3 Databases, data organization and data processing

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3.1 Introduction

In the age of transition towards the information society, many different kinds of information and data are being continuously produced and distributed all over the world. Faster computers, the internet, earth observation satellites, and the development of new software and new technologies for various disciplines shape the production, transfer and exchange of information in all spheres of life. Moreover, many questions cannot be solved on a local, regional or national level because they have an international or even global nature. Considering the sheer volume and diversity of information, ever greater demands are being made on the collection, processing, structuring, standardization, sources, accuracy, updating and presentation of data. One general rule is that data collection is very time-consuming and expensive.

This chapter takes a look at selected aspects concerning the spatial data needed in the field of landscape-ecological investigations.

3.2 The problems faced

Landscape-ecological research deals with the study of various landscapes. Each landscape is the result of its natural and anthropogenic development over a long time and represents a certain part of geographical space. Landscapes consist of abiotic, biotic and anthropogenic components and are subject to permanent changes and developments. They are areas where humans, animals and plants live and act, and reflect the interactions between mankind and the environment.

Various sciences such as geography, landscape ecology, landscape planning, biology and environmental science investigate landscapes from their own specific angle. In addition to natural components, man-made influences and their consequences are studied. Apart from the capture and analysis of the state landscape structures are in and how they are changing, the processes taking place (e.g. fluxes of matter and energy) are becoming increasingly important for the latest landscape-ecological studies. Yet besides analysis, the ecological assessment of landscapes is also playing an growing role within landscape-ecological investigations, with selected small parts of landscapes being investigated and assessed. Furthermore, growing attention is being directed to statements and predictions about future landscape development, especially for larger coherent geographical spaces. Some aspects of the history of landscape assessment can be found in the article by Müller & Volk in Chap. 2 of this book.

Landscape-ecological investigations take place on different spatial scales (micro-, meso-, macroscale), in different dimensions (e.g. topological, chorological, regional, geospherical dimensions), and in different periods. This complexity needs to be considered, as it influences the availability, selection and use of information necessary for such research, its validity, and the transfer of results to other landscapes or to other parts of a landscape.

Such complex, diverse investigations call for a large and varied quantity of data. In fact without different kinds of data on different scales and dimensions, landscape-ecological investigations are simply not possible. The permanently increasing quantity of data makes high demands on methods and procedures of its collection, processing, analysis, standardization, visualization and storage in databases. In this field geographical information systems (GISs) and digital image processing have become indispensable and efficient tools for landscape-ecological investigations. But nevertheless some problems arise between the demands on landscape-ecological data on the one hand and reality on the other.

Regarding the increasing role of data, some aspects concerning their need, their sources, methods of capture and processing, data quality, updating, storage and data organization, the problems of standardization, and the possibilities and boundaries of their use are to be investigated and discussed in this chapter.

3.3 The need for data resulting from tasks, objectives and specific features of landscape ecological investigations

Landscape-ecological investigations have always needed plenty of different data. Depending on changing and increasing tasks and objectives, the need for data has grown with respect to type, relevance to the present, accuracy and availability. Besides the introduction and usage of new and better information technologies, demands have increased such that the data have to be available to many users, not only in an analogue form but also in a digital, standardized form.

Data needs result from the tasks and objectives, as well as from certain specific features of landscape-ecological investigations.

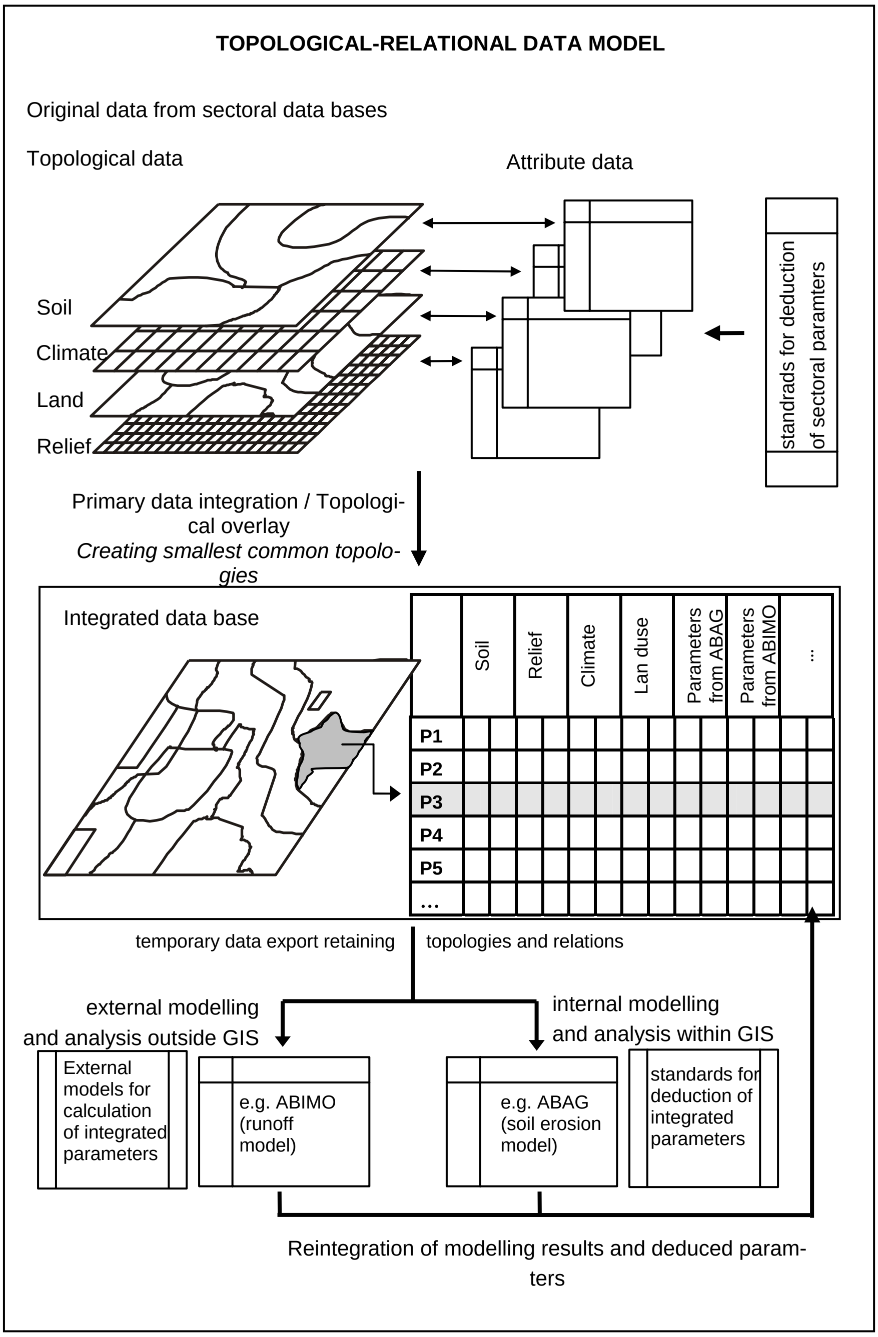

Fig. 3.1: Example for a topological-relational data model (Petry 2001)

3.3.1 The specific of landscape ecological investigations

Questions arising landscape-ecological research are of enormous breadth and diversity. According to Leser (1997), landscape ecology deals with interacting factors of a landscape ecosystem which is functionally and visually represented in a landscape. In reality, a landscape ecosystem is a very complex structure of natural, biotic and anthropogenic activities. By means of direct and indirect relations, these factors form a higher functional coherence which is spatially represented in a landscape. Just mentioning that landscapes represent the living space per se.

According to Leser (1997), some axiomatic basic rules apply to landscape- ecological systems regardless of the specific viewpoint of disciplines' broad research nature. These axioms are as follows:

- Landscape-ecological systems are everywhere.
- Landscape-ecological systems appear as geographical spaces.
- Landscape-ecological systems function all the time.
- Landscape-ecological systems function as three-dimensional structures of activities.
- Landscape-ecological systems function locally, i.e. in the topological dimension
- Landscape ecological systems always function in laws of nature even if they have been changed or they have been changed anthropogenically
- Landscape ecological systems are structures of activities with a basic dependence on biotic factors and abiotic factors
- Landscape-ecological systems function in a variable manner, albeit generally within certain limits dictated by climate.

Assuming that landscape-ecological systems or landscapes always function on the basis of natural laws, regardless of anthropogenic influence, landscape-ecological research deals with the abiotic and biotic components of landscapes, their appearances, their mutually relative nature, their mutual positive or negative influences, their anthropogenic influences and their consequences for a certain time, vertical and lateral fluxes of matter and energy, and so on.

3.3.2 Tasks and objectives of landscape ecological work

Landscapes exist in space and time, they are highly complex, and they cannot be measured. Therefore parts of landscape ecosystems, e.g. soils, water or vegetation, individual processes within their balances (water, fluxes and air), and individual functions are investigated in order to characterize a landscape.

Mosimann (1999) describes the central themes of landscape-ecological work as follows:

- Land use and the protection of resources
- Natural structural elements of landscape and their importance for flora, fauna, and landscape balance
- Estimation and assessment of landscape-ecological functions

- Ecological space division
- Ecological risk analysis
- Environmental monitoring and assessment.

Yet apart from analysing individual landscape elements and their mutual influence, landscape-ecological work also involves other tasks. Meyer presents several procedures for landscape-ecological assessment in Chap. 8. One main task consists in landscape-ecological process research, i.e. determining and understanding the vertical and lateral processes which take place in landscapes (or parts thereof). Furthermore, forecasts for the future development of landscapes are required - an important aspect for landscape planning and practice. Steinhardt (1999) emphasizes that after decades of mainly location-related research, a modern landscape ecology has to provide both information for geographical spaces whose dimensions are relevant for planning processes, and the required methodological equipment. Observation in space and time and the description of processes taking place in large landscapes are of fundamental interest but are difficult to organize because of the natural variability of real processes and the heterogeneity of spaces of reference.

Landscapes have to simultaneously fulfil several functions: production functions, regulation functions, capability functions and information functions. One main aim of landscape-ecological research comprises preserving and re-establishing the multiple use of landscapes by avoiding and/or minimizing use conflicts. Therefore investigating landscape balance is necessary to derive strategies for future landscape developments.

3.3.3 The role of geographical dimensions and scales

The assumption that nature is structured hierarchically and based on the holistic axiom - that the whole is more than the sum of its individual components - was introduced into ecology back in the 1940s (Steinhardt 1999). In this sense an ordered whole consists of a hierarchy of multilayered systems, where each higher level is formed by systems of a lower level. The change or transformation process between different levels is always connected with qualitative leaps and bounds. This theoretical concept can be applied to geoecological systems, too. According to Steinhardt (1999), investigating geosystems is tied to hierarchical principles: besides capturing their components (elements, relations, structures), separation must be performed vis-à-vis the surroundings, which always involves a certain range.

