FLOOD RISK AND FLOOD HAZARD MAPS - VISUALIZATION OF HYDROLOGICAL RISKS

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Abstract

Hydrological models are an important basis of flood forecasting and early warning systems. They provide significant data of the hydrological risk. In combination with other modelling techniques, such as hydrodynamic models, they can be used to assess the extent and impacts of hydrological events. The new European Flood Directive forces all member states to evaluate flood risk on a catchment scale, compile maps of flood hazard and flood risk for prone areas and inform on a local level about these risks. Flood hazard and flood risk maps are important tools to communicate flood risk to different target groups. They provide compiled information events to relevant public bodies like water management authorities, municipalities or disaster control staffs, but also the broad public. For almost each section of a river basin run-off and water levels can be defined based on the likelihood of annual recurrence, using a combination of hydrological and hydrodynamic models, or based on historical records and mappings. In combination with data of the vulnerability of a region risk maps can be derived.
The project RISKCATCH addresses the issue of hydrological risks and vulnerability assessment in the focus of the flood risk management process. Flood hazard maps and flood risk maps were compiled by Austrian and German partners at test sites in these two countries regarding existing national and international guidelines and were evaluated by the French partner within the so called "experimental graphic semiology". This is a method to record the eye movement of a person watching a map. It provides information how the test person is parsing and reading the map. A questionnaire asking for negative and positive aspects and complexity of each single map completes the experimental graphic semiology. The results indicate how these types of maps can be improved to fit the needs of different user groups. As an outcome recommendations are developed to water management authorities how to derive maps from hydrological and hydrodynamic model results and provide information about hydrological risks.

Keywords: *flood risk, flood hazard, risk management, visualisation, flood risk map, flood hazard map, flood directive.*

1 INTRODUCTION

Nowadays there are a lot of research institutes working in the field of flood risk assessment in different projects like EUROFlood, EUROTAS, FLOODAWARE or FLOODsite. In the field of interregional cooperation (Interreg), risk maps as a first element of risk management have been developed and tested in the project IRMA and TIMIS for the Rhine catchment. Complex considerations and assessments of the complete flood process chain, linking different processes leading to flood disasters have been made. From precipitation to runoff generation and concentration in the catchment towards flood routing in the river network. Possible failure of flood protection measures, inundation within a certain area and the economic damage are evaluated through different methods (Deutsches Forschungsnetz Naturkatastrophen, 2004). A countless number of methods are integrated to repeat random sampling to compute its results. For example Monte Carlo methods are often used when simulating physical and mathematical systems. Because of their reliance on repeated computation and random or pseudo-random numbers, Monte Carlo methods are most suited to calculation by a computer and tend to be used when it is infeasible or impossible to compute an exact result with a deterministic algorithm – like in the calculation of probabilities and in the field of risk analysis.

Currently, there is a huge amount of research results available – on local, regional, national and international levels also related to practical considerations. In 2006 the European Union published the drafts of the Directive on the assessment and management of flood risk to harmonise the research activities and the final results in the different European countries.

The project RISKCATCH, funded under the CRUE ERA-NET initiative by the German Federal Ministry of Education and Research and the French Ministry of Ecology and Sustainable Development, addresses the issue of hydrological risks and vulnerability assessment in the focus of the flood risk management process.

The project area in Bavaria is situated at the two rivers Vils and Rott,. The Vils river has a catchment size of about 1450km² and is flowing into the Danube river after 120km. The catchment of the Rott river is 1200km², and its length is about 100km. Both catchments are part of the tertiary hilly landscape, an intensively used agricultural landscape. Rural structures, settlements with scattered buildings, the intensive agricultural use are determining factors. However, during the last two decades there was a remarkable increase of industrial and commercial use of land in potential inundated areas.

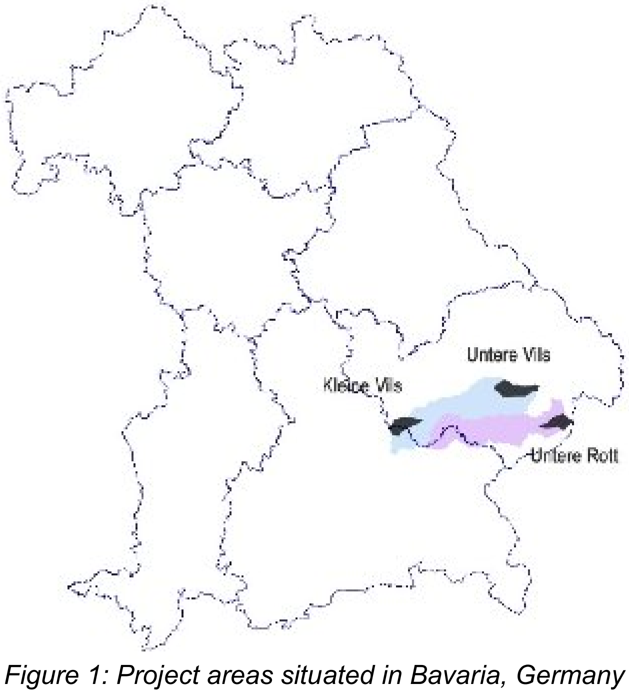


Figure 1: Project areas situated in Bavaria, Germany

The RISKCATCH project aimed to deliver new, practical and viable solutions for an integrated risk-assessment-based management of natural hazards in Alpine environments and related forelands with a special focus on the interaction of technical and non-technical measures during recent flood events in catchment areas. But also the project used already available results from other projects or experience from other countries. Comparing the status quo and historical development of risk and forecasting possible future developments based on scenarios, necessary action was derived and efficiency of non-technical measures of flood defence was evaluated. Based on the assessment of historical and possible future development of hazard, values at risk and vulnerability, non-technical measures were evaluated from an economic and technical point of view. Regarding different scenarios of the temporal development of risk, maps were generated and assessed. Finally these maps were the basis for a study on perception using the method known as the "experimental graphic semiology (EGS)".

2 METHODOLOGY

The main focus of the project, also presented in this paper, was a user-oriented transfer of the mentioned available results e.g. outputs of hydrological and hydrodynamic models, necessary modifications and final output in exemplary maps, which were finally evaluated by test persons from differing stakeholder groups.

