Geovisualization as support of decision-making in crisis situations

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Introduction

The growing number of people and their concentrating in places of heightened risk brings about a number of phenomena which the society rates as disasters. Crisis situations in the environment which put lives and property in jeopardy have become a reality of the present world. The risky processes taking place in the environment can be triggered by individual natural and human factors. Their occurrence, influence and impact are conditioned by the given type of contemporary landscape. With view of effective crisis management in all its stages it is essential to have access to a high-quality landscape geo-database with data on risk processes or phenomena. Geovisualization of potential or existing crisis processes plays a key role in the decisions of crisis management and in people's reactions.

Concentration of people in crisis areas

The origins of universe, the Earth and life, including all the dynamic evolution processes in progress attest to the fact that nature as such knows no disasters. It is humans who classify natural processes or technical failures as disasters, because they have an adverse impact on great numbers of people, their lives and property. The accelerating growth of global economy and world population increase the number of disasters and their destructive impact.
CHALUPA, P. (2005).

The pace of world population growth is increasing. While between 1830-1930 the mankind required a hundred years to increase its numbers by a billion, in late 20th century the same increase took only 11 years. Half of world population, 3 billion people, lives in areas with imminent disaster risks (table 1).

Table 1: Areas of greatest concentrations of threatened people

- the Nile delta (floods, fertile soil capable of sustaining large numbers of people).
- the Ganges basin (floods, fertile soil capable of sustaining large numbers of people).
- the island of Java (earthquakes, volcanic activity, fertile soil capable of sustaining large numbers of people).

- North and East China (floods, industrial accidents, fertile soil capable of sustaining large numbers of people, industry providing many jobs, concentrated populations calling for new jobs in the service sector).
- industrial parts of Europe (industrial accidents, floods, industrial and service sectors securing high employment levels).
- Northern part of the US East coast (industry and services securing high employment)

As the level of urbanization continues to grow, risk phenomena in densely populated and often urbanized areas bring about great losses in lives and also material losses. The latter can be reduced through readiness of both people and all components of crisis management and through correct decisions when the phenomenon is in progress. A three-dimensional image of the distribution of people, material and the progress of a crisis phenomenon is a vital prerequisite for such readiness.

Classification of disaster phenomena based on landscape's natural components

In order to achieve a visual clarity of cartographic data designed for use in moments of crisis, it is essential to accurately specify their content. This will be radically different for individual stages of origin and development of a disaster phenomenon. The proposed classification according to NOVÁK, S., WEINHÖFER, M. (2005) essential to designing the structure of map content in such a way which would prevent introduction of unnecessary data into maps and thus would eliminate the ratio of information interference. The classification of a disaster phenomenon was carried out in relation to its original geosphere, the stage of its development, interconnectedness with other geospheres and its impact. Table 2 shows results of this process.

Classification of disaster phenomena in relation to the landscape's natural components

The analysis of potential crisis situations revealed interesting findings:

- phasing of the development of a disaster phenomenon can be done only with a significant extent of generalization
- it is advisable that the proportion of geospheres on the phenomenon's development be graded on a subtler scale
- a disaster phenomenon can be assigned to a single geosphere only with great difficulties
- in some cases, evaluation based on such assessment criteria proved ambiguous

Table 2: Classification of disaster phenomena in relation to the landscape's natural components

