Using Flow Maps to Visualize Time-Series Data: Comparing the Effectiveness of a Paper Map Series, a Computer Map Series, and Animation

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Abstract:
Motion and change through time are important aspects of thematic maps. Traditionally, such data have been visualized using a series of paper maps that represent multiple snapshots of a location over time. These maps are visually compared by the map reader when analyzing change over time for a location. This static view of change over time has worked well for cartographers in the past, but today computer animation allows cartographers to emphasize the dynamic nature of this data. By animating a map, change over time can be represented on one map rather than in a traditional map series. This study compared a paper map series, a computer map series, and animated maps of the same data to assess the effectiveness of each technique for memorizing data symbolized by graduated flow lines. Subjects were asked to study the maps and to memorize two types of information: quantity data at specified locations on the maps and trend patterns that occurred over the maps. Memorization of the information was subsequently tested using a series of multiple choice questions. Analysis of response times and accuracy rates for these questions suggest that animation does not improve learning ability for quantity evaluations. It does appear, however, to improve subjects' abilities to learn and remember trend patterns in the data. Results also indicate gender differences in using animated maps.

Article:
INTRODUCTION
Visualization is defined by Tufte (1983) as the process of using visual representations to describe, explore, and summarize sets of data to better comprehend their patterns and relationships. Geographic visualization deals primarily with the representation of spatial data. The emergence of thematic mapping in the late eighteenth and early nineteenth centuries is considered by many to be the beginning of visualization in cartography (MacEachren 1992). By focusing on the location and distribution of a single feature, thematic maps present specific information and aid in discovering previously hidden aspects of the data.

Motion and change through time are important aspects of thematic mapping. In fact, MacEachren (1992, 126) notes that "[g]eographers are seldom interested in a static view of the world." Understanding how and why changes occur over time requires the ability to see what has changed and where it has changed. In visualizing temporal change on static maps, cartographers have traditionally chosen between two strategies. They may either depict limited aspects of temporal change on a single map, or they may use a map series to show multiple snapshots of a location over time. The resulting map sets are then visually compared by the map reader when analyzing change over time for a location.

These static views of change over time have worked well for cartographers in the past. In today's computer-oriented world, however, animation can be used to emphasize the temporally dynamic nature of data. Through animation, cartographers can incorporate temporal change directly into the map. Time-series data can be viewed in continuous succession or as movement across the screen rather than as separate static events. This capability is certainly intriguing and bound to capture the imagination, but what advantages, if any, does it bring to map reading and map use?

The study reported here provides some insight into this question by evaluating subjects' abilities to memorize and recall temporal patterns and information when mapped using either a paper map series, a computer map series, or animated maps. Subjects were asked to study the maps and to memorize two types of information: quantity data at specified locations on the maps and trend patterns that occurred across the maps. Memorization of the information was subsequently tested using a series of multiple choice questions to evaluate how well each map display worked for obtaining and recalling these two quite different forms of geographic information.

The thematic mapping technique used to symbolize the temporal *data* in this study was the graduated flow line. The choice of the graduated flow line was deliberate. There has been no research conducted into the proper visualization of linear from-to relationships in an animated form (Tobler 1987). Instead, the majority of animation research has focused on areal representations (Moellering 1984; Slocum, Robeson, and Egbert 1990), although dot symbolization has also been examined (Dorling 1992). Results of these studies suggest that animated maps using such symbolization techniques require the map reader to constantly shift eye focus throughout the animation. The obvious consequence of this requirement is that it is not possible to observe changes in one section of the *map* while concentrating on another section. Therefore, since the map is constantly changing, portions of the data are missed. An animated flow line, however, could allow the map reader to focus on one *point, the forward* tip, throughout the animation. Since the data represented by points on the line are sequential, the change in data will be followed smoothly by the eye. This characteristic of graduated flow lines should make this technique more easily transferred to an animated format.

THEMATIC MAPPING USING FLOW LINES

In thematic cartography, line symbols are used to show a variety of relationships. In their simpler forms they may show connectivity between places, boundaries separating regions, or differences in categorical attributes of linear objects. The symbolization of such data is most often accomplished using qualitative methods, where cartographers represent differences in values by varying the direction, color, or shape of the lines in question. When the goal of the map is to show quantitative differences, then symbolization *becomes more complex.* Here, differences in data values are shown most frequently by varying line widths to match the varying data values. This technique is commonly referred to as graduated flow line mapping. It was first introduced in the early to mid-nineteenth century to aid investigators in creating external visualizations of new topics and relationships (Wood 1994).

Graduated flow line mapping is ideal for symbolizing data that contains a distinct from-to relationship (Dent 1993). Monmonier (1993, 189) notes that "[f]lows - of people, products, or information - often seem to beg for cartographic portrayal." While size or value may be a secondary variable to impart importance to the linear feature, direction has the dominant role. The movement from one place or area to another deserves prominent and unambiguous symbolization and this can be achieved quite *clearly* by using graduated flow lines. In choosing a symbol to represent migration data, for example, Tobler (1987, 157) states that "[t]he simplest graphic is the rectangular flow band with width proportional to the flow and stretching from starting centroid to ending centroid."

Tobler also notes, however, that there are no rules that allow an unambiguous choice for the scale of the line. Most perceptual studies on graduated symbols have concentrated primarily on circles, squares, wedges, and text (e.g., Flannery 1971; Crawford 1971; 1973; Cox 1976; Groop and Cole 1978; Shortridge 1979). In her review of graduated symbol studies, Fraczek (1984) found that few studies deal with symbols other than circles. The few references found on the subject of graduated flow lines do offer suggestions for symbol scaling. Tobler (1987) notes that having the width proportional to the flow magnitude is thought to be more correctly interpreted than other methods, although he points out that this has not been proven. Monmonier (1993) states that thick lines are cumbersome and that size is less flexible when using line symbols as opposed to point symbols. There are no known studies examining the scaling of flow lines or the utility of flow line mapping in an animated context.