Hydrology

There is an consensus that risks resulting from hydrological extremes are on the increase. This point of view is fuelled by evidence both from recent changes in the frequency and severity of floods as well as droughts and outputs from climate models which predict increases in hydrological variability (IPCC, 2007). Major flood events like the ones in 2002 and 2005 have led to concerns about the levels of protection provided by existing flood defences and their consequences.
During the last years the characteristics of floods and land use patterns in the flood plains changed fundamentally. These changes are affected by climatic developments, land use changes, river development and training and also by measures of flood defence, enabling building in the former flood plains and reducing the natural detention and profile for flood runoff. The main question is how much upcoming impacts and actual changes will influence the future runoff scenario and change the characteristics of floods and extreme discharges.
In combination with land use maps, development plans and historical maps describing the changes of land use and damage potential in the flood plain these hydraulic and hydrological data sets were used to analyse the developments and flood related problems for the status quo (ex post perspective). In combination with data for the existing technical facilities of flood defence the effects (level of protection and restrictions) of the classical flood defence was also evaluated and later on compared with non-technical measures. Future developments and the related scenarios from the point of risk management were derived and assessed.

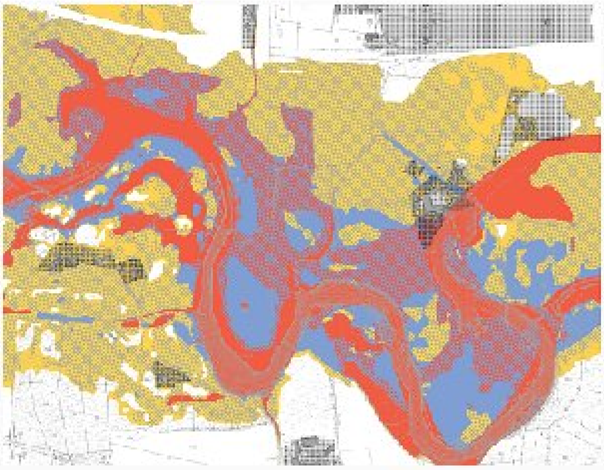
Hydrodynamic Modelling

Hydrodynamic models delivered the basic data. This data was derived from models, pre-processed and compiled in maps. In Bavaria HydroAS 2D in combination with

SMS is a standard software model to model and simulate flood events and model data was derived from this software. It was pre-processed in SMS and evaluated and visualised in ArcGIS 9 to derive the relevant maps. In this case is was not the standard hydrodynamic modelling which is of interest – it is much more about what do create out of the modelling results (inundated area, water depth, flow velocity). As input data results like flow velocity, water level and extent of the flood event were available and included in further considerations.

Hazard and risk

As shown by Dorner et. al. (2006), maps are indicating different information about floods and related risks and have high relevance to visualize hydrological data in a spatial context. Regarding hydrological aspects especially the visualisation of probabilities is bound to restrictions e.g. if run-off is influenced by controlled detention structures:



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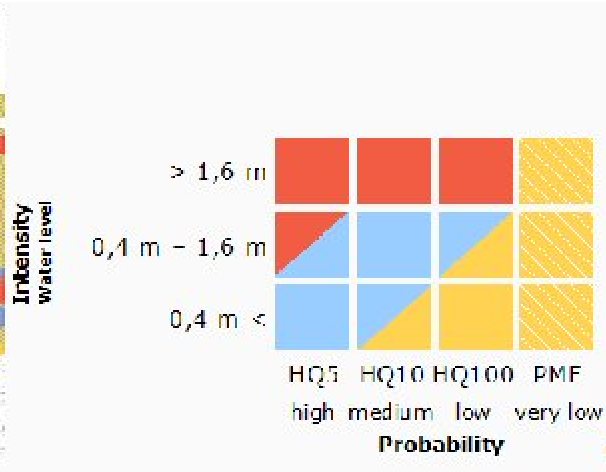

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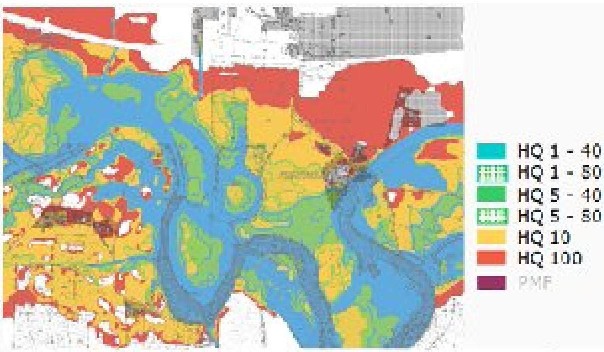

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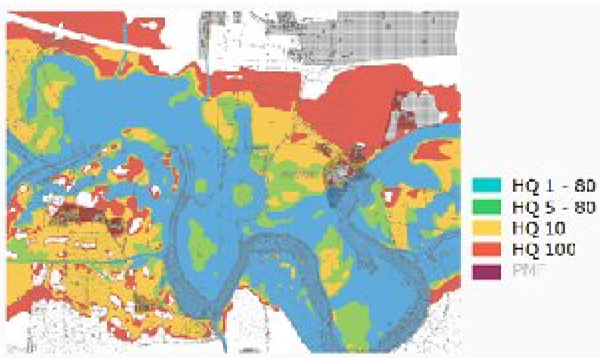

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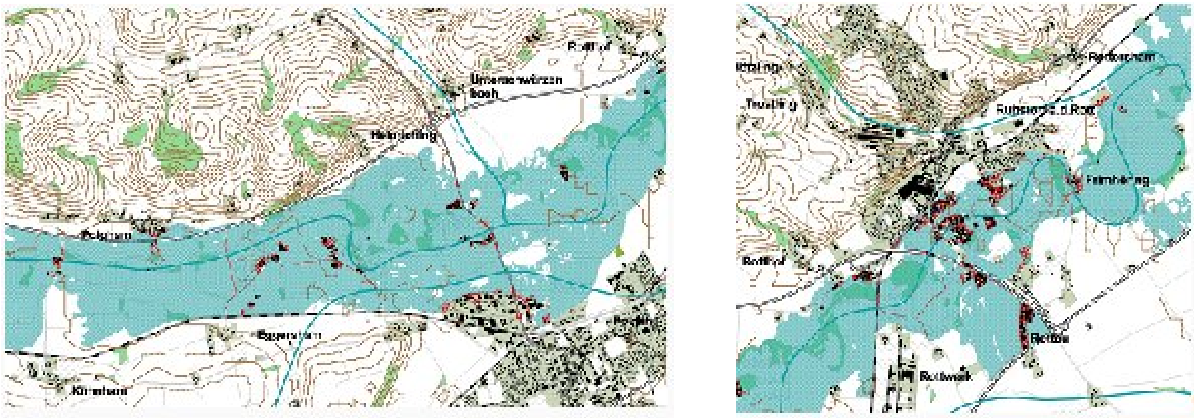

e) *f)*

Figure 2: a) an intensity-probability diagramm or risk index makes it possible to combine both risk components in one map; b) explaines the derivation of the different risk levels; c) and d) show the extent of flood with different recurrence probabilities;e) and f) indicate the extent of extreme events (HQ100) on a large scale to provide an overview e.g. for the broad public.

