Decision-Making with Conflicting Cartographic Information: The Case of Groundwater Vulnerability Maps

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Conflicting cartographic information can cause problems when used to support planning decisions. Creation of conflicting information is becoming more common as geographic visualization and modeling software are used to develop multiple maps that represent different views of the same data. This paper presents groundwater vulnerability mapping as an example of information conflicts of this type. Three different vulnerability models applied to the same test data produced radically different results. This information was presented to a group of local planners to examine how they would deal with the conflicts. Through this exercise it became apparent that each planner used highly individual criteria to evaluate the results from the models. A continuum of strategies describes the range of responses from aspatial to spatial approaches. Jung's theory of psychological types is applied to further understand variation in responses. Avenues for further research are suggested in the representation of cartographic information conflicts, the role of psychological types in decision-making with maps, and the role of group dynamics in decision-making with maps.

INTRODUCTION

Conflicting visual information in cartographic representations is a potential problem in all map displays and geographic analyses. The use of multiple representations for both display and analysis has become common practice with the widespread use of geographic visualization and analysis software (e.g., geographic information systems - GIS). These software products aid in the generation of many different views of one data set, the comparison of different data sets, the use of different methods for processing data, and the construction of different analytical models. The use of these tools for purposes of visualization provides a context through which many additional insights about a topic may be gained. In this paper, the question of conflicting information in cartographic displays is pursued in order to assess variations in map use strategies and interpretations when information is contradictory. This issue became apparent during a project that investigated the use of GIS for implementing three different groundwater vulnerability models from the same data set (Rader and Janke, 1995). Different representations of groundwater vulnerability effectively illustrate the use of multiple views as suggested by Tufte (1990), Muehrcke (1990), and Monmonier (1991), since maps produced with these models supposedly represent 'similar' information. However, the maps (see Figure 1.) are quite dissimilar, and the conclusions derived from their use may be contradictory. Visual information conflicts such as these may be common to many GIS analyses.

"In many cases, decision makers fail to distinguish between the maps and the models that they represent."

Maps produced from groundwater vulnerability assessments are a primary information source employed by decision makers in developing landuse policy. Decision makers often have neither the original data nor the knowledge to assess the validity of the different models. In many cases, decision makers fail to distinguish between the maps and the models that they represent. With increased use of GIS and modeling techniques, multiple maps representing 'similar' information will likely be available and produce information conflicts for decision makers. Ultimately, knowledge about how people resolve problems with conflicting visual information should provide strategies for improving both cartographic displays and users' interpretations of these displays. To examine this question, a map use exercise based on maps from different groundwater vulnerability models was presented to a group of local planners, elected officials, and groundwater specialists.

The first part of this paper describes the vulnerability models, the context for their use, and a more formal problem statement. An overview of the map use exercise and the results are then presented. Finally, issues pertaining to the strategies that decision makers employ for dealing with visual information conflicts are discussed. In approaching this study, it is hoped that concrete recommendations can be provided on how to resolve information conflicts between maps. However, the participants' disparate responses indicated that the fundamental role of maps in decision-making was at issue and that diverse approaches to problems of conflicting information were in operation. Parallels with Jung's psychological typology are drawn upon to help understand variations in decision-making strategies. Finally, avenues for further research are suggested.

Conflicting Visual Information in Cartographic Representation and Planning

The potential for conflicting cartographic representations appears in several ways. The desirability of multiple maps for purposes of visualization has been documented by several authors. Tufte (1990) noted that small multiple maps are well suited for time series data; Monmonier (1991) suggested that multiple views of a geographic data set are more truthful (i.e., ethical) because they provide a comparative frame of reference; and Muehrcke (1990, 9) observed that a more thorough understanding may be obtained by using several different maps created from the same set of data. However, while additional insights may be generated through multiple views, visual information conflicts may arise if views display contradictory information. The question that should be asked is, what happens when map users are presented with conflicting or contradictory information?

Little work has addressed the problem of conflicting visual information between multiple cartographic displays. Typically, cartographic studies have examined map similarity and pattern comparison (Olson 1972, Monmonier 1974, Lloyd and Steinke 1976, Peterson 1985, and MacEachren and Ganter 1990). These studies have examined perceived relationships between several maps, impacts of map complexity, and map similarity. While these have provided a background for understanding the perceptual characteristics of map displays, the question of conflicts in information content between several maps remains. This becomes increasingly important in geographic information processing technologies where multiple displays may be produced from the same data set. For example, different views may be accomplished through changes in classing and symbolization schemes or the combination of multiple layers in overlay analysis.

