THE DIGITAL TERRAIN MODEL AS A DATA BASE FOR HYDROLOGICAL AND GEOMORPHOLOGICAL ANALYSES

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Introduction

All land based activities, natural and those performed by man, are influenced by the geomorphology of the area in which they occur. Geomorphologic or terrain characteristics such as slope, aspect and elevation influence a number of natural processes including soil formation, floral development, erosion-sedimentation and hydrology. The same parameters are important considerations in the location and modification of man's structures and activities on the land surface; as an example, the internal and external costs/impacts for man's activities increase directly with slope. Despite the obvious influence of terrain characteristics on process response systems that man is interested in managing to his advantage, e.g., soil erosion, nonpoint source pollution, stormwater runoff, little has been done in determining the causal relationships involved.

Much of this lack of understanding can be attributed to a lack of technology to aid in defining these relationships. The technology required must be able to both define the terrain characteristics of an area in unambiguous and spatially unique terms and utilize these data as data inputs to process-response models for analysis. Such an approach implies that the process-response models must be sensitive to not only the terrain parameters of interest but also the unique spatial location in which they occur. The latter consideration is particularly important to allow both location and terrain characteristics to be independent variables in analyses. Relationships derived under these conditions are, then, transferable to any other terrain. The nature of the technology required to bring about such understanding is simulation modeling, in this case, the simulation of terrain.

Conceptually, the terrain model must attain two special conditions: 1) provide a continuous surface and 2) define the spatial/locational relationships of the surface. The former condition is necessary to provide model continuity; the latter defines model connectivity. To date only one conceptual model has been developed for terrain representation that meets both these conditions: the triangulated irregular network (TIN). The TIN concept has been used to develop digital terrain models (DTM's) as part of the ADAPT system, which is a computer-based geomodeling technology developed by W. E. Gates and Associates. The ADAPT system has utilized the terrain simulation provided by TIN to produce sophisticated engineering and planning information both rapidly and at low cost. (An example ADAPT system application, a hydrologic study conducted in northeast Ohio, is presented in another paper in these proceedings. Reference 1.) The subsequent sections of this paper are intended to describe the TIN concept and its applicability as a data base for terrain and hydrologic analyses.

The TIN Concept

The triangulated irregular network concept is based on the surveying technique of triangulation in which uniformly sloping triangular areas are defined by lines of constant slope. The three vertices of a triangle are assigned unique locations in space-latitude, longitude and elevation-which in turn define a uniquely oriented triangular plane in space (see Figure 1). In order to prevent warping or discontinuities in the surface between triangles the network design process allows a maximum of one adjacent triangle along any triangle side (see Figure 2). The triangular network, then, provides the basis for a continuous surface representation and an appropriate DTM.

Perhaps the best feature of the TIN and, at the same time, the least liked by many professionals in the DTM field is the manual design of the DTM which is a

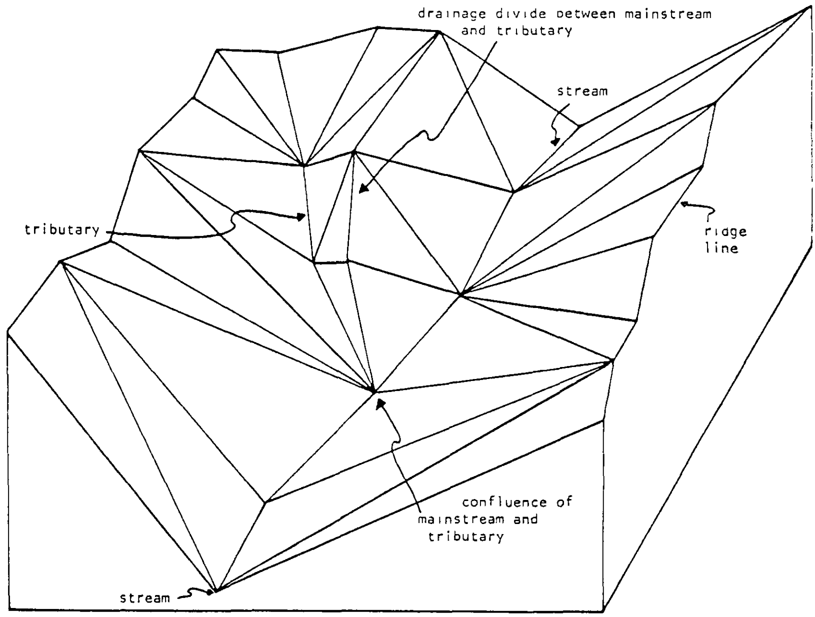
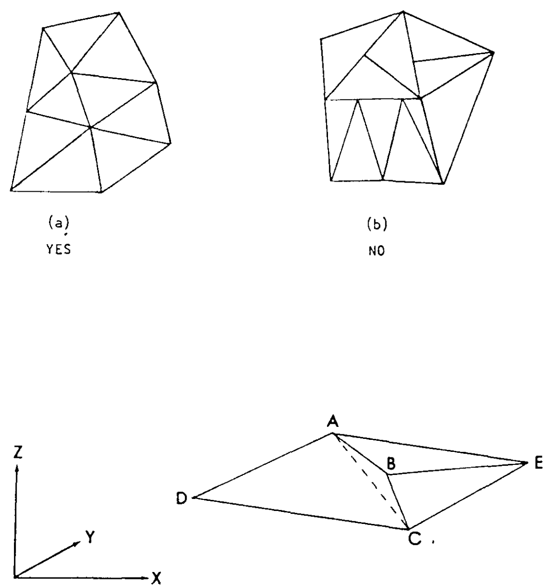


