# Water Quality Mapping for Water Management

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**This paper explores how maps can support water quality management as part of a common project between a water management organization (Service Départementale de L'eau du Conseil Général de Haute-Loire - France) and a research laboratory (Centre de Recherche sur l'Environnement et l'Aménagement - Université de Saint-Etienne - France). Visualization tools are proposed to bring together the different stakeholders in the negotiation process for water management. Two fundamental questions are examined here: (1) how do we communicate the different water quality information to the various stakeholders to improve their awareness of the environment; and (2) how could we evaluate the effectiveness of a cartographic visualization system in the process of negotiation between different stakeholders. Alternative methods are proposed here to present and evaluate water quality information in the form of maps.**

## INTRODUCTION

The process of environmental management has changed in recent years, particularly in the field of water management. In France, two major changes are characteristic of the 1992 Water Law, emphasizing (1) the importance of evaluating "the biological potential of the hydrosystem", and (2) the need for a concerted form of management that involves the various stakeholders. Thus, water management is becoming a more public and democratic process. The discussion/negotiation process prior to decision-making is extended to all individual or collective stakeholders in the watershed. Water quality information concerns all of the stakeholders, but, maps that represent water quality have mostly been designed for and by expert users. Therefore, it is necessary to find ways to communicate information about water quality to a larger audience using the current tools and technologies. The focus here is on two fundamental questions: (1) how to communicate the different water quality information to the various stakeholders and improve the symbology of this information; and (2) can these symbology improvements in cartographic visualization systems produce an increase in stakeholder awareness, and improve the effectiveness of the discussion/negotiation process in participatory planning. The overall purpose of this research is to evaluate water quality mapping methods for non-specialists. To achieve this objective, it is necessary to identify the various needs, determine the stakeholders views on the present environment, and propose cartographic visualizations to improve these views. This research is closely related to the main goals of the Commission on Visualization (International Cartographic Association 1997):

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(1) to begin filling the void in understanding how digital geo-information technology interacts with the cognitive and decision-support functions of maps; and
(2) to help cartographers make the transition from being designers of maps to designers of map-based thinking and decision-support tools. A secondary goal is to consider how geo-information technology applied to geographic thinking and decision-support interacts with the social functions of maps and the social context of map use.

This paper is divided into three parts. First we present the importance of water quality in general; the different information intrinsic to water quality, the necessity of water management in a group setting, and existing tools to address this problem. The second section discusses the use of cartographic visualization within this framework, and explores possibilities for improving the representation of water quality by proposing alternative representations and by considering the potential of cartographic visualization. The final discussion presents a method for evaluating the effectiveness of the cartographic visualization in water management issues. The conclusion proposes some directions to extend this field of research.

## WATER QUALITY AND WATER MANAGEMENT

### Water quality and concerted management

The health concerns associated with drinking polluted water make water quality a primary concern. However, environmental criteria are becoming increasingly important in the definition of management policies. In France, the 1992 Water Law protects not only drinking water but also "the biological potential of the hydrosystem." The purpose of this law is to pursue water management without a specific economic objective. It is now the law that all stakeholders must take part in the process of water management. Stakeholders are individuals or groups that are interested in using the water and/or maintaining its quality. Good water quality also reduces the costs of the decontamination of drinking water and increases the quality of the river system for other uses, including recreation. From a socioeconomic point of view, good water quality, especially in rural areas, is a factor in attracting tourists and an important element in the quality of life. Consequently, it promotes the welfare of people that live within an area. According to Hirsch (in Solley et al. 1998), "With increased demands for water for instream uses such as river-based recreation, esthetic enjoyment and fish and wildlife habitat, the overall competition for good quality water will continue to increase." While the quality of water for drinking will continue to be a primary concern, overall issues of water quality, particularly the biological potential of the hydrosystem, will determine water quality management.

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Knowing the current state of stream water quality and its evolution is necessary in determining policies for the improvement of quality, uses, and supervision of the testing process (Reseau de Bassin de Donnees sur l'Eau 1997, p. 1). Information on water quality is used by the various stakeholders to make decisions concerning future management. This information, particularly its presentation in the form of maps, is paramount for the management of this resource. Water quality is more than simply quantitative data about the concentration of, for example, nitrates, phosphates, or oxygen. It may also include the human sources of pollution, sectors of recovery (areas where the river is undergoing a natural cleansing process), or possible uses. Water quality is a quantifiable variable and can be scientifically tested. The interpretation of data, however, could lead to a more subjective interpretation. Lastly, the data and its interpretation are of primary importance when groups of people attempt to manage the quality of water.

