cartographic techniques

Views of the Rivers: Representing Streamflow of the Greater Yellowstone Ecosystem

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INTRODUCTION

Cartographers often work with temporal data associated with a spatial phenomenon that requires a novel method for representation. This article presents a pixel-based graphing technique for representing temporal data that is not fraught with the "amplified cartographic challenge" [Harrower 2003] that comes with animating a map. Temporal variables such as day and year may be used as coordinates to plot a pixel-based map of variations over time for any given phenomenon at a specified location.

Temporal streamflow data is one example where this pixel-based technique can be applied to produce a raster hydrograph. This method offers increased visual analysis of multi-dimensional data. As hydrologists and water resource managers experience a tremendous growth in geographical and temporal hydrologic data [Fuhrman 2000], this method of visualization can help them interpret, model, and disseminate data and information. This technique also provides a baseline that supports collective decision making [Brewer I et al. 2000, MacEachren, in press]. The raster methodology enhances the plotting of temporal streamflow data for water resource management, collaboration, and public outreach, which is a major need in GIScience [Marcus et al. 2004].

SETTING

The Greater Yellowstone Area (GYA) encompasses Yellowstone National Park and a surrounding area of approximately 7.7 million hectares [Keiter and Boyce 1994]. The GYA contains the headwaters of three major river systems: the Snake/Columbia, the Yellowstone/Missouri, and the Green/Colorado, but the semiarid climate and seasonality of flow make this an area of water scarcity. The GYA's wide variety of water data users and managers, the diverse river systems, and the need for improvements in collaborative management throughout the region prompted the influential Hydrologist Luna Leopold to state in 1986 that: "Both government agencies and private groups must understand the hydrology of Yellowstone's rivers and streams before meaningful policy may be achieved" [Dana 1990: 78]. Innovative visualization methods like the raster hydrograph contribute to an improving understanding of magnitude, frequency, and timing of peak and low streamflows in the GYA. That better understanding then enhances the collaborative management of surface water resources in the region.

PORTRAYAL METHODS OF TEMPORAL VARIATIONS IN STREAMFLOW

Traditional portrayals of temporal variations in flow are typically shown by graphs. Exceedance probability graphs (or their inverse - recurrence interval graphs) are widely used and display the probability that a flow of a given size will be equaled or exceeded in a given time. Exceedance probability charts are available for all gauged rivers in the United States through the U.S. Geological Survey (USGS) online database (Figure 1). These powerful displays provide a simple way to see temporal magnitude-frequency relations in large datasets.

Hydrographs plot discharge versus time and are also widely used to portray variations in streamflow over time (Figure 2). Hydrographs are familiar, easy to understand, and available online from the USGS. Hydrographs, however, can fail to display the full range of within-year and between-year variability, especially for large datasets. Figure 2A, for example, shows between-year variability from 1921 to 2003, while Figure 2B shows within-year variability for the 1996 water year at the same site. Detailed within-year fluctuations are not displayed in Figure 2A, nor are between-year fluctuations displayed in Figure 2B. A more robust plotting technique is needed to display inter- and intra-annual variability simultaneously.

Koehler [2004] advocates a new raster-hydrograph approach, originally developed by Keim [2000], which uses dual-time axes to show inter- and intra-annual variations simultaneously. Figure 3, shows the raster hydrograph which enables the user to determine temporal changes based on overall brightness and color distribution, with sharp borders representing discontinuities. The inter-annual streamflow patterns shown

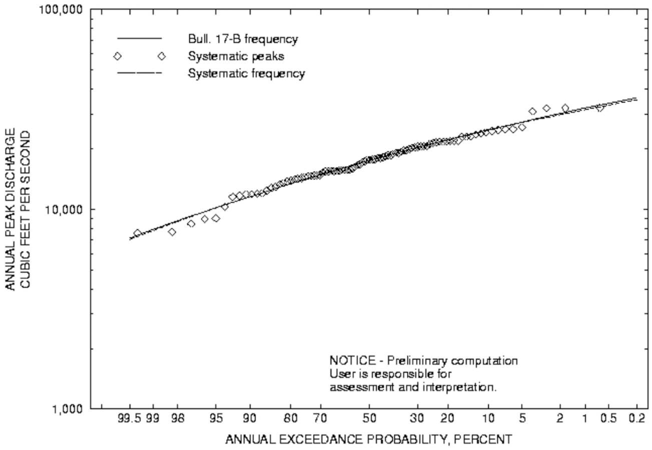

Figure 1. An exceedance plot of annual peak discharge for the Yellowstone River at Corwin Springs, MT 1911-1998. The chart provides a simple way of visually portraying 87 years of data. The exceedance probability indicates the likelihood that a discharge of a given size or greater will occur in a given year (USGS 1998: http://mt.water.usgs.gov/freq?site=06191500).