VISUALIZING TIME-SERIES DATA

Regardless of the thematic mapping technique chosen, the cartographer's goal is ".. . to provoke intuitive appreciation of the salient characteristics of a data set" (Robertson 1988, 243). Time-series data has traditionally been difficult for cartographers to handle due to the limiting factors of the printed static map. Fortunately, many of these restrictions disappear in a digital cartographic environment. The electronic map is an ideal medium for the organization, presentation, and communication of the growing volume of today's digital spatial data. New mapping techniques associated with the digital realm, however, need to be studied by cartographic researchers. Results of research that have been gathered on the perceptual and cognitive aspects of traditional printed maps and subsequently used to improve map design may very well not apply to these new forms of spatial visualization. Taylor (1993, 50) goes so far as to state that "Relatively little cartographic research has been carried out in this area but its obvious importance may lead to a revitalization of research and applications in the field of cartographic communication."

Traditional Visualization Techniques. To effectively map change in data over time, two strategies have been traditionally used in cartography. The first is a single map that shows limited aspects of change in or across space. The second is a series of maps that can be visually compared (MacEachren 1992). Single map representations can take the form of either dance maps or change maps (Monmonier 1990). Dance maps, a term coined from choreography diagrams, often use directional symbols to portray change over time. These symbols can vary in size to represent relative magnitude, or vary in label, color, or pattern to represent a particular group or time period. An example might be a map showing the changing center of population for the United States over some specified time period. Change maps depict only the change between time events. Symbols vary in value, size, or some other visual variable to represent change in direction, rate, or absolute amount of change. In this case, the map might be a choropleth map of the United States where change in the population for each state is shown for a given time period.

Map series representations present individual snapshots of a single time period for each map in the series, These maps have been called chess maps, after the diagrams of chess matches published in newspapers (Monmonier 1990). Sometimes a dynamic process can only be observed by a series of single-data cartographic snapshots. A set of separate maps evenly spaced in time allows the reader to assess direction, pace of change, and patterns of density for individual dates. Scale, format, symbols, and classification must be standardized between the separate maps in the series to facilitate comparisons. Juxtaposition is also desirable to aid the eye's need to jump back and forth between maps to detect differences (Monmonier 1993). If the maps are not juxtaposed on the same page, this may cause confusion as the map user flips between pages to compare the maps. Such confusion will naturally hinder the communication of information to the map user (Campbell and Egbert 1990). To avoid these problems, several researchers have proposed using animation to bring both the temporal and spatial aspects of data together in a single, integrated display (Moellering 1980; Calkins 1984; Campbell and Egbert 1990; Weber and Buttenfield 1993).

Animation as a Visualization Technique. Animation has been a topic in cartography for over thirty-five years (Thrower 1959; 1961). As a potential visualization technique, it has been recognized as a way to give an impression of continuous change to match the constantly changing process of the mapped phenomena. The computer entered the realm of animation in the mid-1960's, allowing individual frames to be photographed straight from the monitor (Cornwell and Robinson 1966). Today, advances in both hardware and software allow the cartographer many options in representing geographic data (Gersmehl 1990).

Visualizing geographic data using animation can be accomplished in a variety of ways (see Moellering 1984; DiBiase, et al. 1992; Dorling 1992). Of these, Darling's (1992) work is most closely aligned with this research. Dorling separates animation into three categories. He defines animating space as the process of panning and zooming around a two-dimensional static image. This is not normally considered cartographic animation.

Animating time is a process where actions are played out on a nonmoving map. Hence, time is used to show differences in space and movement is used to represent a function of time. Three-dimensional animation is the process that makes use of movement, perspective, shading, and shadows to compensate for the lack of an actual third dimension. In his experiences experimenting with cartographic animations, Darling found that animating space was the most useful technique. He found animating time useful in illustrating change to other people, but less useful for investigational purposes. This technique works best when movement is involved. The brain's poor visual memory was identified as a factor in these results. Three-dimensional animation was found to be confusing, though this is the direction currently being pursued in scientific visualization.

Cartographic animation is a visualization tool that may be used to increase understanding of data distributions over and above that gained from traditional paper map series or computer map series. Caution must be exercised when using animation so that the data relationships are of primary importance and animation is used as a tool and not just to showcase technology (Calkins 1984; Campbell and Egbert 1990). For example, in a study on sequenced choropleth maps, the test subjects greatly preferred the animated sequencing; however, test results did not support the usefulness of the technique (Slocum, Robeson, and Egbert 1990). Research with regard to information retention, visualization ability, choice of thematic method, graphic symbolization, and legend design, as well as the new choice of dynamic variables, is needed to ascertain the best ways of displaying animated maps (Campbell and Egbert 1990; MacEachren and DiBiase 1991; DiBiase et al. 1992; Karl 1992; Monmonier 1992; 1993; Peterson 1995).

RESEARCH HYPOTHESES

Graduated flow maps illustrate the movement of any measurable quantitative variable from one area or place to another (Dent 1993). Map readers typically use flow maps to ascertain movement of quantities, whether depicted exactly or in classes. For time-series data, they can also use flow maps to determine general trend patterns. A general question of whether the technique of animation allows the map reader to better learn and remember flow line data was broken into two separate research hypotheses. These hypotheses, stated below, were designed to test two map reading tasks, quantity evaluation and trend pattern recognition:

- When compared to printed and static computer map series, animated map displays should not significantly improve map reader's response times or accuracy rates for quantity evaluation tasks.

- Map readers should be able to complete trend pattern recognition tasks more quickly and more accurately in an animated environment.

