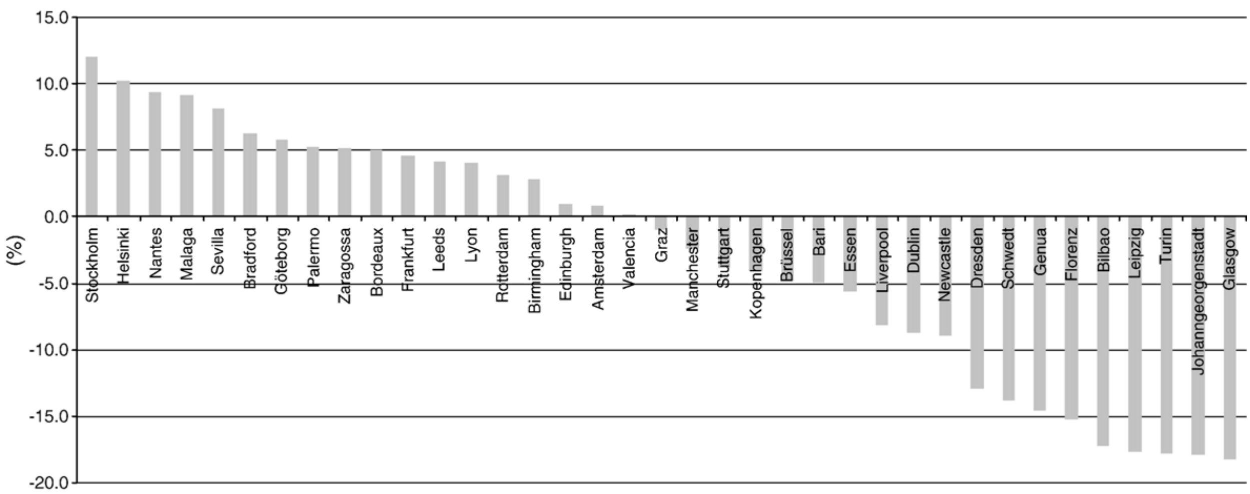

Fig. 1. Growing and shrinking cities in Europe: population development between 1981 and 1996. Leipzig is in close proximity to West and East European cities.

Table 1
Targets of growth and shrinkage (according to Wiechmann, 2003. Modified)

	Growth	Shrinkage
Overall goal	Steering of growth and environmental impact	Steering of decline and land abandonment
Concept/Plan	Agenda 2030; 30 ha-target by German Council for Sustainable Development	Federal Program for urban restructuring and demolition (for eastern and western Germany)
New construction	According to demand	Supply of residential and commercial space outweighs the demand by far
Space per resident	Housing space per person (for Leipzig: minimum 5 m^2/person) Recreation area per resident (10 m^2/person)	Housing space per person (for Leipzig: minimum>>5 m^2/person) Recreation area per resident (>>10 m^2/person)
Spatial structure	Compact city; dispersed periphery (sprawl), evolution	Perforated city (with compact clusters)
Housing structure	Construction, re-densification of inner city areas, creation of new settlements in suburbia	De-densification, deconstruction, dilapidation, regeneration, spacious housing
Urban green and recreation	Protection, definition of targets	Adaptation of targets, qualitative development
Public infrastructure	Centralized system	Decentralized systems, adaptation to lower demand and lower densities

core cities and their function as residential places. Later, in the mid-1990s, due to continuing out-migration to the West a rapid emptying of the housing stock started (Jessen, 2006). Finally, in the late 1990s, reconstructed old built-up housing estates were as affected by vacancy as GDR-era prefabricated blocks.

Today, empty and devastated housing areas accompanied by unused infrastructure produce pattern of 'urban perforation' in many eastern German cities (Lüdke-Daldrup, 2001; Haase et al., submitted). On the one hand, urban policy makers need to counteract this decline in the urban fabric. On the other, they are urged to create urban livelihoods that 'accept' shrinkage in the form of vacancies as long-term phenomena. Thus, urban renewal in eastern Germany became a new attribute in the form of the targeted reduction in prevailing empty housing and commercial estates (Kabisch, 2005). Additionally, urban policy makers initiated integrated programs as a new approach to urban regeneration, focussing not exclusively on the urban fabric, but also on social, economic and ecological aspects (Stadt Leipzig, 2005a,b). In this vein, 1999, the action of the "Social City" (*Soziale Stadt*) started to counteract the increasing social and spatial segregation resulting from urban shrinkage. Until recently, this program supports 390 initiatives in 260 German cities (www.sozialestadt.de).

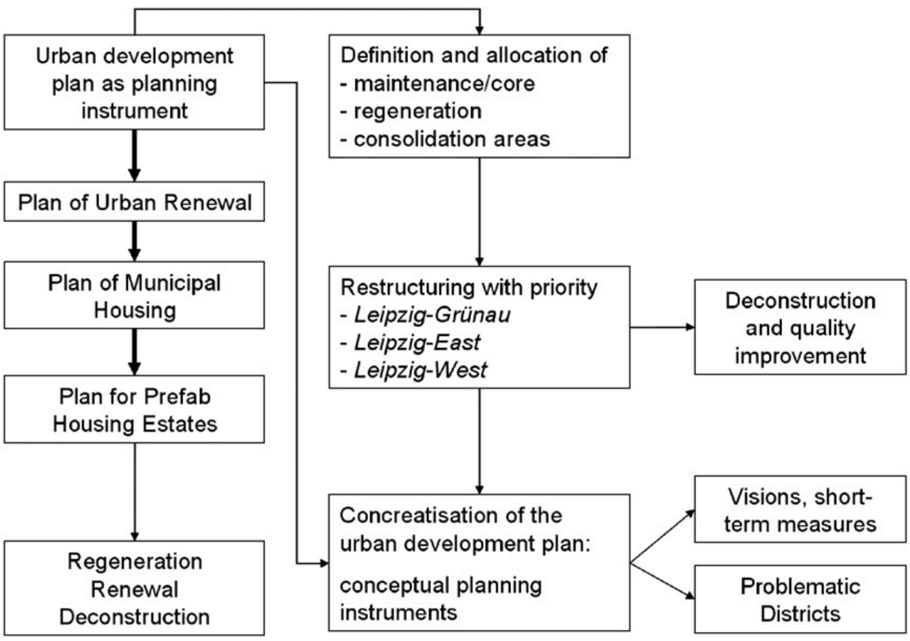

Fig. 2. Scheme of how urban renewal competes with shrinkage and vacancy problems, and where urban green comes into play.

In order to regulate the enormous housing vacancies, consequently, the action program '*Stadtumbau*' was implemented in 2002 (www.exwost.de). The basic idea of this program focuses predominantly on the consolidation of the housing market aiming at a better balance between housing demand and supply. Although demolition occurs in many parts of cities such as Leipzig, Chemnitz, Zwickau, Halle or Magdeburg, the supply of dwellings still outweighs the demand by far (Haase and Haase, submitted for publication). Further, '*Stadtumbau*' is to support municipal housing cooperatives and private house owners who are economically weakened by the high vacancies. In doing so, either an up-valuation or demolition of vacant buildings is financed (Stadt Leipzig, 2005a,b; Fig. 2).

Looking specifically at Leipzig, three different strategies have been implemented: firstly, the already mentioned initiative of the 'Social City' to foster urban regeneration using a manifold scenery of subsidies. Secondly, the two EU-programs "URBAN II" and "EFRE" have been used to support regeneration of the early-industrialised West Leipzig and to support urban housing renewal in East Leipzig (e.g. LOOP — Leipzig Owner Occupier Programme; EU, 2007). In terms of urban environment, ecology and local livelihoods both programs fund mainly actions to improve the urban quality of life, to assist in cultural and social beliefs and support medium and small enterprises (Table 2).

In the following empirical analysis, the paper focuses on two typical urban structure types: the old Wilhelminian housing estates and the large prefabricated estates of the 70s–80s (Table 3). Both types are to be found throughout the entire city but in our analysis we focus on representative examples to narrow down the issues of socio-ecological features of shrinkage to the level where impacts are measurable: firstly, the Wilhelminian housing area in the eastern part of the city (in the following referred to as East Leipzig) and the socialist prefab housing estate of Leipzig-Grünau in the western periphery (Fig. 3).

2.3. Two shrinking neighbourhoods in Leipzig

Within the Wilhelminian old built-up area of East Leipzig (here: the municipal districts of *Neustadt-Neuschönefeld, Volkmarsdorf*) we find small backyards, a heterogeneous and patchy green infrastructure between the housing complexes and small streets with very limited space for front-yards and trees. East Leipzig is dominated by close block-structures with a mainly residential function and — as a former workers' area —

Table 2
Activities of the urban renewal "East"

Type	Title	Purpose	Application in Leipzig
Programs of urban development	Federal Program of Urban renewal (SEP)	Regeneration of houses Improvement of public spaces Enlargement of urban greenery Ordinary measures	Areas of regeneration in the core city
	Development of new built-up housing estates (WENG)	Improvement of housing environment sensitive urban development of existing dwellings and housing estates	Leipzig-Grünau (1995–2005)
Integrated Programs	The Social City	Stabilisation of the urban fabric in combination with economic impulses	started 1999
		Renewal/creation of urban green Regeneration of the housing estates Reconstruction Improvement of image and identity of local districts Creation of identifying places	Leipzig-Grünau (since 2006) East Leipzig (until 2002)
	European Fund of Regional Development (EFRE)	Support of employment initiatives	East Leipzig
	URBAN II (European Regional development Fund ERDF)	Urban renewal and regeneration	Leipzig-West (LOOP since 2001)
		Increase urban competitiveness compared with suburbs	
	Federal program for urban restructuring and demolition "Stadtumbau Ost"	Specific program for eastern Germany due to extreme vacancies	Leipzig-Grünau (since 2006)
		Consolidation of the residential market and improvement Deconstruction Creation and regeneration of open spaces and public greenery	

Table 3
Shrinkage, vacancies and demolition, new open spaces for the 2 test sites of Leipzig-Grünau and East Leipzig* compared to the Federal State of Saxony**

Indicator		Leipzig-Grünau	East Leipzig	Saxony
Population development	1990–2004	−35,600	−5959	−123,500
Inhabitants >60	1990–2004	1676	−1,130	159,300
Residential vacancy	2004 (%)	20–30	25–>50	19.6 (2002)
Demolition of houses until	2002 (%)***	Reference housing stock (includes demolitions until 2002)	Reference housing stock (includes demolitions until 2002)	–
	2005 (%)	6.54	2.17	–
	2007/10 (%)	19.12	3.16	–
Planned demolition target	2020 (%)	–	8.69	14.00

* Selected parts of the respective district had been under investigation.
** Own calculations.
*** Housing stock of 2002 acts as reference stock > demolitions happened before 2002, therefore housing stock of 2002 is already affected by demolition.

is extremely narrow, overbuilt and mixed with small industrial areas and technical infrastructure. Neglected during GDR-time, East Leipzig had to register a loss of residents amounting to 30% during recent years. The building stock selectively reaches a share of about 50% vacancy (*Neustadt-Neuschönefeld*; Stadt Leipzig, 2003). The reasons therefore are of multi-dimensional character: a constant out-migration of inhabitants to other parts of the city leaving the poor, unemployed and uneducated behind (Stadt Leipzig, 2002a,b) leads to further vacancy and devastation, which cause an atmosphere of insecurity, precarious social conditions, and creates a basically negative image within the city.

As one of the most visible consequences, since 2002 up to the present about 2% of the residential stock has been demolished (Schetke, 2006). Two future demolition scenarios have been designed: Up to 2010 about 10% demolition is approximated for the areas of highest share of vacancy. By 2020, the city aims at 30% dilapidation corresponding to a prognostic share of vacancy of 14% until then. In terms of the spatial patterns that remain under shrinkage and such selective demolition, perforation will dominate the neighbourhoods (Lüdke-Daldrup, 2001; Haase et al., submitted for publication). The emerging open spaces will encompass a main greenway upgraded by structural elements such as aforestations, additional single green, and this will be designed under the slogan of 'stepping stones'. Altogether, these components form a new green infrastructural element in East Leipzig connecting the neighbourhood with the outskirts of the city (Stadt Leipzig, 2003).

The large prefabricated housing estate of Leipzig-Grünau confronts us with a completely different picture: it belongs to the largest prefab-areas of the former GDR taking up an area of almost 9 ha. For this paper, three housing complexes covering an area of 1 km^2 each were under investigation (Schetke, 2006). As does East Leipzig, also Leipzig-Grünau suffers from an extreme out-migration. Alone between 1983 and 2003, the number of inhabitants decreased from 85,000 to 50,000 (Stadt Leipzig, 2005a,b) followed by a rising overflow of housing space.

These developments require new urban planning approaches that would involve a fitting of existing living

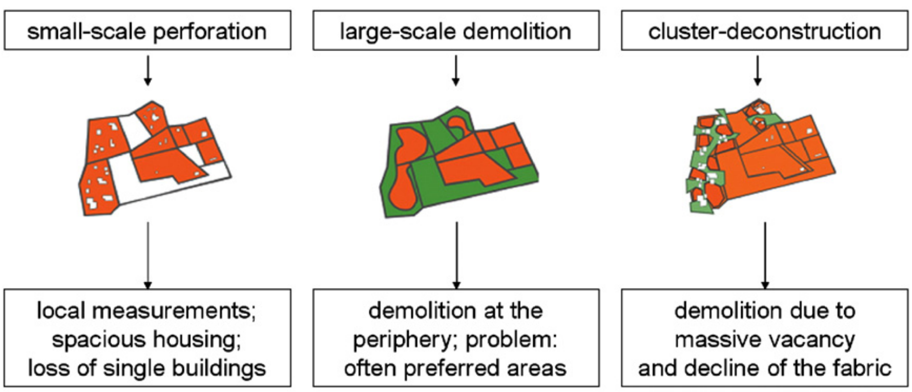

Fig. 3. Examples of urban shrinkage pattern in Leipzig-Grünau and East Leipzig.

spaces with decreasing population numbers by adjusting the size of the quarter through demolition, conversion of living spaces and reuse of brownfields in the form of newly created follow-up landscapes named '*Wohnfolgelandschaften*' (Stadt Leipzig, 2002a,b). This additional space is one of the current challenges for urban planners to tackle (Rößler et al., 2005). By end of 2006 about 20% of the urban fabric will have been demolished (Schetke, 2006). In contrast to East Leipzig, the urban structure of Leipzig-Grünau is characterized by wide open lawns, large backyards and plazas. Compared to the old built-up structures where a deficit remains in terms of green space, Grünau suffers from a deficit of quality of urban green which has never been improved since the area had been built in the 1970s and 1980s. Therefore, primary planning goals include the qualification of green spaces by improving them according to specific user groups as well as the strengthening of private green spaces by creating allotments, terraces, patios and cosy backyards (Stadt Leipzig, 2002b; cf. again Fig. 2).

Although renewal programs provide a rough framework for managing the shrinking fabric of the neighbourhoods, specific concepts for the future design of open space and greenery have to be planned in more detail.

3. Methodology

3.1. MCA and DSS

An all-encompassing examination of pathways and scenarios of urban renewal in a shrinking city requires an approach depicting different dimensions of sustainability. A Multi-Criteria Analysis (MCA) allows the integration of manifold aspects of a problem and considers conflicts of interest of different stakeholders (e.g. residents) within a planning process (Nijkamp et al., 2002; Nijkamp and Vreeker, 2000). Concerning the definition of a sustainable state of a system or an urban region, Nijkamp and Ouwersloot (2003) suggest a critical (or minimum) framework of the research area using respective Critical Target Values (CTV) for assessment purposes (Fig. 4).

The MCA is a helpful instrument to realize regional sustainable development when being integrated into spatial planning (Nijkamp and Ouwersloot, 2003; Thérivel, 2004). Beside the MCA, decision support systems (DSS) represent another instrument in urban planning by bundling planning alternatives and scientific knowledge as well as facilitating consensus of the stakeholders. Consequently, a combined approach of MCA and DSS offers a tool to handle spatial decision problems quantitatively. However, the tool does not give an objective answer in the sense of "what to do best" (Rauschmayer, 2000; Belton and Steward, 2002; Gal et al., 1999). But, it supports decision makers by firstly identifying (sustainable) decision criteria and secondly by assessing action options referring to these criteria and thirdly by merging the assessments analytically (Rauschmayer, 2000; Laing, 2006). They synthesize assessment techniques with judgement methods and form a sound analytical base for decision analysis (Nijkamp et al., 2002).

For this paper, criteria and indicators for two dimensions of sustainability, the social and the ecological, have been developed based on the interdisciplinary criteria catalogue (ICC) produced by the 'URGE — Urban Green Spaces' EU-project (Coles and Grayson, 2004; Venn and Niemela, 2004; Fig. 5) and experiences from an EU-FP5-project Re Urban Mobil on re-urbanisation processes in inner city areas (www.re-urban.com; Haase et al., 2007, in press). Additionally, a list of environmental target values used by city planners in Leipzig (in German: *urbane Umweltqualitätsziele*) has been incorporated to substantiate the assessment.

Each dimension spreads into criteria and respective indicators being of quantitative and qualitative nature. An interdisciplinary indicator catalogue with clear quantification rules is one of the major outputs of this work (see Table A1: equations and valuation). Each indicator has a

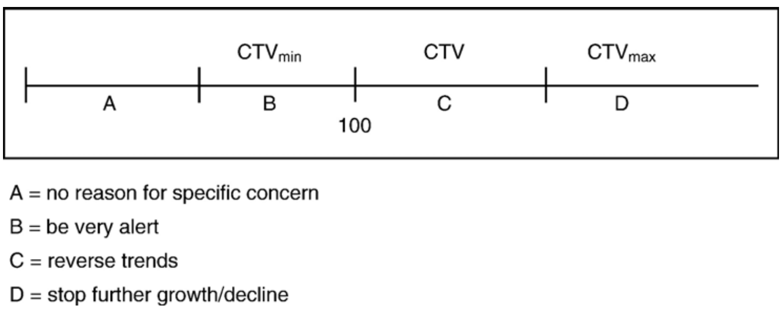

Fig. 4. Critical Target Values (CTV) used for assessment (modified according to Nijkamp et al., 2002).

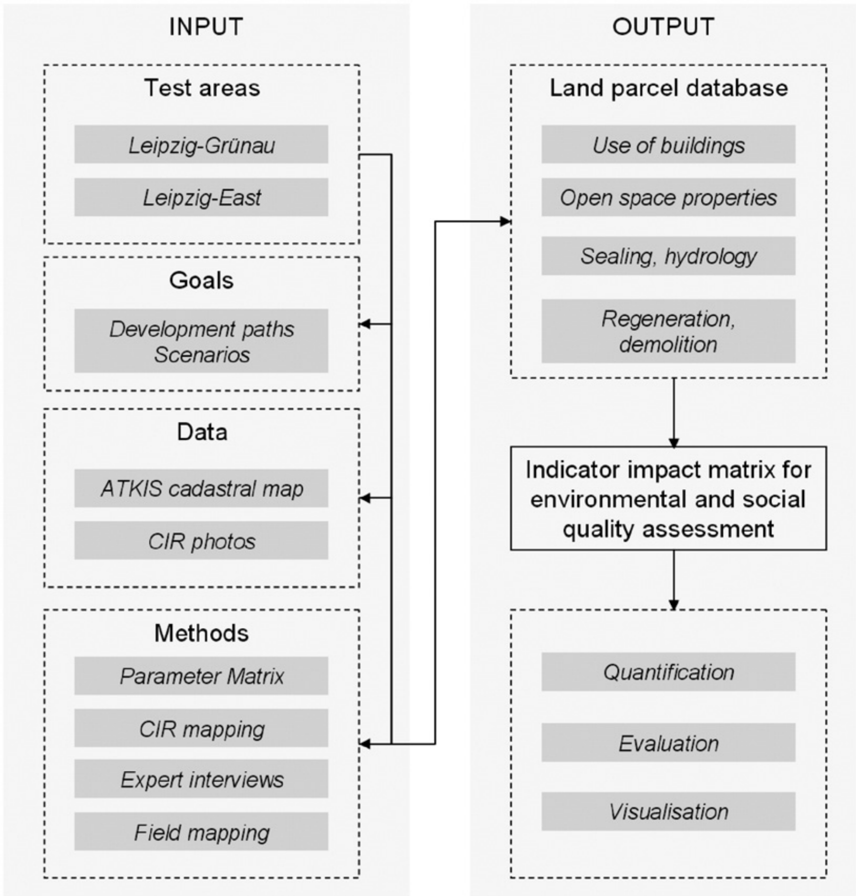

Fig. 5. Conceptual approach.

spatial dimension, and the whole catalogue is GIS-coupled to relate it easily to spatial entities and scenarios, which are predominantly used in planning procedures (Phua and Minova, 2004). In the following section we will present the individual indicators.

3.2. Indicators for shrinking environments

3.2.1. The indicator matrix

The indicator matrix represents a nested framework starting from the dimension of sustainability (Eq. (1))

$$D_S = \sum_{1,2,\ldots} C_S \quad (1)$$

where D_S is the respective dimension of sustainability and C_S the respective criterion.

Each criterion consists itself of a set of quantifiable sustainability indicators (Eq. (2)):

$$C_S = \sum_{1,2,\ldots} I_S \quad (2)$$

where I_S represents the indicator.

While exploring parts of the URGE ICC, many new indicators had been developed and tested based on official available data. For several indicator values (e.g. living space) a normalization of the number of inhabitants had been executed before the assessment. For Leipzig-Grünau, an additional normalisation of the data by height of the buildings and share of these buildings (floor type) of a test area (10 ha each) had to be applied because of the heterogeneous building structure in Grünau ranging from 5 to 16 floors. The final set consists of 2 dimensions and 10 criteria (the respective indicators are listed in Table A1):

1) Ecological dimension:
   a. Soil quality: The use of soil resources is one of the most sensible aspects in urban ecology. Soil quality, and the fulfilment of soil functions, depends significantly on its degree of conversion and imperviousness. The sealing of soil, and thus a degradation of its quality, is a typical factor in each urbanisation process. Looking at urban shrinkage, a loss of the urban fabric and the revitalisation of sealed areas are opportunities of (a partial)

recovering of the soil quality. This criterion is therefore used to evaluate these (positive) impacts of shrinkage on soil resources.

b. Hydrology, water balance: Land surfaces have to fulfil several functions that are highly relevant for the urban ecosystem and highly vulnerable towards conversion. These functions such as groundwater regeneration, precipitation water retention or the filtering of pollutants depend on the degree of imperviousness. Urbanisation normally diminishes these functions. Again, the process of urban shrinkage offers ways to regain them and thus contribute to a limited recovering of the urban bio-physical system.
c. Quality of urban green: In densely populated urban areas the demolition of buildings is considered to have mainly positive impacts on urban green spaces. But not only the quantity of the new green areas needs to be monitored. Their quality and thus a positive contribution to the urban ecosystems on the one hand and to citizen's quality of life on the other have to be examined, too.
d. Quantity of urban green determines the potential of urban green infrastructure to successfully fulfil resident's demands. It is further relevant for the wellbeing of an urban ecosystem and its ability to provide suitable habitats. The context of urban shrinkage also here offers perspectives to get more urban green at all. Therefore, this criterion is evaluated regarding its persistence (= offer of re-creational function and to prevent habitat fragmentation; www.urge-project.ufz.de; URGE, 2004).

2) Social Dimension:
   e. Green supply: Urban green spaces are rare resources which are in need of protection. They are in demand to fulfil different functions such as recreation and determine resident's quality of life. In this context, urban shrinkage offers new options for preserving urban green spaces and outweighing a potential undersupply with recreational areas. Not only availability and persistence have to be measured and assessed, but properties of green spaces as well, such as size, height and distance to houses/roads, in order to become relevant for recreational purposes.
   f. Population: The evaluation of the population structure is an important criterion to visualise and to assess the effects of both urban renewal and shrinkage. Particularly in terms of urban shrinkage, out-migration and aging come to pass influencing the population structure. In the examined neighbourhoods these aspects are of high uncertainty. The same is true for the (already existing) diffusion of the social network. Set against this background, the two questions have been raised, firstly, whether there is any change in population decline resulting from demolition and, secondly, whether any integration of the local residents within urban planning is under way.
   g. Infrastructure: As a result of decreasing numbers of inhabitants and the loss of housing substance, the supply with and the accessibility of facilities of social and technical infrastructure are in flux. These facilities often determine the quality of life of the residents and the urban quality of a neighbourhood (environmental standards due to BBR, ExWoSt-Working Group "Future cities"(Schöning and Borchard, 1992). Therefore, its reduction means a major negative impact of shrinkage upon citizens.
   h. Urban fabric and housing: Urban shrinkage is not only determined by a decrease in total population, but is also detectable because of its declining building substance due to residential vacancy. In order to come to terms with shrinkage, demolition and renovation are implemented. Accordingly, this criterion is not only applied to monitor quantitative and qualitative changes in the housing stock, but also to transfer related indicators monitoring the living conditions of the local residents.

3.2.2. Data compilation

The availability of data on urban development in Leipzig is fairly good. Table 4 indicates the spatially explicit data used for the MCA and the respective impact assessment. Compiling the database for the two test areas, East Leipzig and Grünau, analogous and digital data were primarily used in order to get an initial picture of the overall data quality at district, block and building scale.

Additionally, when digital data did not provide a full picture of the current situation or the change from a previous state to the current one, field data compilation in the form of mapping had been carried out. Table 5 gives an overview of the high-grain classification of urban greenery that had been created via mapping. Despite the expenditure of time and budget, efforts to create such a detailed data base on the urban open space are very worthwhile in order to scale the impact assessment down to the scale of alternative land (unit) uses. The results in Section 4 prove this statement.

3.2.3. Expert interviews

A broad collection of data showing the supply with social infrastructure has been important for depicting the

Table 4
Data used

Criterion	Data set	Spatial and temporal resolution	References; availability
Soil	Urban soil map	1.50,000	Haase and Nuissl (2007)
Hydrology	Model data for the long-term water balance	1:25,000	Haase and Nuissl (2007)
Land use	Topographic Map	1:25,000	Haase and Nuissl (2007)
	CIR aerial photographs	1:10,000	Saxon State Agency for Environment
	Cadastral Map	1:500	City of Leipzig
	Field Mapping		
Vegetation	Biotope Map	1:10,000	Saxon State Agency for Environment
	Field Mapping		
Buildings, fabric	Cadastral Map	1:500	City of Leipzig
Socio-demographic data	Municipal Statistics	Local districts	City of Leipzig
Infrastructure	Vector data	Single features	Municipal transport cooperative Municipal Agency for Education
Residential vacancy	Municipal Statistics Field Mapping	Local districts	City of Leipzig
Demolition	Plans, Reports Field Mapping	Varying	City of Leipzig own exploration

impact of shrinkage on the social sector. Since these individual data are scarcely or incompletely published for a single neighbourhood, additional expert interviews were necessary (Schetke, 2006). Thus a series of four interviews were carried out, not to get a quantitative view, but in order to gain qualitative and decision-relevant knowledge on how demolition procedures actually evolve, on future plans (still not printed) concerning school and kindergarten closures in the respective test areas and, finally, on greenery development that was either not detectable via remote sensing or field mapping. This qualitative knowledge fed the discussion of the quantitative results in Section 5 and helped to set up data for some of the indicators. For the interviews (1) the municipal department of green planning and (2) the municipal department of housing and urban reconstruction of the city of Leipzig, (3) the municipal agency for education and (4) district managers had been chosen.

3.3. Scenario building and integrated assessment

Urban land-use changes are highly dynamic. Thus, in this paper for each indicator value a range of states had been created following the land use development for a time interval. This provides the user with data on the variability and 'typical' change rates for the respective

Table 5
Land use classes and associated urban green

Land use type	Sealing rate (%)	Urban green or open land associated	Reference/citation
Road	100	–	Own classification
House gardens	50	Place, promenade	Env. Atlas of Berlin
Open land	11	Park	Env. Atlas of Berlin
Park	12	Park	Env. Atlas of Berlin
Courtyard	20	Courtyard	Env. Atlas of Berlin
Allotment	20	Allotment	Env. Atlas of Berlin
Sports ground	45	Sports ground	Env. Atlas of Berlin
Detached houses	60	House garden	Env. Atlas of Berlin
Railway	80	–	Env. Atlas of Berlin
Industry, commerce	89	–	Env. Atlas of Berlin
Surfaced courtyard	80	Inner Courtyard	Env. Atlas of Berlin
Courtyard	50	Partially sealed surface	EA [a] Baden- Württemberg
(sealed) Fallow land	50	Partially sealed surface	EA [a] Baden- Württemberg
Green area	11	Green area	Env. Atlas of Berlin
Surfaced courtyard	100	–	Own classification
School ground	50	Partially sealed surface	EA [a] Baden- Württemberg
Playground	50	Partially sealed surface	EA [a] Baden- Württemberg
Square	55	Place, promenade	Env. Atlas of Berlin

[a] Environmental Agency.

urban structure type (scenarios 2002 and 2006). Whereas for previous states historic data on key land use elements can be used to compile a 'historic land use status' (Haase et al., 2007), for the future scenarios (2007 and 2010, 2020) another methodology was applied: based on existing planning documents and the expert interviews mentioned above, interdisciplinary reference scenarios were created that represent a likely future for all relevant aspects for both test areas Leipzig-Grünau and East Leipzig. Although the scenario time lines for both areas differ, the goals and actions are absolutely comparable. The time lines differ due to the fact that the program '*Stadtumbau Ost*' is easier to apply at housing estates of large (municipal) housing companies than at single houses of private owners with a limited financial background. Thus the same degree of demolition will be reached earlier in Grünau than in East Leipzig.

