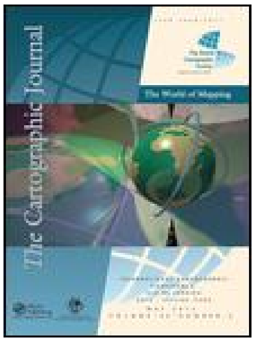

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How to Enhance Cartographic Visualisations of Natural Hazards Assessment Results

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How to Enhance Cartographic Visualisations of Natural Hazards Assessment Results

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Cartographic visualisations are important tools for the communication of hazard related data among stakeholders. Although these representations are essential for various hazard management tasks, an analysis of existing hazard visualisations showed that they often disregard cartographic principles. This leads to confusion on the part of users through poor representations and consequently to an impairment of the information flow. The objective of this research is to offer suggestions for enhanced hazard visualisations to facilitate hazard management tasks and decision making. Existing cartographic shortcomings are identified based on an extensive analysis of hazard visualisations and an expert survey. These shortcomings are discussed and improvements for important cartographic elements are presented.

Keywords: natural hazards, hazard maps, map analysis, cartographic rules

INTRODUCTION

Natural hazards assessment is a fundamental part of risk management and serves as an important basis to protect human lives and infrastructure from dangerous natural processes (Kienholz, 2005).Visualisations of natural hazards assessments are important tools for communication of the spatial distribution of hazards among concerned parties (Petrascheck and Kienholz, 2003). This is one reason that maps for the identification of areas subject to natural hazards exist for large areas of the world (NatHazMap, 2010).

However, as many of these maps are produced by natural hazards specialists rather than cartographers, they often ignore cartographic principles, which results in overloaded and unbalanced maps that are hard to interpret.

Even in countries where the creation of hazard maps is a standard procedure (sometimes even regulated by law) and mapmakers can follow existing design rules, these maps cannot satisfy the needs of all users. Many detailed hazard maps were developed for the purpose of land-use planning. Recent analyses of past events, however, confirmed that hazard maps are not only used to identify endangered areas as basis for land-use planning, but for many other hazard management tasks such as emergency planning, the planning of physical protection of infrastructure, or risk assessment. These tasks are carried out by specialists with different backgrounds, skills and goals, and the differing needs of this heterogeneous user group cannot be satisfied by traditional hazard maps. Thus, natural hazard assessments need to be conducted independent of a specific future use (Bezzola and Hegg, 2008). The results can then be edited for and presented to specific user groups in form of customized hazard visualisations.

Visualisations of assessment results are not only of importance for end-users of hazard maps, but already during the assessment stage: in alpine regions especially, numerous hazardous processes such as snow avalanches, floods, debris flows, rock fall or landslides can occur in one location. As a consequence, many scientists and engineers are involved in the hazard assessment process. Since a consensus of the overall hazard situation can only be achieved if all results are correctly interpreted, knowledge exchange between experts assessing natural hazards has to be guaranteed. This communication can be facilitated with the help of maps.

The issue of inappropriate visualisations can be solved if hazard assessment results and/or knowledge derived from these assessments are visualized in form of cartographically correct maps that are customized for specific user groups. The objective of this paper is to present suggestions for visualisation of detailed natural hazards assessments results so that (1) no information is lost; (2) maps are understandable for all involved parties; and thus, (3) communication among experts is facilitated.

In order to find suitable visualisation methods, we analysed and assessed over a hundred hazard visualisations and conducted an expert survey with natural hazard specialists. Based on the derived shortcomings and user needs, we provide suggestions for the enhancement and extension of hazard visualisations.

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EXISTING NATURAL HAZARD VISUALISATIONS

Hazard mapping has a long history; the first hazard maps for snow avalanches were created over 50 years ago and shortly after the first legislations were passed to ensure the generation of hazard maps. Examples are the Colorado State legislation passed in 1974 or the Swiss Federal Law on land-use management of 1979. Early maps contained hand drawn trajectories of historical events (e.g. Ives *et al.*, 1976) and were followed by more sophisticated visualisations in which several hazardous processes such as debris flows, flooding and rock fall are incorporated in the same map (e.g. Kienholz, 1977). A detailed overview on the history of Swiss hazard mapping can be found in Kunz and Hurni (2008).

During the last decades, hazard visualisations for various natural hazard processes such as earthquakes, volcanic eruptions, tsunamis, hurricanes and droughts have been compiled for large areas of the world. However, most of them are limited to general maps depicting locations of past events.

Owing to the fact that gravitational hazards (e.g. snow avalanches, debris flows, rock fall and landslides) and floods are often spatially confined and can be predicted quite accurately, large-scale hazard maps are usually limited to these processes.

Today, most large-scale hazard visualisations are based on predictions of intensities and probabilities of potential natural hazard events. Most of these predictions include at some stage the use of numerical models or simulations and analyses with geographic information systems (GIS). Cartographic visualisations of these high-resolution digital data are often generated in GIS environments, which offer the advantage to choose from existing map layouts, symbolisation and colour schemes. However, since most maps are generated by natural hazard specialists without a cartographic background, cartographic rules are often ignored. Most GIS users are conditioned to default colour schemes (Harrower and Brewer, 2003) and only make use of basic cartographic techniques, not exhausting the potential of cartography.

Analysis of existing hazard visualisations

The acknowledgment of the importance of risk and hazard visualisation has resulted in a number of analyses and evaluations of existing maps (e.g. Chesneau, 2004; Fuchs *et al.*, 2009; Hagemeier-Klose and Wagner, 2009). While these studies focus on either one specific natural process (mostly flooding) or region, we performed a general analysis including various processes and visualisations from around the globe. For this purpose, we analysed 106 analog, digital, animated and interactive maps from numerous countries. These visualisations were published in atlases, research papers, newspaper articles and on the Internet. They depict the characteristics of floods, earthquakes, forest fires, snow avalanches, debris flows/landslides, storms, rock fall and volcanic activities. The analysis was not restricted to hazard maps for land-use planning but comprised visualisations of hazards, intensities, probabilities of occurrence, risk, as well as attributes of historical events. The underlying data were either based on calculated (modelled) outcomes of possible scenarios or on the analyses of real, historical events.

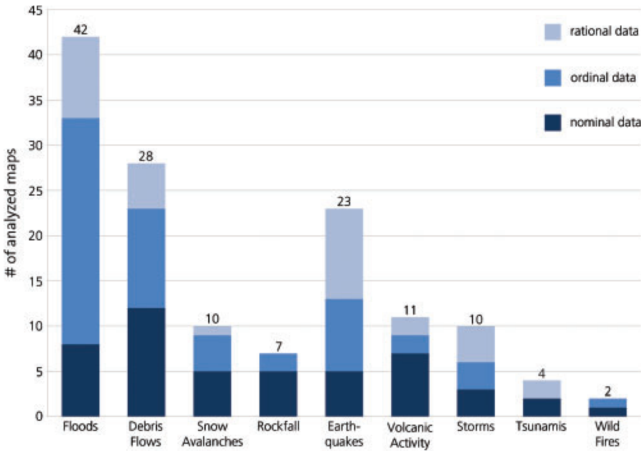

Figure 1. Quantitative overview on the analysed natural hazards processes (number of analysed maps is displayed above each bar) and the according data types

Our analysis of these cartographic representations consists of the quantitative assessment of essential map elements, namely, depicted processes, data types, map scale, applied visual variables, as well as type of symbolisation, number of data classes, type of base map, animations/dynamic map parts and interactivity.