In the area of natural hazards, risks are defined as a function of probability of occurrence and extent of damage. Extent of damage is constituted by the two factors damage potential and vulnerability. In general, this function has gained acceptance in accordance with the definition of the United Nations (e.g., Varnes, 1984, UN/ISDR, 2004) and is indicated in the form of a product as follows:

$$R = p_{Si} \cdot A_{Oj} \cdot p_{Oj,Si} \cdot v_{Oj,Si} \qquad (1)$$

where R = risk

p_{Si} = probability of scenario i

A_{Oj} = value at risk of object j

$p_{Oj,\,Si}$ = probability of exposure of object j to scenario i

$v_{Oj,\,Si}$ = vulnerability of object j, dependent on scenario i

In Alpine countries, mainly in Austria and Switzerland, the procedure of hazard assessment is methodologically reliable in determining the hazard potential and the related probability of occurrence (p_{Si}) by mapping, examining, modelling, and assessing individual processes and defined design events (see e.g. Kienholz, 1977; Grunder, 1984; Bollinger et al., 1992; Kienholz & Krummenacher, 1995, see eq. 1). So far, little attention has been given to the damage potential (A_{Oj}) affected by hazardous processes, particularly concerning spatial patterns and temporal shifts. Studies related to the probability of exposure of an object ($p_{Oj,\,Si}$) to a defined scenario and the appropriate vulnerability of the object ($v_{Oj,\,Si}$) have predominantly been carried out so far in terms of expert's reports. Only few approaches and conceptual proposals determine the risk of property and human life (e.g., Wilhelm, 1997; Heinimann, et al. 1998; Borter, 1999).

The different approaches of several German federal states concerning hazard maps showed some similarities. The approach of Switzerland (e.g. BWW et. al. 1997) to indicate hazard uses the two parameters intensity and probability. It combines them in a matrix (probability-intensity-matrix) to indicate different levels of hazard. This approach was extended by a third dimension to include also the vulnerability and receive a scale of color indicators to visualize risk.

In a further step the hazard map was developed towards a risk map by taking further geographical data but also statistical data into account. Using the approach of Switzerland, a 3-dimensional cube was developed representing three input values:

- Probability

- Intensity
- Vulnerability

Depending on the intended use of the map, different parameters can be added as this third vulnerability dimension.

The European Flood Directive recommends the creation of flood risk maps with different criteria:

- Flood event with a high probability (HQ 10)
- Flood event with a medium probability (HQ 100)
- Flood event with a low probability (extreme event)

- Content: water depth
- Content: water velocity
- Content: areas with embankment erosion and sediment deposit

- Amount of potentially affected inhabitants
- Potential Economical damage
- Potential Environmental damage

Simultaneously it is necessary to keep the basis of these maps very flexible and to automatise the creational processes because of the claimed actualisation of these risk maps within a 6 year frequency.

Therefore a modification of the Swiss approach (probability-intensity-matrix) was necessary. Finally the use of the following three parameters completed the new “risk cube”:

- Probability
- Intensity
- Vulnerability

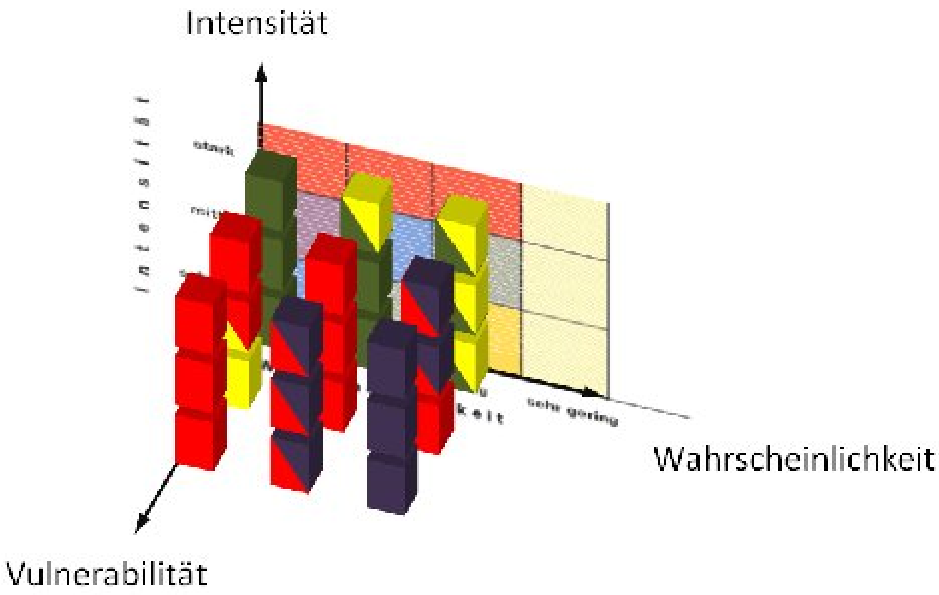

Figure 3: Risk cube including 3 dimensions: probability, intensity and vulnerability

The intensity is reflecting two different factors: water depth and velocity of the water body. Critical water depths and velocities have been explored and can be derived from hydrodynamic models. The values evaluated for the hazard maps were also used for risk maps. The detail had to be reduced to three relevant levels to fulfil the criteria of the risk cube.

- 0,0 – 0,5m

- 0,5 – 1,2m
- >1,2m

The European Flood Directive defines three relevant flood events:

- HQ 10
- HQ 100
- HQ 1000 (extreme event)

The third dimension is defined by the category of the risk map. It can be differentiated between the number of affected persons, the economical risks and the environmental risks.

Experimental Graphic Semiology

Quality is an important aspect when looking at the European Directive on the assessment and management of flood. Therefore two major questions must be dealt with:

- How to evaluate the quality of a map?
- And how to produce a map adapted to the treated problems and especially to its public recipient?