3.3.1. Integration using the FLAG-model

The final integration of all indicators for both dimensions of sustainability — the social and the environmental — had been carried out using the FLAG model computed by the SAMISOFT 1.0.0 software (Nijkamp and Ouwersloot, 2003). The FLAG Model judges scenarios in relation to predefined standards (Vreeker et al., 2001). It works with the critical threshold values mentioned in Section 3.1 (CVTs; Leeuwen et al., 2003), where each indicator is classified according to its costs or utility values (indicator type; Fig. 6). In other words, this typification of the indicators provides information whether the increase or decrease in the indicator value has a positive or negative impact on the system under investigation.

Within the FLAG approach, calculated indicator values are set against the background of (normative

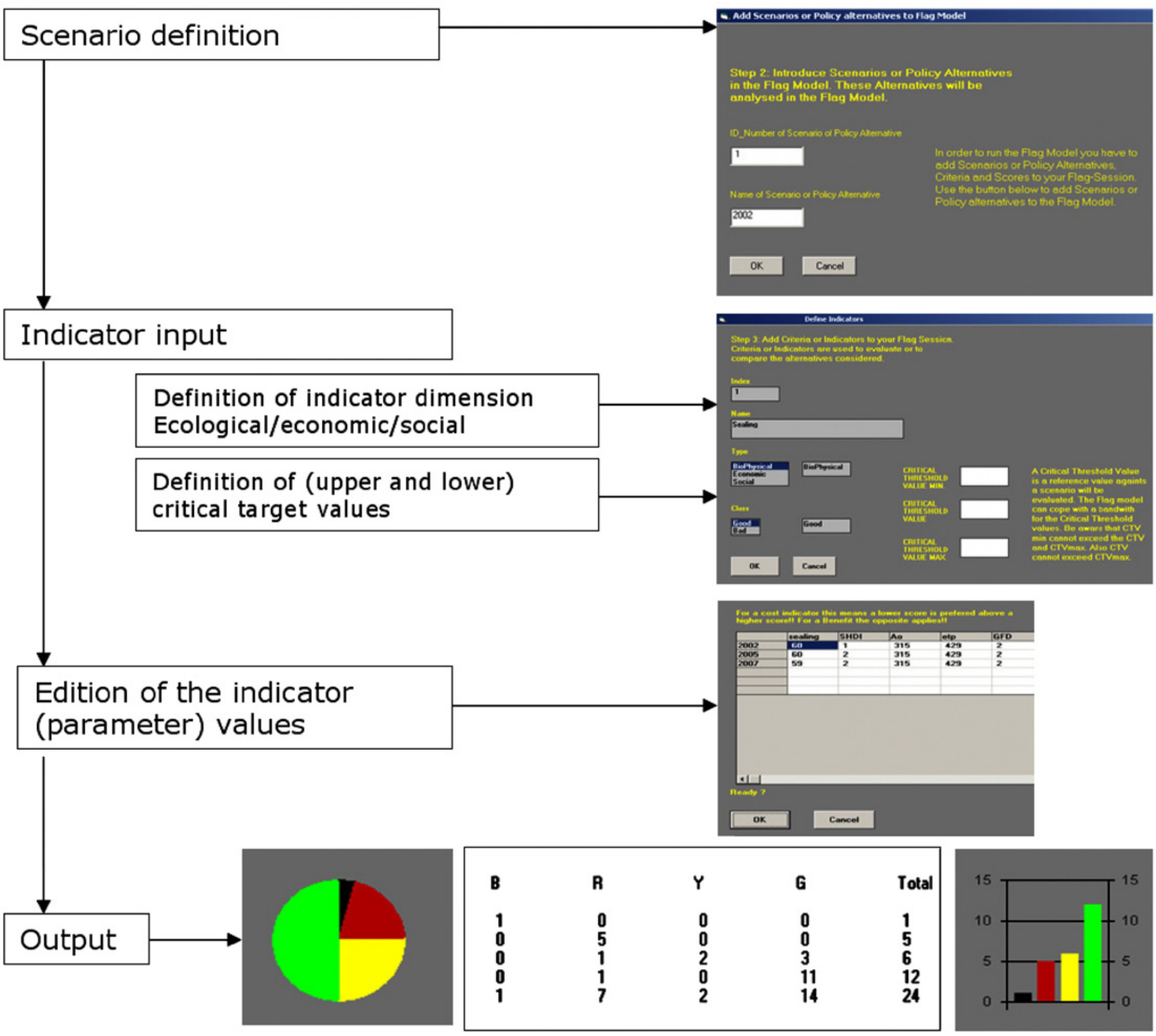

Fig. 6. Workflow FLAG model.

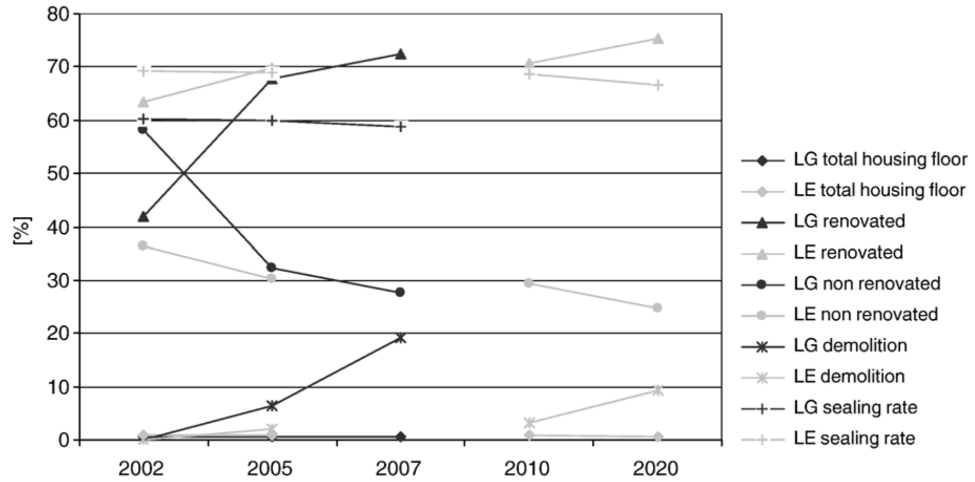

Fig. 7. Change of structural pattern in shrinking neighbourhoods 2002–2020 (LG = Leipzig-Grünau; LE = East Leipzig).

reference) standard values (CTV_{min}), target values (CTV) and maximum values (CTV_{max}). Besides the determination of threshold values for quantitative indicators, the integration of qualitative indicators such as 'persistence of schools' has been possible with FLAG simply by indicating 0, 1, and 2 as upper and lower threshold values. Uncertainties due to the indicator estimation or calculation are acknowledged by the FLAG system since it defines a validity space and not a concrete value that has to be matched.

4. Results: application of the indicator matrix

In this section we discuss some exemplary results of the study on urban shrinkage and its consequences for the socio-environment of local neighbourhoods applying the indicator matrix in the two test areas of Leipzig-Grünau and East Leipzig. The complete list of results obtained in the study is given in Tables A2 and A3 to be found in the Appendix of the paper.

Starting with the socialist prefabricated housing estates of Leipzig-Grünau, the analysis showed that by the year 2007 about one fifth of the examined neighbourhoods of the district will be demolished. Whereas before 2005 the majority of the demolished buildings were of non-renovated nature, after this date also partially renovated houses will be subject to dilapidation. Consequently, the share of non-renovated buildings will decrease from <60% in 2002 to <30% in 2007. Simultaneously, the share of renovated houses increases up to 72% (2002: 41%) caused by both decreasing building stock and continuous renovation actions. As a result of these changes in the urban fabric, the overall sealing rate in Leipzig-Grünau decreases, although this decrease is relatively small compared to the decline in the fabric: from 60 to 58%. This is mainly due to the original

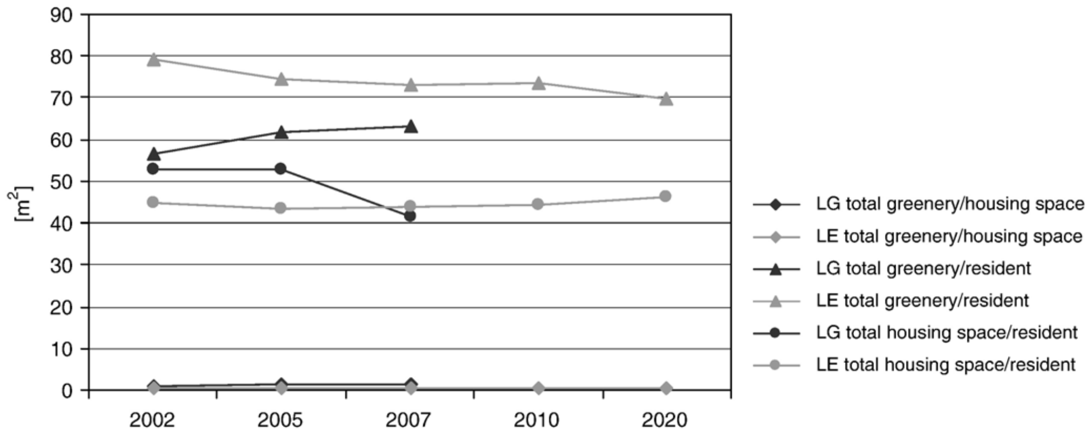

Fig. 8. Change in neighbourhood greenery and housing space 2002–2020 (LG = Leipzig-Grünau; LE = East Leipzig).

generous availability of urban green and open space in the whole district of Leipzig-Grünau (graphs in Fig. 8 and calculation results in Tables A1, A2).

Looking at the Wilhelminian old-built-up multi-storey housing estates of the neighborhoods of East Leipzig being examined here, the share of renovated fabric will be generally lower than in Grünau, even, when looking further into the future, by the year 2020: it will positively change from 63.5% (2002) to 75.3%. About 9% of the share of the buildings will be demolished by 2020 (Schetke, 2006; Fig. 7 and calculation results in Tables A1, A2).

Assuming a further decline in the population in Leipzig-Grünau, based on the trend since 1990, a calculated demolition of about 20% of the whole fabric will lead to a decrease in the housing area per resident from 53 m^2 to 42 m^2 in 2007 (Schetke, 2006). Conversely, the mean share of urban green per resident increases from 56 m^2 to a marvellous 63 m^2, a value that exceeds the so-called minimum target value of available urban greenery per resident of 5 m^2 by 12 times (the target of 5 m^2 was set up by the city planning department of Stadt Leipzig, 2003; Fig. 8). Coming from this general quantitative perspective, a further differentiation of the various forms of urban green provides more specific information according to which of these 63 m^2 are publicly used, and if yes, whether they are conveniently accessible for the majority of the local residents.

When computing the mean share of urban green in the direct housing area using a 50 m-distance-buffer around each house (= house gardens), the accessible urban green area remains stable between 34–37 m^2. Compared to this, urban green within a distance of 5 walking minutes (= represented by a buffer of 500 m; public urban green) increases from 9 to 11 m^2 (Fig. 8). The total amount of open space and urban green “gained” at the final stage of the demolition program will reach 1.61 ha, which represents some 6.5 m^2 per resident. Most of this quantified urban greenery is of a public nature and thus accessible to all residents of Leipzig-Grünau and all the other districts of the city.

Coming to the old built-up district of East Leipzig, in accordance with the development of Grünau, the mean housing area per resident will decrease from 80 m^2 to 69.1 m^2 by 2020. As in Leipzig-Grünau too, the mean share of urban green per resident in East Leipzig is considerably higher than the minimum target value requires: it increases from 43.55 m^2 in 2002 to a comfortable 46.1 m^2 in 2020.

In terms of the ecological impact of the delineated demolition activities in both neighbourhoods, most significant changes brought out the analysis of the Largest Patch Index (LPI) and the Shannon’s Diversity Index (SHDI; cf. Betts, 2000). The LPI will particularly increase in the inner parts of the blocks of houses in Grünau (from 3.85 to 4.13). Consequently, also the SHDI increases from 2.39 to 2.44 in 2007, offering an increased potential for biotic life. For East Leipzig, due to the different buildings and green structure, both LPI and SHDI are generally lower (Tables A2; A3): the LPI varies remarkably when looking specifically at different land use types within the old built-up district: whereas it increases for the inner parts (inner courtyards) of the blocks ($1.01 \rightarrow 1.21$) as well as for interspersed urban brownfields ($1.31 \rightarrow 1.51$), it decreases in small courtyards from 3.94 to 3.19. Compared to this, the diversity of the areas increases at the final stage of demolition in 2020 to 1.73 (Table A2).

When looking at the social impact side of shrinkage, in Leipzig-Grünau as well as in East Leipzig, although expected, a severe drop in the accessibility of social infrastructure or per-capita-relations is unlikely to happen. During all scenarios and in both test areas the distance-values of social infrastructure (schools, retail trade shopping facilities, main roads) do not exceed threshold values but remain mostly positively far below them. A single exception is the original increase in main roads and public transport facilities. Here an increase in distance can be shown in 2005 due to demolitions, mainly along the main roads in. This decreases in 2007 due to reverse trends of demolition mainly within the blocks, whereas the distance remains slightly increasing by 2020 in East Leipzig (Tables A2; A3). The relative proportion of inhabitants to number of schools or kindergartens slightly increases, partly due to closures in Leipzig-Grünau or even due to an increased number of inhabitants in East Leipzig.

5. Discussion

The results of the study impressively show the heterogeneity of the impact of the shrinkage process on urban open and green space as well as on infrastructure in different urban housing types or structural types. The results of the study prove evidence of different urban development pathways: whereas, due to a heterogeneous house owner structure in the old built-up structure of East Leipzig renewal began early, most changes occurred afterwards in the homogeneous prefabricated fabric structures of Leipzig-Grünau. Here, 18 housing cooperatives determine the residential market while the majority of the houses in East Leipzig are in the hands of private owners. The demolition of large housing complexes in Leipzig-Grünau produce considerably more open space and a higher impact on the local livelihood than the demolition of single houses in Eastern Leipzig that creates a more patchy housing pattern (cf. again Fig. 3).

Although theoretically assumed, the recent demolition phase has nearly no impact on the local sealing rate and on the adjusted hydrological indicators. A sealing rate of 60% in 2002 which matches the upper reference value of the average sealing rate of GDR-time prefabricated areas (see the city of Dresden with 50–55%; Arlt and Lehmann, 2005) has been reduced after demolition to 58.7%. This is mainly due to very low outlines of the residential buildings which are enormous in height but not in the area they cover. Furthermore, in East Leipzig the effects have been low due to the highly spread-out locations of demolition, but have no further negative consequence as the sealing rate has never exceeded critical values (69% in 2002 and 67% in 2020 vs. 79% as CTV_{max}).

However, the contributions of the newly emerging open spaces to an enhancement of the local green quality should be discussed in different ways. Regarding the configuration, related ecosystem services and therefore the 'value' of the new green spaces, the indicator LAI (leaf area index) gives the most complex overview on the green quality of an area. In both neighbourhoods the LAI does not indicate a significant increase in its mean value. But going into detail, a considerable contribution to the local green structure could be noted in East Leipzig. Here the newly emerging green areas had a constantly higher LAI than these in Leipzig-Grünau (LAI of 3 compared to 1.5). This is mainly due to a planned afforestation of the new open spaces as parts of new pocket-sized parks and green corridors. In Leipzig-Grünau, the most common reuse of formerly sealed areas was realised in the form of monotonous meadows. Therefore an integration of new open spaces in existing green corridors or in the surrounding urban structure is only partially possible in this neighbourhood. At this point a benefit from additional green spaces cannot be found with either ecological or social aspects. Therefore, one can summarize that the new green spaces in Leipzig East are characterised by a high LAI but are — due to the fragmented urban structure — quite small and have therefore low impact on the overall green quality of the neighbourhood. Contrary to that, in Leipzig-Grünau the size of the new green spaces is — due to the spacious urban structure — comparably high with lower ecological quality and has therefore low impact on the overall green quality of the neighbourhood. But beside urban reasons, a major decisive point of this diverse development in both neighbourhoods can be found in regarding simple economic motives. Simple vegetated grassland (Leipzig-Grünau) requires 15 €/m^2 for landscaping and annual care, whereas a heterogeneous park with different arrangements of local tree, hedgerow and herbal species would cost 50–60 €/m^2 (East Leipzig). Coming back to the matter of size it is easy to understand that the afforestation and integration of several small areas into an existing green-corridor or park is economically more feasible than the same procedure applied to many large areas. But still, in the future it will become more and more difficult to enhance either green quality or social quality of life, as a surplus of new open spaces will become more a curse than a blessing. This is because there are nearly no ideas existing concerning the final purpose of the new open space or green area as to whether it should be used as a site for business, leisure or art (as pointed out in Turner, 2006).

In terms of the quantity of urban green, positive effects can be seen, which occurred due to demolition within the assessed scenarios. In particular this is happening in Leipzig-Grünau, where the ratio of public and private green has changed to 2:1 after reaching the final demolition state in 2007. These conditions are a particularly positive state compared to the less favourable situation in East Leipzig with a 0.5:1-ratio of public and private green and a lower share of urban greenery in total. In both districts the total area of private green will not change (e.g. no additional gardens or internal green). Compared to a target value of 6 m^2 (UQZ) green per inhabitant, we started with 45 m^2 in East Leipzig and will finish with 46 m^2 in 2020. For Leipzig-Grünau it is about 56 m^2 in 2002 and 63 m^2 in 2007. Thus, the question is more how to design these large green spaces in a residential area.

Coming to the impact of shrinkage on social infrastructure, one has to conclude that it is both remarkable and visible, but does not lead to a significant decrease in local quality of life in terms of longer distances to primary schools, no changes in the number of kindergartens and available leisure infrastructure until 2007/2020. According to planners, severe cuts in supply with social infrastructure have already been made in recent years, leading to an almost stable situation. This picture changes in terms of the transport infrastructure: the accessibility of main roads — and with that the connection to public transport services and to supply with convenience goods — in Leipzig-Grünau continuously increases from 2002: 250 m, to 2005: 290 m and 2007: up to 300 m, being a consequence of the demolition of unattractive buildings that had been affected by traffic noise. The main parts of the shopping infrastructure in Leipzig-Grünau are in a distance of >250 m from the housing blocks, but do not reach the critical distance of >500 m (= maximum value). In East Leipzig, for all scenarios (2002, 2005, 2010, 2020) this accessibility does not change considerably and remains within the threshold values.

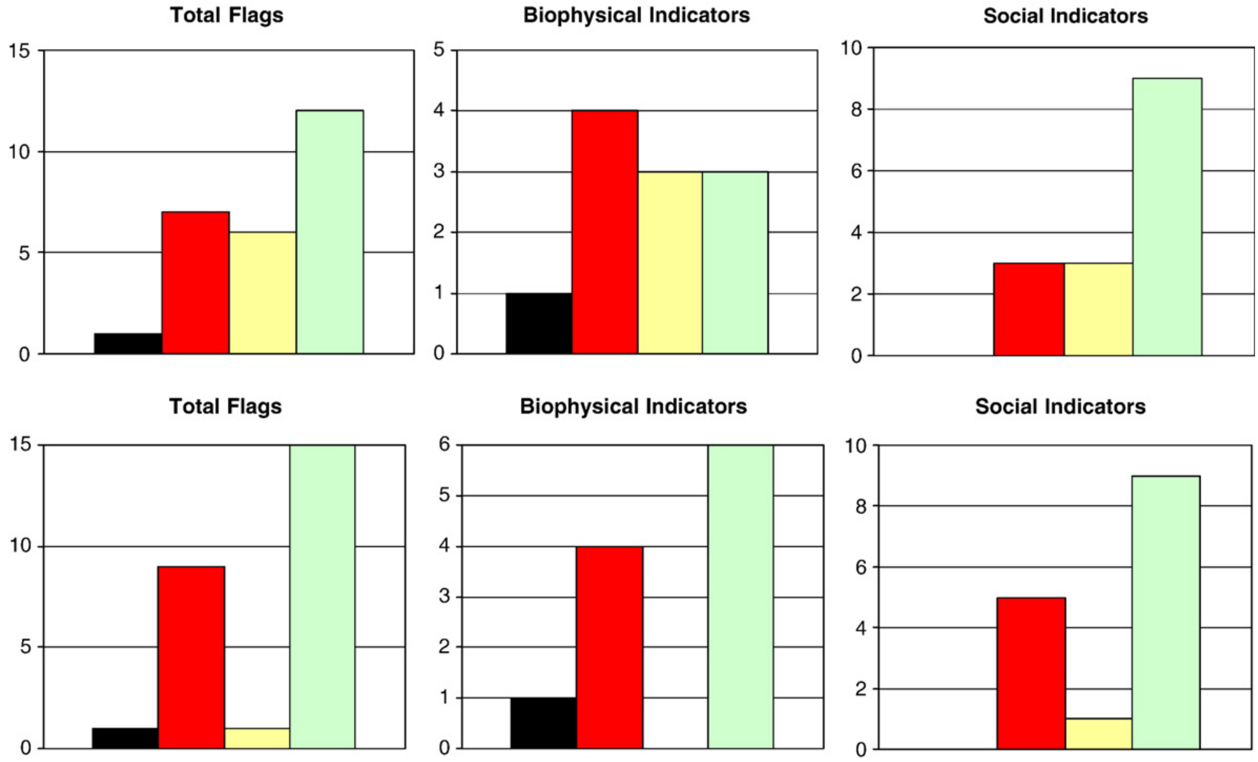

Fig. 9. FLAG model result for Leipzig-Grünau, a comparison of the scenarios 2002 and 2007. The colours of the columns mean: black = stop further growth, red = reverse development needed, yellow = target value reached, green = acceptable.

To cross-reference the future land use, environmental and social situation against, firstly, the current state and, secondly, policy target values, integration of the single indicators of each criterion and dimension have been completed using the FLAG approach (introduced in Section 3.3; Figs. 6, 9). The approach is very valuable in terms of the coherent consideration of qualitative and quantitative results obtained in the study (as argued in Hyde and Maier, 2006).

Starting in 2002, Leipzig-Grünau started with many green flags for the social dimension, but fewer for the environmental. For the environmental dimension, we found the highest number of red flags (Fig. 9). Coming then to the scenario time steps of 2005 and 2007, the general picture of the flags changed; as already discussed for single indicators, the ecological situation is still improving, but there remain 4 dots of red flags, and the medium values disappear. For the social dimension the situation worsens from 3 to 5 red flags with 9 green flags remaining, here also the medium yellow flags decrease; in total the picture gets more diverse with a 'two-peak' flag distribution (Fig. 9).

Conversely, the socio-environmental situation in East Leipzig obviously improves from 2002 to 2020, for both social and bio-physical indicators the green flags increase to a maximum of 17 flags in total, black flags remain stable at a low level, red flags and yellow flags decrease considerably in 2005 and in the two future scenarios 2010 and 2020.

6. Conclusions

The aim of this paper was to present a methodology and a set of interdisciplinary indicators in order to assess socio-environmental patterns emerging under urban shrinkage and its impacts upon urban ecosystems and residents. We used the urban quality of life and sustainable urban development concepts as targets for our quantitative indicator set.

Land use and urban fabric development in shrinking cities are still in need of micro-scale findings of empirical research. We presented an innovative study that differentiates all the heterogeneous processes and phenomena of shrinkage in order to illustrate its impact on the socio-environmental urban dimensions. As a result of this study, we have found that for a neighbourhood such as Leipzig-Grünau, increasing demolition can lead to blurred structures, while for parts of East Leipzig it can be a blessing.

Based on the results of the MCA, the authors see different development options for both test areas under conditions of further shrinkage. Perforation turns Leipzig-Grünau into a greener and more nature-oriented area and creates space for more spacious livelihoods with semi-natural biotopes. Following current trends of the housing sector development in Germany, there is still a continuous ‘thirst for land’ by land developers and project planners despite declining population numbers. Thus, urban expansion seems to be another option, too. Districts such as East Leipzig might counteract urban sprawl since re-densification and re-urbanisation will take place. Here, in particular a quality enhancement of urban green will lead to a higher quality of life and thus attract urban dwellers to these neighborhoods.

Taking into account what has been found in this study, the indicator set gives an idea for a long-term monitoring approach of sustainable urban open space development and urban greenery at the district level (according to the initial ideas of URGE, and thus as a kind of enhancement). Scientific evidence is needed that clearly sets out the socio-economic benefits and multiple contributions of urban green spaces to the quality of urban life (Bryant, 2006). Only then, an influence of local decision making in European cities towards reinforcing the contribution of the greenery to a healthy living environment is possible, particularly for a case involving a shrinking city. The MCA presented here provides a valuable contribution through combining different dimensions of sustainability when looking at urban shrinkage as required by Ravetz (2000) or Wiek and Binder (2005).

The study has further proved that there exists a strong overlap of the different functions of urban green such as stated in Turner (2006): scenic value, ecological value, hydrological value and recreational value. Normally, these values overlap. They are not likely to be co-incident and they are not likely to be confined to open space in public ownership. Yet, each of them is needed by landscape planning in order to conserve and enhance the quality of the environment. Still missing are indicators looking at acceptance, utilization and economic value of urban green (Breuste, 2003). They might supply an answer as to whether demolition influences urban green spaces positively, or if it has less importance. The results of this study clearly show that the structure of the urban fabric — huge open lawns in Leipzig-Grünau or cosy backyards in Leipzig East — has a strong influence on the shape of open and green spaces after demolition.

In conclusion, the development and application of such a multi-criteria methodology forms a sound scientific base for an overall and more integrated socio-environmental planning in relation to population, urban fabric, green and infrastructure network of shrinking cities.