Type of disaster phenomenon	Geosphere	Conditions of origin	Demonstration	Impact	Geospheres interface					Territorial and time attack	
Strong storm	Atmosphere	Strong cold fronts or storms caused by long-term hot weather	Local intense rainfall, storms, hail and strong gusty wind	Local flooding, damaged houses and roads, damaged vegetation		●	●	•	•	Local	Short-term
Tornado	Atmosphere	Big storm cloud	Extremely strong whirlwind with vertical axis	Destruction of the affected part of landscape		•	●			Local	Short-term
Tropical cyclone	Atmosphere	Above the overheated surface of the ocean	Strong cyclone with intense storms and winds of extreme speed	Devastation of extended surface area, losses in lives		●	●	•	•	Regional	Mid-term
Flood	Hydrosphere	Strong long-lasting rains, saturated soil incapable of further water absorption	Overflowing of running water into flood areas, water collecting in depressions	Destruction of vegetation and soil cover, buildings and infrastructure. Losses in lives.	●		●	•	●	Local - regional	Short-term – long-term
Snow slide	Hydrosphere	Steep slopes accumulation of a layer of snow which is pulled down through gravitation	Mass of snow moving at speed of up to 100 km/h, carrying material along and shaping the landscape	Devastation of landscape in the area of impact.	●		●	•		Local	Short-term
Tsunami	Hydrosphere	Movement of lithospheric plates under the sea level.	Afflux of a wave of great strength which gains height near the coast	Total destruction of coastal areas, great losses in lives.			●	●	●	Local - regional	Short-term

Biodiversity loss	Biosphere	Change of the organisms' living environment.	Extinction of plant and animal species.	Decreased stability of biological systems.		•		•	●	Regional-global	Long-term
Species infestation	Biosphere	Favourable living conditions of one biological species.	Population explosion.	Displacement of other species, disruption of ecological environment.	•	•		•	●	Local - global	Mid-term - long-term
Mudslide	Hydrosphere	Oversaturation of soil cover and substratum on the slopes with water.	Rapid movement of material saturated in water down the slope.	Destruction of the affected slope, caving-in of the valley bottom, losses in lives.		●	●		●	Local	Short-term - midterm
Earthquake	Lithosphere	Release of energy in a part of earth's crust or its outside mantle.	Transient tremors of earth of differing intensity.	Re-modelling of georelief, destruction of buildings, losses in lives.		●	•		•	Local - regional	Short-term
Volcanic activity	Litosphere	Reduced earth's crust, predominantly in areas where lithospheric plates clash .	Magma and gasses eruptions, rapid spread of pyroclastic cloud.	Terrain covered with hardening lava, destruction of the original cover.	●	●	●		●	Local - regional	Short-term-long-term
Fertility loss	Pedosphere	Soil erosion, salinization, compaction, desertification.	Reduced or entirely lost fertility.	Damage or complete disappearance of vegetation cover.	•	•	●	•		Local - regional	Long-term

● High interface

• Low interface

Crisis situations and geo-information technologies

Crisis situation, their occurrence, development and impact can be reduced through a number of measures in a wide spectrum of social spheres. Their characteristic feature is their projection into space or area. Natural, technical and humanity sciences can play a part by providing data, expert knowledge or the presence of specialists. This can be utilized in the stages of prevention, rescue operations and remediation during a crisis situation. At all these stages it is essential that advanced geo-information technologies, good-quality geodata and formalized expert knowledge be drawn upon.

Geodata, geographical information, knowledge and experience can be utilized already when assessing an area in terms of its proclivity to a given harmful phenomenon or process. They can also be used when planning the optimal measures during such a phenomenon's possible occurrence, when solving a real situation and also during the area's remediation.

Implementation of geoinformation technologies is a step forward in the efforts to achieve more objective, faster and more tangible results which facilitate a more efficient work of crisis management at all its stages.

Owing to its synthetic approach, geography enables the crisis management to integrate, both spatially and factually, the findings and data provided by other relevant scientific disciplines. An example of geography's synthetic abilities employment is geodata integration in a digital landscape model, which is a form of representation of an area's reality in the maximum objective manner reflecting the space where crisis management is applied.

Integrated geodata assisting crisis management

Nature's individual qualities are mutually balanced and inseparable. Yet, the data on these qualities are collected separately through thematic mapping. The motivations for such approach have been determined by the historical development of geo-sciences and the existing specialization essential for a thorough study of individual components of natural landscape. These components include geological structure and relief, atmosphere, waters, energies, soil and biota. Although the study of each of these components requires at least basic knowledge of the remaining components, the data concerning these components – more specifically maps – are markedly specialized in terms of their subject. It is the only way how to depict and represent details of spatial differentiation of the given component's features.