It is expected that the emerging visualization technique of animation will not improve the evaluation of specific flow quantities. Quantity evaluation is more of an informational or investigative task. Dorling (1992) reports that animation does not serve this purpose well. Quantity evaluation is site and time specific; each point in each time period is learned separately. To properly evaluate the amount of flow, not only does the map reader have to locate the points of interest along the line, but also compare the width of the line at those points to the legend. Animation should not aid in the comparison between the map and the legend.

It is expected, however, that animation will improve the recognition of flow trend patterns. This expectation also is derived from Dorling (1992), who found that animations were useful when illustrating change to map readers, especially when movement was involved. Since patterns are not dependent on studying the legend, the points of interest can be observed and compared directly over time. Attention does not have to shift away from the animated sequence. Also, animation allows the map reader to view changes over time on a single display by expanding or shrinking the line accordingly. In contrast, paper map series and computer map series require the map reader to make comparisons across multiple maps to judge differences in line widths over time.

EXPERIMENTAL DESIGN

This study compared subjects' abilities to learn time-series graduated flow line data using three different visualization techniques: paper map series, computer map series, and animation. The primary intent was to assess the usefulness of these different visualization techniques for two types of spatial tasks: quantity evaluation and trend pattern recognition.

Subjects. Sixty-five volunteers from undergraduate geography classes at San Diego State University participated in the study. The subject group consisted of 39 males and 26 females. Participants received class credit for completing the experiment.

Materials. The maps used were highly simplified, imaginary representations of a river and its surrounding watershed. The river was made up of twenty-three line segments, roughly equal in length. Two points representing water flow gauging stations were identified along the length of the river. These stations, identified by leader lines on the map, were located at the mid-points of segments four and eighteen. A title, legend, and year indicator were also included (Figure 1). The legend showed flow lines for five absolute quantities. These quantities represented aggregate annual water flow for the river depicted. For each of the five flow quantities in the data set, a corresponding line width was assigned. These widths were measured in pixels for the computer maps and in inches for the paper maps. The paper maps were rendered to match the computer maps as closely as possible in all aspects of design.

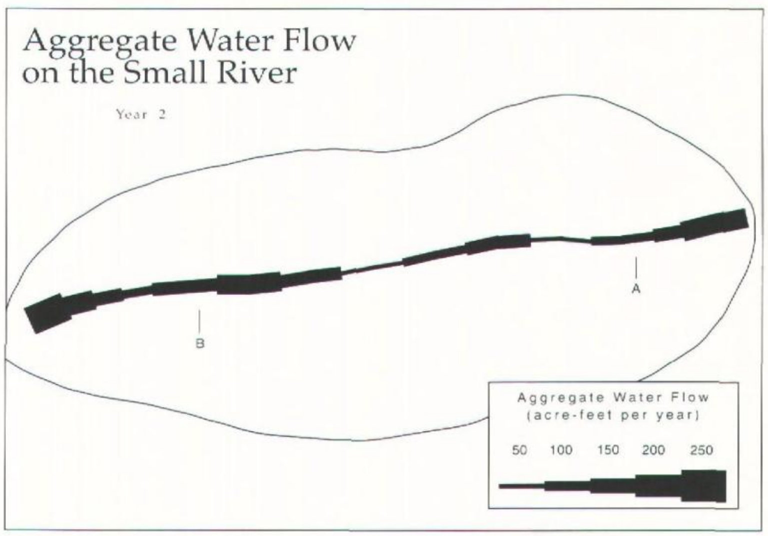

Figure 1. Typical test map

Data Sets. Four independent data sets representing aggregate annual water flow were created for the experiment, two for each type of map task. For the quantity evaluation task, data were generated *for* the *two* line segments containing gauging stations by rolling a six-sided die. Once the gauging station values were determined, the values for the remaining segments of the river were assigned to create a roughly smooth flowing surface. This method was repeated three times to establish data for each of three different time periods. As the trend pattern recognition data were assigned specifically to enforce trend patterns at each of the two target line segments over a six year time interval, no die roll was employed. Identical methods were used to generate the second data sets.

The extra data sets were necessary to effectively evaluate the visualization techniques. In an earlier pilot study, subject responses indicated that learning the quantities and trend patterns at three points over six time periods led to accuracy rates no better than chance. Two changes in the experimental *design provided subjects* with a better chance of completing the tasks successfully. First, the number of gauging stations on the test maps was reduced from three to two. The data sets used in testing were also shortened from six years worth of data to three years for the quantity evaluation tasks. This change in experimental design reduced the total number of possible tasks for the subjects to perform. The use of additional data sets counteracted this effect. Using two data sets, subjects completed twenty-four tasks. Half the tasks were quantity evaluations and half were trend pattern recognition tasks. Six tasks of each type were composed from each data set.

Once the data were determined, answer sets were generated. Random rolls of a six-sided die determined the order of question presentation. Each question had three choices, presented to the subject in a multiple-choice *format.* Die rolls also determined the values for the two incorrect choices, as well as the position of the correct answer on the question display. Three test maps (one for each year's worth of data) were then rendered for each of two data sets; these were used for the quantity evaluation tasks. For the trend pattern recognition tasks, six maps were rendered for each data set.

Visualization and Testing Procedures. Each subject was randomly assigned to one of three groups. The control group viewed a series of paper maps. The second group viewed a series of static maps similar to the paper maps on a computer screen. This group was included to represent a middle ground between the paper and animated environments. The final group viewed animated map sequences. Subjects in all groups performed the same two task types: quantity evaluation tasks and trend pattern recognition tasks. Each subject performed practice tests prior to taking the actual experiment. These tests allowed them to become familiar with the specific task requirements and the method of query and response used. Different data sets were used for these preliminary tests.

