A HIERARCHICAL APPROACH FOR MESOSCALE ASSESSMENT OF LANDSCAPE FUNCTIONS: MODELING – PARAMETERS - INTEGRATION IN ENVIRONMENTAL PLANNING

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Introduction

The landscape is created by a characteristic distribution of its components (land use, land cover, soil, morphology, hydrology, climate, geology etc.) which results in the landscape structure. The components of the landscape structure are interrelated by fluxes of water, material, energy and information (landscape ecological processes) which result in the landscape balance. Human impacts – such as land use - affect these interactions by changed conditions for the fluxes. The human factor „land use” within the complex ecosystem has a strong impact on the adaptability, the regeneration and regulation capability of the landscape balance. As most of the relevant processes in the landscape are depending mainly on the mobile agent water, they have influences reaching from small to large scales. But the understanding of these processes on large scale is still insufficient, as most of the process-oriented studies are carried out on small scales. Concepts for sustainable development have to consider the implementation of information on the landscape balance on larger scale, because most of the environmental changes become obvious on the landscape level. For the characterization of the ecological and economic capability of the landscape, the concept of landscape functions has been proved useful (cp. Bastian 1999; de Groot, 1992, Marks et al., 1992). But most of the given and useful suggestions for the assessment of landscape functions are limited to scales up to 1:25.000 (cp. Marks et al. 1992), and the importance of parameters – and the parameters itself - of the landscape functions change in a hierarchical spatio-temporal way (cp. Helming & Frielinghaus, 1999; Klijn, 1995; Volk, 1999). This problem should be solved by an investigation of their scale-specific applicability.

Therefore, the following questions should be answered:

• How does the importance of parameters (and parameters themselves) of their landscape balance components - morphology, soil, hydrology, land use and cover and climate - change on different scales?
• *How does the impact of land use and land use changes affect the landscape balance on different scales?*

In our project, the parameters and indicators suggested by other studies were proved (cp. AG Boden, 1994; Bastian & Schreiber, 1994; Frede & Dabbert, 1999; Marks et al., 1992) and modified for their capability at the middle and upper mesoscale (cp Krysanova et al., 1996). For an integrated landscape analysis, we aim at combining both „top-down” and „bottom-up” approaches with GIS-coupled model applications. In cooperation with governmental authorities and environmental and geological agencies, we checked out the integration possibilities of the assessment and modeling results into landscape planning processes. This paper includes examples of our approach – at first focused to a „top-down” method - applied to regions of Eastern Germany.

**Study areas**

The presented approach is tested in various study areas in the states of Saxony-Anhalt and Saxony (Germany) with different conditions at the concerned scales. Thus, the applicability and transferability of the approach will be checked out. Within the paper, the approach will be shown examples of the Dessau district in the east of Saxony-Anhalt and some of its test areas.

**Dessau district: landscape structure and land use**

Dessau district is located in the east part of Saxony-Anhalt (Eastern Germany) and covers an area of about 4,300 sq. km. The region is divided by the river Elbe. The landscapes show a heterogenous structure with very different conditions, they vary from holocene floodplains and old-morainic landscapes to very fertile loess plains. According to the founded widespread fertile soils and lignite resources, agriculture, industries and other human activities have determined the main features of the region. These activities have strong impacts on the landscape balance (especially soils and both surface and groundwater) and thus on the regulation functions of the landscape. The political changes in the last years have caused new administrative units as well as new agricultural structures, and water management systems. For instance, this has lead to marginalisation of agricultural land in poor sandy areas and to intensification of agricultural land use on the loess plains (cp. Petry & Krönert, 1998). Beside socio-economic impacts, this is leading to conflicts between agriculture, nature conservation and groundwater abstraction for drinking water supply.

