Development of Temporal Mapping Techniques to Support Urban Retrospectives Database

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ABSTRACT

The U.S. Geological Survey (USGS), through the Urban Dynamics Program, is exploring the effects metropolitan areas have had on America historically, and how the dynamics of urban growth will forge America in the 21st century. Based on previous pilot studies of the San Francisco-Sacramento and Baltimore-Washington Regions, four additional studies of super-metropolitan regions that include Portland-Vancouver, Chicago-Milwaukee, New York, and Philadelphia-Wilmington-Trenton are being done by the USGS National Mapping Division. As a part of the Urban Retrospectives research activity, the USGS is using historical maps and aerial photography to understand the urban growth of the Philadelphia-Wilmington-Trenton metropolitan region over time and space. Urban Retrospectives projects will develop digital databases representing temporal urban growth and multitheme data layers. Temporal urban databases will provide information for analyzing and visualizing historical patterns of the urban growth experienced in a region. A method has been developed that uses image-editing software to extract land use and land cover layers from raster images of scanned USGS topographic maps and convert that data into temporal vector coverages. The resulting vector database will provide a framework for devising applications, modeling urban growth, and analyzing the effects urbanization has on the landscape

INTRODUCTION

The U.S. Geological Survey (USGS) is participating in a team effort with Federal, State, and local government agencies in developing temporal mapping databases. On the basis of earlier research efforts in the San Francisco-Sacramento region (Kirtland and others, 1994; Acevedo and Bell, 1994; and Bell and others, 1995) and the Baltimore-Washington region (Clark and others, 1996; and Crawford and others, 1996), the USGS is committed to build temporal databases that document urban growth in the Portland-Vancouver, Chicago-Milwaukee, New York, and Philadelphia-Wilmington-Trenton metropolitan regions. This paper focuses on developing the temporal database, collection techniques, and methodology for the Philadelphia-Wilmington-Trenton study area. The temporal database consists of urban development, principal transportation, hydrography, and woodland data themes.

The primary goals of this study are to build a geospatial temporal database that reflects urban growth and to provide a framework for using Geographic Information Systems (GIS) to analyze the effects urbanization has on the landscape. The urban development theme, a primary data layer, depicts the land transformation resulting from human impact on the land. The principal transportation theme, a multidata layer, documents the transportation features that provided the infrastructure for urban development. The hydrography theme identifies the surface water features that influenced urbanization and ecosystems. The woodland theme shows changes in the forest areas from both rural and urban developments.

This temporal database will help global change research scientists, urban planners, and geographers study patterns of urban growth; assess ecological, environmental, and climatic impacts from urban change; and model and predict future urbanization patterns and effects.

APPROACH

The temporal database was built by using USGS quadrangles and acquiring data from other information sources. The major source of data was the USGS 1:62,500- and 1:24,000-scale series maps since they were compiled from aerial photographs.. Any gaps in temporal data were filled by acquiring data from other Federal, State, and local agencies covering the Philadelphia metropolitan area. The temporal database represents human-induced land transformation during a 50-year time period, from the 1940's to the 1990's. Various collection techniques were used, depending on the source material, which ranged from paper historical maps to digital contemporary data sources.

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SOURCE MATERIALS

The primary sources for urban development, principal transportation, hydrography, and woodland data layers were derived from USGS historical maps and recent planimetric, topographic, and cartographic products. Other contemporary sources included digital line graphs, digital geographic information and analysis system land use and land cover, and multiresolution land characterization data. From the 1940's to 1990's, Maps from the 1940's to the 1990's were acquired from the USGS Cartographic Information Center and the USGS National Mapping Division map library. The most useful maps were the USGS 1:24,000- and 1:62,500-scale series, which provided the necessary detail for map interpretation and compilation. Other sources, such as the USGS digital elevation models, digital line graphs, digital orthophoto quadrangles, and satellite images, are used to enhance the data and provide a better perspective of the region.