". . . what happens when map users are presented with conflicting or contradictory information?"

Wood (1992, 186) suggests that presenting multiple "relationships constituted by the interplay of the data" is a desirable artifact of the mapping process. Muehrcke (1990) has extended this discussion to include the idea of "map stability." Map stability refers to whether or not changes in the way data are processed or symbolized have an impact on the message perceived. However, what happens when views directly conflict with one another? While seeing small differences in representations illustrates the impact of cartographic methods on displays, seeing large differences may call into question both cartographic and modeling methods and possibly their ultimate utility.

Planning involves the design and consideration of a series of alternatives. Monmonier (1991) reviewed the use of maps in zoning and environmental protection. Maps serve as tools for making planning decisions and communicating a plan's spatial implications. In DiBiase's (1990) continuum of visual thinking and visual communication, planning maps operate in both the private and public realms. The maps are used in planning policy decisions, essentially a thinking task, and in presenting planning policy decisions, essentially a communication task. In this context, the power of maps to persuade should not be overlooked (Harley 1989, Wood 1992). The 'official' nature of maps often operates at a subconscious level.

Monmonier (1991, 71) notes that "without maps, planning would be chaotic, furthermore even with maps, many would argue that planning is chaotic." In addition, he comments that errors in map compilation can be significant and that the same information is often used to develop different plans (Monmonier 1991). Planning scenarios often involve creating different conceptual models about a future reality. Different scenarios can often produce markedly different results. The 'stability' of results may be re-framed with the concept of 'model stability.' Model stability describes how representations change through the use of different models for combining data layers that were processed using the same cartographic methods. This is a case common to many GIS analyses that employ different conceptual models for describing a process. While individual data layers may have high map stability, the final maps made from different models may be unstable. The inherent stability or instability of the models may influence how decisions are made with different maps. The implementation of different models therefore has the potential to produce information conflicts. Conflicting information is a major source of chaos in the planning process.

"While individual data layers may have high map stability, the final maps made from different models may be unstable."

Groundwater Vulnerability: An Example

Maps that result from groundwater vulnerability models provide an apt example of potential cartographic information conflicts in planning. Beginning in the early 1970s, a variety of vulnerability models were developed in response to environmental concerns about drinking water. Significant health effects from drinking contaminated water have been documented; these include cancers (Armijo 1981; Lee and Nielsen 1987; Canter 1987), blue-baby disease (Lukens 1987), and central nervous system birth defects (Scragg et al. 1982). By the mid-1980s, it became apparent that planning and management tools were needed to identify places that have high vulnerability to contamination (Aller et al. 1985).

Several types of models have been developed to assess vulnerability. These models can be grouped into four major categories: hydrogeologic setting models, parameter weighting / scoring models, empirical models, and simulation models (Geraghty & Miller, Inc. and ICF, Inc. 1990). Hydrogeologic setting models use qualitative site-based assessments to rank the relative vulnerability of different areas with varying geomorphic, geological, and groundwater characteristics. Parameter weighting / scoring models numerically rank and weight susceptibility factors and calculate relative vulnerability scores for areas with different hydrogeologic characteristics. Weights are often assigned to account for variations in the relative importance of factors in particular situations, e.g., areas with thin soil. Empirical models use data that relate known occurrences of contaminants in groundwater to hydrogeologic characteristics through the application of leaching models or statistical inference. Finally, simulation models attempt to predict contaminant leaching through interactions between hydrogeologic characteristics and contaminant fate, such as dilution, breakdown, absorption, and volatilization (Geraghty & Miller, Inc. and ICF, Inc. 1990, 6-1).

Most of the models that have been applied in the context of GIS have been hydrogeologic setting or parameter weighting/scoring models. DRASTIC (Aller et al. 1987) is a general-purpose, parameter weighting model that was developed for the US EPA for vulnerability assessments at county and state levels. Several other models have been developed for state-wide assessments, including the Wisconsin Susceptibility Model (WISM) (Schmidt 1987), which uses weighted hydrogeologic characteristics to model vulnerability, and an aquifer vulnerability model of Michigan (Lusch et al. 1992), which uses hydrogeologic characteristics for determining relative risk. All of these models use a combination of data layers that include soil, subsurface geomorphic characteristics, geology, recharge rates, and topography.

Little research has addressed differences in model performance. The authors of the models often state that results from different models are not directly comparable (Aller et. al 1985; Schmidt 1987). Furthermore, Merchant (1994) notes that there is little validation of these models in the context of GIS and that there are a number of questions concerning the impact GIS processing methods have on model performance. Rader and Janke (1995) implemented several models popular in Wisconsin to address the question of model differences. In applying the models, the data layers and processing methods were held constant so that variations in the results were due to differences in model design.

