A Digital Map That Doesn't Look Like One:

U.S. GEOLOGICAL SURVEY USES NEW COMPUTER GRAPHICS TECHNIQUES TO ENHANCE SATELLITE MAPS

James R. Wray
U. S. Geological Survey

When a team of scientists from collaborating government agencies set out to inventory land cover in the Arctic National Wildlife Refuge, Alaska, they used computer graphics to do more than display digital data collected by sensors aboard an orbiting satellite. They used computer graphics to produce the color separations (film images from which printing plates are made) for the Wildlife Refuge map. Their object was to produce a full-color land cover and vegetation map of nearly 2,600 square miles.

The newly published map is "Vegetation and Land Cover, Arctic National Wildlife Coastal Plain, Alaska" (USGS map I-1443). Unfolded, the map measures 72 by 36 cm (28.5 by 14.3 inches). The scale is 1:250,000 (2.5 km per cm, or about 4 statute miles per inch). The area shown is bordered on the north by the Beaufort Sea and Arctic Ocea. Fifty kilometers to the east lies the Canadian border. Ninety kilometers to the west lies Prudhoe Bay, the present center of petroleum production on the Alaskan North Slope and the starting point of the Alaska Pipeline. An area measurement table is printed on the back of the map for ease in comparing land cover statistics with the corresponding survey townships shown on the map.

Adaptation of two articles published by the National Computer Graphics Association in Computer Graphics News, January-February 1983, pp. 8-9, 15, 20. The articles describe USGS color-lithoprinted map I-1443, Vegetation and Land Cover, Arctic National Wildlife Refuge Coastal Plain, Alaska, scale 1:250,000. Folded copies can be ordered from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colorado 80225. The price is $2.50 each postpaid to the addresses in U.S. and Canada. Land cover data are also available on tape. Contact National Cartographic Information Center, USGS, Reston, Virginia 22092. The Western portion of map I-1443, with legend, accompanies the articles in CGN. The USGS published map and the portion published in CGN were both reproduced by the method described here.

The agencies collaborating with USGS in the preparation of the map were the U.S. Fish and Wildlife Service, the U.S. Minerals Management Service, and the U.S. Army Corps of Engineers. Together, these agencies are addressing a national resource management problem: assessment of the fragile Arctic coastal environment prior to seismic exploration for petroleum. One purpose of the effort is to find and transport new oil while minimizing harm to the environment. In combination with other information, the map is intended to help find gravel and water for construction and to define prospective routes for supplies and pipelines while avoiding vegetation areas grazed by caribou and other wildlife.

The U.S. Geological Survey's National Mapping Division used a laser plotter to portray digital land cover information as thematic map area symbols at map publication size and scale. When printed, the symbols appear in multiple colors. These colors are produced by overlaying the four process ink colors--yellow, magenta, cyan, and black--in dot patterns, or screens. The dot screens for the map (120 lines per inch) were also made on the laser plotter.

When plates were made for printing the map, the land cover theme data were combined with the black lines and lettering of a more conventionally produced base map. Because of this and a filtering technique that was used, this digital map does not look like other digital maps derived from multispectral data.

Data Capture and Correction

Printing the map by computer graphics was only the final stage. Each preceding stage also included the use of computer graphics. The first stage was capture of the multispectral data by scanners aboard Landsat. For the Arctic vegetation map, parts of three Landsat scenes were used, one from a Canadian ground station. For each whole Landsat "scene," covering 10,000 square nautical miles, there are four spectral bands. For each spectral band, there are 2,240 scan lines of 3,340 pixels (picture elements), each 0.46 hectare (1.1 acre) in size. Landsat data, stored on computer-compatible tape, contain values for 7.5 million pixels per band and scene. These data can be reformatted to accommodate a particular user's hardware and software.

The second stage is a geometric correction that transforms the sensor scan line data to the regular grid cells of a map projection and coordinate system. The correction is done in two steps in conjunction with the third, or classification, stage. The resulting pixels are 50 by 50 meters on the ground (0.25 hectare, or 0.6 acre). They are defined in the Universal Transverse Mercator (UTM) projection and rectangular coordinate system used on many USGS maps, including the topographic maps of the Refuge area.

Land Cover Classification and Area Measurement

The third stage was the computer-aided categorization of the multispectral data into vegetation and land cover classes. This involved not only analysis of Landsat data but also visits to the field and reference to other "ground truth." The aim was to interpret the spatial patterns of statistically significant spectral classes that were identified by computer-aided analysis. The spectral classes were combined into land cover classes that seemed suitable for the task. A filtering technique was used to reduce the "salt-and-pepper" look that characterizes many digital maps portraying spectral classes. Much of the classification work and its refinement was done through interactive computer graphics.