Landscape-ecological data are directly related to different geographical dimensions, a term which was first defined by Ernst Neef in the early 1960s (Neef 1963). He described scale zones with the same contents as a dimension. If a change in scale opens a new level of geographical facts and changed statements are possible, a change in the dimension of the geographical observation will take place. Based on the theory of geographical dimensions, which is important for geographical space divisions, a distinction is drawn between a topological, chorological, regional and geospherical dimension. Each dimension corresponds to a certain degree of generalization and reflects a particular degree of homogeneity and heterogeneity.

In the topological dimension, the ‘tops’ represent the smallest landscape-ecological base units. The tops should be of an approximately homogeneous content, i.e. the area of a top should have the same characteristics, the same structure and the same structure of activities, a unique mechanism of matter and energy balance, and exhibit the same ecological behaviour pattern. However, the homogeneity of the tops is relative and not necessary for all their components. Selected reference parameters and certain intervals are determined within which variation is allowed and neglected. Although tops are homogeneous, they can be distinguished into smaller parts of a heterogeneous character. Steinhardt (1999) wrote that the degree of heterogeneity between units of the same dimension level must differ significantly from the degree of heterogeneity within this unit. Therefore the heterogeneity of the unit at the lower level of dimension is a standardized measurement to signify separation from the higher dimension level.

In the chorological dimension, the chores are the landscape-ecological base units and represent a certain spatial structure. They have a heterogeneous character and consist of several homogeneous topological spatial units. Their determination takes place according to the landscape-ecological base units, landscape-genetic parameters of the chores, their spatial context and present dynamic characteristics which cover the whole unit.

The next higher level after the chorological dimension is the regional one. It represents large spatial extents of the geosphere. Therefore they cannot be derived from topological units. They are only partly based on chorological units. They form homogeneous areas on a very high level of integration.

The geospherical dimension serves for a landscape-ecological description of phenomena important for the whole geosphere. They can be landscape zones, continents or the earth. They are determined by planetary processes which are represented by a unique structure of a certain landscape zone and visually and/or ecofunctionally differ from neighbouring geo-regions (Leser 1997). Steinhardt (1999) discusses the present developments concerning the theory of geographical dimensions and the links between homogeneity and heterogeneity in different geographical dimensions and contributes to this topic in Chap. 6.

The specific features of each geographical dimension can only be represented by an adequate dimensional framework and on a certain (map) scale. However, strict limits do not exist between the scales. Instead, the transitions are fluid between the scales during a change from a lower to a higher dimensional stage. Steinhardt (1999) gives an overview of the different geoscientific levels of hierarchy exemplified by hydrological processes. An attempt to assign map scales to different geographical dimension stages can be found in the “Brockhaus abc Kartenkunde” (Ogrissek 1983). Topological units such as climatopes, physiotopes and ecotopes are represented cartographically at large scales between 1:5,000 and 1:25,000, which reflect the microscale of the geographical dimension theory. The chorological dimension includes three-dimensional stages, the microchores at a scale of 1:25,000 up to 1:100,000, the meso chores at a scale of 1:100,000 up to 1:1,500,000, and the macro chores at a scale of 1:1,500,000 up to 1:5,000,000. The microregion, mesoregion and macroregion belong to the levels of the regional dimension. They can be represented in maps of a small scale which can start from 1:750,000 (1:500,000) and reach up to 1:10 million or even smaller. Both the chorological dimension and the regional dimension represent the mesocale of the geographical dimension theory. The geospherical dimension can be represented by landscape zones or landscape belts at very small scales, e.g. 1:10 million or even smaller. They can be assigned to the macroscale.

3.3.4 The need for data

Knowing very well that it will never be possible to recognize and understand all the processes taking place in landscapes, it will nevertheless be possible to improve our knowledge about the function of landscapes step by step. The more information we have, the better the possibilities and chances to understand individual landscape-ecological processes and landscapes as a whole. The availability of complex landscape-ecological knowledge is a basic condition for keeping, protecting, restoring and developing diverse landscapes with different structures.

Because of the high demands on landscape-ecological investigations, many different sorts of data are necessary. Information about soil, water, vegetation, morphology, climate, land use, land cover, biotope types, landscape units, weather, landscape and natural conservation, administrative divisions and many more characteristics exist for different geographical spaces and at different scales. This is exactly what explains one major difference from non-spatial data.

Different tasks and objectives of landscape-ecological investigations essentially determine the data needed to represent a certain part of a landscape in a particular geographical dimension and at an adequate scale.

3.4 Types of data, data sources and methods of data acquisition

From analysis to assessment all landscape ecological investigations represent an integrative field of research and require a solid and diverse data base. The data can be differentiated concerning their topological or theme, the geographical space, the geographical dimension and the scale, the method of registration, the source, and the time (point in time or period).

With regard to the topological it is possible to divide data in two main parts, topographic data and thematic data.

As follows an overview shall be given over kinds of data nessecary for landscape ecological investigations, their sources and methods of acquisition.

3.4.1 Topographic information

Topographic data provide fundamental information about objects and conditions, their kind, geographical location, size, form, arrangement, and neighbourhood which allow an orientation in a certain terrain. These include information about settlements, industrial and other technical building complexes, traffic routes, stretches of running and standing water, relief, soil conditions, land cover and land use and others. Topographic information are mainly represented in official topographic maps on different scales, which are produced, updated and offered by national ordnance surveys. In the following the specific situation concerning the availability of topographic information in the Federal Republic of Germany shall be described.

In Germany the national ordnance survey of each federal state is responsible for the supply of topographic information for the whole particular federal state for different users in different spheres like ordnance survey and cartography, army, economy, planning, sciences, tourism and private persons. The national ordnance surveys are the only authorities which are allowed to produce and offer topographic information. They also have to update them in certain periodes. This is a sovereign task and of national importance.

3.4.1.1 Topographic maps

Topographic information has long been represented in topographic maps on different scales. Generally speaking, we differentiate between large-scale, medium-scale and small-scale official topographic maps. However, the boundaries between the different scales are not hard and fast, and may be very small depending on the viewpoint. Among the large-scale topographic maps, a difference is found between the staes in western Germany and those in the east. This different approach is explained by the historical development of Germany as two separate states from 1949 until 1990. The states in western Germany use a topographic map for the whole country with a scale of 1:5,000, the so-called German basic map. By contrast, the basic scale for topographic maps in eastern Germany is 1:10,000. Both topographic maps have been the basis for all other topographic maps on smaller scales and have been updated in certain periods. Since unification they continue to be maintained as the two basic scales for topographic maps. Because of the very high costs and the time needed time, integrating the two basic scales and creating one single topographic basic map for the whole country with a single scale has not yet been considered.

In the field of medium and small scales, there exists a unique order of scales in both western and eastern Germany. Topographic maps on the scales of 1:25,000, 1:50,000 and 1:100,000 are available in medium scales. Topographic maps on scales less than 1:100,000 are among the small-scale maps. In this field topographic maps on the scale of 1:200,000 exist for the whole country. Topographic maps on scales smaller than 1:100,000, the so-called topographic overview maps, on scales of 1:200,000, 1:500,000, 1:1 million (international world map), 1:1.5 million and 1:2.5 million are produced, updated and supplied by the Federal Agency for Cartography and Geodesy based in Frankfurt am Main, Leipzig and Berlin.

Besides these topographic maps mentioned, the national ordnance survey of each federal state offers specific topographic maps such as topographic regional maps and topographic special maps on different scales and maps of administrative divisions into municipalities, districts, administrative districts and federal states. Maps for certain surroundings, selected administrative units like districts, administrative districts, individual federal states or for the whole country belong to the topographic regional maps. Topographic special maps are topographic maps combined with specific thematic information, such as maps of natural parks, maps for hiking and recreation, and “leisure” maps.

Besides the present topographic maps, historical topographic maps on the scale of 1:25,000 (*Messtischblätter*) exist in printed form for the federal states for different points in time. They can be used to study the development and change of the topographic situation. In the field of landscape-ecological investigations, historical topographic maps serve for example to record the historical landscape-ecological situation, past land cover and land use, landscape structuring elements, relief and others, and their changes in time. Yet there are also other historical topographic maps on different scales, for instance the “Map of the German Reich” on a scale of 1:100,000.

All these maps are available and can be bought in the form of multicoloured or sometimes printed maps which can be coloured in by the user.

3.4.1.2 Topographic raster data

Parallel to the development and introduction of new information technologies into many spheres during the last 10 years, the need for topographic information in digital form has also arisen. Therefore the federal ordnance surveys have begun transferring their information from analogue to digital form. They now offer digital topographic information in two new products - raster data and the ATKIS data.

Topographic raster data are easily produced. As topographic maps are printed in single colours, the folios for printing each colour are scanned at a certain resolution and transferred to digital form. “Digital raster data” are the result of this process. Every map sheet consists of four data layers, representing map elements in one color. The ground plan (map frame, boundaries, settlements, transport routes, map names in black) consists of all the map elements which are printed in black. The second layer contains all the map elements printed in blue, i.e. the contours of water, water areas and map names in blue. Relief with the contour lines and map names in brown represent the third layer. The fourth layer comprises the vegetation, printed in green. Small scales also contain a layer for roads and built-up areas. In addition to these layers, every map sheet has a header file with the coordinates and pass points. Some federal ordnance surveys offer more than the four mentioned layers for selected scales, but this varies from one federal state to the next. In these cases, the map names in black are separated from the other elements of the ground plan, and the contours of water and map names in blue are separated from the water areas. Sometimes the administrative boundaries are shown in an independent layer. These raster data can be bought on the scales 1:10,000, 1:25,000, 1:50,000, 1:100,000 and 1:200,000. They are very useful for simply augmenting thematic maps with topographic elements. However, before they can be used within a geographical information system (GIS), they must first be georeferenced. This means the pixels have to be given specific coordinates delivered by the federal surveys. This step could be saved for many users if federal surveys offered the data in a georeferenced form from the start.

One disadvantage of such raster data is that only complete individual layers can be combined with other data. The selection of individual topographic elements from one layer, for example a certain water area, is not possible. Different numbers of layers in individual federal states cause problems if topographic raster data is to be used for a geographical region which is located in two or more federal states. By an agreeing on a unique number of layers on different scales in each federal state, standardization could be achieved in the field of topographic raster data.

3.4.1.3 ATKIS data

Unlike topographic raster data, ATKIS data are digital topographic vector data. Since the end of the 1980s, the national ordnance surveys and the land registry authorities of all the federal states in Germany have been working on a unique basic information system for topographic information. The acronym ATKIS stands for Official Topographic/Cartographic Information System. The development of ATKIS results from the increasing need for digital topographic vector data among science, trade and industry, planning, etc. The advantages of such a system include a unique spatial basis for the whole country, a unique data structure, a unique interface in the form of the unique database interface (EDBS), the independence of the map sheet vector data, and a larger share of permanently updated content.