Figure 1. An Example of Triangulation Representing Terrain.

requirement and not an option. There are no random points or lines in a TIN; each vertex location is a high information point, e.g., a stream confluence or ridge intersection, and each line is a high information line, e.g., a stream segment or a slopebreak. In addition, because triangles can vary in size and shape there are no inherent constraints imposed by the TIN in the degree of terrain representation possible. (Generally speaking, the more detailed a terrain representation is the easier it is to design; however, the incurred production and operating costs per unit area go up dramatically with increased detail.) As a result, a DTM designer must not only be skilled at perceiving terrain in three dimensions from elevation contour maps but must be able to perceive the level of surface abstraction appropriate for the purposes the DTM is intended to serve. These design requirements, although somewhat demanding, are necessary to produce a TIN



If Z-coordinate of the vertex B is not on line AC (in space), then a surface discontinuity exists between ΔADC and Δ's ABE and BCE.

Figure 2. The Surface Continuity Solution for a TIN

which does in fact represent an actual terrain surface. A TIN DTM is by design an intelligent (i.e., nonrandom) network and because of this feature allows for computer software to be developed which automatically defines the spatial and locational character (i.e., connectivity) of the DTM.

Development Of A DTM Data Base

There are a number of ways to set up a DTM data base from a TIN. The ADAPT approach, which is the one most familiar to the author, creates a triangle (i.e., cell) file and a vertex file from the TIN. Each triangular cell is uniquely numbered as is each vertex by ADAPT software. The latter specification enables adjacent triangle pairs to be identified by software, thus, establishing the neighborhood relationships or topology of the DTM. In addition, the latitude and longitude for each vertex and triangle centroid is calculated and stored. This specification enables the DTM to be geodetically correct as to spatial location as well as providing an absolute coordinate system. This unambiguous and geodetically-correct topologic system provides the framework for both surface continuity and connectivity.

The fundamental topographic data for each cell, i.e., area, slope and aspect, are calculated from the vertex coordinates and stored in the triangle file. In conjunction with the DTM topology the topographic data define in digital format the three-dimensional character of the terrain surface.

Some Applications Of A DTM Data Base

As an example of how this DTM data base can generate terrain information, ADAPT software has been developed which automatically defines the stream and overland flow networks embedded in the DTM from the stored topologic and topographic data in the triangle file. Additional software uses this information to partition the DTM into any hydrologic unit specified. Thus, the hydrologic connectivity of a TIN DTM is automatically derived from the digital format.