As the choice of map symbolisation and scale is a consequence of the characteristics of the depicted data, we primarily structured the analysed maps according to the visualized natural processes.

If thematic data are integrated in a map, it is either visualized in a continuous way or grouped into different classes. Classifications are either based on nominal, ordinal, interval or ratio scales. Nominal data can be distinguished but no ranking is possible; examples are land-use classes or geological categories. Ordinal data can be distinguished and ranked with respect to one another, for example, hazard classes. On interval scales a certain distance along the scale stands for the same magnitude no matter where on the scale it is measured, but the scale origin ('zero') does not represent the absence of the parameter being measured. Fahrenheit and Celsius temperature scales are examples. Ratio scales are similar to interval scales with the difference that 'zero' on the scale represents the absence of the thing being measured. Examples of rational data are water depths of an inundated area in metre, or impact pressures of a snow avalanche in kPa. A summary of the data types present in the 106 analysed maps is shown in Figure 1.

Some natural processes such as earthquakes, forest fires, storms, tsunamis and volcanic activity have regional or even inter-regional impacts. Hazard maps are often based on estimations about potential hazardous events. Forecasts of such regional events can only be made with a coarse spatial resolution. Other natural processes such as floods, debris flows/landslides, rock fall and snow avalanches occur spatially defined and may be estimated more accurately. This fact is reflected in Figure 2 that gives an overview of the correlation between assessed processes and according map scales.

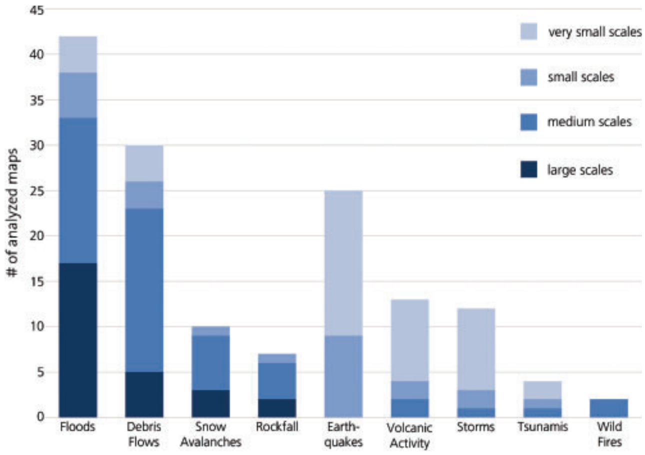

Figure 2. Quantitative overview on natural hazards processes and their representation in the four scale groups large (1 : 500–1 : 15 000), medium (1 : 15 000–1 : 300 000), small (1 : 300 000–1 : 15 000 000) and very small (1 : 15 000 000–1 : 230 000 000)

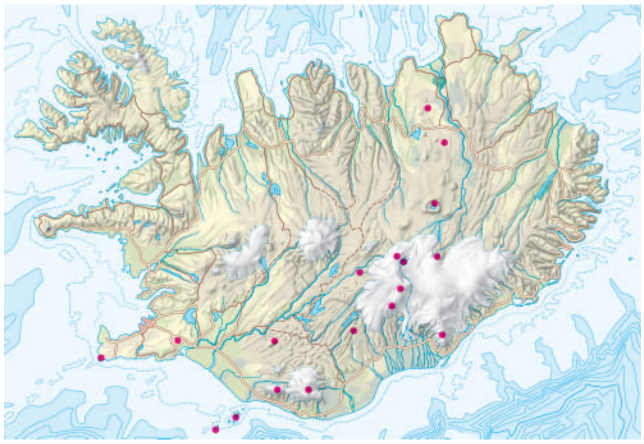

Figure 3. Small scale map (1 : 4 000 000) depicting the location of active volcanoes (pink dots) in Iceland (SWA, 2008, modified)

The assessed maps range from 1 : 500 to 1 : 230 000 000 in scale. We grouped them into the following three classes: large scale (1 : 500–1 : 15 000), medium scale (1 : 15 000–1 : 300 000), small scale (1 : 300 000–1 : 15 000 000) and very small scale (1 : 15 000 000–1 : 230 000 000). The classification into these groups was based on the fact that the maps represent either distinct places such as towns, larger regions, countries or the whole world and thus a clustering of the scales into the above mentioned classes could be observed. However, the scale of a map is not only a consequence of the depicted processes and available data, but also of the intended purpose of the map. The classification into different scale groups can therefore also be regarded as classification into intended map uses. According to Chesneau (2004), risk maps serve either for information, as basis for action or for controlling tasks. In this paper, we only discuss hazard maps, but as hazard is a component of risk (risk is defined as a function of hazard and the expected consequences; for further discussions about the definition of risk, see Varnes, 1984; Morgan *et al.*, 1992), the same purposes apply for both types of maps. Information consists of general information and detailed information as basis for preventive actions. If the maps are intended for general information, they have to give an overview on the hazard situation and are therefore mostly published in small or very small scales depicting a country or even the whole world. Information as basis for preventive actions aims at sensitizing the general public to the hazards they are exposed to and consequently to encourage them to actively take preventive measures. For this purpose, these maps need to be on a regional or even local level (medium or large scales). Another use of hazard maps is to act as a basis for hazard management actions such as the planning of protection measures. In this case, the maps can be of varying scale, depending on the process and the size of the affected areas. In case of an event, hazard visualisations are needed for immediate intervention. These maps need to be as detailed as possible and therefore available on a local level (large scale).

The map scale is also correlated with data types. The analysed maps included nominal, ordinal and rational data types. Nominal data are primarily used in maps of very

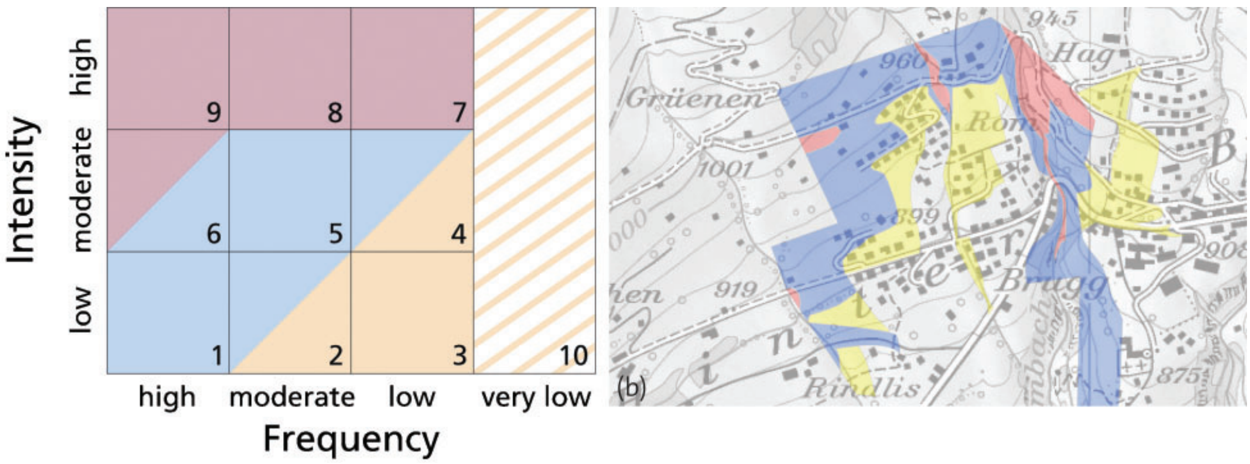

Figure 4. (a) Matrix for the determination of hazard classes: intensity and probability of an event are reduced to the parameter hazard zone (Loat and Petrascheck, 1997), and (b) finally visualized in a hazard map [base map reproduced with the authorisation of swisstopo (JD100042); hazard data: courtesy of Canton SG]

