PLOTTER AND PRINTER REQUIREMENTS TO PORTRAY GEOGRAPHIC INFORMATION SYSTEM VISUALIZATIONS

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ABSTRACT: Most graphics for visualization of data from Geographic Information Systems (GIS) are still plotted or imaged on paper and film media. These images, often in color, are required to satisfy needs varying from intermediate plots for data verification and review to printed final documents distributed to thousands of customers. These documents must accurately show GIS data. Visualizations are also required to aid data checking and verification, intermediate and final reviews, preliminary cartographic design checking, and as final cartographic products. Many GIS sites use plotters selected and installed on the basis of technology that is readily available rather than devices installed explicitly to support the data used in the GIS or to correctly convey the design and colors of thematic maps. However, the characteristics of plotters, printers, imagesetters, and offset lithography must be considered when producing a product from a GIS data set and the selected hardware also must support the defined, known data standards in the GIS. This paper presents a discussion of the resolution thresholds and characteristics of devices necessary to visualize GIS data.

U. S. Geological Survey plotted or printed maps and images are often the visual culmination of hydrologic projects using Geographic Information System (GIS), satellite interpretation, or photogrammetry technologies. Sooner or later in a project, plotters, imagesetters, or printers often are used in support of a GIS project. Paper and film products produced by a GIS and other digital imaging systems must meet several requirements to properly support the visualizations of data. These factors based on the resolution and spatial accuracy of the data or imagery include: dimensional stability; plotter accuracy; accessibility; color integrity; plot generation speed, accurate thematic design rendition; customer requirements; timeliness; ease of use; product life cycle; and plotting device reliability. There is no great difference in the concept of preparing data for visualization on a plotter versus printing the final data. The concepts for both are comparable but each method can serve to support different project needs. The goal is obtaining the best possible product to meet those needs.

The cartography technology assessment project of the U. S. Geological Survey, Office of Water Information supports assessment and innovation of new technologies applied to bridge spatial and hydrologic analysis with thematic cartography and information distribution. One purpose of this project is to assess and document the required capability and precision of a variety of plotters and imaging systems necessary to maintain the data integrity and accuracy of hydrologic study data, including data products such as thematic maps and raster images. The plotter and imaging accuracy includes positional accuracy as well as gray scale and color capabilities.

The project assesses and documents factors, in addition to the required spatial quality, that influence the selection of plotting or printing technologies used in typical GIS projects. Examples of other factors that affect plotter or imagesetter selection include: finishing and final size of plots; performance and reliability; plotter speed and sustained plot rate; support for specific substrates of plotter media; and cost per plot. The project currently is compiling comparisons of a variety of plotters and printers to more fully define the ability of devices to properly maintain the original thematic cartographic design or spatial data details, especially for raster data.

The range of colors and resolutions affect the design choices for thematic cartography. The range of colors available on higher resolution, 24-

bit computer monitors exceeds the available range of plotters. This, and other differences, requires that thematic cartographers continue to identify the correct output device when designing thematic maps. The success or failure of the final map depends on a faithful representation of the original design. Using a more economical but less capable plotter often does not allow a reader to correctly interpret the hydrologic data and other spatial information.

A number of recent technological innovations have provided numerous economical plotters and on-demand printers to scientists for visualization of their data. Often these plotters and printers serve to produce intermediate paper copy prior to publishing the information using traditional or digital lithography. This is because variations in color occur due to different color models, lack of device profiles, combination of plotter technology with selected substrate, dot gain and other differences between the plotting, imagesetting and lithography technologies.

The continued advances in plotter and imagesetter technology do not happen at the same rate as advances in GIS or image interpretation sciences. A basic procedure in map production is to determine and understand what technologies will be used to print or image the final product. The constant, and increasingly rapid, evolution in plotting and printing technologies as well as the mapping, remote sensing, and the photogrammetric sciences requires continual review and assessment of device availability and planned procedures.

The cartography assessment project also has been determining the process required to successfully implement a GIS digital mapping system. Recent tests have been conducted in the area of map design as it relates to digital offset lithography and print-on-demand systems. Several digital lithography and print-on-demand tests included some smaller format presses, in addition to plotters, that allow imaging directly on the printing drum. These test assessed document management as well as correct visualization of hydrologic data. Measurements of cost and quality were made. Plotters offered costs of $2 to $30 per sheet for a 24 by 30 inch plot. Film negatives and positives generally cost $25 or more per square foot. Ink jet plots are generally the least expensive plots, followed by electrostatic, dye-sublimination, and film negatives, respectively. The quality of each type of plot was generally in alignment with the price -- the higher the cost the better the quality. Ink-jet plot quality was enhanced by using a better, but more costly, substrate. The durability of the plot image should be considered when selecting an output device.

The project is assessing the minimum resolution standards that an imagesetter must meet to plot digital orthophoto quadrangles and other raster data. The data is often sampled to one meter accuracy at 256 levels of gray or 8-bits of data at a map scale of 1:12,000. A device resolution of at least 2,395 dots per inch (94 lines per millimeter) using a 150 line-per-inch screening algorithm is necessary to correctly image 256 levels of gray. These numbers are based on the generally used and accepted equation:

$$\left(\frac{\text{device resolution}}{\text{line per inch}}\right)^2 + 1 = \text{shades of gray}$$

Device resolution is the maximum number of addressable pixels per inch. For purposes of this paper is will be considered that both horizontal and vertical pixels per inch are identical.