**Regional Planning in the region: Where is an information about the landscape balance?**

In Germany, regional management plans are instruments within the spatial planning system in order to set guidelines for the landscape development on the regional scale. Designated priority areas for „landscape functions” are committal on the community level. But there is lack of information about landscape ecological processes and the impact of land use changes on the landscape balance. For instance, the priority areas for agriculture are designated only in the western part of the district,
with very fertile chernozem soils. The following points were not considered within this economical-oriented decision:

- Parts have to be irrigated – belonging to the dryest part within the district.
- About 90% of this area is already used by agriculture – very low landscape diversity and high potential water erosion are the consequence.
- The long-term accumulation of high amounts of nutrients and agricultural chemicals in the cohesive soils.

Taking the parameter „Field Capacity“ – derived from soil data – as an indicator for soil fertility, it becomes obvious, that many other parts within the region show similar conditions like the fertile Western parts (see Fig. 1). But - unfortunately from an agricultural point of view - they are not considered as priority areas, although about 58% of the whole district is used by agriculture. The priority areas within the existing regional plan are designated on the basis of single functions and land use interests. But it is the main task of regional planning to integrate the different functions under consideration of their interactions. In this context GIS-based integrated landscape analysis is an important knowledge base for the planning process. Thus, the scale-specific derivation of useful indicators and parameters for analyzing and optimizing the regulation and production functions of the different landscape types is an important topic of our studies.

Fig. 1. „Field Capacity” as an indicator for soil fertility (after Petry & Krönert, 1998).
A hierarchical approach for the investigation of landscape balance and landscape functions assessment

Strategies of sustainable land use assume research and assessment methods for each scale level (micro-, meso-, macroscale). Landscape ecology as an interdisciplinary science has to provide the investigation methods for all these different scales. Therefore, we develop a hierarchical approach for the analysis of the landscape balance and for the landscape functions assessment. The main hypothesis of our approach is that the basic components for landscape ecological processes – morphology, soil, hydrology, land use and land cover and climate – are similar over all scale levels. Only the importance of the factors (and the factors themselves) of these components changes for each scale (cp. Helming & Frielinghaus, 1999; Klijn, 1995; Volk, 1999).

Data base and Geographical Informationssystem

Integrated landscape ecological analysis requires a huge amount of different information about soil, morphology, both surface and groundwater, land use and land cover, climate, as well as about the governmental spatial planning targets (priority and conservation areas). In the management of this information and the analysis of the landscape ecological interactions, Geographical Information Systems (Arc/Info, ArcView) are useful instruments. The necessary data base is gained mainly by the data exchange within our cooperations with geological and meteorological survey agencies, planning and environmental management authorities. These institutions are using also Arc/Info and ArcView, which made the data exchange and the data processing much easier. As a data source for the land use on the landscape scale, an information of the CORINE project land cover were taken (cp. Statistisches Bundesamt, 1996). Additional information about the land use and land cover situation is derived from satellite images with remote sensing tools (Erdas Imagine). Morphological data are derived from Digital Elevation Models (DEM) with spatial resolution of 250 m (scale larger 1:50.000) and 40 m (scale 1:25.000 to 1:50.000). For the scale 1:25.000 to 1:50.000, the climate data were received from weather stations, the soil data for this scale have to be derived from existing maps. Currently, it is still an unsolved problem to get all the relevant data layers for large areas in high spatio-temporal resolutions.

Models

For calculation and simulation of the parameters of the landscape balance (water balance, matter, nutrient and energy fluxes), different model systems (e.g. ABIMO, ASGi) are coupled within GIS and tested on the concerned scale levels. The input data for these models had to be prepared and modified according to the model configurations (aggregation, generalisation, etc.). The solution of this problem requires the development of modification methods. (cp. Volk & Steinhardt, 1998).

For calculation of the fundamental elements of the water balance on the landscape scale, the runoff simulation model „ABIMO” is used (cp. Glugla & Fürtig 1997). This model system enables large scale calculations of the long-term mean values of total runoff and actual evapotranspiration. „Mean annual runoff” is defined here as the
difference between longterm mean annual precipitation and actual evapotranspiration. In case of a solely vertical water seeping, this value corresponds the ground water recharge. According to the fact that this situation is very rare in reality, this value must be understand as the sum of both surface and subsurface runoff. Therefore, the results were modified with a runoff quotient determined by Röder (1998), based on Dörhöfer & Josupait (1980), which includes information about slope inclination and soil moisture. This modification allows the distinction between surface runoff and interflow on the one hand, and groundwater recharge on the other hand.

