The 20th-Century Topographic Survey as Source Data for Long-Term Landscape Studies at Local and Regional Scales

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Abstract

Historical topographic maps are the only systematically collected data resource covering the entire nation for long-term landscape change studies over the 20th century for geographical and environmental research. The paper discusses aspects of the historical U.S. Geological Survey topographic maps that present constraints on the design of a database for such studies. Problems involved in this approach include locating the required maps, understanding land feature classification differences between topographic vs. land use/land cover maps, the approximation of error between different map editions of the same area, and the identification of true changes on the landscape between time periods. Suggested approaches to these issues are illustrated using an example of such a study by the author.

Keywords: topographic maps, temporal GIS, landscape change.

Background and Objectives

Environmental studies share an accepted basis that the cumulative effect of historical land use is a major driver of environmental problems in the present (Allen & Hoekstra, 1992). Environmental change has much longer impacts and greater implications than previously thought. The need for long-term land use change study has been outlined in various global change research plans and agendas, such as the International Human Dimensions Programme on Global Environmental Change. An example of responses to this recognized need is the revised guidelines for national emissions inventories published in 1997 by the Intergovernmental Panel on Climate Change (IPCC) contain a set of rules governing the inclusion of carbon sequestration (primarily forest cover) and land use in national inventories (IPCC, 1997). However, improved methods for such studies are still needed.

Land use change has been identified as a significant component of other factors of environmental change, including water quality, the carbon cycle, and climate, that are interrelated across scales, from the local to the global. Land surface change monitoring contributes to understanding landscape development of different intensities across scales. Global changes often begin with decisions made at the local level (Kates and Torrie 1998).

The study of these subjects requires long histories of systematic data collection. Previous land use affects current environmental quality indicators, and will aid in anticipating future impacts. The U.S. Geological Survey (USGS) has the only systematically collected mapping series covering the end of the nineteenth through the end of the twentieth centuries that were made readily available to the public through the map repository system at participating libraries. Augmenting the topographic series with aerial photography and digital ortho-photo quadrangles (DOQ) offers unique opportunities for the study of long-term landscape change. This paper discusses analytical techniques to integrate historical topographic survey maps and other national cartographic products for the study of long-term land use and land cover change. These techniques enable researchers to identify and quantify, through time, certain categories of land cover (water, forest, urbanization, and open space, in addition to specific cultural features) at the local and regional scale. The paper discusses the data base compilation, analytical techniques, and data models for the temporal cartographic modeling of these processes. In addition to change detection, the paper discusses techniques for data classification and integration at various scales.

Previous similar studies were done by the USGS Urban Dynamics Project, using various methods to compile cartographic histories of several cities to study and model urban growth using the Project

Gigalopolis SLEUTH model (USGS 2000). Other methods relevant to environmental research use a sampling technique to compile land surface data with time (Matlock 1997). Methods using the scans of topographical maps have the advantage of complete (not sampled) coverage.

The land use histories surrounding two intensive monitoring sites in the Delaware River Basin (CEMRI 2004); the Delaware Water Gap and the French Creek watersheds, both in eastern Pennsylvania. The work in this study will be discussed as an example application, but the method can be applied to any part of the country. Because this study offers a method using a national topographic survey, a map series that many nations employ for various reasons, these techniques could be extended to study land use change at internationally.

Approach and Procedures

Compiling the data base

Multiple map archives based on different data base structures make identifying the appropriate historical maps for a particular project a challenge. Possible historical map sources include the Science Information & Library Services Center of the USGS Natural Science Network (NSN), Federal map depositories, historical societies, and state and local government agencies. Certain requirements should be established in advance of the search to minimize the map acquisition time; these include the geographic extent of the project area, the map series or types with the appropriate scale for the problem to be investigated, the features that are needed to be represented on the maps to achieve the project objectives, and the computer storage formats for retaining catalogue query results.

Information from the USGS Historical Map Archive data base at the USGS library in Reston, Virginia lists all USGS map scales and types including special maps and advance sheets. Most maps will be from either the 15 minute quadrangle series (1:62,500 scale maps) or the 7.5 minute series (1:24,000 scale maps). The 15 minute series was produced from about 1890 through 1945. Maps published after 1946 in the 15 minute format are four 7.5 minute maps combined and reduced in scale to 1:62,500. The 7.5' series was published from about 1940 through the 1990s. Recently, *The National Map* replaced the traditional topographic quadrangle maps as the national mapping model (USGS 2004).