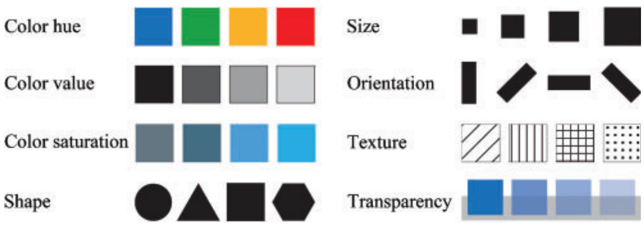

Figure 5. Overview on the visual variables colour hue, colour value, colour saturation, shape, size, orientation, texture and transparency (Bertin, 1983; MacEachren, 1994; Wilkinson, 1999). Illustrations: Schnabel (2007)

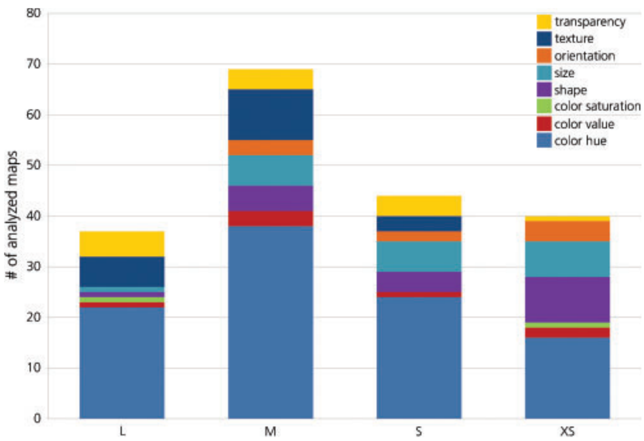

Figure 6. Quantitative overview on the used visual variables colour hue, colour value, colour saturation, shape, size, orientation, texture and transparency ordered by scale (L=large scales, M=medium scales, S=small scales, XS=very small scales)

small, small and medium scale, where the purpose of the map is an overview about the presence or absence of certain natural processes. An example is the map shown in Figure 3, which shows the location of active volcanoes.

Detailed maps for the planning of preventive or protection measures and intervention actions contain either ordinal or rational data. Ordinal scales are often used for hazard classes. They usually result from a multiplication of two variables, for example, intensity and probability of an event, and are grouped into low-, moderate- and high-hazard zones. With the help of such a multiplication, two variables are merged into one, reducing the number of thematic parameters and therefore facilitating the visualisation process. Figure 4a shows the matrix that explains the relation between hazard classes (1–10) and the underlying parameters intensity and probability as well as the colour code of the according hazard zones. Low-hazard zones are depicted in yellow, moderate-hazard zones in blue and high-hazard zones in red. An example of a resulting hazard map is shown in Figure 4b.

Since we only assessed 2D maps, Jacques Bertin's (1983) definition of the characteristics of point, linear and areal symbolisation served as a basis. These six visual variables colour hue, colour value, shape, size, orientation and texture have been actively discussed and extended by several authors. A sound discussion of the history of visual variables can be found in Huber *et al.* (2007). However, we only included variables that were present in at least one of the assessed maps.

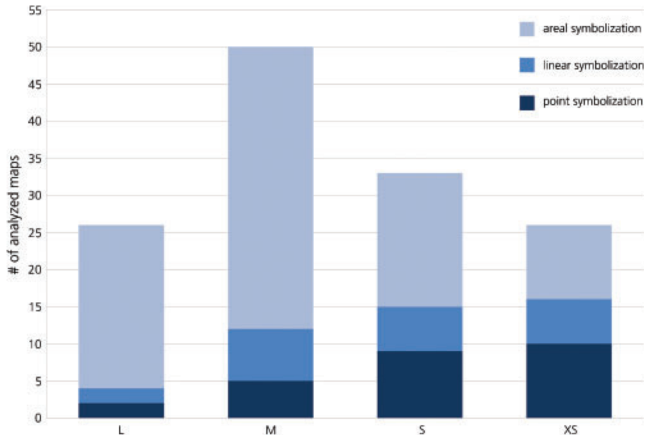

Figure 7. Quantitative overview on used symbolisation types (point, linear and areal) ordered by scale (L=large scales, M=medium scales, S=small scales, XS=very small scales)

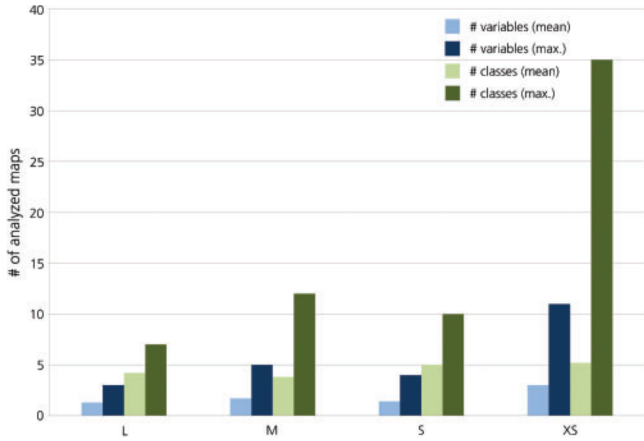

Figure 8. Quantitative overview on number of used variables and number of data classes ordered by scale (L=large scales, M=medium scales, S=small scales, XS=very small scales)

Bertin's six visual variables were consequently extended with colour saturation (added by MacEachren, 1994) and transparency (added by Wilkinson, 1999). These variables were analysed in order to assess which variables are used for natural hazard visualisations and what values they are assigned. Figure 5 gives an overview on the visual variables and Figure 6 shows the quantitative results of this analysis.

Many of the analysed maps depict more than one natural process on the same map sheet. If the maps are sorted by natural process, one map is listed more than once. The following analysis results are therefore presented ordered by scale in order to facilitate the interpretation of the quantitative analysis.

Apart from scale, data type and visual variables, other important cartographic elements are the type of symbolisation (point, line or areal), the number of visualized thematic variables, the maximum number of data classes, the type of base map, the presence of animations and dynamic maps and the level of interactivity. Figures 7–10 show the quantitative analysis results of these elements.

In summary, the results show that most large-scale visualisations depict only one or two different thematic

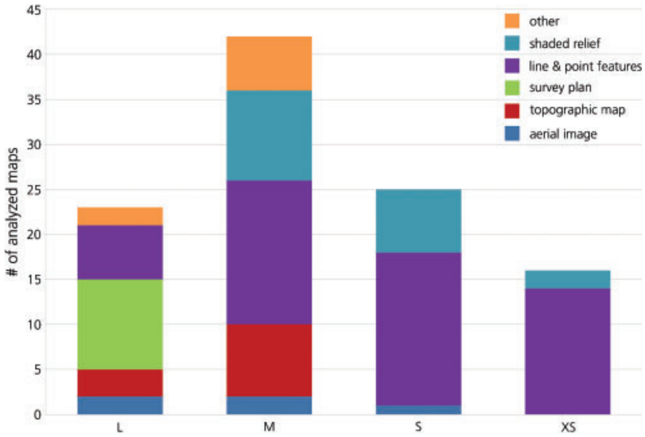

Figure 9. Quantitative overview on type of base map ordered by scale (L=large scales, M=medium scales, S=small scales, XS=very small scales)