A data base with higher spatio-temporal resolution enables detailed surface hydrological and other analysis (e.g. calculation of subbasins, direction of the matter and nutrient transport, etc.), which is used for the endepth investigations in test areas. This data base will also be integrated in the model „ASGi” (cp. Kleeberg & Becker, 1998). The calculation results of this model allows derivation of qualitative and quantitative informations about water, matter, nutrient and energy fluxes in catchments, watersheds, and subbasins. Both models – ABIMO and ASGi – allow also calculation of scenarios (impact on land use on the landscape balance).

Preliminary

Groundwater recharge (scale level 1:50.000 and larger)

The groundwater recharge – which is related to the function of groundwater protection - is defined here as a function of the landscape (cp. Marks et al., 1992). ABIMO calculations allow regional assessments of the fundamental elements of landscape water balance and comparison of areas with different groundwater recharge and runoff. This can be done in relation to the dominating natural conditions and the land use types.

The highest values of groundwater recharge are registrated in the morainic parts in the north and south of the study area, with permeable, sandy substrates (see Fig.2).

Very low rates show the dry western parts with prevailing chernozems and cohesive substrates. Within the priority areas for groundwater abstraction in these western parts, only the abstraction wells are protected. But these sites are not necessarily the places where the groundwater recharge and the potential contamination takes place. It becomes obvious that our calculations can be used for a better designation of priority areas for groundwater abstraction and protection.

Land use scenarios (scale level 1:50.000 and larger)

Beside these regionwide analysis, scenarios were elaborated about the impact of land use changes on the groundwater recharge of three test areas (cp. Volk, 1999; Volk & Bannholzer, 1999). These investigations were also aimed at defining the scale specific applicability of the model. One of these scenarios is prepared for a test area in the dry western part with chernozems, dominated by agricultural land use (90% of the area) and a very low landscape diversity. The conflicts in this area are resulting from an overlap of the agricultural land use and the groundwater abstraction (see page 311), and an urgent need for nature development (nature conservation areas are limited to about
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The consequences are:

a) high potential erosion disposition;
b) a potential accumulation of agrochemicals and nutrients in the soils, and
c) a loss of biodiversity

Generally, the groundwater recharge in this area is very low, caused by the low precipitation rates and the prevailing cohesive substrates (see Tab. I). Our calculations show for instance, that afforestations of 10% or 20% of the agricultural areas would lead only to a slight decrease in the groundwater recharge of 5 or 9 mm/a. The results would justify an increase of areas used by forests and hedgerows for nature development.

The partly high amplitudes of the groundwater recharge of small areas within the test areas are not represented in these average values (cp. Volk & Bannholzer, 1999). It means, that these scenarios can give only a coarse identification of the impact of land use changes on the water balance for large areas. More detailed studies require other models and a data base with a higher spatio-temporal resolution. The presented

**Table I. Groundwater recharge rates in the test area „Köthener Ackerland“: Current conditions and land use scenarios**

<table>
<thead>
<tr>
<th>Current land use conditions and scenarios</th>
<th>Mean groundwater recharge in mm/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current conditions</td>
<td>55</td>
</tr>
<tr>
<td>Total afforestation of agricultural areas</td>
<td>23</td>
</tr>
<tr>
<td>Afforestation of 10% of the agricultural areas</td>
<td>50</td>
</tr>
<tr>
<td>Afforestation of 20% of the agricultural areas</td>
<td>46</td>
</tr>
</tbody>
</table>

Fig. 2. Groundwater recharge and existing priority areas for groundwater abstraction in the district of Dessau (after Petry & Krönert, 1998).
scenario is an example for the analysis of interactions between landscape functions in relation to land use changes. Therefore, the calculations form a base for the local water management authority as well as the regional planning authority as a decision instrument, e.g. for developing ecological networks.

