Surface Modeling with GIS

By

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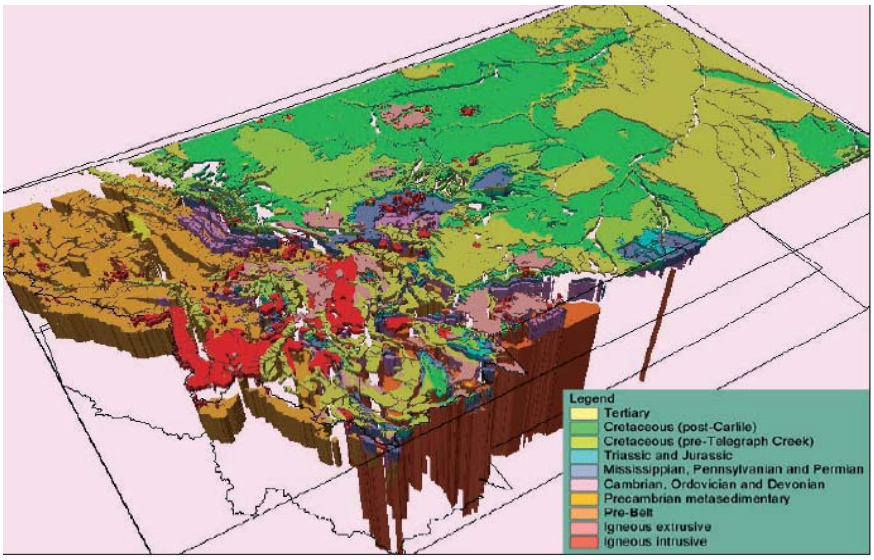

For

CRP 514: Introduction to GIS

Course Instructor:
Dr. Baqer Al-Ramadan

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Outline

Abstract

This paper provides an introduction to surface modeling with GIS and related extensions in the context of contour maps. The spatial analysis extension provides the ability to generate grids and contours with a variety of data- interpolation method. This paper discusses how ArcGIS provide a tool for generating structural surface models. Raster, Triangulated Irregular Network, and vector are the three principal methods used to generate structural modeling for both surface and subsurface in GIS. Emphasis is on the functionality of ArcGIS to handle multiple datasets and maps as well as data visualization techniques using GIS- ArcScene. The need for 3D information is rapidly increasing. ArcScene, the three-dimensional viewing application that is part of ArcGIS 3D Analyst extension, allows earth scientist to create both traditional and unconventional three dimensional displays from real world data. The flexibility of assigning Z-values from various sources makes ArcScene a powerful tool for anyone who needs to show the quantitative variations in three dimensional data.

1. Introduction

Surface geologic modeling is a complex task for geographic Information System (GIS) technology. However, the spatial nature of geo-objects always drives GIS to be part of modeling systems. The traditional activities in which GIS is involved in geosciences are data management, visualization, spatial analysis. Current developments allow the full GIS capabilities on a desktop computer with full integration of the industry-standard relational database management system, geostatistical functionality, 3D visualization, 3D geoprocessing, and web-based mapping. (Lucas D. Setijadji, 2003).

Recent additions and modifications to ArcGIS have made it more capable of surfacing, contouring, and 3D functions that were once available only from within the Arc/Info environment. The spatial analysis extension provides the ability to generate grids and contours with a variety of data-interpolation method. (Jonathan D. Arthur and William H. Pollock, 1997). This paper provides an introduction to surface modeling with GIS and related extensions in the context of contour maps. You can use existing models, or you can create your own from a variety of data sources.

The main methods of creating surface models are by interpolation and triangulation. (Jonathan D. Arthur and William H. Pollock 1997).

2. Objective

The main objective of this paper is to provide an introduction to surface modeling and griding techniques with GIS "TIN, Raster and vector Models" and related extensions in the context of contour maps and also visualize structural surface and sub-surface models as three- dimensions using GIS-ArcScene.

5. Gridding (Modeling) Technique

5.1 What is a Grid?

A surface model (or grid) is a set of points that are regularly distributed estimates of some attribute over an area (Figure-1). Grids are usually generated from a control point dataset. Control points are a set of points that are randomly distributed and are samples of some attributes over and area (Figure-1).