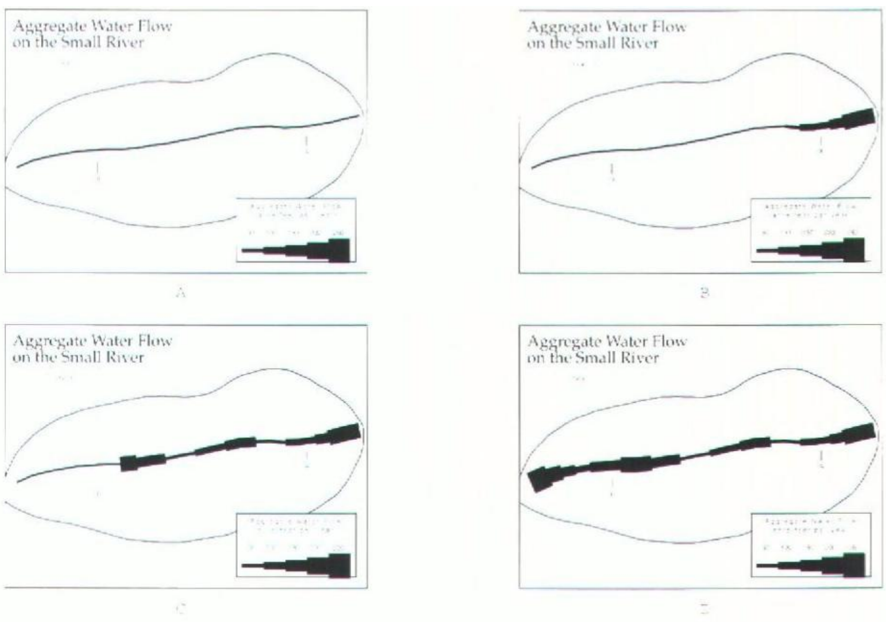

Figure 2. Flow line animation process. Plate A represents the test map before the animation begins. The animation proceeds through plates B and C until the entire line is represented, as shown in Plate D.

The quantity evaluation tasks tested subject memory of data quantities for multiple time periods. Subjects, tested individually, studied the quantities represented by the graduated flow lines at each gauging station for three years. Those assigned to the paper map group studied a set of three paper maps. Subjects who viewed the maps on the computer studied a series of maps in sequential order by year. Subjects assigned to the animation group viewed a sequence of three years' worth of data in a controlled animation program.

The animation sequence was such that when the sequence began, the linear feature had no data represented; the line was thin and of uniform width (Figure 2). The linear feature was then over-written by line segments representing the aggregate flow data for the year being shown. This overwriting moved from the starting point to the ending point of the line. Duration of the overwriting movement was six seconds. Once the first year's data were fully represented, another second passed as the time period incremented. The first year's flow line was then overwritten by the second year's flow line (Figure 3). This process continued until all three years had been presented. The screen was then cleared to indicate to the subject that the cycle was complete. The entire sequence was then repeated using the same data for two more cycles.

The static computer display operated in a slightly different manner. Each map was viewed for seven seconds and then was replaced by the next map in the series. The entire static computer map series was repeated three times. Subjects could not control either the animation or static computer display sequence. The total viewing time for each of the computer displays equaled the length of time that subjects in the control group studied the paper maps (approximately 1 minute). The viewing time, as well as the cycling time for the computer generated maps and animation, were determined during a pilot study undertaken before gathering data for this study. At the conclusion of the specified viewing time, the paper maps were removed from view, and both computer visualizations ended.

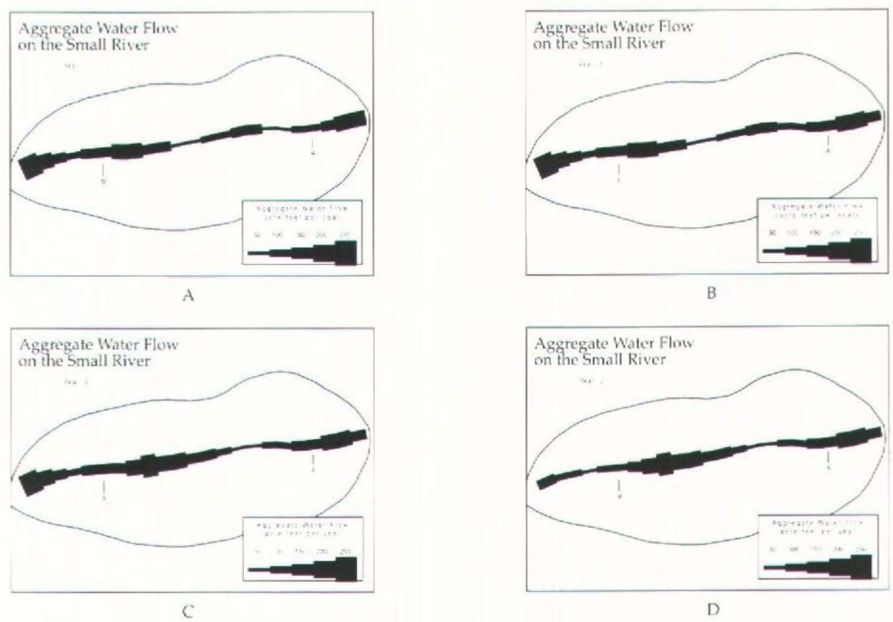

Figure 3. Continuation of the flow line animation process. Plate A represents the test map after the first year has been depicted. The animation continues as the line is overwritten by new data as shown in plates B and C until the entire line is represented by new data, as shown in Plate D.

All subjects, regardless of the group to which they were assigned, answered the test questions on the computer so that reaction times could be recorded. Subject short-term memory was purged by displaying a text screen containing instructions on the correct method for answering the test questions. The elapsed time taken to read the instructions was between thirty and sixty seconds. Each subject was then shown a computer graphic depicting the outline of the river and the gauging station locations without any data representation. When the test questions began, a specific gauging station, year, and three numeric quantities were shown under the reference graphic (Figure 4). The subject was asked to indicate which of the values best described the quantity of flow that occurred at that station for the year in question. The answer and response time for each query were recorded, as was the type of visualization strategy used to memorize the data. Subjects made responses by pressing one of the three labeled keys on the computer keyboard. After completing the questions for the first data set, they repeated the process for the second data set. Twelve queries were made in this section of the study.

