Use of the 1:2,000,000 Digital Line Graph Data in Emergency Response

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ABSTRACT

Environmental emergencies often have effects that are distributed over the earth's surface. As a result, maps are usually the most effective way to portray the impact of an emergency. The Atmospheric Release Advisory Capability (ARAC) at Lawrence Livermore National Laboratory is an emergency response organization that utilizes computer-assisted cartography. ARAC provides real-time assessments of the consequences of atmospheric releases of radioactive material. The products of this service are isopleths of the material concentration plotted over a base map of geographic features.

Because ARAC's commitments encompass the entire United States, the ability to produce base maps anywhere in the United States is very important. At present ARAC is using data derived from the United States Geological Survey's 1:2,000,000 Digital Line Graph (DLG) database to meets its small-scale mapping needs. The DLG data set contains much of the information needed to serve in this emergency response application. However, certain enhancements are required to produce the necessary base maps. To create a data set suitable for ARAC, several preprocessing steps are needed. These include transforming the coordinate system, extracting relevant features as individual entities, correcting coding errors, and matching the edges along adjacent sectional files.

INTRODUCTION

Maps play an important role in many fields of endeavor. They are indispensible tools for identifying and representing locations, distributions and spatial variations. Any entity that is near or on the surface of the earth can be mapped at its position with respect to other objects. Collections of entities and extended phenomena are often mapped as distributions. The protrayal of spatially-varying phenomena on a map facilitates the comprehension of their variation. Thus maps can be applied to any field of inquiry involving location or spatial variation. Cartography, the art and science of making maps, is most closely allied with geography, which includes the task of studying spatial variation and its underlying causes. However, numerous other fields place heavy reliance on maps.

The recent application of computers to cartography has profoundly influenced the field. Performing mundane tasks in map-making, such as the calculation of map projection coordinates, is one example of the computer's utility. While the influence of the computer is not limited to the reproduction of tedious manual operations at a higher speed, the rapid creation of new maps tailored to evolving requirements permits the use of cartography in applications where traditional methods would be far too slow. Operational emergency response is an area where automated cartography plays such a role.

An example of an emergency response system where heavy reliance is placed on maps produced by computer is provided by the Atmospheric Release Advisory Capability (ARAC) located at Lawrence Livermore National Laboratory. ARAC uses numerical models to estimate the dispersion of radioactive material in the atmosphere. The execution of these models requires the integration and manipulation of various kinds of spatial data. Measured and derived data must be presented coherently so as to provide a clear picture of an evolving problem during an emergency response. To provide a locational reference for these presentations, base maps, composed of the transportation network and hydrography along with various political and administrative boundaries, are required. Much of the data used in these base maps is generated by a tablet digitizing system. However, such digitization is time-consuming and expensive to complete. As a result, attempts are being made to take advantage of digital map data produced by government agencies in creating base maps. The 1:2,000,000 Digital Line Graph (DLG), produced by the U.S. Geological Survey (USGS), is an example of such digital map data. While 1:2,000,000 DLG data is too coarse for many applications, its does meet a number of the requirements for ARAC mapping. Consequently, substantial effort has been expended in incorporating this data into the ARAC system. This paper will discuss the ARAC project and its mapping needs, the 1:2,000,000 DLG database, and some of the problems in the data set that, when corrected, make the information more useful.

ARAC

ARAC is an emergency response system capable of addressing accidents in which radioactive material is released into the atmosphere. The ARAC system, which resides at the Lawrence Livermore National Laboratory (LLNL), is composed of computer systems, numerical models, data-gathering systems, data analysis techniques, and highly trained operational personnel (Dickerson and others 1983; Dickerson and others 1985). ARAC has responded to such real-world events as the Three Mile Island (Knox and others 1981) and Chernobyl (Dickerson and Sullivan 1986) reactor accidents, as well as the COSMOS satellite reentries.