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Such concerted effort in water quality management provides "those people who depend on the aquatic resources for their health, livelihood or quality of life a meaningful role in the management of resources" (Environmental Protection Agency (E.P.A.) 1996, p. 4). This dialogue has become one of the most important elements in water management. No longer are solutions proposed based on complex models or expert opinion. Rather, it is now a question of presenting information to the stakeholders in a meaningful and comprehendable manner. According to different authors, (Moreno-Sanchez et al. 1996; E.P.A. 1996) environmental conflicts must be negotiated to minimize social conflicts and negative impacts to the environment. But, the stakeholders need information that meets their objectives. The tourist will be interested in water quality for fishing or swimming at various points, whereas the hydrobiologist may want to know the sectors of recovery, or the amount of aquatic life supported by the river.

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**Concerted management and visualization tools**

As with any other attempt to manage the environment, the management of water requires a total diagnosis of the problem and the related ecological and humans factors (Montgolfier and Natali 1987). This diagnosis is possible through the analysis of structured data within a Geographic Information System (GIS), but, the use of a GIS for management and decision-making does not meet our needs for several reasons. First, water management is often done by small organizations without sophisticated GIS resources. Second, the validity of the results of future conditions generated by the GIS depends on the sophistication of mathematical models and the quality of the data. This sophisticated form of analysis is again not possible with the smaller GIS systems that are normally available to regional agencies. Third, the use of such models do not take into account the knowledge of the users who need to take part in the process of negotiation. As Carver points out (1998, p. 2), the development of highly specific systems could eliminate certain groups from the decision-making process. The GIS still confers an unwarranted power to the organization that uses it. Goodchild, et al. (1994b, p. 166) point out that to limit the conflicts in decision-making, the mature GIS must be available to all those involved. The use of a GIS is thus essential in water quality management, but more like a spatial database than a powerful analysis tool. However, the use of such systems is meaningless unless the results can be communicated to a larger audience in an effective manner. "Because stakeholders work together, actions are based upon shared information and a common understanding of the roles, priorities, and responsibilities of all involved parties" (E.P.A. 1996, p. 3).

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Once the data is structured, it is necessary to consider the access by different stakeholders who are often unfamiliar with computing. The information processing systems of public participation offer solutions in this field. Since the end of the 1980's, these tools have been developed with the objective of integrating citizens into a wide-ranging debate that involves both social and technological elements (Jankowski 1998, p. 1). "The chance to participate in the creation of these plans promotes environmental awareness and increases the likelihood of voluntary compliance with environmental legislation and dispositions" (Moreno-Sanchez et al. 1996). A variety of such systems have been proposed including the "Consensus Conference", the "Public Participation GIS" (PPGIS), or the "Spatial Understanding and Decision Support System" (SUDSS) (Jankowski 1998). Other systems that have been proposed include the "Collaborative Spatial Decision Making" (CSDM) (Bennett 1994), the "Interactive Decision Map" (Lotov et al. 1997), and the "Electronic Meeting System" (EMS) (Faber 1995). Three preliminary stages to their successful implementation are essential:

(1) Knowing the various stakeholders and their concerns. Bennett argues that (1994, p. 1): "Before we can design a CSDM system that can support this kind of consensus building we must understand how policy

and management initiatives affect interrelated human, biological and physical processes through time and space." This knowledge should be gained through an inquiry and would enable the second step.

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(2) When proposing information adapted to the user's needs, the degree of abstraction must be reduced. For example, what does "fair physicochemical" water quality mean to the average user? New criteria referring to the uses, according to the various parameters of quality, are being studied. For example, the "deterioration method" proposed by the French Water Agencies transforms water quality information into "various possible uses." For this method to be effective, it is essential to reduce times between the analysis of quality and the access to the results by the users. Without proposing models of future states, it is necessary to provide tendencies, according to past results. Finally, water quality contains other important information about the hydrosystem which should be visualized, such as sectors of degradation or recovery. Widening the circle of the water quality data processing and management must be associated with an improvement in the transmission of this information.

(3) Proposing cartographic representations of water quality information that are designed according to the competence and needs of the various users. To know the objectives of various individuals and groups, the tools of analysis and representation must be adapted to the differences in competence of the participants. Armstrong and Densham (1995, p. 57) note: "The support of interactive, group decision-making processes requires the development of new kinds of cartographic displays." To be effective, cartographic visualization must adapt to the user and to the available technology. If not, it risks becoming a gadget and loses its heuristic aspect and its intrinsic functionality for assistance in spatial thinking (Caquard 1998, p. 5).

