A REVIEW OF COLOUR AND CARTOGRAPHY IN AVALANCHE DANGER VISUALIZATION

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ABSTRACT: Attention is being given to the visualization of avalanche danger through the use of geographic information systems (GIS), much of it focusing on the representation of the danger scale. Effort is underway in the avalanche community to review the adequacy of the five-level scale in communicating risk understanding to the public. Recent research in related fields support change in convention and adoption of a set of cartographic and signal word design rules. This paper reviews the use of color in the conveyance of snow avalanche hazard, danger through cartographic visualization. It concludes with suggested avalanche danger scale colour models for three desired understanding outcomes and cartographic techniques for evaluation through further research.

Keywords: avalanche danger scale, risk communication, visualization, avalanche mapping

> "Assessments of change, dynamics, and cause and effect are at the heart of thinking and explanation. To understand is to know *what cause provokes what effect, by what means, at what rate*. How then is such knowledge to be represented?" (Tufte, 1997)

1 INTRODUCTION

We experience danger every day. We encounter many hazards minor and great. We are bombarded with signal word safety messages (e.g. danger, caution, warning) and interact with safety devices so regularly they become background noise in our routines. In the later 1990s, Canada and the U.S. adopted an ordinal, five-level scale to communicate public avalanche danger. These levels are used to summarize the danger for specific geographic regions in public avalanche bulletins issued on a regular basis throughout the winter. A recommendation to Parks Canada in the 2003 Backcountry Avalanche Risk Review (O'Gorman et al., 2003) proposed a "review of the language in the current danger scale with a view to assessing potential refinements and introducing improvements to enhance both its understandability and utility to backcountry recreational users."

The unique geographic relevancy of avalanche danger has prompted both recent developments and widespread interest in the use of GIS in the identification, representation, and forecasting of snow avalanche hazard and risk. Internet mapping is being used increasingly to communicate the avalanche danger to the public. Cartographic guidelines have been established for avalanche risk mapping in Canada (CAA, 2002), however similar cartographic rules have not been established for the graphic representation of public avalanche danger.

Research in fields such as ergonomics suggests the original choices of colours for the avalanche danger scale are no longer optimal (Griffin and Leonard, 1997). They may confound understanding and perception of the risk message.

In this article I review colours associated with the North American avalanche danger scale with inclusion of research on improving warning communication, describe other examples of hazard-zone mapping, and conclude with proposed colour models for three desired understanding outcomes.

2 CARTOGRAPHY and COLOUR

Cartography is science and art. It is the intelligent generalizing and selecting of features to

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be represented by the effective use of lines and colours (Raisz, 1938). Raisz attributes P.E. James with recounting the essential problem of cartography, "to reduce the larger patterns of the face of the earth to such proportions that they can be comprehended in a single view." Use of black and white is commonly the special case in cartography with colour considered a fundamental to mapping. Colour is described as the most complex single cartographic medium, most interesting element of cartographic design, and the most frustrating (Robinson, 1953; Robinson and Sale, 1969). Colour assists in the gestalt of a picture; the instantaneous mental organization of what is figure and what is ground (Sharpe, 1974).

A literature review for cartographic reference to colour was conducted for this paper. Assembled here are a handful of design guidelines for colour use appropriate to the task of demarking areas and conveying the underlying concepts of avalanche danger on a map.

- The first principle in bringing colour to information: Above all, do no harm. (Tufte, 1990)
- Avoid colourings that deceive the viewer regarding the scientific accuracy of a map. (Eckert according to Robinson, 1952)
- Use colour as a simplifying and clarifying element. (Robinson and Sale, 1969)
- Coloured spots against a muted field highlight and italicize data. (Imhof according to Tufte, 1990)
- Select colours that produce appropriate subjective effects. (Robinson and Sale, 1969)
- Where colour fails to convey, symbology might be used to serve the attention getting purpose. (Griffith & Leonard, 1997)
- Know how to obtain desired final printed colour [especially web publication]. (Robinson et al., 1978)

Multiple signals and overlapping methods of data representation will help overcome the ambiguities and visual complication of a design. Edward Tufte (1990) cautions only "a crystalline, lucid redundancy will do".

3 HAZARD-ZONE MAPPING

Monmonier brings the concept of hazard-zone mapping to a wide audience in the *Cartographies of Danger*, coining it as a recent (post 1950) phenomenon. He supposes a revolutionary dependence on danger maps by the public (1997). However, maps of avalanche hazard zones have been around over a hundred years and are well entrenched in land-use planning and zoning (Niemczyk, 1982; Mears, 1992).

The delineation of zones for avalanche hazard and risk analysis for land-use planning was first codified in Switzerland. Red, blue, yellow, and white zones are used to differentiate frequent and destructive avalanches from less frequent and less powerful. Red and blue are used in many states; Alaska uses them to differentiate risks of 1-in-10 year and 1-in-100 year probabilities. Guidelines have been established for Canada specifying red, blue, and white zones identified by colour coding or text when mapping the hazard area associated with avalanche risk assessments (CAA, 2002).

