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Extraction of Terrain Features from Digital Elevation Models

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Abstract

Digital elevation models (DEMs) are being used to determine variable inputs for hydrologic models in the Delaware River basin. Recently developed software for analysis of DEMs has been applied to watershed and streamline delineation. The results compare favorably with similar delineations taken from topographic maps. Additionally, output from this software has been used to extract other hydrologic information from the DEM, including flow direction, channel location, and an index describing the slope and shape of a watershed.

Introduction

The U.S. Geological Survey (USGS) is conducting a multidisciplinary study of the potential effects of climate change on the hydrology of the Delaware River basin (Ayers and Leavesley, 1988). The hydrologic model TOPMODEL (Beven and Kirkby, 1979) has been used to predict runoff characteristics. The input data required for TOPMODEL include topography, stream-channel length, and watershed boundaries. A digital elevation model (DEM) is a digital representation of land surface elevations by a grid of elevation data values. Software developed by Jenson and Domingue (1988) has been used to delineate watershed boundaries and to determine flow directions from DEMs in portions of the Delaware River basin. This paper describes the use of this software for the development of the input data necessary for hydrologic modeling.

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Methods

Topographic data were obtained from a 1:250,000-scale DEMs distributed by the USGS (U.S. Geological Survey, 1987). The data were resampled at a 90-meter grid spacing at the USGS's EROS Data Center to the Universal Transverse Mercator projection.

The resampled DEM was then processed by using a "toolbox" of terrain analysis Fortran programs (Jenson and Domingue, 1988) that fill depressions in the DEM data set, create a flow direction data set (DIR), and create a data set that contains the number of upslope DEM cells that "pour" into each cell (COUNT). For example, cells along ridge tops have a value of zero and cells along stream channels have a much higher COUNT value.

Filling of depressions is the first step in, and one of the important capabilities of, this package of terrain-analysis software. This step is performed because depressions (groups of cells that have no available outflow path) complicate the calculation of overland flow paths. If depressions exist in a data set, is necessary to simulate "uphill" drainage after a flow path enters a depression. The filling of depressions resolves this problem and simplifies subsequent analysis tasks (Jenson and Domingue, 1988).

Seeding of watersheds is the process by which starting points for delineation of a watershed are chosen. Automatic seeding of watersheds using the SEED program is based on the change in COUNT in the downhill flow direction. A large change in COUNT from a point to the next point downstream indicates that the cell is located at a position where drainages converge (i.e. a stream junction), and therefore indicates a reasonable position for the outflow point (seed) of a watershed. These watershed seeds can be edited by using a general-purpose image-processing system; watersheds then can be formed using the WTRSHED program. A full explanation of these programs with numerical examples is given by Jenson and Domingue (1988).

A drainage network was generated from the COUNT data set by selecting all cells with a COUNT value greater than a chosen value and designating them to be part of the drainage network. In this study, this selection was done using a COUNT value of than 1,000 cells (8.1 km ^{2}); The resulting drainage network subsequently was compared with streams digitized from a USGS 1:250,000-scale topographic map.

Automatic seedpoints were chosen based on a minimum watershed size of 2,000 cells (16.2 km^2). Watershed delineation from these seed points was then performed, and the resulting watersheds were compared with watersheds visually interpreted from the USGS 1:250,000-scale topographic map.

Some of the derived data sets described above were then used to generate a data set needed for the variable-source-area rainfall/runoff model TOPMODEL (Beven and Kirkby, 1979). In the model, the dynamics of runoff production are controlled, in part, by watershed slope and shape. These topographic characteristics are quantified by the spatial distribution of ln (a/tan β),

where ln is the natural logarithm,

a is the drainage area upslope, and

tan β is the tangent of the slope (Beven and Kirkby, 1979).

In order to generate values of ln (a/tan β), a slope data set was created based on the depressionless DEM and the DIR (flow direction) data sets. Because the upslope area at any point on the DEM is given by the COUNT value at that point multiplied by the area per DEM cell, values of ln (a/tan β) were calculated easily for every cell in the DEM.

Results

Figure 1a shows the drainage network that was delineated using the COUNT data set in plan view together with watersheds extracted from the DEM. All of the figures shown here represent a subsection of a larger area chosen for testing and analysis. The prevalence of flat areas or depressions--depressions become flat areas during the depression-filling step--in this data set may be seen in Figure 1b.

Figure 1c compares the automatically seeded watershed boundaries with those interpreted from the USGS 1:250,000-scale topographic map. The similarity is striking, especially considering the large amount of flat area shown in figure 1b and the artifacts that often exist in 1:250,000-scale DEMs.