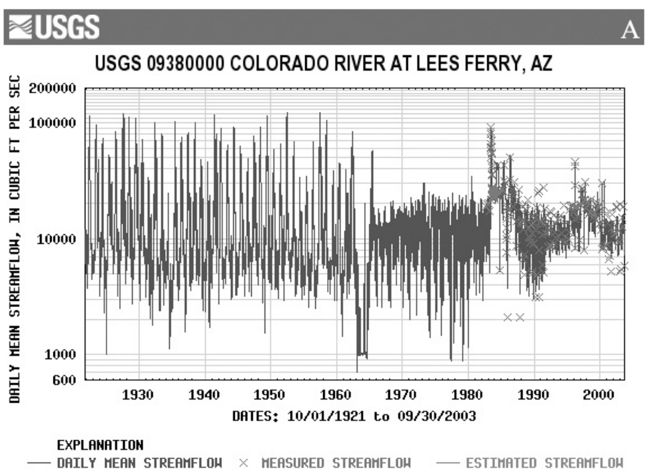

Figure 2a. Hydrograph depicting average annual flow from 1921 to 2003 at Lees Ferry on the Colorado River. (USGS 2005a: http://nwis.waterdata.usgs.gov/az/nwis/nwisman/?site_no09380000&agency_cd=USGS).

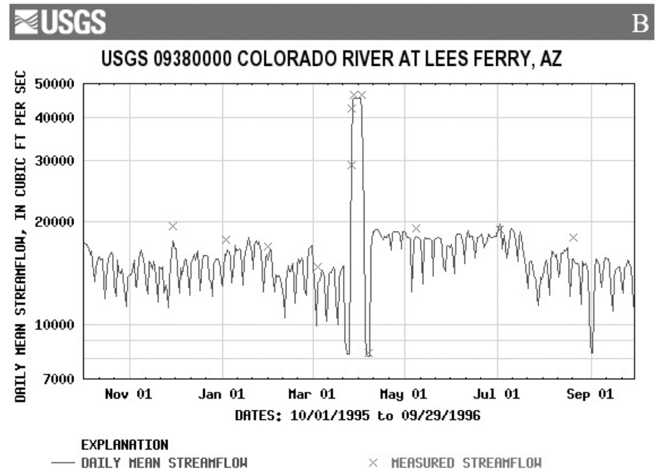

Figure 2b. Hydrograph depicting average daily flow in 1996 at Lees Ferry on the Colorado River. (USGS 2005a: http://nwis.waterdata.usgs.gov/az/nwis/nwisman/?site_no09380000&agency_cd=USGS).

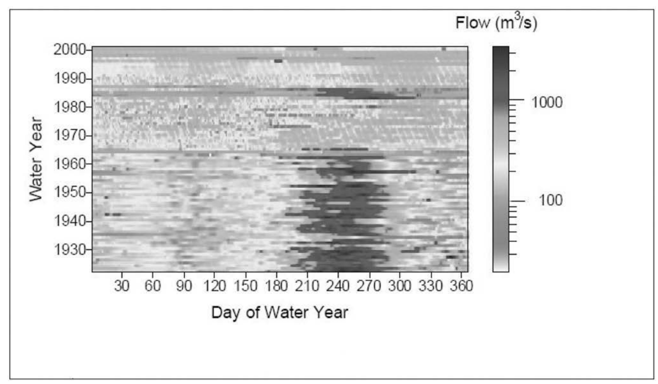

Figure 3. Raster hydrograph shows inter- and intra-annual variability simultaneously, Colorado River at Lees Ferry, AZ 1921-2002 (Koehler 2004:161). *(see page 80 for color version)*

in Figure 2a are apparent, as well as intra-annual streamflow of Figure 2b, but not for every single year of record, thus providing a denser display of inter- and intra-annual variations than the traditional hydrograph. Moreover, these pixel-based patterns provide visual representation of the frequency and clustering of events of a given discharge, thus providing similar information to that of the recurrence interval plot (Figure 1).