STUDY AREA

The study area for this paper covers several counties surrounding Philadelphia in the States of New Jersey, Delaware, and the Commonwealth of Pennsylvania. New Jersey counties are Mercer, Burlington, Camden, Gloucester, and Salem. The only Delaware county is New Castle. Pennsylvania counties include Bucks, Chester, Delaware, Montgomery, and Philadelphia. The study area contains the Philadelphia Metropolitan Region, which is a nine-county area of the Delaware Valley Regional Planning Commission.

DATA THEME DEFINITIONS

Urban or Built-up Land

Urban or built-up land is defined as areas characterized by buildings, asphalt, concrete, suburban gardens, and a systematic street pattern. Classes of urban development include residential, commercial, industrial, transportation, communications, utilities, and mixed urban. Political boundaries, such as city limits, are not used to define urban limits. Undeveloped land competely surrounded by developed areas, such as cemeteries, golf courses, and urban parks, is classified as other urban.

Principal Transportation

Principal transportation is defined as the roads, railroads, airports, and other transportation features that provide the infrastructure for urban development. The transportation data layer documents the evolution of principal transportation routes. Principal transportation routes are considered the network that supports the development of the urban core because such development requires the transport of people and materials.

Hydrography
Hydrography is defined as open water bodies and includes streams, canals, rivers, lakes, reservoirs, bays, and estuaries. The hydrography data layer identifies hydrologic changes resulting from urbanization.

Woodland
Woodland is defined as forest land and includes deciduous, evergreen, and mixed forest land and orchards. The woodland data layer identifies deforestation or reforestation resulting from urbanization or conservation.

COLLECTION CRITERIA

Urban or Built-up Land
Urban or built-up land was compiled using criteria based on either urban tint (on USGS maps), housing density, road density, or degree of land disturbance evident on the source materials. A residential density of three houses per 2.5 acres is defined as the minimum level of urban development. The extent of urban areas is determined by the existence of a dense, systematic street pattern and the relative concentration of buildings. For collection, the minimum polygon width is defined as 1/10 mile or 528 feet.

Areas identified as urban or built-up were classified using the Land Use and Land Cover Classification System, USGS Professional Paper 964 (Anderson and others, 1976). The Anderson Level II classification definitions have been modified to accommodate limitations in the historical source materials and to better categorize land use intensity. All urban or built-up areas were collected as polygons and compiled into a separate coverage. Areas within the urban development were assigned to the Anderson Mixed Urban or Built-up category 16. Areas with less intensive use, such as parks, cemeteries, golf courses, and undeveloped land, were assigned to the Anderson Other Urban or Built-up category 17.

Pink, purple, and gray tints on USGS maps represent dense residential areas where too many houses and other structures exist to be individually symbolized. These tinted areas were collected as Anderson Mixed Urban or Built-up category 16. Green or white areas within the urban tint are collected as Anderson Other Urban or Built-up category 17.

Linear residential developments are defined by a minimum width of 1/10 mile, minimum length of 2 mile, and a minimum of 12 houses total, represented on both sides of the road (Crawford and others, 1996). Nonlinear residential developments are defined by a systematic road network, a minimum of three houses in 2.5 acres, a main highway, and a community population of at least 500.

Principal Transportation
Depicting the evolutionary development of a transportation system requires that implicit and explicit compilation criteria be defined to aid in the development of a principal transportation data layer (Clark and others, 1996).

Implicit compilation criteria are based on various factors that together rate the quality of a transportation route. These factors are connectivity, lineage, mobility, and alignment:

*Connectivity is a measure that describes the level to which a route links together urban centers or other modes of transportation, such as ports, railways, or airports.
*Lineage is a measure that describes the documented history of a route. It refers to the historical presence of a transportation route in literature or historical events.
*Mobility is a measure of the inherent road quality or design that indicates the level of service or accessibility for a particular route.
*Alignment is a measure of the rectilinear characteristics of a transportation route. One of the primary evolutionary features of roads has been based on the ability of humans to straighten roads by overcoming geographic features that once were barriers to travel.

The presence of ancillary transportation features, such as bridges, tunnels, and ferries, is one of the factors that support the application of implicit compilation criteria. The presence and nature of the names applied to these routes also help determine principal transportation routes. The descriptive titles of these routes often provide insight into their uses.