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Appendix A

Table A1
Multicriteria indicator catalogue and qualification rules

Criterion	Indicator	Equation	Target value(s)	
Soil quality	Degree of sealing (%) $S\mu$ = sealing A = area	$S\mu = \frac{\sum_{i=1}^{m} S_i[\%]^* A_i[\%]}{100[\%]}$	Prefab estates 20–100	Tenement blocks 59–79
Hydrology, water balance	Surface run-off $A_o\mu$ (mm; %) A = area	$A o\mu = \frac{\sum_{i=1}^{m} Ao_i[\%]^* A_i[\%]}{100[\%]}$	14.5–21.5–61.0	
	Seeping rate $S\mu$ (mm;%) A = area	$S\mu = \frac{\sum_{i=1}^{m} S_i[\%]^* A[\%]}{100[\%]}$	28.0–31.5–34.5	
	Etpμ (mm; %) A = area	$\mathrm{Etp}\mu = \frac{\sum_{i=1}^{m} \mathrm{Etp}_i[\%]^* A[\%]}{100[\%]}$	18.5–47.0–59.0	
	Housing floor space (m^2)		0 = increase, 1 = constant, 2 = decrease	

Table A1 (*continued*)

Criterion	Indicator	Equation	Target value(s)
Quality of green	Leaf Area Index (LAI) A=area	$\mathrm{LAI} = \frac{\sum_{i=1}^{m}\left(\mathrm{LAI}_i{}^{*}A[\%]\right)}{100[\%]}$	<2 low, 2–5 medium, >5 high
	Largest patch Index (LPI) A=area	$\mathrm{LPI} = \frac{\max_{j=1}^{n}\left(a_{ij}\right)}{A}{}^{*}100$	0=decrease,1=constant, 2=increase
	Shannon's Diversity Index (SHDI)	$\mathrm{SHDI} = -\sum_{i=1}^{m} p_i \ln p_i$	0=decrease,1=constant, 2=increase
Quantity of green	Protection of green		yes (0) — cond. (1) — no 2)
	Total size of greenery G=greenery GA=green area	$G = \sum_{i=1}^{m} \mathrm{GA}_i$	0=decrease,1=constant, 2=increase
	Degree of isolation I=isolation A=area Bd=buffer distance	$I_\mu = \frac{\sum_{i=1}^{m}\left(A_{iB}[\%]^{*}\mathrm{Bd}_i\right)}{100[\%]}$	<500 m–<1000 m–>1 km
Green supply	Recreational area in 50 m distance	$\mathrm{Green/Inh.}_{50\mathrm{m}} = \frac{\mathrm{green}_{\mathrm{radius\_50m}}}{inhabitants}$	<5 m^2/inh. need for action (target=10 m^2/inh.)
	Area neighbourhood green (500 m)	$\mathrm{Green}_{500\mathrm{m}} = \sum_{i=1}^{m} \mathrm{green}_{\mathrm{radius\_500m}}[\mathrm{m}^2]$	≥0,5 ha
	Share greenery in local district Dist=distance G=green area	$\mathrm{Dist}(G)_B[m] = \frac{\sum_{i=1}^{m} F_{iB}{}^{*}\mathrm{Bd}_{iB}}{100}$	within the radius of 1 km≥1 green area >=2500 m^2
	Maximum distance to green >0,5 ha (within 500 m)	$EGrfl_B[\mathrm{m}] = \frac{\sum_{i=1}^{m} GgfF_{iB}{}^{*}\mathrm{Pd}_{iB}}{100}$	<0,5 ha (0), =0,5 ha (1), >0,5 ha (2) [= ≥0,5 ha of house gardens in a distance of ≤500 m)
Population	Total population i=floor type N=neighbourhood T=test area F=floorspace f=number of floors A=area L=living space R=resident	$F_i = \frac{(A^{*}100)}{F_N}$; $L_i = F_i{}^{*}f_i$; $L_N = \sum_{i=1}^{m} Le_i$; $L(R)_N = \frac{L_N}{\sum R_N}$; $R_i = \frac{(L_i{}^{*}R)}{L_N}$; $A(\%)_{i,t} = \frac{F_{i,t}{}^{*}F_i}{100\%}$; $R_i = \frac{\left(A(\%)_i{}^{*}R_N\right)}{100\%}$; $\sum_{i=1}^{m} R_{\mathrm{test\_area},F} = \frac{\sum_{i=1}^{m} R_{\mathrm{complex,floortype}}{}^{*}\sum_{i=1}^{m} A(\%)_{\mathrm{urban\_fabric,test\_area}}[\%]}{\sum_{i=1}^{m} A(\%)_{\mathrm{urb.fabric,complex}}[\%]}$	0=decrease,1=constant, 2=increase
	Public participation		0=decrease,1=constant, 2=increase
Infrastructure	Max. distance to main roads D_R=distance to main road B=Buffer	$GgrF[\%]_{250B} = \frac{\left(GgrF[\mathrm{m}^2]_{250B}{}^{*}100[\%]\right)}{GgrF_{\mathrm{Testgebiet}}}$; $D_{RB}[\mathrm{m}] = \frac{\sum_{i=1}^{m} GgrF_{iB}{}^{*}\mathrm{Pd}_{iB}}{100}$	>500 m–>250 m–<250 m

(continued on next page)

Table A1 (*continued*)

Criterion	Indicator	Equation	Target value(s)
Infrastructure	Max. distance to primary school D_{PS} = distance to supermarket	$GgrF[\%]_{500B} = \frac{(GgrF[m^2]_{500B} * 100[\%])}{GgrF_{test\ area\ t}}$ $D_{PSB}[m] = \frac{\sum_{i=1}^{m} GgrF_{iB} * Pd_{iB}}{100}$	>2000 m–>1000 m–<500
	Persistence of leisure facilities Max. distance to supermarket D_{sup} = distance to supermarket Bd = buffer distance	$GgrF[\%]_{250B} = \frac{(GgrF[m^2]_{250B} * 100[\%])}{GgrF_{test\ area}}$ $D_{SupB}[m] = \frac{\sum_{i=1}^{m} GgrF_{iB} * Bd_{iB}}{100}$	0 = decrease, 1 = constant, 2 = increase >500 m–>250 m–<250 m
	Persistence of schools		0 = decrease, 1 = constant, 2 = increase
	Persistence of kindergartens		0 = decrease, 1 = constant, 2 = increase
Urban fabric and housing	Share of non-renovated houses (= H_{nonren}) F = floorspace	$H_{nonren}[\%] = \frac{\left(\sum_{i=1}^{m} F_i[m^2] * 100[\%]\right)}{F \sum_{1,2,\ldots} i[m^2]}$	0 = decrease, 1 = constant, 2 = increase
	Share of renovated houses (= H_{ren}) F = floorspace	$H_{ren}[\%] = \frac{\left(\sum_{i=1}^{m} F_i[m^2] * 100[\%]\right)}{F \sum_{1,2,\ldots} i[m^2]}$	0 = decrease, 1 = constant, 2 = increase
	Share of demolition D = demolition F = floorspace	$D[\%] = \frac{\left(\sum_{i=1}^{m} F_i[m^2] * 100[\%]\right)}{F \sum_{1,2,\ldots} i[m^2]}$	0 = decrease, 1 = constant, 2 = increase

Table A2
Indicator matrix for both study areas, Leipzig-Grünau and East Leipzig

Test area	Indicator	Mean values and qualitative assessment values			STD		
Leipzig-Grünau		2002	2005	2007	2002	2005	2007
	Degree of sealing (%)	60.29	59.81	58.69	5.62	5.41	5.75
	Surface run-off (%)	31.51	31.23	30.58	3.25	3.12	3.32
	Seeping rate (%)	27.04	27.08	27.17	0.07	0.08	0.11
	Evapotranspiration (%)	42.92	43.18	43.78	3.36	3.31	3.48
	Housing floor density	0.61	0.57	0.47	0.06	0.04	0.02
	Leaf Area Index (LAI)	1.47	1.48	1.50	0.27	0.27	0.28
	Largest Patch Index (LPI): ↓	1	2	2			
	LPI house gardens	5.58	5.58	5.58	3.70	3.70	3.70
	LPI open space	6.56	6.56	6.56	8.35	8.35	8.35
	LPI courtyard	3.85	3.87	4.13	2.87	2.91	3.04
	Shannon's Diversity Index (SHDI)	2.39	2.41	2.44	0.09	0.08	0.08
	Total greenery	1	2	2			
	Degree of isolation [m]	251.54	251.53	251.50	2.67	2.65	2.59
	Neighbourhood Recreation area (m^2/ inh.) > radius 50 m	35	37	34	6.22	5.87	6.05
	Total Neighbourhood Recreation area (ha) > radius 500 m	9.15	9.63	10.7	8.41	8.31	8.62
	Total Neighbourhood Recreation area > radius 1 km	1	1	2			
	Distance to neighbourhood greenery	<500 m	<500 m	<500 m			
	Total population	10362.15	9547.48	9547.48	1000.53	816.00	816.00
	Public participation	1	1	1			
	Distance to main roads (m)	362.33	392.76	387.05	97.44	120.13	115.76
	Distance to primary school (m)	507.09	509.42	511.28	82.59	78.05	77.72

Table A2 (*continued*)

Test area	Indicator	Mean values and qualitative assessment values			STD		
Leipzig-Grünau		2002	2005	2007	2002	2005	2007
	Persistence of recreational facilities	1	2	2			
	Distance to shopping mall (m)	341.41	348.84	307.07	24.30	32.57	55.74
	Persistence of all schools	1	2	2			
	Persistence of all kindergartens	1	1	1			
	Not renovated houses (%)	58.07 (0)	32.25 (0)	27.50 (0)	4.50	11.40	10.38
	(partially) renovated houses (%)	41.93 (2)	67.75 (2)	72.50 (2)	4.50	11.40	10.38
	Demolition (%)	0.00 (2)	6.46 (2)	19.18 (2)	0.00	3.15	3.28

East Leipzig (Neustadt-Neuschönefeld/Volkmarsdorf)		2002	2005	2010	2020	2002	2005	2010	2020
	Degree of sealing (%)	69.33	68.91	68.51	66.69	1.67	1.41	1.45	2.36
	Surface run-off (%)	38.08	37.84	37.01	36.56	1,08	0.90	0.93	1.45
	Seeping rate (%)	25.18	25.21	25.25	25.40	0.37	0.43	0.33	0.40
	Evapotranspiration (%)	37.,55	37.77	37.99	38.96	0.81	0.94	0.69	1.18
	Housing floor density	0.78	0.76	0.75	0.70	0.10	0.10	0,10	0.13
	Leaf Area Index (LAI)	1.26	1.27	1.29	1.34	0.07	0.06	0.07	0.09
	LPI house gardens	0.31	0,31	0.31	0.31	0.18	0.18	0.18	0.18
	LPI open space	1.08	1,08	10.8	1.21	0.98	0.98	0.98	1.02
	LPI large courtyard	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
	LPI small courtyard	3.04	3.09	3,19	3.19	2.67	2.67	2.67	2.67
	LPI park	2.67	2.67	2,67	2.67	5.35	5.35	5.35	5.35
	LPI public garden	1.04	10.04	1.04	1.04	0.67	0.67	0.67	0.67
	Shannon's Diversity Index (SHDI)	1.65	1.66	1,67	1.73	0.18	0,18	0.18	0.16
	Total greenery	1	2	2	2	–			
	Degree of isolation [m]	250	250	250	250	0	0	0	0
	Neighbourhood Recreation area (m^2/ inh.)>radius 50 m	34	30	30	27	2.76	1.53	0.19	4.53
	Total Neighbourhood Recreation area (ha)>radius 500 m	8.57	9.01	9.41	11.20	2.07	2.16	2.06	0.85
	Total Neighbourhood Recreation area>radius 1 km	1	2	2	2				
	Distance to neighbourhood greenery	<500 m	<500 m	<500 m	<500 m				
	Total population	8671	9021	9021	9021	850.64	939.04	939.04	939.04
	Public participation	1	1	1	1				
	Distance to main roads (m)	290.74	291.64	292.07	294.73	57.18	58.26	58.74	57.11
	Distance to primary school (m)	773.26	769.69	767.11	747.47	341.87	338.24	334.79	256.61
	Persistence of recreational facilities	1	1	1	1				
	Distance to shopping mall (m)	339.76	341.02	341.21	346.83	11.57	12.69	12.96	6.84
	Persistence of all schools	1	1	1	1				
	Persistence of all kindergartens	1	1	1	1				
	Not renovated houses (%)	36.50	30.11	29.39	24.66	4.83	4.30	4.15	0.07
	(partially) renovated houses (%)	63.50	69.89	70.61	75.34	4.83	4.30	4.15	0.07
	Demolition (%)	0.00	2.17	3.15	9.24	0.00	0.45	0.70	5.26

1 = constant 2 = increase 3 = decrease.

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28

Potential of Biodiversity and Recreation in Shrinking Cities: Contextualization and Operationalization

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Summary

Whereas environmental and social impacts of urban sprawl are widely discussed among scholars from both the natural and social sciences, the spatial consequences of urban shrinkage are almost neglected when discussing the impacts of land-use change. Within the last decade, *shrinkage* and *perforation* have arisen as new terms to explain the land-use development of urban area faced with demographic decline, particularly decreasing fertility, aging and outmigration. Although shrinkage is far from being a 'desired' scenario for urban policymakers, this chapter argues that a perforation of the built-up structure in dense cities might bring up many positive implications and potential for urban biodiversity. The chapter introduces an approach of how to incorporate biodiversity into urban shrinkage. The approach is

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extended by presenting an integrative indicator matrix focusing mainly on the ecological as well as the social impacts of shrinkage embedded in scenario analysis.

Keywords

urban shrinkage, perforation, demolition, green space, biodiversity, urban wilderness, multi-criteria analysis (MCA)

Introduction

The challenge of shrinkage for urban land-use development

Environmental and social impacts of urban growth and the inherent land take are widely reflected and discussed among scientists from different disciplines. In contrast, urban decline, particularly, its spatial consequences, still lack comprehensive analysis and evaluation. Since the term *decline* has a negative connotation for urban policymakers as well as for urban residents, growth still dominates the political agenda for the majority of European cities (Müller & Siedentop, 2004).

Recently, *shrinkage* and *perforation* appeared as new terminologies to depict the demographic (depopulation, aging and outmigration) and land-use change ('dilution' of the built-up area and the demolition of buildings) that urban regions in Eastern Germany are faced with. But shrinkage is far from being an east German phenomenon: As Rieniets (2006), for example, argues, phases of shrinkage are as much a part of worldwide urban development as are phases of growth. Because of wars, natural catastrophes, epidemics, or even the abandonment of large mines, urban shrinkage already has been evidenced between the 1920s and 1940s. English cities also experienced considerable decrease in population due to deindustrialization in the post-war period as well as industrial agglomerations in the north-eastern United States (Rieniets, 2006).

Although shrinkage, after decades of predominant growth, is by no means a 'desired' scenario for urban planners and policymakers, this chapter argues, from an environmental scientist's perspective, that a perforation of the built environment in cities can have some substantially positive implications. Examples for that can be found in focusing on urban green infrastructure, recreational services, and biodiversity.

Environmental implications of urban shrinkage

The environmental implications of urban shrinkage can be divided into two parts. First, the quality of housing and urban green infrastructure supply that serves as a typical and well-established indicator of the quality of life in cities (Santos & Martins, 2007). Second, biodiversity benefits from the perforating land-use pattern that emerged out of de-urbanization, as included in the basic ecosystem services compiled by Costanza *et al.* (1997).

Drivers of shrinkage

As a notably massive form of spatial and functional urban decline, urban shrinkage – the opposite of urban sprawl, which underscores urban dynamics in most of the literature on urban land-use change (e.g., Antrop, 2004; Kasanko *et al.*, 2006, Schetke *et al.*, 2008) – increasingly affects urban land-use pattern and, consequently, habitats and species distribution. Due to recent demographic changes and economic weakness, every sixth city in the world can be defined as a shrinking city (Rieniets, 2006). Here, large parts of inner cities are affected by an absolute and relative population loss as well as an industrial blight, both of which produce residential and commercial vacancies or urban brownfields. Brownfields are defined in this chapter as unused abandoned former residential or commercial sites that often, but not exclusively, appear to remain sealed and hold a range of pollutants.

Demographic change and economic decline produce modified urban land-use pattern and densities. Compared with the beginning of the 1990s, after the reunification of Germany, there is now a massive surplus of housing and commercial buildings in the former GDR, which have been demolished. As a consequence, a considerable surplus of urban brownfield land has been created. Furthermore, the decline in the urban fabric has affected the social infrastructure and urban green space of local neighbourhoods. Here, urban planning enters into 'uncharted territory' since it needs to assess the socio-environmental impact of shrinkage and discover ecologically positive as well as negative effects.

In order to carry out such an evaluation quantitatively, a multi-criteria assessment (MCA) scheme was developed and applied. We present an application of an indicator set in order to characterize the impact of shrinkage on

urban land-use pattern, the quality of urban green space and green structure as well as the effects on residents.

Eastern Germany – a pilot case

In eastern Germany, where this phenomenon serves as the empirical background for this chapter, shrinkage increasingly affects formerly expanding industrial urban regions (Chilla, 2007). Currently, there are more than 1 million flats (excluding 350,000 housing units) that have been demolished since the German reunification and transition to a democratic society in 1990. Additionally, the current annual abandonment of commercial land in Germany is ±10 ha (Jessen, 2006). Outmigration and deindustrialization are the main reasons for the creation of both types of brownfield land. As a result of the particularly large-scale demolition of housing stock, urban land-use patterns and the images of residential areas and perceptions of their inhabitants are changing considerably. Moreover, the vacancy of property and its subsequent demolition modify the biophysical ('natural') environment of a town (see Figure 28.1).

The experiences from eastern German cities indicate that shrinkage results in considerable and obvious spatial and visual effects: a 'perforation' of the urban structure, patchy patterns or even islands of demographic and economic upgrading, re-urbanization and/or dis-urbanization at the local level (Haase *et al.*, 2007, 2008) as well as the creation of new green 'stepping

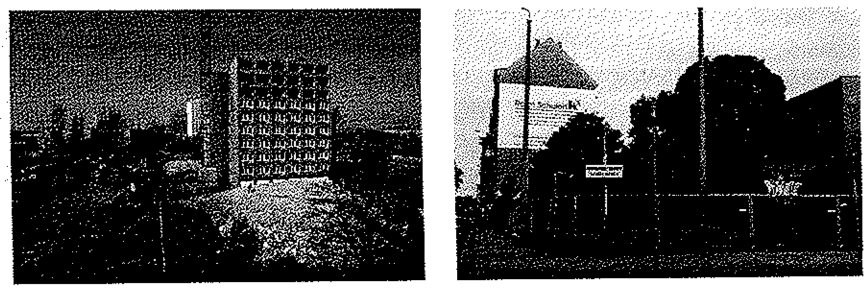

Figure 28.1 **A typical land-use feature of urban 'shrinkage' in eastern Germany: demolition of prefabricated housing estates to reduce housing surplus and thus 'regulate' local housing markets on the one hand. On the other, remaining vacant slots within the old built-up housing structure types (Source: UFZ).**

Figure 28.2 **Large-scale demolition of densely built-up housing structures in inner parts of the Wilhelminian-time city (built between 1870 and 1910): new open spaces for experimental design of recreational green infrastructure (Source: D. Haase).**

stones' and other green structures. In addition, there is small-scale fragmentation (in the form of a fragmented 'housing geography') or splintering of the urban population (Buzar *et al.*, 2007). A substantial number of residential vacancies occur in many housing estates, and commercial vacancies occur in inner-city shopping malls, with large-scale brownfield land occurring in both the inner city and suburbia. The latter have consequences for building and population densities and the creation of impervious surfaces (Sander, 2006; cf. Figure 28.2). Furthermore, these enormous changes within the built environment of shrinking cities provide important opportunities for urban biodiversity (Schetke & Haase, 2008).

Biodiversity aspects of urban shrinkage

New places and new pattern

Mehnert *et al.* (2005) found a positive correlation between the total amount of urban green infrastructure (parks, allotments, cemeteries, forest, etc.) and the suitability of habitat for breeding birds (e.g., for the green woodpecker, *Picus viridus*). Strauss and Biedermann (2006) reported the positive response of different species to large areas of inner-city grassy brownfields and negative reactions to the absence of them. Such open or wasteland patches (Figure 28.3)

Figure 28.3 **Natural secondary succession only occasionally occurs on demolition sites due to the fact that many of the sites retain an impervious surface (Source: D. Haase).**

are niches in which rare species thrive (e.g., Bolund & Hunhammar, 1999; Shochart *et al.*, 2006). This is particularly true for demolished sites in the core and inner city or dense residential zones, where areas of urban biodiversity benefit from shrinkage and can therefore be created at the local level.

A calculation example for the quantitative assessment of demolition effects within urban structures is given below.

In order to measure how shrinkage affects biodiversity, several recently demolished sites allocated in the Wilhelminian Period (1870–1910) and socialist prefabricated housing estates in Leipzig were analysed in terms of their spatial shape, configuration and the resulting habitat quality for the Whitethroat (*Sylvia communis*), an indicator species of open land.

The pre- and post-demolition situations at 50 sites were compared using the following indices: Largest Patch Index (LPI) of open land uses, Edge Density (ED), Habitat Suitability Index (HSI) and Shannon Diversity Index (SHDI). In doing so, LPI is defined as

$$LPI = \frac{\max\limits_{j=1}^{n}(a_{ij})}{A} * 100$$

where a is the area of single patches and A is the total area.

The edge density is defined as

$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10,000)$$

where ED is edge density, A is the total area and e is the edge vector.

Finally, the Shannon Diversity Index SHDI is according to Forman (1995) formally given as

$$SHDI = -\sum_{i=1}^{m} p_i \ln p_i$$

where p is the single patch. The HSI was calculated using the approach of the ecological niche which is formalized by the $\sum$ of cells with a certain probability of species presence (Mehnert *et al.*, 2005). For calculation and mapping purpose, we used the *Biomapper* software tool (Hirzel *et al.*, 2002).

The results of the study are shown in Figure 28.4. Edge density and patch size are the variables that most benefit from selective, single house or block demolition compared to only slight changes in Shannon diversity due to the uniform grasslands that emerged after demolition at many sites, particularly in the prefabricated peripheral districts. For species such as the Whitethroat (*Sylvia communis*), demolition seems to offer an increase of its preferred open habitat structures (cf. HSI values in Figure 28.4).

At a superior spatial level, the perforated urban landscape (which is less dense and more heterogeneous in terms of land use) possesses a higher share of rural, open and brownfield land uses than densely built-up inner cities. Still, there exists no clear idea of what perforation in a final state might look like. Nevertheless, concepts for this 'urban land-use type' have already been developed, such as the remaining urban core being divided into equitable sub-centres or a polycentric structure with fewer dense or even empty patches. Others foresee the fragmented built-up body as the most probable urban development pathway (Lüdke-Daldrup, 2001).

Figure 28.5 provides an indication of what perforation might look like in an old built-up Wilhelminian-Period housing neighbourhood (cf. Figure 28.5): the aim of the urban planning department is to maintain the buildings of the inner part of the city in favour of a de-densification and demolition of the outer parts. In these outer parts, existing green spaces are foreseen to be enlarged; thus vacant houses adjacent to these green spaces will be demolished. In doing so, larger connected open spaces are created while the connectivity of the built-up structures decreases.

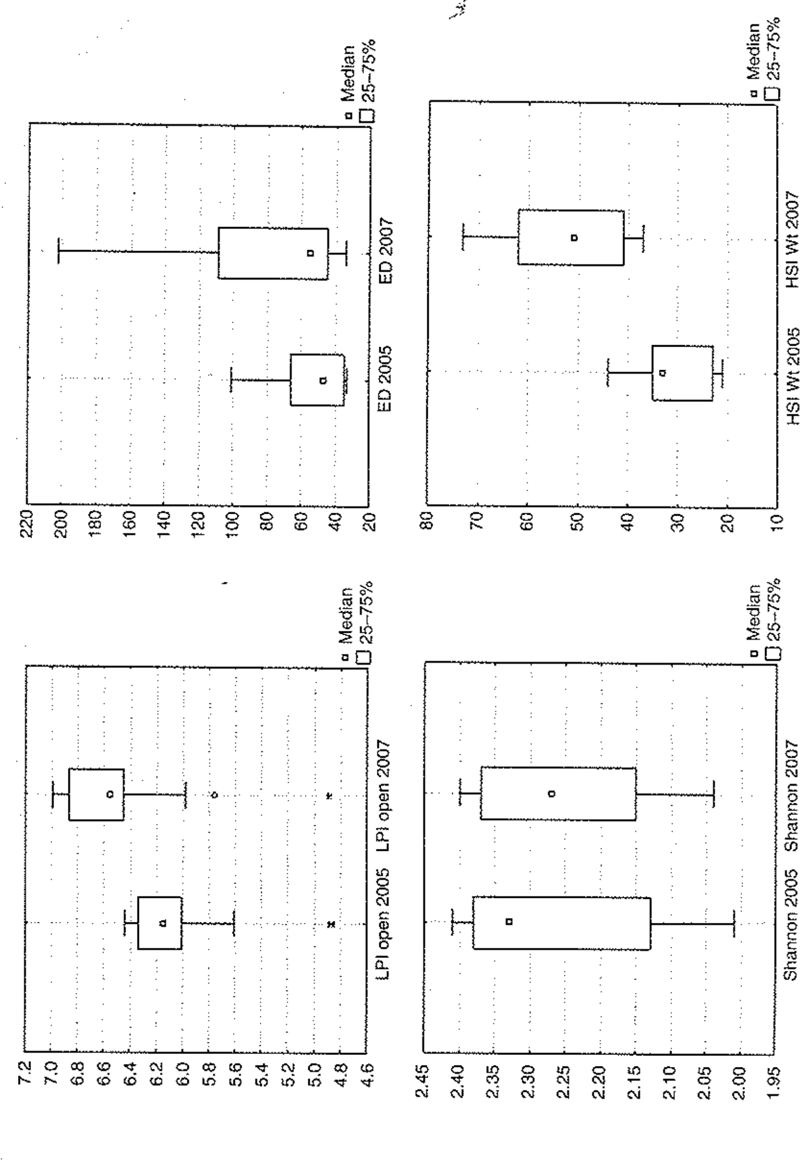

Figure 28.4 Largest Patch Index (LPI open) of open land uses such as park, allotment, courtyard, brownfield, waste land, etc. Edge Density (ED), Shannon Diversity and Habitat Suitability Index (HSI) for a range of recently demolished sites in Leipzig – a comparison of the pre- (2005) and post-demolition (2007) status.

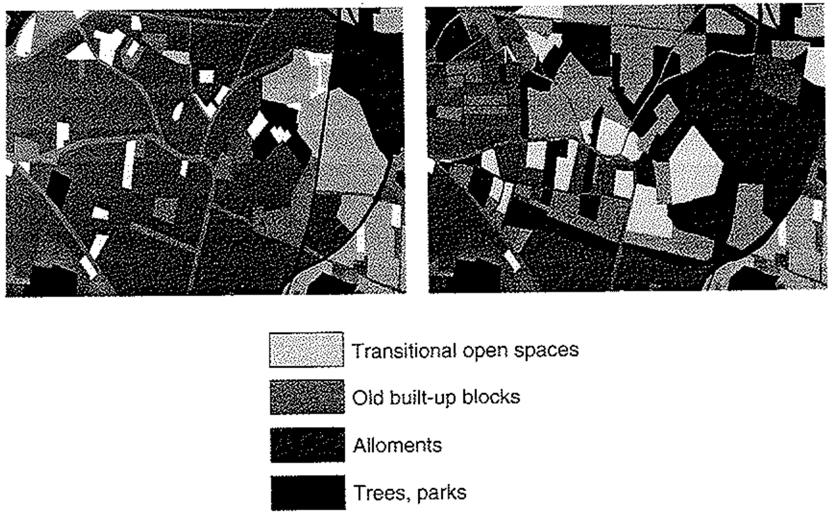

Figure 28.5 **Land-use change scenario 'perforation' due to demolition and restructuring of an old built-up Wilhelminian-style housing neighbourhood in Leipzig-East (according to Haase *et al.*, 2007). The left map shows the situation of a dense housing structure before the demolition, the right map shows the reduced housing stock and the new transitional open spaces resulting from demolition.**

From an ecologist's point of view, these forms of urban perforation result in a structural diversity of urban land uses and an increase in the amount of edge. However, generally positive or negative effects of urban perforation as well as urban shrinkage, in a broader sense, on urban ecosystems and biodiversity have not yet been statistically verified through empirical studies. First results related to a 10–15-years time-scale can be found in Schetke and Haase (2008).

However, the disuse of buildings, demolition and the abandonment of land are not logically followed by a 'resurgence' of nature. Previously developed land may have considerable soil contamination. Moreover, inappropriate subsequent or interim use of the waste/demolished site, such as leaving the area unused and retaining its impervious surface, will produce a negative environmental impact: the patch then benefits neither the quality of life (housing, recreation, leisure) nor the functions of the ecosystem (water regulation, soil biology, microbiological life). An increase in such brownfield or abandoned sites makes inner-city neighbourhoods less attractive, which encourages continuing urban sprawl (Haase & Nuissl, 2007).

Recreational potential of new green and brown sites in shrinkage

Urban shrinkage allows us to contemplate a 'resurgence' of nature into inner urban areas that are densely populated and have been built up 'for ages'. In this vein, ideas regarding 'urban wilderness' for recreational and educational purposes are of interest to planners and landscape architects who are faced with urban shrinkage or decline (Rink, 2005).

Leipzig, a 'model city' as we have seen, has made the novel suggestion of creating urban greenery in the form of temporary gardens or interim use agreements (in German 'Gestattungsvereinbarung') at core city demolition sites (as a kind of planned alternative) and spontaneous and ruderal nature on former brownfields (as a kind of unplanned alternative).

De Sousa (2003) perceives green sites developed from inner-urban brownfield sites as 'flagships' or 'experimental fields' that serve as models for the future provision of green space with the objectives of improving local biodiversity and human lifestyles. Shrinkage also results from demolition of multi-storey housing stock, which forms a transition towards more spacious housing and living conditions in densely urbanized environments. Larger apartments with non-classical layouts and integrated patios and terraces, as well as higher shares of urban green and 'landscape' within the neighbourhood are emerging (Haase, 2008).

Urban shrinkage as a multidimensional impact on urban land: a proposal for its integrated assessment using scenario analysis

Under conditions of demolition and perforation of the built-up area, amount and shape of urban green spaces and related recreation facilities and habitat qualities need to be rethought and, if necessary, reshaped because of an amount of 'new' open land in the inner parts of the city that is emerging. This open land does not only change the total amount of green space but has also a range of impacts on both structure and (ecological) quality of urban green. Beside that, demolition and perforation also modify determining factors for the residents' quality of life, such as per capita values of recreation space and accessibility of social, recreation and transportation infrastructure.

Regarding this complex setting of potential spatio-environmental impacts of shrinkage, we propose an integrated assessment approach based on an interdisciplinary indicator catalogue representing a nested framework starting from the dimensions of sustainability (eqn. 28.1):

$$D_S = \sum_{1,2,\ldots} C_S \qquad (28.1)$$

where D_S is the respective dimension of sustainability and C_S the respective criterion. Each criterion consists itself of a set of quantifiable sustainability indicators (eqn. 28.2):

$$C_S = \sum_{1,2,\ldots} I_S \qquad (28.2)$$

where I_S represents the indicator (Schetke & Haase, 2008).