Poff and Ward [1990] developed a technique similar to the raster hydrograph that displays long-term at-a-station discharge in three-dimensions to reveal within- and between-year variability (Figure 4). The three-dimensional surface plot shows inter- and intra-annual streamflow simultaneously, but the heights on the vertical axis are difficult to interpret and are not as precise as the planar view of the raster hydrographs. The sequence of temporal records values also increases towards the axes' origins, which is not intuitive for time series data.

RASTER-BASED TEMPORAL VIEWS

The raster hydrograph is a multivariate representation of data where the X-axis is the day of water year, the Y-axis is the water year, and the Z-axis is the log10 of the daily mean streamflow value. We applied the raster-based techniques [Keim 2000 and Koehler 2004] to determine the potential of this technique for visualization of variations in streamflow. We developed raster hydrographs (Figure 5) for the Snake River, which is dam-regulated, and the Yellowstone River, which has no dams. Mean daily discharge values from the USGS included 36,529 observations at the Snake River near

Moran and 33,969 observations at the Yellowstone River at Corwin Springs.

The hydrologic time-series data were formatted in Microsoft Excel to the described X, Y, and Z values and then imported to Golden Software's Surfer 8.0, a commercially available contouring, gridding, and surface mapping software product. Surfer supports conversion of X, Y, Z tabular data into a grid and displays the result as a raster image. The gridding method used nearest neighbor sampling to create grid files (.grd) without interpolation so every pixel in the raster grid represents an observation in the he X-axis and year on the Y -axis as an Image Map. In place of latitude and longitude used on conventional Image Maps, the raster hydrograph method uses the temporal variables of day (X) and year (Y) as coordinates to plot a map of streamflow (Z) over time.

Discharge in Figure 5 is broken into visual classes using a sequential multi-hue color scheme based on the percent of all discharge values equal to or below a given value. This percentage-based approach provides equivalent color schemes for both hydrographs and enables quick visual comparisons between the two stations. Class breaks for the percentiles (Figure 6) follow class breaks used by the USGS WaterWatch system [USGS 2005b]. The classification system standardizes the data allowing for comparison between sites thus highlighting spatial variations.

Colors used to show percentage classes follow sequential lightness steps with a partial spectral transition in hue from yellow to green to blue (Figure 6). The sequential multi-hue color scheme maximizes

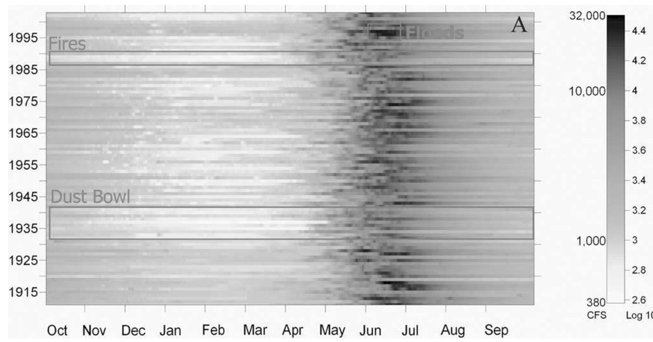

Figure 5a. Raster hydrograph for the Yellowstone River at Corwin Springs, MT. (see page 81 for color version)

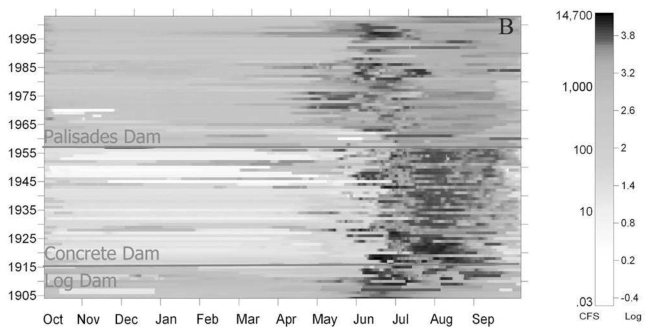

Figure 5b. Raster hydrograph for the Snake River near Moran, WY. (see page 81 for color version)

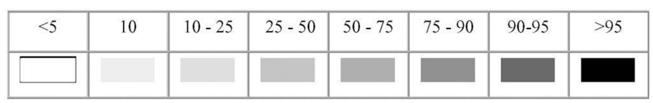

Figure 6. Percentile class breaks with corresponding multi-hue color scheme. (see page 81 for color version)

the ability to see small differences in values [Keim 2000], while the use of progressively darker steps with increasing amounts of blue for larger flows fits with viewer expectations, an important consideration with a quantitatively sequential dataset [Brewer 1994]. Anomalies are represented with the use of white for flows less than the 5th percentile and black for flows greater than the 95th percentile. This sequential multi-hue color scheme differs from Koehler's raster hydrograph spectral color scheme (Figure 3) which is not as intuitive for quantitative data and is better suited for qualitative data.