To quantify risk perception, the output maps were presented to a group of stakeholders from different European countries. The method used is based on the approach of experimental graphic semiology, reversing the traditional communication pattern from transmitter to receiver. Starting from receiver, the maps were presented to the test persons using an ophthalmic device for the record of the eye movements during picture reading. The test was accompanied by a specific survey; hence, the cognitive perception of risk maps was evaluated. All maps were presented to the test persons for a relatively short time period to identify the most attractive components of each map. The eye movements were subsequently statistically analysed in order to assess patterns of visual perception for each map and to study the reading behaviour for text elements included in the maps. The visual strategies of each test person were quantified.
The experimental graphic semiology is made possible thanks to a recent specific equipment used in ophthalmology: the photo-oculographe and can be subdivided in 3 stages:

1. **Construction of the maps and the experimental protocol:** Exchanges between the various partners allowed the development of the maps of reference while varying various elements of graphic semiology (cf Diagram 3, p. 11 below). Examples of significant maps, in terms of information of the public and risk management of flood were considered. The German and Austrian partners carried out a first proposal of maps having to be used as support with the ocular tests. The French partner made draft amendments. These exchanges are at the origin of the choice of the variables which were tested (position of the title and the legend, level of detail of the legend, melts of map…) and of the development of the 17 maps having been used as reference for the ocular tests and the investigation known as cognitive. The creation of a form of cognitive investigation (having for objective to specify the results of the ocular recordings) and the identification of the various candidates also belonged to this preliminary stage.
2. **Realization of EGS approach:** It consisted in recording the ocular movements of the various candidates and in exposing to them to the desired moments the questionnaire (cognitive investigation). It also consisted in

extracting the data (iconic and statistical) as well as the acquisition data quantified (provided in appendix of this report/ratio).

3. **Analyzes, interpretation of the results obtained and recommendations:** Then the results resulting from the statistical processing (calculation of the averages by map and group of candidates), of the results of the recording of the ocular movements (statistical, space and dynamics) and of the cognitive investigation were analyzed and interpreted.

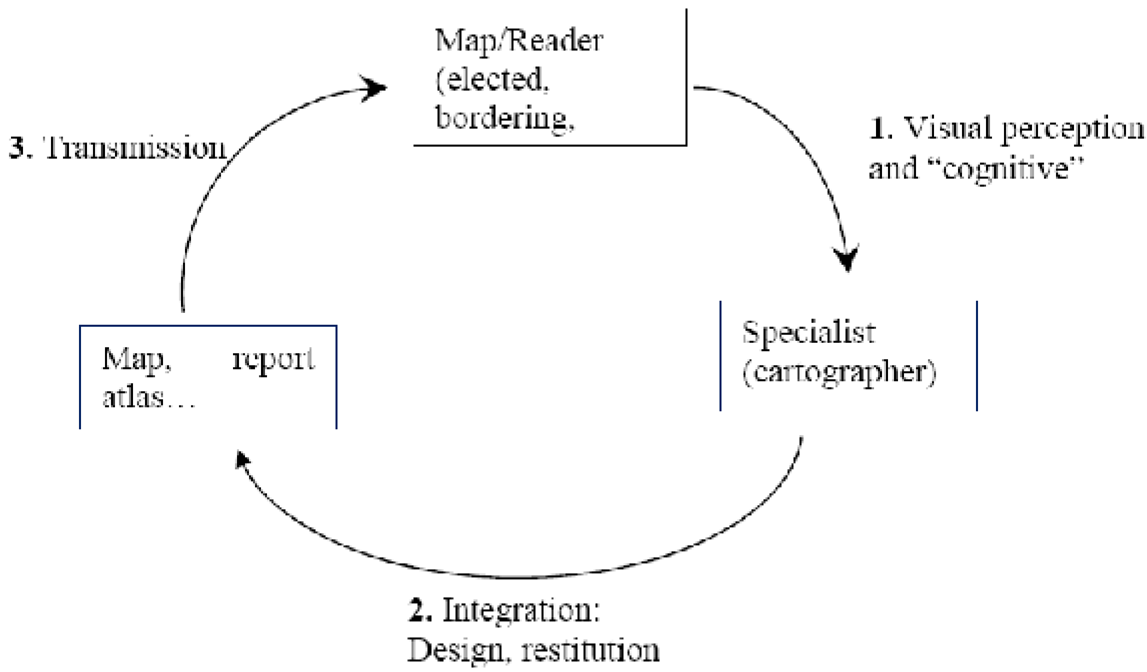

Figure 4: Principle of the experimental graphic semiology

3 RESULTS

Historical Development

The historical development of risk was analysed using historical maps. Findings show remarkable changes in land use patterns especially during the last 20 to 50 years. First land register maps showing also the land use were established around 1850. The following set of land register maps was used to analyse land use changes and resulting changes of risk patterns in the landscape of the Lower Vils valley:

- Land register map of 1850
- Land register map of 1920
- Land register map of 1970
- Land register map of 2000

On the basis of digitalised areas equal to their utilisation of the appropriate time periods it was possible to describe settlements and intensification of land use in the flood plain.