ATKIS is being developed in the form of a digital landscape model (DLM) for three scale ranges. Digital landscape models have been created as DLM25 for scales from 1:10,000 up to 1:50,000, as DLM200 for scales from 1:50,000 to 1:500,000, and as DLM1000 for scales from 1:500,000 to 1:1 million (Landesamt für Landesvermessung und Datenverarbeitung Sachsen-Anhalt 1999). DLM25 has been built up by the ordnance survey authorities of the federal states. The Federal Agency for Cartography and Geodesy is responsible for developing DLM200 and DLM1000 for the whole of Germany.

ATKIS is structured in different components, the digital landscape model and digital administrative boundaries (DVG). The digital landscape model consists of two parts, a digital situation model (DSM) on a scale of 1:25,000 and a digital terrain model (DGM). Two-dimensional vector data structured on objects and the objects describing attribute data belong to the contents of the digital situation model. This information is independent of scale. On the recommendation of the ordnance surveys, it can be used on scales of 1:10,000 to 1:50,000. The contents of the digital situation model mainly correspond to the topographic map on the scale of 1:25.000. Individual objects are registered in the “ATKIS-OK”, a catalogue of object types created and published by a working group of the ordnance survey authorities of the German federal states in 1998 (Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland [AdV] 1998). The aim of this catalogue is to structure landscapes by topographic points of view, classify topographic phenomena in landscape objects, determine the contents of the digital landscape model, and provide instructions necessary for modelling (AdV 1998). The catalogue is structured on an attribute-oriented basis. Landscapes can be roughly structured in types of objects, and with the help of attributes they can be structured in detail. Thus the catalogue enables a free selection of topographic phenomena, and - if already integrated - of specialized facts. It is an open catalogue which can be augmented with further types of objects, topographic and specialized attributes.

ATKIS data are registered and offered for sale by each federal ordnance survey only for its respective territory. Although data covering a geographical region within two or more federal states currently have to be ordered in two or more federal states, the newly founded Geo-data Centre of the Federal Agency for Cartography and Geodesy will eventually offer all ATKIS data for the whole country.

Besides the digital situation model, the digital terrain model (DGM) belongs to the digital landscape model. Whereas digital situation models completely covering each federal state already exist with small differences from one federal state to the next, digital terrain models are not yet available for the whole area of each federal state. Digital terrain models contain elevation information in the form of a regular point raster with different resolutions. In comparison to two-dimensional data, ATKIS data digital elevation models provide three-dimensional terrain data. Each registered point of the surface (of the earth) is represented by both an x and y coordinate, and by a z value for the elevation. The distance between the elevation points, i.e. the raster size, varies among 10 metres, 20 metres, 25 metres, 40 metres, 50 metres, 80 metres and 200 metres in different federal states. The elevation accuracy is determined by data sources, aerial photographs and topographic maps on different scales, and by raster size. In Saxony-Anhalt, for example, the elevation lines of the topographic map on the scale of 1:10,000 have been digitized to derive the digital elevation model. Each federal state uses its own interpolation algorithm without any form of coordination with the other federal states. The federal ordnance surveys claim accuracy of about ± 2 metres for high-resolution digital terrain models. DGMs with a lower resolution of 25 metres up to 50 metres have an accuracy of between ± 2 meters and ± 5 meters. As a result, problems can occur if data of digital terrain models of different federal states are to be integrated.

The derivation of three-dimensional digital terrain models from the DGMs provides basic information for landscape-ecological investigations because relief is one of the most important landscape-ecological regulation parameters concerning the spatial structure of landscapes, fluxes of matter and energy, vegetation, land use and so on.

Depending on a certain landscape-ecological task, the spatial resolution of a digital elevation model and its use for a certain scale have to be considered before it is used. Digital administrative boundaries represent the second main part of ATKIS. The federal surveys recommend using these data on a scale of 1:50,000 up to 1:1 million. The following table gives an overview of the types of topographic information available in Germany.

Table 3.1: Overview of the available topographic information in the Federal Republic of Germany

Type of Topographic Information	Scale	Spatial availability	Producer and provider
Topographic maps	1:5,000 (Deutsche Grundkarte)	Old federal states only: Bavaria, Baden-Württemberg, Saarland, North Rhine Westphalia, Hesse, Rhineland-Palatinate, Schleswig-Holstein, Lower Saxony, Bremen, Bremerhaven, Hamburg, Berlin	Ordnance Survey of each federal state
	1:10,000	New federal states only: Saxony, Saxony-Anhalt, Thuringia, Brandenburg, Mecklenburg-Vorpommern, Berlin	Ordnance Survey of each federal state
	1:25,000	Old and new federal states	Ordnance Survey of each federal state
	1:50,000	Old and new federal states	Ordnance Survey of each federal state
	1:100,000	Old and new federal states	Ordnance Survey of each federal state
	1:200,000	Old and new federal states	Ordnance Survey of each federal state; Federal Agency for Cartography and Geodesy
	1:500,000	Old and new federal states	Federal Agency for Cartography and Geodesy
	1:1 million and smaller	Old and new federal states	Federal Agency for Cartography and Geodesy
Topographic special maps	different scales	Old and new federal states or selected areas	Ordnance Survey of each federal state

Type of Topographic	Scale	Spatial availability	Producer and provider

Information			
Historical to-pographic maps	1:25,000 (Mess-tischblätter)	Old and new federal states	Ordnance Survey of each federal state
	1:100,000 (Karte des Deutschen Reiches)	Old and new federal states	Ordnance Survey of each federal state; Federal Agency for Cartography and Geodesy
Digital raster data	1:10,000	New federal states	Ordnance Survey of each federal state
	1:25,000	Old and new federal states	Ordnance Survey of each federal state
	1:50,000	Old and new federal states	Ordnance Survey of each federal state
	1:100,000	Old and new federal states	Ordnance Survey of each federal state
	1:200,000	Old and new federal states	Ordnance Survey of each federal state
Digital ATKIS-data 1. Digital landscape model (DLM) DLM25 DLM200 DLM1,000 1.1 Digital situation model (DSM) 1.2 Digital terrain model (DGM) 2. Digital administrative boundaries (DVG)	 usable on 1:10,000-1:50,000 usable on 1:50,000-1:500,000 usable on 1:500,000-1:1million 1:25,000 (usable on 1:10,000-1:50,000) usable on 1:50,000-1:1 million	 Old and new federal states	 Ordnance Survey of each federal state Federal Agency for Cartography and Geodesy Ordnance Survey of each federal state Ordnance Survey of each federal state Ordnance Survey of each federal state

Topographic information has a great advantage in contrary to other information necessary for landscape-ecological investigations. It is generated on the basis of unique viewpoints, with sufficient accuracy over a certain range of different scales ensured by federal ordnance surveys. Topographic information is available for the whole country and is updated at certain periods. It is offered for sale by the federal ordnance surveys in both analogue form and digital form. When acquiring topographic information in the form of maps or digital data, users have to comply with strict rules improsed by the federal ordnance surveys concerning the duplication and publication of topographic data, and they have to pay for each data representation.

ATKIS with its components provides updated, more or less unique topographic information which can be used to build up spatially orientated professional information systems. ATKIS has not yet been completed. At present, individual parts of ATKIS are available at the different levels of their development in each federal state. For the whole of Germany, the first level of ATKIS - the creation of the geo-database - was finished at the end of the 1990s. Despite a few problems, the development of ATKIS is an example for the standardization of topographic information for the Federal Republic of Germany as a whole.

3.4.2 Thematic information

Thematic information plays the more important role for landscape-ecological investigations. In comparison to topographic information, the situation in this field is quite different. Due to the diverse tasks and objectives of landscape-ecological work, much thematic information already exists or has been produced. However, it is much more heterogeneous then topographic information. Thematic information is only available for selected geographical spaces, in a certain geographical dimension and scale, with a certain accuracy, for a specific point in time. In a few cases it covers the area of the whole country. Mostly, however, the information has been created for small, limited geographical spaces. Thematic information has different sources. On the one hand it can be of an original nature. This means it is the result of terrain investigations or terrain measurements. Such investigations are expensive and call for huge volumes of time and resources. Therefore they can only be carried out for small geographical spaces. On the other hand, thematic information mainly results from secondary sources. The latter may be thematic maps, thematic atlases, descriptions and others. The information is available for larger geographical spaces.

The information is scattered throughout various scientific institutions, official authorities and agencies, and environmental and planning bureaus. As nobody knows who has what kind of information in an analogue and/or digital form, inquiries about data are arduous and sometimes unsuccessful. The fact is that each regional landscape-ecological study entails specific data inquiries.

The specific situation in the field of thematic information for landscape-ecological investigations in Germany is considered below. Important sources of thematic information are mentioned. The basic thematic information available and the differences stem from different historical periods in the former “German Reich”, the existence of two German states over a period of 40 years, and the present Federal Republic of Germany. The information is very heterogeneous regarding its accuracy and sharpness of content, scale and availability.

In view of the great variety of thematic information, only selected aspects concerning type, availability, sources and importance for landscape-ecological investigations can be discussed.

3.4.2.1 Information of classification of nature areas

Natural areas are parts of the geosphere which can be characterized by certain abiotic and biotic geocomponents and geoprocesses determined by natural laws and anthropogenic influences. They have a unique structure and a unique structure of activities. Natural areas can be divided with the help of two methods, the natural spatial order and the classification of natural areas. Both methods represent different geographical dimensions. Depending on the extent of the geographical space investigated, natural area units of different geographical dimensions are distinguished due to the theory of geographical dimensions. The method of the natural spatial order enables natural area units of a homogeneous character to be extracted, characterizing homogeneous ecological units of a certain function with a specific flux and energy balance. The method of classifying natural areas serves the extraction of landscape spaces in the form of types and in a certain hierarchical order.

The results of such divisions of natural areas are represented in ‘natural area maps’, landscape-ecological maps or maps of classification of natural areas on different scales. In such complex or synthetic maps, natural area units of the topological, chorological or regional dimension with a unique landscape-ecological character determined by climate, water, soil, substratum, relief and vegetation give an overview of the classification of natural areas of a certain geographical space.

One example of such a map is that of the natural area types on a scale of 1:750,000 in the “Atlas Deutsche Demokratische Republik” (Akademie der Wissenschaften der Deutschen Demokratischen Republik 1981). In East Germany, the plan was to draw up a map of the natural spatial types on scales of 1:50,000 and 1:200,000 for the whole country. However, this project was not completed; only individual map sheets were made on both scales, and so there is no map of the natural areas on a larger scale then in the national atlas for the territory of East Germany.

An updated map of the natural areas and natural spatial potentils has since been created covering the whole of Saxony at a scale of 1:50,000.

The “Digitaler Landschaftsökologischer Atlas Baden-Württemberg” (Institut für Angewandte Forschung “Landschaftsentwicklung & Landschaftsinformatik” [IAF] der Fachhochschule Nürtingen 1996), the digital landscape-ecological atlas of Baden-Württemberg (at a scale of 1:200,000), consists of 37 thematic maps for the whole territory of this federal state. One basic spatial division is a map of natural areas structured in so-called complexes of sites, partial landscapes and large landscapes representing different geographical dimensions.