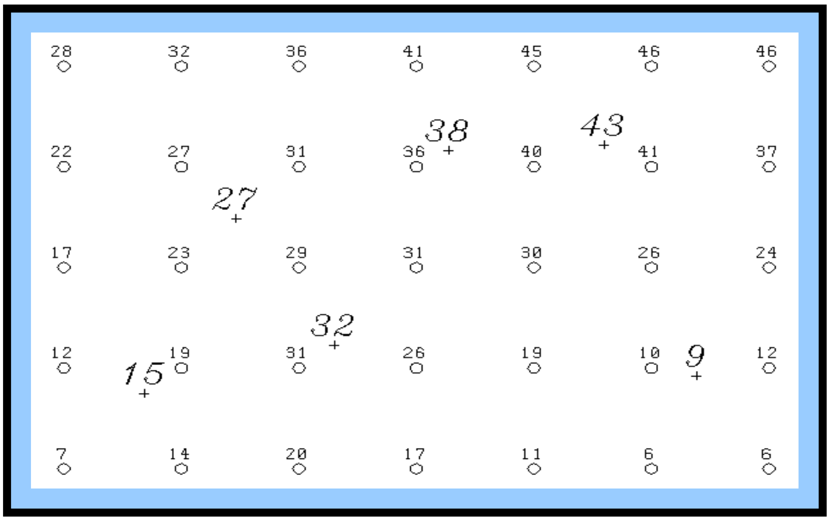

Figure-1 Grid with control points data. (ZmapPlus Mapping (2002), Subsurface Mapping and Non-Default Griding Techniques. Landmark- Houston USA.)

Grid is generated on any Z-values that are represented on the Z-axis in 3D dimensional X, Y, and Z coordinate system. Some examples of control point data sets include: well top picks and other borehole-related data, 2D and 3D seismic data, gravity and magnetic survey, existing contour map and temperature & pressure.

5.2 The purpose of Gridding

Grids are produced in order to achieve an even distribution of points. Some examples of functionality that depend on the even distribution of points includes: generating contours on a map, producing perspective (3D) display, drawing grid profiles (cross section), performing grid operation, volumetric calculations, and back interpolation- the ability to query the grid at any location to determine a reasonable value.

None of the function can work with randomly distributed control-point data sets; the datasets must always be girded first.

5.3 Grid Terminology

The following is a list of terms commonly associated with grids: Grid nodes individual estimated values that cumulatively make up the entire grid. Grid columns and rows – grid nodes are arranged in columns and rows, and a specific grid node can be uniquely identified by the column and row it resides in. Grid cells – the region bounded by four grid nodes. Many computer functions are performed on a cell-by-cell basis. Grid increment – the spacing between columns (x-inc) and rows (y-inc) of grid nodes. The grid increment is a parameter that you can set that determines the size of features that can be retained by grid node spacing (Figure-2).

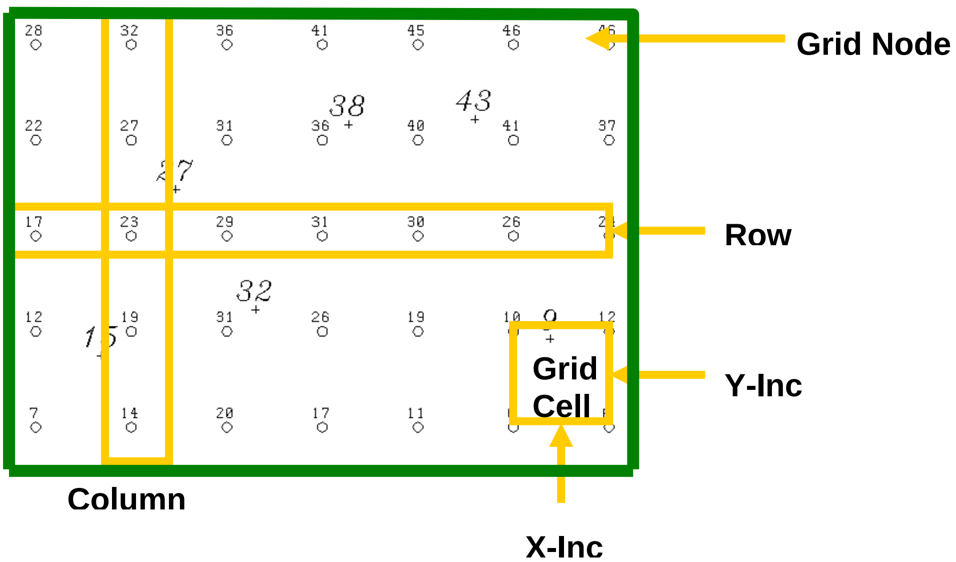

Figure-2 Grid Terminology; ZmapPlus Mapping (2002), Subsurface Mapping and Non-Default Griding Techniques. Landmark- Houston USA.