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In regard to these preliminary stages, the Multimedia-GIS (MM-GIS) seems to be an ideal solution. This tool uses the Geographic Information System (GIS) to georeference, structure and analyze data, and multimedia to create presentations with cross-links to spatial features (Raper and Livingstone 1995). It is also suitable for displaying different cartographic representations to users. "Multimedia applications that present environmental issues in a clear and compelling fashion are desirable in supporting the environmental agency in their education and negotiation functions" (Moreno-Sanchez et al. 1996). Furthermore the MM-GIS can be easily accessible by all the stakeholders through the Internet.

## CARTOGRAPHIC REPRESENTATIONS OF STREAM WATER QUALITY

### Water quality mapping on the Internet

In spite of the general development of maps on the Internet (Peterson 1997, p. 1), examples of water quality maps on the Internet are few. The cost of the data and the sensitivity of this kind of information are still barriers to their availability. Nevertheless, some interesting sites concerning water quality can be found. For example, the "Department of Mathematical Methods for Economic Decision Analysis" of the "Russian Academy of Sciences, Computing Center" <http://www.ccas.ru/mmes/mmeda/resource/program/main.htm> allows the user to visualize the mathematical results of modeling in real time. In this multicriterion application (agricultural output, level of the lake, and water quality), the user chooses which of the three criteria will be emphasized according to what are considered bearable for the others. The final map is a visualization of the result of mathematical modeling. The map itself is not interactive. While the approach is interesting, Openshaw et al. (1994, p. 138) point out: "In

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some applications the insights that are gained may be built into computer models and theories, in others there may be no need for any other form of analysis because visualization is itself sufficient."

Two other sites of interest are: "The Natural Resources Monitoring Network - Shepparton Science & Technology Center" <http://www.sheppstc.org.au/water/dynamic/water.asp> in Australia and, the "Irish Environmental Protection Agency's National Freshwater Quality Database" <http://www.compass.ie/epa/system.html>. These sites allow the interactive access to the various water quality data on different areas. The Australian site includes explanatory photographs and textual elements. These two sites are of greater interest to this study because they are designed for more general use. This type of site will see greater applicability as with, "Projet IMAGE" (Ministere de l'Environnement et de la Faune Quebecois) and "Projet de l'Office International de l'Eau français." The Internet must improve access and make it possible to use cartographic visualization. The effectiveness of the message must also be improved by adapting the rules of graphic communication.

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**Proposals for water quality representations**

Water quality is often depicted by representing data with point symbols on maps. Points are easy to represent and are precise in time and space as they correspond to the measurement location of water quality. Nevertheless, this representation is limited because only a small part of space is indicated. Furthermore, points of poor water quality are emphasized because there is usually more information about these points, and they are of more interest to the water quality organizations than points of good water quality. For example, on the tributaries of the Lignon river, the points of very good and good quality drain (i.e., represent) an average watershed of 5.1 km2, whereas those of bad or very bad quality drain an average watershed of 0.4 km2 (Fig. 1). The visual result may be an overestimation of the polluted points as the watershed appears on the map to be more polluted than it is in reality.

This phenomenon can be mitigated by an interpolation of points on the network or by a linear representation since the line represents a larger part of the network. Lines are often used because they are considered easier to understand for the viewer, but there is no empirical support for this. The line representation is simply an extrapolation of the specific point values. Thus, the linear representation must be used with care because the represented information appears more precise than it is. Therefore, the choice in representation between the line and the point is not a neutral decision and may modify the message of the map.

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While point and line symbols are frequently used, a third cartographic form of representation, almost never used for water quality mapping, is area. However, this can be an important form of representation because water quality is completely dependent on the impact of the human activities on the whole of the drained watershed area, as well as the capacity of nature to assimilate these impacts (phenomena of deposition, dilution and self-cleansing). Even if these phenomena are complex and difficult to define, normally, when quality improves downstream, the capabilities of nature are higher than the human impact, and vice versa. Extrapolations of the water quality data to the drained watershed can provide this information (Fig. 2). It makes it possible for the user to locate himself spatially in relation to water quality and ask the question: "Does my area contribute to the pollution of the river?" Visually, the advantage is that it produces representations that are simple and very easy to understand. This trans-