"The basic problem is that even when using a common data set processed in the same way, the results are vastly different."

Three models were used: SCAM (Soil Contamination Attenuation Model) (Zaporozec 1985), WISM (Wisconsin Susceptibility Model) (Schmidt 1987), and DRASTIC (Aller et al. 1985). All are parameter scoring/weighting models that use several data layers, although not all models use all of the layers, nor do they consistently weight the layers. Maps derived from the three models for a site in St. Croix County, Wisconsin are displayed in Figure 1. The basic problem is that even when using a common data set processed in the same way, the results are vastly different. It is important to reiterate that the models' developers state that the models are not directly comparable. Regardless, it is likely that the maps represent the same thing to the lay person and many decision-makers.

Statistical analysis of the relationships between the models further corroborate the visual disparities (Table 1.). Correlation coefficients demonstrate little or no relationship in the SCAM -DRASTIC pair and very weak relationships in DRASTIC-WISM and WISM-SCAM pairs. The comparison map and coefficients of areal correspondences between the models indicate complete divergence over 22 percent of the area, with similar ratings between two of the three models over 70 percent of the area, and complete correspondence over 7 percent of the area. The coefficient of areal correspondence only indicates agreement or disagreement across the models. Therefore, the models produce conflicting risk ratings, both graphically and statistically.

Maps produced from these assessments are often the primary information used by officials for making landuse policy decisions concerning groundwater. Often, officials neither have the data nor the knowledge to assess the validity of the models. This has led to the following question:

> Given that groundwater vulnerability models produce different results and, therefore, different maps, how do decision makers respond when confronted with conflicting cartographic information?