The fourth stage--after some iterations of the second and third--produced area measurements of land cover classes, tallied by some useful area subdivisions. For the Refuge map, data were aggregated by public land survey township, each approximately 6 by 6 miles. Township boundaries and corners are shown on the USGS topographic maps, from which they were digitized; these data were then combined with the land cover data. The computer "measures" surface area simply by counting map cells by class and township.

Preparation for Printing

The fifth stage was the application of computer graphics to the preparation of the theme data (and map base) for lithoprinting. The map base was adapted and redrawn by conventional methods from portions of four USGS topographic maps. On these maps, the UTM grid is shown for zones 6 and 7 at 50,000-meter and 100,000-meter intervals; the geographic grid is shown by tick crosses every 15 minutes of latitude and 30 minutes of longitude. Public land lines and townships are numbered in Ranges East and Townships North from the Umiat Meridian and Base Line, respectively.

To prepare cellular land cover theme data for map printing, the raster units in UTM grid zone 7 were transformed to zone 6; this made possible the reproduction of each color separation in one piece. For each ink color, the computer operating the laser drum plotter read the file data (i.e., a class code) for each cell; the plotter converted each class to a pattern of angled and sized dots. The dots were exposed directly onto publication-size, dimensionally stable photographic film from which the lithoprinting plates were made. (At least one film, or color separation, is needed for each ink color.)

In four-color lithoprinting, a dot pattern in one transparent process ink color is overprinted with a dot pattern in another process ink color. The individual ink dots escape detection under normal reading conditions, but they can be seen with a hand lens. Under the white light of normal reading conditions, the white of the printing paper and the overlapping or juxtaposition of transparent ink dots of different sizes and process ink colors produce a palette of colors and shades.

Graphic arts specialists at USGS have produced color printing charts that show which combinations of inks and dot screens produce which map colors. The map designer selects color symbols from the charts. Whether the halftone dots on color separation films are then made by mechanical screens, or, as here, by laser-printed screens, the results can be predicted before work is committed to the printing press.

In combining these technologies to produce the Arctic vegetation map, the team, in effect, took data acquired in one multispectral mode by satellite-borne sensors, interpreted them, and converted them to another multispectral mode for map printing. Computer graphics helped by enabling the cartographer to add legend boxes and color area symbols to the map file and layout. For the vegetation and land cover area theme data, the traditional technique of hand scribing was not used; neither were the screens for the legend symbols cut or stripped. However, a handmade mask insured that map areas screened by the laser plotter fitted the area outlines shown on the map base, which was made by hand.

Finally, the digital land cover theme data in 12 classes were combined on the printing press with the black lines and lettering of the base map. This technique has long been used by mapmakers. What the Arctic vegetation map demonstrates is the feasibility of combining recent developments in automated digital thematic cartography with the base map elements--lines, lettering, and mask--prepared by conventional analog cartography. (Even these details could have been processed digitally. The lettering for map text is already set by computer, but it is still mounted by hand.)

Moreover, the digital data base and laser plotter can be used to produce black-and-white or color variations of the theme data for other land cover class combinations, and to show them at other scales and screen densities. These variations can be examined interactively on color video display devices before a choice of exact format for the hard-copy map is made. Many current and anticipated uses (other than map publishing) do not require the hard copy at all.

Prospects

The Wildlife Refuge map represents one step in a continuing effort to apply to pressing environmental problems the use of locational and temporal data, a geographic information system, and spatial analysis, combined with both traditional and emerging cartographic techniques. Sharpening these tools will provide increasingly responsive and flexible ways of managing natural resources. A wide variety of new custom maps and other graphics will shortly be possible. However, they are more likely to be custom-made byproducts of the geographic information system than multipurpose graphic products.

Foreseeable developments include preparation of interim vegetation and land cover maps for standard map quadrangles (in Alaska) as part of a nationwide inventory; preparation of a prototype larger scale digital vegetation and land cover map of a drilling site area west of Prudhoe Bay; further assessment of the accuracy of theme contents and their map positions; demonstration of land cover change detection and information update by remote sensing techniques; and the merging of digital land cover data with other information, such as census demographic data and digital elevation models, for application to other resource management problems.

For other areas in Alaska, the U.S. Bureau of Land Management, the U.S. Fish and Wildlife Service, and USGS are already using interactive computer graphics to analyze wildlife habitats and to review proposed drilling sites and service routes. A team of USGS hydrologists, geographers, and cartographers is also applying computer graphics technology to estimate the amount of ground water used for irrigation in important agricultural areas in the conterminous United States. Another application is analysis of land use and land cover by census area in the vicinity of nuclear reactors. Also under consideration is a regional land use analysis to estimate potential damage to buildings from acid rain and other depositions. These projects offer additional demonstrations of derivative products made by computer graphic techniques. However, most of these projects must await application of the reproduction techniques demonstrated by the USGS Arctic vegetation map before their impressive results can be presented adequately in hard-copy map form.