The trend pattern recognition tasks tested subject memory of overall trends for six years. In this section of the study, subjects learned trend patterns over time at each gauging station rather than specific quantities. Except for the type of questions asked, the testing and data collection processes were similar to the quantity evaluation section of the experiment. Here, subjects determined if the trend between a specified pair of times was increasing, decreasing, or unchanged (Figure 5). The number of years viewed was increased from three to six to better illustrate changing trend patterns. Since the total number of years was increased, the number of viewing cycles for the static computer display and animation groups was also increased from three to four cycles. As with the quantity evaluation section, the total viewing time for each of the computer displays equaled the length of time that subjects in the control group studied the paper maps (approximately 2 1/2 minutes). Two data sets were used and a total of twelve queries was also made in this section of the study.

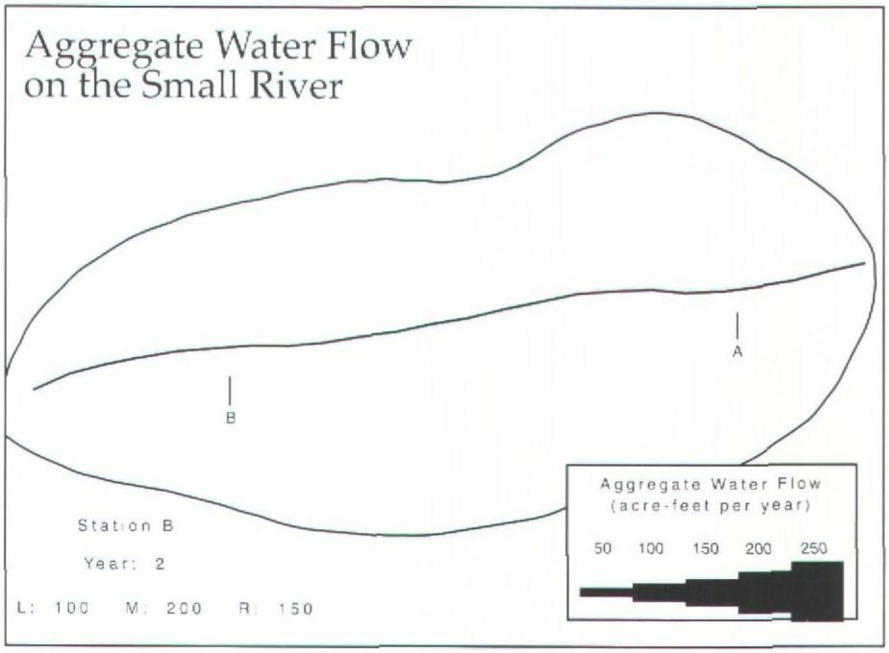

Figure 4. Query screen for quantity evaluations.

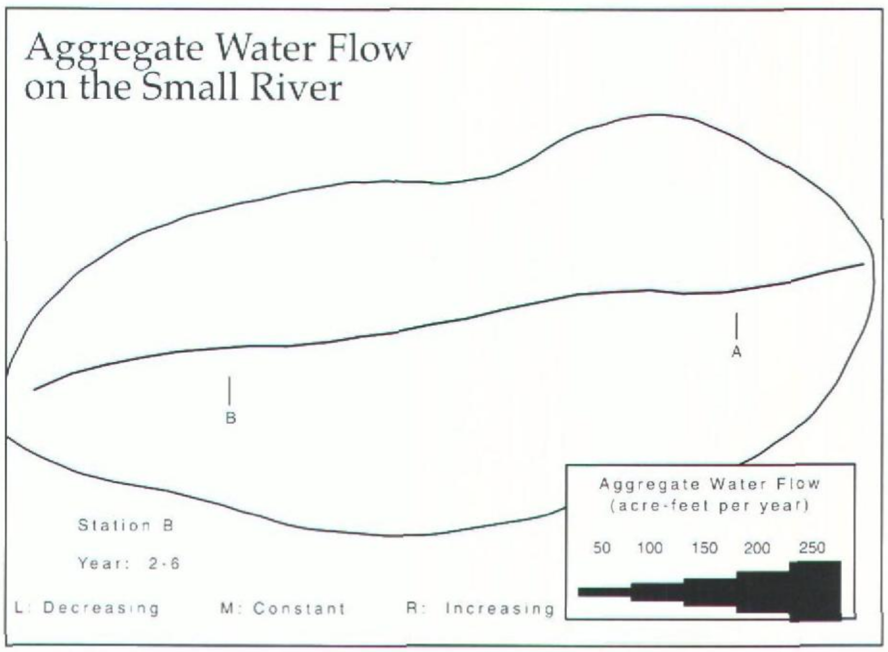

Figure 5. Query screen for trend pattern evaluations

The final section of the study required that each subject group view the other visualization techniques. Viewing times were only for as long as the animation sequence took to run through one cycle. The purpose here was not for subjects to memorize data, but for them to form impressions of the other visualization strategies available in the study. An informal written survey was then given to ascertain their impressions of these visualization techniques.

DATA ANALYSIS

The method of analysis used in this study was a standard analysis of variance (ANOVA). The dependent variables used in these analyses were reaction times and accuracy rates. Visualization method (paper map series, computer map series, animation) and map reading task (quantity evaluation, trend pattern recognition) were recorded for use as the independent variables. Gender was not originally included in the experimental design; however, due to the high turn-out of female volunteers, a gender factor was included in the model.