5.4 The Effect Cell size (Grid Increment)

The final grid increment is the distance between grid nodes in the grid. It is absolutely the most important girding parameter, because it controls the level of detail retained in the surface model. (ZmapPlus, Griding & Contouring technique).

A large final grid increment averages data values and produces a trend grid, figure 3a. As the relative grid node spacing gets smaller, the grid is able to retain higher frequency detail inherent in the samples, Figure 3b. As the relative grid increment gets too small, the surface model is unable to retain an overall trend between the sample, creating localized closures around the data points, Figure 3c.

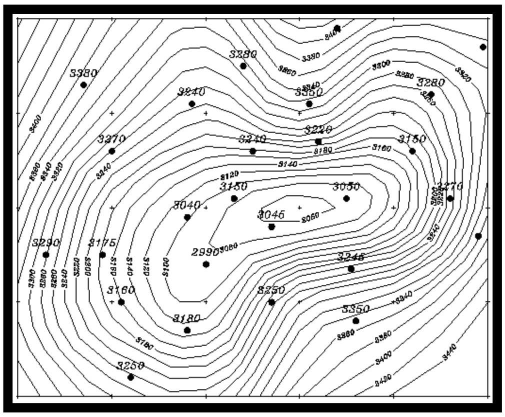

Figure 3a Grid-Inc 200
Establishes trend- does not honor data points.
Averages data values over a large area.

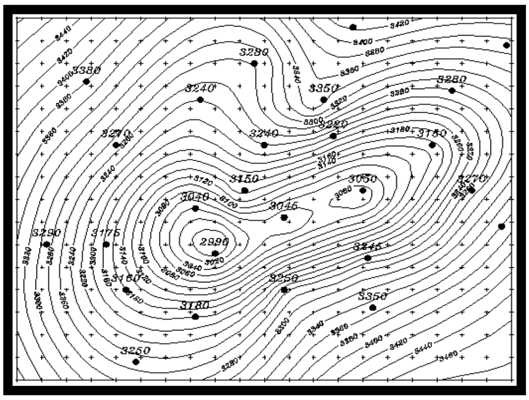

Figure 3b, this grid: 50Has the default grid increment for this data set
Honors individual data points & Preserves trend

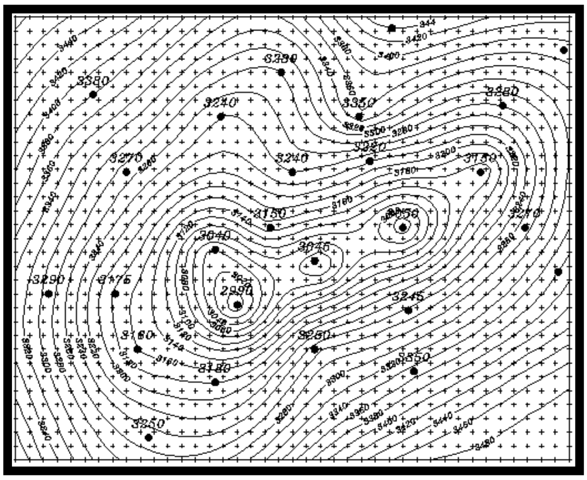

Figure 3c This grid: 25

Honors the original data points very well, loses trend in void data areas and forms artificial closures around data points

The above pictures show final grid increments of 200, 50, and 25 respectively for the same data set.

6. Models Structures with GIS

The ideal structure for a digital elevation model (DEM) depends on the intended use of the data and how it might relate to the structure of the model. Figure 4 illustrates the three principal ways of structuring a DEM Raster, TIN, and vector models.