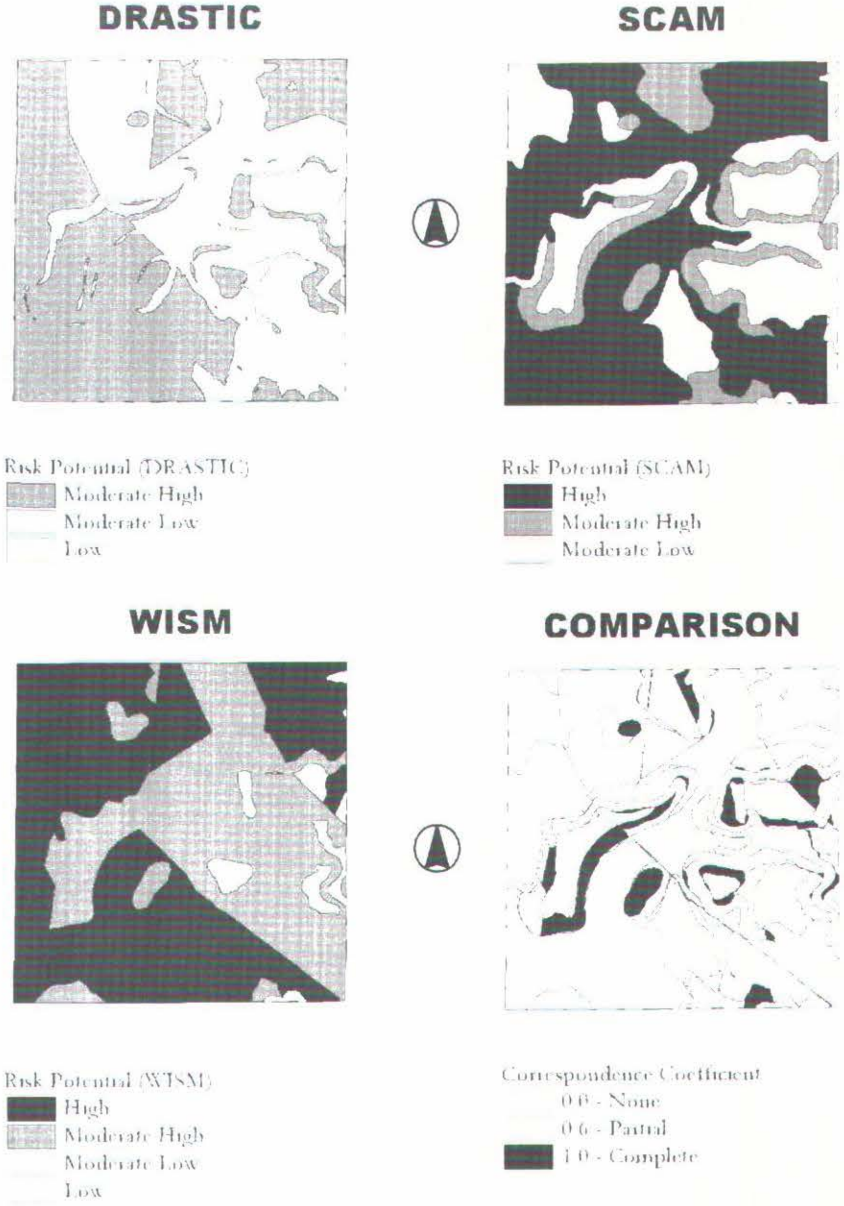


Figure 1. Groundwater Vulnerability Model Results

In asking this question, an attempt is made to understand how visual data impact decisions, especially where multiple views of the data present conflicting information.

METHODS

In order to examine the impact that conflicting visual information has on planning decisions regarding groundwater protection, the study was designed using the three conflicting maps seen earlier in Figure 1. While the models are not explicitly designed for site-level assessments, they serve a function in screening sites for further consideration. In all cases, a site-level assessment would need to be conducted prior to a final decision.

Thirteen local decision makers participated in the map-use exercise. These people were chosen because they represent typical users of vulnerability maps in planning-based decisions. The participants included five planners, three local government board members, two geologists, one civil engineer, one developer, and one farmer. Only three of the thirteen

> *"While the models are not explicitly designed for site-level assessments, they serve a function in screening sites for further consideration."*

Correlation Coefficients (standardized unclassed scores)	
SCAM-DRASTIC	0.049
DRASTIC-WISM	0.279
WISM-SCAM	0.311

Coefficient of Areal Correspondence (classed scores)	
None	22.4%
Partial	70.3%
Complete	7.3%

Table 1. Relationships between Groundwater Vulnerability Models

participants had significant experience with groundwater vulnerability models and mapping.

"The exercise had the participants identify potential sites for houses using the information on groundwater vulnerability for each of three different maps."

The exercise had the participants identify potential sites for houses using the information on groundwater vulnerability for each of three different maps. Each map was divided into four quadrants. Participants were asked to assume that all sites were equally accessible within each quadrant and that each site would have its own well and septic system. For each map, they also rated the vulnerability for each quadrant, chose the best location for a house in each quadrant, and selected the overall best quadrant for a house. A sample test page is reproduced in Figure 2. From these questions, information on perceived relative vulnerability levels and locational behavior were obtained. Such site selection problems are realistic and critical tasks for planners.

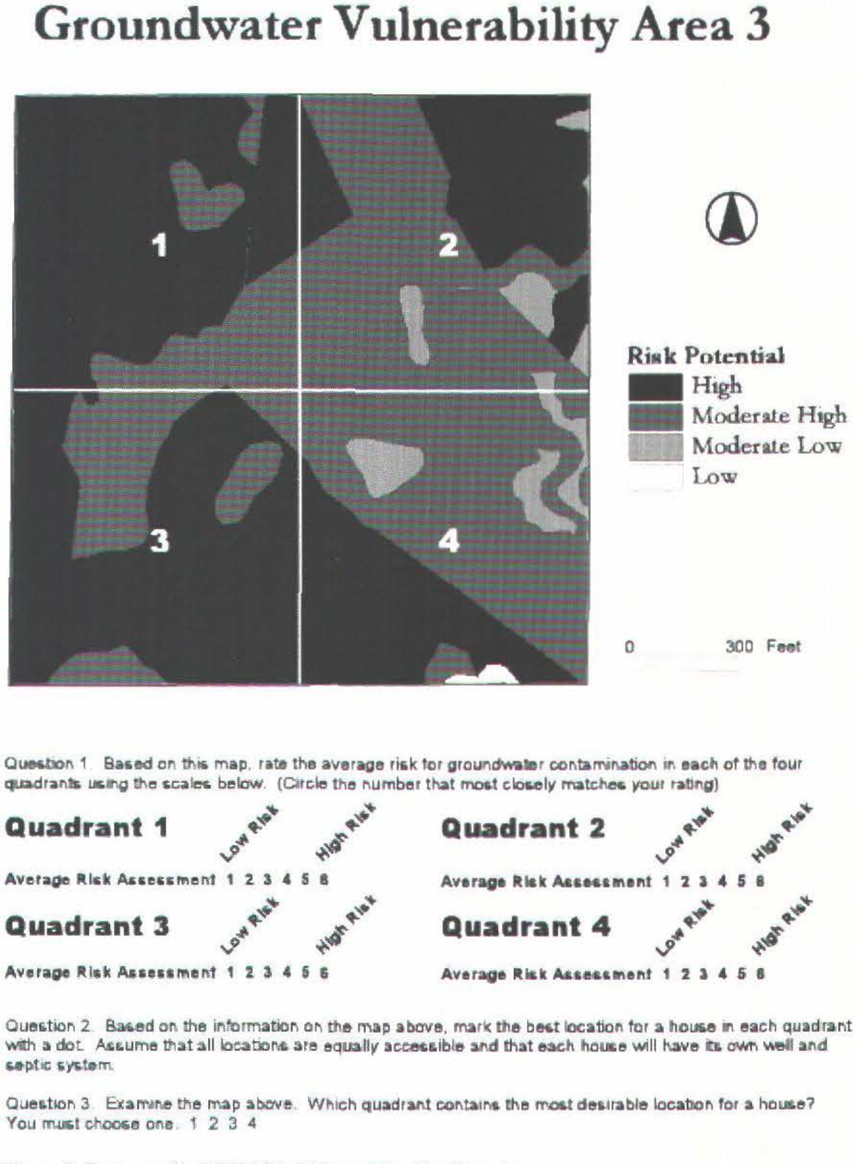
The three specific task questions were:

1) Based on this map, rate the average risk for groundwater contamination in each of the four quadrants using the scales below.
2) Based on the information on the map above, mark the best location for a house in each quadrant with a dot. Assume that all locations are equally accessible and that each house will have its own well and septic system.
3) Examine the map above. Which quadrant contains the most desirable location for a house? You must choose one.

In designing the test pages, the three maps were simply labeled as Areas 1, 2, and 3. Since the vulnerability maps had extremely low correlation coefficients (0.049 - 0.311), the maps were not rotated or flipped to mask that the maps represented the same area. In general, as the correlation coefficient of the map pairs falls below 0.84, it becomes increasingly more difficult for subject to judge similarity (Olson 1972). None of the participants noticed that the maps represented the same area during the exercise. This slight deception was later revealed to the participants and formed the basis for a discussion of how to resolve information conflicts between the maps.

"Participants were then asked to describe how they would resolve the information conflicts between the maps, considering that the maps represented the same area."

Once the participants answered the three sets of questions, they were given a description of how the different maps were constructed using a GIS. At this point, the fact that the three maps represented the same area was revealed. Participants were then asked to describe how they would resolve the information conflicts between the maps, considering that the maps represented the same area. After answering this question individually, participants were divided into two focus groups for a discussion of the models and an opportunity to examine how information conflicts might be resolved in a group setting. Each of the authors facilitated one of the groups and transcribed the discussion. After the focus groups finished, each participant responded to a questionnaire on their previous experi-



Groundwater Vulnerability Area 3

Question 1. Based on this map, rate the average risk for groundwater contamination in each of the four quadrants using the scales below. (Circle the number that most closely matches your rating)

Quadrant 1 Low Risk High Risk

Average Risk Assessment 1 2 3 4 5 6

Quadrant 2 Low Risk High Risk

Average Risk Assessment 1 2 3 4 5 6

Quadrant 3 Low Risk High Risk

Average Risk Assessment 1 2 3 4 5 6

Quadrant 4 Low Risk High Risk

Average Risk Assessment 1 2 3 4 5 6

Question 2. Based on the information on the map above, mark the best location for a house in each quadrant with a dot. Assume that all locations are equally accessible and that each house will have its own well and septic system.

Question 3. Examine the map above. Which quadrant contains the most desirable location for a house? You must choose one. 1 2 3 4

Figure 2. Test page for WISM Model from Map Use Exercise

ences with vulnerability maps and models and their uses in landuse planning.

RESULTS

Analysis of variance (ANOVA) was used to test the relationship between the vulnerability ratings for each quadrant. The results indicated that the participants' average vulnerability ratings in all but one quadrant were significantly different (*p* less than .05) between most map pairs. (See Table 2.) Quadrant three (SW) was the only quadrant where the ratings were similar between all maps. Overall vulnerability ratings for each map were compared using ANOVA, and all map pair comparisons were significantly different (*p* less than .01). Therefore, the participants' perceived vulnerability ratings were significantly different. This indicates that the maps exhibit a potential for information conflicts.