Visual analysis of the raster hydrograph for the Yellowstone River (Figure 5A) reveals rich patterns. The overall pattern shows variations in inter- and intra-annual flows consistent with the signature of a wild and unregulated river. Apparent within these generally consistent annual gradients are anomalies such as the floods of 1996 and 1997 and the Dust Bowl drought during 1933 through 1940.

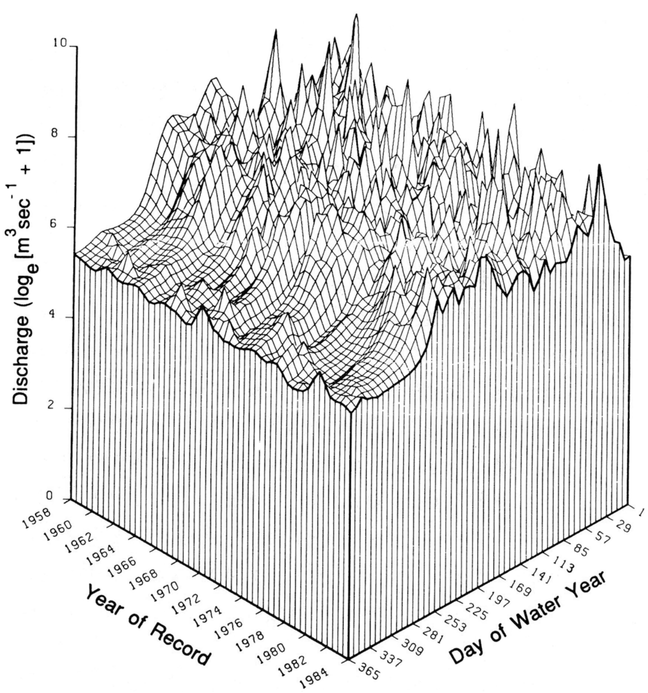

Figure 4. Poff and Ward 3-D hydrograph. (Poss and Ward 1990:637).

In contrast, the raster hydrograph for the Snake River (Figure 5B) reveals abrupt changes in flow patterns that are indicative of a regulated river. The U.S. Bureau of Reclamation built the Jackson Lake dam in 1916, shifting annual peak flows to late summer. The completion in 1958 of the Palisades Dam approximately 100 miles downstream allowed the Bureau to shift discharges again and create an earlier seasonal peak and maintain higher winter flows.

THREE-DIMENSIONAL RASTER HYDROGRAPHS

The raster hydrographs (Figure 5) create a narrative of flow at a point along a river. By preserving the day, year, and discharge dimensions of the data, this approach reduces the loss of resolution that occurs when data are averaged, or when only peak values are highlighted. However, these temporal views may be difficult for non-experts to interpret and even experts require some training to grasp the concept. Therefore following Poff and Ward [1990], we developed a three-dimensional plotting technique to determine whether it would provide a more intuitive method for visualizing discharge data. The three-dimensional hydrographs in Figure 5 differ from the Poff and Ward [1990] work because we use a raster rather than vector–based representation. We also use a sequential multi-hue color scheme, and the temporal values increase away from the axes' origins, which is more intuitive for quantitative time series data.

Our three-dimensional surface hydrographs (Figure 7) were produced using Surfer to render 3-D Surface Maps from the grid file. Daily mean discharge is represented as surface heights using percentile-based color classification schemes identical to those used for the previously described planar raster hydrograph. The two stations dramatically illustrate the difference between natural (Figure 7A) and regulated (Figure 7B) flow regimes. Fueled by spring runoff, seasonal pulses of streamflow characterize the natural runoff of the Yellowstone River, which appears as a wave. In contrast, sharp spikes and abrupt declines in discharge in the regulated Snake River create a "flowscape" that takes on the appearance of an urban skyline.