**Groundwater protection, runoff regulation and erosion risk**

Potential risk zones for vertical and horizontal material (and nutrient) fluxes

The functions of groundwater recharge and protection and runoff regulation are strongly interrelated. They are affected by the impacts of land use on the landscape structure and interrelated landscape ecological processes (water, material and energy fluxes).

These fluxes are depending essentially on land use and land cover and the morphological conditions of the surface. In a first step, potential risk areas with vertical material and nutrient leaching from agricultural areas were identified under the application of modified assessment techniques (cp. AG Boden, 1994; Frede & Dabbert, 1999; Marks et al., 1992). The areas are characterized by the criteria „arable land use“, „groundwater recharge over 180 mm” and „slope inclination 0 - 2°”. Due to the low spatio-temporal resolution of the existing data base at the upper mesoscale, the derivation of additional morphological parameters (e.g. curvature, surface hydrological analysis) is not useful. The risk areas are concentrated in the northern and partly in southern part of the study area, where permeable substrate dominates. The result give also evidence the low function of groundwater protection of these sandy areas.

The first identification of potential risk areas with lateral material and nutrient outwash is enabled by selecting areas characterized by „arable land use”, „cohesive substrate” and „slope inclination >1°”. Because of its flatness, there are only few risk areas for horizontal material and nutrient fluxes in the study area. In the sloped areas in the northern and southern morainic parts of the district, the risk zones are limited to a few areas with cohesive substrates. According to our calculations, most of the identified risk zones for lateral matter fluxes corresponds largely with the areas with high surface runoff – which results in a high water erodibility. The agricultural areas in the western part show a very low landscape diversity with prevailing chernozems, which are particular at risk for water and wind erosion. Some of the risk zones are located in priority areas. The results are summarized in Fig. 3.

Next step: Quantification and qualification of vertical and horizontal material (and nutrient) fluxes (scale „1:25.000 to 1:50.000”)

The application of data base with a higher spatio-temporal resolution allows further morphological and surface hydrological analysis, to get information about the direction of the material and nutrient transport. In addition to a renewed calculation of the groundwater recharge and the surface runoff, this enables an improved differentiation of the risk areas for vertical and horizontal fluxes. Also, useful information can be derived concerning potential risk areas at streams and rivers.

The derivation of the topographic factor LS in Arc/Info (Grid modul) and the determination of the factors K_B (substrate dependent rate of the erodibility factor K) and R (precipitation and surface runoff factor, after Schwertmann et al. 1990)
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allows by their combination the application of a modified usage of the Universal Soil Loss Equation (cp. Wishmeier & Smith 1978) after BGR (1994). This modified usage allows also an estimation of the mean soil loss for larger areas. For the verification of the investigations, several mappings and hydrochemical analysis of water samples are carried out. Additionally, first investigations about the interactions between surface runoff and material transport were done for some subbasins. These investigations can be considered as a forestep to the following application of the model ASGi, which allows the mathematical description of the transport processes and the registration of nutrient in- and output. Fig 4 gives an overview about the above mentioned investigations.

Conclusions and outlook

The presented studies show a hierarchical method for the investigation of the landscape balance and landscape functions on the middle and upper mesoscale (Tab. 2). In a first step, the method enables an analysis of the basic elements of the groundwater recharge and an estimation of the surface runoff at the scale 1:50.000 and larger. At this level, scenarios about the impact of land use changes on the groundwater recharge for areas larger than 100km² can be calculated. The combination with other data layers allows the identification of potential risk areas for material and nutrient output. The results can contribute to an improvement of the protection of our natural resources, especially soil and both surface and groundwater, at the regional scale. Analysis at this scale level is a „coarse” filter that sets the background and identifies the direction for subsequent analysis.
In the second step, the scale level is changed to 1:25,000 to 1:50,000. At this scale, the identified risk areas are investigated in detail - with other methods and a data base with a higher spatio-temporal resolution. These calculations allows a more detailed assessment of the landscape functions. This is reached by the enabled definition of the water, material and nutrient transport mechanisms and the identification of nutrient or material in- and output zones of areas or at streams and rivers.