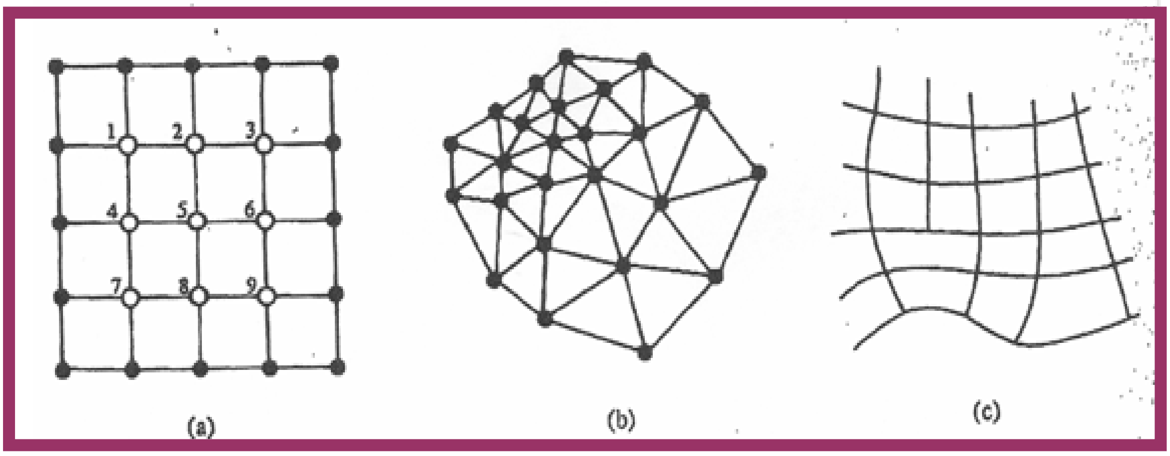

Figure-4 Method of structuring an elevation data network: (a) Raster grid. (b) TIN model. (c) Vector model. (Ian D. Moore, GIS and Land-surface process modeling).

6.1 Raster Model

Raster surfaces are usually in grid format that consist of a rectangular array of uniformly spaced cells with Z-values (figure 5). Grid cell values are calculated from a mathematical function relating nearby control points. Usually this function is a form of a spatial average, where the closer control points are weighted more heavily than the more distance once.

Variants of this function include fitting a plane or curved surface to the control data in order to estimate grid cell values by mean of regression or projection. Contours are then generated based on the regularly spaced grid values. (Jonathan D. Arthur and William H. Pollock (1997). The data can be stored in a variety of ways, but the most efficient is as Z coordinates corresponding to sequential points along a profile with the starting point and grid spacing also specified. (Ian D. Moor, A. Keith Turner, John P.Wilson, Susan Jenson, and Lawrence E. Band; 1993)

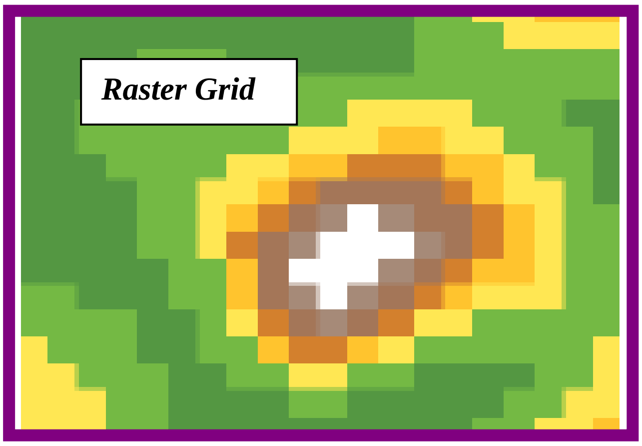

Figure 5 Raster Model (ArcGIS- ESRI, Creating surface models, page-78)

The most widely used data structures consist of square grid networks because of their ease of computer implementation and computational efficiency. However, they do have several disadvantages. They cannot easily handle abrupt change in elevation. The size of grid mesh affects the result obtained and the computational efficiency. The computed upslope flow paths used in hydrological analysis tend to zigzag and therefore are somewhat unrealistic. Also another disadvantage with grid-based contours is that control point data may not exactly fit the contours, because the contours are based on calculated cell values. (Ian D. Moor, A. Keith Turner, John P. Wilson, Susan K. Jenson, and Lawrence E. Band; 1993).

The advantages of grid interpolation are that complex surface model algorithms are better suited for a continuous array of evenly spaced data rather than an irregular spatial distribution. (ArcGIS9-Creating Surface Models). Two-grid interpolation Functions, spline and inverse distance weighted (IDW), are available in pull down menus with in 3D Analyst and Spatial Analyst. The Spatial Analyst provides much more user control and spatial analysis tools than the 3D analyst. Additional interpolators available through both of these ArcView GIS extensions include kriging and trend.