ARAC models

ARAC relies on a number of numerical models that simulate the transport and diffusion of material through the atmosphere. Of these many programs and models, the primary model exists as a stream of five codes that are executed in a regular cycle as a problem evolves. These codes are three-dimensional and incorporate the effects of topography and complex meteorology. Meteorological data from around the world is received in real-time from the Air Force Global Weather Central. Elevation and map databases are built as part of the maintenance of the ARAC system. Detailed elevation data is derived from the Defense Mapping Agency's Planar data in the U.S. (Walker 1984) and from their Level I Digital Terrain Elevation Data for areas outside the U.S. Coarse elevation data for long range transport modeling is extracted from the U.S. Geophysical Data Center's ETOPO5 data set. This body of information, along with descriptions of the accident scenario, is integrated by the assessor in order to select various model parameters. This complete data set is used by the models to produce real-time assessments of dose distribution as well as short-term projections of the future distribution. Mapping has an important role to play in this process (Walker 1985). First, maps are used by the assessors to validate all of

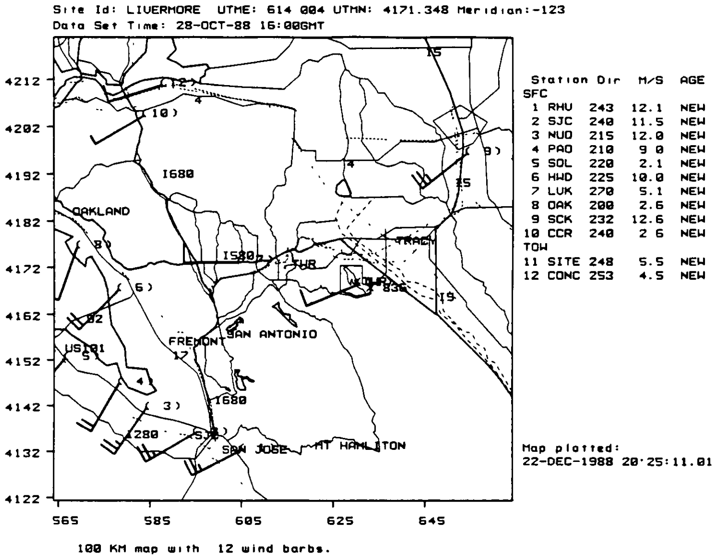

Figure 1. A map of wind barbs showing wind speed and direction at the measurement locations for validating the quality of incoming meteorological data.

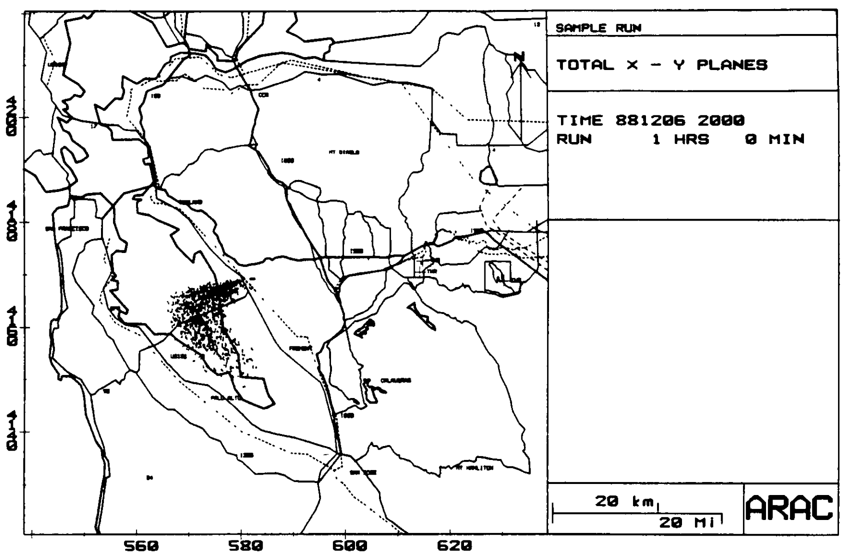

Figure 2. A map produced by a model showing marker particles used to simulate transport and diffusion in the atmosphere.

the input data quickly and accurately (see Figure 1). Second, each model in the stream produces a series of picture frames, many of which are maps, that allow the assessor to follow the evolution of the modeling process (see Figure 2). Lastly, the results of an ARAC assessment are distributed as a graphical image, i.e., a map is drawn that incorporates isopleths of material concentration or dose (see Figure 3).