The analysis was performed using the General Linear Model of the SPSS statistical software package. Subject responses and reaction times were aggregated separately over the map reading tasks, which resulted in two data sets of 126 observations each. As is usual with reaction time analysis, times for incorrect answers were treated as missing data and therefore not factored into the aggregate reaction time data set. The general model tested the following main effects and interactions: GENDER, MAP TASK, VISUALIZATION GROUP, TASK*GROUP, GENDER*GROUP and GENDER*TASK*GROUP. These interactions were chosen to specifically evaluate the comparisons between visualization techniques. Custom hypothesis tests were also developed to address the interaction effects in greater detail. These were specified as planned comparisons and as such do not necessarily have to have a significant overall F from the ANOVA to carry them out or return a significant result (Snodgrass, Levy-Barger, and Haydon 1985).

Source	df	F	Significance
Model	11	1.262	.255
Gender	1	.427	.515
Map Task	1	1.094	.298
Map Group	2	.566	.569
Task*Group	2	.312	.732
Gender*Group	2	3.597	.031
Gender*Task*Group	3	1.556	.204
Error	114		
Total	126		

Table 1. ANOVA Results for Accuracy Scores

Accuracy Rate Evaluations. Table 1, which provides the results of the overall ANOVA for accuracy rates, clearly shows that the model was not significant at the .05 level. Of all the main effects and interaction effects tested, only the GENDER*GROUP interaction was significant. Figure 6b shows graphically the form that this interaction took. This graph suggests that females completed the map tasks more accurately when using the paper map series, while males performed the tasks more accurately on the computer. Custom hypothesis tests confirmed that there was a significant difference in accuracy rates for female subjects who used the paper map series versus females who used the computer map series to complete the map tasks (F(1,119) = 5.155, P = 0.025). Differences in accuracy rates between animation and the other visualization techniques were not significantly different for females. There is a definite trend, however, suggesting that female subjects who used the paper map series performed the tasks more accurately than those who used animation (see Table 2 for mean accuracy scores). No significant differences were found between the accuracy rates of the different visualization techniques for male subjects.

A custom hypothesis test was also performed for the TASK" GROUP interaction, plotted in Figure 6a. This graph suggests there were no significant differences in the accuracy with which different tasks were performed between the visualization groups. Further testing using planned comparisons confirmed this interpretation of the graph.

Reaction Time Evaluation. As Table 3 shows, the overall model for reaction times was not significant at the .05 level either. Furthermore, none of the main effects or interaction effects tested were significant in this model. A custom hypothesis test designed to look more closely at the TASK*GROLTP interaction showed that there were no significant differences in response times for quantity evaluation tasks across visualization groups (F(2,119) = 1.700, P = 0.187). This test did indicate, however, that there was a significant difference in response times for the trend pattern recognition tasks across the visualization groups (F(2,119) = 3.651, P = 0.029). Figure 7a suggests that subjects using the paper map series had the most difficulty answering trend pattern recognition questions, while those in the animation group had the least difficulty (see Table 4 for mean reaction time scores). Planned comparison tests confirmed that the mean reaction times for subjects using the paper map series were significantly longer than those using the animation (F(1,119) = 7.265, P = 0.008). The difference in means between subjects using the paper map series and those using the computer map series were not significantly different, nor were there any significant differences between users of the computer map series and the animation users.