One outcome shall be the recommendation for land use variants with decreased material and nutrient outwash. For the important and difficult verification of the "large scale results", the analysis have to be linked hierarchically with investigations and measurements on smaller scales in cooperation with other working groups and environmental and water management authorities. Future work will include the optimization of the scale specific application possibilities of GIS-model couplings, as well as the derivation and examination of further parameters of landscape ecological processes and structures. Due to our contacts to governmental and environmental authorities, we are aiming at the contribution of landscape ecological knowledge in landscape related planning processes. The investigations are considered as a base for establishing sustainable land use.

Fig. 4. Detailed analysis of landscape ecological processes, an example from the Rossel watershed.
Tab. II. The hierarchical approach for the scale specific investigations of the landscape balance. Suggestions for the integration of its results in landscape planning

<table>
<thead>
<tr>
<th>Scale level</th>
<th>Spatial planning level</th>
<th>Assessment Units</th>
<th>Data base (different spatial resolutions)</th>
<th>Model applications</th>
<th>Derived informations and application possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:50.000 and large</td>
<td>Regional level</td>
<td>landscape units, large river catchments, areas with similar conditions</td>
<td>Soil, Morphology (DEM100-250), Climate, Water, Watersheds, Land Use, Landscape Units, Spatial Planning Targets</td>
<td>ABIMO: Description of the fundamental elements of the water cycle (e.g. runoff)</td>
<td>Water balance and land use scenarios, limited for areas &gt;100 km²</td>
</tr>
<tr>
<td>(areas &gt;10⁸ km²)</td>
<td>(First identifications, coarse classifications)</td>
<td></td>
<td></td>
<td>(Coarse) Identification of potential risk zones with (water) and material fluxes (combination of modeling results with assessment guidelines)</td>
<td>Analyses of land use conflicts on the regional scale and recommendations for land use (environmental and resource management and conservation)</td>
</tr>
<tr>
<td>1:25.000 to 1:50.000</td>
<td>Regional level</td>
<td>watersheds, subbasins, conservation areas, indicated danger zones (cp. above)</td>
<td>Soil, Morphology (DEM40-100), Climate, Water, Watersheds, Subbasins, Land Use, Spatial Planning Targets</td>
<td>ABIMO, ASGi, (CANDY) Investigation of vertical and horizontal material and energy fluxes (Nitrogen transport, Erosion)</td>
<td>Identification of subbasins, streamnet and order (flow of matter and nutrients)</td>
</tr>
<tr>
<td>(areas 10-10⁸ km²)</td>
<td>District level</td>
<td>(Quantitative and qualitative information and assessments)</td>
<td></td>
<td></td>
<td>Indication of rivers and streams affected by matter and nutrient input.</td>
</tr>
<tr>
<td>1:10.000 to 1:25.000</td>
<td>Community level</td>
<td>fields, biotopes, river sections (incl. mapping/measuring)</td>
<td>Soil, Morphology (DEM&lt;40m), Climate, Water, Subbasins, Land Use, Spatial Planning Targets</td>
<td>Physical and empirical Models (WEPP, AGNPS, CANDY)</td>
<td>Modeling of water balance and material and energy fluxes (qualitative and quantitative information) within the risk zones Combination of modelling results with assessment methods: Recommendations for land use variants for a reduction of material/nutrient output related to agricultural areas</td>
</tr>
<tr>
<td>(areas 100m² to 10 km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Material and nutrient output (outwash) related to fields</td>
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<td></td>
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<td>Polymorphic landscape assessment and land use optimization</td>
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</tbody>
</table>
References


