Modelling with limited data

Digital Terrain Model: a 3-D model of a surface, such as topography or the top of a seam. It is usually created as a set of abutting triangles where the corners of the triangles are known XYZ points.

Kriging: a geostatistical technique for interpolation that takes account of the spatial auto-correlation of a variable (eg the metal grade) to produce the best linear unbiased estimate.

Structural models of multi-strata deposits can still be created, even where many of the strata are not identified in the drill-hole logs

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THE data for creating a 3-D structural model of a series of strata is usually provided by a set of drill-holes where the elevation of the top of each stratum is identified in the holes. However, when drilling a stratified deposit, it is unusual for all holes to intersect all strata. Some holes may terminate before reaching the bottom stratum, other holes may start part way down the sequence, not all strata may exist over the area of interest, some holes may not have been analysed for all strata and the quality of data from some holes may be poor.

Creating triangulated digital terrain model (DTM) surfaces from incomplete data will often lead to crossing strata, which are difficult to resolve. Manually interpreting the missing elevations in each hole may be possible if there are few holes, few strata and few missing values, but, for other cases, a more automatic method is required.

If all strata could be identified in all holes, modelling would be straightforward as a DTM surface could be created for the top of each stratum and there would be no crossovers. However, when data is missing, overlaps are likely to occur if surfaces are interpolated without any additional controls. It is possible to adjust the DTM surfaces interactively but this can be a lengthy process.

An alternative approach would be to interpolate the elevations for each stratum onto a series of 2-D grid models and then apply rules to resolve any overlaps. However, the rules would be complex as they would need to take into account both the sequence of strata at every grid point and also the elevations of the strata at all adjacent grid points in order to avoid large steps in elevation between successive points.

IMPLEMENTED SOLUTION

The method implemented here is to interpolate missing elevations for every stratum in the sequence onto each hole using the surrounding actual intersection data and then apply a set of rules to resolve any overlaps within each hole. This ensures that the resulting DTM wireframe surfaces for each stratum do not overlap.

The estimation process allows a full range of interpolation methods to be selected. This includes polygonal, inverse power of distance and various types of kriging.

Search criteria including the search volume, anisotropy ratios and the minimum/maximum number of data points can be selected individually for each stratum. If there are insufficient data within the search volume, an absent data elevation is assigned to the stratum at that point. A method for resolving absent data values is incorporated into the rules.

At the end of the interpolation stage, every stratum in every hole will have one of the following elevation values:

- Actual value, defined from the original hole logs.
- Estimated value, defined by interpolation.
- Absent data value; insufficient actual data within search volume.

However, when the data is sparse and there are many estimated values, some of the strata may be out of sequence. To correct this, a set of rules is applied (see box below).

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The rules are applied where Z(i) is the elevation of stratum, 'i' where '1' is the youngest (top elevation), and 'n' the oldest (lowest elevation). These rules require one of the strata to be selected as the reference stratum for which the estimated elevations cannot be changed (in the rules below, the top of the lowest stratum is taken). The rules are applied to each stratum in turn starting from the bottom (i=n) and working up to the top (i=1). Lower and upper strata refer to the stratum immediately below or above the current stratum, respectively:

If Z(n) = absent, then flag an error	ie ensure the reference stratum bedrock Z(n) is estimated into all cells. Otherwise exit.
If Z(i) is an actual pick, no adjustment will be made	Thus the following adjustments only apply to estimated or absent values.
If Z(i) < Z(i+1), then Z(i) = Z(i+1)	ie if the elevation of the current stratum is estimated below the lower stratum, set it equal to the elevation of the lower stratum. This means the stratum is pinched out onto the lower stratum and so the thickness is estimated as zero.
If Z(i) = absent, then Z(i) = Z(i+1)	ie if the elevation of the current stratum is absent, it is set equal to the elevation of the lower stratum. This also means that, in effect, the current stratum is pinched out on the lower stratum.
If Z(i-1) is actual and Z(i) > Z(i-1), then Z(i) = Z(i-1)	ie if the upper stratum is an actual value and the elevation of the current stratum is estimated to be above the upper stratum, reset it equal to the upper stratum.

Using the above rules, it may still be possible, although unlikely, to have strata out of sequence and so a second set of rules is applied. Starting at the top (i=1) and working downwards:

If Z(i) is estimated and Z(i) > Z(i-1), then Z(i) = Z(i-1)	ie if the current elevation is estimated and is below the elevation of the lower stratum, reset it equal to the elevation of the lower stratum.

Using the above rules, there are elevation values for all 'n' strata for all holes. If stratum 'i' doesn't exist in a particular area, then Z(i) = Z(i+1), so the elevation of the top of the stratum exists but the stratum has zero thickness.

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CREATING MODELS

Triangulated DTM surfaces are created for all strata. Because the elevations exist even if the stratum has zero thickness, all DTMs extend over the full area covered by the holes.

These are referred to as DTM type 1. DTM type 2 is created by removing triangles where a stratum has zero thickness. It is helpful to display both types of DTM independently to help understand and interpret the deposit.

A 3-D block model representing all strata is created by filling the space between each stratum in DTM type 1 with subcells. The planar dimensions of a subcell are user-definable, but the dimension of each subcell in the vertical direction is calculated automatically so that it fits exactly between the current stratum and the top of the lower stratum. The model created using this method (model type 1) is therefore not split on horizontal benches.

A second model, model type 2, can be created in which all subcells are split along the horizontal planes corresponding to a user-selected bench height. Thus, the thicker strata may contain several full benches plus both an upper and lower subcell of less than the bench height.