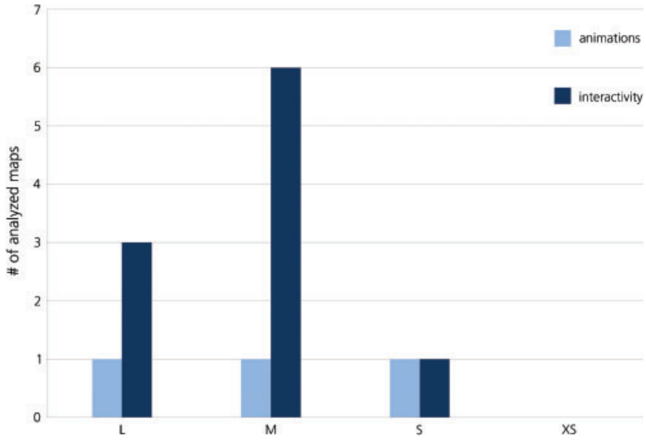

Figure 10. Quantitative overview on present animations and interactivity ordered by scale (L=large scales, M=medium scales, S=small scales, XS=very small scales)

topics (83%), usually depicted by coloured areas. Point symbolisation is primarily used in small and very small scales, facilitating the inclusion of more thematic parameters. However, these point data illustrate historical events rather than predictions. Where point symbols are used, size is used to illustrate the intensity of a natural hazard event. In the case of lines, line width is altered in proportion to the depicted intensity. The visual variable transparency is often used on data layers to allow for the simultaneous interpretation of base map and thematic symbolisation. However, none of the reviewed maps contained transparency to display quantitative distinctions or differences in importance or intensity.

USER NEEDS

Users

The user group of hazard visualisations is very heterogeneous; natural hazards experts and specialists produce and use them for different tasks, such as spatial planning, dimensioning of protective structures, emergency planning, calculations for insurance purposes, etc. In addition, the general public is also interested in these maps as they identify whether someone lives in a hazard prone area or not. However, the focus of this research is on the improvement of communication among experts and therefore information transfer to the general public is not subject of this paper. Addressed users are experts in the field of natural hazard assessment and management. Even with this condition, the user group is still heterogeneous as it consists of engineers, scientists, land use planners and other professionals. However, although the background, skills and needs of these experts vary, they are all interested in the same basic questions:

- Which areas are endangered by natural hazards?
- Which natural processes can occur?
- How intense and how frequent are potential events?
- Who/what is affected (people and infrastructure)?

Expert survey

In order to gain insight into what professionals think about current hazard visualisations, we conducted a survey with 34 natural hazard experts in October and November 2009. The online questionnaire consisted of four introductory questions that concerned the level of experience, the range of assessed processes and methods used for hazard assessments. All experts worked in the field of natural hazards management and had an average experience of 14 years. The processes they assessed comprised floods, debris flows, landslides, rock fall, snow avalanches and sink holes.

Since only Swiss experts were interviewed, the answers refer to existing hazard maps in Switzerland. We are aware that the experience of this small circle of specialists does not allow for a universal conclusion. However, since hazard mapping in Switzerland has a long history and Swiss hazard maps are some of the most advanced in the world (Hagemeier-Klose and Wagner, 2009), the gathered opinions can serve as a basis for the definition of user needs as well as the location of shortcomings in existing large-scale hazard maps.

The main part of the survey was divided into two sections; one part aimed at getting an overview on the topic of uncertainty visualisation in hazard maps, while the other addressed general visualisation issues of existing hazard maps. The questions about uncertainty visualisation are used for a different part of this research and are not included in this paper. The first questions about general visualisation issues concerned the visual variable colour hue and we asked if the choice of colour hue for hazard zones as it is used in Switzerland (red/blue/yellow, see Zimmermann *et al.*, 2005) is considered to be appropriate. Almost 80% of the experts consider this colour scheme an established standard which should not be altered. As we also allowed the expert to provide comments about the answer, we learned that many experts got used to this scheme over time, but would likely choose a different colour scheme if they could. The second question asked if the hazard maps of Switzerland are easily readable and understood. According to 68% of the experts, complex visualisations like the synoptic hazard map (more information about these composite maps will be given in the

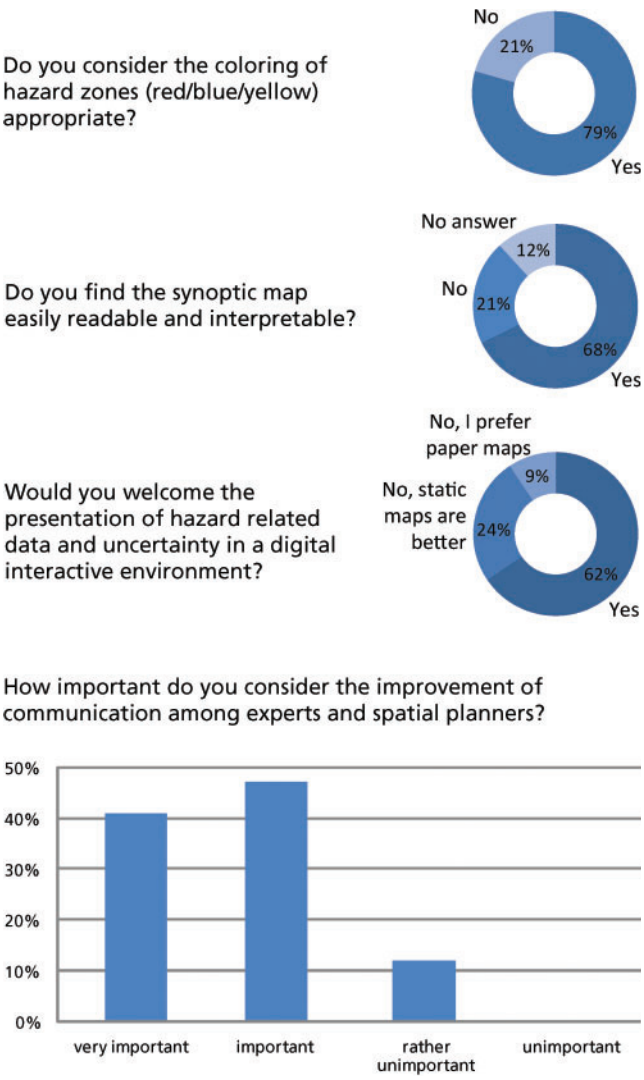

Figure 11. Questions and answers of the online expert survey about existing natural hazard maps

section on 'Shortcomings in existing hazard visualisations and suggestions for improvement') can be interpreted by experienced experts. However, provided comments revealed that as soon as these experts have to explain this information to third parties, different visualisations have to be used as the existing maps are too complex. Finally, we asked how important the improvement of communication among experts and spatial planners was. The high priority of this issue was confirmed by the experts: 41% consider this very important and 47% important. In the last questions, the experts were asked if they would welcome the presentation of hazard-related data in digital interactive environments. The majority (62%) of the experts agreed that such environments are helpful and can facilitate the comprehension of complex illustrations. However, it was pointed out that paper maps are still required and in use; therefore, digital solutions should also provide print options resulting in high-quality maps.

Figure 11 gives an overview on questions and answers of the expert survey.