The Federal Depository Library Program sends topographic survey materials (as well as other government publications) to about 1,600 map libraries. Some of these libraries request all publications while others request just the maps relevant to a particular area. These customers are likely to have received map indices as well. These library localities are distributed throughout the United States. ESIC offices have more information on the records of these maps, but other cartobibliographic search methods generally are more accessible to the public.

The USGS state indices list the publication histories of topographic maps at various scales by either name or corner coordinates. These historical map indexes covering maps published through 1993 are on microfiche. These listings include various products sold by the NSN, such as the U.S. Fish & Wildlife Service's National Wetlands Inventory, the USGS Water Resources Discipline's maps of flood prone areas, geological maps, and some state maps. Often, maps are cross-indexed if the names of the topographic quadrangles were changed.

Searches can be conducted on internal production data files located at the four USGS topographic mapping centers in Reston, Virginia; Rolla, Missouri; Denver, Colorado; and Menlo Park, California. Map Catalog (MAPCAT) is a data base that lists each of the publication dates for a specific topographic map. Each entry includes the latitude and longitude of the southeast corner of the map (in case the name changed), so one can query by name or quad corner. Each mapping center used a different interface. Using the Cartographic Products System (CPS) interface, one can query regular and irregular blocks of quadrangles (Wright 2000). Not all historical maps are listed in MAPCAT and some maps have only partially populated data fields. MAPCAT query fields include:

- Status (current or historical),
- SE corner latitude-longitude coordinates,
- Map name,
- Scale,
- Map series identifier, and

Dates of publication, survey or field check, reprint, and revision.

The dates of the aerial photographs used to compile the maps are in the MAPCAT tables as well. (Photogrammetry replaced field checking to update maps beginning in the 1930s.) Several past databases have been migrated to Geographic Data Archive (GDA). The Science Information & Library Services Center also has map images on microfiche. These databases are internal to the USGS but inquiries from the public will get a response. If a visit to the USGS production center is impractical, at least one excellent cartobibliography is available in book form about the USGS national topographic maps (Moffat 1985).

All these sources have their strengths and weaknesses. Problems may arise in verifying the completeness of data obtained in the computer file searches, because sources can confuse the dates in various stages of the map compilation process, resulting in duplicate listings of the same map with different dates. Ultimately, the researcher may need to settle for having just the maps found in the map drawers of the archive.

For the example study of a watershed used in this paper, the results from the queries formed the basis of hardcopy and softcopy tables that were useful for identifying what historical maps should be selected and acquired for studying the area's landscape change with time. Tables were made by editing the query results files, saving them as ASCII comma-delimited text, and then importing them into a database or spreadsheet program. In addition to information from catalogues, the dates of publication (editions, imprints, and reprints), field survey, photo inspection and revision, and dates of photography, file names of scans, geographic Information System (GIS) layers, and any notes on findings proved to be important for each historical map.

Two particular tables were most helpful. The first is a spreadsheet organized by quadrangle name; the other is a table of quadrangles organized by some historical structure, such as decades (table 1). This timeline can be converted into various informative graphics in later stages of the study and publications of research results.

The digital analysis begins with scanning the set of historical topographic maps. The USGS Historical Topographic Map Library typically scans historical maps at 600 dots per inch (dpi) for archival purposes. In some cases, the historical maps are scanned at higher resolutions (800 dpi) if the linework on the map warrants the increased scanning resolution. For the purposes of this investigation, the scanned images were resampled to a lower dpi (approx. 250 to 500 dpi) for ease of data manipulation and to conserve disk drive storage space. To identify the saved file and to collect metadata for the archived digital file, the Historical

Topographic Map Library adheres to Federal Geographic Data Committee naming conventions. This raster size resulted in a resolution of 8 feet per pixel.

Features on the maps were digitized using Geographic Information System (GIS) software. For vector datasets, an important aspect in the process of digitizing features from temporally sequential maps was to copy forward the exact same linework for existing features from the earliest quadrangle so that minimal or no shifting of feature position occurs. If a feature is collected twice, from two sequential maps, the linework may not match exactly, causing sliver polygons that cause problems in the later comparative, landscape change analysis. Linework copied from earlier maps may also shift relative to their depiction on later editions of the quadrangle due to improvements in surveying technology; ways to improve the quality of data collection will be discussed later.

A cross-walk of land classification categories was designed to convert to a classification system needed for other types of integrated, multi-disciplinary environmental studies. Initially, in the earliest maps, the categories are hydrography (blue), hypsography (brown), and cultural features (black). The observed set of features found on the early 20th-century USGS quadrangles, primarily the 15-minute series, is categorized in table 2. All classified polygons contained feature descriptors in the metadata, as well. The legends of the 7.5' series later in the 20th century reflect the wider range of feature categories.