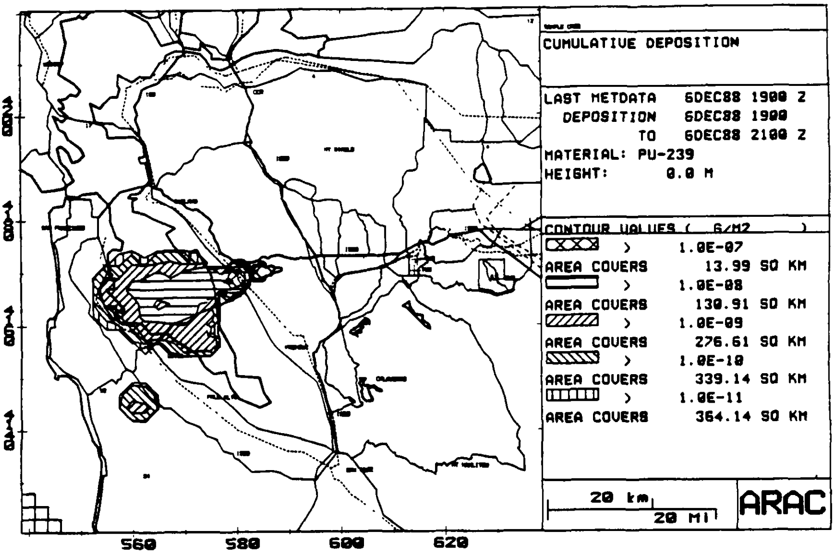

Figure 3. A typical ARAC product showing the deposition pattern of released material which is Plutonium-239 in this example.

Mapping requirements

The operational and emergency response nature of the ARAC system places a number of basic constraints on the mapping component of the system. For example, the time limitations that exist in an emergency along with the need to easily integrate the maps with other computer-based information imply that all mapping must take place on the computer. The time constraints also imply that all or nearly all of the digital map data must already exist in a easily accessible form before an emergency occurs. Most of the map data currently used by ARAC is produced on a primitive tablet digitizing system. This system is based on old hardware and has numerous fundamental limitations. Thus, the current system makes it difficult to make quality digital maps and is also quite slow. The quality problems are readily apparent in the sample maps shown in Figures 1,2 and 3. Some of these difficulties will eventually be alleviated with the design or acquisition of a new digitizing system. However, tablet digitizing is likely to remain too time-consuming to complete after the start of an emergency. As a result, digitizing is only effective for sites that subscribe to ARAC's service and for which preparation is possible before the occurrence of a release.

While ARAC supports a substantial number of Department of Energy and Department of Defense sites, most incidents to which ARAC has responded have been at unexpected locations anywhere on the globe for which there was no specific preparation. The spatial extent over which the effects of a release are a concern range from less than ten kilometers to an entire hemisphere. Consequently, complete coverage of the globe with digital map data at a wide range of scales is desirable. The volume of such data needed to meet these broad requirements is enormous and clearly beyond the digitizing capabilities of a small project such as ARAC. Instead, ARAC relies on the national mapping agencies for the creation of digital map data that can meet its requirements.