Elsewhere at USGS, the National Mapping Program is applying digital cartographic technology to the processing of the point, line, and area symbols that appear on topographic maps, and to the indexing of geographic names. Some of these locational information data sets are already available on computer-compatible tape. Users can now perform their own analyses of spatial data; they can even print their own hard-copy maps.

NEW PRECISION IN MAPPING POSSIBLE WITH LASER PLOTTER

by James R. Wray
U. S. Geological Survey

The U.S. Geological Survey's map of Vegetation and Land Cover, Arctic National Wildlife Refuge, Alaska (Map I-1443), was printed by using a laser drum plotter as a computer-graphics output device. Use of the plotter involves more than pushing a button. The process begins with a carefully designed, hand-drafted, full-scale layout of the proposed map. This provides a frame of reference for the placement of copy by the cartographer and the operator of the laser plotter. For example, the layout is used to scan-digitize map legend boxes and other color areas not represented in the land cover data file. The layout thus serves to coordinate copy generated on the laser plotter and copy that is created in some other way.

Next, the laser plotter operator must be told the location and size/scale values of the source tape file and the codes for the theme classes that are used. The data cells may be original Landsat pixels, re-sampled rectangular or square pixels in a map orientation, re-sampled raster units in convenient map grid cells, or even raster-scanned or vector-defined map polygons rendered in digital format. Data in one format can be converted to another, but the new digital size/scale values must be known.

The next step is to cast the source file onto a new tape in the particular run-length encoding format required by the graphic output hardware. This is not a problem when the scan-digitizing and digital plotting are in one integrated system that shares hardware and software. However, when the digitizing and plotting are not in the same system--as for the Arctic vegetation data scan-digitized by sensors on Landsat--the run-length encoding for the laser plotter becomes a crucial task requiring programming know-how that is still scarce.

Assigning Gray-scale Codes

Next, a monochrome, gray-scale plot is made to check the fit of the theme data to the base map before the color separation laser plots are made. To do this, theme classes are encoded for gray-scale densities. This requires yet another tape. Classes can be combined so that their number does not exceed the number that the graphic output device can handle in one operation. Once again, the laser plotter operator must know the format of the data on the new tape, the required display format on film, and the location and size/scale relationship between the two.

A trial laser positive plot is made on dimensionally stable film. This is laid over a base map--preferably the base with which the area theme data will be combined in lithoprinting. If the image size is not very close to the intended size the prepatory steps must be checked for errors.

A check for fit between digital plot and base map determines what size adjustments, if any, are needed. Both the output device and the processing of the reproduction medium itself can affect map position adjustments. The trial plot provides clues as to what new adjustments are needed. Scale change in one direction can be made independently of a scale change in the other. Change instructions are given to the output device iteratively and new plots are made until a best fit is achieved (or a decision is made to go back to the drawing board).

Assigning Screen Density Codes

In assigning dot screen density values to the land cover classes, for both the gray-scale map and the color map, it helps to anticipate likely spatial patterns and to note where density contrast will be useful in checking the fit of the laser plot to the base. It thus helps to have class area measurements available when assigning density values and codes. Using mechanical screens with a mesh of 120 lines per inch, USGS has a choice of perhaps a dozen densities between no copy (zero percent density) and solid copy (100 percent density). (Other mechanical screen meshes are also available.) In contrast, the laser plotter makes possible many densities, in many meshes. At 120 lines per inch the laser plotter offers about 60 density choices. Moreover, angles of dot lines can be specified separately for each color separation.

To facilitate visual discrimination, classes forming small clusters may be assigned higher densities than those occurring in larger clusters. It also helps to assign density values in a geometric progression (such as 0, 7, 13, 25, 50, and 100 percent), rather than in an arithmetic progression (such as 0, 10, 20, 30 percent, etc.). Of course, only seldom are there enough such density value classes available, and compromises are made. A larger number of classes are usually desired, although a map reader cannot easily distinguish differences that are much less than one order of magnitude. So, there is a limit of perhaps 15 classes. This limit is imposed not by the data or output device, but by the user's ability to discriminate and assimilate. These mechanical and human limits imposed on computer graphic presentation are not yet well understood and do not apply to statistical presentation of the same spatial data. In graphics, these limits enforce generalization and make possible a grasp of the whole picture that numbers alone do not offer.

Assigning Color Codes

The next step is to re-code the theme classes by color and density categories. This information separates the yellow, magenta, cyan, and black components of the final class-color symbols. In the case of the Arctic vegetation map, the output hardware and software imposed a 12 density-category limit per operation. Each density category was assigned a unique code; then, a new laser plotter tape was made for six density categories requiring yellow ink and three density categories requiring black ink. A second new tape was made for the five density categories requiring magenta ink and six density categories requiring cyan. The color area symbols for the legend boxes, the square-mile and square-kilometer area scales, and extension of the open water symbol to the map border are also "colored."