4 AVALANCHE DANGER VISUALIZATION

4.1 Visualization

Avalanche safety lies in efforts to overcome uncertainty in the understanding of the current and future state of the snowpack. This section builds a framework of support for a set of avalanche danger visualization cartographic guidelines to support understanding. The earlier mentioned essential problem of reducing the larger patterns to such proportions that they can be comprehended in a single view can also be attributed to visualization. Keller and Keller (1993) suggest three steps to follow for successful visualization:

- Identify the visualization goal, whether it is exploration, analysis, or presentation.
- Remove mental roadblocks.
- Decide whether data or phenomena are being visualized.

The mental application (visualization) of the components defining avalanche danger to specific geography and terrain configurations are the logical foundation for significant interest in GIS as medium, method, and data organization. A brief Internet search on 25 March 2004 substantiated this trend, revealing several conference papers, four 3rd year or better university geography/GIS course projects, and two-master's theses on GIS and avalanches. Several of the avalanche forecast centers throughout the world are currently

attempting to convey the avalanche danger information through mapping or coloured visual hierarchy on the screen. Long before GIS and Internet mapping, Robinson (1952) described a challenge: "the manner of presentation becomes of primary significance […] and approaches critical consequence with respect to the special purpose map, the map which treats but a few categories of data." The cartographic communication of avalanche danger is a prime example of such a special purpose map. The representation of the five levels of the North American avalanche danger scale must communicate critical consequence and support understanding.

Visualization can be successfully accomplished by applying a set of cartographic guidelines according to the desired understanding of the avalanche danger scale. Table 1 provides the salient descriptors from the current North American avalanche danger scale and three colour model interpretations. These three models can enhance understanding through colour choices associated with the signal words of the avalanche danger scale. The first illustrates the natural hazard colour model based on the existing cartographic guidelines (CAA, 2002).

The next two address the interactive hazard based on human actions. The second is based on a travel-control stoplight model and the third is associated with human consequence as a basis of information for risk-based decision-making.

Danger Scale Descriptors			Interpretive Colour Models		
N. American Danger Level and Colour	Avalanche Probability of Human Trigger	Geographic Distribution	Natural Hazard Probability	Recommended Action in Avalanche Terrain	Severity of Risk Consequence
Low (green)	Unlikely		Very unlikely (blue)	Generally safe (green)	Minimal
Moderate (yellow)	Possible	Steeper terrain on certain aspects.	Unlikely (blue)	Caution (yellow)	Death or severe injury (red)
Considerable (orange)	Probable	Steeper terrain	Possible (red)	Increasingly cautious (yellow)	Death or severe injury (red)
High (red)	Likely	All avalanche terrain	Likely (red)	Travel not recommended (red)	Death or severe injury (red)
Extreme (red w/ black)	Certain	Widespread, full path runouts	Certain (red)	Avoid travel (black)	Death or severe injury, multiple casualties

Table 1. Colour models for enhancement of the avalanche danger scale are shown in the right two columns.

4.2 Travel Guidance Model

This model begins with the primary rule of *do no harm*. In terms of travel advice, there are two geographical regions in avalanche hazard / danger: you are, as Kesey says, "either on the bus or not on the bus." (Perry and Babbs, 1990) You are in avalanche danger being in the avalanche path or not in avalanche danger if you are not in the avalanche path. To do no harm in communicating avalanche danger, green could be reserved for go/no danger/no avalanche risk. If it is used for low hazard in a path, there is no differentiation between avalanche terrain and non-avalanche terrain. However the use of green concurs with the widely used decision support description of "green light terrain" (Fredston and Fesler, 1994). Blue has been specified in avalanche risk mapping guidelines (CAA, 2002) as areas of lower risk and is therefore a logical choice to replace green for Low. Using blue for low danger avoids confusion with other "green-light" public information systems.

Yellow is difficult to use without significant thought to its background or contrast. The danger information should be of the highest visual hierarchy on the map without detracting from the essential topographic information on the base map. The gestalt of figure/ground with yellow as figure is unfortunately best with black ground (Sharpe, 1974). Yellow does adequately represent caution, the correct response to the conditions of Moderate danger. Yellow can be used for a large area without becoming loud. In a five level scale, yellow can still be used to highlight or italicize the condition.

Orange has no place in the scale. In a study with appropriate test design, orange consistently failed to be associated with any perceived level of risk (Griffin and Leonard, 1997). Orange works solely as part of a spectrum being between yellow and red when seen in the danger scale table, index, or contoured data. Orange by itself does not add information to the understanding. Understanding does not lose anything by being black and white even when the index is visible with the right map. Orange in fact is synonymous with high visibility safety equipment.

It is accepted that the colour orange cannot consistently be printed or projected using red/green/blue (RGB) and cyan/magenta/yellow/black (CMYK) formats. Cartography requires printing or projecting to a screen or monitor. This obstacle may account for its low ranking by the subjects in the ergonomic studies. They were presented with printed samples. Orange fails to meet many of the colour guidelines of cartography in its application to avalanche danger signal words. It confounds and confuses the intended message.