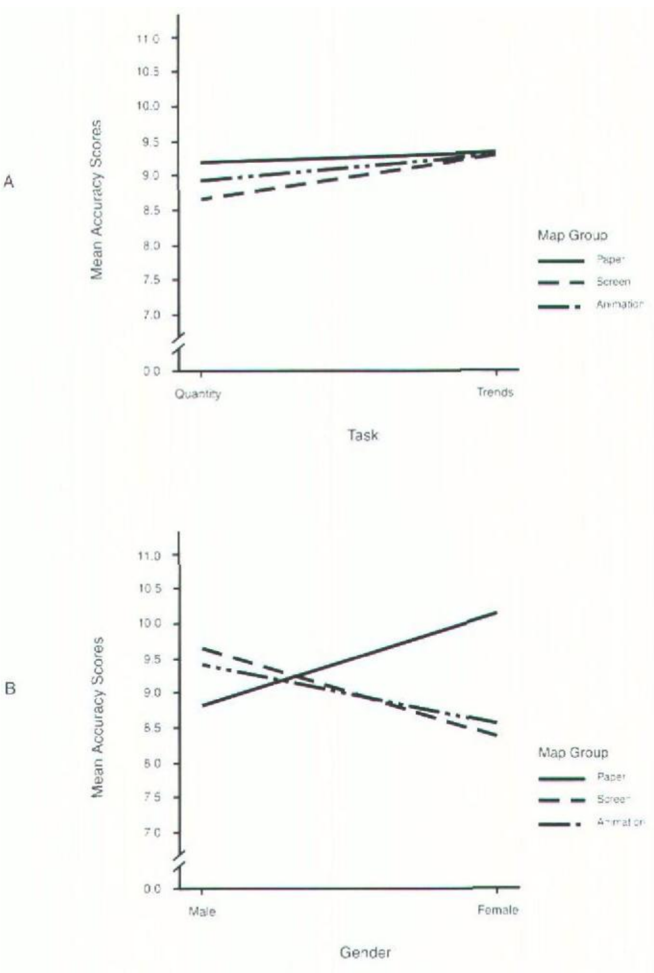

*Figure 6. Accuracy interaction plots for (a) group*task and (b) group*gender*

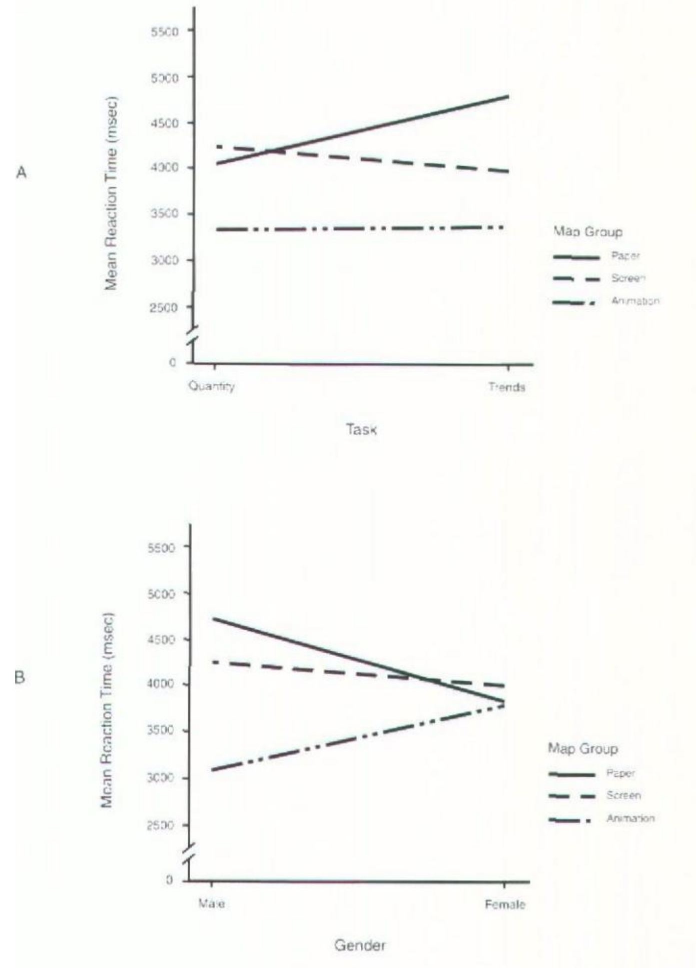

*Figure 7. Reaction time interaction plots for (a) group*task and (b) group*gender*

Figure 7b shows the interaction of GENDER*GROUP visually. Planned comparison tests for this interaction effect indicated that there was a significant difference in mean response times for males across the different visualization groups ($F(2,199) = 6136$, $P = 0.002$). Further testing showed that there was a significant difference in the means between male subjects using the paper map series and those using animation to complete the tasks ($F(1,119) = 12.993$, $P = 0.000$). There were also significant differences between male subjects using the computer map series and those using animation ($F(1,119) = 5.385$, $P = 0.022$). No significant difference was detected between the subjects using the paper map series and those using the computer map series. The planned comparison tests also showed no significant differences in visualization group means for female subjects.

Map Task	Total	Male	Female
Total	9.11	9.26	8.90
Paper Map Series	9.26	8.82	10.14
Computer Map Series	8.98	9.65	8.36
Animation	9.10	9.42	8.56

Table 2. Means for Accuracy Scores

Source	df	F	Significance
Model	11	1.613	.104
Gender	1	.221	.639
Map Task	1	.448	.505
Map Type Group	2	2.668	.074
Task*Group	2	.979	.379
Gender*Group	2	2.293	.106
Gender*Task*Group	3	.596	.619
Error	114		
Total	126		

Table 3. ANOVA Results for Reaction Times

DISCUSSION

Results from the statistical analyses suggest that there were no significant differences in the accuracy with which subjects performed the quantity evaluation tasks for the different visualization groups. Subject response times for this type of task were also not significantly affected by the visualization group to which the subject was assigned. Both of these results support the hypothesis that animation would not significantly improve subjects' abilities to complete these types of spatial tasks. Quantity evaluations are informational tasks that utilize not only the flow line but also the map legend. Since animation does not aid in comparisons between the flow line and the legend, it makes sense that animating the mapped data for these types of tasks would not improve one's ability to perform them. In fact, animation *could* possibly cause map readers to ignore the legend altogether by drawing their attention to the moving line.

The accuracy with which subjects completed the trend pattern recognition tasks was also not significantly influenced by visualization group. However, subject response times for these tasks did differ significantly on the basis of the visualization technique used. Those subjects who used the animation to answer these questions responded significantly faster than subjects who used paper map series. Although accuracy rates were not significantly higher with this visualization technique, as had originally been hypothesized, they were not significantly lower either. This, coupled with the significantly faster reaction times suggest that animation may be a useful tool for communicating trend patterns to map users. Such illustrative tasks, where a direct comparison between the data on the map and the legend is not necessary, seems to be better illustrated with animation than informational tasks, a finding that is supported by Dorling (1992).

Though not a strict gender study, the number of female participants prompted the inclusion of a gender factor in the data analysis. Since the hypotheses and experimental design were generated prior to *the* inclusion of the gender factor, discussion of gender results are treated as informational only and not related to the hypotheses directly. The significant interaction between gender and visualization group for accuracy rates was primarily a consequence of the high scores by females using the paper map series (Table 5). Average response times for females did not differ significantly between the different visualization groups. Since females achieved a significantly higher accuracy rate with the paper map series, but took roughly the same amount of time to access the answers from memory, it appears that they retained spatial information better from the paper maps. The constant reaction times, however, suggest that they were not able to process the information any more easily when using this form of cartographic representation.

Reaction time data gathered from the male subjects indicates that they completed the tasks significantly more quickly when using animation. Furthermore, there does not appear to be a trade-off between response time and accuracy, as accuracy rates did not differ significantly for males across the visualization techniques. This suggests that the males in this study learned and remembered information better when using animation.

Subjects also participated in an informal written survey conducted at the end of the experiment. The purpose of the survey was to gain insight into the preferences of the subjects regarding the visualizations used in the study. Subject observations, suggestions concerning the animation process, and comments regarding ways to improve the communication of data were recorded. Table 6 illustrates the preferences of the subjects by visualization group. Results show that each group preferred the visualization technique on which they were tested. It is interesting that the paper map series were chosen second by both computer groups. Group totals show paper maps were preferred by close to half of the subjects, with animation second and the computer map series last.