Here, criteria and indicators are even-weighted. In considering the potentials of shrinkage for biodiversity and recreational as well as spatial cohesion aspects of an urban area, the following indicators have been applied (cf. Figure 28.6; Table 28.1):

As a first step, a map of the changed land use/cover is necessary. This should be preferably carried out using digital databases that are recorded

Figure 28.6 **Concept of multi-criteria indication of urban shrinkage (US) on land surface, biodiversity, recreation and social cohesion (Pop. = population; urbG = urban green; access. = accessibility) (according to Schetke & Haase, 2008).**

Table 28.1 **Indicator set to assess the socio-environmental impacts of urban shrinkage (according to Schetke and Haase (2008); City of Leipzig Environmental Quality Standards; City of Berlin (Environmental Atlas); Zerbe *et al.* (2003); Forman (1995); Zerbe *et al.* (2003); Whitford *et al.* (2001); URGE-Project; Mehnert *et al.* (2005); Urban Green Spaces Task Force, (2002); Santos & Martins (2007)).**

Dimension	Criterion	Indicator	Reference
Physical conditions	Soil quality	Sealing rate	City of Leipzig (Environmental Quality Standards), City of Berlin (Environmental Atlas)
	Groundwater regeneration	Groundwater recharge rate	City of Leipzig (Environmental Quality Standards), City of Berlin (Environmental Atlas)
	Water-holding capacity	**Evapotranspiration**	City of Leipzig (Environmental Quality Standards), City of Berlin (Environmental Atlas)
	Rainfall water retention	Surface run-off rate	City of Leipzig (Environmental Quality Standards), City of Berlin (Environmental Atlas)
	Filtering of pollutants	Groundwater recharge rate	City of Leipzig (Environmental Quality Standards), City of Berlin (Environmental Atlas)
Ecology	Quality of urban green	Shannon Diversity Index, Simpson Diversity Index	McKinney (2002), Zerbe *et al.* (2003)
		Leaf Area Index (LAI)	URGE-Project
		Number of species	Forman (1995), Zerbe *et al.* (2003), Whitford *et al.* (2001)
		α and β-diversity	Forman (1995), Zerbe *et al.* (2003), Whitford *et al.* (2001)
		Habitat Suitability Index (HSI)	Mehnert *et al.* (2005)
		Area of protected green	URGE-Project
		Degree of isolation	URGE-Project
	Quantity of urban green	Total area of urban green	On-site analysis
		Share of urban green per area	City of Leipzig (Environmental Quality Standards)
		Share of public green	On-site analysis (Schetke & Haase, 2008)
		Largest Patch Index (LPI)	On-site analysis (Schetke & Haase, 2008)
		Edge density (ED)	On-site analysis (Schetke & Haase, 2008)

(Cont'd)

Table 28.1 (*Continued*)

Dimension	Criterion	Indicator	Reference
Social, recreation	Green supply	Green per resident	City of Leipzig (Environmental Quality Standards)
	Accessibility	Green supply within walking distance	City of Leipzig (Environmental Quality Standards)
		Green area accessible with public transport	English Nature, 1996; Urban Green Spaces Task Force, 2002
		Maximum distance to green >0.5 ha	City of Leipzig (Environmental Quality Standards)
	Population	Number of residents	Communal statistics city of Leipzig
		Population density	Santos & Martins (2007)
	Infrastructure	Social services in walking distance	City of Leipzig (Environmental Quality Standards)
		Health care in walking distance	City of Leipzig; English Nature, 1996; Urban Green Spaces Task Force, (2002)
		Primary schools in walking distance	City of Leipzig (Environmental Quality Standards)
		Public transport in walking distance	City of Leipzig (Environmental Quality Standards)
Land use	Urban fabric	Share of renovated houses	On-Site analysis (Schetke & Haase, 2008)
		Share of non-renovated houses	On-Site analysis (Schetke & Haase, 2008)
		Built-up density	On-Site analysis (Schetke & Haase, 2008)
		Demolition rate	On-Site analysis (Schetke & Haase, 2008)
		Built-up land per resident	On-Site analysis (Schetke & Haase, 2008)
	Housing	Residential space per resident	On-Site analysis (Schetke & Haase, 2008)
		Housing costs	Santos & Martins (2007)

regularly (soil cover information systems, biotope maps, cadastral maps, etc.). In some cases, field-mapping is indispensable, particularly when the amount of reference data is lower than the land-use changes expected or when the degree of imperviousness cannot be estimated from the respective land-use change. An illustrative map is given in Figure 28.7.

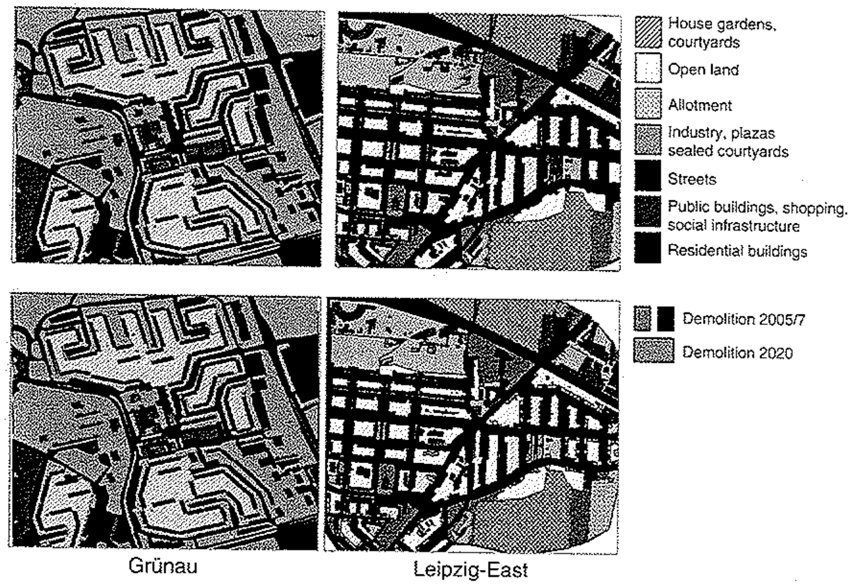

Figure 28.7 **Based on own mapping and cadastral data, a small-scale data sets showing the new 'perforated' urban landscape of remaining built-up and open land structures has been developed (Schetke & Haase, 2008).**

The maps provide the base for the actual indicator value calculation using models, equations and formalized rules published in Schetke and Haase (2008). This cannot be discussed here in detail as the chapter focuses more on the third part of the integrated impact assessment itself.

This final integration of all indicators for the different dimensions of sustainability is realized using the FLAG model computed by the SAMISOFT 1.0.0 software (Nijkamp & Ouwersloot, 2003). The FLAG Model (Figure 28.8) evaluates scenarios in relation to predefined standards (Vreeker *et al.*, 2001). It works with critical threshold values (CTVs; Leeuwen *et al.*, 2003) deriving from scientific literature and/or individual urban development targets, such as environmental quality standards (cf. Table 28.1).

Within the FLAG approach, calculated indicator values are set against the background of (normative reference) standard values (CTV_{min}), target values (CTV) and maximum values (CTV_{max}). Besides the determination of threshold values for quantitative indicators, the integration of qualitative indicators such as 'persistence of schools' has been possible with FLAG simply

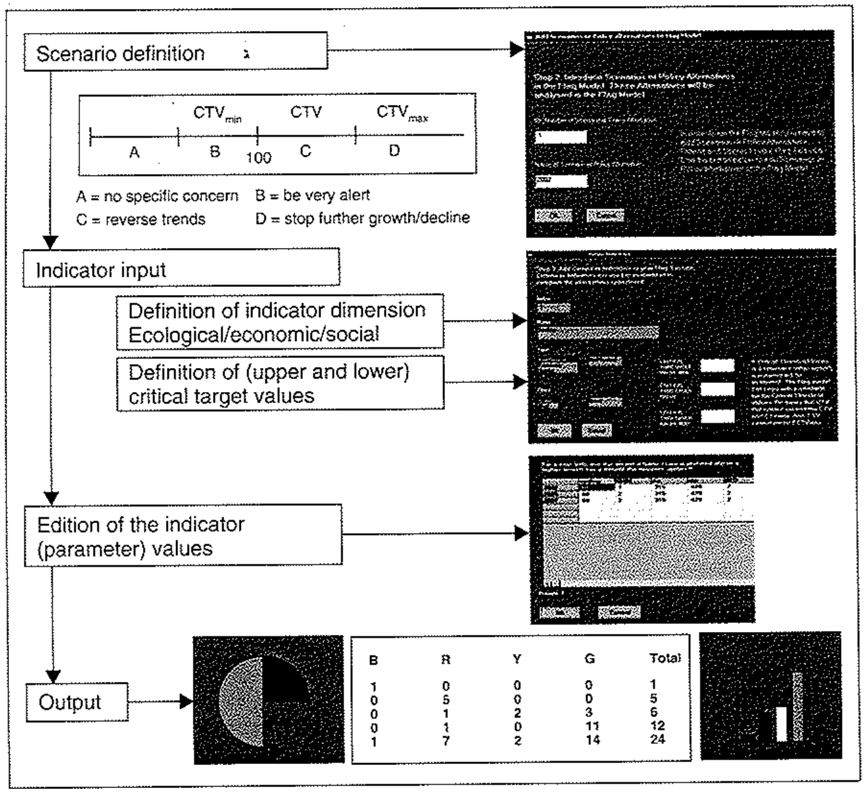

Figure 28.8 **The set-up of the Flag model that serves for a simple integration of indicators representing the different dimensions of sustainability (according to Schetke & Haase, 2008).**

by indicating 0, 1, and 2 as upper and lower threshold values. Uncertainties due to the indicator estimation or calculation are acknowledged by the FLAG system since it defines a validity space and not a concrete value that has to be matched.

Using the example test site of eastern Leipzig and bringing environmental and social components together, we see a differentiated picture of what is caused by urban shrinkage and demolition (see Figure 28.9): generally, we detect an increase in the number of green bars of our ecological indicators (indicated as 'biophysical') which indicates the positive impacts of demolition

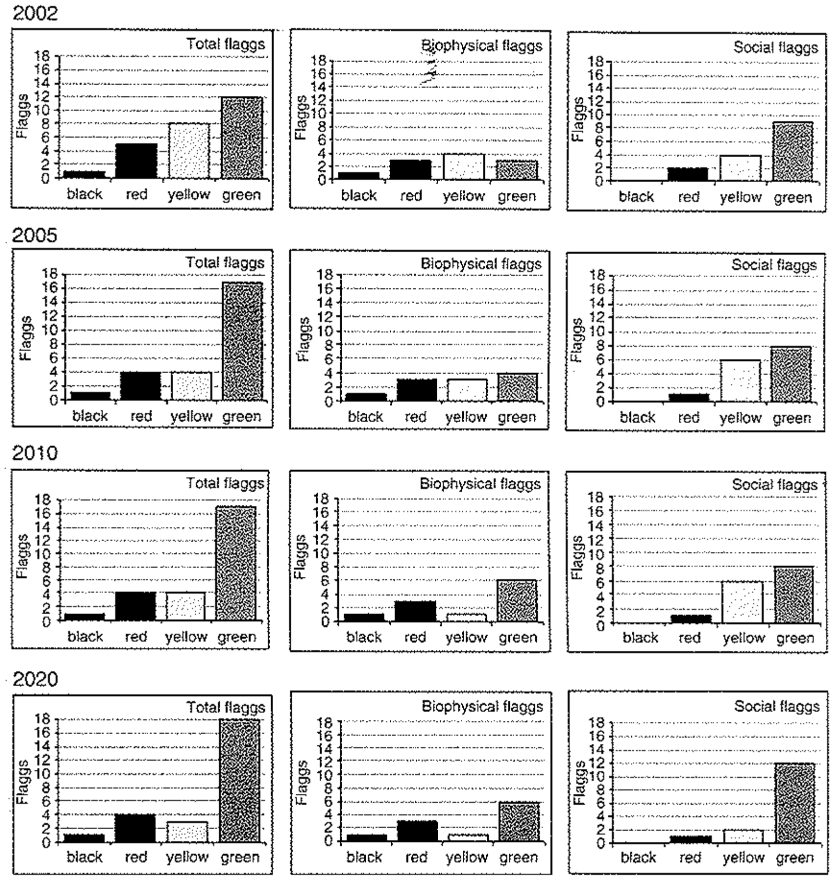

Figure 28.9 **FLAG model result for eastern Leipzig – a comparison of the scenarios 2002, 2005, 2010 and 2020. The colours of the columns mean: black = stop the development immediately, red = reverse development needed, yellow = target value reached, green = acceptable.**

and land-use perforation. The number of open (and temporarily) green spaces increase. Compared to that the black bars remain, which means that perforation does not influence those areas which reveal the worst environmental situations. Due to demographic consolidation and a measurable additional supply of urban green space also the social indicators show a positive trend towards the year 2020.

In the following paragraphs, we will selectively highlight the results of the MCA-assessment for East Leipzig in order to get a precise picture of the ecological and social benefits that this neighbourhood obtains from shrinkage.

The demolition of large housing complexes such as those of the socialist prefabricated housing estates of Leipzig-Grünau produce considerably more open space and a higher impact on the local lifestyle especially when compared with the more patchy pattern produced by the demolition of single houses in the older densely developed areas such as East Leipzig.

The recent demolition phase in East Leipzig and Leipzig-Grünau have had little impact on the local sealing rate and on the adjusted hydrological indicators, however it is expected that considerable long-term changes are likely as a result of the continuing demolition. In East Leipzig, the effects have been low due to the highly dispersed demolition sites. No further negative consequence appears likely because the sealing rate has never exceeded the critical values (69% in 2002 and 67% in 2020). Because it includes information on configuration and structural integrity of the urban green space, the indicator of the leaf area index (LAI) gives the most complex overview of the green quality. At the detailed level, an important small-scale contribution to the local green structure can be found in East Leipzig. This is mainly due to the foreseen tree plantings in the new open spaces as parts of new pocket-sized parks and green corridors.

For East Leipzig, one can summarize that the new green spaces in East Leipzig are characterized by a high LAI but are – due to the fragmented urban structure – quite small and therefore make only a small contribution to the overall green quality of the neighbourhood (LAI 2002 with 1.26 vs.1.34 in 2020; Schetke & Haase, 2008). Due to a fragmented building and green structure (ratio of green area/housing areas: 0.57 vs. 1.07 in Leipzig-Grünau), both the LPI and the SHDI are generally lower than in a prefabricated housing estate such as Leipzig-Grünau. The LPI varies remarkably when specifically looking at different land-use types within East Leipzig. Whereas it increases for the inner parts (inner courtyards) of the blocks (1.01 → 1.21) as well as for interspersed urban brownfields (1.31 → 1.51), it decreases in small courtyards from 3.94 to 3.19. Compared to this, the diversity of the areas (SHDI) increases at the final stage of demolition from 1.65 in 2002 to 1.73 in 2020 (Leipzig-Grünau: 2.39 in 2002 vs. 2.44 in 2007).

In terms of the quantity of urban green, positive benefits can be seen, which occurred as a result of demolition within the assessed scenarios. Compared

with a target value of 6 m^2 green per resident (Stadt Leipzig, 2003), we started with 45 m^2 in East Leipzig (in 2002) and will finish with 46 m^2 in 2020. When computing the mean share of urban green space within the housing area using a 50 m-distance-buffer around each house (= house gardens), the accessible urban green area remains stable between 34 and 27 m^2. Compared with this, urban green space within a distance of 5 minutes walking (= represented by a buffer of 500 m; public urban green) increases from 9 to 11 m^2/resident. The total amount of open space and urban green 'gained' at the final stage of the demolition programme in 2020 in Leipzig-East will be 1.71 ha, which represents a total amount of 36.10 m^2 of green space per resident. Most of this quantified urban greenery is of a public nature and thus accessible to all residents of Leipzig-East. But also small semi-public areas such as pocket-sized parks located on single lots are emerging and contributing not only to an increased small-scale biodiversity but also to residents' quality of life.

When looking at the impact of shrinkage on the social infrastructure (e.g. schools and hospitals) of Leipzig-Grünau and East Leipzig, although expected, a severe drop in the accessibility of social infrastructure or per-capita-relations is unlikely to happen. During all scenarios and in both test areas, the distance-values of social infrastructure (schools, retail trade shopping facilities, main roads) do not exceed threshold values but remain mostly positively far below them. Compared with the effects of land-use perforation in Leipzig-Grünau, where we find a turn into a greener and more nature-oriented development along with space for more spacious livelihoods with semi-natural biotopes, East Leipzig is likely to face a re-densification and re-urbanization which limits the space for new green spaces. This limited area for green development requires a higher quality of the green spaces in terms of recreation potential and habitat quality.

Conclusions

As we have shown, there is considerable potential for biodiversity and the improvement of urban green systems within shrinking cities. The same applies to social and residential improvement, which was outlined peripherally in the last section. Using Leipzig as an example, exploiting the opportunities of urban shrinkage to provide more green space may help to attract new residents for a longer period of time and encourage the existing population to stay instead of choosing the detached-house alternative.

We have identified the positive structural enrichment of green space resulting from shrinkage in relation to single species measured by edge density or diversity indices and newly emerging spatial pattern. In addition, we have presented a MCA-scheme extending the findings to landscape metrics and embedding them into a set of ecological as well as social indicators. Here, the chapter shows an indicator-based integrated assessment approach which quantifies the effects of urban shrinkage and land-use perforation. Interdisciplinary decision-making requires integrative tools for the assessment and future planning of urban neighbourhoods faced by these complex phenomena. This is a valuable contribution in combining different dimensions of sustainability in urban shrinkage and to assess its socio-environmental impacts within a long-term scenario analysis.

Based on the findings of biodiversity and green space potentials, it is argued that disused residential and commercial properties and their subsequent demolition provide opportunities for the enlargement of urban green space and, to some extent, the ecological restoration of cities.

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Flood Risk Management: Research and Practice – Samuels et al. (eds)

A multicriteria flood risk assessment and mapping approach

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ABSTRACT: Flood risk analysis and assessment are integral parts of the flood risk management approach. However, some deficits can be recognised in today's practice with regard to the following aspects: a) The focus of flood risk assessment is still very much on economic flood risks. Social and environmental flood risks are often neglected. Consequently, the results of risk assessment can be incomplete and biased. b) The spatial distribution of risks as well as of the benefits of flood mitigation measures is rarely considered. c) Uncertainties in the results of risk assessment are often ignored. In this paper we want to present a GIS-based multicriteria flood risk assessment and mapping approach. Our approach can be used for an integrated assessment of economic, as well as social and environmental flood risks. Furthermore, the spatial distribution of these multiple risks as well as of the effects of risk reduction measures can be shown by this mapping technique. Moreover, possibilities are shown how to deal with uncertainties in criteria values and to demonstrate their influence on the overall assessment. The approach is applied to a pilot study at the River Mulde in Saxony, Germany, heavily affected by the hazardous flood in 2002. Therefore, a GIS-dataset of economic as well as social and environmental risk criteria was built up. Two different multicriteria decision rules, a disjunctive approach and an additive weighting approach are used to come to an overall assessment and mapping of flood risk in the area. Both, the risk calculation and mapping of single criteria as well as the multicriteria analysis are supported by a software tool (FloodCalc) which has been developed for this purpose.

1 INTRODUCTION

The comprehensive analysis and assessment of flood risk is an essential part of the risk management approach, which is the conceptual basis for the new EU "directive on the assessment and management of flood risk" (EU 2006/C 311 E/02). However, the practical application of flood risk assessment still has to face some problems:

1. Social and environmental flood risks are often neglected. The term risk, defined as the probability of negative consequences (Knight 1921, Schanze 2006, FLOODsite Consortium 2005) encompasses all kinds of consequences of flooding. Nevertheless, current practice of risk assessment still focuses on economic damages which can be easily measured in monetary terms, while social and environmental consequences are often neglected. Consequently, the results of risk assessment can be incomplete and biased.
2. The spatial allocation and distribution of risks as well as of the benefits of flood mitigation measures is rarely considered. For example, the evaluation and selection of appropriate mitigation measures is mostly based on their overall net benefit. Therefore, it is often not considered which areas benefit most from a measure and which areas do not. This may lead to spatial disparities of flood risk which are not desirable or acceptable.
3. Uncertainties in the results of risk assessment are often ignored. Although sophisticated methods in all parts of risk analysis and assessment have been elaborated over the past decades in order to give a reasonably exact estimation of flood risk, the results of risk assessment are still to some degree uncertain or imprecise (Nachtnebel 2007, Downton & Pielke 2005, Handmer 2003). These uncertainties are often not communicated to the decision makers, i.e. a non-existent precision of estimation is pretended. This might facilitate the decision for the decision maker but reduces the scope of decision and could lead to a solution which is not optimal.

The methodological framework presented in this paper tries to tackle these three problems Hereby, the focus is set on the first point. In this context, multicriteria analysis (MCA) is an appropriate method of incorporating all relevant types of consequences without measuring them on one monetary scale. It provides an alternative to the complex monetary evaluation and internalisation of intangible consequences.

MCA is combined with Geographical Information Systems (GIS) in order to show the spatial distribution of flood risks and risk reducing effects, respectively. Finally, at least for the economic risk criterion a very basic approach is applied in order to document the uncertainties associated with flood risk assessment.

We expect that such integrated risk mapping techniques will gain importance also with regard to the new European "directive on the assessment and management of flood risk" (EU 2006/C 311 E/02). This directive requires, in article 6, a risk mapping of social, economic and environmental flood risk.

The paper is structured as follows. Our multicriteria risk mapping approach is described in chapter 2, also showing exemplary results from a case study. In chapter 3 we briefly show how this approach could be used also for the mapping of the effects of risk management measures. In the final chapter our findings are summarised and conclusions are drawn.

2 MULTICRITERIA RISK MAPPING APPROACH

In the following our multicriteria risk mapping approach should be introduced. This approach has been developed in the context of the FLOODsite-project and is described in greater detail in Meyer et al. (2007) and Meyer et al. (2008). Both, the risk calculation and mapping of single criteria as well as the multicriteria analysis are supported by an alpha-version of a software tool (FloodCalc). The approach is tested at the Vereinigte Mulde River in the Free State of Saxony, Germany. This river stretch is approximately 60 kilometres long, i.e. the approach should be capable to deal with flood risk assessment on a basin scale. However, for better visualization, the maps in the following are restricted to a small 4 × 4 km section around the city of Eilenburg, located in the northern part of the area.

As risk indicators the evaluation criteria described in Table 1 are applied. With this set of criteria we consider all three dimensions of sustainability. However, in order to keep the approach applicable this set of criteria is only quite small and simple. For a more comprehensive assessment criteria can be added or the given criteria might be further improved.

Table 1. Evaluation criteria for flood risk for all 3 dimensions of sustainability.

Flood risk dimension	Criteria	Sub-criteria	damage unit […/a]	description	method/ data
Economic	Annual Average Damage		€	damages on assets (buildings, inventories etc.)	meso-scale damage evaluation approach, based on official statistics, land use data & depth-damage functions
Environmental	Aggregated environmental risk	Erosion potential	affected: yes/no	areas with erosion potential of pollutants	data from flood in 2002
		Accumulation potential	affected: yes/no	areas with accumulation potential of pollutants	data from flood in 2002
		Inundation of oligotrophic biotopes	affected: yes/no	areas of biotopes vulnerable to inundation	identification of vulnerable biotopes based on biotope-type data
Social	Annual average affected population		number of people affected	number of people affected at their home	meso-scale approach, based on official statistics and land use data
	Probability of social hot spots of being affected		affected: yes/no	social hots spot like hospitals, schools, old peoples homes etc.	point data of social hots spots based on own surveys

The general procedure of the multicriteria risk mapping approach is shown in Figure 1. Based on inundation depth data for flood events with a different exceedence probability (1:10, 1:25, 1:50, 1:100, 1:200, 1:500)[1] and information on the spatial distribution of elements at risk for the different criteria (step 1) absolute damages or affected units, respectively, are calculated for these different flood events (step 3). Based on these different damage figures and their associated probabilities the expected annual average damage or flood impact is calculated (step5) by means of equation 1 (DVWK 1985).

$$\overline{D} = \sum_{i=1}^{k} D[i] * \Delta P_i \tag{1}$$

$$D[i] = \frac{D(P_{i-1}) + D(P_i)}{2} \tag{2}$$

where $\overline{D}$ is the annual average damage, D[i] the mean damage of two damage estimations with a certain exceedence probability and ΔP_i the probability of the interval between those points.

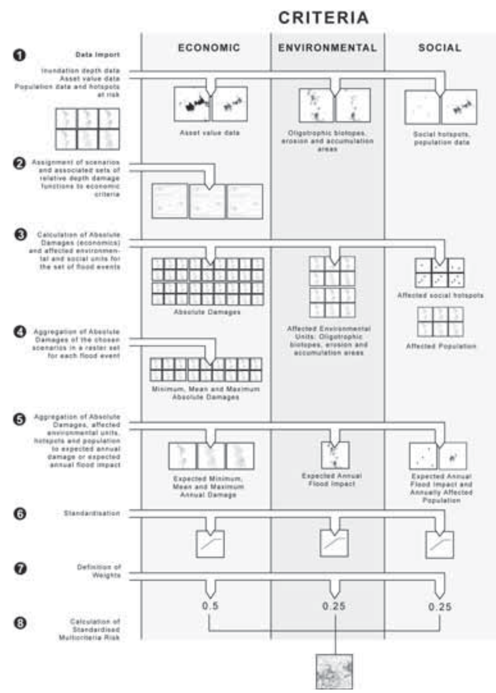

Figure 1. Stepwise procedure of the multicriteria risk mapping approach (additive weighting approach).

The units of measurement for each of the criteria are shown in Table 1. Each of the different risk maps is then standardised to values between 0 and 1 (step 6), weighted (step 7) and finally aggregated to a multicriteria risk map (step 8). All these calculations are carried out for grid with a spatial resolution of 10 m. The procedure for the different criteria will be described in more detail in the following.

2.1 *Economic risk criterion*

For the assessment of the economic risk criterion a meso-scale damage evaluation approach is applied (Meyer 2005). The general procedure is the following:

The total value of assets at risk (step 1) and its spatial distribution are estimated based on data from official statistics (the net value of fixed assets for different economic sectors) which is then assigned to corresponding land use categories taken from official topographic data (ATKIS-DLM). In order to consider methodological uncertainties two different spatial modelling keys are applied here.

Relative depth-damage curves are then used to calculate the damaged share of these values, depending on inundation depth (step 2). Methodological uncertainties are considered here by applying three different sets of depth/damage curves.[2]

Damage evaluation is carried out for every combination of asset value map and damage function set, resulting in six different damage estimations for each flood event (step 3).

Based on these different damage values a mean damage can be calculated for each grid cell as well as a minimum and maximum damage value (step 4). The different damage estimations for the inundation events considered are then used to calculate the AAD according to equation 1 (step 5). This is conducted for the mean as well as for the minimum and maximum damage estimations so that the final output is a mean, minimum and maximum AAD per grid cell, accordingly. The spatial distribution of the mean annual average damage for the city of Eilenburg is shown in Figure 2.

2.2 *Environmental risk criterion*

In order to assess the environmental risk of an inundation in the Mulde floodplains, three sub-criteria have been selected (Table 1):

[1]The inundation depth for each of these events is calculated by our colleague Gerald Wenk from UFZ by a quasi 2D hydrodynamic model (HEC-RAS).

[2]Three different sets of damage functions were applied, taken from the KRIM-project at the German North-Sea coast (Mai et al. 2007), a damage evaluation study from the River Rhine (IKSR 2001), and from the Dutch standard method (Kok et al. 2004).

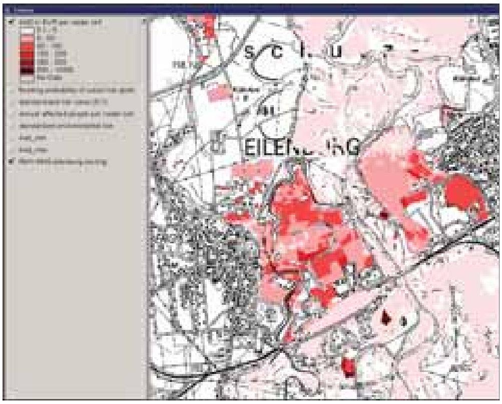

Figure 2. Annual Average Damage (AAD) (City of Eilenburg): mean estimation. Source: Topographic map: Landesvermessungsamt Sachsen; damage estimation: own calculations.

1. The erosion potential of areas, i.e. where pollutants might be mobilised during a flood.
2. The accumulation potential of areas, i.e. where new polluted sites might be created by a flood. The identification of both erosion and accumulation areas is based on data from the Mulde flood in 2002.
3. Inundation of oligotrophic biotopes, i.e. biotopes which might be negatively affected by a longer inundation. These areas are identified by biotope-type data for the area.

After intersecting the maps for these subcriteria with inundation data (step 1) a simple Boolean yes/no damage function is applied for each sub-criterion and grid cell, depending on whether the area is affected or not. Because the three criteria are different in terms of their environmental impact but may occur simultaneously during one unique flood event, we suggest calculating a sum of the values given for each sub-criterion to estimate a first environmental impact potential of a flood. The list is not complete and has to be amplified according to both other case study requirements and general improvements.

Analogous to the calculation of economic damage, damage maps for environmental consequences can be produced for each flooding event (step 3). Each raster cell can hereby achieve "damage values" between 0–3. Based on these different damage maps an environmental risk map is calculated by using equation 1 (step 5). This risk value can be interpreted as annual average environmental flood impact, expressed in the point scale described above. In Figure 3 these values are already standardised in values from 0 to 1 (step 6).

2.3 *Social risk criteria*

As social risk criteria two quite simple indicators are used: the annual average affected population and the probability of social hot spots like hospitals, schools, old people's homes etc. of being flooded (see Table 1).

For the determination of the affected population first of all the spatial distribution of the population is calculated by a meso-scale approach (step 1; Meyer 2005). By intersecting this population density map with the inundation data the number of affected people can be estimated for each event (step 3). According to equation 1, the number of the annual average affected population can be calculated (step 5; see Figure 3).

As "social hot spots" the locations of hospitals, schools, old people's and children's homes are identified (step 1). For reasons of simplicity we assume

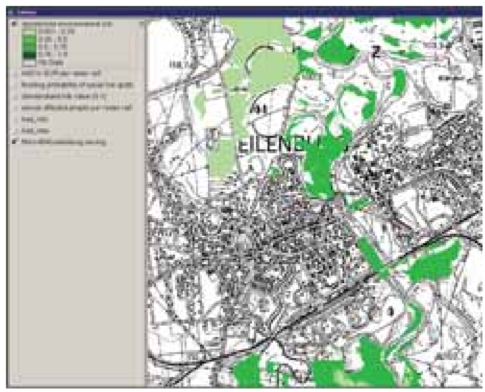

Figure 3. Environmental risk: standardised values (0–1). Source: Topographic map: Landesvermessungsamt Sachsen; damage estimation: own calculations.