A method using the raster data model for GIS was tested on the French Creek watershed data for the CEMRI study. The 15' and 7.5' map formats were resolved by combining 7.5' maps together where they form parts of the same 15' quadrangle. In this case, the difference in scale was just ignored. Then, using a graphics software package, the scans were separated into layers by color based on the historical USGS topographical map color scheme, although not by symbol shape. By converting the raster files into vector files, the layers then were coded with a land use classification category by adding an attribute. Sets of files were grouped temporally into decades of the second one-half of the 20th century (Varanka 2004).

Procedure for c*hange detection*

Depending on the objectives of the study for which the data are being collected and the selected temporal sampling method, the maps can be used alone or in relation to one another. Some initial change can be noticed by observing the tables compiled from the map catalogue queries. The costs of mapping the country were often split between state and Federal partnerships that then also jointly prioritized the areas to be mapped & updated. Areas of natural resources and dense population were considered first, and less populated, agricultural areas – given that both the rate of change was slower and there were fewer people needing the maps - postponed (Monmonier 1982). New map editions were drafted when sufficient change was determined to justify the work. Thus, quadrangles may vary spatially, as well, because different individual topographers were responsible for individual maps. The parts of the map that a particular topographer was responsible for is indicated on a small figure on each sheet.

Early in the topographic mapping, new editions of maps appeared after a field survey of the content. After the introduction of photogrammetry, the years of the updates, or photo revision, of existing editions are helpful indicators of major changes, as well. Where the term 'map inspected' appears in the lower left-hand corner of the margin of the map, then the map was compared to recent photography to see if the map was still current. Sometimes visual inspection between two maps will reveal if map content is different between them. The term "Reprinted" refers to the reprinting of an edition of a map with little or no change in map content. These can be identified by a change in the reprinting date, but no change in the revision, photography, survey, or field check dates. The margin of the map was updated or errors were sometimes corrected. More historical information about the USGS Topographic Survey that is relevant for historical research and change detection can be found in histories of the USGS (Thompson 1979;).

Although the scale is the same between maps, accuracy between different sheets or editions varies. The integration is possible by setting a tolerance. A margin of error was needed to discount differences not attributable to variation in land surface change, such as variation in the digitizing between different editions (Usery 2002). This margin was set at the National Map Accuracy Standard for that scale of map. (The standard is 40 feet for the 7.5 minute series and about 104 feet for the 15 minute series.) Some of such discrepancy is evident in the change detection output. For example, a shift in a feature will result in almost equal areas of gain and loss within consistent land use categories. Discounting the quantity of change within the margin of error may correspond to levels of real change that are considered negligible for the intended study as a whole.

Land cover change in the raster database was identified on a pixel-by-pixel basis, comparing one layer to the other, using a land use change transition matrix. The results were graphically displayed in a map. Many GIS software packages offer short statistics describing the data file; particularly valuable is the total summary of units (acres, meters, pixels, etc.) of the land use/land cover categories or features on it. This summary is directly relevant to eliminating versions of maps with few changes between them and later to help quantify the land surface change.

Where vertical overlay for temporal comparison will be used, layers need to be integrated. When possible, the overlay of temporally sequential versions of quadrangle maps over each other for change analysis should be monitored during data collection. Although the digitizing may be accurate, mis-registrations may occur during digitizing because of paper shrinkage or other reasons. Some time can be saved and duplication avoided by using the earliest version of the map as a base and then digitizing new features from later map editions in relation to it; conversely, later features may have been more accurately surveyed and plotted with the introduction of photogrammetric methods in map compilation.

Where mis-registrations occur, methods of correction or management can be considered. If the problem is simply because of mis-registration between layers, it may be easily fixed if there are common features between layers (road intersections, grid tics, lat-long marks, etc); it's possible to use these to geometrically adjust ('rubber sheet') the maps to each other. Use one sheet as the standard and rectify all other sheets to it. This problem is similar to data integration or conflation issues, but has the advantage in that the one of the multiple lines do not exist, so that all layers can be overlayed with transparent backgrounds and duplicate lines deleted. Another approach to integrating the data vertically (temporally) is to create buffers or fuzzy modeling of the features to indicate degrees of error (Plewe 2003). In the end, automated methods may not be able to entirely replace human evaluation of the product.