Detailed comments about the existing situation emphasize the fact that we should distinguish between the product 'hazard map' and other cartographic hazard representations (or visualisations). The product 'hazard map' is designed for the needs of spatial planning using official design rules. Since these design rules have been used for a long time, experts have become familiar with them and changing them would lead to confusion. However, when other cartographic hazard representations, such as intensity maps, maps of phenomena, maps of historic events, intervention maps, etc., are concerned, no general design rules exist. These customized maps can serve for different hazard management purposes, whereas traditional hazard maps clearly serve the purpose of implementing hazard zones in spatial planning. The consequence for the design of cartographic hazard representations in general is that mapmakers can make use of existing techniques used for hazard maps, but one is not bound to existing standards of hazard maps (such as defined colour schemes). These hazard representations can therefore be adapted according to specific user needs and tasks.

In summary, the user needs can be described as follows: standards of existing hazard maps for land-use planning should remain as they are. Further hazard management tasks, however, require hazard visualisations that are customized according to the user needs. This customisation includes, for example, the choice of scales, colours, base maps and number of hazard classes. The objective of such customized maps is to support the analysis of available data as well as decision making. In addition, they should serve for enhanced knowledge transfer and communication among various natural hazards specialists.

SHORTCOMINGS IN EXISTING HAZARD VISUALISATIONS AND SUGGESTIONS FOR IMPROVEMENT

In order to provide suggestions for improved cartographic representations, shortcomings of existing hazard visualisations have to be summarized and analysed. In this section, we present the shortcomings we identified through our map analysis and the expert survey.

The most urgent need, as identified in our expert survey, is to improve the communication and knowledge transfer among experts and spatial planners. The challenge of transferring natural hazard assessment results is to convey the large volume of knowledge in a comprehensible format. While maps with only one thematic element are usually well understood, the integration of further thematic layers is often cartographically challenging and more difficult to interpret by map users.

The results of our analysis showed that assessment results of gravitational hazards (snow avalanches, debris flows and rock fall) as well as flooding are often available in a high spatial resolution, allowing for large-scale maps. The compilation of these large-scale visualisations often creates problems, because huge amounts of data need to be edited and integrated in visualisations. Swiss synoptic hazard maps are examples of such large-scale, multi-layered maps and serve as a good example to demonstrate existing shortcomings. We therefore place emphasis on large-scale visualisations of gravitational hazards and flooding for the remainder of this paper.

Figure 12. Different styles of synoptic hazard maps: (a) the underlying processes are symbolized by lines in different colour hues, (b) abbreviations of the processes with the corresponding hazard zone are used [base map reproduced with the authorisation of swisstopo (JD100042); hazard data: courtesy of Canton SG]

Synoptic hazard maps are syntheses of several hazard maps. Hazard zones of all occurring natural hazard processes are combined. The main goal is to define the overall hazard situation which is reached by showing the highest hazard zone of all occurring processes. However, the inclusion of the underlying processes results in multivariate visualisations and forms a cartographic challenge. Figure 12 shows two examples of how this task has been approached.

The challenge is to combine a base map with several layers of thematic topics and the according symbolisations. All these elements have to be adjusted in order to result in high-quality maps from which important elements are identifiable at first glance. One of the basic steps in map design is the analysis of the data to be visualized. Strategies for data visualisation can only be made if the characteristics and the amount of data are known. As we emphasize on large-scale visualisation of alpine natural hazards, the following characteristics define the data that should be visualized:

- results of natural hazard assessments: intensities, frequencies, hazard levels, etc. of snow avalanches, flooding, debris flows, rock fall or landslides;
- overlaying data: several processes can occur in the same location and sometimes more than one result (e.g. snow height, velocity and pressure for snow avalanches) per process has to be visualized;
- type and resolution of data: data are either available in raster or vector format. Raster as well as point data resolution ranges from 2 to 10 m if originating from numerical modelling.

These characteristics have to be considered during all stages of cartographic design.

The following paragraphs give an overview of cartographic elements in which we identified shortcomings. These shortcomings lead to chaotic, overloaded or confusing maps, and consequently hinder the interpretation of visualisations. We therefore suggest improvements for these selected map elements. In addition to principles that must be followed irrespective of the media the maps are published in, we also provide suggestions for publication in digital interactive environments. With the integration of high-quality cartographic content into interactive environments, guided exploration and versatile visualisations will facilitate the understanding of complex data.

Colour

Thematic parameters in the large-scale maps subject to our analysis are mostly symbolized by coloured areas. Different thematic parameters are favorably distinguished by varying colour hues. In order to reflect the characteristic of the process, blue colours are often used for the illustration of water depths or wave heights, while the choice of red colour schemes is associated with risk, hazard and danger. With the exception of these two examples, there is hardly any connection between the choice of colour hue and the characteristics of the natural phenomenon. This fact is also reflected in some answers of the expert survey, where the choice of colours is questioned. The choice of colour hue should be made carefully because it is an important variable to create visual attention (Wolfe and Horowitz, 2004). A poor choice of colour can confuse map users (Keller and Keller, 1994).

The visual variables colour saturation and colour value are sparsely used although they are well suited to illustrate differences in quantity (Figure 13a).

A further weak point is the ignorance of the fact that 8% of all men are affected by colour vision deficiencies (Birch, 1993). If colours schemes are not adapted to their needs, the displayed information cannot be interpreted. For users with defective colour vision at least one colour scheme with strong contrasts should be offered. Jenny and Kelso (2007) or Olson and Brewer (1997) provide further information on design suggestions for colour vision impaired map users.

Harrower and Brewer (2003) provide advice for suitable colour schemes that are attractive, support the message of the map and are appropriately matched to the nature of the data. There are three types of colour schemes: (1) sequential schemes which are suitable to depict classes of increasing

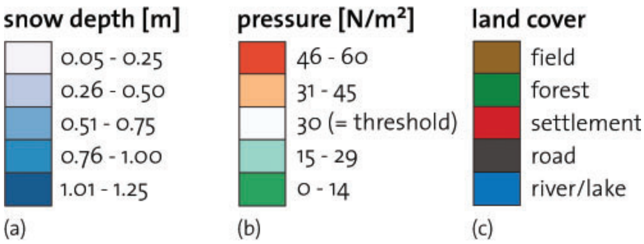

Figure 13. Examples of a sequential scheme (a), a diverging scheme (b) and a qualitative scheme (c)

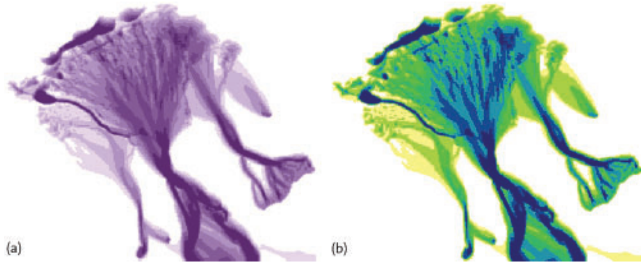

Figure 14. Classes depicted in single-hue colour schemes (a) are harder to distinguish than classes depicted in multi-hue colour schemes (b)

values (e.g. intensities); (2) diverging schemes with which values above/below a critical value can be emphasized (e.g. critical pressure to destroy a house); and (3) qualitative schemes which illustrate different classes of nominal data rather than magnitude differences (e.g. land cover). Examples of these different colour schemes are shown in Figure 13.

The choice of colour has also to allow for a distinction between data classes. For many of the analysed maps, this distinction is difficult or impossible. With the use of multi-hue colour schemes (use of two different colour hues for opposite ends of scheme) instead of single-hue colour schemes, the distinction of different data classes is facilitated. Figure 14 illustrates the difference between such schemes.

Some colours are associated with a meaning or a characteristic. Red for example is associated with danger and risk in the USA, but is a colour of joy in China (Edsall, 2007). Such variations between cultures have to be considered before depending on such conventions.