An updated map of the division of the whole country into natural areas does not exist. Therefore landscape ecologists use the historical map of the classification of natural areas of Germany, the “Naturräumliche Gliederung Deutschlands mit Höhenschichten”, on a scale of 1:1 million created and described by Meynen and Schmithüsen in their “Handbuch der naturräumlichen Gliederung Deutschlands”

(1952-1963), a handbook for the classification of natural areas of Germany in the 1950s.

These are just a few examples of the great number of maps of the natural spatial order and the classification of natural areas in Germany.

3.4.2.2 Soil information

Thematic information about the soil, which is one of the most important landscape-ecological parameters, exists in different kinds and on different scales.

One of the oldest sources of thematic information covering the whole country is the “Reichsbodenschätzung”. Between 1935 and 1956, agricultural soils (subdivided into arable land and grassland) were taxed depending on their natural conditions and fertility. According to Bastian and Schreiber (1999, p. 484), characteristics such as soil substrates, different state levels and their modes of origin were used for the taxation of arable land. Grassland was taxed with the help of soil types, different state levels, climate and water. The original data were mapped at large scales (1:500, 1:1,000, 1:2,000, 1:2,500 or 1:2,730). Later on, the results were presented in thematic maps. The “Deutsche Grundkarte - Böden” on a scale of 1:5,000 was developed on the basis of the results of the “Reichsbodenschätzung” for the old Federal Republic of Germany. The results were shown for the area of East Germany on the scale of 1:10,000. More information about the “Reichsbodenschätzung” is contained in Chap. 2 of this book. Two other available sources for soil information, albeit only for the whole of East Germany, are the “Mittelmaßstäbige landwirtschaftliche Standortkartierung (MMK)” and the “Forstliche Standortkartierung (FSK)”. The first one, made between 1976 and 1982, provides basic information for the land use of agricultural areas depending on their location. The MMK can be used to characterize heterogenic location units by substrate, soil and soil water conditions, the structure of the soil cover and the relief conditions. The results of the MMK are represented on two scales, 1:25,000 and 1:100,000.

The FSK only contains soil information for areas used by forestry. It provides information about the soils, soil water, relief and climate and their vegetation. The results were shown in maps on a scale of 1:10,000.

The MMK and FSK complement each other, making soil information of areas used for agriculture and by forestry available for the territory of eastern Germany. However, they do not contain any information about areas which are not used by agriculture or forestry, such as built-up areas or opencast mining districts. Both maps have been transferred to a digital form, and are available from various environmental authorities in eastern Germany. The combination of both maps reveals differences regarding the spatial separation of areas used by agriculture and by forestry. In some cases agriculturally used areas in the MMK differ from the areas shown with the same use in the FSK. The same situation is found in the areas used by forestry. Therefore, joint use entails fitting both maps to each other. They are one of the most important sources for obtaining detailed information about soil conditions in the topological and chorological dimension.

The Federal Institute of Geosciences and Natural Resources (BGR) sells soil maps on different scales covering the whole of Germany - both as printed colour maps and in digital form.

The first one is the “Soil Map of the Federal Republic of Germany” (BÜK1000) on a scale of 1:1 million. It gives an overview of the distribution of dominant soil types and parent material throughout Germany. This map is the result of unifying the digital soil map of western Germany on a scale of 1:1 million and the soil map of eastern Germany on a scale of 1:500,000 (Bundesanstalt für Geowissenschaften und Rohstoffe, Niedersächsisches Landesamt für Bodenforschung, Geowissenschaftliche Gemeinschaftsaufgaben 1999). At first “it was necessary to match the soil systems used in East and West Germany and to develop standardized descriptions of soil units.” (Bundesanstalt für Geowissenschaften und Rohstoffe 1995, p. 4) “The map shows 72 soil mapping units, described in the legend on the basis of the German and FAO soil system. Each soil unit has been assigned a characteristic soil profile as an aid to map interpretation. For the first time the subdivision of the country into 12 soil regions has been represented on the map.... It is an important part of the spatial database integrated in the Soil Information System currently being established at the Federal Institute of Geosciences and Natural Resources (FISBo BGR). It can be used together with the characteristic soil profiles to derive thematic maps related to nationwide soil protection. The scale of the BÜK 1000 makes it especially suitable for small-scale evaluations at the federal or EU level.” (Bundesanstalt für Geowissenschaften und Rohstoffe 1995, p. 4)

Based on the BÜK 1000, a second soil map on a scale of 1:2 million (BÜK 2000) was derived covering the whole country. Through an insignificant generalization of the 72 soil mapping units, the map now shows 61 soil mapping units. The third soil map offered by the BGR is a soil map on the scale 1:5 million (BÜK 5000). This map is the result of a significant generalization of the BÜK 2000, with the original 61 soil mapping units being generalized and summarized to form 19 soil mapping units.

In addition to these soil maps, the BGR has started creating a large-scale map of soil landscapes for the whole country. This map is based on the BÜK 1000 map and represents 38 mapping units with 329 areas. Moreover, on the same basis a map of the distribution of soils at the level of soil regions with 12 mapping units with 173 individual areas exists. These soil regions differ with respect to orography and lithography.

In connection with the geographical dimensions, the soil maps mentioned above can be used for investigations at the regional dimension.

Furthermore, a soil map with a scale of 1:200,000 is being developed. The map will ultimately consist of 56 map sheets with between and 100 mapping units. At present only individual map sheets are available, e.g. CC7934 Munich, CC3926 Braunschweig and CC4734 Leipzig. Other map sheets are in preparation. Because of its larger scale, this soil map can be used for investigations in the chorological dimension.

Information about the maps and data produced and available from the Federal Institute of Geosciences and Natural Resources can be found on the internet under http://www.bgr.de. In addition, important descriptive information about each product is contained in the metadata catalogue (Bundesanstalt für Geowissenschaften und Rohstoffe, Niedersächsisches Landesamt für Bodenforschung, Geowissenschaftliche Gemeinschaftsaufgaben 1999).

Apart from soil data and maps on small scales covering Germany as a whole, each federal state has soil maps on larger scales at its disposal. In western Germany, soil maps on different scales exist for the whole federal state or parts thereof. For example, in Bavaria and North Rhine Westphalia soil maps on a scale of 1:50,000 are available. In Lower Saxony soil maps on a scale of 1:200,000 and 1:25,000 have been developed. After German unification in 1990 and the administrative division of East Germany into five federal states, there was a great demand for (not to mention a severe shortage of) various up-to-date thematic maps for the territories of these new administrative units. The Federal Authorities of the Environment and Geology have tackled the the development of new maps and digital data for each federal state. In Saxony and Thuringia, for example, a soil map (BÜK400) has been developed on a scale of 1:400,000 covering the whole territory of each federal state. The soil map of Saxony-Anhalt was developed on the scale 1:500,000. A comparison of these maps along the boundaries shows that the maps were made separately without any adjustment between the federal states. This is an avoidable disadvantage if a user needs soil information crossing the boundaries of federal states.

In addition to the soil map on the scale of 1:400,000 in Saxony, a new soil map on the scale of 1:50,000 has been prepared covering the whole territory. The first three map sheets have already been published. This map can be used for landscape-ecological investigations in the microchorological and mesochorological dimension.

3.4.2.3 Geological and hydrogeological information

The main sources of geological and hydrogeological information are geological and hydrogeological maps on different scales. Geological maps show the spatial distribution, stratification, age and other characteristics of rock. As a rule the beds underground below the soil are shown.

Older and younger geological maps on the scales 1:25,000, 1:50,000, 1:100,000 and 1:200,000 exist for the whole of the Federal Republic of Germany. In East Germany, two specific geological maps on the scale 1:50,000, the lithofacies map and the hydrogeological map, were produced for the whole territory.

In addition, the above-mentioned authorities produced new geological maps for the territory of their federal states. At first in Saxony and in Thuringia they made maps on the scale of 1:400,000 which gave an overview of the geological situation. Whereas the soil maps are island maps, the geological maps are framework maps. This means that the problem of adjustment does not arise in the same manner if boundaries are crossed during investigations.

The Saxony Federal Authority of the Environment and Geology has developed a new geological map of the glacial covered areas of Saxony on a scale of 1:50,000. This map consists of 20 map sheets. Each map sheet represents the solid rock and the loose rock of the terrain surface. The map is designed to act as a basis for the assessment of soil formation, water flow, the distribution of usable solid and loose rock, possible reaches of environmental damage, and the possibilities of building landfills, etc.

The location, size, depth and quality of groundwater occurrences, possibilities of extracting groundwater and the water yield of different rock beds are shown in hydrogeological maps. Moreover, they contain hints about filtering ability, the chemical conditions and the risk of groundwater contamination. Hydrogeological maps on scales of 1:25,000 and 1:50,000 exist for western Germany. In East Germany, the hydrogeological map on a scale of 1:50,000 was developed for the whole territory. Each map sheet consisted of between three and ten map sheets of different topics. They are the Hydrogeological Basic Map - Quaternary Aquifers, the Map of Hydrological Characteristic Values, the Map of Groundwater Contours, and the Map of Groundwater Risks.

3.4.2.4 Relief information

Relief is one of the most important regulation parameters of landscape-ecological processes. The main sources of relief information are the topographic maps on various scales and the digital elevation models. These maps and digital elevation models can be used to determine the elevation, the slope and the relief intensity. A detailed description of available topographic maps and digital elevation models is contained in Chap. 3.4.1.

Specific relief maps provide information and a spatial impression of the relief with the help of shading. One example is the relief map in the “Atlas Deutsche Demokratische Republik” (Akademie der Wissenschaften der Deutschen Demokratischen Republik 1981) on a scale of 1:750,000. In this atlas, a hypsometric map gives an overview of the spatial distribution of the elevation conditions. Another map shows the georelief and local processes influencing relief on the same scale.

3.4.2.5 Information about watercourses

The system of stretches of surface and underground flowing and standing water is one of the most important components of the landscape balance and the living space of the bios. Water is a very important medium of transport for fluxes of matter, both underground and on the surface. Information about the surface water, the surface runoff, its quality and quantity have been measured and collected. By comparison, there is a lack of information about subsurface runoff. The vertical and lateral transport processes and the spatial distribution of fluxes with the help of water have not yet been sufficiently investigated, and there is a great need for data to ascertain and understand the role of water within the landscape and the landscape balance.

Basic information about the location, width and length, size, depth, natural and artificial water conduits and the direction and rapidity of flow, the water level of surface flowing and standing water, watersheds, underground water conduits, springs and others aspects is contained in topographic maps on various scales. Information about the groundwater isohypses are part of hydrogeological maps.

Water grade maps show the quality of important running water with the help of different classes. Each class provides information about the degree of load and the degree of water pollution. These maps give initial information about the polluted and unpolluted parts of rivers and streams. An example of such a map is the “Gewässergütekarte 1991” (Sächsisches Landesamt für Umwelt und Geologie 1992), a water grade map of Saxony on a scale of 1:400,000.