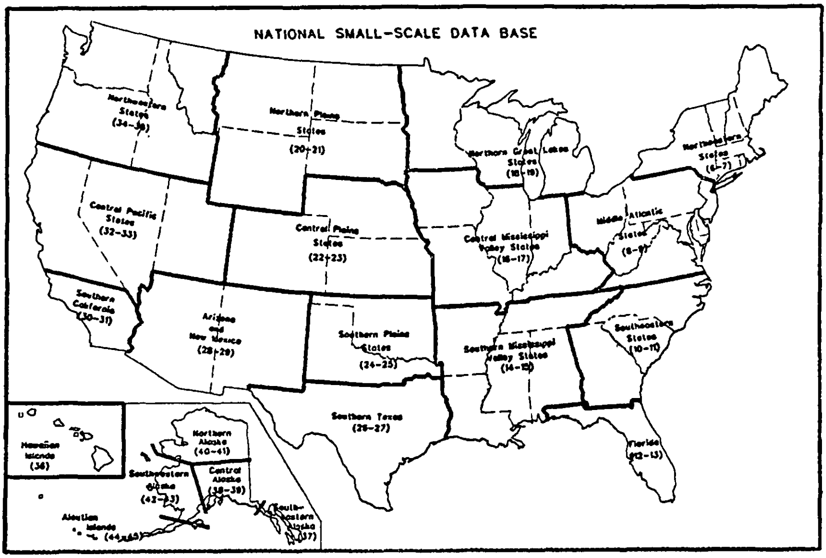

Figure 4. The coverage of the U.S. by reference map sheets in the National Atlas and in the 1:2,000,000 DLG database (from USGS).

At present, ARAC utilizes digital data to produce small-scale maps for long range transport problems. A data base produced by the National Center for Atmospheric Research is used for very small-scale maps of global or hemispheric extent. For larger-scale problems up to about 1:2,000,000 in scale, ARAC has made use of World Data Bank II (Porny 1977) which was produced by the Central Intelligence Agency. While this data set provides global coverage, it has some disadvantages including the lack of transportation networks, limited attribute coding and no topological structure. To improve ARAC's mapping capabilities in this scale range, the USGS 1:2,000,000 DLG data set has been examined closely.

1:2,000,000 DLG

The 1:2,000,000 DLG data was produced in response to a perceived "urgent multi-user requirement for a national small-scale digital cartographic data base" (Stephens and others 1979). To meet this need, the USGS chose to digitize, in vector format, the General Reference Maps from *The National Atlas of the United States of America* which were drawn at the scale of 1:2,000,000. These reference maps, published in 1970, cover the entire U.S. in 21 separate sheets (15 for the conterminous U.S.). The breakdown of the U.S. into these sheets is illustrated in Figure 4. Digitization began in 1979 and the complete database was available in 1984. In some cases, the information that was digitized was updated because the original information was gathered in the late 1960s.

Structure

The digitizing methodology is reflected in the structure of the database. The map separates for each of the different sheets were digitized into separate files. The map separates comprise seven overlays containing the following classes of information: (1) roads, (2) railroads, (3) streams, (4) waterbodies, (5) political boundaries,

(6) administrative boundaries, and (7) cultural features. Cultural features on these maps are civilian and military airports symbolized as points. The choice of vector representation as opposed to raster grids reflects the line orientation of the various overlays which consist of linear features, area features with linear bounds, or point locations. Such information can be stored more efficiently as vectors than in grids.

To support more advanced cartographic and geographic applications of this data, USGS implemented a topological structure for each overlay in a sheet along with two non-topological data structures. Thus, there are three DLG formats referred to as DLG-1, DLG-2 and DLG-3, with DLG-3 supporting topological data. This paper only considers the DLG-3 format. Topological information explicitly defines spatial relationships among cartographic objects such as connectedness and adjacency (Peucker and Chrisman 1975). While such relationships can be derived from the geometry of the data, this is usually difficult and expensive. The topological information normally associated with vector cartographic data is based on graph theory; this is reflected in the name *Digital Line Graph* used by USGS for their distribution format for cartographic data. A good overview of the DLG format is presented in Luman (1987).