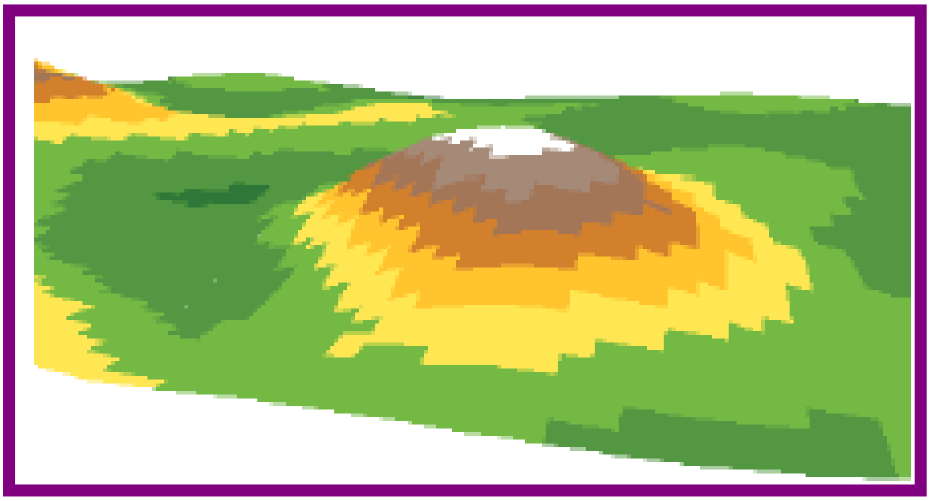

Figure-6 Raster Grid in perspective view (ArcGIS, ESRI, Creating surface models, page 78)

6.2 TIN Model

The Triangulated Irregular Network (TIN) is a surface representation based on randomly or irregularly spaced data points that have x,y, and z coordinates. A typical example of this coordinate system is longitude (x), and latitude (y), and an elevation or concentration (Z). Non-overlapping, connecting triangles are drawn between all data points where the data points (or control points) are the vertices (Figure 7)