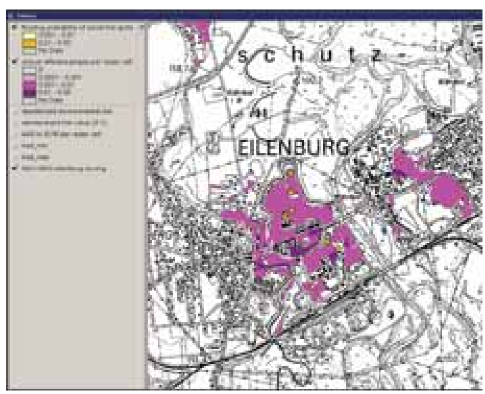

Figure 4. Annual affected population and social hot spots at risk and their probability of being flooded. Source: Topographic map: Landesvermessungsamt Sachsen; social hot spot risk: own calculations.

that each of the hot spots has the same vulnerability, no matter e.g. the size of a hospital or school. Intersecting the social hot spots map with the inundation maps leads to the determination of affected hotspots per inundation scenario (step 3). By applying equation 1 an approximate estimation of the probability of being affected can be calculated for each hot spot (step 5; Figure 4).

2.4 *Multicriteria decision rules*

For the aggregation of the different risk maps (step 8) the user of the FloodCalc software tool can choose between two different multicriteria decision rules, a disjunctive approach (see e.g. Zimmermann & Gutsche 1991) and a simple additive weighting approach (see e.g. Malczewski 1999).

The general idea of the disjunctive approach is that the decision maker has to define a threshold level for each criterion. E.g. in order to select areas which have a high risk of flooding, the decision maker has to determine for each risk criterion a critical value which defines the border between low/acceptable risk and high/unacceptable risk. If this threshold value is exceeded in only one of the criteria, the area is selected as a high risk area. Such a simple approach can be used for example for a quick screening and pre-selection of high risk areas.

Figure 5 shows sample results of the disjunctive approach for arbitrarily chosen threshold values for each of the criteria:

- Economic risk: >100 € (annual average damage per raster cell)
- Environmental risk: >0.4 (standardised environmental risk)
- Population: >0.001 (annual affected people per raster cell)
- Social hot spots: >0.01 (annual probability of being flooded)

All red areas exceed the threshold value in at least one criterion, some areas (in darker red) in more than one criterion.

The additive weighting approach applies the following model:

$$V_i = \sum_j w_j v_{ij} \tag{3}$$

Where V_i is the overall value or utility of the grid cell i, v_{ij} is the standardised value of grid cell i regarding criterion j (step 6) and w_j is the standardised weight for criterion j (step 7). I.e. a weighted standardised average of the single criterion values for each area is calculated. Figure 6 shows exemplary results if a relatively high weight of 0.4 is given to the economic and the population criterion, as these two are often considered as the most important protection goods.

For a real site specific assessment both approaches would of course require the involvement of decision makers in order to determine the threshold values or weights given to each criterion. In our examples such a participation of decision makers did not take place (yet) so arbitrary set of threshold values and weights are chosen.

However, the approach allows to show the sensitivity of the results against different sets of weights. In figure 7, for example, the standardised risk value is shown when the social, environmental and economic dimensions of risk are weighted equally (0.33 each).

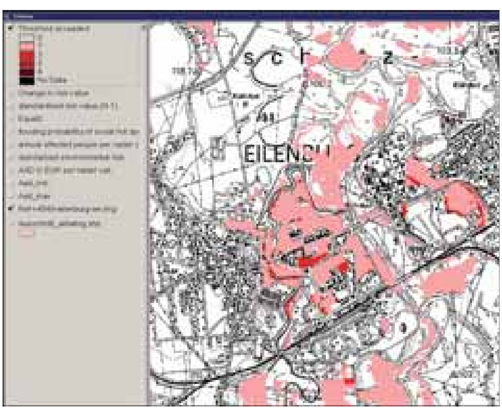

Figure 5. Example for selected "high risk areas" by the disjunctive approach. Source: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations.

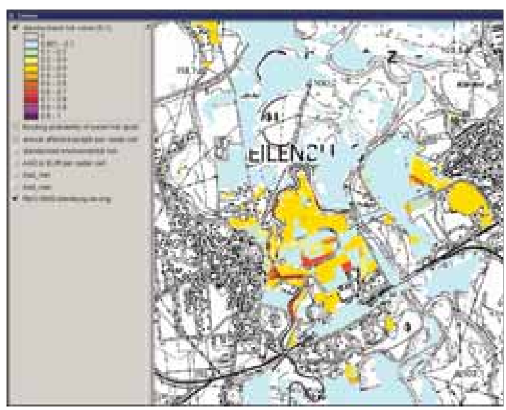

Figure 6. Standardised multicriteria risk: large weight on economic & population criteria (0.4 each). Source: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations.

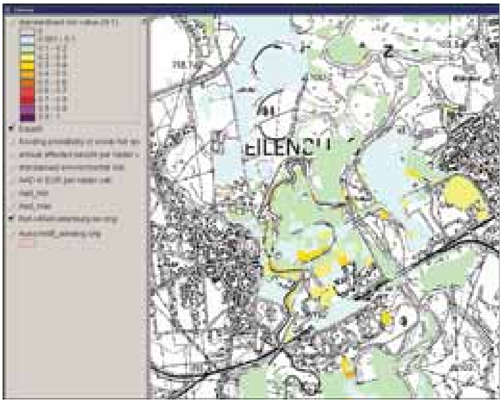

Figure 7. Standardised multicriteria risk: equal weighting of the social, environmental and economic risk dimension (0.33 each). Source: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations.

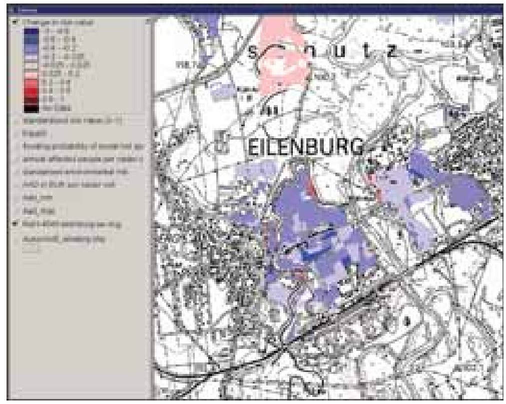

Figure 8. Change in standardised multicriteria risk due to measures planned in the flood protection concept (weights as in Figure 6). Source: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations.

In practice, such a sensitivity analysis of weight sets can be used to visualize the changes in the risk maps if weight sets of different stakeholder groups are used. But also the sensitivity with regard to uncertainties in the criteria values can be shown by conducting the same calculation with the minimum and maximum criteria value map. However, in our example this would be only possible for the economic criterion (see section 2.1)

3 MAPPING THE EFFECTS OF RISK MANAGEMENT MEASURES

The approach described in the last chapter focuses on flood risk assessment, which can be used for the identification of areas where flood risk is so high that mitigation measures are necessary. However, the next step within a flood risk management approach would be to develop alternative measures or projects for the mitigation of these unacceptable risks. In this context, our approach can be also used to show the spatial distribution of the risk reducing effects of such measures.

For our pilot study we calculated risk maps for the status quo as well as for the situation after implementing all measures which are planned in the flood protection concept for the Mulde River. By calculating the difference in the standardised risk value between the situation with and without these measures the effect of the planned measures can be illustrated. This is done in Figure 8 showing the benefiting areas in blue (negative values = risk reduction). In this example (and under these weighting conditions) nearly all flood-prone parts of Eilenburg would profit from the planned flood risk mitigation measures by a decrease of the standardised multicriteria risk of of up to 0.6 points. However, this approach could also be used to identify areas which have to face disadvantages due to the planned measures.

4 SUMMARY & CONCLUSIONS

The approach introduced in this paper aims to improve flood risk assessment in three ways: Firstly, to include non-monetary risks in the overall flood risk assessment. Secondly, to show the spatial distribution of these multicriteria risks. Thirdly, to show possibilities for dealing with the uncertainties associated with the criteria evaluation.

Therefore, we developed a framework for a GIS-based multicriteria analysis which can be applied for an integrated assessment and mapping of flood risks. This approach was applied to a pilot site, the Vereinigte Mulde in the federal state of Saxony, Germany.

First of all a set of evaluation criteria was selected which encompasses economic as well as environmental and social flood risk indicators. For each of the criteria, damage evaluation methods were applied in order to produce risk maps. Two different MCA approaches were tested in order to aggregate these different criteria risk maps: a disjunctive approach and an additive weighting approach. Our pilot study showed that both are appropriate for use within the framework of multicriteria risk mapping. The additive weighting approach would furthermore be applicable to show the spatial distribution of benefits of certain flood risk reduction measures. As documented for the economic criterion, uncertainties in flood risk assessment can be considered in a simple way by calculating mean, minimum and maximum risk estimations.

As a further result, an alpha version of a software tool was developed (FloodCalc; Scheuer & Meyer 2007), which supports not only the calculation and mapping of the different damage and risk criteria, but also the two different MCA-procedures mentioned above.

However, our approach should be seen only as a first step towards an integrated risk mapping approach. Several points need further improvement.

Firstly, the set of criteria could be extended or improved and the methods for the calculation of these risk criteria could be further refined. Secondly, uncertainties are documented only for the economic criterion. This could be extended also to the other criteria. Finally, and maybe most important, the selection and weighting of criteria are crucial parts of any multicriteria approach which have high influence on its outcomes. Here, rules and procedures have to be further elaborated for the involvement of decision makers and stakeholders to ensure the legitimacy of judgements.

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ORIGINAL PAPER

A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany

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Abstract In this paper we develop a GIS-based multicriteria flood risk assessment and mapping approach. This approach includes flood risks which are not measured in monetary terms; it shows the spatial distribution of multiple risks, and it is able to deal with uncertainties in criteria values and to show their influence on the overall flood risk assessment. Additionally, the approach can be used to show the spatial allocation of the flood effects if risk reduction measures are implemented. The approach is applied to a pilot study for the River Mulde in Saxony, Germany, heavily affected by the hazardous flood in 2002. Therefore, a GIS database of economic, social and environmental risk criteria was created. Two different multicriteria decision rules, a disjunctive and an additive weighting approach, are utilised for an overall flood risk assessment in the area. For implementation, a software tool (FloodCalc) was developed supporting both, the risk calculation of the single criteria as well as the multicriteria analysis.

Keywords Multicriteria analysis · Flood risk · Evaluation criteria · Risk maps · Criterion weights · Decision rules

1 Introduction

1.1 Background

In recent years, a shift in flood policy from the traditional concept of "flood protection" towards the new paradigm of "flood risk management" can be recognised (Schanze 2006).

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Flood risk management can be roughly divided into two parts (ebd.): flood risk analysis and assessment on the one hand and risk mitigation on the other. Broadly speaking, the purpose of flood risk assessment is to establish where risk is unacceptably high, i.e. where mitigation actions would be necessary. Risk mitigation means to propose, evaluate and select measures to alleviate risks in these areas.

The comprehensive analysis and assessment of flood risk is therefore an essential part of the whole risk management concept. In this context, three deficits in today's practice of flood risk management can be identified:

1. Social and environmental flood risks are often neglected. The term risk is defined in the context of flood risk management by the Eq. 1

$$\text{Risk} = \text{Probability} * \text{Consequence (Gouldby and Samuels 2005)} \quad (1)$$

which goes back to the definition of risk introduced by Knight (1921). Here, the term consequence encompasses all kinds of consequences of flooding. Nevertheless, the current practice of risk assessment still focuses on damages that can be easily measured in monetary terms. More precisely, risk analysis mainly deals with damage to assets, while social and environmental consequences are often neglected. In consequence, flood risk management often manages only certain parts of flood risk. On that basis, an optimised allocation and design of flood mitigation measures cannot be ensured; such an optimisation is the more likely, the more social and environmental risk are spatially separated from economic risks.

2. The spatial allocation and distribution of risks as well as of the benefits of flood mitigation measures are rarely considered. For example, the evaluation and selection of appropriate mitigation measures are mostly based on their overall net benefit. Therefore, it is often not considered which areas benefit most from a measure and which areas do not. This may lead to spatial disparities of flood risk which are not desirable or acceptable.
3. Uncertainties in the results of risk assessment are often ignored. Although sophisticated methods in all parts of risk analysis and assessment have been elaborated over the past decades in order to give a reasonably exact estimation of flood risk, the results of risk assessment are still to some degree uncertain or imprecise. These uncertainties are often not communicated to the decision makers, i.e. a non-existent precision of estimation is pretended. This might facilitate the decision for the decision maker but reduces the scope of decision and could lead to a solution which is not optimal.

The methodological framework presented in this paper tries to provide solutions for these three problems. Here, the focus is set on the first point. In this context, multicriteria analysis (MCA) is an appropriate method of incorporating all relevant types of consequences without measuring them on one monetary scale. It provides an alternative to the complex monetary evaluation and internalisation of intangible consequences.

The second point can be considered by mapping risks and risk reducing effects, respectively. Geographical Information Systems (GIS) with their ability to handle spatial data are an appropriate tool for processing spatial data on flood risk. The approach presented in this paper combines MCA with GIS. Finally, at least some possibilities will be shown on how to deal with uncertainties in the results of risk assessment in this spatial MCA framework. We expect that such integrated risk mapping techniques will gain importance also with regard to the new European "directive on the assessment and management of flood risk" (EU 2006/C 311 E/02). This directive requires, in article 6, a risk mapping of social, economic and environmental flood risk.

This paper is structured as follows. In the remainder of this chapter a brief overview of the state of the art in the MCA of flood risk will be given. In Chapter 2 we present our approach which is illustrated by the example of the Mulde River. Both approach and results will be discussed in Chapter 3 before conclusions are drawn in the final chapter.

1.2 State of the art in multicriteria analysis of flood risk

There is plenty of literature on MCA or multicriteria decision-making in general (Bana and Costa 1990; Zimmermann and Gutsche 1991; Vincke 1992; Munda 1995; Belton and Stewart 2002). Most of these textbooks set the focus on the mathematical core of MCA, the decision rules and the various approaches and methods existing, like Multi Attribute Utility Theory (MAUT), Outranking, Analytical Hierarchy Process (AHP), etc. More brief overviews of existing approaches are also given, e.g. in Merz and Buck (1999), DTLR (2001) and Omann (2004). Others set their focus on one approach, like Keeney and Raiffa (1993) on the MAUT approach, Drechsler (1999; see also Klauer et al. 2006) on extensions of the PROMETHEE approach, or on the Hasse–Diagramm technique (Brüggemann et al. 1999; Pudenz et al. 2000; Simon 2003; Soerensen et al. 2004).

Spatial MCA, in contrast, is a relatively new but growing research field which is still developing with the further improvement of GIS (Malczewski 2006). A very comprehensive textbook on the combination of MCA and GIS was written by Malczewski (1999). Examples for the application and new approaches of spatial MCA are Tkach and Simonovic (1997); Malczewski (1999); Malczewski et al. (2003); Thinh and Hedel (2004); Simonovic and Nirupama (2005); Malczewski (2006); Strager and Rosenberger (2006) and Aceves-Quesada et al. (2006). For a complete review and categorisation of refereed journal articles on spatial multicriteria decision analysis, see Malczewski (2006).

The application of MCA in general and especially spatial MCA in the context of flood risk management is still rare: Brouwer and van Ek (2004) evaluate long-term flood risk management options in the Netherlands with MCA using the DEFINTE software (Janssen et al. 2003). In the UK a report on the applicability of MCA procedures in the common cost-benefit analysis appraisal technique for flood risk management measures was written by RPA (2004) for the responsible state department DEFRA. Also the official manual for damage evaluation in the UK (Penning-Rowsell et al. 2003) includes a section on multicriteria evaluation of flood protection measures. Both are based on MAUT approaches. In the federal state of Saxony, Germany, a point-based MCA approach is used for the prioritisation of flood defence structures (Socher et al. 2006). Bana and Costa (2004) used the MACBETH approach for the evaluation of alternative flood control measures in Portugal. Akter and Simonovic (2005) finally deal with flood risk management and MCA in the Red River Basin in Canada. They focus on methodologies to incorporate multiple stakeholders' opinions in multiobjective decision-making. However, all these studies do not consider the spatial dimension of flood risk.

Only few examples for the application of spatial MCA in the field of flood risk analysis and management exist. Tkach and Simonovic (1997), for example, analyse the spatial distribution of the multiple effects of different flood protection alternatives in the Red River Basin, using a GIS-based variant of the Compromise Programming (CP) MCA-technique which they call Spatial Compromise Programming (SCP). Simonovic and Nirupama (2005) expand this approach by integrating fuzzy set techniques in order to deal with uncertainties in the evaluation criteria. A rather similar approach, also based on SCP, is used by Thinh and Vogel (2006) for land use suitability assessment in the Dresden region (Saxony), also including flood risk as a criteria. However, most of the multicriteria approaches in the context of flood risk focus on the evaluation of flood mitigation measures instead of flood risk mapping.

2 Approach

Our objective is to provide an approach which is capable of an integrated assessment and mapping of economic, environmental and social flood risks. This means that firstly, evaluation criteria have to be chosen for the different risk dimensions. Secondly, methods have to be identified in order to assess these risk criteria in a spatially differentiated way, i.e. risk maps have to be created for each of the chosen criteria. And thirdly, these different risk maps have to be aggregated by means of appropriate multicriteria decision rules in order to get an overall risk assessment and mapping.

This approach differs from multicriteria project appraisals in the context of flood risk management, where different risk reduction measures like dikes, polders or warning systems are evaluated by means of MCA techniques (see e.g. RPA 2004). In our case, not decision alternatives but areas (grid cells) are assessed by multicriteria techniques in order to make their overall flood risk comparable and to create flood risk maps. However, this multicriteria risk mapping approach can be used in a second step also for the evaluation and mapping of the risk reducing effects of certain flood protection measures, as shown in Sect. 4.

The Vereinigte Mulde River in the federal state of Saxony in Germany was chosen as a pilot area (Fig. 1). The Mulde was heavily affected by the flood in August 2002. Mid-size towns such as Grimma or Eilenburg and many smaller cities and villages had to face serious damage (Freistaat Sachsen 2003). Our risk calculations were carried out for the entire area. In order to illustrate the results in a higher spatial scale the following, detailed subset maps will focus on the city of Grimma, located in the southern part of the pilot area.

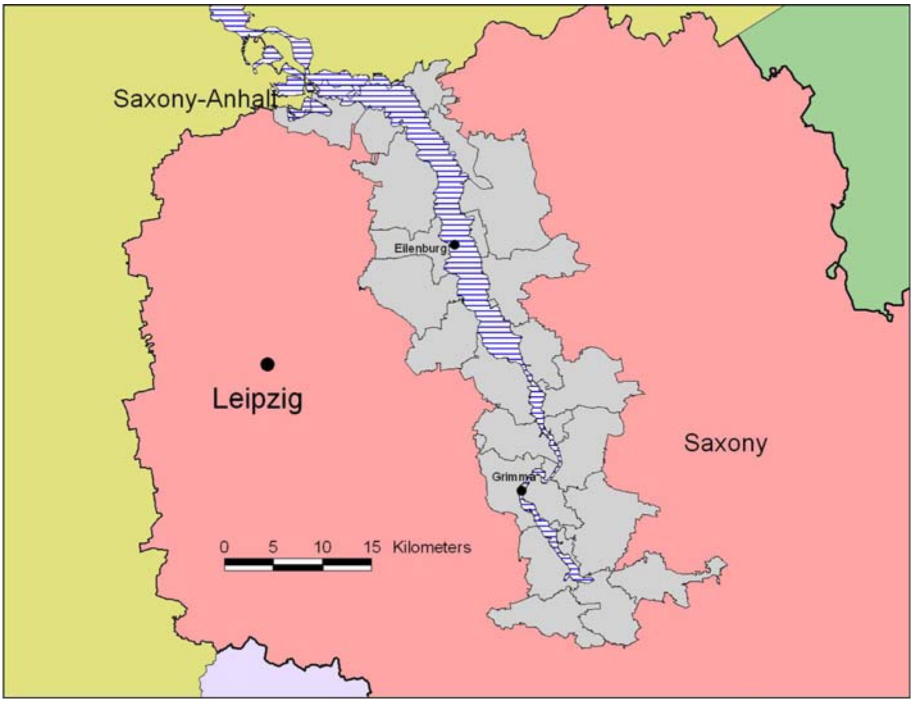

Fig. 1 Pilot area: Saxonian municipalities along the Vereinigte Mulde river (grey), Mulde floodplains and inundation area in August 2002 (blue-striped)

2.1 Evaluation criteria

The selection of evaluation criteria is a crucial step of each MCA approach. The inclusion or exclusion of criteria can greatly influence the results of the evaluation process. The evaluation criteria should be complete on the one hand to make sure that the whole problem is encompassed; on the other hand the set of criteria should be kept minimal to reduce the complexity of the evaluation process (Keeney and Raiffa 1993). For our study different flood risk MCA studies were examined with regard to the risk criteria they apply. Based on this the criteria described in Table 1 were selected.

In Table 1 information is given also on the units of measurement for each criterion as well as on the methods and data used for their evaluation. These methods will be further explained in the following section. The rationale for selection of these criteria is on the one hand to cover the three main dimensions of flood risk: economic, social and environmental risks. On the other hand this list is kept minimal and simple for reasons of applicability. For a more comprehensive analysis it might be desirable to extend this set by more criteria and to improve the criteria. Therefore it would also be advisable to include decision makers and stakeholders in the selection process.

2.2 Criteria evaluation: risk maps

For each alternative or grid cell the performance of each criterion needs to be evaluated. Regarding GIS-based flood risk assessment, the result is a risk map for each criterion. Our basis for the assessment of flood risk in the pilot study is the definition of risk expressed by eq.1 (Gouldby and Samuels 2005):

$$\text{Risk} = \text{Probability} * \text{Consequence} \tag{1}$$

In other words, this is the expected annual average damage of flooding, where "damage" covers economic, social as well as environmental negative consequences. For the practical application of flood risk assessment this means that the damage has to be evaluated for flood events of different probability. Based on these damage evaluations for different events a damage-probability curve can be constructed (see Fig. 2). The risk (or the annual average damage), as we use this term in our paper, is shown by the area or the integral under the curve.[1] However, the exact run of the curve is often not easy to specify as only a few points on it are known. Hence, in most cases an approximation is made by calculating risk with the following formula (DVWK 1985; Eqs. 2 and 3):

$$\bar{D} = \sum_{i=1}^{k} D[i] * \Delta P_i \tag{2}$$

[1] It should be noted that this risk formula is often criticised especially in social science for several reasons (see e.g. Banse and Bechmann 1998): Firstly, it implies that an "objective risk" exists and can be measured. This is often not the case because of large uncertainties in the data, variations in time and very complex perceptions and evaluations of risks among people. Secondly, the risk formula suggests that risk is somehow naturally given. In contrast to that sociologists like Renn (1998) argue that risk is always associated with human decisions or actions: "risks refer to the possibility that human actions or events lead to consequences that affect aspects of what humans value". With regard to flood risk this means that this current risk situation (whether it can be quantified or not) is always a product of human actions or decisions, like for example to settle in the floodplain (or not), to build up protection measures (or not), etc. These aspects should be kept in mind when assessing risks. We nevertheless use the risk formula in the following as we believe that even an uncertain estimation of a risk measure can be a valuable information basis for new human decisions.

Table 1 Evaluation criteria for flood risk for all three dimensions of sustainability

Flood risk dimension	Criteria	Sub-criteria	Damage unit […/a]	Description	Method/data
Economic	Annual average damage		€	Damages on assets (buildings, inventories, etc.)	Meso-scale damage evaluation approach, based on official statistics, land use data and depth-damage functions
Environmental	Aggregated environmental risk	Erosion potential	Affected: yes/no	Areas with erosion potential of pollutants	Data from flood in 2002
		Accumulation potential	Affected: yes/no	Areas with accumulation potential of pollutants	Data from flood in 2002
		Inundation of oligotrophic biotopes	Affected: yes/no	Areas of biotopes vulnerable to inundation	identification of vulnerable biotopes based on biotope-type data
Social	Annual average affected population		Number of people affected	Number of people affected at their home	Meso-scale approach, based on official statistics and land use data
	Probability of social hot spots of being affected		Affected: yes/no	Social hot spots like hospitals, schools, old peoples homes, etc.	Point data of social hot spots based on own surveys

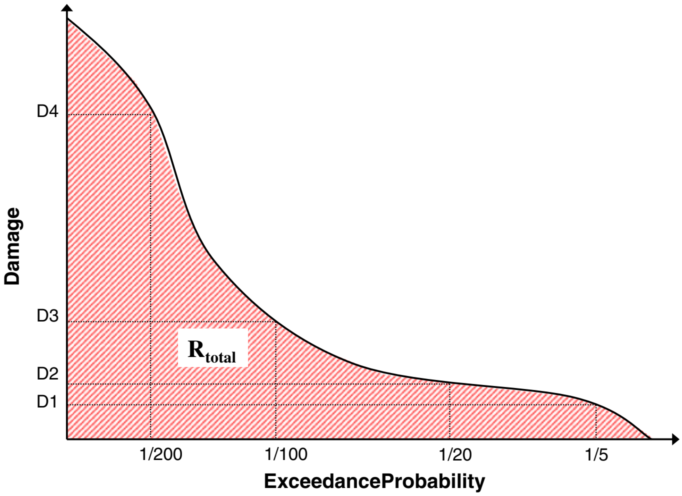

Fig. 2 Damage-probability curve.

$$D[i] = \frac{D(P_{i-1}) + D(P_i)}{2} \tag{3}$$

$\bar{D}$is the annual average damage with $D[i]$ = mean damage of two known points of the curve and $\Delta P_i = |P_i - P_{i-1}|$ = probability of the interval between those points. Equations 3 and 4 assume a linear run of the curve between each of the known points.

The basis for all our damage evaluations in the Mulde pilot site is inundation data for events of different exceedance probability (1:10, 1:25, 1:50, 1:100, 1:200, 1:500), calculated by a quasi 2D-hydrodynamic modelling (HEC-RAS)[2]. For each of these events the inundation depth and thus the inundation area is held in a grid with a spatial resolution of 10m (Fig. 3).

2.2.1 *Economic risk*

For the economic risk criterion, flood damage for each of the events mentioned above is calculated by means of a meso-scale damage evaluation approach (Meyer 2005, for the description of other damage evaluation approaches see e.g. Messner et al. 2007). The overall procedure is the following:

1. The total value of assets at risk and its spatial distribution are estimated based on data from official statistics which is then assigned to corresponding land use categories. Therefore, first of all, the net value of fixed assets is taken from official statistics (system of national accounts) for different economic sectors at the level of the federal state, in this case the federal state of Saxony. The value of stocks, which is not included in fixed assets, is estimated by assuming a typical relation between fixed assets and stocks for each economic sector, which is also derived from official statistics. The value of private household inventories, which is also not included in fixed assets, is estimated by an approximate value per square metre taken from

[2] This hydrodynamic modelling was done by Gerald Wenk, Helmholtz Centre for Environmental Research, Department Aquatic Ecosystem Analysis and Management.

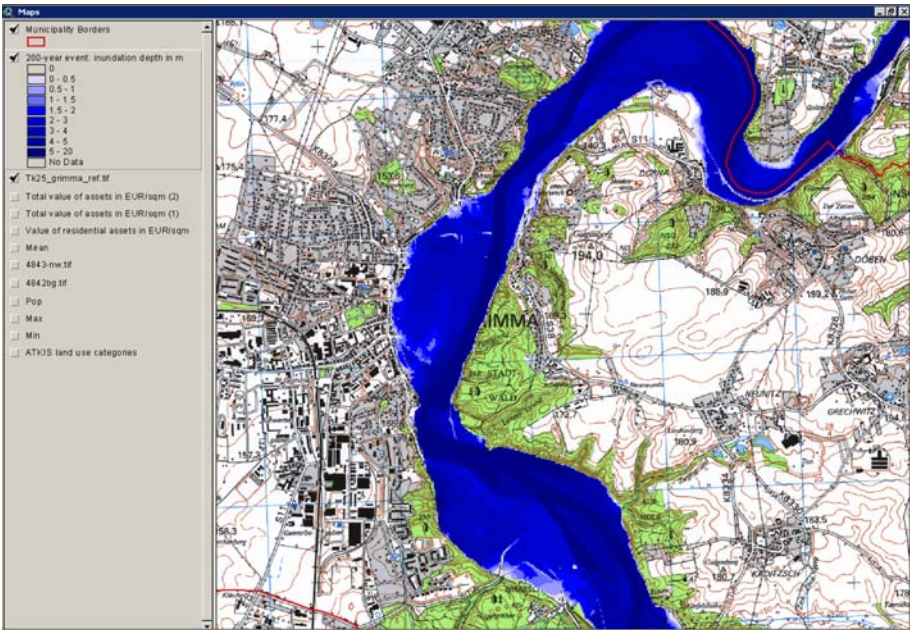

Fig. 3 Expected inundation depth for a 200-year flood event (City of Grimma). *Source*: Topographic map: Landesvermessungsamt Sachsen; Inundation data: Calculation by Wenk and Rode 2007

insurance data. Secondly, these values of fixed assets for each economic sector in Saxony are disaggregated to municipality level by using the number of employees as an allocation key. That is, for each economic sector the value of fixed assets per employee is calculated for Saxony and then multiplied by the number of employees in these sectors in the municipalities in order to estimate the total value of fixed assets in each municipality. Thirdly, these values are assigned to land use categories which correspond to the respective sectors. As land use data source ATKIS-DLM data is used (digital landscape model of the official topographic-cartographic information system). Although ATKIS is currently enhanced in this respect, it does not yet provide information on single buildings in the Mulde area. Instead it shows aggregated areas with more or less the same use, e.g. residential areas, industry and commercial areas, farm- or grassland, etc. By cross-checking the definitions of land use categories with that of the economic sectors an allocation key is developed, which assigns the value of each sector to one or more land use categories. For example, the value of the sector private housing is assigned to the land use categories residential areas and areas of mixed use. By assigning all values to the corresponding areas in a GIS and dividing the values by the area, a final map of the total value of assets (as well as of its components) per square metre can be produced (cf. Fig. 4).