Intuitive map interpretation (especially in the case of multiple overlays) can be facilitated by the choice of a colour which represents the natural characteristic of the thematic parameter (e.g. blue for water and brown for mud flows). Furthermore, it has to be considered that only colour hue is appropriate for qualitative phenomena, as value (lightness) and saturation differences suggest quantitative differences (Slocum *et al.*, 2008).

If maps are published in a digital interactive environment, different colour schemes can be offered and interactively be chosen by the users. The resulting customisation of hazard visualisations can satisfy differing user needs because standard colour schemes, schemes suitable for colour vision impaired users, as well as many other options, can be provided.

Finally, it also has to be considered on which media the map will be published; colour schemes will look differently

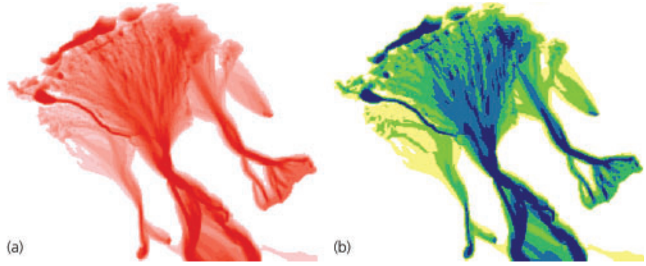

Figure 15. Too many classes (a) are harder to distinguish than fewer classes (b), here combined with a multi-hue colour scheme

depending on software and hardware configurations. Harrower and Brewer (2003) discuss hardware considerations such as different computer screens or printing techniques.

Data classes

The distinction between data classes in the analysed maps is sometimes difficult due to an unsuitable choice of colour, but often this is aggravated by the creation of too many classes; we found maps with up to 35 classes, specifying numerous different hazard, risk and damage zones. While differences in colour hue can be perceived for numerous data classes, differences in value or saturation can only be distinguished for a limited number of classes. The number of data classes for ordinal and rational data is essential in map design; many classes result in an 'information rich' map with less generalisation but can compromise map legibility (Harrower and Brewer, 2003). If too many classes are used, distinction between colour value and saturation of single classes becomes difficult (Figure 15a).

Slocum *et al.* (2008) suggest using 5–7 classes. If the classes are spatially evenly distributed, more classes can be used because similar colours can be distinguished more easily if they are situated next to each other (Harrower and Brewer, 2003). The choice of a colour scheme that characterizes the nature of a process combined with a small number of data classes that are distinguished by varying colour value or saturation allows for an unambiguous and intuitive representation even in the case of symbolisation overlays.

In an interactive environment, the task of choosing the number of classes can be left to the users, as this facilitates the data analysis. However, in order to prevent the use of too many classes, there should be an upper limit instituted as suggested by Harrower and Brewer (2003).

Base map

Base maps are important for general orientation (geospatial reference) and detailed localisation of areas of interest. The base maps in our assessment include raster data (topographic maps, survey maps, aerial images, shaded reliefs and geomorphologic maps) as well as linear features (buildings, road/railway/river networks, contour lines, coordinate grid, boundaries and coastlines). Although these maps serve as background for the thematic parameters, the contrast between base map and thematic symbolisation is not always optimal; many base maps are too dominant. This hinders the interpretation of the thematic data (Figure 16a).

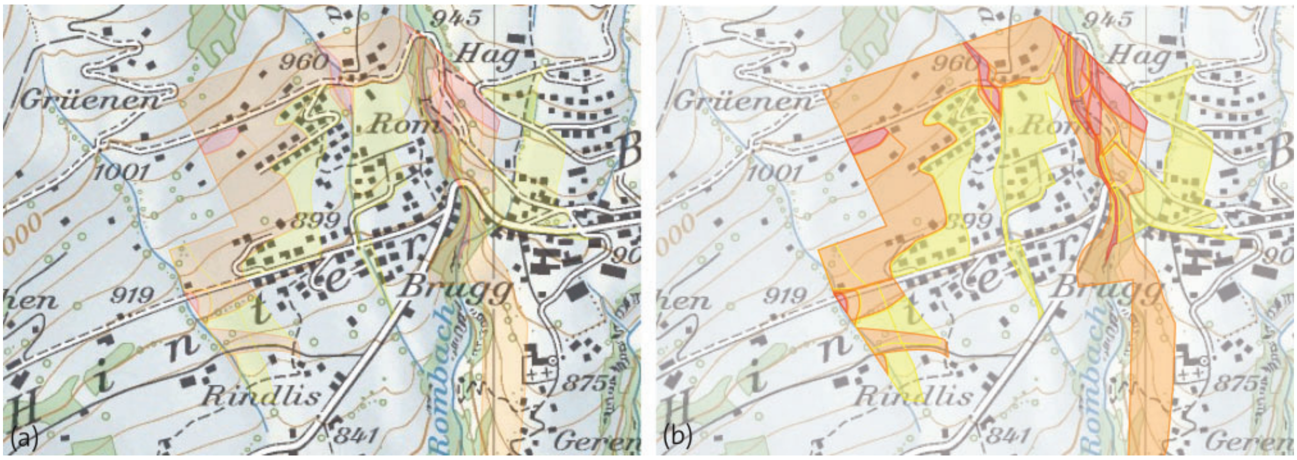

Figure 16. Transparent thematic layers on dominant base maps (a) are less distinctive than bright thematic layers on transparent backgrounds (b) [base map reproduced with the authorisation of swisstopo (JD100042); hazard data: courtesy of Canton SG]

Base maps have to be accurate and in accordance with the thematic data in order to avoid an offset of the two map layers. However, the visual match between base map and thematic symbolisation must also be considered, as it is important for a clear map design (Spiess, 1971). Therefore, elements of the base map have to be graphically subdued compared to thematic symbolisation; bright colours, strong hues, salient symbols and labelling are reserved for the thematic topics (Imhof, 1972). Fuchs *et al.* (2009) conclude that less information on the base map distracts less from the important thematic features. For backgrounds with an extensive amount of information such as aerial images or topographic maps, contrast has to be adjusted so it is evident that the thematic elements represent the primary content of the map (Figure 16b).

Substance and graphical features of base maps depend on the scale, on the content and goal of the thematic map to be produced, but also on available resources. Therefore, existing base maps or elements thereof are used and all further graphic design has to be adapted to them (Imhof, 1972).

Today, a variety of digital base data are widely available and vector data allow for a more selective choice and individual symbolisation of basic elements. In digital interactive environments, we can not only offer different elements for the map background, but also vary the level of transparency for the adjustment of base map and thematic elements. If zooming is possible in wide ranges, so-called adaptive zooming (Brühlmeier, 2000) is recommended: different base maps (raster or vector) are set as default background for predefined ranges of scale.

Texture

Texture is mainly used for areal symbolisation and acts assortatively; the denser the texture, the higher the value (Imhof, 1972). The visual variable texture is well suited to associate map symbolisation with natural phenomenon (e.g. waves for inundated areas, snowflakes for snow avalanches, etc.). Such associations are important for intuitive comprehension.

For the majority (over 90%) of the analysed large- and medium-scale hazard maps, areal symbolisation is used, with colour hue as the most frequently used visual variable. Although the visual variable texture would be well suited to solve overlay problems in multivariate maps, only few of the analysed maps contain the visual variable texture. In three black-and-white maps, textures are used as colour substitutes and also in some coloured maps, texture is used instead of an additional colour. However, good examples for the use of texture could be observed; in one map, wave-like patterns are applied for the visualisation of inundated areas. Spacing between the waves is proportional to water depth (i.e. the deeper the water, the denser the texture). Unfortunately, this is an isolated case and most map makers did not make use of the cartographic potential of textures.