Information about the water flow and the rate of flow provide flood measurement points.

Further information is contained in individual thematic maps and regional thematic atlases. However, some parameters still have to be especially measured.

For example, the “Atlas Deutsche Demokratische Republik” (Akademie der Wissenschaften der Deutschen Demokratischen Republik 1981) contains a map with a hydrographic overview of the stretches of water and their density on a scale of 1:750,000. This atlas also contains a hydrological map with information about the average amount of runoff and the runoff of the surface waters.

3.4.2.6 Climatic information

The climate reflects the summary of atmospheric conditions over a long period for a certain geographical space, for example a certain location, a landscape, a region or a country. It is one of the factors of the landscape balance. The main climatic elements are the radiation, air pressure, air humidity, temperature, wind, evaporation, rainfall and cloudiness. These climatic elements determine in their combination with climatic factors such as geographical latitude, altitude, exposition, land cover and density of settlements the climate in a certain geographical space. Climatic elements and their changes in time are permanently measured with the help of climatic and meteorological stations distributed at different distances and densities throughout the whole country. The Deutsche Wetterdienst (DWD) - the German Meteorological Service - collects, examines, processes, analyses and assesses all the data and their changes over time. The DWD is the most important provider of climatic data in Germany. It runs and maintains about 4,000 weather, climate, rainfall, sunshine and wind stations in Germany. Depending on the spatial density of the measuring stations, the data are interpolated for a raster of 1km x 1km and are offered for sale in digital form to various users. The accuracy of the data differs from parameter to parameter depending on the spatial density of measuring stations. Besides providing climatic information, the DWD develops specific climate maps, for example wind maps and radiation maps on the basis of rasters with different resolutions (1km x 1km or 200m x 200m) for the whole country and for individual federal states or for a certain location using different models. In addition, the results of climatic measurements are shown and described in various thematic atlases, especially in climate atlases or wind atlases, for example in the “Klimaatlas von Bayern” (Bayrischer Klimaforschungsverbund (BayFORKLIM) 1996) or in the “Bayrischer Solar- und Windatlas” (Bayrisches Staatsministerium für Wirtschaft, Verkehr und Technologie 1997). More information about the tasks, data, products and publications of the DWD can be found on the internet (http://www.dwd.de).

3.4.2.7 Vegetation information

The vegetation is one of the main landscape-ecological characteristics and represents the summary of all plants and societies of plants and their spatial distribution in a certain geographical space or in a landscape. It is determined by and developed under specific conditions such as location, soil, geology, relief, climate, water, land cover and land use. The vegetation is the result of the development of landscapes. The existence, development, rarity and/or loss of a certain vegetation provides information about the structure and the balance of a landscape. The vegetation reacts to changes of landscape balance resulting from anthropogenic influence faster then the soil.

Updated vegetation maps are very rare because the vegetation cover changes. Updated information about the vegetation can be obtained with the help of vegetational mapping in the terrain. As this ties up considerable time and resources, such mapping can only be conducted for selected small geographical spaces.

The biotope maps of the federal states are another source of certain updated vegetation information (cp. 3.4.2.8).

The distribution of species of plants is shown in so-called floristic raster mappings for the whole of Germany. Vegetation is mapped on the basis of topographic maps on a scale of 1:25,000. The results are shown in small scales.

One result of this work is the “Verbreitungsatlas der Farn- und Blütenpflanzen Ostdeutschlands” (Benkert, Fukarek, Korsch 1998), an atlas of the distribution of ferns and phanerogams in eastern Germany on a scale of 1:4 million.

Besides the present vegetation, the potential natural vegetation - the vegetation which would have been developed under natural conditions without any anthropogenic influence - is shown in specific thematic maps. One example is the map of natural vegetation in the “Atlas Deutsche Demokratische Republik” (Akademie der Wissenschaften der Deutschen Demokratischen Republik 1981) on a scale of 1:750,000, which also contains some maps of the spatial distribution of selected plants and plant societies.

3.4.2.8 Land use information

Land use reflects the social use of the limited natural resource area. Natural conditions in different landscapes and social demands determine land use and cause conflicts. Land use influences and/or changes the natural conditions in the landscapes. This means land use is the key and the regulatory instrument for the preservation of these natural systems and re-establishing the multiple use of landscapes. In comparison with the geological or hydrogeological situation, land use is a parameter which is subject to permanent change. Therefore there is a great demand for updated land use information. Given this, more effective methods for capturing land use and land use changes have to be developed in order to derive updated land use information and land use maps.

Presently aerial photographs and satellite images are the main sources for gaining updated information about land use and its changes over time. More information about their role for landscape-ecological investigations is contained in part 3.5.4 of this chapter.

The Statistical Federal Authority recorded land cover information for the whole country during the European project CORINE Land Cover in the 1990s. On the basis of satellite images, using topographic maps and additional sources, the land cover was captured on a scale of 1.100,000 for the whole of Germany for the first time. This information about the main types of land cover is available in digital form. The following land cover types were registered: built-up areas, agriculturally used areas, woodlands and quasi-natural areas, moist areas and water areas. These five land cover types are divided into 15 subtypes - which in turn are subdivided into many more subtypes. Depending on the objective of investigation, detailed subtypes can be aggregated in subtypes and/or main types.

Some federal states have biotope-mapping at their disposal. In Saxony, for example, the State Ministry of the Environment and Agriculture (the former State Ministry of the Environment and Regional Development) of Saxony and the Federal Authority for the Environment and Geology has performed CIR biotope and land use mapping for the whole state. Colour-infrared (CIR) aerial photographs from 1992/93 were used to document the state of natural conditions and land use in Saxony for the first time after German reunification and the formation of the new federal states in eastern Germany. More than 16,000 aerial photographs were interpreted and cartographically prepared on a scale of 1:10,000, and the information was also made available in digital form.

This biotope and land use mapping is the most important data basis for various scientific institutions, official authorities and planning agencies. It provides information about the state of the natural environment and landscapes, and provides data for scientific and planning purposes on a local up to a nationwide level (Frietsch 1997, p.10). The biotopes were initially divided into the following eight main groups: 1. stretches of water; 2. moors and swamps; 3. meadows and ruderal fields; 4. rocks; 5. groups of trees, hedges and bushes; 6. wood and forests; 7. arable field and specific sites; 8. built-up areas, infrastructure and green spaces. These 8 main groups were subdivided into subgroups. The next level is the biotope followed by form, use, secondary use and specific use. Each area has a key-code corresponding to its use. The key-code enables a certain area to be characterized regarding the different subgroups and main groups. This means that depending on a specific objective, an aggregation and generalization of the land use and biotope types is simple with the help of the key-code. Moreover, it means that the CIR biotope and land use mapping of Saxony is a very good example of how to structure data for multiple use in different geographical dimensions. The very detailed mapping allows investigations into the topological, chorological and regional dimension on the basis of the same source and with the same accuracy. This is a great advantage over other thematic data available at different scales with different accuracies and based on different sources.

The other states in eastern Germany have also carried out such biotope and land use mapping. The main disadvantage is that each federal state made its own map without any coordination or adjustment concerning the types and division of biotopes between the neighbouring federal states. As a result, the biotopes along borders do not match. This is a serious problem if borders are crossed during a certain investigation, entailing much work to fit the different areas together.

Besides CIR biotope and land use mapping, the Saxony Federal Authority for the Environment and Geology has also produced a land use map known as the "Landnutzungskarte des Freistaates Sachsen" (Sächsisches Landesamt für Umwelt und Geologie 1996) on a scale of 1:100,000 for the whole of Saxony. Using basis satellite images from 1992/1993, 17 land use types were automatically classified and represented in 15 map sheets based on pixels with a size of 25m x 25m. This map gives an overview of the spatial distribution and size of main land use types. Such a map needs to be permanently updated in order to have up-to-date land use information in Saxony and as a source for the conclusion of main land use changes.

3.4.2.9 Information about landscape protection

Information about protected parts of landscapes or landscapes which need to be protected in the form of nature reserves, landscape reserves and water reserves are an important factor of landscape-ecological investigations. They mainly result from such complex investigations. Natural and landscape protection serves the preservation of landscapes and parts thereof, including all the components necessary to preserve their ecological capability, variability, biodiversity and attractiveness. The protection of landscapes or parts thereof is a consequence of the anthropogenic influence over a certain period. Selected land uses influence landscapes or the landscape balance in a negative way, and so types of land use have to be restricted or even prohibited. Therefore land uses disturbing or changing the natural balance are forbidden in nature reserves, landscape reserves and water reserves.

The spatial distribution of such protected areas is represented in specific thematic maps on different scales. Two examples are the maps "Naturschutz im Land Sachsen-Anhalt. Karte der Schutzgebiete" (Landesamt für Umweltschutz Sachsen-Anhalt 1996) and the map "Naturschutz. Schutzgebiete in Sachsen" (Sächsisches Staatsministerium für Umwelt und Landesentwicklung 1996) on a scale of 1:200,000. A combination of nature reserves and landscape reserves, national parks, biosphere reserves, natural parks and bird reserves in different levels of protection is represented.

3.4.2.10 Field information

Field information is an essential source to augment the other data sources for landscape-ecological investigations, especially in the topological dimension. Mainly in the field of the mesoscale and macroscale level, i.e. in the chorological and regional dimension, data are available in most cases. However, there is a lack at the microscale level. This gap can only be closed by detailed field work in a certain terrain. Terrain measurements and mapping over a certain period provide realistic (original) information about selected landscape-ecological parameters. Knowledge of the details contributes to the cognition and understanding of processes taking place within the landscape, the landscape balance and the landscape as a whole. Field information also plays an important role for validating models used for landscape-ecological investigations.

Standards for landscape-ecological capture were developed by Zepp and Müller (1999). In their book they describe principles and methods for surveying and processing landscape-ecological aspects in the terrain which are necessary for the characterization and spatial differentiation of landscape ecosystems. These standards can only be regarded as proposals because universal norms do not exist for characterizing ecosystems in their complexity. The idea of this book is to give an orientation about essential aspects for the characterization of landscape ecosystems from a scientific point of view. Demands and possibilities are to be represented for a balanced consideration of ecological facts composed of the compartments atmosphere, relief, soil, soil close to the surface, stretches of water, vegetation and fauna. Common standards and methods of data capture, mapping and assessing landscape-ecological parameters are described. In addition, information about the sources of data methods of their processing with the help of geographical information systems (GIS) and a landscape-ecological data catalogue are introduced. This book is an important working instrument for scientists from various disciplines investigating landscape-ecological problems from their own specific viewpoint.

The sources for landscape-ecological data described in 3.4.2 only represent some of the important sources. There exists plenty of other data in various authorities, scientific and other institutions, planning agencies and others. More information can be found in Chapter 8 of this book. The above-mentioned data and data sources show their great number, diversity and variability. In Germany in the field of topographic data, great efforts have been made with the development of the Official Topographic/Cartographic-Information System (ATKIS). This system is a very important step towards the creation of a unique, updated topographic database covering the whole country and suitable for various uses. The standardization of these data enables the investigation of a certain geographical space located in a number of federal states and which crosses federal boundaries.