The Czech Republic has traditionally ranked among countries with a highly diverse and yet thematically thorough territorial documentation. Maps of different scales and of different thematic content are available both in analogue and digital form also for the needs or crisis management. However, based on field research carried out in 2005 by the authors, the crisis management of the Czech Republic fails to utilize the thematic maps.

Regardless the motivation for collecting such territorial data, it remains a fact that the area of the Czech Republic is relatively well-documented both in terms of its natural environment and socio-economic sphere, even though it naturally remains a never completed process.

Especially in the field of environment or landscape's natural components the area of the Czech Republic is covered by analytical analogue and digital thematic maps, their scales ranging from 1:5000 (agricultural soils), 1:10 000 (terrain, forest bioclimate and soils), 1:25 000 (geology) to 1:50 000 (geology, drainage areas).

For obvious reasons, these maps were procured through field mapping carried out by experts in individual fields, the result of their work being analytical (thematic) maps of nature's individual components. The parameters of the depicted natural components are mutually balanced in reality. Yet, when a user of such analytical maps places them on top of one another, it is evident that the thematic layers do not correspond. Under normal circumstances one can assume that a given geological substratum on given humidity and climatic (energetic) conditions will evolve a given type of soil with corresponding vegetation cover. However, when placing the thematic maps on top of one another, a number of combinations of individual parameters which do not occur in nature emerge. These flaws can be removed through logical integration of data during the construction of a digital landscape model. This model includes only the poly-thematic layers whose individual homogenous areas constitute reference units for all the input (possibly other) variables (attributes). The layer of natural background parameters is one of them. Its elementary reference area is the area of a homogenous landscape unit. This unit represents a homogenous areas into which we can input further data which are areally homogenous within the given landscape unit.

The data on the anthropic impact on nature (area use with different aspects of individual form of land use, biotope quality, crop areas, special-purpose areas and others) and data about population exhibit similar discrepancies.

Geo-information on social and individual interests in a given area are significant from the crisis management point of view, as they may markedly influence both the preliminary and the actual measures. Yet, this kind of geo-information is rarely collected. Among relatively well-documented interest phenomena are the records of historically valuable objects, objects of military importance, protected areas and natural objects, protection zones around engineering infrastructure and some constructions, or water resources. Technical maps have only partially managed to document the country's towns. Rural areas exhibit a marked absence of thorough inventory of such interests. A suitable reference unit, however, can be a piece of land registered in a cadastral map. KOLEJKA, J., POKORNÝ, J. (1994).

The most significant physiognomic (observable) unit of our landscape is terrain. It has a close relation to landscape's other natural components, either because it is determined by them (e.g. by the geological structure) or because it spatially differentiates some units as a local differentiation agent (exposure and altitudinal changes of climate, soils and vegetation, organization of drainage). Generally speaking, terrain serves as a "medium" – it is a reference coverage which enables to demonstrate a spatial distribution of other information on the given area. It is a medium or differentiation agent for a number of anthropic activities and an elementary means for modeling visual images of an area in combination with selected (or all) available geo-information.

The entire crisis management is an example of multi-criteria decision-making and as such must be supported by all available relevant information. This, however, cannot be uncritically presented in its original form (often of limited use). It is essential that this form be adjusted (corrected) in such a way that it reflects the current knowledge of the objects and area components, the relations between them and also the technological needs of the processes of crisis management itself, should it be supported by geo-information technologies. There is no other way of efficient protection of lives and property than the use of GIT in decision-making and carrying-out of a wide spectrum of essential activities. The model which provides also this type of data on the surrounding environment is the digital landscape model (herein referred to as DLM).