2. Relative depth/damage curves are then used to calculate the damaged share of these values, depending on inundation depth. Such damage functions show the average susceptibility of each sector against inundation depth. Here, different sets of damage functions from other studies were applied (cf. Fig. 4).

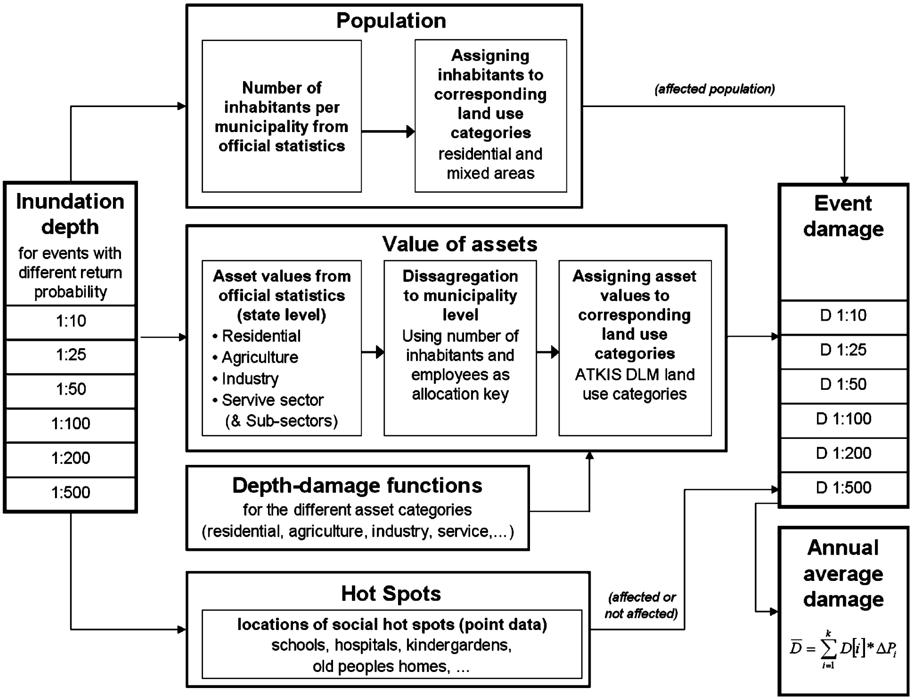

Fig. 4 Evaluation procedure for the socio-economic dimensions of flood risk: population, social hot spots and economic values

Methodological uncertainties in damage evaluation are shown by applying (1) different spatial modelling keys of asset value to land use categories and (2) different sets of depth/damage curves, i.e. (a) damage functions used in the Dutch standard method (Kok et al. 2004), (b) damage functions used in the damage evaluation for the River Rhine (IKSR 2001) and (c) damage functions used in the KRIM-project at the German North-Sea coast (Mai et al. 2007).

For each grid cell a mean damage can be calculated based on these different damage values as well as a minimum and maximum damage value. According to the risk formula mentioned above (Eq. 2) an annual average damage per raster cell is calculated based on the different damage estimations for inundation events of different exceedance probabilities (such as 1:10, 1:25, 1:50, 1:100, 1:200, 1:500). This is conducted for the mean as well as for the minimum and maximum damage estimations so that the final output is a mean, minimum and maximum annual average damage per grid cell, accordingly (cf. Fig. 4).

The mean annual average damage calculated for the pilot area is shown in Fig. 5.

2.2.2 *Environmental risk*

In order to assess the environmental risk of an inundation in the Mulde floodplains, three sub-criteria have been selected (Table 2). A simple Boolean yes/no damage function is applied for each criterion and grid cell, depending on whether the area is affected or not. Because the three criteria are different in terms of their environmental impact but may

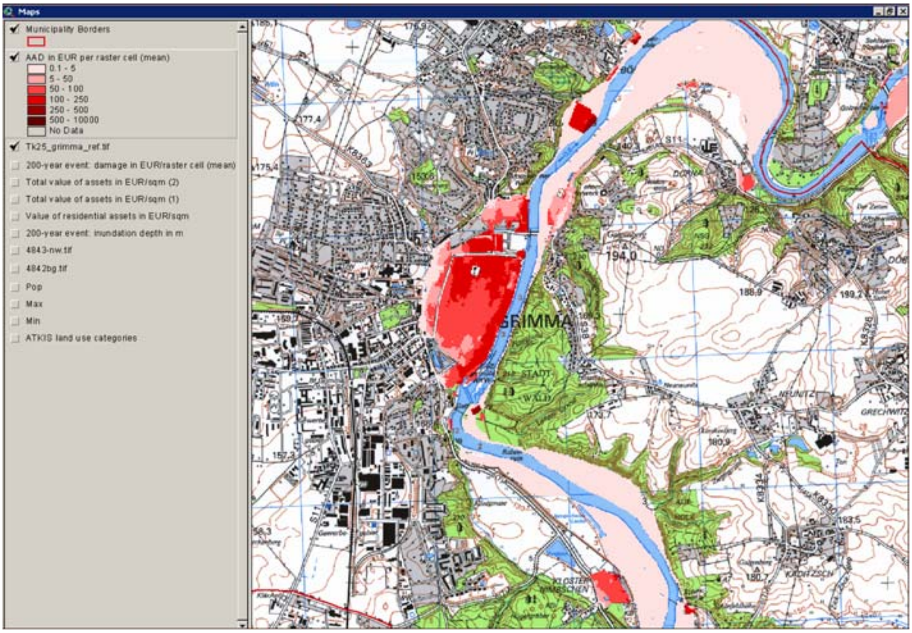

Fig. 5 Annual average damage (AAD) (City of Grimma): mean estimation. *Source*: Topographic map: Landesvermessungsamt Sachsen; damage estimation: own calculations

Table 2 Sub-criteria of environmental flood risk assessment

Indicator/criterion	Potential damage (risk)		Explanation/notes
	Yes	No	
Erosion	1	0	Where erosion of fine grain material occurs pollutants might be mobilised and transported (pollutants = heavy metals bond to clay minerals and organic matter; nutrients such as phosphorus)
Accumulation	1	0	Same as erosion but creation of new polluted sites due to accumulation of the transported material
Inundation of oligotrophic biotopes	1	0	A longer inundation (>1 h) of oligotrophic biotopes might negatively affect these biotopes in the form of eutrophication or drop in the number of species
Final assessment	$\sum$	$\sum$	Aggregated environmental risk criterion

occur simultaneously during one unique flood event, we suggest calculating a sum of the values given for each sub-criterion to estimate a first environmental impact potential of a flood. The list is not complete and has to be amplified according to both other case study requirements and general improvements.

Analogous to the calculation of economic damage, damage maps for environmental consequences can be produced for each flooding event. Each raster cell can hereby achieve "damage values" between 0 and 3. Based on these different damage maps an environmental risk map is calculated by using Eq. 2. This risk value can be interpreted as annual

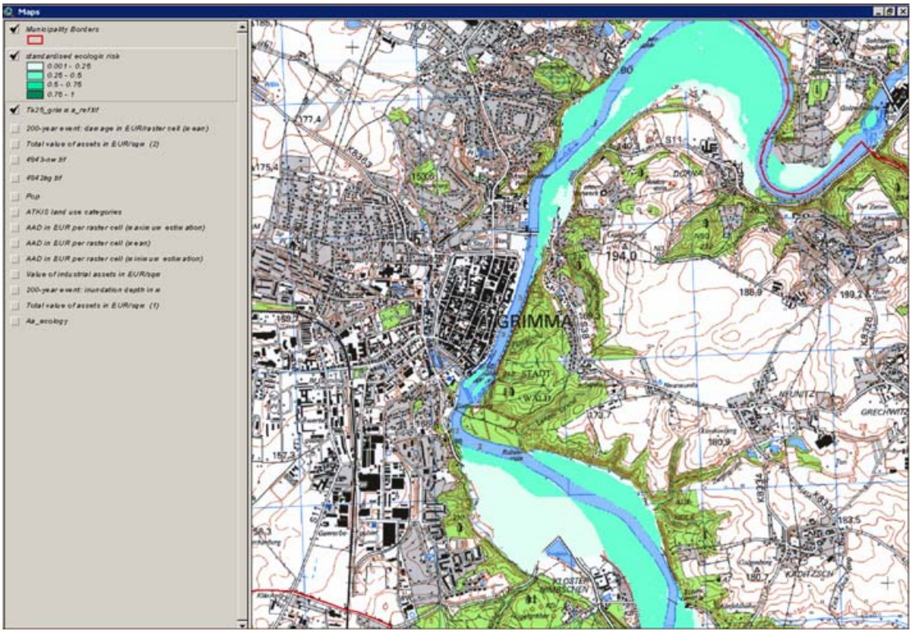

Fig. 6 Environmental risk (City of Grimma): standardised values (0–1). *Source*: Topographic map: Landesvermessungsamt Sachsen; damage estimation: own calculations

average environmental consequence, expressed in the point scale described above. In Fig. 6 these values are already standardised in values from 0 to 1.

2.2.3 *Social risk*

The spatial distribution of the affected population is calculated by a meso-scale approach more or less in the same way as the asset values (Meyer 2005). Therefore, the number of inhabitants is taken from official statistics on municipality level and broken down to corresponding land use categories. By intersecting this population density map with the inundation data the number of affected people can be estimated for each event. According to Eq. 2, the number of the annual average affected population can be calculated (Figs. 4, 7).

As “social hot spots” the locations of hospitals, schools, old people’s and children’s homes are identified. For reasons of simplicity we assume that each of the hot spots has the same vulnerability, no matter the size of a hospital or school or if it is a primary or secondary school. Such differentiations would lead to a more precise evaluation of social hot spots, but they should be conducted by experts in this field for each study. Furthermore, such more detailed information could be easily included in the dataset later on and a sourcecode enhancement by introducing e.g. weighting terms can be done promptly.

Intersecting the social hot spots map with the inundation rasters leads to the determination of affected hotspots per inundation scenario. By applying Eq. 2 an approximate estimation of the probability of being affected can be calculated for each hot spot (Figs. 4, 8).

All methods chosen here to estimate the different risk criteria (inundation modelling as well as damage evaluation) are fairly approximate approaches.

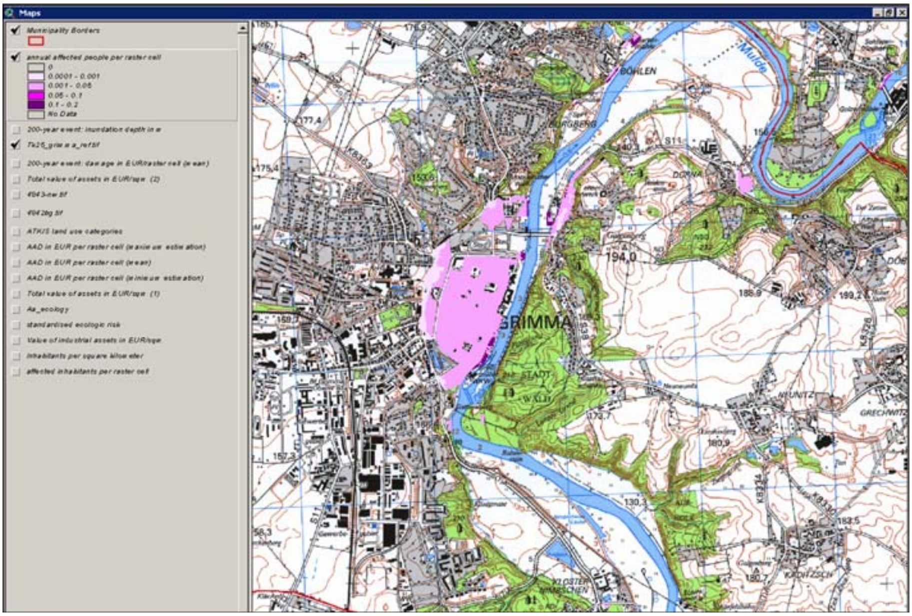

Fig. 7 Annual affected population (City of Grimma). *Source*: Topographic map: Landesvermessungsamt Sachsen; inhabitants: own calculations

2.3 Multicriteria decision rules

The decision rule defines the way the uni-dimensional measurements are aggregated to an overall evaluation under consideration of the weights given to each criterion. It can therefore be considered as the core of MCA. Several approaches exist which are suitable for spatial MCA like conjunctive/disjunctive approaches, AHP, CP, the Hasse-Diagramm technique, MAUT or Outranking approaches.[3] Finally, two approaches were selected, the disjunctive approach and an MAUT approach (simple additive weighting), to be implemented in our software tool and tested for our pilot site at the Mulde River.

The general idea of the disjunctive approach is that the decision maker has to define a threshold level for each criterion. For example, in order to select areas which have a high risk of flooding, the decision maker has to determine for each risk criterion a critical value which defines the border between low/acceptable risk and high/unacceptable risk. If this threshold value is exceeded even in only one of the criteria, the area is selected as a high risk area. This simple approach seems to be appropriate for a quick screening and pre-selection of high risk areas.

The general concept of the MAUT additive weighting approach is to generate a weighted average of the single criterion values for each area (or alternative). Given a set of evaluation criteria and a set of alternatives to be compared as well as scores for each alternative in each criteria and a set of weights for each criterion, the procedure for this is the following:

[3] For a further description of these approaches, see e.g. Zimmermann and Gutsche (1991); Malczewski (1999); Tkach and Simonovic (1997); Thinh and Vogel 2006); Soerensen et al. (2004); Keeney and Raiffa (1993); Drechsler (1999).

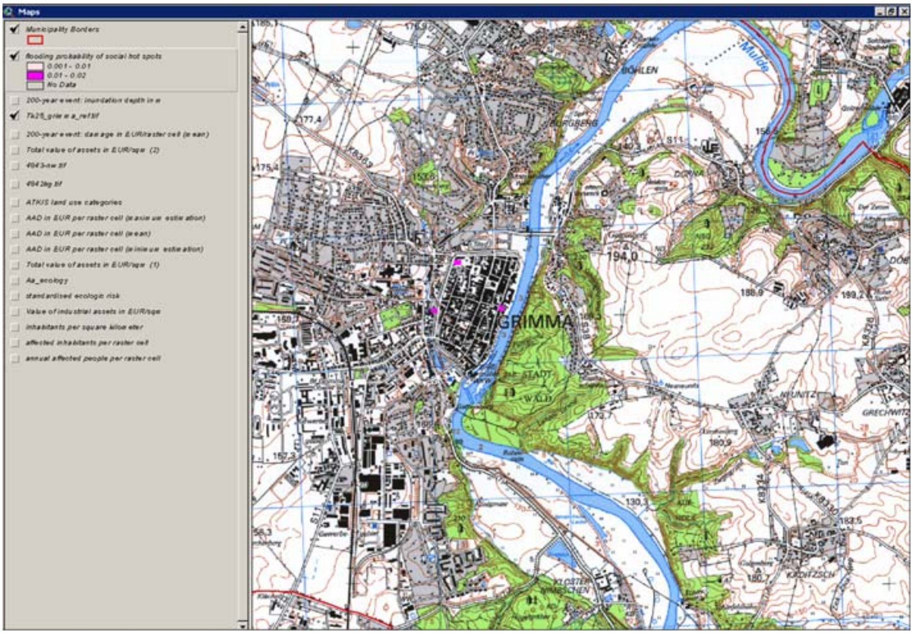

Fig. 8 Social hot spots at risk and their probability of being flooded (City of Grimma). *Source*: Topographic map: Landesvermessungsamt Sachsen; social hot spot risk: own calculations

1. Standardise the criteria scores to values (or utilities) between 0 and 1.
2. Calculate the weighted values for each criterion by multiplying the standardised value with its weight.
3. Calculate the overall value for each alternative by summing the weighted values of each criterion.
4. Rank the alternatives according to their aggregate value.

Both approaches allow decision makers to participate actively in the assessment process, i.e. during the disjunctive approach the decision maker can determine the threshold value between low and high risk for each criterion. For the MAUT approach the decision maker has to determine the weights given to each criterion. Our approach provides the possibility to carry out the point allocation approach, a rating technique where 100 points have to be allocated among the criteria, as well as the swing weight approach. Here, the criterion ranked first is given 100 points and the following criteria receive points according to their relative importance to the preceding criterion. The determination of both the threshold value and the weights is a crucial part of the overall assessment as they significantly influence the overall results.

2.4 Software tool FloodCalc

All computations are carried out by the software tool FloodCalc (Scheuer and Meyer 2007). It allows the uploading of GIS-grid data of inundation depth, value of assets, inhabitants, environmental values and to combine them with different sets of depth-damage function thereby producing damage and finally risk grids. FloodCalc computes the expected annual damage $\bar{D}$, or the annually affected social and environmental units, respectively. Furthermore the tool incorporates both multicriteria decision rules mentioned above and allows decision makers to determine threshold values for the disjunctive approach and criterion weights for the MAUT approach (see Annex 1).

3 Results and sensitivity analysis

Figure 9 shows sample results of the disjunctive approach for arbitrarily chosen threshold values for each of the criteria:

- Economic risk: >100 € (annual average damage per raster cell)
- Population: >0.001 (annual affected people per raster cell)
- Social hot spots: >0.01 (annual probability of being flooded)
- Environmental risk: >0.4 (standardised environmental risk)

All red areas exceed the threshold value in at least one criterion, some areas (in darker red) in more than one criterion.

A sample result of the MAUT additive weighting approach is shown in Fig. 10. In this case a weight of 0.4 is given to both the population and the economic risk criterion, because both are often seen by decision makers as the primary protection goals. The environmental and social hot spot criteria are both provided with a weight of 0.1.

The maps presented above are exemplary results of this multicriteria risk mapping approach. Several factors have a large influence on the results. First of all, the weights given to the criteria have a major impact on the outcomes. The sensitivity of the results depending on the allocation of weights among the different criteria can be shown by

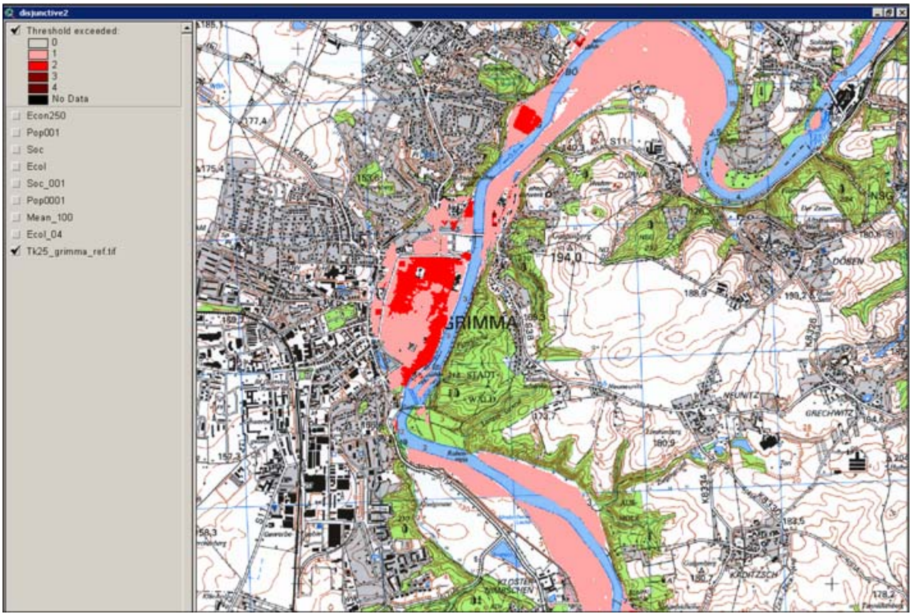

Fig. 9 Example for selected "high risk areas" by the disjunctive approach. *Source*: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations

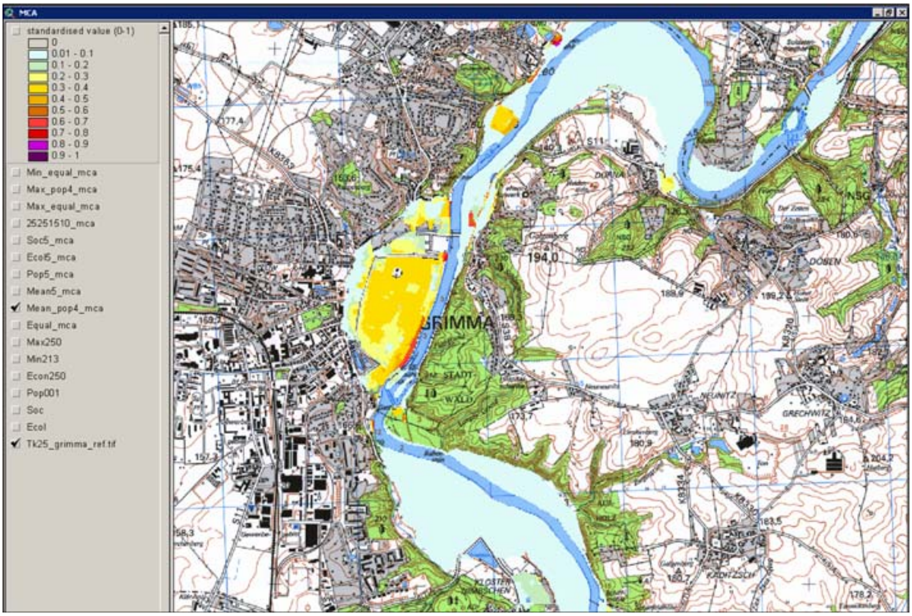

Fig. 10 Standardised multicriteria risk: large weight on economic and population criteria (0.4 each). *Source*: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations

varying the weights, e.g. by giving one of them an arbitrary large weight. Figure 11 shows for example the results if a weight of 0.625 is given to each one of the criteria.

Furthermore, variations in the criteria scores could have a major impact on the overall results. As described in the beginning the results of flood risk assessment are still highly uncertain. This is of course also true for the risk maps described in the preceding chapter. All the methods used for the assessment and mapping of the different criteria are approaches which are appropriate for an approximate estimation of the spatial distribution of risks on a basin scale.

However, in detail their results can be highly uncertain. As described above we tried to document the criteria score uncertainty at least during the estimation of the economic risk criterion by calculating a mean, minimum and maximum annual average damage, depending on the spatial modelling of asset values and the set of damage functions chosen. Figures 12 and 13 show how such a change of the value of one criterion affects the overall results. Both calculations for the minimum and maximum annual average damage value are carried out with the same weighting as in Fig. 10, where the mean value of annual average damage was used.

Looking at the sensitivity of the parameter weighting for the risk value distribution in the test area we found the formerly discussed examples (cf. Figs. 10, 11–13) to have a similar risk value distribution with a dominant peak in the lower value area (0.085–0.255) as well as a second subdominant peak in the medium value area (0.425–0.51). The criteria weighting approach dedicating the highest weights to the "potentially affected" population results in higher numbers of cells with very high risk values (>0.765; Fig. 14) compared to the equal weights approach or the ecologically sensitive approach.

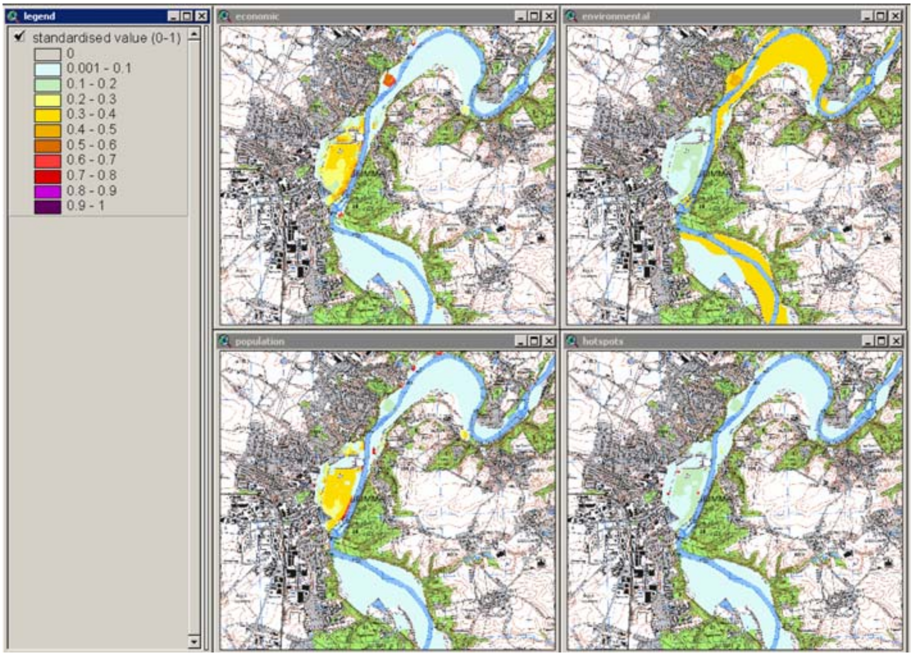

Fig. 11 Sensitivity analysis for weights: standardised multicriteria risk with large weight (0.625) on economic (top left), environmental (top right), population (bottom left) and social hot spot criterion (bottom right). *Source*: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations

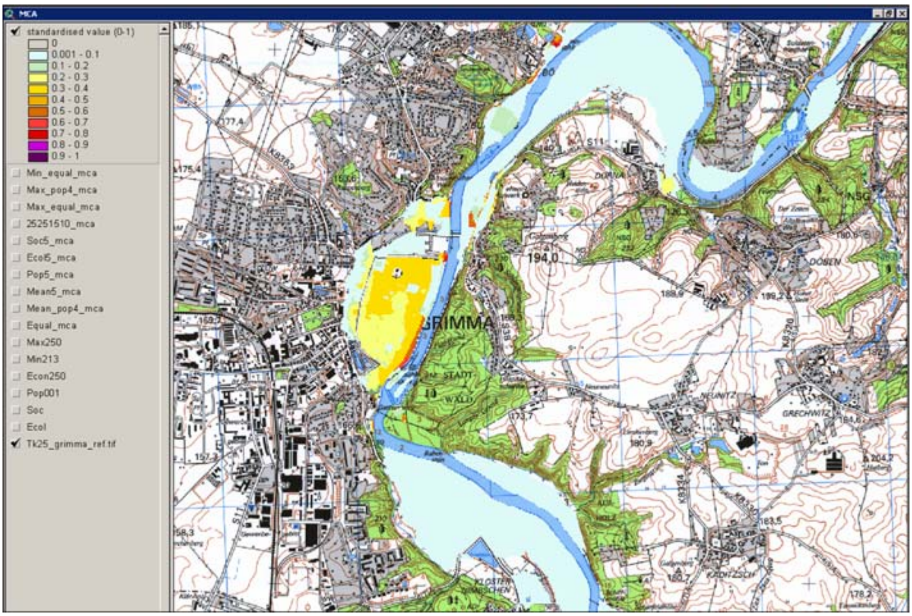

Fig. 12 Standardised multicriteria risk—criteria score sensitivity: minimum value of AAD (weights as in Fig. 10). *Source*: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations

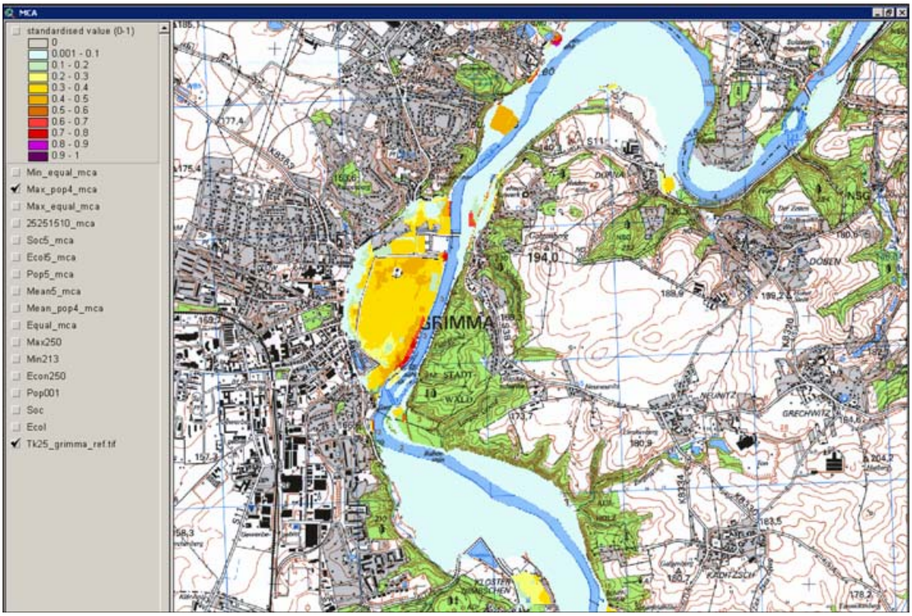

Fig. 13 Standardised multicriteria risk—criteria score sensitivity: minimum value of AAD (weights as in Fig. 10). *Source*: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations

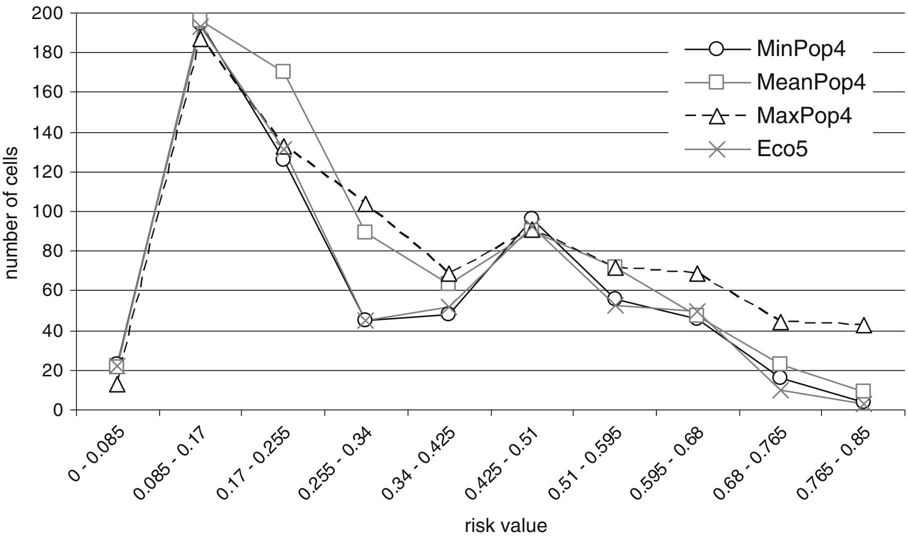

Fig. 14 Risk value distribution for the subset area comparing the standardised multicriteria risk with large weight on economic and population criteria (MeanPop4), the respective minimum (MinPop4) and maximum (MaxPop4) value of annual average economic damage and the standardised multicriteria risk with large weight on environmental criterion (0.625; Eco5)

4 Multicriteria project appraisal

As mentioned in the beginning, our approach mainly focuses on flood risk assessment, i.e. the identification of areas where flood risk is so high that mitigation measures are necessary. However, the next step within a flood risk management approach would be to develop alternative measures or projects for the mitigation of these unacceptable risks. In order to find the best alternative, these projects have to be compared not only by their costs but also with regard to their risk reducing effects. The following should give at least a short impression of how these multicriteria risk maps described above could also be applied for the appraisal of flood risk reduction measures.