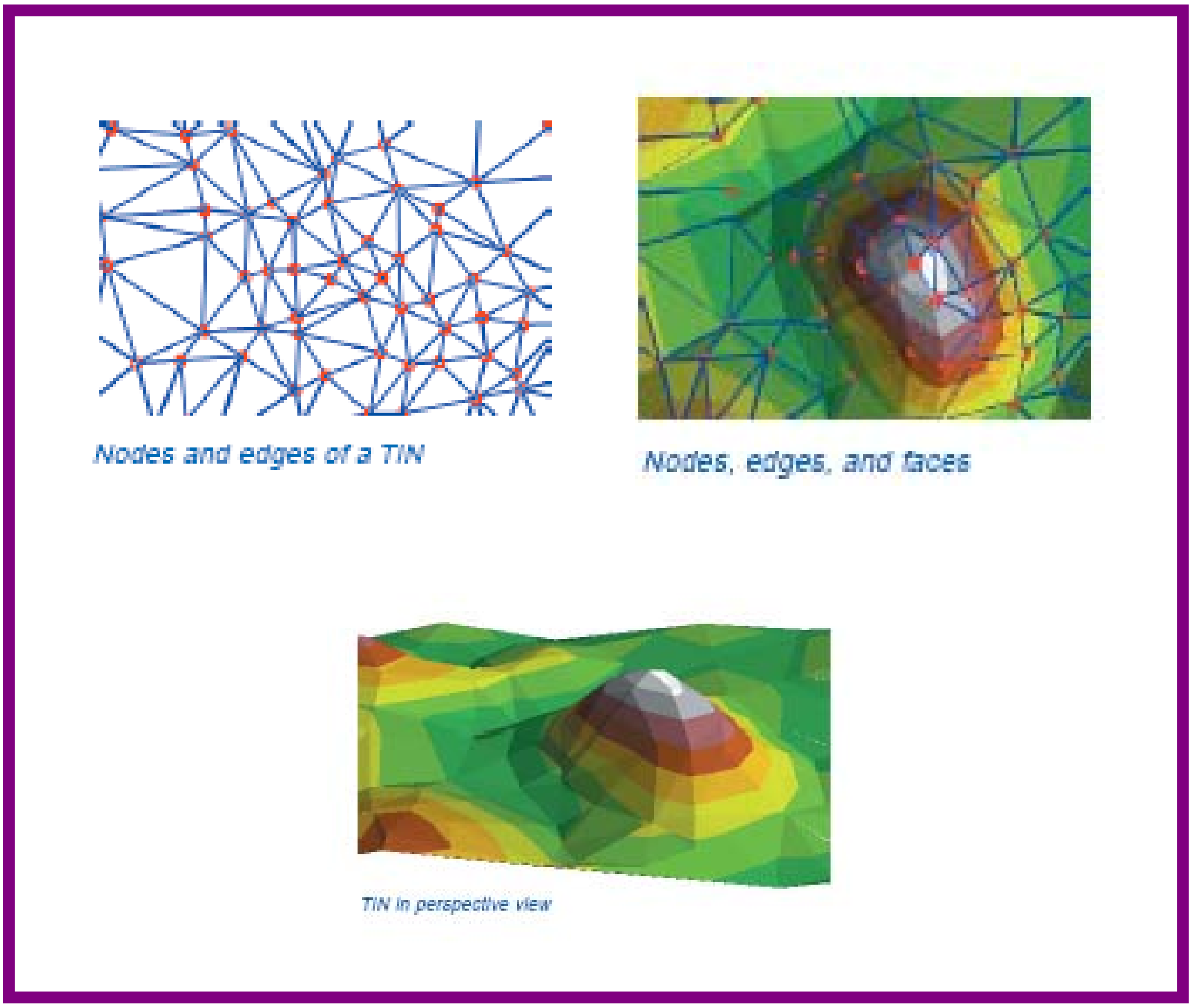

Figure 7 TIN models. (ArcGIS- ESRI, Creating surface models, page-79)

In its basic form, TIN elevations are calculated based on linear regression between control points; contours are then drawn across the sides of the connected, tilting triangular plates (figure 7). (Jonathan D. Arthur and William H. Pollock, 1997). The wide distribution of control- point data yields a coarse, angular surface representation that is not desirable for structure contour and isopack maps; the angular contours do not accurately reflect the natural geologic environment.

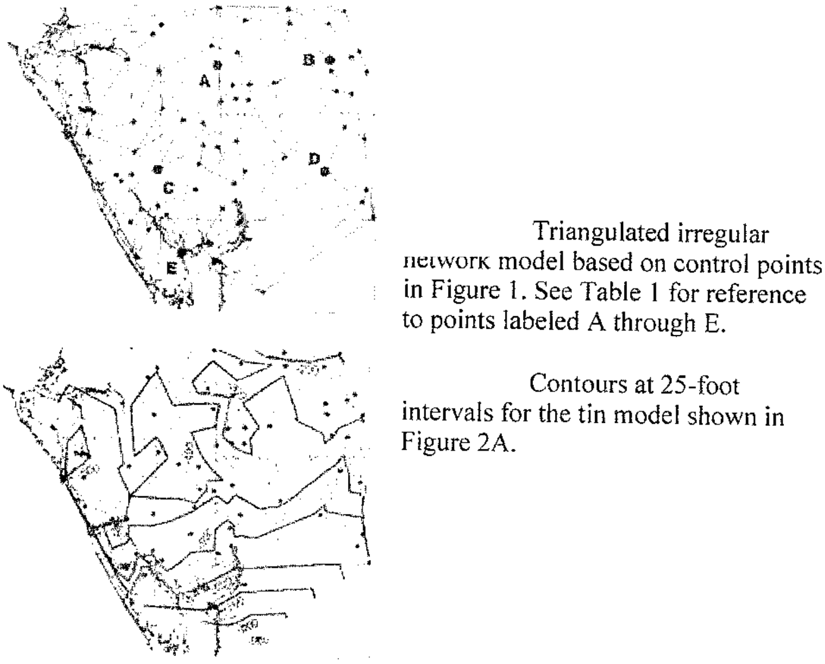

Figure 8 TIN model based on control points. (Jonathan D. Arthur, use of ArcGIS for geologic surface modeling.)

Figure 8 shows a TIN surface model representing the top surface using the control points. The 3D analyst was used to create a model which is contoured at 25-foot intervals. The wide distribution of control-point data yields a coarse, angular surface representation that is not desirable for structure contour and isopach maps; the angular contours do not accurately reflect the natural geologic environment. Two advantages with tin, however, are that it does not interpolate beyond the distribution of the data, and the map is forced to fit the control points. TIN is well suited for the purpose of generating a more highly resolved structure on which to drape or hang feature layers. (Jonathan D. Arthur and William H. Pollock, 1997).