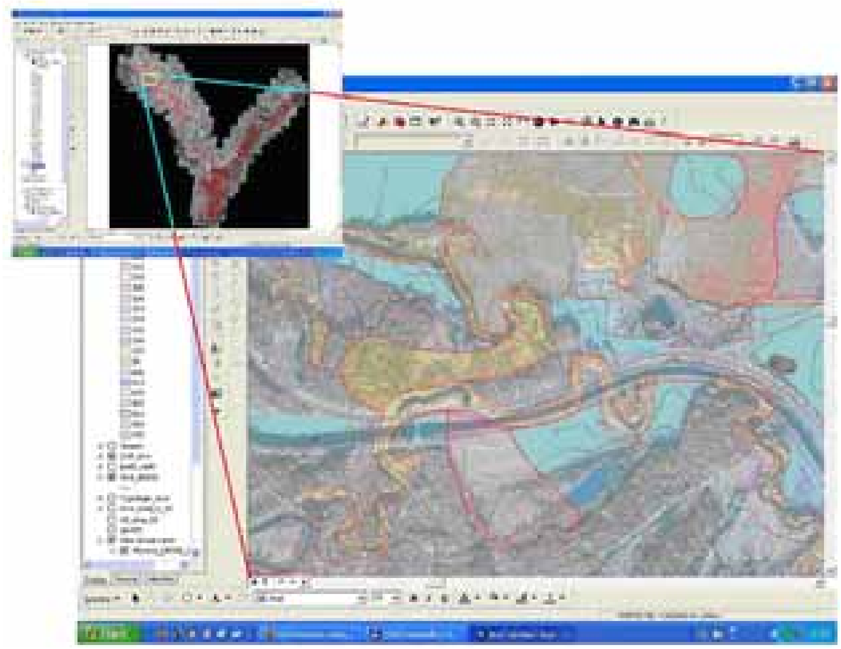

Fig. 1: Example of registered data layers overlay: IKONOS high resolution satellite imagery overlaid with soil, geology, forest etc. data shows logical errors in layer combinations to be removed by full logical data integration.

Digital landscape model – support of crisis management

Digital landscape model (DLM) is a minimum three- or four-dimensional computer-generated scheme of a chosen segment of earth's landscape sphere which represents its basic structural and, in an ideal case, also dynamic features in a simplified, yet integrated form. The model's first three dimensions (spatial coordinates) describe the model's structural aspect, while the fourth dimension represents the aspect of time. In other words, DLM represents a complex 3D or 4D map of the contemporary landscape. It is a product of multilateral data integration into a limited complex of multi-attribute information layers which facilitates various static and dynamic modeling procedures, presentations and simulations which respect the real relations between the area's variables. A purpose manipulation of this model follows the user's instruction to the integrated database while implementing the standard SW GIS tools and/or the instruction from the information base or methodology. DLM consists of multi-thematic integrated layers of "natural background", "anthropic impact" and "development limits" along with a digital relief model (see Fig.2).

In relation to crisis management DLM, as a specially modified and fully integrated GIS area database, displays significantly positive features:

- The original thematic data files are integrated in a single format, the projection, scales/definitions and the individual originally analytic subjects are logically interconnected in the same way as in the real area.
- The reference polygon in the integrated layer of “natural background” is the area of “natural landscape unit” which is described by a vector whose coordinates are the individual parameters of landscape’s natural components.
- If need be, we can input other necessary data into the polygons, as it can be assumed that these multilateral homogenous areas will remain homogenous even in relation to the newly added variable.
- The reference polygon in the integrated layer of “anthropic impact” is land or piece of land with a single form of anthropic use and an identical contemporary quality and intensity of the area’s use and condition.
- The reference area in the integrated layer of “development limits” is land or piece of land which is subject to given social or individual interests. To these homogenous areas can be added other variables on the condition that their values will be identical within the entire area of the homogenous unit.

In the course of the various assessment, modelling and simulation procedures these homogenous reference areas can be approached from any given point while reliable combination of the input parameters is guaranteed. We can also rightly assume that we deal with an isotropic environment for the origin, development, behaviour and impact of a crisis phenomenon.