Line elements (*chains,* in the terminology adopted as a cartographic standard in 1987 (Morrison 1988)) are the central component of the DLG format. Such a line element is composed of a directed locus of points bounded by a beginning node and an ending node. The line element includes pointers to the areas on its left and right as well as attribute information describing what the line represents. Nodes in the DLG format are only associated with a position. Areas are associated with attribute information and a position (not necessarily within the area). Thus the topological structure is simple as well as efficient in terms of storage because only lines contain pointers to the other topological elements. This is desirable for data transfer; however, such a structure requires more computation due to searches through the set of lines to find the lines connected to a node or adjacent to an area. While topological structuring is provided within each overlay of a map sheet, the current DLG format does not provide for topological connections between the different overlays of a sheet (*vertical integration*) or between adjacent map sheets (*horizontal integration*). In addition to the absence of topology between overlays and map sheets, no effort was made to match the geometry of the line elements between overlays and map sheets. For example, streams typically do not end precisely at shorelines and roads are discontinuous at sheet boundaries.

Applications

Published descriptions of applications of the 1:2,000,000 DLG database appear to be rare. The USGS has used the data to reproduce the original Middle Atlantic States Reference Map at 1:2,000,000 scale from the digital data (Dixon 1985). Edge discrepancies were resolved in producing the finished map. The Federal Emergency Management Agency (FEMA) is using this data as the basis for the mapping component for a dial-up system for emergency response called the Integrated Emergency Management Information System (IEMIS) (Jaske 1985). IEMIS was designed to assist FEMA decision-makers during such emergency situations as floods and hurricanes. It also has atmospheric modeling capabilities suitable for releases affecting small areas. IEMIS uses the 1:2,000,000 DLG without addressing the problems of horizontal or vertical integration.

ARAC USE OF DLG

As mentioned above, ARAC perceives the 1:2,000,000 DLG as playing an important role in its wide-ranging mapping requirements. This data has a number of superior characteristics as compared to WDB II, its main competitor in this scale-range. These characteristics include intra-overlay topological structuring, detailed attributing coding, and a consistent and high-quality map source. While these factors make the DLG data set a clear choice for coverage of the U.S., substantial processing has been necessary to tailor the data to the specific needs of ARAC. This processing has the purpose of integrating the data consistently into the larger system that already exists at ARAC as well as improving and supplementing the data where possible. A number of the more interesting processing steps are discussed below.

Feature identification

One of the more obvious shortcomings of the 1:2,000,000 DLG data is the lack of feature identification. For a number of the overlays, there is no information distinguishing individual features. For example, lakes and islands in the waterbodies overlay as well as the data in the streams overlay are not named. They are classified according to their longest dimension or length. In some ARAC applications, it is helpful to name important features such as lakes. Consequently, interactive graphics software was developed to allow operators to select and name those lakes and islands which could be unambiguously identified on a current road atlas composed of state maps of somewhat larger scale than the DLG data. Smaller lakes were typically left unnamed. The task of naming streams was judged to be too time-consuming to attempt at this time. In the case of the roads overlay, the attribute information is sufficient to identify most of the important roads. However, the low-priority given to feature identification in the development of this database is reflected in a substantial number of attribute coding errors. These errors include both classification and numbering mistakes. Because ARAC can be called on to respond to transportation accidents, it is important to have road identification be as accurate as possible. As with the waterbodies, interactive software was developed to allow examination and correction of all mis-labeled roads. The same road atlas used for naming waterbodies was used to verify road names.

Horizontal integration

Since the areas affected by releases are unlikely to fit nicely within a prescribed map sheet boundary, it is desirable to remove any sheet-to-sheet discontinuities. As a result, the creation of seamless map overlays from the DLG data was identified as an important goal. Interactive software has been developed to allow an operator to identify features that are to be edge-matched. The method of matching is based on the following two ideas. First, the difference in location between two boundary nodes is an approximate measure of the absolute location accuracy of the DLG map sheets. Thus, it is reasonable to shift the lines within the range defined by the endpoints. Second, it is important to maintain the topological relationships between elements in both of the sheets being matched. Therefore, no positional changes are made beyond the internal nodes of the two lines being matched.