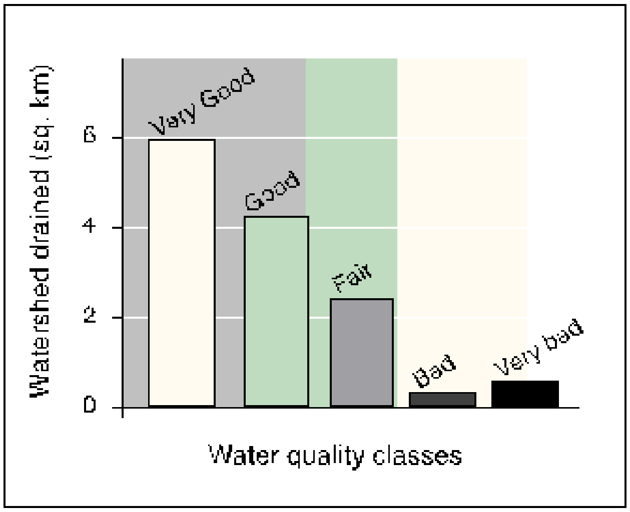


*Figure 1. Differences in area between the watershed drained by the good water quality points and by bad water quality points. On average, a point of very good water quality represents 6 sq. km of the watershed and a very bad one only 0.6 sq. km. The visual result is an overestimation of the polluted points, even if there are only a few of them (Physicochemical quality of the Lignon tributaries / 1992-1997).*

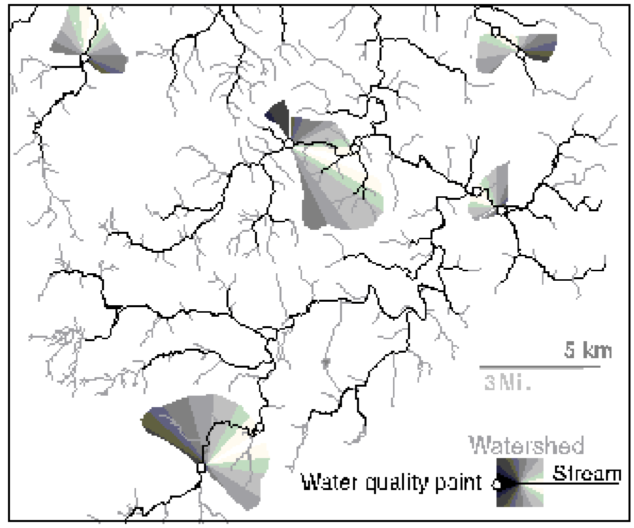


*Figure 2. Watershed and stream sectors where "the capacities of nature are higher than the human impact" (the quality improves downstream).*

formation of a point map to an area map by interpolation corresponds to what Cauvin (1997) calls a "cartographic transformation of state." As Openshaw et al., (1994) point out, loss of precision is the principal limit of this type of transformation. For water quality representation, these limits of precision are two-fold: (1) Spatial precision because a value measured in a point is extrapolated to an area; and (2) Thematic precision, because one deduces other information from water quality such as human impacts and natural phenomena. These thematic transformations must be understood before they can be represented in order to avoid misinterpretation.

Color is generally used to represent the quality of water. It is an excellent selective variable that increases the range of the message (Bertin 1967, p. 91). Although the visual variable of color cannot order (Bertin 1967; Cuff 1973; Gilmartin 1988), colorimetric conventions used for representing water quality seem to be well perceived by map users. In connection with temperature maps, Bemis and Bates (1989, in MacEachren 1995, p. 135) demonstrate that users are able to order colors well, the explanation suggesting that the logic of the order has been learned and is intuitively appealing. This conclusion could apply as well to water quality maps.

*". . . colors cannot be used to represent other features on a map of water quality without interfering with the message."*

In France, the gradation of colors used to represent water quality has been standardized for many years: blue (very good quality), green, yellow, orange and finally red (very bad quality). This gradation is found on the majority of the water quality maps that are available through the Internet. This gradation corresponds to the conclusions of Bertin (1981, p. 221): "For light values, optimum selectivity is obtained by green, yellow, and orange. For dark values, by red, blue, and violet." The counterpart of this convention is that these colors cannot be used to represent other features on a map of water quality without interfering with the message. For example, if the single hydrographic network appears in blue, the reader will tend to interpret a very good water quality. In this case, the blue should be replaced by another color that does not have a water quality connotation, such as a gray, for example.

As Bertin points out, pure colors afford optimum selectivity, and when several variables are combined, selectivity increases. The variation in orientation often affords a selectivity comparable to that of color (Bertin 1981, p. 232). The combination of these two variables will improve the perception. It has also been shown that if the degree of iconicity increases (pictorial representation), the relative abstractness seems to decrease (MacEachren 1995, p. 262). Lastly, according to Forrest and Castener (1985), the perception of color difference is increased by point representation. From the whole of these elements and existing colorimetric conventions, it seems possible to propose other representations for water quality that would improve selectivity while reducing abstraction (Fig. 3). In reference to the representations of uses considered previously, the combination of pictograms, geometrical forms and colors proposed by Forrest and Castener (1985) could be used.