DLM as such can enter various thematic software models (modules) as a whole or as a file of selected analytical maps, which the DLM can be easily broken into, relevant for the module. In such a case (after breaking down into maps) the individual analytical layers geometrically and factually correspond. The use of such an integrated database can dramatically reduce mistakes in calculations carried out by a number of models which use the necessary analytical layers coming from various sources and thus lacking mutual thematic integration. A crisis management procedure can be used in such a model (software).

DLM is an open data system. Its integrated database can be easily demonstrated and visualized on the base of a relief’s digital model. Both the individual integrated data layers and component analytical layers derived from the integrated ones can be put atop the 3D relief. In any case the mutual compatibility of the layers and their representation, visualization and simulation is guaranteed.

Creation of DLM for crisis management needs

Multilateral geodata integration provides space for efficient implementation of geographical knowledge. A professional geographer should have adequate information from auxiliary and component geographical disciplines (regardless a certain degree of specialization) at one's disposal to be able to assess different combinations of available variables, to be able to detect faulty combinations and to rectify them. It is also a geographer's task to be able to detect faults in the products of modelling, visualization and animation. The existing predominantly engineering-oriented solutions frequently provide technically perfect, yet factually often faulty results. Moreover, these faults remain undetected and consequently are not rectified. ZÖLITZ-MÖLLER, R. (2002).

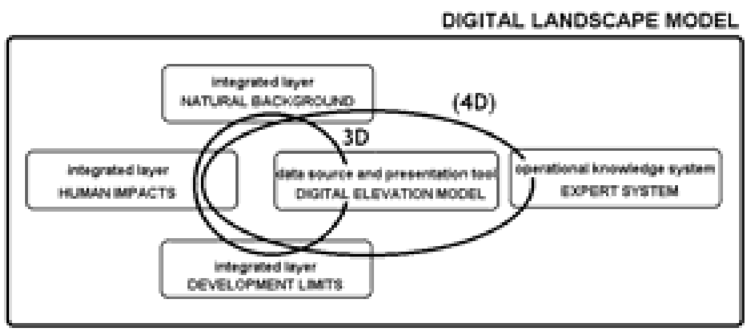

Fig.2: Block diagram of a digital landscape model

Application of digital landscape model in crisis management

A fully integrated geo-spatial database represented by the digital landscape model can be successfully applied at the following stages:

- preventive measures (risk assessment – predicting areas with highest probability of occurrence of the given adverse phenomena),
- intervention planning (modelling of the adverse phenomenon in its various alternatives – classifying the intervention means and target),
- operative decision-making (modelling of the intervention – its place, time and means, as well as presenting the management task to people),
- ensuing rectification measures (expert selection, localization, extent and intensity of the activities).

Geovisualization of digital landscape model in crisis management

Each relevant stage, ranging from preventive measures to rectification, has its own visualization and presentation aspect. It the model and its visualization is based on DLM data, it will acquire a much more realistic (and thus more truthful and reliable) form.
At present a wide range of modelling techniques supporting crisis management are available. Also in the Czech Republic we can utilize software packages which are enable us to model the spread of pollutants in the aerial, water and geological environment. These expert systems are usually attached to GIS. A number of commercial GIS SW packages also contain some of the modelling procedures. What is still lacking, however, is high-quality relevant data layers which are reliable not only from a technical perspective but also and most importantly from the geographical perspective. Considering geo-data available in the Czech Republic, we need to review the aspects of possible alterations of the existing SW in such a way which would enable it to accept geographically real data files. Among other things, this applies to modelling of certain adverse processes, such as toxic, forest and field fires, landslides, spates, strong winds, creep and others in GIS environment and with a relevant cartographic presentation for users who display various levels of acquaintance with the monitored problem. DLM thus plays the role of an elementary and reliable data source, as well as that of a presentation tool.(See Fig. 8)