In the standard method of matching, the distance along the line from the internal node to the boundary node to be matched is determined for both lines. The ratio of these lengths specifies the location of a point located along the line segment between the two boundary nodes. This new connection point determines how much each of the boundary nodes must be shifted to achieve a match. The shift of the

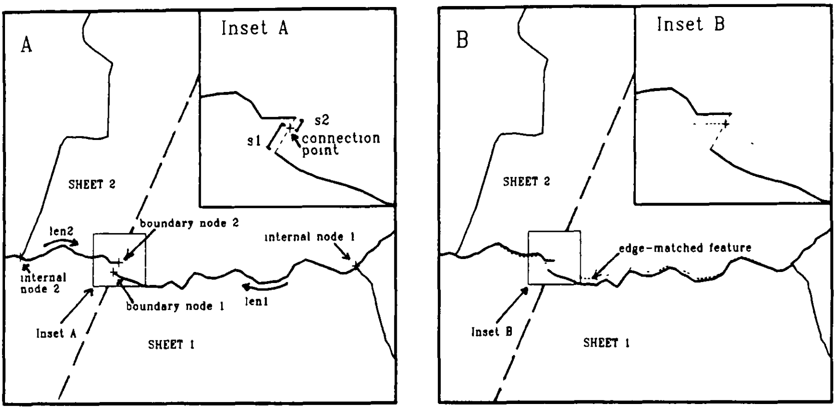

Figure 5. The geometry for matching a linear feature is demonstrated in (A) and (B). The two boundary nodes in (A) mark the points which should match across a sheet boundary. The internal nodes, within the areas of the two sheets, are to be left unchanged by the process. *len*1 and *len*2 are the lengths along the lines from the internal nodes to the boundary nodes in sheets 1 and 2, respectively. The matched lines will meet at the connection point shown in the inset. The connection point is chosen so that $s2/s1 = len2/len1$. The shift required to match the boundary points decreases linearly to zero for the other points along the line as the internal node is approached. The results of this process are shown in (B).

other points between the boundary node and the internal node is the boundary node shift linearly scaled by the relative distance along the line. This linear scaling is chosen so that no shift occurs at the internal node and the full shift occurs at the boundary node (see Figure 5). In other words, the magnitude of the shift at the boundary endpoint decreases linearly to zero as the internal node is approached. This approach normally produces a smooth fit with the shortest line being moved less than the longer line. Other methods are provided to allow some flexibility in handling unusual geometries such as allowing adjustment to only one line instead of both lines.

Vertical integration

There are a number of situations where the absence of vertical integration is problematic. For example, the fact that the streams overlay and the waterbodies overlay are not integrated implies that stream extensions (continuations of streams passing through lakes which allow drainage continuity if the lakes are not plotted) do not necessarily begin and end at lakeshores. In a few extreme cases involving small lakes, the stream extension does not lie within the lake at any point. Related problems occur where streams intersect shorelines and where major rivers (double line streams) intersect the coastline. It was decided to correct the geometry of these problems as much as possible without any operator intervention. The goal was to match intersection points without changing the location of any points on the line if the problem could be corrected by merely shifting the classification of a few points.

Using the stream extension into a lake as an example, software was written to automatically find the intersection of the continuous stream feature with the lakeshore. From this it is possible to determine which points are in the lake and belong to the stream extension and which are outside the lake forming part of the actual stream.