6.3 Vector Model

Vector or contour – based methods consists of digitized contour lines and are stored as digital line graphs (DLGs) in the form of x, y coordinate pairs along each contour line of specified elevation. These can be used to subdivide an area into irregular polygons bounded by adjacent contour lines and adjacent streamlines. Contour – based methods of partitioning catchments (Figure-4) and terrain analysis provide a natural way of structuring hydrological and water quality models because the partitioning is based on the hydraulics of fluid flow in the landscape. (Ian. Moor, A. Keith Turner, John P. Wilson, Susan K. Jenson, and Lawrence E. Band; 1993). Vector analysis is better where are definable regions and relative position of the objects. Also vector is better in modeling routes and networks. They are specifically used in all legal, administrative boundaries, roads, pipelines, power lines, flight paths and transportation routes.

7. 3D models Visualization using GIS-ArcScene

The need for 3D information is rapidly increasing. Currently, many human activities make steps toward the third dimension, i.e. urban planning, environmental monitoring, telecommunications, public rescue operations, landscape planning, transportation monitoring, hydrographical activities, utility management, military applications. Practically, the area of interest grows significantly when 3D functionality is offered on the market.

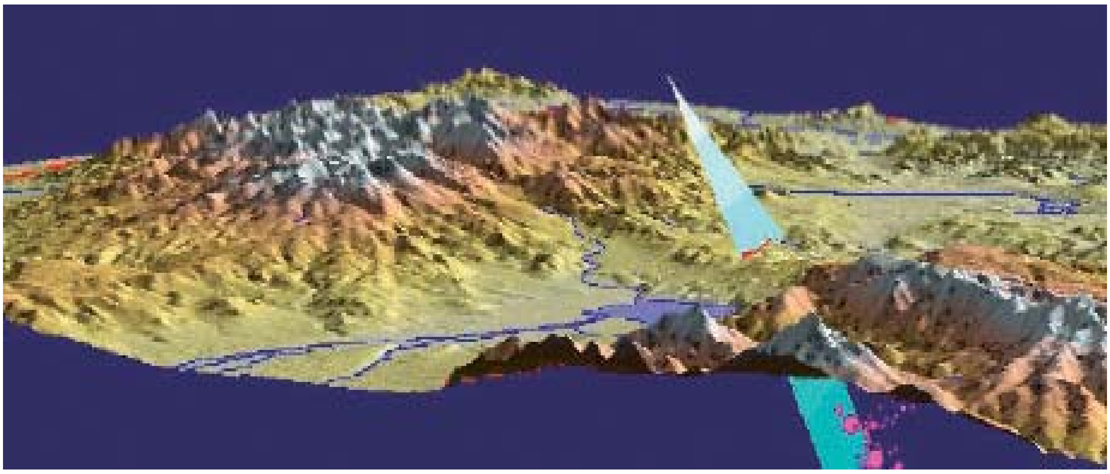

Figure-9 Structure surface model represented by ArcSene (Patrick J. Kennelly, Creating Three Dimensional Display)

ArcScene, the three-dimensional viewing application that is part of ArcGIS 3D Analyst extension, allows earth scientist to create both traditional and unconventional three dimensional displays from real- world data. Figures created from elevation and depth values are commonly used to reveal the earth's surface and expose its interior. Alternatively, other measures can represent a third dimension of earth scientific data. Examples of creating three-dimensional displays with readily available are elevation, magnetic field, and geologic time data. Elevation data is the foundation for the creation of three dimensional displays. Data in digital elevation model (DEM) format is commonly used for storing and displaying topographic surfaces. Also, points, lines, polygons, grids, and images can be positioned in three dimensional spaces with information from underlying data. A feature can be displayed in three-dimensionas with a constant z-vlaue or a z-value derived from an attribute of a feature. Two examples of such displays in earth science are geologic block diagrams and earthquake location (figure-9).