4.3 Consequence Model

Studies in risk communication find the public's perception of hazard is more strongly related to the severity of injury rather than likelihood of injury (Wogalter et al., 1991). This is good. It can alleviate need of the accompanying description of the likelihood of the existence of danger, i.e. probability of natural or human triggered avalanches, in reviewing the comprehension of the danger level.

The potential severity resulting from the occurrence of an avalanche does help to differentiate the scale into two ranges of consequences. The consequence to a human, i.e. the severity, of an avalanche involvement is death or severe injury. The severity does not decrease incrementally as the scale levels incrementally decrease. The two ranges are minimal and high (i.e. not very likely and the remaining levels where human triggered avalanches are possible through certain). This consequence-based model suggests red be used from moderate through extreme.

5 SIMPLIFIED MODEL

5.1 Colour Use

A five level scale leaves the third level in the middle, from the forecaster's perspective this is where the conditions could go either way toward low or high. From the recreationist perspective, it is middle of the road. This is where Considerable falls on the five level scale. Quantitative research has suggested that a five-level scale is undesirable for backcountry danger scale and a four-level scale is preferable (McClung, 2000).

The descriptions presented here in support of the consequence and travel model visually also support a simplified four-level scale. There are two possible ways in which to accomplish this.

The level Extreme is commonly the warning level, an extreme high condition. Including extreme visually may unnecessarily bias the viewer that Considerable is the middle range. One option is to leave off extreme for only avalanche warning conditions. This does not address the confusion over the word considerable. McClung (2000) offers sound and quantifiable support of consolidating Considerable into High based on the similar requirements of the two levels for exercising higher caution.

A simplified colour model of the following relationships is suggested:

Low > Blue
Moderate > Yellow
High > Red
Extreme > Red with Black

5.2 Cartographic Design

If the entire area is coloured in, it leads the viewer to a false impression that the danger rating is all that is important. For ranges on the scale when recreation is not completely ill advised or when the scale of map provides key data, the underlying information of the map should be visible whether it is just for locations or more detailed topography. Outlining the avalanche path in the selected colour, blue or red immediately provides key geographical and consequence information.

A larger amount of additional information is required to make travel under the higher level of risk conditions. The majority of this information directly relates to the questions posed in evaluating the avalanche triangle.

A cartographic design model of the following relationships is suggested:

Low > Area 30% filled with smaller sized blue triangles on a transparent background.
Moderate > Area 30% filled with smaller sized yellow-filled, red-outlined triangles on a transparent background.
High > Area 30% filled with larger sized red triangles on a transparent background.
Extreme > Area 30% filled with smaller sized red-filled, black-outlined triangles on a transparent background.

This highlights the hazard location, consequence, uncertainty in the conditions, and directs the systematic gathering of key information based on fundamental avalanche safety training pedagogy. The font size of the smaller and larger triangles should follow scale relative cartographic lettering guidelines.

6 CLOSING THOUGHTS

I have reviewed colours associated with the North American the avalanche danger scale, explored contributions from recent research to improve warning communication, described other examples of hazard-zone mapping, and suggested a colour and a cartographic model. The suggestions are associated to desired understanding outcomes of three danger/hazard/risk relationship interpretations of the North American five-level avalanche danger scale. The models are applicable to a simplified four-level danger scale.

Orange is not supported in the cartographic representation of avalanche danger. To separate avalanche risk terrain from non-avalanche risk terrain, blue should replace green for representation of low danger. Severity of consequence is most strongly related to perception of risk and therefore red should be used for considerable and high danger and warnings (extreme) as representative of the danger. This will enhance the scales purpose to assist recreationists in evaluating the risk that the conditions may present.

Moderate danger is best represented by yellow to convey caution however production obstacles may indicate blue as the optimal choice. Where the use of solid colour is not appropriate design, the danger scale levels should be differentiated by fill and line symbology drawing on germane avalanche safety concepts such as the avalanche triangle.

This is by no means a full answer to the larger question of a review of the language in the current danger scale to enhance both its understandability and utility to backcountry recreational users but a close look at the role and potential improvement to the scale through better signal colour use. Industry consensus needs to be reached on the desired understanding related to the goal of the avalanche danger scale. Further work needs to be accomplished in selecting the

appropriate symbolization to augment the colour use in a manner that maintains the importance of the specific geographic regions covered. Additionally research to validate actual improvement in understanding needs to be conducted.

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An avalanche (also called a snowslide) is an event that occurs when a cohesive slab of snow lying upon a weaker layer of snow fractures and slides down a steep slope. Avalanches are typically triggered in a starting zone from a mechanical failure in the snowpack (slab avalanche) when the forces of the snow exceed its strength but sometimes only with gradual widening (loose snow avalanche). After initiation, avalanches usually accelerate rapidly and grow in mass and volume as they entrain more snow. If