A series of computer derived graphics are presented in Figure 3 which display alternative characteristics of the same DTM. The watershed modeled is a headwater portion of the Silver Creek basin in Madison County, Kentucky with a total area of 28.5 square miles. The two-dimensional projection of the DTM, which was drawn from a 1:24000 scale U.S.G.S. topographic map, is presented in Figure 3a. The overland flow and stream networks which are generated automatically from stored slope data are presented in Figure 3b. An elevation contour map of the DTM, generated by easily attainable software, is presented in Figure 3c. Contour maps have not been found to be a particularly useful analytical product but they have proven to be a convenient means for the DTM designer to verify the desired accuracy of the terrain model. Figure 3d is a shaded plot display of the aspect (i.e., orientation) of each triangular cell within the watershed. These same characteristics can be analyzed by software to provide statistical data such as the basin average value for slope, area-frequency analyses (e.g., histograms) for aspect or

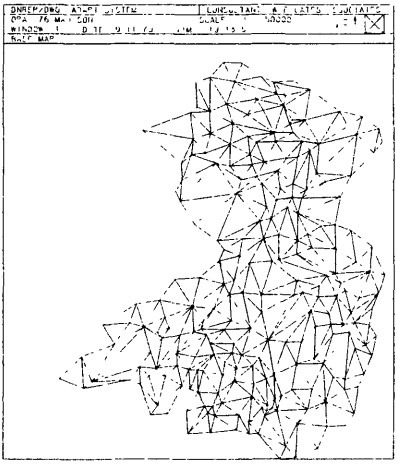


Figure 3a. TIN DTM Projection

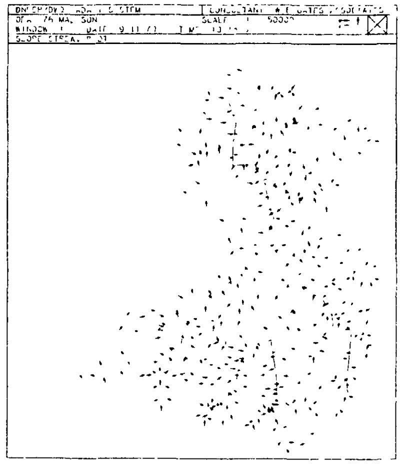


Figure 3b. DTM Overland Flow and Stream Plot

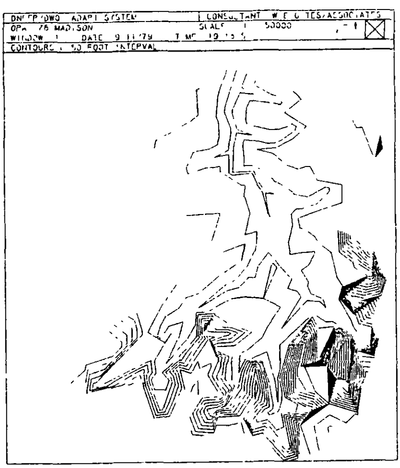


Figure 3c. DTM Contour Plot

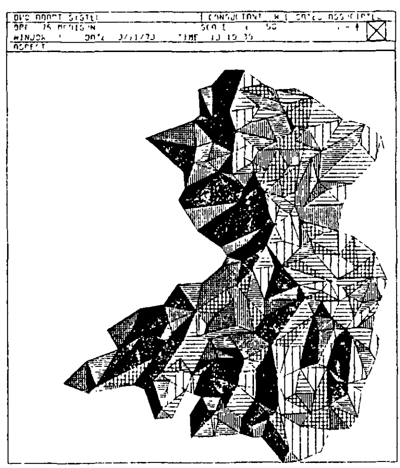


Figure 3d. DTM Aspect Plot

Figure 3. Example Computer Plot Displays of DTM Data Base for Silver Creek, Madison County, Kentucky

total length of streams. The DTM data base can be and has been used as input data for process-response models such as rainfall-runoff and erosion-generation models. With the unique spatial location characteristic of the DTM, it is possible to define the impact of individual land parcels on unit hydrographs or sediment loadings predicted by the models.

Conclusion

Much of the effort currently being devoted to the new and rapidly evolving field referred to as digital terrain modeling focuses on the need of mapping agencies to quickly and accurately produce elevation contour maps using low and high altitude photography as a data base. That one cannot produce a DTM without an accurate elevation contour map should not obviate the fact that a contour map is the starting point, i.e., the data base, for a terrain model. This could explain to a large degree why terrain specialists such as geomorphologists and hydrologists have not participated in the evolution of the field up to this point. The TIN concept, however, provides both a data base consistent with the needs of terrain specialists and a means to utilize the cost-effectiveness of the computer in analyzing the significance of terrain characteristics on processes such as erosion-sedimentation, hydrology and land stability.

References

1. "Joint State/Regional Environmental Planning Using the ADAPT Geographic Information System," Grayman, W. et.al., AUTO-CARTO IV, November 1979.