Explicit compilation criteria are based on the cartographic features used on maps that reveal the significance or effectiveness of a route. Modern cartography and standardized approaches through feature classification and symbolization schemes have alleviated much of the dependence upon implicit compilation criteria. Roads designated as AInterstates@ by the Federal Highway Administration or as APrimary Highway, Class 1" on USGS maps meet the capture conditions.

The classification scheme adopted for primary transportation is a modification of the Anderson Level II, USGS Publications 964, Anderson and others, 1976. All transportation features (roads and railroads) are linear except for airports, which are collected as point features. All roads were compiled into a separate coverage and assigned category 1411. All railroads were compiled into a separate coverage and assigned category 1421. All major airports were compiled into a separate coverage and assigned category 1441.

Hydrography
Hydrography was compiled using the map tint from the rivers, creeks, and reservoirs annotated on USGS quadrangles. The minimum mapping unit for hydrography is 10 acres. The classification scheme adopted for hydrography is a modification of the Anderson Level II classification system. All water bodies were collected as polygons, compiled into one separate coverage, and assigned category 55.

Woodland

The woodland was compiled using the map tint from forest lands depicted on USGS quadrangles. The minimum mapping unit for woodland is 10 acres. The classification scheme adopted for woodland is a modification of the Anderson Level II classification system. All woodland areas were collected as polygons and compiled into one separate coverage. All woodland was assigned category 44.

COMPILATION TECHNIQUES

Data collection methods were developed to avoid manual digitization as much as possible while promoting the raster-to-vector processes. The procedures established are outlined below in chronological order.

Scanning and Georeferencing USGS Topographic Maps

Topographic maps were scanned at 500 dots per inch (dpi) and resampled at 250 dpi. A number of extraneous colors can be introduced during the scanning process; therefore map features were checked and their associated colors remapped to the official USGS digital raster graphic (DRG) color palette. Colors were remapped to green - woodland, light blue - open water bodies, red - class 1 roads, purple - revision, black - miscellaneous manmade culture, white - open areas, and pink or gray - urban areas. The resulting data were saved in TIFF format. Each scan was georeferenced in UTM coordinates and converted to the NAD 27 datum to create a mosaic of the project area. When the process was complete, the results could easily be used to layer or mosaic with other collateral map data in most GIS software.

Joining USGS Topographic Maps

Most of the maps used on this project were from the 15- or 7.5-minute series. As a rule, the older USGS topographic maps are 15-minute series (1:62,500 scale). Any map of a different scale was reduced or enlarged, using Adobe Photoshop, to fit the 15-minute compilation series. The data were collected in 15-minute blocks to streamline the process of mosaicking the study region. USGS topographic maps have collar information surrounding the projection line. This collar was removed so that maps could be digitally joined for the entire project region; it was removed in ArcInfo by using a clip Arc Macro Language (AML) developed for this project. After the AML removed the collars, it edge joined four 7.5-minute quadrangles and resized them to a single 15-minute quadrangle area. The AML also outlined the 15-minute area with a yellow border on all four edges to prevent flooding of unwanted color along the perimeter of the scan when the temporal data are being collected.

Raster Collection Using Graphics Software

Any graphics program that can manipulate color palettes and join layers can be used to collect temporal data using the methods developed on this project. The project team chose Adobe PhotoShop because of its wide choice of graphics tools and layering capabilities. The 250 dpi TIFF files initially brought into Adobe PhotoShop were composed of four NAD27, georeferenced

7.5-minute quadrangles. Using a variety of tools, the operator enhanced each color and separated it into its own layer. Within each layer, the polygons were made solid and the edges were sharpened. Paper maps were used as a reference or guide during collection. In some cases, maps showing photorevision in purple have information from two or three time periods, and each photorevised feature can be collected to its own time period.