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Size could also be used as another visual variable. To Bertin (1967), size is the only visual variable, and to MacEachren, (1995) it is the variable that is the best adapted to transmit quantitative information. The visual variable of size is completely absent from water quality maps. This absence implicitly means that all the points represented only differ by the quality of the water that is associated with them. Is this realistic? Does a deterioration of the water quality at Sheridan, Wyoming, on the Tongue river really have the same consequences as a water degradation of the Missouri river in Kansas City? The volumes of water are different, as are the uses, the users, and the effect on the economy, ecology and social behavior. It seems logical to integrate these quantitative values into the representation of the water quality. The quantitative information could correspond, for example, to the flow, the surface of the watershed drained by each point, or the bifurcation ratio (Fig. 4). The visual variable of size can also be used to represent differences in perception. For example, it is possible to represent the different values that the various stakeholders give to each water quality point. This representation would allow, for example, the visualization on the same map of water quality and the importance that the various stakeholders place on each point. It would then be easier to draw conclusions about the potential conflicts in water usage.

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The last elements to be represented in connection with water quality are changes in space and time. Without this information, it is impossible to properly understand the hydrosystem and to propose future uses. Repre-

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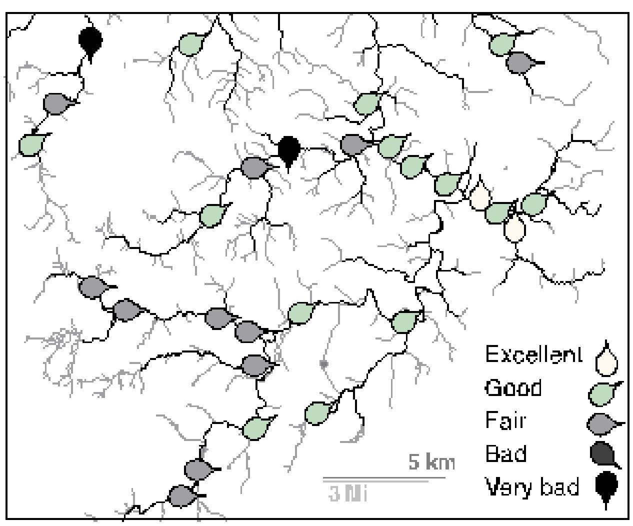


*Figure 3. Association of two visual variables: "color" ("value" in this black and white reproduction) and "orientation with a higher degree of iconicity, to propose another representation of water quality by point.*

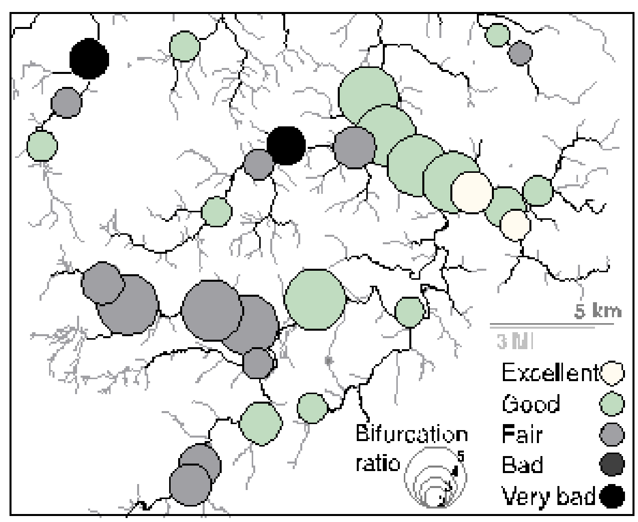


*Figure 4. The visual variable size used to show quantitative values on a water quality map.*

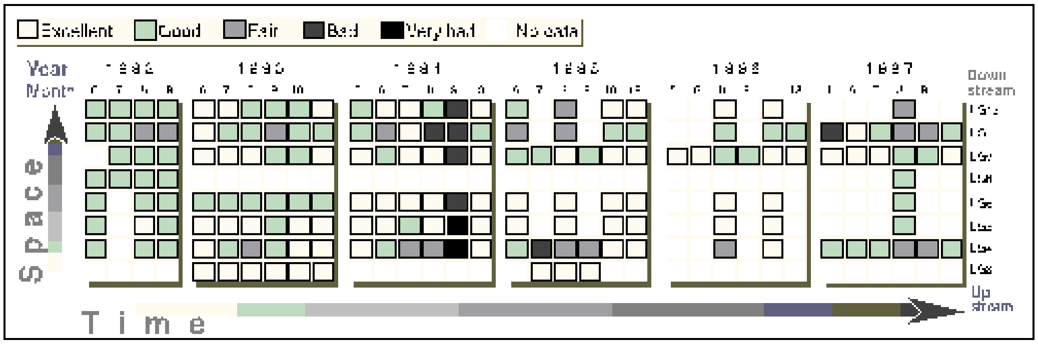


*Figure 5. Schema to represent all of the water quality results of one parameter (physicochemical) on one stream (Lignon river). This representation is an overall picture of a water quality evolution in space (upstream -LG3- (point number 3 on the LiGnon river) to downstream -LG12- (point number 12 on the LiGnon river)) and time (by month between 1992 and 1997).*