Line per inch is the number of printing dots per inch. These dots are formed by imaging a number of pixels in a given area to equal a specified value . A fifty percent gray dot will have one-half the pixels in a given area imaged black with remaining one-half left white on paper or clear on a film positive.

Many paper laser printers have the capability of printing graphics at 300 or 600 pixels per inch. Some newer laser printers have a device resolution of 1,200 pixels per inch. It is noted that some recent introductions have a claimed 1,200 or 1,800 pixel per inch "apparent" device resolution. These may claim a higher visual level of quality but may not produce visually accurate results. Using the above equation and requesting a 150 line per inch screen for an map or image:

Device resolution	Maximum gray levels
300	4
600	16
1200	64

Imagesetters can produce film negatives or positives varying in size from normal book publications to large wall maps using resolutions of up to 4,000 pixels per inch or greater. The final use of the film also determines which way the image reads relative to the film's emulsion. A film negative generally requires the image be wrong-reading when the emulsion is up on the film for creating a printing plate but right-reading when being used for creating an intermediate composite with other negatives.

Using an imagesetter, devices able to image a file to film and generally having a higher resolution, for preparing originals for lithographic offset printing a 150 line per inch screen is used for comparison to the above example.

Device resolution	Maximum gray levels
1270	72
1800	144
2395	256

Relatively new digital lithographic offset presses are available for smaller-format printing with resolutions of 1,270 and 2,540 pixels per inch.

It is possible to achieve a higher number of gray levels by lowering the number of line per inch screen used for plotting or printing. However, this lower screening value results in an increasingly coarser appearing image. A 120 line per inch screen is used for comparison to the 150 line per inch printing screens used in the above examples.

Device resolution	Maximum gray levels
1270	112
1800	225
1916	256

A can be seen, it is possible to maintain the number of maximum gray levels with some sacrifice of visual quality of the printed material by lowering the lines per inch of the printing dot screen.

Another factor that is required to be considered when deciding on device resolutions, line per inch screens and gray levels is the resolution of the GIS, satellite, or photogrammetric raster data. Data sampled and stored at one meter resolution would require an extremely high resolution plotting or imaging device to support complete visualization of this data when plotted or imaged at full scale. For instance, U. S. Geological Survey DOQQ (digital orthophoto quarter-quadrangle) data is captured at 1:12,000 with a one-meter raster cell sampling rate. One meter^2 at a map or image scale of 1:12,000 is equivalent to an area of approximately 0.003 by 0.003 inches when plotted. The equivalent area of a printing dot on a plotted or printed map using a 120 line per inch screen is 0.008 x 0.008 inches. A visual loss in data accuracy is caused by one printing dot taking the physical paper space of more than four pixels of image map or raster data. Therefore, the final plotted or printed material is not a completely accurate representation of the data used for analysis if a fine screen is not used for plotting the raster data.

Tremendous effort normally is expended in the capture, processing, and storage of data. A high level of effort and expense is also required for plotting or printing images. It is suggested that some data reduction or re-sampling be done before requesting a plot of raster data. Re-sampling will greatly reduce the processing time required to create a plot file, reduce storage space requirements, and improve the probability of the image being created correctly. Greater pixel-depth improves color fidelity but also increase storage requirements.

Many software packages also have a default threshold for plot file resolutions. For example, one commonly used GIS software plotting package defaults all data to 500 pixels per inch. This often lowers the resolution of the information without the user being aware of the change in the data. This is also a factor for vector data as the precision of the locations of vertices and nodes is rounded down. For raster data, table 1 shows a comparison of printing dot sizes versus distance on the ground at common U. S. Geological Survey map scales.

The optimal bit-depth for data depends on the final device used for presentation. Digital offset presses, as well as slides and some monitors, require 24-bit data. Images for offset presses should be converted to CMYK (the four-process colors for printing). Data can be 16-bit for plotters since most plotting devices cannot image 24-bit data.

Maps and images often serve as a final visualization and documentation of a GIS project. The effort necessary to create a visually and technically correct image of the data sets need not be intimidating if the required questions and steps are determined during the planning phases of the project. Thematic cartographers experienced with digital techniques may also be a source of support. The initial effort may seem time-consuming but becomes easier each plot or printed map.

Table 1. *Comparison of one square meter of area on the earth's surface at a variety of scales versus equivalent area of a screen dot used for plotting or printing.*

Map scale:	One meter equivalent:	Line per inch screen:	Page area of printed dot
1:12,000	0.003 inches	120	0.008 inches
1:12,000	0.002 inches	120	0.008 inches
1:12,000	0.0016 inches	120	0.008 inches
1:12,000	0.003 inches	133	0.0075 inches
1:12,000	0.002 inches	133	0.0075 inches
1:12,000	0.0016 inches	133	0.0075 inches
1:12,000	0.003 inches	150	0.0066 inches
1:12,000	0.002 inches	150	0.0066 inches
1:12,000	0.0016 inches	150	0.0066 inches
1:12,000	0.003 inches	175	0.0057 inches
1:12,000	0.002 inches	175	0.0057 inches
1:12,000	0.0016 inches	175	0.0057 inches
1:12,000	0.003 inches	300	0.0033 inches
1:12,000	0.002 inches	300	0.0033 inches
1:12,000	0.0016 inches	300	0.0033 inches