Urban or Built-up Compilation

To make annotation decisions easier, the team used Anderson class 16 as High-Density Human Culture (residential, commercial, and industrial built-up areas) and Anderson class 17 as Low-Density Human Culture (parks, cemeteries, golf courses, undeveloped or underdeveloped areas within or adjoining area 16) to visually identify areas for collection. Map interpretation and on-screen delineation were used to compile the classifications. Building clusters that met the collection criteria were encircled using the line tool and then filled with the urban tint color using the polygon fill tool. Areas that fit the Anderson 17 definition were collected with the same tools but filled with another color. When collection was completed for the 15-minute area, each color was selected globally and copied to its own layer. After each layer had been saved, enhancement routines were performed on the data to eliminate any remaining noise.

Primary Transportation Compilation

All USGS-designated class 1 roads were deemed primary transportation on this project. The symbol for class 1 roads is a solid red fill. By using a selection process based on color, the team could collect red roads to a primary transportation layer. To collect only the primary red roads required connecting any breaks in the roads and eliminating unwanted pixels and artifacts. When this process was completed, the line segments for the class 1 roads could be selected manually.

Woodland and Hydrography Compilation

The method developed for raster collection on this project allowed compilation of woodland and open water areas smaller than 5 acres at the 1:62,500 scale. The decision was made to let the end user determine how much detail to keep from the data collected. The end user can eliminate polygons and arcs below a minimal threshold in ArcEdit once the raster layers are converted to Arc coverages. The USGS symbol for orchards is a screen tint showing a number of dots. The method used for collection on this project expanded the dots until a single polygon represented the orchard. After all the layers were collected, a new file was created in which all the layers were vertically integrated to ensure completeness and positional accuracy. If there were any slivers, these were eliminated by expanding each of the colors by 5 and filling the sliver with that particular color. Next, using the magic wand tool and the ›similar= command, the team selected all the white areas and filled them with black. The black areas were saved as Aopen/rural,@ and for now they will be kept in extraneous file that may be used later on in the temporal GIS modeler. Each color can be saved by using the magic wand and the ›similar= command to select all of a particular color, then using the ›inverse= command and the delete key to get rid of all the other colors. After doing this for each color, we were ready to convert the data to a grid file in ArcInfo.

Converting Raster to Vector and Attribution

When ArcInfo was invoked, each polygon layer was brought in as a TIFF and converted to a GRID file using the Arc command Imagegrid. After the file was converted, GRID commands were used to manipulate the data. The GRID command Gridpoly was used to convert the GRID file into an Arc polygon coverage using the defaults. Layers that contained linear features like railroads or class 1 primary roads were converted to an Arc line coverage using the center line raster-to-vector commands of LT4X software. After being converted to Arc coverages, the data were brought into ArcEdit and attributed. Each data layer generally had two attributes, time and classification.

CONCLUSION

The Philadelphia-Wilmington-Trenton study has successfully demonstrated the capabilities of using digital image processing and geographic information systems to compile historic land use information from a variety of digital images, digital cartographic products, and scanned cartographic sources. By providing actual data for better modeling calibrations, the temporal database contributes to the research, technology, and applications needed for understanding the dynamics of urban growth. The temporal database will help many users in the communities understanding the spatial dynamics of historical urban growth and plan for future patterns of land use and land cover. In addition, urban growth can be projected, planned, and managed using current spatial data system technologies.

These databases have a wide range of applications for various users and groups. Federal, State, county, and city planners can use the historical data in the urban growth modeler to project growth in a region and to determine what resources and services will be needed or affected. Both Federal and State emergency management agencies can use the data to anticipate and redirect urban growth around hazard zones such as flood plains, fault lines, hurricane-prone areas, potential mud slide areas, and so on. Environmental groups can use the data to understand the historical effects of urban growth on rivers and forests. This type of data has already proven useful in researching the effects of urban growth and water runoff in the Chesapeake Bay area. Agricultural interests can use the data to understand and anticipate urban growth and rural development spreading into valuable agricultural lands. Real estate agencies, construction firms, and financial institutions can use projected urban growth models to anticipate future housing areas. Academia and historical societies would find the data gathered from historical maps to be of great value in research.

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