Thematic data are available in different geographical dimensions, on different scales and with different accuracies, in analogue and/or digital form for selected small geographical spaces, certain administrative units, individual federal states and the whole country. In contrast to the topographic information, in most cases one main problem is the separate creation of thematic information without any coordination concerning content, accuracy, scale or the geographical dimension between different institutions in different federal states. This results in thematic maps or databases which do not match up at borders between federal states.

The conscientious combination and analysis of data of the same or comparable geographical dimension is essential for scientifically sound landscape-ecological investigations, including landscape assessments and landscape planning. In this field, irrespective of the discipline involved, each scientist must use the available data in a careful, responsible manner.

3.5 Remote sensing data

Human activities affect the land surface, water and the atmosphere. Mankind and the environment, mankind and the natural balance coexist in a complex relationship and need to be observed at different levels of research and by different means. From the ecological viewpoint, human interventions need to be planned and sometimes even channelled, and the accompanying conditions, changes, and dynamics need to be recorded. Causes and effects can only be determined insufficiently by ground data as environmental changes partly occur in large spaces and sometimes even in inaccessible areas. Remote sensing data allow processes of large dimensions to be captured and their changes to be monitored. Information concerning the physical condition of the environment can be gathered by taking ground measurements. However, to investigate and observe large or inaccessible areas, remote sensing data play an important role and deliver the spatial data needed, which can then be added to the ground measurements. Apart from its comparatively large spatial cover, remote sensing has also undergone technical and methodological improvements during the past few decades.

3.5.1 Aerial photography and satellite imagery

Remote sensing is the recording of the earth's surface from a certain distance. It comprises photographically documented aerial pictures and satellite imagery mostly gained in digital form. Recently aerial scanner data have completed this series by combining aerial flight altitude with satellite scanner techniques. Remote sensing data can be classified either by the carrying platform (e.g. hand, car, aircraft, satellite) or by the type of sensor (e.g. camera, scanner). In contrast to aerial photos, which have been developed and analysed since the early 20th century for civil research purposes, scanned or photographic satellite images have only been established for the last thirty years. Both carrier systems, aircraft and satellites, are the indirect observation instruments used to record and display the earth's surface from a certain distance and with a certain spatial extraction depending on parameters such as the recording instrument, its field of view and the flight altitude. It is only by means of systematic analysis that the data collected can be processed and interpreted for research purposes and used for concrete investigations such as layers of information documenting land cover in landscape ecology. Knowledge about recording techniques, parameters of photos and scanned images, and the repetition rate is fundamental to choosing the right system for the application required, appropriate auxiliary data, and also selecting the suitable methodology to analyse the data.

3.5.2 Development of the use of instruments

It was Carl Troll who summarized the applications of aerial photography for geographical field research in 1939 (Troll 1939). During World War I, aerial observation for certain scientific aims started with the sudden emergence of the aircraft sector. As it was at that time that terrestrial field research began to be carried out by aerial photos, series of such photos were produced and put together to form aerial plans and for aerial maps without leaving any land cover unsurveyed. Troll stated that aerial photography unified different earth sciences and called for a precise research methodology for the focused use of such spatial information to support geographical field observation. He realized that based on the complete analysis and evaluation of the aerial data, not only topographical information could be gained but also maps for geology, soil sciences, vegetation, and landscape ecology, and that aerial photos could thus serve spatial planning.

Since then the great demands made on remote sensing and the nature of the tasks have remained more or less the same. What has changed is that nowadays remote sensing techniques belong to many different devices. With the progress made in techniques, greater distances from the earth's surface have become possible using satellites as sensor carriers in addition to aeroplanes. Opto-electronical scanners and radar systems complement the recording devices that started with camera systems. Observation devices have thus changed and become more diverse (Lillesand & Kiefer 1999).

Over the past 20 years, satellite data have become increasingly sophisticated, enabling high-resolution images, and their usage has spread to many fields. Operational systems with scanners and radar devices can register an area in wavelengths beyond the visual range of human beings.

Starting with the US aeronautics and space programme, developments over the past 35 years in the field of remote sensing have accelerated. The first useful colour photos of the earth were taken by an automatic camera aboard the American Mercury capsule in May 1961, followed by photos from the Gemini mission in June 1965 and later from Apollo 9 in March 1969. The first weather satellites were launched in the 1960s by the United States. Meteorological satellites followed in the 1970s with the NOAA, GEOS and METEOSAT missions.

The launch of the US satellite ERTS-1 (Earth Resources Technology Satellite, later renamed Landsat 1) on 23 July 1972 marked the breakthrough for earth observation from space. The whole Landsat series, 1-5 and now 7, has delivered image data of almost all the earth's territories at regular, fairly short intervals. Landsat 5 Thematic Mapper was constructed to take pictures for about 6 or 7 years, but having been in the orbit since 1984 it still delivers data regularly. Thus data availability of more or less the same quality has been enabled for almost two decades. The launch of Landsat 7 ETM (Enhanced Thematic Mapper) continues with a better system and radiometric correction. The new sensors have been sent into orbit with almost the same traditional sensors of Landsat 4 and 5 TM but enhanced with a higher resolution thermal band and additionally equipped with a panchromatic sensor. The thermal band of Landsat TM and ETM is outstanding and not available from other producers of multispectral satellites. However, as other satellite series have started to take images in multispectral and panchromatic modes at the same time, it is the ETM sensor of Landsat 7 that assures competitiveness (see Richards 1999).

From the 1980s onwards, a multitude of national activities for remote sensing applications with improved satellite systems emerged. Important European Space Agency projects include the European radar satellites ERS-1 and ERS-2.

In 1986 France launched its first Spot satellite (Système pour l'Observation de la Terre), which was then followed by another three missions, Spot 2-4. Its HRV Sensor (Haute Résolution Visible/High-resolution Visible Sensor) operates in two modes, namely the multispectral mode and the panchromatic mode. Thanks to its side-viewing features, the HRV instruments are capable of plotting contours by taking stereoscopic images, as well as imaging a particular location more frequently, without waiting for an overhead pass. SPOT-4 carries an additional "Vegetation" instrument in order to provide the capability of small-scale monitoring of the earth's vegetation (pixel size = 1.15 km at nadir).

The first Indian Remote Sensing Satellite was launched in 1988. Named IRS-1A, it was equipped with a sensor called LISS (Linear Imaging Self-Scanning Sensor). LISS-I and LISS-II are both multispectral cameras. There followed IRS-1B, and, with IRS-1C a second generation of remote sensing satellite series was built with enhanced capabilities in terms of spatial resolution and spectral bands. IRS-1C was launched on 28 December 1995 and was followed (Kramer 1996) by IRS-1D three years later. Satellites of the series 1C and 1D carry three sensors, PAN which is a panchromatic camera, LISS-III, and WiFS (Wide Field Sensor). These products compete directly with Landsat TM and ETM as well as with Spot image data (see Tab. 3.2).

One of the latest satellite systems for landscape-ecological investigations on large scales is the Ikonos satellite, launched in September 1999, with a spatial resolution of 4 metres on the multispectral sensor mode and 1 metre on the panchromatic mode. For ecological research, such as the urban nature within building complexes, panchromatic and multispectral images can be combined to be able to interpret near-infrared, for example, with a 1-metre resolution capability. The viewing geometry only offers an 11-kilometre-wide ground track, but this is sufficient for large-scale investigations, especially as the geometric resolution calls for new methodological approaches and a high demand on data storage when working with several composed images.

For earth observation from space, a wide range of instruments is and will continue to be used in combination with other instruments. With their active and passive sensor techniques they cover a large band width of the electromagnetic spectrum. In over 80 missions more than 200 different instruments are to be used and examined during the next 15 years. The sensors can be categorized as follows:

- Instruments for atmospheric chemistry
- Atmosphere explorer
- Cloud profile and rain radar instruments
- Radiometer to record the earth’s radiation balance
- High-resolution systems
- Multispectral radiometer
- Active radar
- Lidar (acronym for “light detection and ranging”)
- All-round radiometer
- Radiometer for the colour of the sea
- Polarimetric radiometer
- Radar altimeters
- Wind radiometer

Dimensions of satellite image data	Examples of multispectral sensors (spectral range)			Potential applications
Electro-magnetic	**Landsat-TM / [-ETM]**	**SPOT-MS and Pan**	**IRS-1C /D LISS and Pan**	▪ separating different forms of land cover (e.g. soil and vegetation, deciduous and coniferous forest; coastal mapping) ▪ investigation of plant stress (high reflexion for healthy vegetation ▪ differentiation of plant species (absorption of chlorophyll) ▪ recording of plant vitality; investigation of biomass ▪ differentiation: cloud / snow; estimating plant humidity and soil moisture ▪ thermal mapping; investigating the influence of heat on plants ▪ geological mapping; ▪ land use monitoring; spatial planning; ▪ Stereoscopic interpretation (digital elevation models - only Spot pan)
spectrometric: intervals of used spectral fields of a sensor *radiometric*: number of discrete values (dependent on the capacity of the available detectors of a system) into which the measured signals can be divided (e.g. 128, 256, 1024 grey levels)	Band 1: 0.45-0.52 µm VIS Band 2: 0.52-0.60 µm VIS Band 3: 0.63-0.69 µm VIS Band 4: 0.76-0.90 µm NIR Band 5: 1.55-1.75 µm MIR Band 6: 10.40-12.5 µm (thermal-IR) Band 7: 2.08-2.35mm MIR [Pan: Band 8: 0.50-0.90 µm]	Band 1: 0.50-0.59 µm Band 2: 0.61-0.68 µm Band 3: 0.79-0.89 µm Pan: 0.51-0.73 µm	Band 1: 0.52-0.59 µm Band 2: 0.62-0.68 µm Band 3: 0.77-0.86 µm Band 4: 1.55-1.75 µm Pan: 0.5-0.75 µm	
Spatial ▪ Size of ground elements (dependent on the geometric characteristics of a sensor) ▪ Swath width	30 x 30 m (bands 1-5 / 7) 120 x 120 m (band 6 TM) [60 x 60 m (band 6 ETM)] Pan: 15 x 15 m 185 x 185 km	20 x 20 m Pan: 10 x 10 m 60 x 80 km	23.5 m (bands 1-3) 70.8 m (band 4) Pan: 5.8 m 142 x 142 km (LISS); 70 km (Pan)	In the multispectral mode only a scale for regional planning is possible. Data fusion (e.g. resolution merge) with panchromatic images allow a large scale level.
In time Cycle of repetition between two images of the same area (repetition rate)	16 days	26 days	24 days	Resource management for land and water; landscape monitoring

Table 3.2: Dimensions and potential applications of satellite images using selected examples of sensors

The listing shows a wide range of existing sensors. For Central Europe and the demands in landscape-ecological research the most important sensors are the high-resolution systems. These sensors characterize the largest application range of all instrument categories. They serve for the registration of vegetation classes and the erosion of coast lines, but also for geological mapping. For example of opencast mining areas. They will be dealt with later, especially in Chap. 5. Other important systems include hyperspectral scanners, as well as multispectral and passive radar radiometers. Hyperspectral data are still being tested and asre mainly used on aircraft. The multispectral radiometers are important sources for recording processes in the biosphere, because they collect information about influences on the global vegetation which in turn allow conclusions about the ecosystem. The latter 'SAR' (synthetic aperture radiometer) data are especially important for agriculture and forestry, as well as for measurements of snow and ice cover.