Model area

In order to verify the functionality of a digital model depicting selected crisis situations, we chose an area representing a Central European agricultural area subject to long-term intensive farming with an entirely changed landscape.
For this area covering approximately 50 km^2 and located in the southern part of the Czech Republic the following steps were taken:

- digital landscape model according to SVATOŇOVÁ, H. , VRANKA, P. (2003) was created
- reconstruction of land use was carried out, using military aerial survey from 1953
- modelling of crisis phenomena in landscape, with erosion, landslide and floods taken as examples
- comparison of potential risks of selected phenomena in relation to the way human use of landscape
- dynamic geovisualization of landscape changes and the course of a potential flood

Fig.3: Ravines in agricultural terraces

The assessment of erosion and landslide risks was done through identifying potentially endangered areas (in DLM geo-database) and with the help of the AnnAGNPS model.
Figures 4 and 5 show the results of modelling.

Fig.4: 3D model of areas endangered with erosion according to DLM

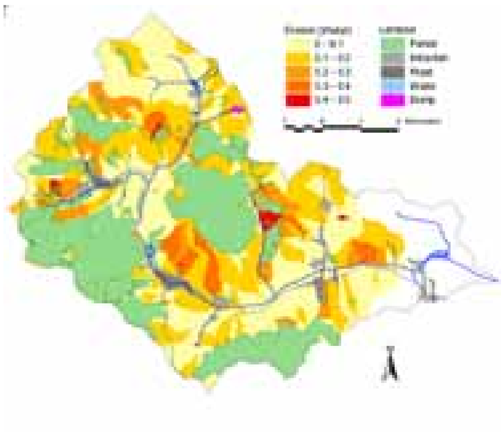

Fig.5: Modelling of erosion in specialized AnnAGNPS model based on DLM data

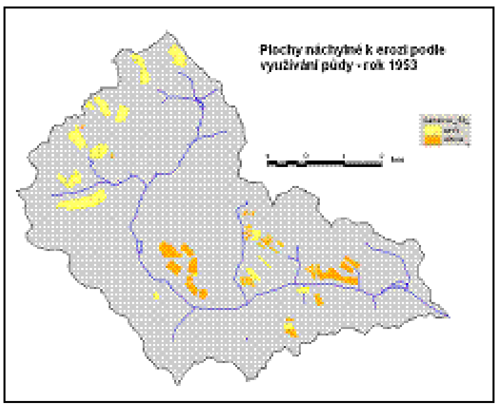

Fig.6: Erosion risks in the 1950s

(areas prone to erosion in relation to land use – year 1953)

Modelling of areas endangered by erosion and landslides validated the hypothesis about the significant role human activity plays in triggering a number of negative landscape processes. A radical intervention in a long-term way of agricultural land use in the Czech Republic accounted for probably the most dramatic change of agricultural landscape in its thousand-year-long development. Human interference with landscape results in growing pollution of rivers by fertilizer runoff, recurrent floods affecting a number of people, irreplaceable losses of valuable soil due to erosion and also landslides putting buildings and people's lives in danger. SVATOŇOVÁ, H. (2005).

Cartographic possibilities of data geovisualization in crisis management

Cartographic presentation of phenomena applicable in crisis management requires rigorous observance of elementary principles in map creation. Most importantly, the map's purpose and all the partial aspects connected to the map's use in non-standard and extreme situations need to be taken into account. In such situations there is no space for difficult interpretation of ambiguous maps which contain information which may mark the difference between life and death. And it is prevention which is the keynote when constructing map images of the endangered areas. Component aspects of map creation for the uses of crisis management can be found in various publications. Yet, a complex approach to their assessment and methodology of their construction are missing (thematic cartography pays minimum attention to these often urgently needed maps). CLOCUM, T.A., et al. (2005). When preparing maps designed to assist the decision-making of crisis management we initially determined two basic steps required to specify the cartographic expression of phenomena for the needs of crisis management.