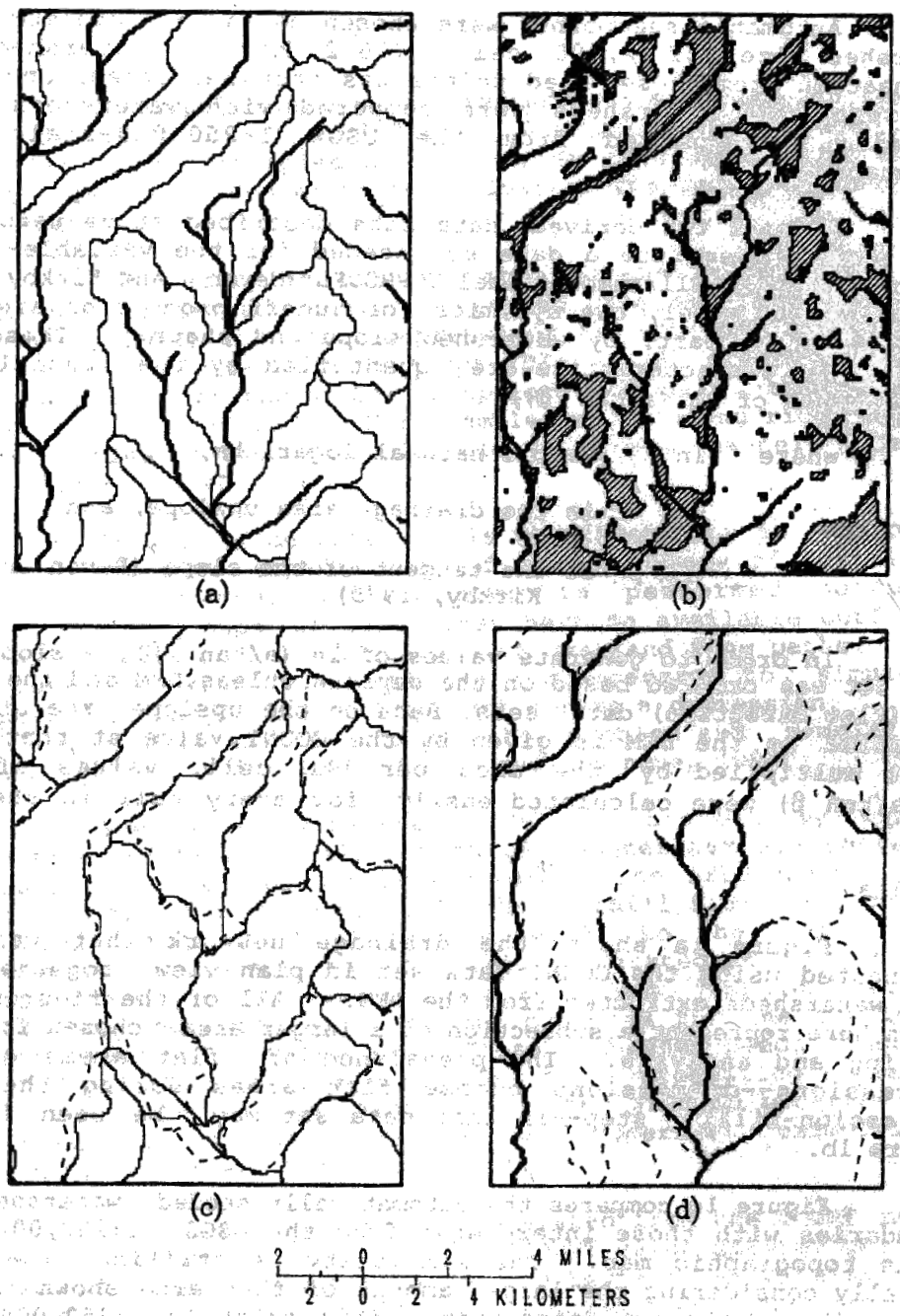

Figure 1. Results from application of terrain-analysis software. (a) DEM-generated watersheds (light line) and drainage lines (heavy line). (b) DEM-generated drainage lines (heavy line) and flat areas (shaded) (c) DEM-generated watersheds (solid) and watersheds manually interpreted from U.S. Geological Survey topographic map (dashed). (d) DEM-generated drainage lines (solid) with streams taken from a U.S. Geological Survey topographic map (dashed).