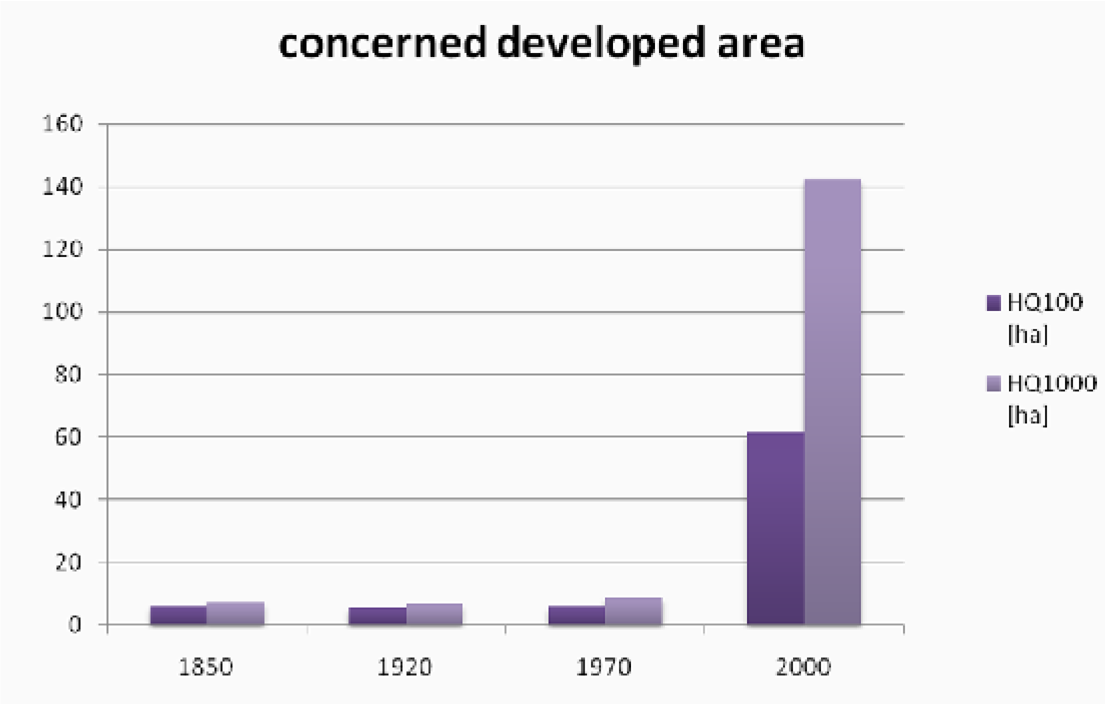

Figure 5: Concerned developed areas of the Lower Vils region within the time period of 1850-2000

The comparison of the different time periods showed a tenfold increase of the concerned developed area looking at the inundated area of the one hundred year flood. Considering the thousand year flood, the affected area in the year 2000 is twenty times bigger as it was in 1850. This is only a comparison of land use patterns, but it can be guessed the development of values exceeds these numbers.
In combination with land use maps, development plans and historical maps describing the changes of land use and damage potential in the flood plain these hydraulic and hydrological data sets were used to analyse the developments and flood related problems for the status quo from the ex post perspective (Fig. 6).

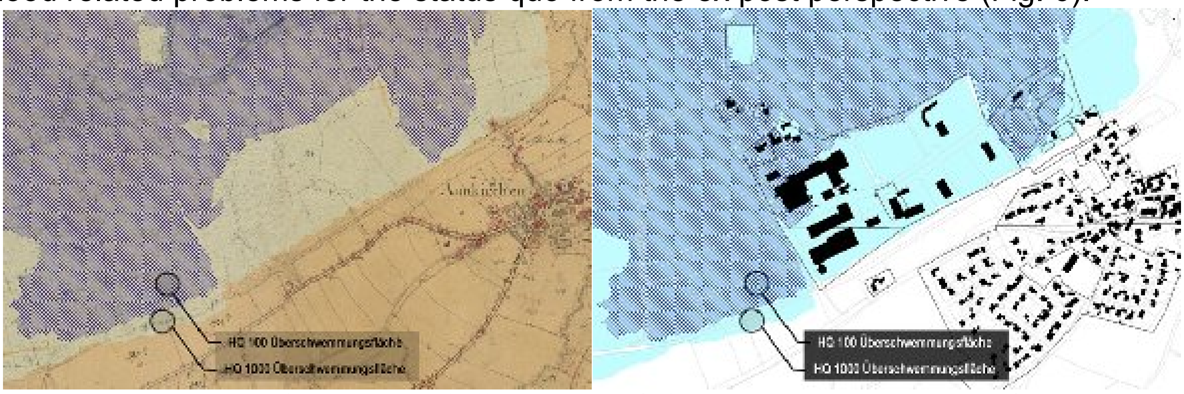

Figure 6: Comparison of affected areas (left: year 1850, right: year 2000)

A realistic economical comparison wasn't possible because of the lack of economical data, but should be a task for future research.

Hydrological issues

Within the catchment of Vils and Rott there are two major storage reservoirs available for flood control. The storage reservoir situated in the middle of the Rott catchment was built between 1968 and 1971 and has a total capacity of 13.9 Mio m³ and a flood retention capacity of 12.75 Mio m³. One of the main purposes was the protection of fertile agricultural areas, flood defense for settlements in the downstream river valley as well as recreation. The actual hydrological calculations show that the estimations of the design floods, used for the construction of the reservoir, were underestimated. The evaluation of the control strategy of the reservoir based on actual data and a new hydrological model for the river Rott proved, that the expectations about the detention effect were too optimistic. For the storage reservoir a new control strategy was suggested, including

- an increase of the flood discharge without any detention and
- a flexibilisation of the control strategy for higher discharges.

At the Rott already minor events are flooding wide areas of the intensive used flood plain. Starting at a discharge at the outlet of the reservoir of 40 m³/s the first bridge and agricultural sites and at 120 m³/s first buildings and settlements are affected. At the moment the basic discharge is set to a maximum of 40 m³/s. An increase up to 80 m³/s would be possible without much harm to buildings or infrastructure. But even with an improved steering concept the reservoir, due to it's defined capacity, isn't able to provide a full protection for all assets in the underflow. Hydrodynamic modelling showed the consequences of a change in the steering control. (Dorner et. al. 2006)