Quadrant four (SE) was judged by the participants to be the most suitable location for a house on all of the maps. This quadrant also received the lowest average risk ratings for each of the maps. This indicates that even though there were significant differences in vulnerability ratings for this quadrant, it was still the best general area for a house. In this

*"The results indicated that the participants' average vulnerability ratings in all but one quadrant were significantly different (***p*** less than .05) between most map pairs."*

Quadrant 1	Quadrant 2
SCAM-DRASTIC*	**SCAM-DRASTIC***
DRASTIC-WISM*	*DRASTIC-WISM*
WISM-SCAM*	**WISM-SCAM***
Quadrant 3	**Quadrant 4**
SCAM-DRASTIC	*SCAM-DRASTIC*
DRASTIC-WISM	**DRASTIC-WISM***
WISM-SCAN	**WISM-SCAM***

***SIGNIFICANTLY DIFFERENT at p < .05**

Table 2. Vulnerability Ratings between Map Pairs by Quadrant (ANOVA)

context, the information content was reasonably stable. In other words, the maps produced the same result for the determination of the best quadrant for a house although the maps were different.

The best location for a house within each quadrant varied by map (Figure 3.). It is not surprising that in areas where locational choices are constrained, more clustered patterns occur. SCAM and WISM models provided high constraints, and therefore the participants' responses tended to cluster. These clusters occurred in different locations in all quadrants except quadrant three (SW). The DRASTIC model, in contrast, had fewer constraints on location. The patterns produced were dispersed in the northern quadrants, and as constraints became more severe, the patterns became more clustered in the southern quadrants. The southern clusters occurred in different locations on all three maps.

DISCUSSION

Differences in both vulnerability ratings and locational preferences indicate that different results would be obtained depending on which map was used for analysis. The problem, as stated, is what happens when people are confronted with two or more maps that present contradictory results. It is important to remember that the results produced with the different models were based upon the same data set, although the models incorporated the data in different ways.

To examine how people deal with conflicting cartographic information, the following question was asked:

> Given that these results were developed from the same data set, for the same area, and yield conflicting information, describe how you would deal with this in the context of making planning decisions?

After writing a response to this question on their own, each participant joined a focus group for a discussion. This allowed an examination of both individual and group decision-making strategies and to ask additional follow-up questions concerning the use of the maps and their utility.

"Some participants suggested throwing out the maps completely and using 'common sense.' "

After examining the individual responses, a number of similarities and differences in participants' comments were noted. Responses varied by how important maps were to the decision-making process. Some participants suggested throwing out the maps completely and using 'common sense.' Others defined the problem as political, referring to administrative and zoning codes that dictate acceptable procedures and regulations and require minimal map use for arriving at a decision. In the middle, some participants suggested using a combination of the models or using the models as 'advisory to decision-making.' Finally, some participants suggested 'improving existing models or developing new models' that would provide more valid maps.

The importance of the map and spatial approaches to the problem varied greatly. These approaches could be characterized by a continuum from aspatial to spatial (Figure 4.); with less reliance on the map defining the aspatial end and more reliance on the map defining the spatial end of the continuum. The implicit assumption at the aspatial end of the continuum is that the map is unnecessary. Common sense, unreflective opinions, or rules-of-thumb fall at the aspatial end of the continuum, because they often do not explicitly consider local ecological conditions. For example, "everyone knows that you don't put your well next to your septic system." While initially these may appear to be spatial approaches, these approaches do not involve the evaluation of specific site characteristics. In certain circumstances, for example, in areas with deep wells, the 'rule' may have little practical meaning. The issue is that one does not need map-based information to apply the rule. The implicit assumption at the spatial end of the continuum is that a map is needed, but that the existing models need to be refined.

The question arises, why do people view the utility of maps (and models) with such divergence? There are many different possible explanations. One could be that the participants were drawn from a varied pool of expertise, and individual differences in background, education, training, experience, and decision-making roles could account for these variations. Another possibility is that participants placed different interpretations on the context of the problem. However, responses from individuals with similar backgrounds ranged across the full continuum. For example, the planners made comments that ranged across the continuum in spite of their similarities in training and decision-making roles. Therefore, it appears that individual cognitive style, irrespective of training or context, may be a more significant factor in explaining how people deal with conflicting cartographic information.

In the broader context of cognitive psychology and human behavior, Jung (1983, 129) also questioned how individuals could interpret the same material so differently? Jung concluded that people belonged to different psychological types and these types accounted for variations in individual decision-making processes. The basis of Jung's typology consists of four dichotomous variables: introversion / extraversion, intuition / sensation, thinking / feeling, and judging / perceiving. These variables combine to form 16 different psychological types. Jung (1983, 132) stated that there are never pure types and that all individuals exhibit varying degrees of all characteristics. A type is defined by the predominant mode of behavior. Readers may be more familiar with the extension of this work on personality types by Myers and Briggs (Myers 1962).