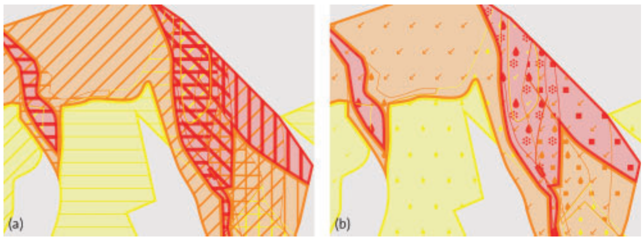

Figure 17. Overlaying texture is hard to interpret (a) while gridded patterns prevent occlusion of symbolisation (b) (illustration: Romer, 2009; hazard data: courtesy of Canton SG)

If more than one thematic data layer is displayed, textures can overlay and lead to omission of important information. Also, if texture is not carefully chosen and applied, it can appear chaotic and disturb the overall balance of the map (Figure 17a). An example to prevent such overlays is a gridded pattern. Since every layer has a designated position for its symbols that cannot be occupied by another layer, symbolisation overlays are avoided (Figure 17b).

Legend

The legend supports the orientation of the map reader and contains information on the depicted thematic topics. If the legend is not clearly visible or if it is ignored by the map readers, they cannot decipher the map content which can result in misinterpretation.

Legends should be kept short (Fuchs *et al.*, 2009) and only contain descriptions of depicted content. Legend entries have to be identical to the map symbolisation (e.g. line width, size of point symbolisation, etc.). If zooming is possible, the legend entries have to be adjusted for each zoom level. For advanced digital cartographic information systems, interactive features such as automatic size adjustment of the legend window, integrated functions for the customisation of symbolisation and the bidirectional highlighting of legend entries and active data classes facilitate the handling of the systems. For more information on such smart legends, consult Cron *et al.* (2008).

Generalisation

Whenever real-world phenomena are scaled down in order to be presented on a map, a certain degree of generalisation must be applied. Generalisations include interpretation, selection and omission of available data which means that cartographers consciously pre-process data for their users. In order to keep the map appearance balanced, some available information might have to be neglected or assigned a lower level of importance. Detailed information about cartographic generalisation can be found in Hurni and Sell (2009).

Modern computing environments allow for hazard assessments with high spatial resolution, which results in the generation of enormous amounts of data. This raw data have to be pre-processed before it can be visualized in order to avoid chaotic and overloaded maps.

Before hazard assessment results can be displayed, editorial work has to be consciously performed by the map maker. An example is the smoothing of coarse raster data so that the outlines are not jagged and can be integrated in the map without being visually striking (Figure 18). Another important task is the filtering of raw data before it is presented to the map readers. The more responsibility is taken during this task, the easier a map can be read and interpreted by the users.

Animation

The nature of dynamic processes can be emphasized by animations. An example found among the analysed maps is a sequence of satellite images taken during a flood event. This is a suitable means to get an overview on inundated areas and to locate the source (e.g. breach of river embankment) of the inundation. The disadvantage is that no detailed information such as water depth is available. Other animations include 2.5D city models where the rising of the water level during a flood is displayed. A similar example shows the spreading of a forest fire by a sequence of 2D intensity maps mapped on a digital elevation model. This method has also been extended to versions with animated columns or other 3D objects on the surface of a digital elevation model. Animations are especially interesting for time dependant processes as they help to understand manifold data.

But although motion is a beneficial attribute to guide the deployment of attention, Monmonier and Gluck (1994), Oberholzer and Hurni (2000), Wolfe and Horowitz (2004), as well as Kardos *et al.* (2006), found that blinking areas, animated choropleth maps and other dynamic variables can be considered annoying and visually unappealing by map readers and distract them from other map elements. If dynamic map elements are used, they should be chosen carefully and only applied for the most relevant information as other visualisations will be marginalized.

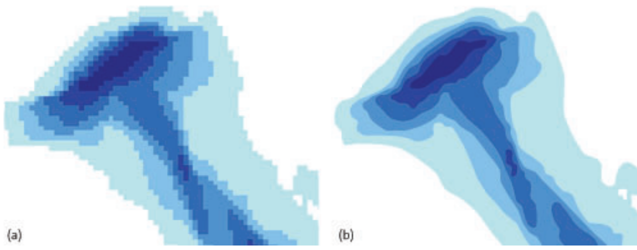

Figure 18. Raw raster data (a) can be visually striking and should be smoothed in order to obtain a natural appearance (b)

Interactivity

Twelve of the assessed maps are part of online map applications. These so-called geoportals offer different levels of interactivity. Zooming and panning as well as the management of layer visibility are possible in all analysed geoportals. More sophisticated portals offer further functionality such as tooltips or windows with information on attribute values, measurement of distances, search functions and print options.

If hazard assessments have been performed on a local level, assessment results are available in high spatial resolution. Many providers of geoportals make these detailed data accessible for their users. However, the display of these data only makes sense if the concept of adaptive zooming (Brühlmeier, 2000) is applied. Otherwise, the display is clogged with too much information that is not graspable by the user.

CONCLUSIONS

The analysis of over a hundred hazard visualisations and the results of an expert survey enabled us to indentify existing shortcomings of hazard visualisations and to suggest improvements for certain map elements. The visual variable colour hue is most frequently used for the depiction of hazardous processes and large-scale maps are dominated by areal symbolisation filled in different colour hues. The choice of a colour scheme has to be performed with care as it is not only important for a visually appealing map, but also to facilitate the distinction between data classes and the general visual exploration of the data. The potential of texture was found to be underestimated by mapmakers, as only few maps exhibit the use of texture, although they can associate map symbolisation with the characteristics of natural phenomenon which facilitates the intuitive interpretation of the map. In addition, texture can be used to avoid the overlay of map symbolisation in the case of multivariate mapping. Another vital element of hazard visualisation is the base map. Accurate and high-resolution base maps that are adjusted to the symbolisation of thematic data are a prerequisite for a high-quality map design. If maps are published in digital interactive environments, the concept of adaptive zooming has to be applied in order to avoid overloaded and confusing visualisations.

Apart from the coordination of these elements, maps also have to be adjusted to the needs of the user group. As the user group of natural hazard visualisations is heterogeneous, digital interactive environments can offer solutions to customize different map elements according to differing user needs. Many maps are designed by practitioners with limited resources and under time pressure. However, with only a small investment of time, maps can be enormously upgraded if the most important cartographic principles are followed.

The combination of cartographically well-designed maps with interactive functionality of digital environments leads to customized maps, therefore to a better understanding of map displays, and consequently to the enhancement of the communication of hazard assessment results.

BIOGRAPHICAL NOTES

Melanie Kunz is a research assistant and PhD student at the Institute of Cartography at the ETH Zurich. After her studies in geomatics engineering at ETH Zurich, she worked as a project engineer in the field of river engineering and hazard mapping before returning to ETH Zurich. Research in connection with her PhD thesis includes the establishment of an interactive cartographic system for the visualisation of natural hazard data as well as the challenge of determining and visualizing uncertainties inherent to natural hazards assessments.

Lorenz Hurni is professor of cartography and director of the Institute of Cartography at the ETH Zurich. He is managing editor-in-chief of the Atlas of Switzerland, the Swiss National Atlas, and the Swiss World Atlas, the official school atlas. His current research focus is on cartographic data models, tools for the production of printed and multimedia maps, as well as interactive, multidimensional multimedia map representations.