The operational sensor data most frequently used for landscape-ecological investigations is presented in Tab. 3.2, their spectral, spatial and radiometric resolution being accompanied by general application possibilities.

3.5.3 The importance of resolution

The possibilities for observing details of the earth's surface by means of remote sensing data depend mainly on the resolution capabilities of the different sensors. These dimensions are a source of both possibilities and limitations for image processing, interpretation and analysis (Bähr & Vögtle 1998).

- Repetition rate
  The resolution in time indicates how often measurements are repeated of the same area. Regarding satellite systems, repetition is determined by its orbit.
- Ground resolution
  The spatial resolution that is the smallest linear (or angular) separation between two objects achieved by a sensor is one of the most important factors for interpreting remote sensing data, because the realization of details is directly dependent on the ground resolution. Great demands are made on spatial resolution, e.g. for updating regional and spatial planning, for agricultural statistics (harvest trends), and for the analysis of forest damage.
- Spectral resolution
  The power of a system to separate single wave lengths is defined as its spectral resolution. It relates to the number and size of the wavelength intervals ('bands') into which the electromagnetic spectrum can be divided and for which the sensor is constructed.
- Radiometric resolution
  The radiometric resolution characterizes the number of levels into which the signal received by the sensor can be divided. For instance, in one spectral band 256 grey levels can be displayed.

Landscape-ecological targets use and apply geographical knowledge especially with respect to regional geographical realization when it comes to solving practical tasks. Applying landscape ecology means investigating actual practical problems of the use, demands, development and protection of a landscape by the human beings. It also serves to assess changes to its natural features and its function. Moreover, there is a close relationship between these ecological tasks and integrated spatial planning.

With regard to the complex subject ‘landscape’ and the ordinary levels of spatial planning, classifications are undertaken that allow the characterization of systematic and hierarchical structural levels. When taking remote sensing data into account to work on different levels, the resolution plays a crucial role. The ground resolution enables work at certain scales but prohibits work at more detailed scales than those defined. If sensor data possess a ground resolution of 30 metres, these data will only be suitable for planning to a limited extent. Certain other tasks such as protection programmes need a refined land use mosaic and thus the interpretation of a multitemporal data set within the same year and within one phenological phase (e.g. land use monitoring). Hence the repetition rate is important for several high quality imageries within a defined period of time, and it usually takes several years to repeat aerial flights over the same region. The spectral dimension is the basis for classifying differences between different land use types and, the more bands that are available, the more sophisticated a classification scheme and a subdivision of classes can be. Examples include classifying different crops or finding spectral differences within standing water. Conclusions can thus be made for instance for the evaluation of agricultural management systems, or water depth and water quality, pollutant inputs, etc. (Banzhaf & Kasperidus 1998).

3.5.4 Landscape balance

Multitemporal analyses help record structural changes as well as general environmental and landscape modifications. Thus the component of process investigation is taken into account. This technique for monitoring a landscape and its land use is one of the advantages within the applications of remote sensing data and their methodologies. One attempt to gain information about the link between processes of the ecosystem and structures is to differentiate structural units (e.g. the forest stands) and the subsequent investigation of the influences of these differentiating elements (in forest stands this would be the tree species) on landscape functions (e.g. groundwater regeneration) (Kratz & Suhling 1997). Such scientific insights are a basic prerequisite for the sustainable prevention of landscape functions. The advantage of this improvement is the multitemporal and spatially extensive possibility of registering parts of landscapes in connection with the use of remote sensing and geographical information systemss. However, it is not possible to provide any evidence about the issue of fluxes and process courses with remotely sensed data (Volk & Steinhardt 1999, pp. 234).

Methods of satellite remote sensing are used to rapidly record large areas. Parameters such as land use, vegetation and soil characteristics, to mention just those of vital importance, can be recorded for landscape-ecological questions. The spectral reflection and degree of emission from the visible to the infrared and microwave range provides information on the leaf area index, temperature and moisture contents of vegetation and its type, damage, biomass and, by applying active radar images, even soil moisture might be estimated. As vegetation is of fundamental importance for the albedo and terrestrial water balance, it mainly influences the atmospheric water vapour content. It makes the hydrological cycle a condition, for example, but is also responsible for land erosion and the composition of the atmosphere. The proportion of precipitation and evaporation defines the character of water balance on the continent. Evaporation depends not only on climatic conditions but also on soil features, tillage and the vegetation cover. This means it is dependent on factors manipulated by the human being and the way land use is carried out. Hence man interferes actively in the water balance of a region and fixes the usable water availability and quantity. For water balance, soil models, and the modelling of other landscape-ecological quantities, it is thus essential to derive the active biomass spatially as well as the land use types in the ecosystems. Analysed image data are essential for spatial investigations, although it should be borne in mind that they are only one information layer for landscape-ecological models (Volk & Steinhardt 1998).

Landscape-ecological models need to be standardized to be able to compare the individual analyses. They can be of great use for regional and global differences and changes because individual point measurements and different devices in different regions neglect the need for comparison. Interpolation methods may help but the more heterogeneous a landscape is, the more doubtful the interpolated point measurements will be. In this context, satellite data are very helpful in minimizing the spatial variability as well as the variability in time to which data registration is often subject because it is collected in a synoptic data set over hundreds of kilometers. It will be shown in Chap. 5 that using the same sensor as one data layer in different investigation approaches will bring stable results, but changing the sensor and consequently inserting different data qualities within the very same analysis will evoke wider variation and thus a worse analysis.

Images from space should aid the forestry commission to survey the stands and damage to the forest. Annual changes in forestry can easily be documented by satellite data and therefore commissions can react more rapidly to negative changes, or those affecting large area. At the same time the ground data need to be continued even if they are much more time-consuming because detailed surveys are necessary to compare them with spatial data and to offer test areas for the calibration and validation of spatial data. Point measurements are generally of great use but they neglect an overview. Therefore, the more detailed landscape-ecological analysis is, the closer the link between point-measured data and spatial data derived from different satellite sensors. And the better this connection works and the more accurate satellite image data is for planning commissions, the less the need for aerial photography. Aerial photography is much more expensive and analysis much more time-consuming than satellite imagary is. A satellite image costs a few thousands of dollars, whereas an aerial flight mission for a small-scale mapping of for example the Erzgebirge mountain range can be performed for about $25,000 (Bundesministerium für Bildung und Forschung 2000).

Another field of interest for the use of satellite images and further new technologies is agriculture. The latest projects have focused on for example the spatial quality assessment of grain during the growing period up to the harvest. Typical regions are taken as test areas for certain fruit/grain to identify and observe its development over the whole vegetation period. Together with additional pieces of information linked in a geographical information system, the yield can be estimated and the quality of the grain can be concluded. Such an economical assessnent can be undertaken while the grain is still growing in the field. Arguments like “The farmer knows the growing conditions on his fields much better than a satellite image can” must still be accepted, at least today regarding agriculture in Central Europe. However, in test regions remote sensing data have started to provide detailed information in fields.

Competitive economics and environmental regulations are two important forces driving precision farming to improve agricultural efficiency by matching inputs - such as water, seed type, fertilizer, and weed, disease, and pest sprays - with soil types and terrain.

The electronics revolution of the past few decades has spawned two technologies that will impact on agriculture in the next decade. These technologies are geographical information systems and the Global Positioning System (GPS). Along with GISs and GPS, a wide range of sensors, monitors and controllers have appeared for agricultural equipment such as shaft monitors, pressure transducers and servo motors. Together they will enable farmers to use electronic guidance aids to direct equipment movements more accurately, provide precise positioning for all equipment actions and chemical applications and, analyse all this data in association with other sources of data (agronomic, climatic, etc). This will add up to a new, powerful toolbox of management tools for the progressive farm manager.

In terms of records and analysis, precision farming may produce an explosion in the amount of records available for farm management. Electronic sensors can collect a lot of data in a short period of time. A lot of new data is generated every year (yields, weeds, etc.). Farmers will want to keep track of the yearly data to study trends in fertility, yields, salinity and numerous other parameters. This means a large database is needed with the capability to archive and retrieve data for future analysis.

Precision farming should not be thought of as only yield-mapping or variable-rate fertilizer application, and evaluated only by one or the other. Its technologies will affect the entire production function (and by extension, the management function) of the farm. Precision farming allows for improved economic analysis by monitoring and fine-tuning production. The variability of crop yield in a field allows risks to be accurately assessed. By knowing the cost of inputs, farmers can also calculate return over cash costs for each acre. Certain parts of the field which always produce below the break -even line can then be isolated for the development of a site-specific management plan.

Precision farming makes farm planning both easier and more complex. There is much more map data to utilize in determining long-term cropping plans, erosion controls, salinity controls and the assessment of tillage systems. But as the amount of data grows, more work is needed to interpret the data - and this increases the risk of misinterpretation. Farmers implementing this technique will probably work closer with several professionals in the agricultural, GPS and computing sciences. What is perhaps more important for the success of precision farming, at least initially, is the increased knowledge that a farmer needs of his natural resources in the field. This includes a better understanding of soil types, hydrology, microclimate, aerial photography and aerial scanner data. The latter is the most important key source of data, and no farmer should start precision farming without it (Goddard 1997).

When in spring 1992 the European Commission resolved to implement a reform of European agricultural policy, a new market policy was launched that was no longer financed by price support but based on spatial compensation payment. Every farmer who produces grain, protein plants or other specific seeds only gets world market prices for his products. They are usually lower than the those the years before with guaranteed prices. By way of compensation for the difference, the farmer receives compensation payments according to the area of his arable land. At the same time the farmer is obliged to set aside 10 percent of his production area. As supervision is hard and individual checks are expensive, remote sensing data offer an ideal instrument for spatial analysis and the control of agricultural production. Image analysis offers opportunities for field scale survey and monitoring provided that three images are available within one growing season.

3.5.5 Outlook

We have seen that satellite imagery is subject to improved techniques and that methods of image analysis will need to make progress in order to keep up with this rapid development. Compared to aerial flight missions, satellite images can be acquired much more often, regularly, much more cheaply.

The time intervals between data acquisition and the supply of processed data need to be shortened immensely. Tasks that can be fulfilled with satellite image data were exemplified and illustrated in this chapter. A close link between ground data, individual measurements and remote sensing data is indispensable to calibrate and validate the data and to obtain precise results.