sentation in the form of a diagram enables this (Fig. 5). This schematic representation makes it possible to compare different years or different points very quickly. Moreover, it allows the representation of various temporal or spatial steps, or more regular steps over time (i.e., each month) and space (i.e., each mile). This would make it possible to reveal the spatial-temporal aspects in the acquisition of information. For example, why isn't there any information for July of 1996 in the diagram (Fig. 5)? Or, is it necessary to analyze two points that always have the same values?

This kind of representation is limited because it only allows the visualization of one stream at a time. It is thus difficult to compare the various streams from the same watershed. But, the main criticism is summarized by Hearnshaw (1994, p. 195): "Our understanding of data on time, as a variable, is best displayed using time as the display variable." In other words, the use of this static representation to communicate active phenomena can be improved by animation.

*"A considerable amount of work has already been done in the field of cartographic animation*

**Cartographic visualization and water quality**

Animated presentations are ideally suited to represent change over time (Hearnshaw 1994; Peterson 1995). A considerable amount of work has already been done in the field of cartographic animation concerning, for example, the role of the legend (Kraak et al. 1997), the characteristics of temporal visualizations (MacEachren et al. 1994), the visualization of dynamic forms (DiBiase et al. 1991; Peterson 1996), and the various dynamic variables (DiBiase et al. 1992; MacEachren 1995). Applications of animation in cartographic visualization are numerous. For example, the dynamic variables could emphasize: (1) the year or months when the pollution was the greatest; (2) the points where the water quality varies appreciably during the year; (3) the tendencies of water quality change (improvement, degradation or status quo); (4) the rate of change in quality for each point between each analysis; or (5) the existence of causality between water quality and flow. These dynamic variables seem to further the understanding of the operation of the system by the user. Their use to suggest trends must also be considered because as Margolis (1987) points out (in MacEachren 1995, p. 362), decisions are often made by matching present situations against a collection of patterns (or schemata) representing past experience and "knowledge".

*". . . I agree with Kaplan when he compares a theory to a map. For him, theories are remarkable in the questions they do not answer and thereby guide and stimulate intelligent research."*

But, proposing trends doesn't mean proposing solutions. Indeed, I agree with Kaplan (in Weizenbaum 1976, p. 95) when he compares a theory to a map. For him, theories are remarkable in the questions they do not answer and thereby guide and stimulate intelligent research. The heuristic and pedagogic functions of the map are emphasized here, and these functions are probably increased by dynamic visualization. For many authors, changes in the modes of visualization are a fundamental element of dynamic visualization (DiBiase et al. 1991; Turk 1994; Cian et al. 1994; Peterson 1995; MacEachren 1995). Indeed, the multiplicity of representations seems to support comprehension by adjusting the map to user's needs and capacities and are more truthful (i.e., ethical) because they provide a comparative frame of reference (Muehrcke 1990; Monmonier 1991). Therefore, interactivity and multimedia must be used. Interactivity would improve the potential for personal research on the part of the stakeholders, and promote multiple visualizations. Photography, for example, offers other possibilities for geographic communication. It is an uncoded message – a perfect analog of reality (Barthes 1977). The photograph can help answer three types of questions: "Can we see the pollution in a stream?" (macro photography); "Where is the exact point at which water quality was examined?" (landscape photography); and "Where does the pollution come from?" (aerial photograph). The didactic potential of photos must be used even if, as Bertin (1967) points out, the photograph is highly ambiguous because of its polysemia (having many possible meanings). This limit can be mitigated by the use of other media like graphic symbols, text or sound (see Krygier (1994) for a discussion of sound variables). The combination of animation, interactivity and multimedia should enable us to propose an effective tool to communicate water quality. But, how effective will it be in the concerted management of water quality?

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## EFFECTIVENESS OF CARTOGRAPHIC REPRESENTATION

A number of cartographers have deplored the lack of knowledge about the effectiveness of the various forms of cartographic visualization (Unwin et al. 1994; MacEachren 1995; Rader and Janke 1998). But, how can we effectively evaluate the effectiveness of a strategy of visualization? For a preliminary approach to this question, it would seem appropriate to establish a relative classification of the gain in stakeholder understanding that different representations enable, in reference to an initial representation they already have. In doing so, one must consider that testing visualization techniques on persons who are not actually concerned by the area or the theme represented may not be indicative of the potential visual impact of a given representation. Unlike many cartographic studies, the approach proposed here examines maps in actual use - a "naturalistic" form of research (Petchenik 1983). An inquiry is proposed here to evaluate the effectiveness of maps for water quality management in a concerted map use environment. The inquiry is divided into two parts: (1) a questionnaire submitted to the users before they access the maps, and (2) the same questionnaire afterwards.