IMPROVING THE MODELS

If there are a lot of missing data, or if some of the actual data is unreliable, the resulting models may include anomalies. The easiest way to correct these is to view the surfaces and the holes in section, then delete an existing point or digitise a new point. New points need not be on existing holes. If a new point is digitised, a dummy hole will be created at that XY location and included with the actual holes and processed in the same way.

Another method of improving the models is to use surface geology information. If the stratum outcropping at the surface can be identified, it is possible to create a grid of points defining an XYZ location attributed with that stratum. These also can be converted to holes and used to enhance the model.

The process for creating the models is an iterative one. The procedure involves using the initial data and they are checked visually. Data problems are identified and fixed, and extra data are added to control the strata position.

A new set of models are then generated and validated and the process is repeated. To facilitate the procedure, the total area can be divided into user-defined sub-areas and models generated for each individual sub-area.

IMPLEMENTING THE RULES

The rules for resolving overlaps are described in an earlier section. Implementing these rules does not require any programming or script writing, but is done using the general-purpose 'expression translator' process in Datamine's Studio program. This allows columns in any file to be created or modified using standard arithmetic and logical functions. The simple and friendly interface makes it easy for anyone to create, test and save a set of rules.

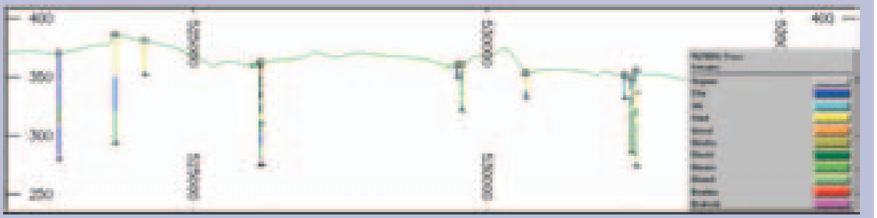
CASE STUDY: WATERLOO PROJECT

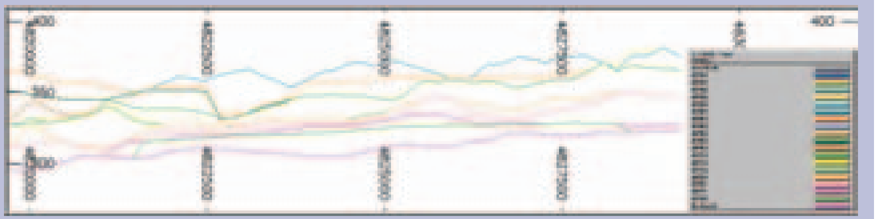
Datamine's Studio program for geological modelling and mine design has been used successfully by the Ontario Geological Survey in the Waterloo region to model a series of 19 aquifers and aquitards. Data was collected from over 17,000 holes where the number of identifiable strata per hole averaged just 2.2.

A main aim of the project was to achieve a better understanding of the geometry and inherent properties of the Quaternary sediments that overlie the bedrock surface within the region to help with the development of source-water protection plans and with the development of a geoscience-based management plan for the groundwater resource.

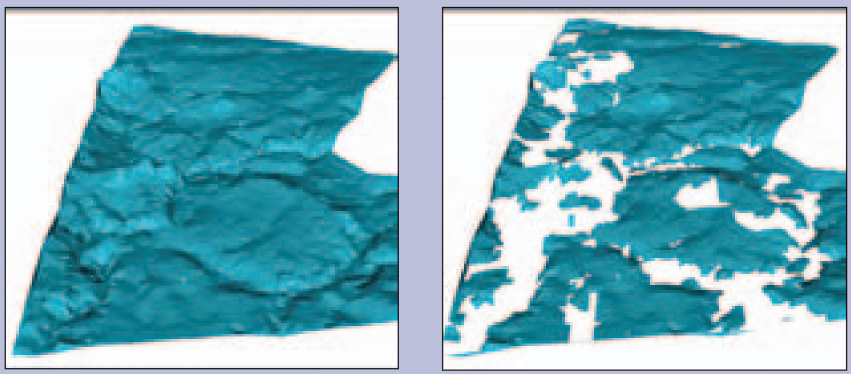
The area, just under 1,400 km^2, contains 19 strata, with more than 17,000 holes and over 38,000 stratum records. Less than 20% of the data are classed as definitive (which means being logged by a trained geoscientist) and the quality of the remaining 80% of the data varies considerably.

Typical west-east sections are shown below, the first including topography and holes; the second is a section through the DTM surfaces. A vertical exaggeration of 20 is used.

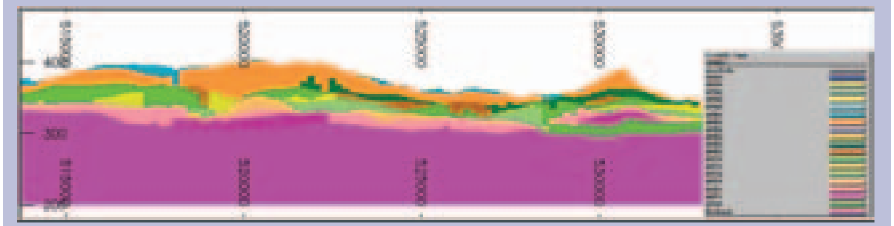




The figures below show a 3-D view of an aquitard DTM wireframe surface. The left-hand figure is a type 1 surface, showing the full extent of the surface even where the stratum has zero thickness. For the right-hand figure, type 2, the zero-thickness areas have been removed



Below: the section through the block model is coloured according to stratum. In this example, a 200 by 200 m cell size was used



Datamine's Studio program includes a range of options for reporting statistics of the resource. The results are classified both by stratum and by aquifer/aquitard designation. The data transfer options allow gridded surface elevations for any of the strata to be exported for use in other applications.

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