The longer-term discharge patterns are more pronounced in the three-dimensional images than in the planar raster hydrographs. However, the three-dimensional oblique view compromises accuracy and precision; some data points are hidden and it is difficult to estimate discharge along the z-axis. Some experts recommend avoiding three-dimensional graphs for these reasons [Helsel and Hirsch 1991, Tufte 1983]. Yet, based on required degrees of precision or accuracy, different plotting techniques support varying levels of perceptual tasks [Cleveland and McGill 1984]. The plan view raster hydrograph supports perceptual

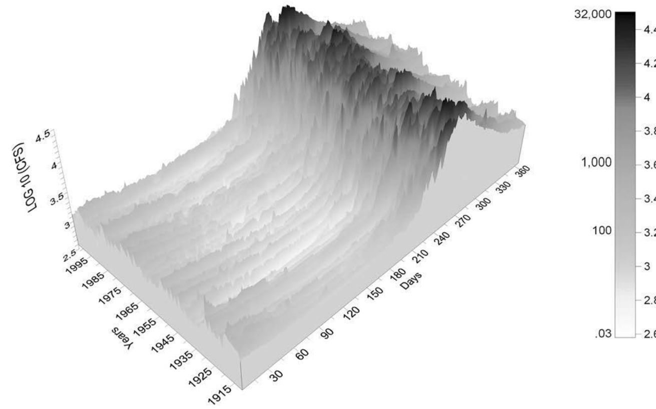

Figure 7a. Three-dimensional raster hydrograph for the Yellowstone River at Corwin Springs, MT. (see page 82 for color version)

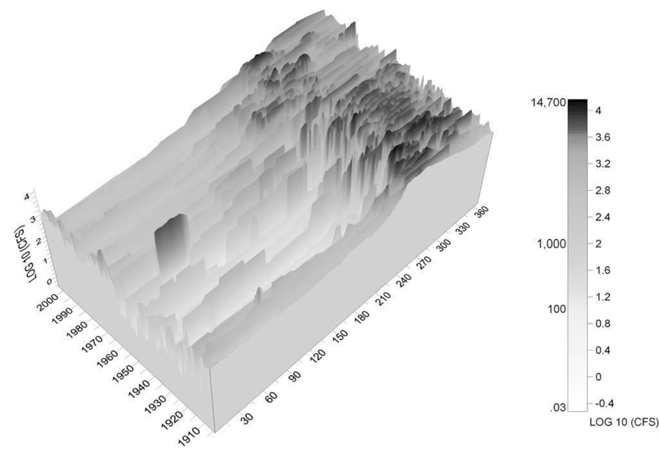

Figure 7b. Three-dimensional raster hydrograph for the Snake River at Moran, WY. (see page 82 for color version)

tasks that require accuracy and the ability to extract quantitative information, while the three-dimensional surface plots are useful for visualizing broad trends. Presenting both three-dimensional surface and planar raster hydrographs on one page offers the advantages of both techniques without compromising accuracy (Figure 8).

DISCUSSION

Water resource managers need improved graphical communication tools [Koehler 2004]. Cleveland [1984] indicated that better use of data graphics in science could be accomplished by developing guidelines for presentation. In addition, traditional methods are inadequate to characterize the multi-dimensional nature of long-term historical records, and that there is a need for the research and development of new methods for data presentation of time-series streamflow data. The development of guidelines for streamflow data is addressed in the following section.

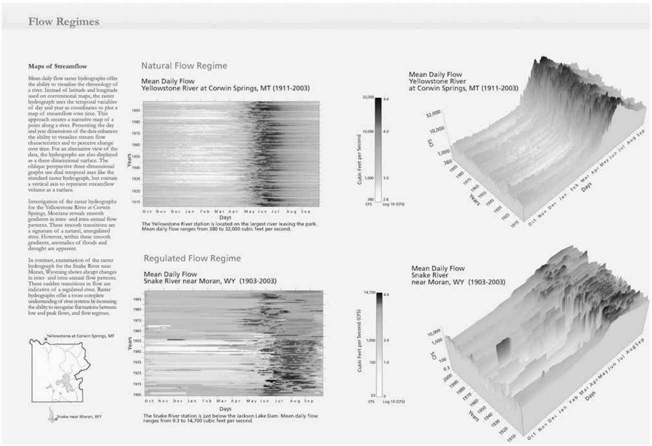

Figure 8. The Flow Regimes *page pair. (see page 83 for color version)*

Guidelines for Plotting Streamflow Data

In the process of producing graphics we identified and followed a series of general guidelines for producing streamflow graphics. The guidelines highlight key concepts related to working with dense data sets and surface water records. The recommendations from Tufte [1983] and Koehler [2004] and our own work provide the criteria for the effective display of streamflow data:

- Show all data equally and truthfully, avoiding distortion.
- Maximize data to ink ratio.
- Avoid "chart junk", which is non-data ink that distracts and confuses.
- Use an intuitive color scheme for quantitative data.
- Use a classification schemes that allows for comparison between sites.
- Present inter- and intra-annual streamflow patterns simultaneously.

The raster hydrographs (Figures 8) fulfill these guidelines. They show short- and long-term streamflow patterns simultaneously, give equal coverage to all 70,000 data points, use a minimum of ink to show these points, use a sequential hue color scheme that is intuitive (black for the highest flows, white for the lowest flow periods), and use a percentile classification scheme that facilitates comparing patterns between sites.

The principles from the guidelines have been widely ignored in the creation of hydrologic graphs and this is not exclusive to streamflow specific temporal maps. Use of these guidelines allows the presentation of inter- and intra-annual streamflow variations simultaneously and improves the ability to compare and contrast regulated and unregulated flow regimes. Raster hydrographs offer a more complete understanding of river systems by increasing the ability to recognize fluctuations between low and peak flows and flow regimes. The application of these guidelines for plotting streamflow enhances dissemination, communication and collaborative understanding of complex hydrologic systems.

SUMMARY

The utility of this time-series raster-based graphing technique is not limited to streamflow data; it may be applied to a variety of temporal data. Any type of time-series data collected in intervals such as months to years or minutes to hours may be plotted with this approach. Climatic and transportation data for example are complex datasets well-suited to be plotted as raster images to visualize multi-dimensional properties. In addition, statistical techniques exist for analysis of patterns on the raster hydrographs. Spatial pattern analysis permits quantifiable measurements and delineation of patterns on a raster image. FRAGSTATS, a landscape ecology public domain software application can compute patch-analysis statistics of these temporal graphs.

Temporal graphs use coordinates to plot a pixel-based image of variables such as streamflow by applying sound cartographic theory of color schemes and data classification. The technique displays all data points simultaneously providing a powerful static representation and an alternative to map animation. This new pixel –based technique allows for increased visualization of time related factors for a wide variety of data exploration and cartographic representation.

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reviews

The Gay & Lesbian Atlas
Gary J. Gates and Jason Ost
Washington, D.C.: Urban Institute Press, 2004.
Paper, 11” x 8.5”, 242 pages, $49.50
ISBN 0-87766-721-7

Reviewed by Mark Harrower
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While it may come as no surprise that San Francisco and New York are home to large gay and lesbian populations, few might guess that Albuquerque and Jersey City are among the country’s “gayest” cities, nor suspect that North Dakota and Wyoming rank among states with the highest concentrations of senior gay and lesbian couples. Insights such as these can be found throughout *The Gay and Lesbian Atlas* created by demographers Gary Gates and Jason Ost. The *Atlas* is the first detailed spatial account of America’s gay and lesbian households and offers a unique statistical and geographic portrait of these understudied communities. Published by the Urban Institute Press, *The Gay and Lesbian Atlas* mines Census 2000 data on the characteristics of 594,391 same-sex “unmarried partner” couples, a category which appeared in the Census for the first time in 2000 allowing researchers their first nation-wide look at just exactly where same-sex couples call home.

Gates and Ost acknowledge that there is an unambiguous political dimension to this atlas, and they seek to raise awareness and dispel stereotypes. “While the words ‘we are everywhere’ can be heard frequently at gay at lesbian political events, Census 2000 provided the first empirical confirmation of the rallying cry. The finding that same-sex unmarried partners were present in 99.3 percent of all counties in the United States was one of the most commonly reported statistics from [its] release.” (p. 2). They go on to say

> “Of course, the importance of understanding the location patterns of gay and lesbian couples goes beyond simply acknowledging that they exist. It goes beyond recognition of their political clout. Gay and lesbian service providers, activist organizations, and an increasing number of companies seeking to market to the gay and lesbian population can all benefit from a more precise understanding of the location patterns and demographic characteristics of this population.” (p. 3)