For our pilot study we calculated risk maps for the status quo as well as for the situation after implementing all measures which are planned in the flood protection concept for the Mulde River. By calculating the difference in the standardised risk value between the situation with and without these measures, the effect of the planned measures can be illustrated. This is done in Fig. 15 showing the benefiting areas in blue (positive values = risk reduction). It can be seen that in this example (and under these weighting conditions) especially the city centre of Grimma would profit from the planned flood protection measure by a decrease of the standardised multicriteria risk of about 0.2–0.3 points. While typical cost-benefit analyses for risk reduction measures consider only the overall risk reducing effect, our approach also shows the spatial distribution of benefits.

5 Discussion

In the previous sections we demonstrated for a test area how our approach can be used to create multicriteria risk maps as well as to determine the risk reducing effects of flood risk

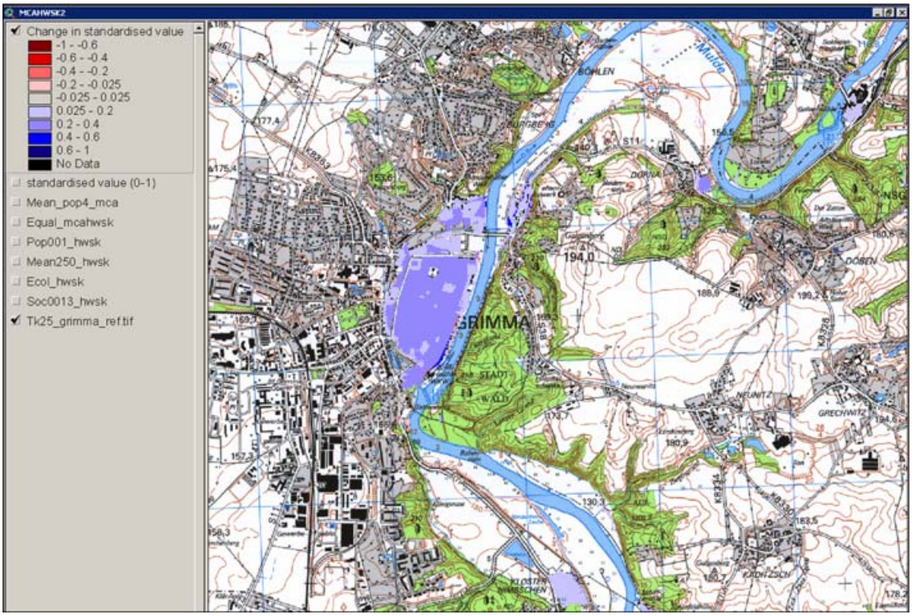

Fig. 15 Change in standardised multicriteria risk due to HWSK measures (weights as in Fig. 10). *Source*: Topographic map: Landesvermessungsamt Sachsen; risk estimation: own calculations

management projects. However, like sensitivity analysis has shown, the results are of course especially dependent on the weights given to the different criteria. Figure 11 shows that especially urban areas will receive high risk values if large weights is given to the social and economic criteria, whereas a higher weight on the environmental criterion leads to higher risk values in the more rural areas. This underlines the point that the determination of weights together with decision makers is a crucial part of a multicriteria approach (Munda 2006, Proctor and Drechsler 2006). In our pilot study this was not done. For a “real” multicriteria decision support this would, of course, be an important step in the whole process. The question who is allowed and legitimised to participate in such a decision-making process seems to be another important research task.

There are also some other points where further improvement of the approach seems to be desirable: The set of risk criteria used in our pilot study can be considered only as a first attempt to cover the economic as well as the environmental and social dimension of risks. For a more comprehensive study it should be verified whether more criteria should be included in order to show a more complete picture of flood risk. It may for example be useful to also include cultural heritage sites as a criterion or to also incorporate the potential environmental benefits of flooding.

Furthermore, the criteria used could be further elaborated, e.g. information on vulnerable groups could be integrated in the population criterion. The environmental criterion should also be further developed e.g. by specifying the functional relationships between flood characteristics and environmental effects in more detail. Even the economic criterion, which required most effort among the criteria used, is calculated by a meso-scale approach. If more precise results were required here, this could be replaced by a micro-scale approach.

With regard to the multicriteria decision rules applied, the additive weighting approach is a very basic form of a MAUT approach. In order to represent the stakeholders’ preferences on single criteria in a better way e.g. value functions could be developed together with the decision makers and integrated into the decision rule for criteria standardisation. Furthermore a comparison with other decision rules, like Compromise Programming, would be interesting.

Finally, only a very basic approach has been used to document uncertainties in the evaluation of the economic criterion, considering the uncertainties due to different spatial allocation keys and different sets of damage functions used. Other sources of uncertainty in risk mapping e.g. with regard to the determination of event probabilities, inundation modelling or asset value statistics are not considered in our approach. For a real project it would be furthermore necessary to document uncertainties in all criteria and not only one.

6 Conclusions

In this paper we have shown an approach to improve flood risk assessment in three ways: Firstly, to include non-monetary risks in the overall flood risk assessment. Secondly, to do this in a spatially differentiated way, i.e. to describe also the spatial distribution of these multicriteria risks. Thirdly, to show possibilities for dealing with the uncertainties associated with the criteria evaluation.

Therefore, we developed a framework for a GIS-based MCA which can be applied for an integrated assessment and mapping of flood risks. This approach was applied to a pilot site, the Vereinigte Mulde in the federal state of Saxony, Germany.

First of all, a set of evaluation criteria was selected which encompasses economic as well as environmental and social flood risk indicators. For each of the criteria, damage evaluation methods were applied in order to produce risk maps. Two different MCA approaches were tested in order to aggregate these different criteria risk maps: a disjunctive approach and an additive weighting approach. Our pilot study showed that both are appropriate for use within the framework of multicriteria risk mapping. The additive weighting approach would furthermore be applicable to show the spatial distribution of benefits of certain flood risk reduction measures. Regarding the consideration of uncertainties, at least for the economic criteria, an approach was shown as to how such uncertainties can be documented and dealt with.

As a further result, an alpha version of a software tool was developed (FloodCalc; Scheuer and Meyer 2007), which supports not only the calculation and mapping of the different damage and risk criteria, but also the two different MCA procedures mentioned above. For a more comprehensive application, our approach should be further developed with regard to the criteria used, the methods for their evaluation and the inclusion of uncertainties. Further attention should also be given to methods and rules for including decision makers into the assessment process.

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Annex 1: FloodCalc tool

FloodCalc is a software tool written in Python to carry out various flood damage/risk assessment calculations. The utility is raster-based and allows the import and export of the ASCII grid file format that can be written and read by most GIS software. The usage of ASCII grid files enables the user to incorporate various data sources, i.e. raster output from non-GIS programs, into an analysis. The usage of Python makes it easy to migrate the program to different operating systems, as the language is available for all major OS. The source code can but must not be compiled, so that an adaptation of the application to specific questions, or enhancements in general, can easily be accomplished.

FloodCalc requires various input data in the mentioned raster format, primarily inundation depth, value of assets, social statistics data (i.e. a population distribution or socio-economic points of interest) and environmental values, as described earlier. By assigning a depth-damage function to each asset category during the raster import process, FloodCalc is able to compute the relative and absolute damage per raster cell for each asset category. All intermediate grids are stored internally, and can be exported to an ASCII grid file if needed.

In the current development stage, social data loaded into the program is analysed by intersecting the grid of inundation depth with each social data layer, thereby deducing inhabitants or social hotspots affected by a particular flood event. Environmental data is dealt with in a similar approach: In a first step, affected grid cells per environmental value layer are determined by intersecting each raster with the inundation depth, with the Boolean values 0 for non-affected pixels and 1 for affected pixels being assigned to temporary grids respectively. In a second step, all previous results are aggregated. These analysis capabilities could be extended in future versions of the program by implementing depth-damage functions for specific social or environmental value categories.

Furthermore, annual damage can be computed for a series of inundation events. To do so, the user has to provide a set of damage raster and the corresponding occurrence probabilities. The software will then compute the expected annual economic damage $\bar{D}$, or the annually affected social and environmental units, respectively, using the Eq. 2.

FloodCalc also offers two basic approaches for a MCA: a simple additive weighting and a disjunctive approach. The implemented additive weighting procedure normalizes the input rasters, being annual damage for assets as well as affected environmental and social values, according to three normalization procedures the user can choose from: linearly over the whole range of values, per threshold defined in standard deviation units added to the mean value of a grid, or by providing a user-defined threshold value. All normalized grids are then weighted and summed up, the weights being previously allocated to each criterion by the user and normalized by the program. If an initial and final weights set and the desired number of steps are provided, FloodCalc automatically alternates the weights and exports the desired number of raster maps as ASCII grids. The utility also lets the user choose to export the normalized, intermediate grids.

The disjunctive approach allows the user to select specific raster cells by entering a threshold value for each grid that is analysed. Hence, FloodCalc automatically selects those pixels with a cell value higher than the chosen threshold for each layer, by assigning the Boolean value 1 to the respective cells. The selected cells are then aggregated. Like described above for the additive weighting approach, the user can also allocate weights to each layer prior to aggregation.

Further modifications of the utility should aim to improve the overall performance at first, and only later on implementing new features such as weighting functions for differently sized and functionally variable social hot spots or the improvement and extension of the implemented MCA approaches. It is suggested to refacture parts of the code in order to achieve the aforementioned points. This has already been done partially to increase the number of grid cells the software can handle. So far, the utility can handle about 4.2 million grid cells per raster, which covers an area of about 400 km^2 in a resolution of 10×10 m.

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Flood Risk Assessment in European River Basins—Concept, Methods, and Challenges Exemplified at the Mulde River

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ABSTRACT

Flood risk assessment is an essential part of flood risk management, a concept that is becoming more and more popular in European flood policy and is part of the new European Union flood directive. This paper gives a brief introduction into the general concept and methods of flood risk assessment. Furthermore, 3 problems in the practical application of flood risk assessment, particularly on the river basin scale, are discussed: First, uncertainties in flood risk assessment; second, the inclusion of social and environmental flood risk factors; and third, the consideration of the spatial dimension of flood risk. In the 2nd part of the paper a multicriteria risk mapping approach is introduced that is intended to address these 3 problems.

Keywords: Risk assessment   Flood   Multicriteria analysis

INTRODUCTION: FLOOD RISK ASSESSMENT AND MANAGEMENT

In recent years a shift in flood policy in Europe from the old concept of "flood protection" or "flood defense" to the new paradigm of "flood risk management" can be recognized (Schanze 2006; Johnson et al. 2007). To simplify matters, flood protection aims at preventing flood hazards up to a certain magnitude by providing a certain protection level (e.g., against floods up to an exceedence probability once in 100 y). Such protection levels are mostly established by means of structural measures such as dikes, reservoirs, flood polders, or river channel improvements

In contrast, flood risk management does not only considers the hazard but also the possible consequences. Therefore, flood risk management measures not only aim to control flood waters but also consider possibilities to reduce the vulnerability for flooding; for example, by reducing the number of elements at risk and/or their susceptibility (Messner and Meyer 2006). Furthermore, flood risk management attempts to adjust flood protection to the risk situation by concentrating risk reduction measures to areas with high expected damage in order to spend public funds in an economically efficient way (Messner and Meyer 2006).

Flood risk management can be broadly divided in 2 steps (Schanze 2006): Flood risk assessment and flood risk reduction. While the objective of risk assessment is to provide information on current or future flood risks in order to find out where these risks are unacceptable high, risk reduction aims at finding measures to decrease flood risk. Thereby, the whole spectrum of flood risk reduction measures is considered. That means measures aimed at reducing the flood hazard, like dikes or retention measures, are taken into account, but also measures that focus on the reduction of vulnerability, like land use restrictions in the flood plain, warning systems, or insurance.

This concept of flood risk management is the basis for the new European Union "directive on the assessment and management of flood risk" (Directive 2007/60/EC). This directive prescribes risk assessment and mapping as well as the development of flood risk management plans, aimed at reducing adverse consequences (see especially Articles 4, 6, and 7 of the directive). Furthermore, the directive determines that these actions should be carried out at a river basin scale.

The term risk is understood in the context of flood risk management as the probability of negative consequences (FLOODsite Consortium 2005; Schanze 2006). By considering the negative consequences or damage of floods for the whole range of probabilities, flood risk can be expressed as the expected annual average damage due to flooding, whereas damage covers economic, social, as well as environmental consequences. This understanding goes back to the definition of risk introduced by Knight (1921; e.g., Köck 2001; Hansjürgens 2004). Especially in social science this definition of risk is often criticized because it suggests that risk is something measurable, objective, and naturally given (e.g., Banse and Bechmann 1998), but the measurability of risk is often restricted, for example, because of high

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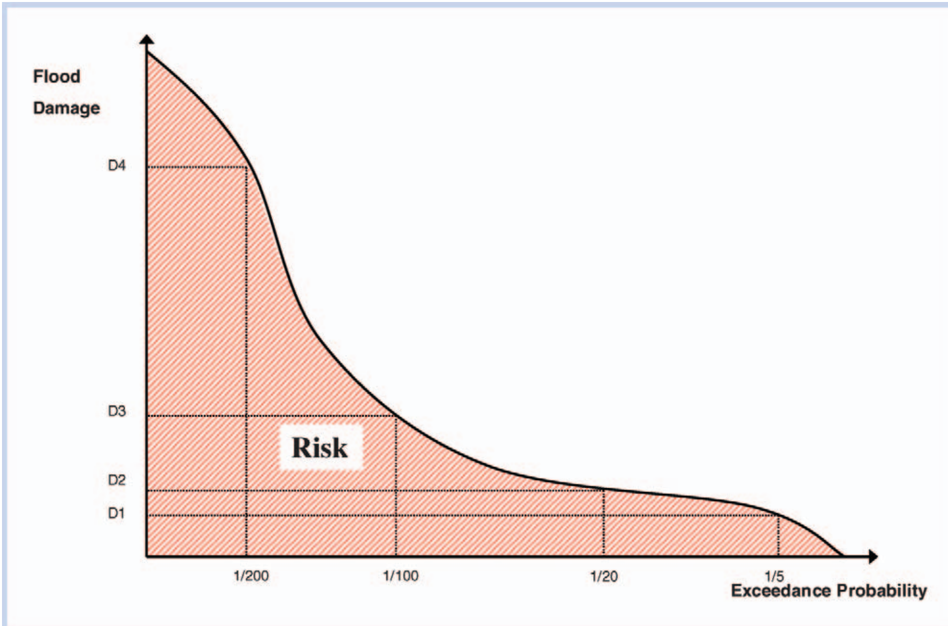


Figure 1. Damage–probability curve.

uncertainties. Furthermore, sociologists like Renn (1998) argue that risk is not naturally given but is always associated with human decisions or actions. We nevertheless apply this risk formula in the following because we believe that even an uncertain estimation of a risk measure can be a valuable basis of information for new human decisions.

For the practical application of flood risk assessment, flood damage has to be estimated for flood events of different probability in order to construct a damage-probability curve (see Figure 1). The risk (or the annual average damage) is shown by the area or the integral under the curve. An approximation of this area can be expressed using the following equations (DVWK 1985; Eqns.1 and 2):

$$\bar{D} = \sum_{i=1}^{k} D[i] \times \Delta P_i \quad (1)$$

$$D[i] = \frac{D(P_i - 1) + D(P_i)}{2} \quad (2)$$

where $\bar{D}$ is the annual average damage, $D[i]$ the mean damage of 2 known points of the curve, and $\Delta P_i = |P_i - P_{i-1}|$ the probability of the interval between those points.

This shows that the ex-ante evaluation of flood damages is an essential part of risk assessment. A large variety of approaches currently exists for the estimation of flood damage. Usually they deploy the following kind of input data in order to estimate flood damage (Messner et al. 2007):

- Inundation characteristics, such as data especially on the estimated area and inundation depth of a flood event, calculated by hydrodynamic models;
- Information on number and type of the exposed elements at risk (people, properties, biotopes, etc.), usually gathered from land use data sources;
- Information concerning the value of these elements at risk (either in monetary or nonmonetary terms);
- Information on the susceptibility of these elements at risk, usually expressed by depth–damage relationships.

Apart from these general components, damage evaluation approaches differ considerably in detail. Regarding their spatial scale and accuracy level the existing methods can be broadly differentiated into macro-, meso-, and micro-scale approaches (Messner et al. 2007). Macro-scale approaches often rely on land use information with a low spatial resolution and/or low typological differentiation in order to reduce the effort of analysis and hence permit considering large river basins as a whole (see IKSR 2001; Sayers et al. 2002). Micro-scale approaches (for example, Penning-Rowsell et al. 2003) on the other hand try to achieve more accurate results by applying very detailed, object-oriented land use data, as well as value and susceptibility information. However, this requires more effort, which often restricts these approaches to small areas. Meso-scale approaches (for example, Klaus and Schmidtke 1990; Kok et al. 2004) fit in somewhere between macro- and micro-scale approaches with regard to both accuracy and effort. Hence, they are often applied in small- or medium-sized river basins, coastal stretches, or dike ring areas. In our example in the second part of this paper, we therefore apply a meso-scale approach for the Mulde River basin.

As this last example shows the new approach of flood risk management still has to face problems with regard to its practical application, especially on a river basin scale. Three of these practical problems will be described in the following section. After that, a multicriteria risk assessment approach will be briefly introduced which considers these 3 problems.

CURRENT PROBLEMS IN RISK ASSESSMENT ON A RIVER BASIN SCALE

Uncertainties in risk assessment: A trade-off between accuracy and effort

Even though great improvements within methods of flood damage evaluation and risk assessment have been made during the last decades, the uncertainties in the results are still high; for example, due to data problems in all parts of risk analysis (Handmer 2003; Downton and Pielke 2005; Nachtnebel 2007; Apel et al. 2008). These uncertainties cannot be reduced completely. Hence, an objective flood risk may exist but will never be exactly quantified.

However, as stated above, flood risk assessment approaches differ concerning the degree of accuracy they are able to achieve. Thus, it is a question of which degree of uncertainty in flood risk assessment one is willing to accept with respect to the objective of the study. The choice of an appropriate risk assessment approach is hence always a trade-off between accuracy and effort. In order to support decisions on concrete risk reduction measures for a specific site, detailed micro-scale approaches should be applied. On the other hand these micro-approaches are mostly not applicable on a river basin scale due to their high effort and enormous data requirements. For flood risk assessment on a river basin scale, therefore, mainly macro- or meso-scale approaches are applied, which could lead to considerable uncertainties in the results, especially with regard to the spatial accuracy of the results, because land use data sources or damage functions with a high level of aggregation are applied.

In any case, pseudo-accuracy should be avoided by documenting and, if possible, quantifying the uncertainties within the risk assessment results. This can be either documented by a range (i.e., a lower and upper and maybe a mean value), by a standard deviation figure, or by means of a probability distribution.

Thereby, the request for transparent documentation of the uncertainties of risk assessment can be satisfied (Köck 2001). However, it should be noted that risk assessment should not be the only decision-determining criteria but only one source of information within the decision-making process.

Social and environmental flood risks are often neglected

The current practice of flood risk assessment as described at the beginning of this paper still focuses on economic damages, especially damage to buildings and their inventories. In contrast, social and environmental effects of flooding—for instance, loss of life, stress, or destruction of biotopes—are often not considered or considered in a very limited manner. This is partly because they are not, or at least not easily, measurable in monetary terms and hence not comparable with economic damages. In consequence, flood risk assessment is often incomplete and hence biased, because an important intangible part of the overall risk is neglected. This should be modified by the new European Union flood directive (Directive 2007/60/EC), which demands in Article 6 a risk assessment and mapping of social, economic, and environmental flood risk and also directly refers to the Water Framework Directive (Directive 2000/60/EC). However, an aggregation of these different risk dimensions is not necessarily required.

Nevertheless, approaches exist that make it possible to include the "intangible" effects in an overall risk assessment. The traditional approach of environmental economics would be to monetize such public goods by methods like contingent valuation or hedonic pricing (Hanley and Spash 1993). However, such valuations of life and environmental goods are still often criticized and not only due to ethical reasons (see e.g., Hansjürgens 2004 for a discussion of such criticisms).

Another way of including intangibles in an overall assessment is multicriteria analysis (see e.g., Keeney and Raiffa 1993; Malczewski 1999). Here, each criterion can be measured on its own scale. Generally speaking, the key to the aggregation of the different risks is a weighting of the different criteria. This requires an involvement of decision makers and stakeholders in the assessment process.

The spatial dimension of risks and risk reducing effects is often not considered

The spatial distribution of risks as well as the effects of flood mitigation measures is rarely taken into account. Thus, the evaluation and selection of appropriate reduction measures are mostly based on their overall net benefit. Therefore, it is often not considered which areas benefit most from a measure and which areas do not. This may lead to spatial disparities of flood risk that are not desirable or even acceptable.

Furthermore, little attention is given at present to the effects flood risk reduction measures have to areas downstream in the river basin. So, for example, for the evaluation of dikes often only local risk reducing effects are considered as benefits while negative effects on the flood peak in downstream areas are neglected.

MULTICRITERIA RISK MAPPING APPROACH

In the following discussion, an approach is briefly introduced that is intended to address the 3 problems mentioned above. This multicriteria risk mapping approach has been developed in the context of the FLOODsite-project and is described in greater detail in Meyer et al. (2007) and Meyer et al. (2008). By combining GIS-based risk mapping with multicriteria analysis (Malczewski 1999) our approach is able to show the spatial distribution of risks and to consider not only economic but also social and environmental risk criteria. At least for the economic risk criterion a very basic approach is applied in order to document the uncertainties associated with flood risk assessment. The approach is tested at the Vereinigte Mulde River in the Free State of Saxony, Germany. This river stretch is approximately 60 km long (i.e., the approach should be capable of dealing with flood risk assessment on a basin scale). However, for better visualization, the maps in the following are restricted to a small 4 × 4 km section around the city of Eilenburg, located in the northern part of the area.

As risk criteria the evaluation criteria described in Table 1 are applied. With this set of criteria we consider all 3 dimensions of sustainability (the social, economic, and environmental dimensions). However, in order to keep the approach applicable this set of criteria is quite small and simple. For a more comprehensive assessment, criteria can be added or the given criteria might be further improved.

The general procedure of the multicriteria risk mapping approach is shown in Figure 2. The basis for all damage evaluations is inundation depth data for flood events with a different exceedence probability of discharge (1:10, 1:25, 1:50, 1:100, 1:200, 1:500) calculated by Wenk (Schanze et al. 2008) using HEC-RAS, a quasi 2D hydrodynamic model (www.hec.usace.army.mil/software/hec-ras/). This is combined with information on the spatial distribution of elements at risk for the different criteria (Step 1) in order to calculate absolute damage or affected units, respectively, for these different flood events (Step 3). Based on these different damage figures and their associated probabilities the expected annual average damage or flood impact is calculated by means of Equation 1 (Step 5). The units of measurement for each of the criteria are shown in Table 1. Each of the different criteria

Table 1. Evaluation criteria for flood risk for all 3 dimensions of sustainability

Flood risk dimension	Criteria	Subcriteria	Damage unit [. . ./year]	Description	Method/data
Economic	Annual average damage		€	Damages on assets (buildings, inventories etc.)	Meso-scale damage evaluation approach, based on official statistics, land use data, and depth–damage functions
Environmental	Aggregated environmental risk	Erosion potential	Affected: yes/no	Areas with erosion potential of pollutants	Data from flood in 2002
		Accumulation potential	Affected: yes/no	Areas with accumulation potential of pollutants	Data from flood in 2002
		Inundation of oligotrophic biotopes	Affected: yes/no	Areas of biotopes vulnerable to inundation	Identification of vulnerable biotopes based on biotope-type data
Social	Annual average affected population		Number of people affected	Number of people affected at their home	Meso-scale approach, based on official statistics and land use data
	Probability of vulnerable community locations of being affected		Affected: yes/no	Vulnerable community locations like hospitals, schools, elderly peoples' homes, etc.	Point data of vulnerable community locations based on own surveys

risk maps is then standardized to values between 0 and 1 (Step 6), weighted (Step 7), and finally, aggregated to a multicriteria risk map (Step 8). All these calculations are carried out for a grid with a spatial resolution of 10 m. The procedure for the different criteria will be described in more detail below.

For the economic risk criterion we focus on direct damages, like damage to buildings and inventories, because this is the most important economic damage category (Messner et al. 2007). For the assessment of direct damages a meso-scale damage evaluation approach is applied (see Meyer 2005). The general procedure is the following: The total value of assets at risk (Step 1) and the spatial distribution are estimated based on data from official statistics combined with land use data. For different economic sectors the net value of fixed assets, which includes residential and nonresidential buildings and fixed inventories as well as the value of stocks and household goods, are calculated based on official statistics. The different value categories are then assigned to corresponding land use categories, taken from ATKIS-DLM, the German official topographic data source. In order to consider methodological uncertainties 2 different spatial modeling keys are applied here.

Relative depth–damage curves are then used to calculate the damaged share of these values, depending on inundation depth (Step 2). Methodological uncertainties are considered here by applying 3 different sets of depth–damage curves. Three different sets of damage functions were applied, taken from the KRIM project at the German North-Sea coast (Mai et al. 2007), a damage evaluation study from the River Rhine (IKSR 2001), and from the Dutch standard method (Kok et al. 2004). Damage evaluation is carried out for every combination of asset value map and damage function set, resulting in 6 different damage estimations for each flood event (Step 3).

Based on these different damage values a mean damage can be calculated for each grid cell as well as a minimum and maximum damage value (Step 4). The different damage estimations for the inundation events considered are then used to calculate the annual average damage according to the Equation 1 (Step 5). This is conducted for the mean as well as for the minimum and maximum damage estimations so that the final output is a mean, minimum, and maximum annual average damage per grid cell, accordingly. The spatial distribution of the mean annual average damage for the city of Eilenburg is shown in Figure 3.