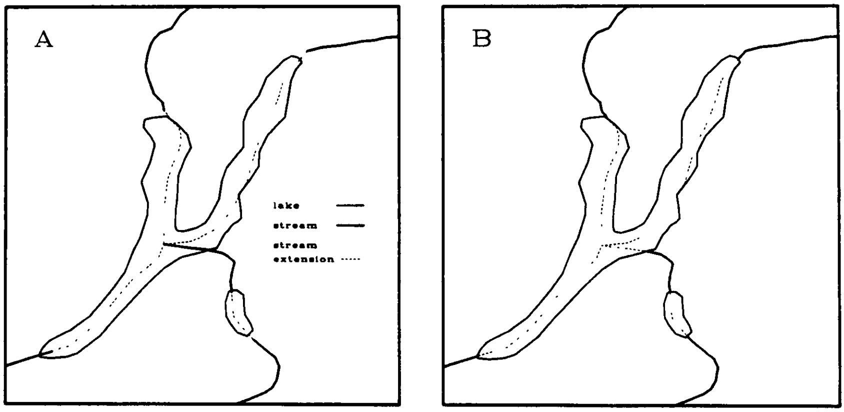

Figure 6. The mislocation of the change from a stream to a stream extension is shown in (A). The corrected alignment appears in (B).

The appropriate points are placed into the appropriate lines and the node is moved to the intersection point. In this case, no locations are changed except for the node (see Figure 6). Situations where neither the stream or the stream extension intersect the lake are not addressed. In the case of a stream intersecting a coastline or a lakeshore where no extension continues into the lake, two situations exist. One, the stream terminates within the waterbody, in which case the stream is truncated at the intersection point. No existing points are moved, only a few are eliminated. If the stream falls short of the shoreline, then the last line segment of the stream is extended until the shoreline is intersected unless a point on the coastline is closer, in which case that point is added to the end of the stream. Thus, vertical integration is accomplished with a minimal change in the preexisting geometry.

Other processing which reflects more specific requirements of the ARAC system includes translation to binary format, coordinate transformations and splitting the seamless map into quadrangles of standard size to match other existing ARAC databases. A regional map produced from the ARAC version of the DLG data is shown in Figure 7.

CONCLUSIONS

The USGS 1:2,000,000 database is a useful source of map information for some applications. Its utility can be improved to the extent that the problems of feature identification along with horizontal and vertical integration are addressed. USGS is aware of these problems and limitations (Guptill 1986) and is currently working on an enhanced DLG format that will allow these issues to be addressed (Guptill 1988). We encourage the USGS to actively continue their work in these directions and hope that eventually all their digital cartographic data will reflect these improvements.

Future work in ARAC mapping will center on the acquisition and integration of the new 1:100,000 DLG product which has recently been made available by USGS. The scales most often used in ARAC responses range from 1:100,000 to 1:500,000. As a result, data extracted from the 1:100,000 DLG should meet the majority of ARAC's need for base maps. Many of the problems associated with this database are

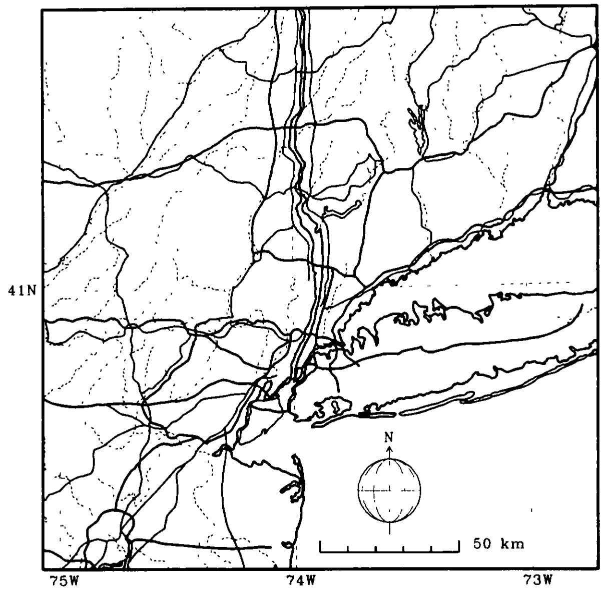

Figure 7. A sample map of the area around New York City showing part of the roads, waterbodies and streams overlays.

related to its size, but these appear to be surmountable with the use of laser disks. Application of line simplificaton algorithms may be required to produce managable quantities of data at scales near 1:500,000. Digital cartographic databases form an important component of the ARAC system and improvements to existing databases and the development of new databases are eagerly awaited.

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