Keirsey and Bates (1984, 23) note that Jung proposed all of the dimensions, but never fully developed the judging / perceiving dimension. Jung emphasized introversion / extraversion as the predominant distinction between psychological types. Introverts emphasize the inner world of concepts and ideas, and extraverts emphasize the outer world of people and things (Myers 1980, 7). The other psychological functions describe how people perceive, come to conclusions, and come to closure. Intuition and sensing, according to Jung (1983, 144), are "the irrational functions" and relate to the perception of events or potential events. Intuition involves indirect perception, and sensing involves direct perception through the five senses (sight, sound, smell, touch, and taste). Thinking and feeling are "the rational functions" and relate to how conclusions are made. Thinking involves the use of logical processes aimed at an impersonal finding, and feeling involves processes based on subjective values (Myers 1980, 3). The final dimension, judging and perceiving, involves preferences

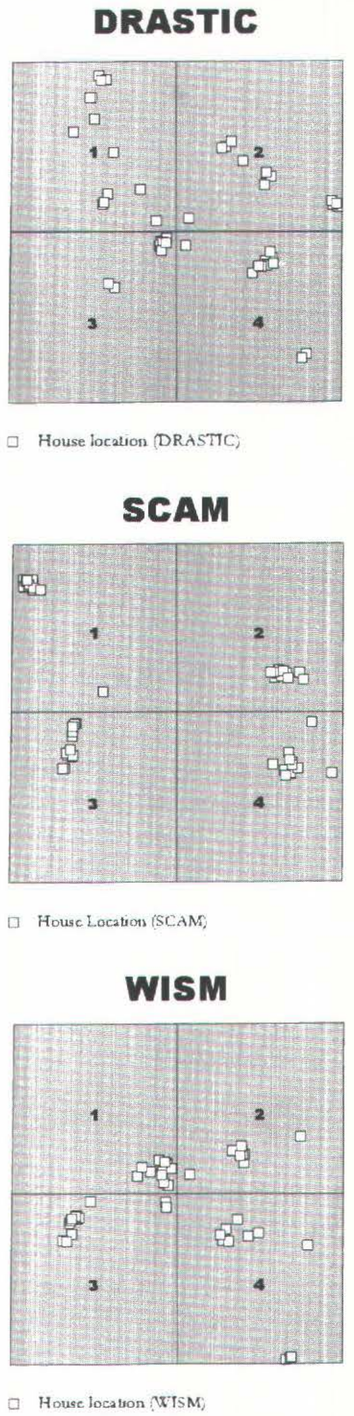


Figure 3. Most Desirable Location for a House by Map.

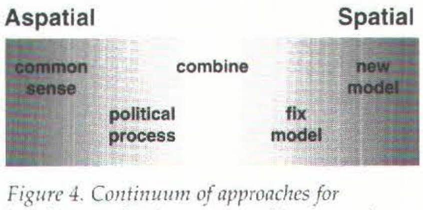


Figure 4. Continuum of approaches for handling conflicting cartographic approaches.

Figure 5. Continuum of psychological types and spatial decision-making.

for degrees of closure. Judging types prefer closure using the available data, and perceiving types defer closure desiring more data.

Returning to the idea of how participants made decisions using the maps, it is possible to arrange several of the psychological functions along a continuum from aspatial to spatial (Figure 5.). This provides a potential framework for explaining the variations in approaches to conflicting information on maps. Common sense approaches align with intuition and feeling and generally appear to be aspatial, whereas modeling approaches align with sensation and thinking and appear to be spatial. Spatial and aspatial are defined solely on the basis of whether or not a map is necessary to the decision-making process. Furthermore, intuitive types prefer approaches that are figurative and employ approximations; in contrast, sensing types prefer approaches that are literal and employ detailed facts (Kroeger 1992, 33). Common sense involves "unreflective opinions" (G. & C. Merriam 1987, 266), rather than careful evaluation of facts. As noted earlier, since common sense does not rely explicitly on site-specific criteria, the aspatial end of the continuum is defined as being largely intuitive. In contrast, the spatial end involves the use of site-specific criteria for evaluation and, therefore, is largely based on sensing.

"Spatial and aspatial are defined solely on the basis of whether or not a map is necessary to the decision-making process."

It is important to note that these psychological dimensions describe a continuum of approaches to decision-making behavior, and each is valid in its own right. These define predominant decision-making preferences and it is possible for people to shift style in some circumstances. The predominant type of introversion/extraversion and the functions of perceiving/judging do not appear to play a role in this context.