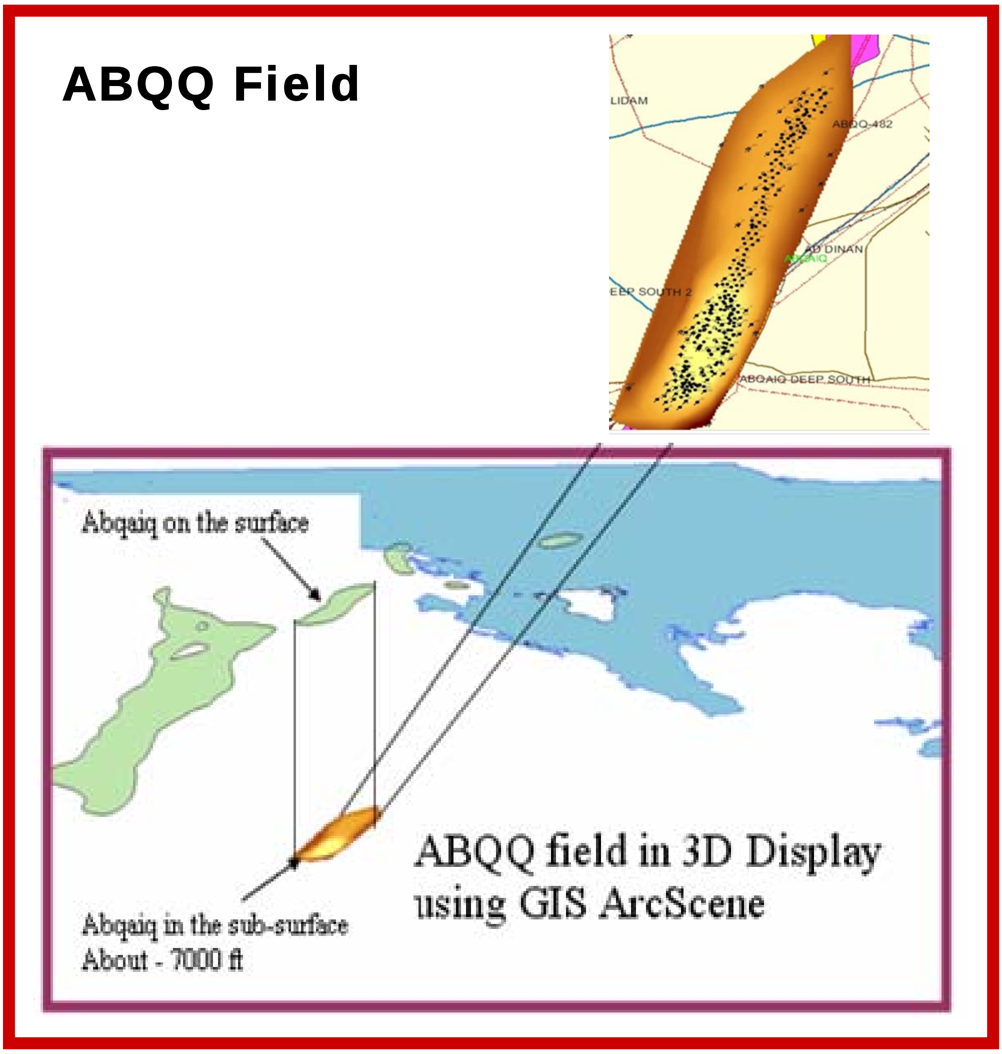

Figure 10 Visualization of top of Arab-D reservoir in 3D using GIS-ArcScene. (Created by Abdul Mohsen Al Maskeen, Saudi Aramco, 2004).

Figure 10 shows how subsurface model is displayed in three dimensionas using GIS-ArcScene utility. Approximately 450 wells from Abqaiq field have been successfully loaded to ArcGIS as x, y, and z-value. Then, the Raster model which represents the top of Arab-D reservoir was generated and displayed as 2D and 3D as shown in figure 10. It is important to display subsurface models, which are not exposed on the surface, in 2D and 3D representation. Subsurface models help explorationist to find the structure of the reservoirs below surface. Also, it helps geologists in planning new proposed wells in terms of the location and orientation. In addition, 3D structural model display will help explorationist determine the flow direction of hydrocarbon, gas and oil flow as well as water flow direction.

8. Conclusions

The main results of this study are as follows:

1. Geographic Information System is used to display and map both surface subsurface data.
2. The spatial analysis extension provides the ability to generate grids and contours with a variety of data- interpolation method.
3. The main methods of creating surface models are by interpolation and triangulation.
4. None of the contouring can work with randomly control-point datasets; the datasets must always be grided first.
5. Raster, Triangulated Irregular Network, and vector models are three principal ways of griding data with GIS.
6. The most widely used data structures consists of square grid networks because of their ease of computer implementation and computational efficiency.
7. The flexibility of assigning Z-values from various sources makes ArcScene a powerful tool for anyone who needs to show the quantitative variations in three dimensional data.

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