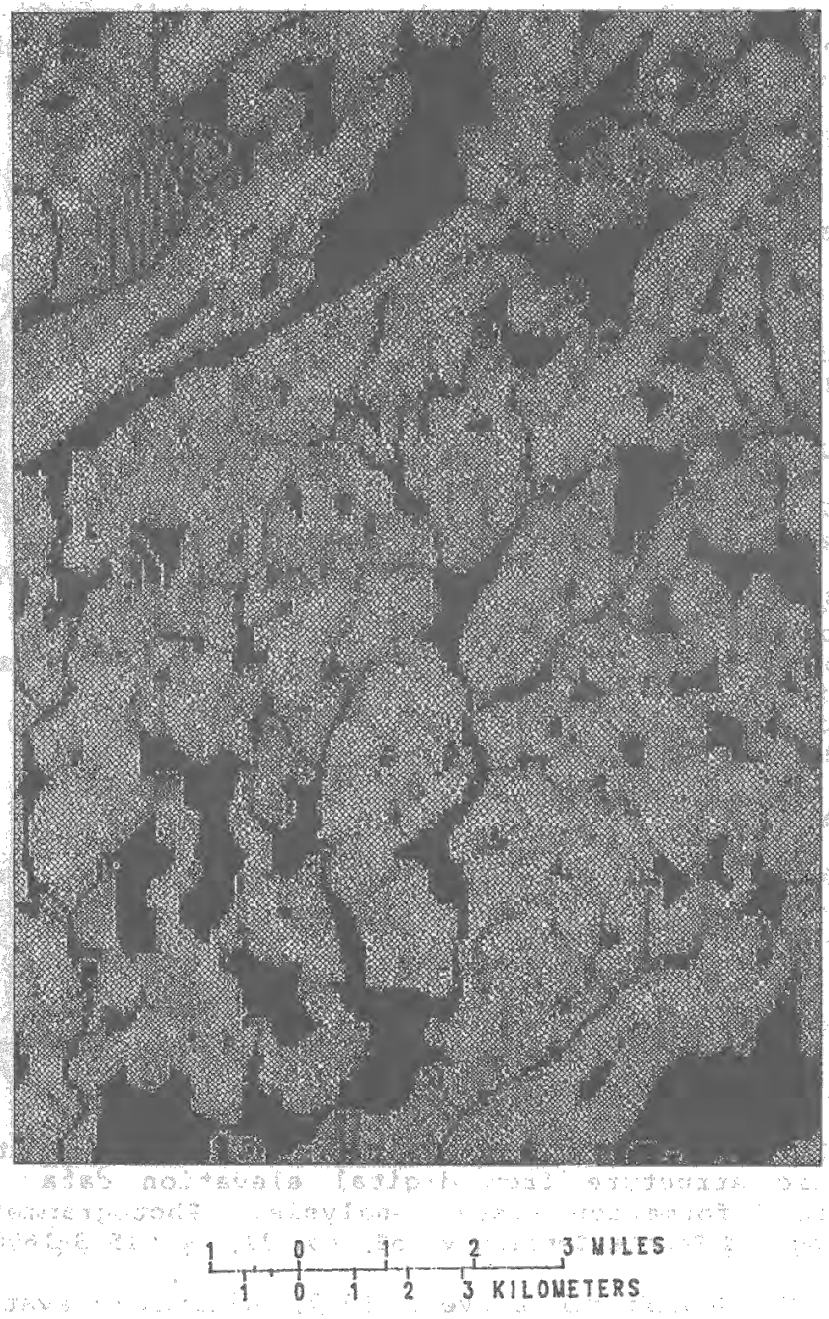

Figure 2. Greyshade plot of ln (a/tan β) values. Darker shades represent higher values. Flat areas are shown in black.

Figure 1d compares streams digitized from a USGS 1:250,000-scale topographic map to the DEM-generated drainage network. The two drainage networks are least similar in flat areas (see fig. 1b) where topography alone does not define stream locations accurately.

Figure 2 shows a greyshade representation of ln (a/tan β) values for the study area shown in the previous figures. Areas where values of ln (a/tan β) are undefined because slope is equal to zero are marked in black. As expected, areas along drainage lines have high values (darker shading) and areas between drainage lines have lower values (lighter shading). Statistics for ln (a/tan β) for a given watershed can be extracted using this data set and the watershed data set to provide input data for TOPMODEL.

Conclusions

The example data sets presented here demonstrate that the terrain analysis algorithms described by Jenson and Domingue (1988) can be effective tools to extract hydrologic information from DEMs for watershed runoff modeling. The quality of hydrographic information produced depends on the quality of the DEM data set. The 1:250,000-scale DEM used in this study area was found to be of acceptable quality for watershed and stream-network delineation at a scale of 1:250,000.

References

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