The first step includes:

- determination of the optimal media for both electronic and traditional cartographic products
- determination of basic standard visual concept of segmenting the map file and its individual parts, especially thematic sections and map sheets
- assessment of the purpose and possibilities of the analytical, complex and synthetic maps in relation to the required objectives of the cartographic products' use
- selection of optimal cartographic means required by electronic or printed maps
- determination of potential users' requirements and tailoring of the maps' content and visual aspect to the required criteria

The second step aims at:

- designing maps and the manner of their use in order to analyse the impact of risk factors on the area as part of active measures designed to minimize the negative effects
- determination of thematic sections and accurate denomination of individual cartographic products
- selection of content elements of the thematic maps in relation to the map's desired purpose, the level of data integration and the possibilities of its cartographic expression
- creation of functional cartographic models for recording potential risks in a given area and for assessing their effects
- determination of basic ways of using the cartographic data – choice of maps and their content elements, order, combination of thematic layers and so on

- definition of principles of using the cartographic data depending on the type and extent of danger, possibly the type of disaster in the area
- determination of the extent of the adverse impact of individual natural and social risks in relation to their intensity and determination of their areal extent
- determination of the complex effects of the expected or present risks with the help of a precisely specified use of cartographic data.

The aforementioned possibilities need to be used in the course of designing and constructing the individual maps. The basis for representation of other thematic elements of map content is the complex field situation presented by customary cartographic means. The basic content of most maps are the water and communication networks. The question remains what should be the degree of detail of their cartographic presentation in individual thematic maps – differentiation in relation to a phenomenon's significance, numeral parameters and so on. Another indispensable element is the geo-relief which determines both the spread of most dangerous phenomena and influences the transport of people, technical support and material. The use of 3D graphic models based on digital relief model (see chapter "Geovisualization of landscape model) proves particularly useful for quick orientation. In built-up areas the representation at least of the buildings' ground plan is indispensable, in some cases their vertical structuring as well. A presentation of vegetation cover is also necessary, as it may serve as an indicator of the area's certain features and at times can be obstacle to communication. BREWER, A. CYNTHIA (2005).

Dynamic landscape elements constitute an autonomous group. Primarily people's movement during the day, week or seasons significantly determines decisions taken during a given crisis situation and thus an exact localization of population in maps is essential. The other dynamic landscape elements are constituted primarily by natural forces – the progress of flood wave, movement of meteorological fronts, spread of diseases and other.

The possibilities of the representation of individual objects and phenomena are determined by available attributes. Their depiction in maps is significantly more complicated when compared to a simple topographical situation, as their combination with other, mostly areal elements, constitutes layering which is difficult to differentiate.

When designing individual maps it is essential that not only the request for individual themes but also the possibility of their joint cartographic presentation in one map be observed. If the required themes cannot be co-ordinated, they will have to be distributed into two or more maps. This will, however, reduce the graphic clarity and operational possibilities of their use.