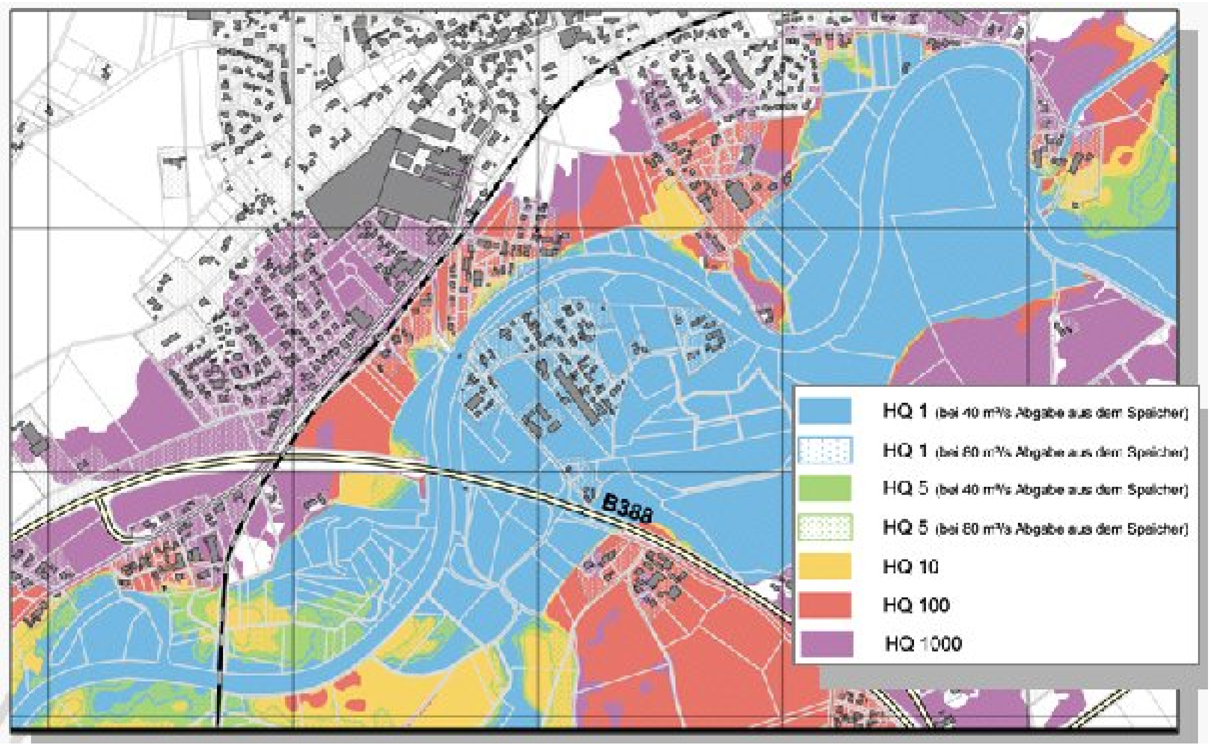

Figure 7: Probability map with different detention pond steering scenarios (HQ1 and HQ5)

The difficulty was to integrate also the result of a flexible control strategy of the reservoir and the uncertainties of future changes to the detention strategy due to political and economic aspects. A leveled concept was designed based on the national standards for flood risk maps, that is under development by a national working group of the LAWA ("Working Group of the Federal States on water issues").

Risk maps

In a first step the population figure used to create a risk map for the region of the Lower Rott showing the amount of affected inhabitants for different flood events (HQ 10, HQ 100, HQ 1000). It is a quite simple approach with quite lot problems to solve. Especially the consideration of precision and level of detail versus costs for data acquisition and compilation is a major concern. This could also cause problems regarding the required actualisation each six years.

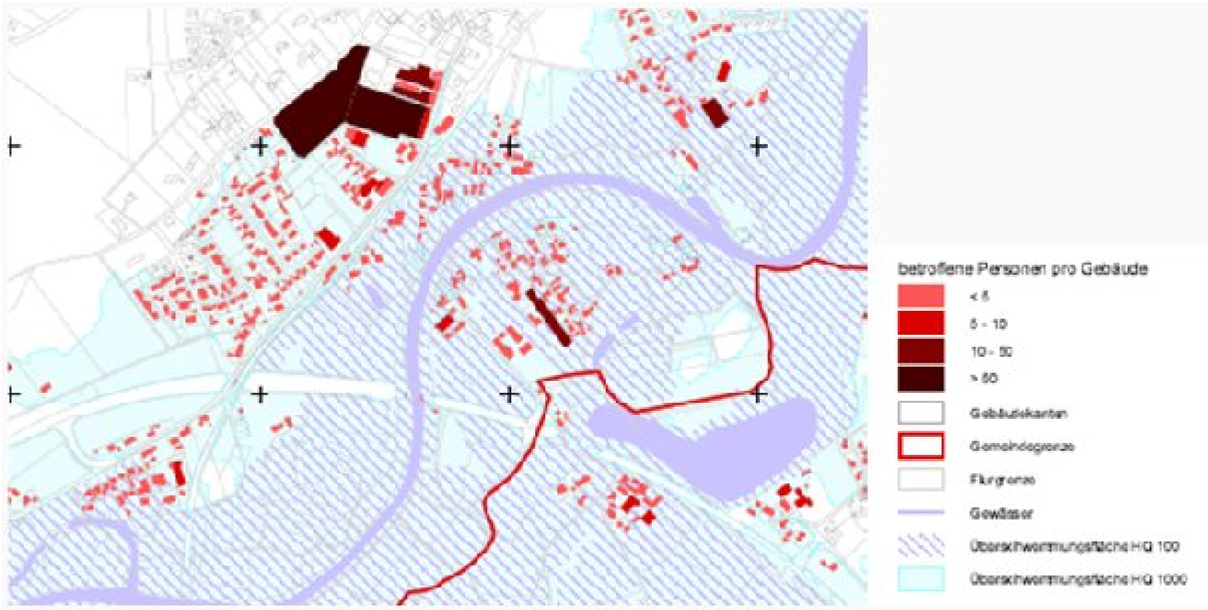

Figure 8: Detail of a risk map (variant 1: inhabitants)

A first modification of the variant was related to the distribution of the inhabitants. A separation of housing structures and industrial and commercial structures was performed on the basis of land use data. But also the statistical data for the inhabitants of each single community was applied to the structure areas. Simultaneously the employees of each single community were applied to the commercial areas in the community.