### Determining pre-conceived notions of water quality

One of the principle limits of the effectiveness of Multimedia GIS (MMGIS) is that the users cannot clearly and completely specify their needs at the beginning of the project (Moreno-Sanchez et al. 1996). "As decision-making becomes increasingly an exercise in public consultation and compromise, decision support requires that all aspects of a project be clearly understood by the public" (Bishop 1994, p. 61). To present the project to the stakeholders and to know the needs of the users are thus two essential steps; but they are not sufficient by themselves. To better plan, design and manage the environment for and with people, their image of the world must be determined (Lynch 1976 in Kitchin 1994, p. 9). These mental conceptions play a large role in our relationship with the environment, our

*"This inquiry must make it possible for users to express their needs and competence . . ."*

general actions, our behavior and our attitudes about people and places (Tuan 1974 in Peterson 1995, p. 11). Taking the cognitive characteristics of the individual users into account seems to be necessary (Turk 1994).

To determine the needs and the perception of the users, a questionnaire will be sent to a representative sample of the various stakeholders. This inquiry provides a reference in terms of perception of space, i.e., environmental cognition: the conscience, the impressions, information, the images and beliefs that the individuals have of the environment (Cian et al. 1994). The first part of this inquiry will specifically address the perception of water quality. This inquiry must make it possible for users to express their needs and competence, but it must also enable them to define their mental conceptions about the environment. For that, three sets of questions associated with a reference map will be given (Table 1).

*"The "negociativity" index is a qualitative measure of the relationship between the initial perception of a stakeholder and their "enhanced" perception as a result of cartographic visualization . . . "*

The results will determine the areas of use, types of use, and time of use of various sections of the stream. The purpose is to identify the potential space-time conflicts between stakeholders, while knowing that the potential for conflicts increases with the concentration of the needs in both space and time. However, "objective" solutions may be found for "objective" conflicts, but to what point are these conflicts objective? The potential conflicts associated with perceptions of the causes of degradation by the various stakeholders can be summarized as a "negociativity" index, providing a major element for concerted environmental management. The "negociativity" index is a qualitative measure of the relationship between the initial perception of a stakeholder and their "enhanced" perception as a result of cartographic visualization, enabling us to test the degree of evolution in their perception of the adverse position and the objective phenomena involved in the conflict. Lastly, the level of shift between perceptions of quality and the actual water quality will provide information about the misperception of water quality information and thus enable us to propose representations that are better adapted to addressing this lack of information.

**Determining the effect of water quality visualizations**

*"The impact of cartographic visualizations will be evaluated based on the change in perception caused by the cartographic visualization."*

The second step of this inquiry consists of an assessment of the evolution of perceptions and behavior generated by cartographic communication (Fig. 6). Stakeholders will view cartographic visualizations of water quality data, and these perceptions of the various stakeholders will be compared to those of the first inquiry. These visualizations will help the stakeholders to understand the shifts between their perception and actual water quality measurements. The impact of cartographic visualizations will be evaluated based on the change in perception caused by the cartographic visualization. This will be determined by giving the same questionnaire as during the first inquiry. In this way, the change in perception

| | Question | Purpose |
|---|---|---|
| 1st | Which sections of river do you use? | To understand the various uses and users in time and space. |
| 2nd | In your opinion, what is the water quality of these sections? | To determine pre-conceived notions of water quality. |
| 3rd | In your opinion, what are the causes of pollution? | To find out how individual stakeholders explain causes of water pollution. |
| => Synthesis : definition of a negotiativity index in space and time | | |

*Table 1. Sets of questions will be given to the different stakeholders along with a reference map and an explanation of the purpose for the research.*