Of course, perceived mis-registration between features may be reflecting genuine feature change on the landscape. Compiling land surface change analysis identifies and defines general patterns of land surface transitions and organizes the data for specific analysis. Change detection is the preliminary step toward topographic map update and maintenance (Spooner 1991; Usery 1989). Several standard GIS overlay techniques can be used to study change. Specific software packages incorporate change detection. After change is analyzed, historical land-cover data possibly may be used to develop process models (Clarke 2004). When used for modeling purposes, high resolution of this type yields a more sensitive parameterization of the output (Usery, et. al. 2004).

Change detection can further be studied between scales of the local to the regional. The integration of the land surface change factors with the other components requires research on the role of and methods for scaling data from intensive study sampling sites to regional assessments. Land-surface data at the regional scale for the Delaware River Basin was borrowed from two remote sensing data-collection programs, the Geographic Information Retrieval and Analysis System (GIRAS) land use/land cover program of the 1970s, and the Multi-Resolution Land Cover (MRLC) collection program, dated about 1992.

To conclude, the vector method employed in the work for the Delaware Water Gap watershed, to digitize polygons rather than to separate by color, resulted in a more specific land classification system, but was more labor-intensive. The method whereby land classification was collected from the maps by color was more automated, but simplified the classification system, because different categories delineated by symbol shape within the same color were grouped together. The better method to choose depends on the level of detail of classification that is required, and whether or not the data will be used for cartographic or statistical analysis of land surface change. Vector attributes will more easily allow the design of a temporal topology in GIS for land use change studies (Marceau, et al. 2001). Raster studies are more dependent on snapshot models, and the associated characteristics of such methods.

The historical topographic survey has it cartographic strengths and weaknesses as a long-term topographic record of the United States, but as the only systematic, long-term cartographic depiction of the country, it can be well leveraged for contemporary and future geographical research. As a government product, there is no question that the design of the maps was influenced by political and economic biases, but these can be anticipated in the increasing historical analysis of these products. The topographic survey has dependable information for a large number of potential applications, and to make this national resource available is of added benefit to what the value of the maps were in their contemporary time.

15' Quad	7.5' Quad	c.19	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990
Ariel				1919	1928	1932						
	Newfoundland								1966	1973	1980/84	1999
Bushkill							1944					
	Bushkill				1923-24		1944		1968/69	1973/74	1983/89	1993
	Skytop						1943/47	1956				1997
	East Stroudsburg						1944	1956				1993
	Twelvemile Pond						1943/47	1956				1997
Delaware Water Gap		1891/93				1936	1942					
	Portland						1943	1955	1969	1971/74	1984	1997
	Stroudsburg							1955		1973	1981	1999
Franklin Furnace		1899					1942					
	Branchville						1942	1954	1965	1971		
Hawley				1919		1935/38						
	Pecks Pond								1966	1973/74	1983/84	1997
	Promised Land								1966/68			1997
Milford				1913/15			1944					
	Edgemere								1965/67	1973/74	1983/88	1992
	Milford							1958/59	1969	1970	1983/87	1995
	Pond Eddy								1965/67	1973/74		1997
	Shohola								1965/67	1973/74	1984	1997
Pocono				1919	1921/23		1943					
	Buck Hill Falls								1966/68	1973/79		1997
	Mount Pocono								1966/67	1973/74		1999
	Pocono Pines									1976		1997
Port Jervis			1906/08					-1956				
	Port Jervis South						1943		1967			1995
Wallpack, or,		1893					-1944		1969	1972		
Dingman's Ferry							1946	1951				
	Culvers Gap						1943	1954	1968	1971/76	1984	1997
	Flatbrookville						1943	1954	1961/67	1971/76		1997
	Lake Maskenozha						1943					1995
Wind Gap				1914/16			1943	1956				
	Brodheadsville									1976		1999
	Saylorsburg							1951	1060/62	1970/76	1983/84	

Table 1. Editions and versions of maps by quadrangle name and decade span.

<u>Water</u> (All water features are areas) Canal Stream Lake Island
<u>Urban</u> (All urban features are areas) Residential Industrial Golf Course, Cemetery, Park Mobile Home Park Lake Shore Development Military Base
<u>Transportation</u> (All transportation features are lines unless labeled area) Road Road Corridor (Area) Trail Transmission Line Transmission Line Corridor (Area) Pipeline Pipeline Corridor (Area) Railroads/Railroad Yard (Area) Airport/Runway (Area) Airfield (Area)
<u>Barren</u> (All barren features are areas) Quarry/Pit/Mine Sand Disturbed Surface
<u>Timber</u> (All timber features are areas) Forest Scattered Forest Scrub/Brush Orchard
<u>Wetlands</u> (All swamp features are areas) Swamp

Table 2. Classification categories collected from early USGS topographic quadrangle maps

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