Map Task	Total	Male	Female
Total Mean	3965	4018	3888
Paper Map Series	4424	4724	3823
Computer Map Series	4107	4239	3987
Animation	3363	3089	3809
Trend Recognition	4051		
Paper Map Series	4792		
Computer Map Series	3975		
Animation	3385		

Table 4. Means for Reaction Times

Gender	Accuracy Rates	Reaction Times
Male		
Paper Map Series	8.82	4724
Computer Map Series	9.65	4239
Animation	9.42	3089
Female		
Paper Map Series	10.14	3823
Computer Map Series	8.36	3987
Animation	8.56	3809

Table 5. Gender Means for Accuracy Rates and Reaction Times

Table 7 presents the breakdown of preferences for males and females. Again, the paper map series was the most preferred method of visualization by both groups. The strong preference by females also coincides with the higher accuracy rates they scored with the paper maps. Males, on the other hand, actually performed more poorly with paper maps. The large percentage of subjects who prefer the paper map series may result from the control they had in examining the sets of maps. Subjects from all groups indicated that control of map viewing was an important factor in their preferences. Those who participated in the computer map series and animation groups stated that user control of the animation was necessary for proper examination of the data.

Visualization Group	Number of Subjects	Map Type	Preference Percentage
Paper Map Series[a]	22	Paper Map Series	77.3%
		Computer Map Series	4.5%
		Animation	18.2%
Computer Map Series[b]	20	Paper Map Series	40.0%
		Computer Map Series	45.0%
		Animation	15.0%
Animation	21	Paper Map Series	28.6%
		Computer Map Series	9.5%
		Animation	61.9%
Total Group	63	Paper Map Series	49.2%
		Computer Map Series	19.1%
		Animation	31.8%

[a]Subject number includes a subject not used in the formal analysis.
[b]One Subject did not state a preference.

Table 6. Test Group Preferences of Visualization Techniques

Several subjects also suggested incorporating color into the animation as a way of improving this visualization technique. The animation used in this study employed only one color throughout the animated sequence. Subjects in all visualization groups felt that evaluations for the quantity section of the study would have been easier had each quantity had its own separate color. They believed that color would have been a better visual cue than comparing widths to the legend. While an interesting idea, implementing this in *a* graduated flow context could be complicated.

Gender	Number Of Subjects	Map Type	Preference Percentage
Male	36	Paper Map Series	44.4%
		Computer Map Series	19.4%
		Animation	36.1%
Female	27	Paper Map Series	55.6%
		Computer Map Series	18.5%
		Animation	25.9%

Table 7. Gender Preferences of Visualization Techniques

Relating changes in color to changes in quantity is not a visually intuitive procedure. Furthermore, the varying visual perceptions of colors would need to be addressed. An interesting alternative, however, might be to vary not only line widths, but also the color value of the line to cue users to quantity changes.

CONCLUSION

This study compared the traditional time-series visualization technique of paper map series to the emerging techniques of computer map series and animation. The general research question examined which visualization technique allowed a map reader to better learn and understand the data presented. Human subjects were asked to perform two separate map reading tasks. The first involved learning specific data values, while the second required learning trend patterns. The expected results were based on Dorling's (1992) findings that informational or investigative purposes of map reading are not well served by animation, while illustrating change through time is enhanced by this technique.

Results of the study indicated that animation did not improve learning ability for quantity values (an informational task), but did enhance the learning of trend patterns (an illustrative task). The study also showed that females preferred the paper map series and completed tasks significantly more accurately with them, while males appeared to learn better with animation. Average reaction times for males were significantly faster with animation. Accuracy rates, however, failed to show a significant increase over the paper map series. Perhaps the difference being seen in this study is related to exposure and use of computers between the genders. It has been suggested, in the popular media at least, that during adolescence males tend to spend much more time using computers than their female counterparts. If true, that could be a factor in the preferences and differences in reaction times and accuracy rates seen between the two groups.

Interestingly, the study group as a whole preferred the paper map series to either of the other visualization methods. Paper was also the preferred technique by both males and females. Subjects felt they had more control with the paper map series than with either the computer map series or the animation. Suggestions for improving the animation technique included allowing the subjects to have direct control over the animated sequence and color coding the quantity values to make them more distinguishable.

Future Research. Animated maps are now possible given current computer technology. Whether or not they are preferable is questionable. Continued study focusing on computer map symbolization, including graduated flow lines, and the effectiveness of animation on perception and memory retention is needed. This study examined two purposes of visualization as outlined by Dorling (1992), investigative and illustrative, using the same symbolization method and representation as used by standard paper maps. The next step would be to separate these two different purposes and research the methods and representations that would improve communication of the data for each one. The methods developed for the investigative purpose might also be carried over into exploratory visualization.

The proper scaling of quantitative flow lines should also be examined in a dynamic environment. The ability to zoom in and out, changing the scale of the map, has consequences for the interpretation of graduated flow lines. How does changing the scale of the flow line, and consequently the legend, affect the ability of the map reader to comprehend the data?

The use of color in an animated flow line sequence should also be examined. The suggestion of the test subjects that quantity be based on hue differences is an intriguing one. The choice or choices of hue and the decision to vary saturation or value or both are all issues that need to be explored. Do you vary width as well as color? The importance of this continued research is a consequence of technological forces. Advances in technology have put the ability to make maps into the hands of non-cartographers. Desk-top mapping programs, developed by non-cartographers, are being used by the general public to create pretty, aesthetically pleasing maps. The meaning of the data is often lost as default classification schemes and color palettes are used. Cartographic techniques for dynamic and static screen-based exploration, classification, and symbolization of data need to be developed so that software manufacturers can incorporate them into end-products to improve cartographic renditions.

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