In order to assess the environmental risk of an inundation in the Mulde floodplains, 3 subcriteria have been selected (Table 1):

1. The erosion potential of areas (i.e., where pollutants might be mobilized during a flood).

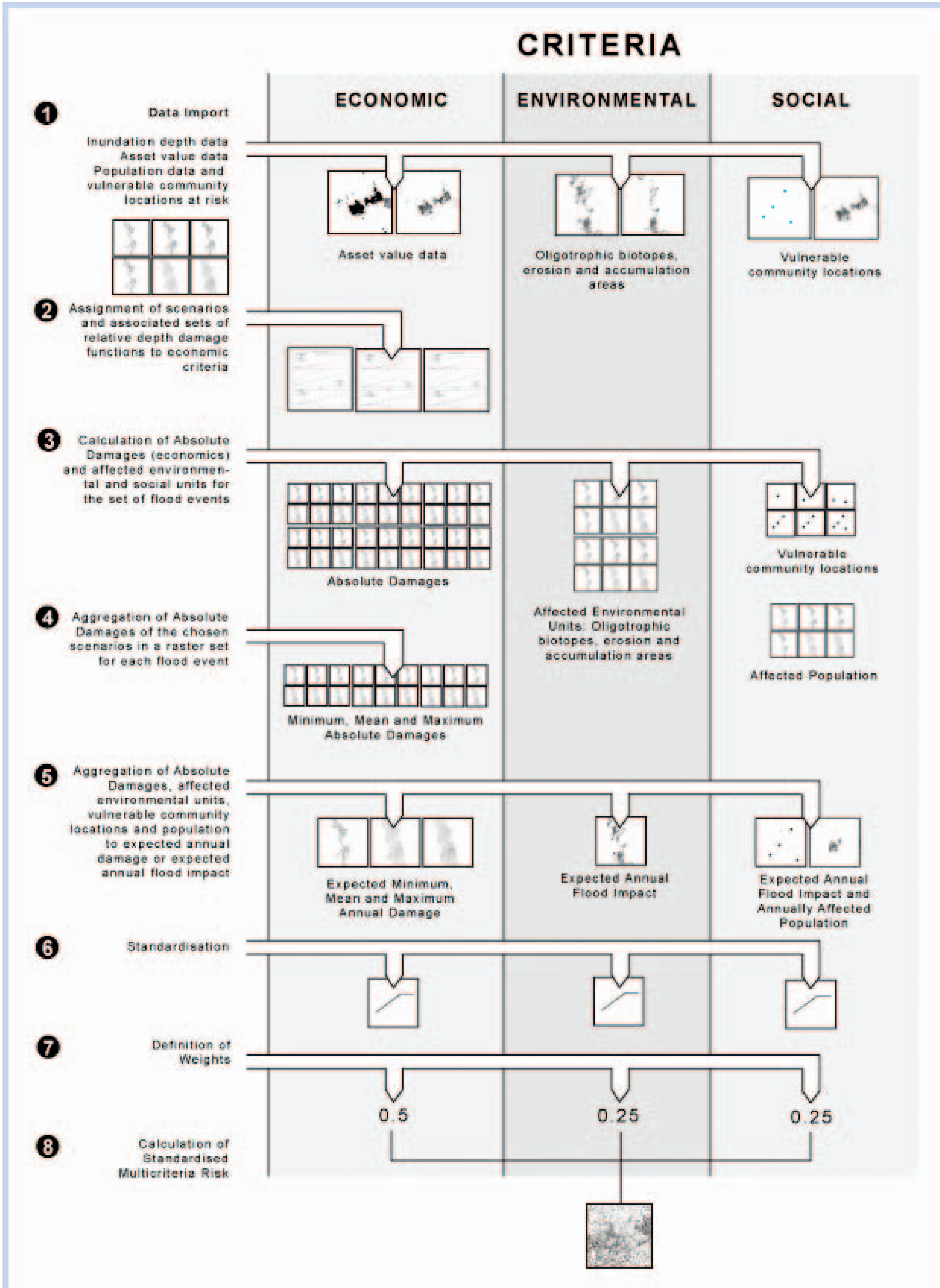
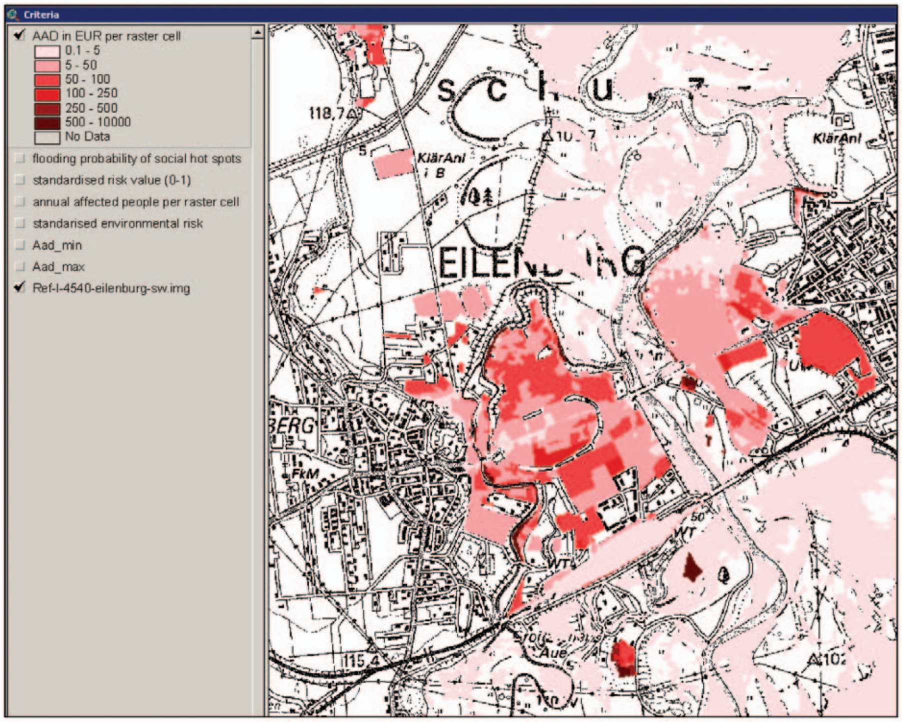


Figure 2. Stepwise procedure of the multicriteria risk mapping approach.

2. The accumulation potential of areas (i.e., where new polluted sites might be created by a flood). The identification of both erosion and accumulation areas is based on data from the Mulde flood in 2002.
3. Inundation of oligotrophic biotopes (i.e., biotopes which might be negatively affected by a longer inundation). These areas are identified by biotope data for the area.

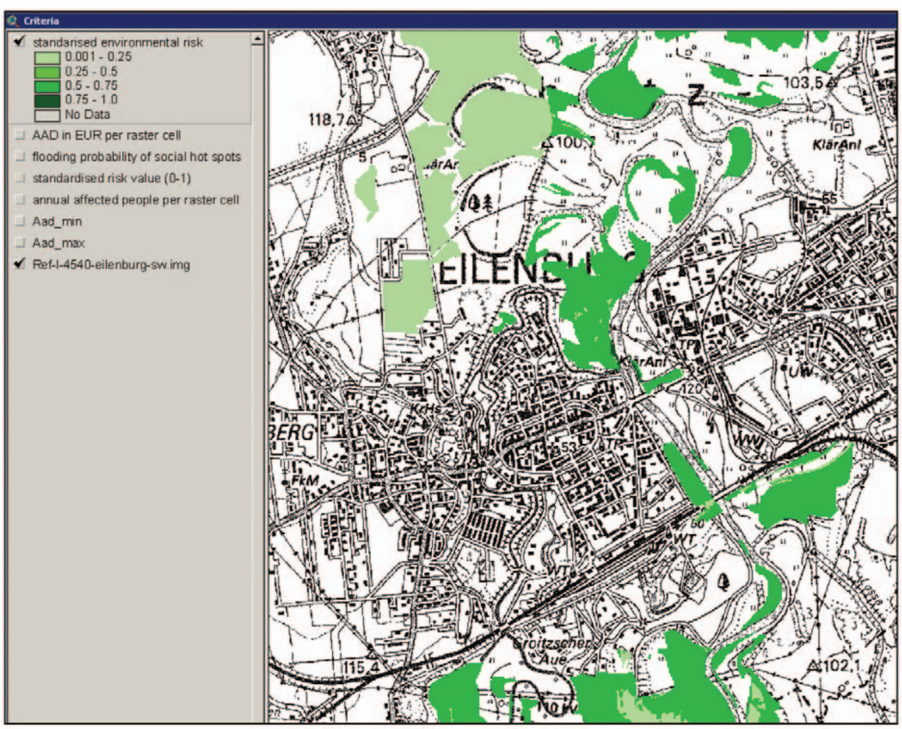
Since we were aiming to develop a simple assessment tool we focused on a limited number of subcriteria for the environmental risk. For regional stakeholders in the Mulde basin the 3 criteria listed were the most crucial showing what material re-allocation occurs in the riparian zone during the flood (subcriteria 1 and 2) and where more long-term affected sites that might be irreversibly damaged (subcriterion 3) are. The area size is an appropriate proxy for all 3 criteria representing the potential risk existing. The data recorded for the delineation of environmental risk zones stem from a study on the remote-sensing and GIS-based identification of the areas affected by the Mulde flood in 2002 (Haase et al. 2003).

After intersecting the maps for these subcriteria with inundation data (Step 1) a simple Boolean yes/no damage function is applied for each criterion and grid cell, depending on whether the area is affected or not. Because the 3 criteria are different in terms of their environmental impact but may occur simultaneously during one unique flood event, we suggest calculating a sum of the values given for each subcriterion to estimate a first environmental impact potential of a flood. The list is not complete and has to be amplified



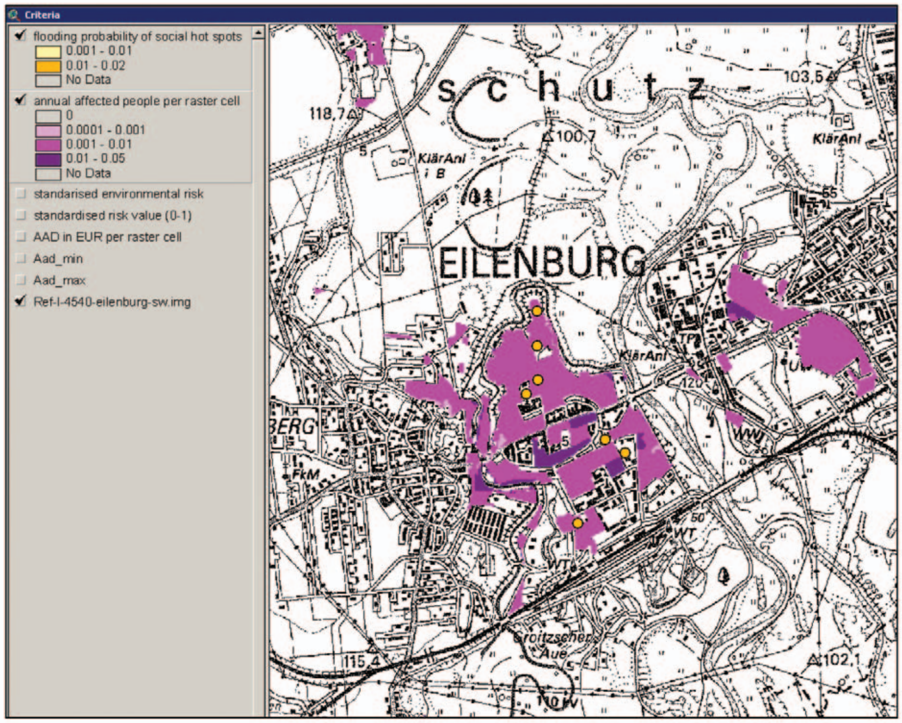
Source: Topographic map: Landesvermessungsamt Sachsen; damage estimation: own calculations

Figure 3. Annual average damage (AAD) (City of Eilenburg): Mean estimation.



Source: Topographic map: Landesvermessungsamt Sachsen; damage estimation: own calculations

Figure 4. Environmental risk: Standardized values (0–1).



Source: Topographic map: Landesvermessungsamt Sachsen; social hot spot risk: own calculations

Figure 5. Annual affected population and vulnerable community locations at risk and their probability of being flooded.

according to both other case study requirements and general improvements.

Analogous to the calculation of economic damage, damage maps for environmental consequences can be produced for each flooding event (Step 3). Each raster cell can hereby achieve "damage values" between 0 and 3. Based on these different damage maps an environmental risk map is calculated by using Equation 1 (Step 5). This risk value can be interpreted as annual average environmental flood impact, expressed in the point scale described above. In Figure 4 these values are already standardized in values from 0 to 1 (Step 6).

As social risk criteria 2 very simple indicators are used: The annual average affected population and the probability of vulnerable community locations like hospitals, schools, and elderly people's homes being flooded (see Table 1). The annual average affected population is chosen as a criterion because it is a simple but comprehensive indicator for the flood risk of the local population in general. The social hot spot criterion is chosen in order to emphasize a bit more on spatial concentration of people with a high susceptibility, like children, the elderly, or chronically ill people.

For the determination of the affected population, first of all the spatial distribution of the population is calculated by a meso-scale approach (Step 1; Meyer 2005). By intersecting this population density map with the inundation data the number of affected people can be estimated for each event (Step 3). With "affected people" we mean the number of inhabitants whose home or at least the first floor of their dwelling is flooded, regardless of how many of these inhabitants are at home at that time and on which floor of the building they live. According to Equation 1, the number of the annual average affected population can be calculated (Step 5; see Figure 5).

As "vulnerable community locations" the locations of hospitals, schools, and homes of the elderly and children are identified (Step 1). For reasons of simplicity we assume that each of the community locations has the same vulnerability, no matter, for example, the size of a hospital or school. For a more detailed study it would of course be desirable to include more variables that would express the vulnerability of each community location. Intersecting the vulnerable community locations map with the inundation maps leads to the determination of affected community locations per inundation scenario (Step 3). By applying Equation 1 an approximate estimation of the probability of being affected can be calculated for each vulnerable community location (Step 5; Figure 5).

For the aggregation of the different risk maps (Step 8) a simple additive weighting approach is used (see e.g., Malczewski 1999). The general model for this is

$$V_i = \sum_j w_j v_{ij} \tag{3}$$

Where V_i is the overall value or utility of the grid cell i, v_{ij} is the standardized value of grid cell i regarding criterion j (Step 6), and w_j is the standardized weight for criterion j (Step 7). This means a weighted standardized average of the single criterion values for each area is calculated.

For a real site-specific assessment this would of course require the involvement of decision makers in order to determine the weights given to each criterion. In our example such a participation of decision makers did not take place (yet) so arbitrary set of weights are chosen. Figure

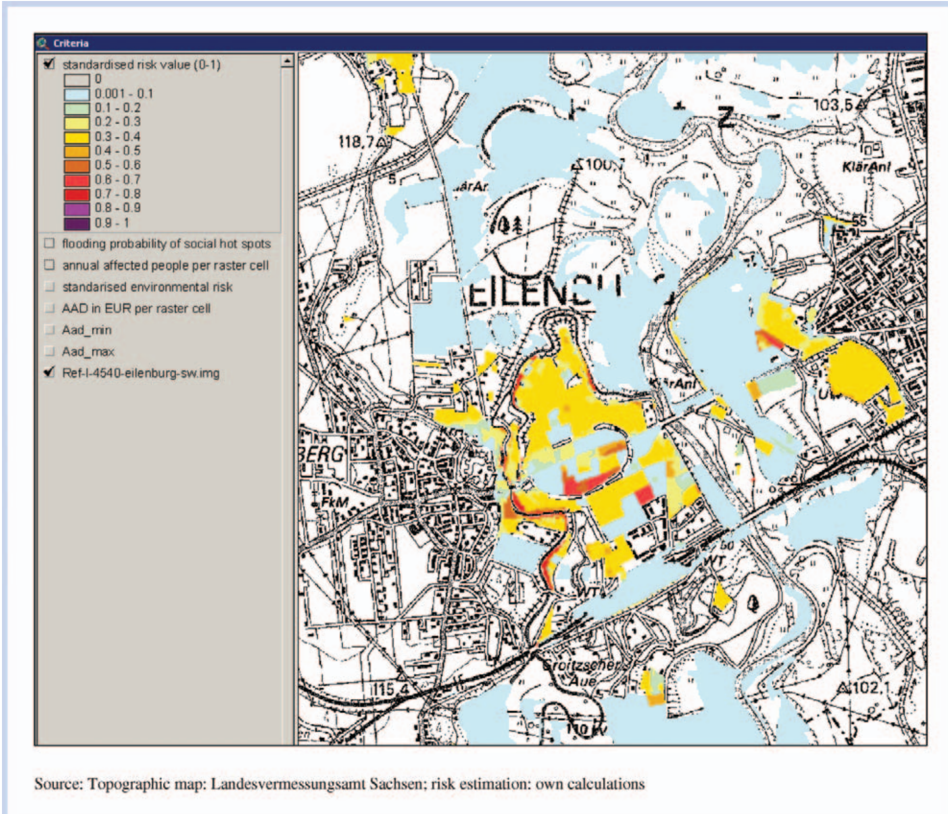


Figure 6. Standardized multicriteria risk: Large weight on economic and population criteria (0.4 each).

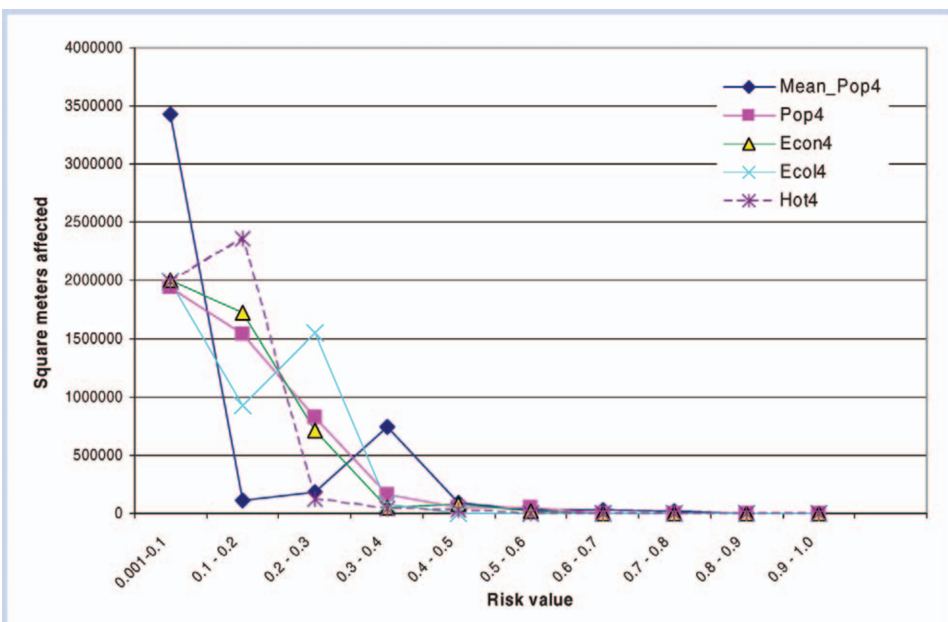


Figure 7. Comparison of risk value distribution for different sets of weights: Large weight (0.4) on the economic and population criterion (Mean_pop4), on the population (Pop4), on the economic (Econ4), on the environmental (Ecol4), and on the vulnerable community location criterion (Hot4).

6 shows, for example, the results if a relatively high weight of 0.4 is given to the economic and the population criterion, as these 2 criteria are often considered as the most important protection goods.

However, the approach also allows showing the sensitivity of the results against different sets of weights. In Figure 7, for example, we compare the risk value distribution of the area shown in Figure 6 for different weight sets. In addition to the weight set displayed in Figure 6 (Mean_Pop4) it also includes 4 different weights set where a large weight of 0.4 is given to each one of the criteria (Pop4, Econ4, Ecol4, and Hot4). All weight sets show a very high number of square meters with very low risk values (0.001–0.1). The “Mean_pop4” weight set, which assigns large weight to 2 criteria, has a further subdominant peak in the value area 0.3 to 0.4 while the other weight sets show subpeaks in lower risk values (0.1–0.3).

In practice, such a sensitivity analysis of weight sets can be used to visualize the changes in the risk maps if weight sets of different stakeholder groups are used. In real world decision situations often several different stakeholder groups with different preference structures are involved in the decision-making process. Representatives from a nature conservation organization, for example, will likely give a high weight to environmental criteria, while representatives from a chamber of commerce will tend to give high weight on economic criteria. Our approach can be used to compare the results of different weight sets in order to find compromise solutions. But the sensitivity with regard to uncertainties in the criteria values can also be shown by conducting the same calculation with the minimum and maximum criteria value map. However, in our example this is only possible for the economic criterion.

SUMMARY AND CONCLUSIONS

The new paradigm of flood risk management is obviously getting more and more popular in flood policy in Europe, and it is the conceptual background for the new European Union flood directive. The assessment of flood risks is an essential part of this approach. This paper briefly described the general concept of assessing flood risk as well as different approaches for flood damage evaluation.

We furthermore outlined 3 problems in the current practical application of flood risk assessment:

1. How to deal with uncertainties in the results of flood risk assessment;
2. How to include social and environmental flood risks;
3. How to properly consider the spatial distribution of flood risks.

We introduced a multicriteria risk mapping approach which tries to consider these 3 problems. First, at least for the economic criterion, methodological uncertainties in the results are documented by mean, maximum, and minimum risk values. Second, our approach includes an exemplary set of economic as well as social and environmental flood risk criteria. These different criteria can be aggregated by means of a multicriteria decision rule being a simple additive weighting approach. Third, the spatial distribution of flood risks as well as risk reducing effects can be displayed by a GIS-based risk mapping approach (i.e., all risk assessment calculations are carried out for a grid with a resolution of 10 m).

However, our approach should be seen only as a first attempt to deal with these problems. The approach still has some limitations and further research tasks can be identified. First, with regard to uncertainties, our approach documented such uncertainties only for the economic criterion. Furthermore, only 2 sources of model uncertainties were considered: Uncertainties resulting from the choice of the spatial allocation key and the set of damage functions. Uncertainties resulting from the inundation model used were not yet considered. Hydraulic models show some uncertainties especially in urban areas, where fluid water flow modeling is highly complex due to the variety of urban structures and thus fluid flow cannot be expressed as overland flow. Furthermore, the documentation of uncertainties in flood risk assessment is of course only a first step. Further research is still needed on how to deal with such uncertain information in the decision-making process in flood risk management and how to determine an appropriate level of accuracy for the different decision problems.

Second, our approach showed how social, environmental, and economic risk criteria can be aggregated, but it also unveiled how important the involvement of decision makers in the evaluation process is, as the selection of criteria and the determination of weights given to them substantially determine the results of the assessment process.

In our example we did not involve stakeholders yet, so the exemplary results shown are still arbitrary. However, literature provides some examples and procedures for how to integrate stakeholders in multicriteria analysis (e.g., Proctor and Drechsler 2006). Consequently, the next step would be to interlink such participation approaches with our multicriteria assessment approach.

Third, a number of problems also arise from the mapping of flood risk. The accuracy of spatial flood risk assessment depends on the resolution of the underlying grid. However, the use of high resolution grids is limited by at least 2 factors: Computational implementation (i.e., system memory availability and addressing) and the level of detail and resolution of the corresponding input data like inundation and land use data. This also means that the mapping of flood risk is always associated with inaccuracies or uncertainties and the right level of spatial resolution is maybe not easy to find. Furthermore, if spatial disparities are identified by risk mapping it is still an open question how to deal with them. Our approach is able to identify high risk areas but it does not yet answer the question of how much they should be reduced and how risk reduction efforts can be distributed “fairly” in river basins (cf. Johnson et al. 2007).

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A4. Diploma- and PhD Theses under my supervision (selection of those with relation to the Habilitation thesis topic)

PhD thesis

2007-9	PhD Michael Strohbach: Environmental impacts of urban land use pattern
2007-9	PhD Nadja Kabisch: Determinants of urbanisation – a quantitative analysis throughout Europe
2007-9	PhD Eva-Maria Elbert: Urban transport modeling in shrinking cities
2006-9	PhD Thilo Weichel: Uncertainties in modelling of urban floods

Diploma thesis

2008	Diploma Christine Kubal: Multi-criteria urban flood risk assessment
2008	Diploma Anna Kunath: Knowledge Elicitation Tools applied to urban brownfield re-use
2007	Diploma Steffen Lauf: Urban land use change modelling using a system dynamics approach
2007	Diploma Nadja Kabisch: Spatio-temporal analysis of reurbanisation
2007	Diploma Franziska Kroll: Environmental effects of demographic change
2006	Diploma Sophie Schetke: Multi-criteria assessment of urban green spaces
2006	Diploma Oliver Purschke: Habitat modeling in Saxony under climate change
2006	Diploma Tobias Finke: Land use change modeling in the Tisza basin – a rule-based approach using the SELES environment
2005	Diploma Jens Weinert: GIS-based analysis of the accessibility of urban retail trade shopping markets
2005	Diploma Karen Lübkemann: Cooperatives in urban green planning
2003	Diploma Kristin Magnucki: Impacts of urban land use on soil functions
2002	Diploma Esther Halke: Environmental impact of long-term land use change

A5. Statutory Declaration

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Habilitationsschrift mit dem Titel „*Dynamics of urban regions. From theory-driven data analysis to quantitative models.*“ selbständig und ohne fremde Hilfe verfasst und keine anderen als die angegebenen Hilfsmittel und Quellen benutzt habe. Die den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen wurden als solche kenntlich gemacht.

Dr. Dagmar Haase, 12.01.2009

A6. Curriculum vitae

Academic carreer

2010	Habilitation thesis at Martin-Luther-University of Halle (Germany) on "Dynamics of urban regions. From theory-driven data analysis to quantitative models".
2009	Professorship for Landscape Ecology at the Humboldt University Berlin
2007	Position of a working group leader for "Modelling of urban systems" at UFZ.
2000ff	Postdoctoral researcher at the Department of Computational Landscape Ecology, Helmholtz Centre for Environmental Research Leipzig-Halle; Research on Integrated Urban Monitoring and Modelling.
1996 – 1999	Doctorate at the Dept. of Geography at the Leipzig University, „Buffering capacity of fluvisols in urban areas", co-operation in a nationally founded project „Pollution in urban floodplains".
1990 – 1995	Diploma in Geography, Geology and Biology at the Martin-Luther-University Halle-Wittenberg (Specialisation: urban floodplains, urban ecosystems, urban forests; GIS) (grade: 1.1)
1990	Georgi-Dimitroff-Oberschule Leipzig: *Abitur* (complies with the English A-levels) (grade: 1.1)

Professional experiences

2006-2009	Coordination of research activities on urban land consumption and impact assessment at the UFZ: Coordination of the UFZ-Research Group on Urban Monitoring and Modelling
2007-2010	Coordination of the modelling activities on „Sustainable Impact Assessment in Urban Regions" within the EU-Integrated Project „PLUREL – Peri-urban land use relationships, Strategies and sustainability assessment tools for urban-rural linkages", budget: 0.7 Mio €, www.plurel.net
2005–2009	Coordination of the case study Tisza Basin and the activities on qualitative modelling and knowledge elicitation within the EU-Integrated Project „NeWater – New Approaches to Adaptive Water Management under Uncertainty", budget: 0.48 Mio €, www.newater.info
2005-2008	Heading of the sub-project „Inundation modelling" within the nationally funded project „3ZM-GRIMEX – an integrated model system for urban floods". Research on parameter efficiency and uncertainties in 2d-Modelling, budget: 45,000 €, www.hochwasser-dresden.de/3ZMGRIMEX
2002–2003	Heading of the sub-project „Detection of the spatial dimension of the Elbe flood" on remote sensing, GIS, 2D-hydrodynamic modelling of urban areas; damage potential analysis and assessment within the BMBF-ad-hoc-Project „Elbe Flood 2002", budget: 25,000 €, www.halle.ufz.de/hochwasser
1997–1999	Project: Pollution of urban floodplains, University of Leipzig, funded by the Saxon Ministry for Science and Art. budget: 150,000€

Editorial boards

The Open Geography Journal, Bentham
Encyclopedia for Sustainability, Springer

Reviewer for

Landscape and Urban Planning. Elsevier
Landscape Ecology. Kluwer
Ecological Indicators. Elsevier
Landscape Online
Advances in Geosciences. Copernicus
Limnologica. Elsevier
Archive for Agronomy and Soil Science. Taylor & Francis
Natural Hazards. Springer
Catena. Elsevier
River Basin Applications. Taylor & Francis
The Open Geography Journal, Bentham
Natural Hazards and Earth System Sciences. Copernicus

Work placements and teaching

2000ff	Supervision of ~50 Diploma and Master thesis and 6 PhD thesis in the field of Landscape Ecology, Land Use Science and Modelling
2009ff	Lectures in Urban Ecology, Spatial Modelling, Statistics and Land Use Science (Humboldt University Berlin)

Skills and qualifications

IT in general	Standard-Office-Packages (Open Office and MS Office), graphic software CorelDraw, Adobe, editing in HTML
Modeling	Agent-based modeling NetLogo, object-oriented programming in Java, development environment SELES, Unified Modeling Language (UML), XML, VenSim, experiences in Simile and Modelmaker
Empirical research	Statistics in SPSS, STATISTICA, questionnaire surveys, in-depth interviews, focus group sessions, qualitative mapping, conceptual modeling
Spatial data	ArcView, ArcGIS, SAGA GIS, UMN Map-Server
Languages	German (native speaker) English (fluent) Spanish (fluent) Russian (working language) French (working language) Polish (elementary skills)

Scholarships

1996–1999	PhD Scholarship of the German “Studienstiftung des deutschen Volkes”: Buffering capacity of fluvisols in urban floodplains. University of Leipzig

Awards

2009	Fellow of the International Environmental Modelling and Software Society