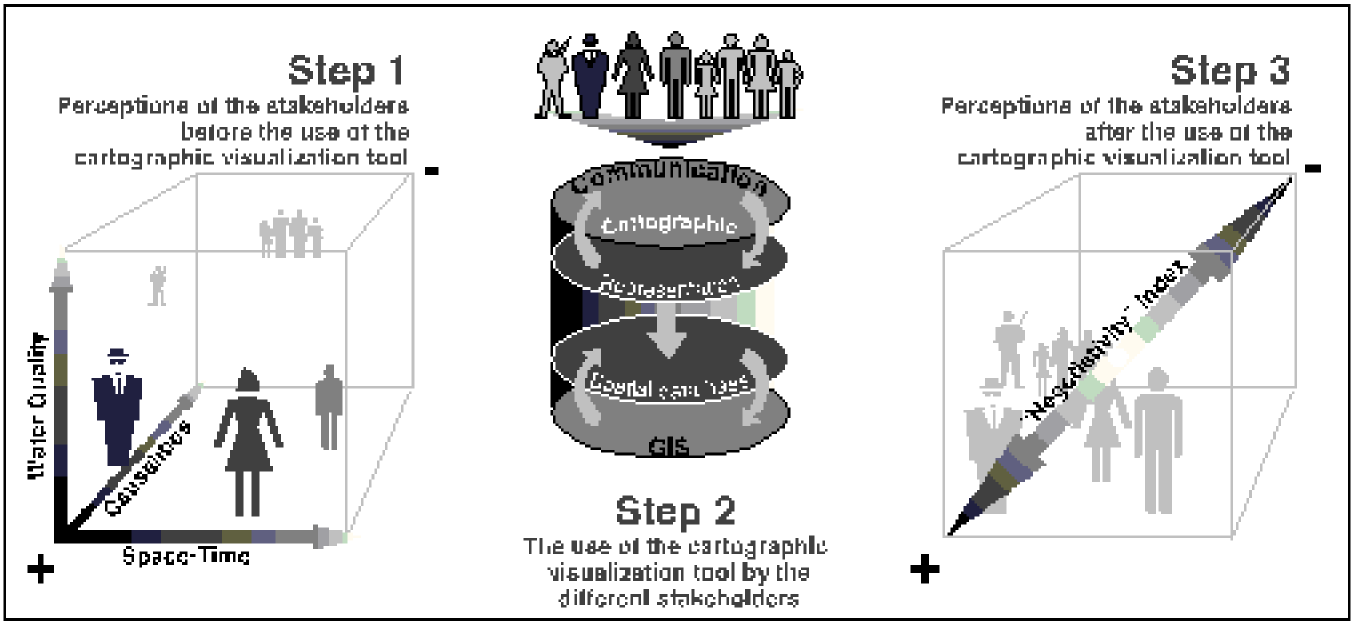


*Figure 6. Assessment of the evolution of perceptions and behavior generated by cartographic communication. Step 1 provides a reference of knowledge and perception of water quality over space and time and causalities of pollution for the various stakeholders. Step 3 provides the same information, but, after using the cartographic visualizations (step 2). The impact of cartographic visualizations will be evaluated by comparing the "negotiativity" index of steps 1 and 3.*

that was generated by this type of communication tool can be quantified. By comparing the results of the two inquiries, an analysis can be made of how geographic visualization can: (1) improve knowledge of the space-time processes influencing water quality; (2) support the access to this information; and (3) help the various stakeholders better understand their impact, the impact of the others and their function within the hydrosystem. The function of this type of tool for concerted management can then be analyzed and new proposals to improve this type of tool can be made.

## CONCLUSION

According to Bishop (1994, p. 64), it is important to continually evaluate each cartographic representation in order to know its legibility according to its use by different people in decision-making. But, as many authors have noted, very little cartographic research has examined maps from this perspective (Unwin et al. 1994; Keller 1995; Torguson 1997; Rader and Janke 1998). This type of research, however, appears necessary for proposing representations adapted to the non-specialist (Kitchin 1994). It will, therefore, be necessary to think about analyzing the effectiveness of various cartographic visualizations in the form of a test, or complementary questions, or even in a "focus group."

The dissemination of water quality information is an interesting field of investigation as well. Indeed, the prohibitory costs of color printing was used in the past as an argument to limit the number of maps that were produced. This argument is meaningless with the potential of the Internet. It will be interesting to study the strategy of water management organizations in order to determine their willingness to make this information freely available.

Finally, the role of the cartographer in this type of project must be considered. Indeed, the multiple views make it possible for the user to find a representation close to their preconceptions and, consequently, ignore others. A detrimental consequence of interaction in mapping would be that each stakeholder finds a particular representation that best defends their interests. In this case, the stakeholders that have the strongest influence will prevail (Carver et al. 1998). It is thus the responsibility of the cartographer to propose robust methods to communicate geographical information correctly. "Cartographic guard rails" must be incorporated according to scientific rules of perception, and to the problems of the users and their perception of space.

How users perceive maps is a necessary question to improve the effectiveness of the cartographic message. But, how cartographic visualizations can improve perceptions of space-time relationships seems to be a fundamental question that needs to be considered for concerted environmental management.

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