Variations in psychological types influence group dynamics in decision-making. The interaction of contrasting types has the potential for increasing both understanding and misunderstanding. This became apparent in our focus group discussions where participants expressed a number of contrasting opinions about the utility and necessity of the maps. In group decisions, people cannot assume that everyone is perceiving and evaluating the data in the same way and therefore will arrive at the same decision. In the focus groups, we observed contrasts in psychological types; decision makers exhibited both aspatial and spatial behaviors as described above. The fact that the maps presented conflicting information may have reinforced each participant's preexisting tendencies toward a psychological type. Those that tended toward the aspatial end of the continuum readily discounted the validity of the maps and their importance to decision-making. In contrast, those that tended toward the spatial end of the continuum looked for refinements to the models in order to improve the maps. In this situation, the discussions were congenial, since no decision had to be made. However, the dynamics in groups that need to make a decision are often less congenial.

"In group decisions, people cannot assume that everyone is perceiving and evaluating the data in the same way and therefore will arrive at the same decision."

At the outset of this project, the application of the Jungian typology was not anticipated, however, this typology provides a way to frame the problem and provide some explanation. Contrasts in styles have a potential for helping to understand how people process and manage conflicting information in a cartographic context. In contexts where multiple decision makers interact to solve a particular problem, in this case policy concerning groundwater vulnerability, diverse decision-making styles come into play. The likely result of varied decision-making styles is multiple outcomes that are internally consistent to the individual decision makers because each person frames the problem context according to her/his psychological type. Diverse results should serve as a reminder to those who are cartographically oriented that not all users approach maps with the same enthusiasm. This alludes to an issue of how we approach conflicting information as a cartographic problem; the problem is not necessarily a question of 'how maps work', but instead, 'how people work with maps'.

SUMMARY AND CONCLUSIONS

In this paper, results were presented from an experiment that investigated how decision-makers respond to conflicting cartographic information using a series of conflicting groundwater vulnerability maps for one area. Thirteen local decision-makers participated in the experiment, and input was collected from them as to how they would deal with information conflicts in a planning situation. The decision-makers then discussed the maps and information conflicts in a group setting to examine how group dynamics might influence the decision-making process. From this, a continuum of strategies was developed that ranged from the aspatial approaches, e.g., discard the maps and use common sense, to spatial approaches, e.g., build a new spatial model that "works."

When the research was initiated, it was viewed as a problem of cartographic visual information processing and it was anticipated that the participants would discuss methods for representing conflicting information. However, the issue turned very quickly away from the original maps to one of how decisions are made using or, in some cases, not using the maps. This allowed the development of a continuum of approaches to the problem and a series of questions as to why such diverse results were obtained. It became apparent that very different internal processes were employed by the participants to evaluate the map data. The divergence of responses suggested that something as fundamental as Jung's psychological types may play a role in how people evaluate map data.

"However, the issue turned very quickly away from the original maps to one of how decisions are made using or, in some cases, not using the maps."

The results from this study present several avenues for further research. The first avenue deals with how to best represent information conflicts and uncertainty between multiple maps. With growing reliance on GIS modeling in environmental decision-making and issues of inter-model stability, methods need to be developed to spatially represent agreement and disagreement between models. MacEachren's (1994) suggestions provide a starting point for such an investigation. The second avenue deals with the role of individual preferences in decision-making and the influence of psychological type on how people work with maps. It is apparent from this research that there are diverse ways in which individuals perceive and understand information and that this may impact the decisions which they ultimately make. Finally, a third avenue deals with how groups make decisions using maps. The dynamics of individuals and groups in the decision-making process are markedly different, and little cartographic research has addressed this interaction.

The role and importance of multiple representations in visualizing spatial problems is well documented, however, there needs to be a concern with the quality of the information that these multiple views present. The potential for conflicting information in cartographic displays becomes quite high when multiple data layers are combined in GIS models. The fact that the same data layers may produce markedly different maps when combined in different combinations or through different models is coming to be a real concern for those who deal with environmental data and decision-making. This concern becomes paramount in situations where different representations may confuse or obscure understanding rather than illuminate it.

"The role and importance of multiple representations in visualizing spatial problems is well documented, however, there needs to be a concern with the quality of the information that these multiple views present."

ACKNOWLEDGMENTS

We thank the three anonymous reviewers for their comments and requests for clarification. We also thank Dr. Rik Seefeldt from the Department of Psychology at the University of Wisconsin - River Falls for assistance with

issues pertaining to psychological typology. All omissions and interpretations however remain our responsibility.

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