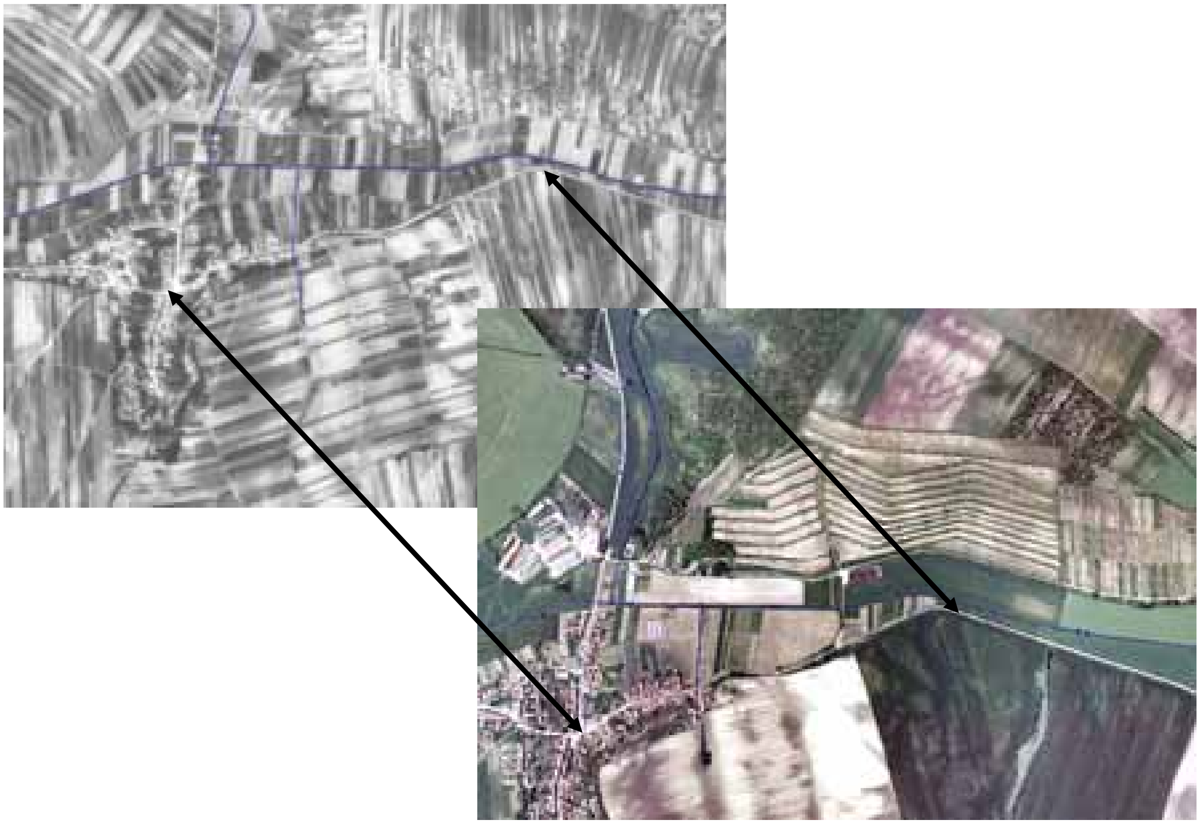

Fig.7: Transformation of the Central European landscape, changed way of agricultural

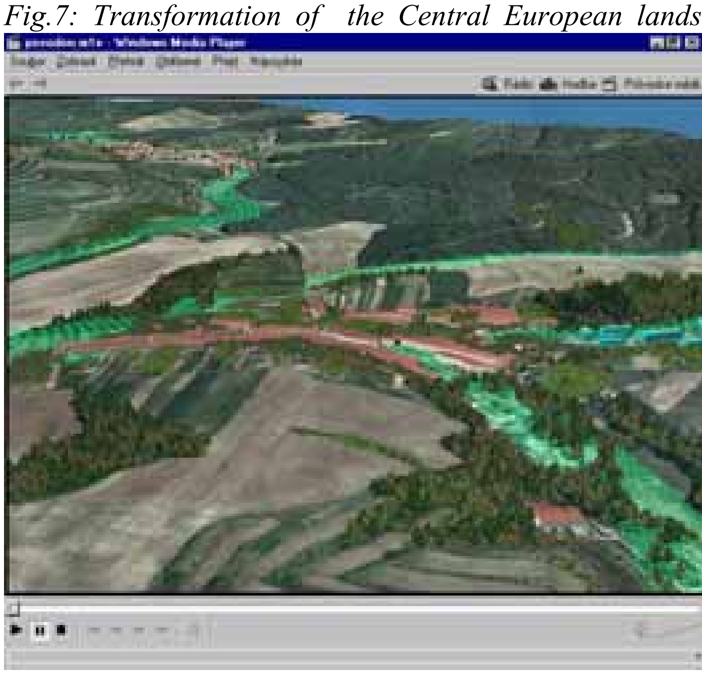

Fig.8: Photorealistic visualization of the maximum extent of a flood in the village of Diváky in South Moravia based on the digital landscape model data

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