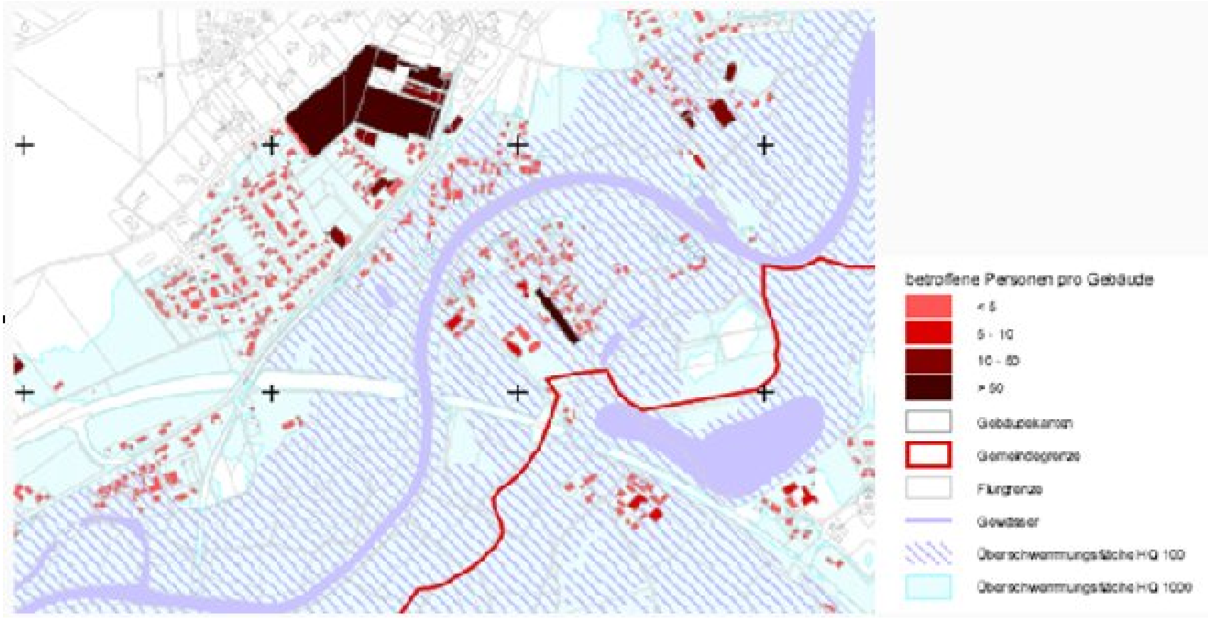

Figure 9: Extraction of a risk map (Variant 2.1: inhabitants and employees)

The variants discuss the fact of affected persons by a certain flood event in a certain area which is also demanded by the European flood directive (European Parliament, Council, 2007). In a further step the principle of the risk cube was applied to risk maps for persons as well.

Figure 10: Extraction of a risk map (Variant 2.2: inhabitants and employees)

Several methods can be identified to estimate the economic damage resulting from flooding. In this case the methodology of the German and Austrian partners in the project differs because of the extent of the selected areas for mapping. The Austrian project partner created very detailed risk maps by describing the expected economical damage for each single house in an inundated area. Because of the large extent of the affected area and the size of the catchment a different approach was chosen to describe risk based on the different types if land use. Therefore the different forms of land use (e.g. agriculturel, grassland, commercial areas etc.) were analyzed based in statistical data of the district and allocated to three vulnerability categories. This approach is quite similar to the regular approach for hazard maps, where land use data is often used as background. In contrast to hazard maps the related economic information behind land use types was also included in the choice of color indicators for risk.

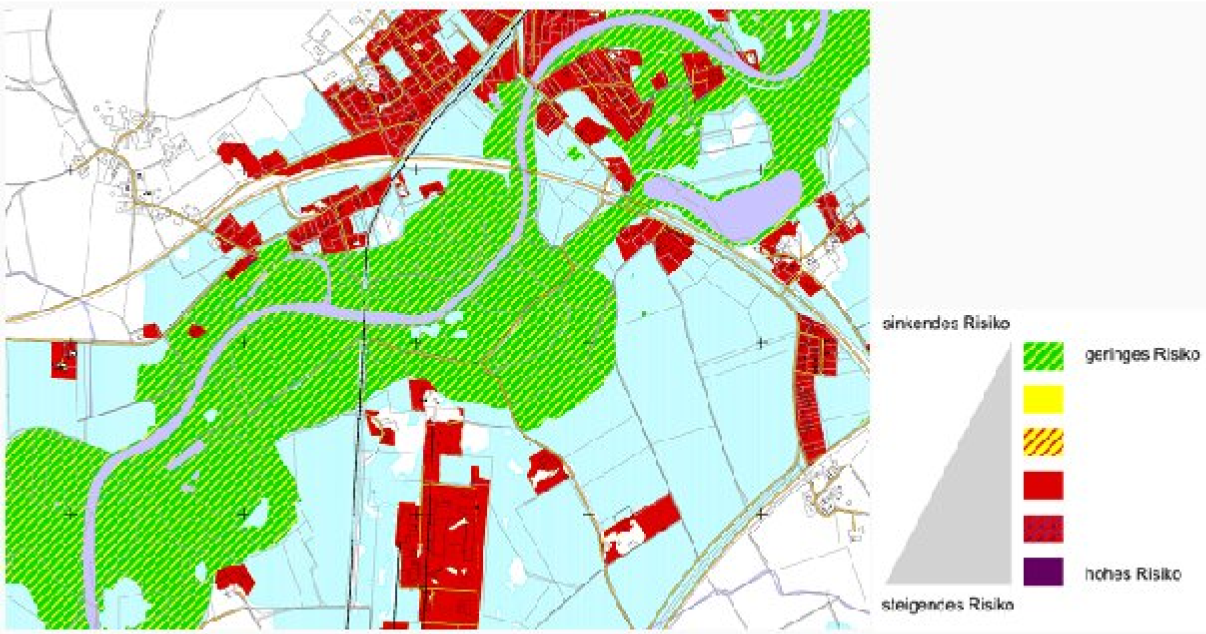

Figure 11: Extraction of a risk map (economical damage)

Experimental Graphic Semiology

This research showed the strong gravitational capacity of:

- Text and in particular the title and legend are probably related to the culture and education.
- Bright colors or dark within the map like legend.

The study also made it possible to check:

- That the respective position of the various elements (title, legend, map) was not neutral in the way in which these components were apprehended visually;
- That the various elements of the map were quite always looked in the same order: center (central element of the map) towards the periphery (legend) then once again of the center (legend and central element) towards the periphery (secondary information).
- The double influence of the map on the visual strategies and the practices of the reader on his way of apprehending the map.
- That there was a phenomenon of habituation (or visual training) from one map to another with measurement of the flow of time.

Particular elements of semiology for the cartographic representation of the risk were for the central element of the map the background of map which must be of clear colour to support contrast with the informative elements and to avoid the overloads of features (level line, road secondary axis …). For the title, the legend and scale (cartridge of "textual" information) the legend has to be written sufficiently large and to respect the following principles:

- The candidates preferred that the legend is placed on the right side of the map and the title was considered to be more locatable and readable when placed in top.

- To limit itself to 5 classes (discretization) for ordered information;
- That the value is represented graphically by a range in only one colour;
- That the various classes appear in order of decreasing values (strongest in top and weakest in bottom);
- Hot colors (red) were preferred with the cold colours (green) to represent principal information.
- The legend could contain additional information but those were to be of limited number and to correspond exclusively to elements present on the map.

At last, the candidates preferred a sufficiently large scale (1:2500) so that the elements of the map are recognizable by the recipients (buildings, pieces…). The following figure shows a conceptual map, which would have satisfied the candidates at most.