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REFERENCES

Bertin, J. (1983). **Semiology of Graphics: Diagrams, Networks, Maps**, University of Wisconsin Press, Madison, WI.

Bezzola, G. R. and Hegg, C. (2008). Ereignisanalyse Hochwasser 2005, Teil 2 – Analyse von Prozessen, Massnahmen und Gefahrengrundlagen, Umwelt-Wissen. BAFU, WSL. Bern, Switzerland.

Birch, J. (1993). **Diagnosis of Defective Colour Vision**, Oxford University Press, Oxford.

Brühlmeier, T. (2000). Interaktive Karten – adaptives Zoomen mit Scalable Vector Graphics. MSc thesis, ETH Zurich. http://www.ika.ethz.ch/teaching/Diplomarbeit-Bruehlmeier.pdf (accessed 4 October 2010).

Chesneau, E. (2004). 'Proposition pour une cartographie du risque', **Le Monde des Cartes**, 181, pp. 55–70.

Cron, J., Wiesmann, S. and Hurni, L. (2008). 'Facilitating the handling of interactive atlases by dynamic grouping of functions – the example of "Smart Legend"', in **Geospatial Vision – New Dimensions in Cartography**, ed. by Moore, A. and Drecki, I., pp. 1–18, Springer, Berlin/Heidelberg.

Edsall, R. (2007). 'Cultural factors in digital cartographic design: implications for communication to diverse users', **Cartography and Geographic Information Science**, 34, pp. 121–128.

Fuchs, S., Spachinger, K., Dorner, W., Rochman, J. and Serrhini, K. (2009). 'Evaluating cartographic design in flood risk mapping', **Environmental Hazards**, 8, pp. 52–70.

Hagemeier-Klose, M. and Wagner, K. (2009). 'Evaluation of flood hazard maps in print and web mapping services as information tools in flood risk communication', **Natural Hazards and Earth System Science**, 9, pp. 563–574.

Harrower, M. and Brewer, C. A. (2003). 'Colorbrewer.org: An online tool for selecting colour schemes for maps', **The Cartographic Journal**, 40, pp. 27–37.

Huber, S., Sieber, R., Rüegsegger, M. and Hurni, L. (2007). 'Multivariate Mapping in High Quality Atlases', in **23rd ICA/ACI International Cartographic Conference ICC**, Moscow, Jun 23–27, CD-ROM.

Hurni, L. and Sell, G. (2009). 'Cartography and architecture: interplay between reality and fiction', **The Cartographic Journal**, 46, pp. 323–332.

Imhof, E. (1972). **Thematische Kartographie**, Lehrbuch der allgemeinen Geographie, Walter de Gruyter & Co., Berlin.

Ives, J. D., Mears, A. I., Carrara, P. E. and Bovis, M. J. (1976). 'Natural hazards in mountain Colorado', **Annals of the Association of American Geographers**, 66, pp. 129–144.

Jenny, B. and Kelso, N. V. (2007). 'Color design for the color vision impaired', **Cartographic Perspectives**, 58, pp. 61–67.

Kardos, J., Moore, A. and Benwell, G. (2006). 'Expressing Attribute Uncertainty in Spatial Data Using Blinking Regions', in **7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences (Accuracy 2006)**, pp. 814–824, Lisbon, Portugal, Jul 5–7.

Keller, P. R. and Keller, M. M. (1994). **Visual Cues: Practical Data Visualization**, IEEE Computer Society Press, Los Alamitos, CA.

Kienholz, H. (1977). 'Kombinierte geomorphologische Gefahrenkarte 1 : 10000 von Grindelwald', **CATENA**, 3, pp. 265–294.

Kienholz, H. (2005). 'Analyse und Bewertung alpiner Naturgefahren – eine Daueraufgabe im Rahmen des integralen Risikomanagements', **Geographica Helvetica**, 2005, pp. 3–15.

Kunz, M. and Hurni, L. (2008). 'Hazard Maps in Switzerland – State-of-the-art and Potential Improvements', in **6th ICA Mountain Cartography Workshop**, Lenk, Feb 11–15, pp. 133–138.

Loat, R. and Petrascheck, A. (1997). Berücksichtigung der Hochwassergefahren bei raumwirksamen Tätigkeiten. BWW, BRP, BUWAL. Bern, Switzerland.

MacEachren, A. M. (1994). **Some Truth with Maps: A Primer on Symbolization and Design**, Association of American Geographers, Washington, DC.

Morgan, G. C., Rawlings, G. E. and Sobkowicz, J. C. (1992). 'Evaluating total risk to communities from large debris flows', in **Geotechnique and Natural Hazards Symposium**, pp. 225–236, BiTech Publishers, Vancouver, BC.

Monmonier, M. and Gluck, M. (1994). 'Focus groups for design improvement in dynamic cartography', **Cartography and Geographic Information Science**, 21, pp. 37–47.

NatHazMap (2010). NatHazMap.com – the web resource for natural hazard maps and information. http://www.nathazmap.com (accessed 11 October 2010).

Oberholzer, C. and Hurni, L. (2000). 'Visualization of change in the Interactive Multimedia Atlas of Switzerland', **Computers and Geosciences**, 26, pp. 37–43.

Olson, J. M. and Brewer, C. A. (1997). 'An evaluation of colour selections to accomodate map users with colour vision impairments', **Annals of the Association of American Geographers**, 87, pp. 103–134.

Petrascheck, A. and Kienholz, H. (2003). 'Hazard assessment and mapping of mountain risks in Switzerland', in **Debris-flow Hazards Mitigation: Mechanics, Predictions, and Assessment**, ed. by Rickenmann, D. and Chen, C., Vol. 1, pp. 25–38, Millpress, Rotterdam.

Romer, S. (2009). Multi-Naturgefahrenkarten: Darstellungsmöglichkeiten untersucht anhand der grafischen Variablen. Unpublished term paper, ETH Zurich, Zurich. http://www.ika.ethz.ch/teaching/VTB-Romer.pdf (accessed 13 December 2010).

Schnabel, O. (2007). Benutzerdefinierte Diagrammsignaturen in Karten. PhD thesis, ETH Zurich. http://e-collection.ethbib.ethz.ch/view/eth:29352 (accessed 13 October 2010).

Slocum, T. A., McMaster, R. B., Kessler, F. C. and Howard, H. H. (2008). **Thematic Cartography and Geovisualization**, Prentice Hall Series in Geographic Information Science, Prentice Hall, Upper Saddle River, NJ.

Spiess, E. (1971). 'Wirksame Basiskarten für thematische Karten', in **Internationales Jahrbuch für Kartographie**, ed. by Arnberger, E. and Aurada, F., ICA, Kartographisches Institut Bertelsmann, Gütersloh, pp. 224–238.

SWA. (2008). **Schweizer Weltatlas**, Ausgabe 2008, Konferenz der kantonalen Erziehungsdirektoren (EDK), Zurich.

Varnes, D. (1984). **Landslide Hazard Zonation: A Review of Principles and Practice**, Unesco, Paris.

Wilkinson, L. (1999). **The Grammar of Graphics**, Satistics and Computing, Springer.

Wolfe, J. M. and Horowitz, T. S. (2004). 'What attributes guide the deployment of visual attention and how do they do it?', **Nature Reviews Neuroscience**, 5, pp. 495–501.

Zimmermann, M., Pozzi, A. and Stoessel, F. (2005). Vademecum – hazard maps and related instruments – the Swiss system and its application abroad – capitalization of experience. DEZA, Bern, Switzerland.