The satellite industry designs devices for all sorts of tasks and challenges, some of which are mentioned above. Mini-satellites are set to become much in demand on the market as they will work more locally and at very low cost, enabling data to be ordered in advance for precisely specified regions. The ground resolution is now approaching 1 metre on various devices, so that decision makers can work on large-scale image maps and with the most up-to-date data.

3.6 GIS and models - important tools for landscape analysis and landscape assessment

According to Duttmann (1999, p. 363), landscape-ecological spatial analysis and spatial assessments need both the supply of complex spatial basic data and the availability of substantial methods to analyse and assess these data. Because of their high functionality concerning processing, analysing and representing spatial data geographical information systems have been established more and more as an essential and indispensible tool in the specific field of landscape analysis, landscape assessment and landscape planning during the last ten years. Due to the rapid development of faster and cheaper computers and higher demands on the software the functionality of GIS has been improved and extended especially in the nineties of the last century.

According to Borrough and McDonnell (1998, p. 11) the “tool base definition of a GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes.” and “geographical information systems have three important components - computer hardware, sets of application software modules, and a proper organizational context including skilled people - which need to be in balance if the system is to function satisfactorily.” (Borrough and Mc Donnell 1998, p. 12)

The main difference between GISs and other kinds of information systems is the spatial reference. This means that in a GIS all the geographical objects and phenomena are registered and processed with the help of two types of data, geometrical data and attribute data. The first ones are information about the geographical location, size, spatial distribution, arrangement and neighbourhood of such objects. The spatial reference can be established by means of different coordinate systems, e.g. geographical coordinates (latitude, longitude) or other spatial reference systems like the Gauss-Krüger coordinate system. The coordinate system need not only be two-dimensional (x-coordinate, y-coordinate); it can be three-dimensional (x-coordinate, y-coordinate, z-coordinate), too. The second ones provide thematic information about an object. This means information can be provided on what kind of object it is. For example, a selected area may represent a certain kind of land use or a specific soil. Linking of both geometrical and attribute data is essential for efficiently and successfully working with a GIS.

Depending on their ability to process certain kinds of data, GISs can be divided into vector-based and raster-based systems. Vector data represent a certain spatial object with the help of their basic elements points, lines and areas. Moreover, relationships with the neighbourhood are described, for example the starting point and the end point of a line and the areas adjacent to it. Raster data do not differentiate between points, lines and areas. Unlike the vector data, they are based on picture elements, or ‘pixels’. Pixels are geometrical base elements which form a matrix of rows and columns of uniform elements in the form of squares or rectangles. They are the result of a specific registration process in which for example the earth’s surface is scanned with the help of specific scanners from a satellite and the results are satellite images or a thematic map is scanned. Hence a geographical object consists of several pixels. The size of a pixel depends on the quality and resolution of the scanner used. More detailed information about different resolutions of images is contained in part 3.5.3 of this chapter. There are no logical links between the pixels. Each pixel contains values about a specific characteristic in the form of gray values or colour values.

During the last decade, a development towards hybrid systems has taken place. Hybrid GISs can process both vector data and raster data. In view of the large variety of data needed for landscape-ecological investigations, hybrid GISs have been increasingly used in this special field. They allow for example the combination of vector data derived from a topographic or a thematic map and raster data from a satellite image.

A GIS consists of hardware, software modules, data and people who can use the software for various purposes. These four main components form a unit. The hardware required for a GIS comprises digitizers and scanners for registering various information, a computer with a monitor, the keyboard and the mouse, a printer (or plotter) for the analogue output of registered, processed and cartographically or graphically presented data, disk drives, CD-ROM drives, CD-ROM writers and other devices. The software consists of several modules for capturing, creating, storing, administering, processing, manipulating, analysing and representing different spatial data. Spatial data in the form of vector and/or raster data with their geometrical and thematic components are the main part and the core of a GIS. However, to build up and operate a GIS, well-trained personnel are equally import. They must know how to use the different software modules and their interfaces, and be aware of their possibilities and limitations. They have to improve their knowledge permanently. They have to find out about new modules of a certain GIS software and to learn how to use them. New developments in the field of GISs have to be carefully monitored, as only in this way can users remain up-to-date and retain their positions as experts in this very interesting and varied field of work.

There are no set limits to building up a GIS because of the rapid development in hardware. Moreover, various users are calling for the further development of GISs for the organization and manipulation of spatial data, as well as for software improvements.

According to Bill and Fritsch (1991), the software of a GIS consists of four basic modules: data input, data management, data analysis and data representation. Data input serves both the transfer of analogue data - for example, from topographic or thematic maps into the GIS with the help of special devices such as digitizers or scanners - and the integration of available digital data from various sources and institutions with the help of specific interfaces into the GIS. The spatial data have to be stored and managed within the GIS such that interactive manipulations and certain steps of data processing are possible. In this field, the database system with its two components, the database and the database management system, form the basis for organizing and managing spatial data. Depending on the types of data suitable, data structures have to be found which can be reflected in different types of database models like hierarchical models, network models, relational models and object-oriented models. In addition to these models, the latest development tends concern the integration of knowledge-based systems into a GIS.

GISs are distinguished by varied possibilities for analysing spatial data for a certain purpose. According to Zepp and Müller (1999), the main basic analysis functions of a GIS are geometrical, arithmetical and logical data links, statistical analysis, overlays and intersections, data transformations in the form of raster-vector transformation and vector-raster transformation, coordinate transformations from one coordinate system to another, neighbourhood analysis, relief analysis and generalizations. In addition, most GISs have their own macro language or an interface to a higher programming language so that specific applications can be developed for a certain purpose by users themselves.

GISs have numerous possibilities when it comes to visualizing and displaying spatial data or analysis results. They include cartographic representations on the screen and in the form of printed/plotted maps. The basic graphical elements point, line and area can be cartographically modified and displayed with respect to their size, shape, shading, brightness, orientation and colour. Furthermore, maps can and should be augmented by text, for example geographical names, a title, scale, legend, sources and editors. The tools for showing data have so many free options that users can create their own maps with the help of different cartographical display methods corresponding to the topic and purpose, the scale and geographical dimension, the degree of generalization, etc. The quality of data presentation varies greatly. It depends on the knowledge, experience and (unlimited) creativity of people working in this field.

There are many commercial GIS producers throughout the world. In the field of landscape-ecological investigations, both geographical information systems and digital image processing systems are used. Depending on the tasks at hand and the objectives, and in view of the great variety of data, hybrid systems have come to be more used than only vector-based or raster-based systems. Well-known products in the field of GISs include for example ArcInfo and ArcView, which are available for PCs and workstations. In the field of digital image processing systems, Imagine and Easy Pace should be mentioned. Yet besides these high-quality software packages, a host of other systems exist, e.g. SPANS, PolyGIS, AtlasGIS and IDRISI.

The developers of these complex systems strive to increase the functions of their products by creating new modules and interfaces for exchanging data with other systems, and are also keen to make their products more comfortable and easy-to-use. During the last three or four years, efforts have mainly been directed towards improving PC-based GIS systems, with progress being slower for workstations. One reason is the fact that many more institutions run the software on PC as both hardware and software are cheaper. This trend is exemplified by ArcInfo and ArcView by ESRI. While the further development of ArcView (usable for PCs and workstations) has been permanently advanced by the creation of new modules and improving the handling of this software, the further development of ArcInfo has been neglected.

Despite these efforts in further developing GIS -software, two main aspects, the processing of three-dimensional data and the integration of the time factor, have not yet been considered sufficiently.

Three-dimensional representations of data play an important role in landscape-ecological investigations and have long been called for by users. Therefore ESRI has developed a new module within ArcView called the 3D Analyst. According to the company’s description, this module enables realistic surface models to be created from multiple input sources. This enables the altitude to be determined at any point, ascertaining what can be seen from an observation point, the calculation of volumetric differences between two surfaces, working with 3D vector features to make realistic models of the 3D world, and visualizing data in 3D. The ArcView 3D Analyst is the first GIS module which allows the processing of three-dimensional data.

The integration of the time dimension remains an unsolved problem. Spatial and temporal changes play an important role for landscape-ecological investigations, especially in investigating the landscape balance and its fluxes of matter and energy. According to Zepp and Müller (1999, p. 368) modelling spatially and temporally variable landscape balance processes need both the new data management concepts (including new data management techniques) and expanded simulation and visualization techniques. The latter are essential for real-time simulations and for spatial representations of such simulated processes with the help of GISs.

In view of the available limited modelling and simulating possibilities within a GIS, the simulation of spatial and temporal processes is carried out with the help of external models linked to the GIS. According to Goodchild (1993), there exist two main ways of linking up a GIS to models. The first one is 'loose coupling' or 'low-level coupling', a simple form of model coupling. Each model needs specific input data in a certain data structure. In the case of loose coupling, the GIS solely has the function of a data server, and serves the preparation and derivation of data needed for the model input. In addition the GIS is used for storing and displaying the results of the modelling process. The simulation itself takes place outside the GIS, in an external model. The GIS and model are only linked up for data exchange. Data processing takes place in separate, mutually independent systems.

The second one is 'tight coupling' or high(er)-level coupling. In this case, the GIS and the model are directly linked. Data transfer takes place automatically between the database and the model. A joint interface between the GIS and the model allows both the modelling process and interactions between GIS and model. The availability of such an interface is essential for linking the GIS to the model. An interface can be programmed with the help of the programming language of the GIS itself or for instance with another macrolanguage. The latest developments are usually based on the second type of model coupling. The great advantage of this type of coupling consists in that fact that the data resulting from the modelling process are written to the GIS database immediately.

Depending on the specific problem and objective, the models are created and used for different purposes in the field of landscape-ecological investigations. They are used to model changes concerning individual landscape-ecological parameters or parts of a landscape over a shorter or longer period. According to Leser (1997), ecosystem models have to be 'limited' spatially and functionally with respect to the structure of the ecosystem model and/or the spatial structure, the investigation period or the observation period, the available technical and/or personal infrastructure. The functional structure of the observed real ecosystem has to be recognized within the model. The two components space and time have to be represented sufficiently in the model. Models need real data for simulation processes and for the validation of the models to identify errors during modelling. The input data must have a specific structure depending on the model used. Chap. 7 contains an overview of specific models in the field of landscape-ecological investigations. Moreover, Chaps. 6 and 7 contain the results of applying models in the field of landscape-ecological research.

The large number of different spatial data needed for landscape-ecological analysis, landscape-ecological assessments and landscape planning require suitable instruments and tools to process them. During the past ten years geographical information systems have become the most important and efficient tools for registering, storing, managing, analysing and showing spatial data in a two-dimensional or three-dimensional form. Most GISs available cannot process the dynamic phenomena which also play an important role in investigating landscapes. Therefore, GISs have recently been linked to models to simulate changes in space and time.

Generally speaking, the development of GISs is leaning more and more towards the creation of user-defined GISs. This means that depending on the specific purpose, the users create their own GISs consisting of specific selected modules of a certain software which are then linked together with interfaces programmed by the users themselves.

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