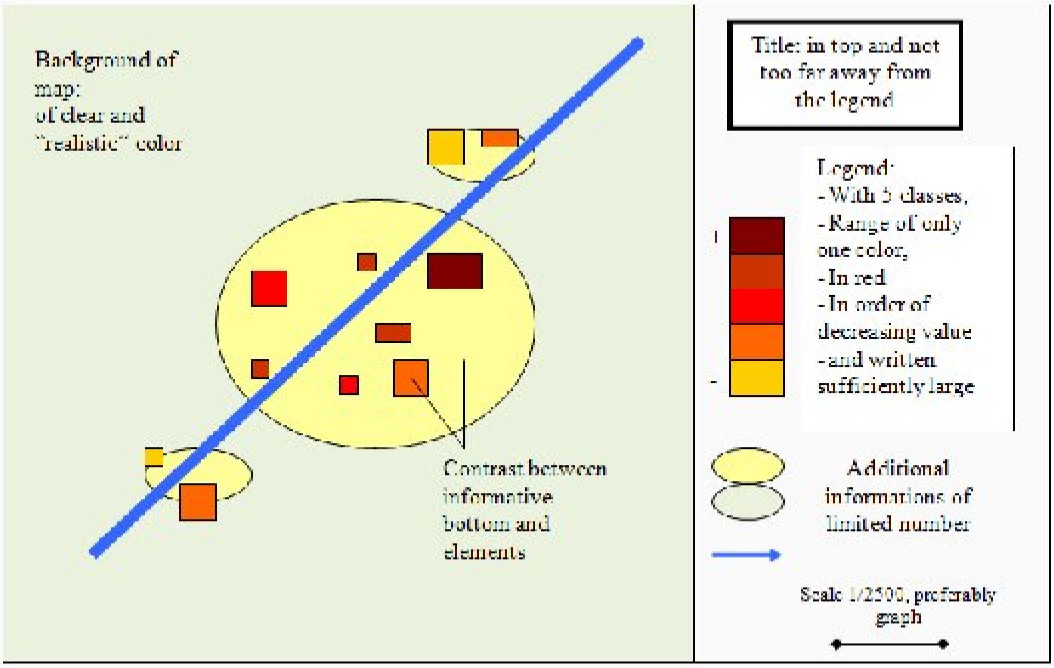

Figure 12: Conceptual map satisfying the demands of the candidates at most

An additional recommendation was to generate a visual strategy near to the following figure when creating a new map.

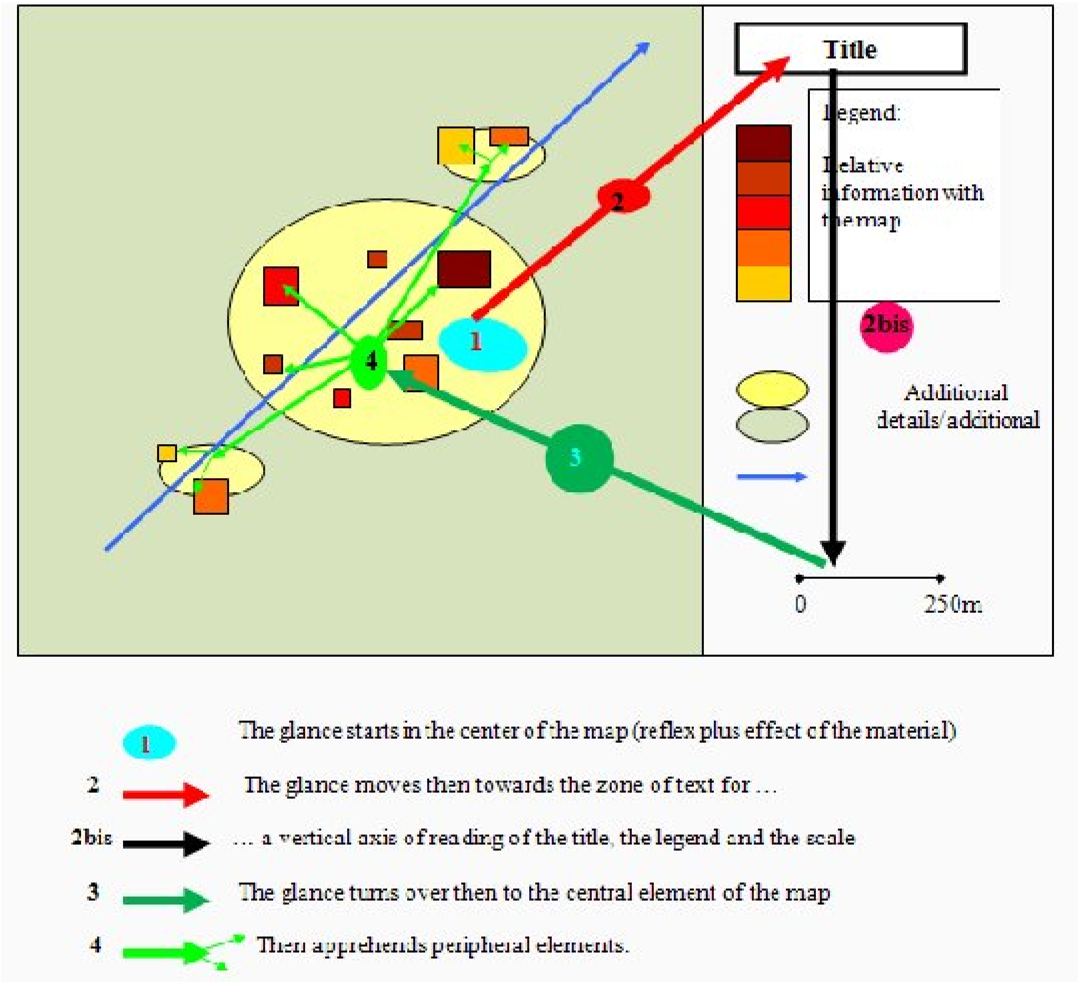

Figure 13: Representation of generated visual strategy

4 CONCLUSION

In the whole European Union and even beyond that border, different approaches to describe risk for certain occurring events have been made. Depending on the level of detail it is more or less cost intensive to generate appropriating significant maps. Relating to the European directive on the assessment and management of flood risks, it is only necessary to build upon available data to assess and manage certain natural risks. Therefore great efforts for describing single houses and damage potentials are not the correct way to fulfil the demands of the European directive, especially because of the fact of costs.

The experimental graphic semiology brings some more results and interesting aspects in the field of risk assessment and distribution. It is helping to improve the graphical layout of our maps, the manageability of the maps as well as the interest of experts, decision makers and layman. Readable maps are important especially for these laymen to understand the relevance and the impacts of such maps.

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