MAKING THE MOST OF WHAT YOU’VE GOT: CREATING 3D SUBSURFACE MODELS WITH DATA OF VARYING QUALITY

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INTRODUCTION

There have been significant technological advances in 3-dimensional (3D) subsurface geologic modeling in recent years allowing for a variety of modeling techniques to be developed that provide the ability to model relatively large data sets in regions underlain by complex geology. However, the accuracy and reliability of model outputs are still constrained by the quality of input data and the spatial analytical techniques used to visualize and analyze these data. The choice of modeling techniques used is dependent largely on the purpose of the project, the nature of available input data, expertise of personnel and time constraints. This presentation will discuss three types of 3D subsurface modeling applications and their relative advantages and limitations. The first is a basic model application using digitized data from readily available sources such as regional water well databases and is most effectively applied in areas underlain by relatively simple ‘layer cake’ stratigraphies. The second involves creation of an integrated database by the addition of information taken from geotechnical reports, highway construction reports and outcrop descriptions and may also involve the application of a variety of spatial analytical techniques to improve model output. This method is most appropriate for use in areas underlain by complex stratigraphies. Finally, the quality of model output can be greatly improved by the implementation of various filtering techniques in areas where simple spatial interpolation of data points produces erroneous results due to the presence of geological barriers such as faults, escarpments and large surface water bodies.

BASIC MODELING TECHNIQUE

In many areas of North America a rich repository of regionally extensive subsurface geological information exists in water well databases (e.g. the Ontario Ministry of the Environment water well database, the Water Branch of Manitoba Conservation database, the Ministry of Water, Land and Air Protection water well database). These datasets are available in digital form and are readily transferable into usable database format for rapid data entry into a 3-dimensional modeling software package (e.g. Rockworks, gOcad, TrapTester, etc.). It is important to note, however, that although water well databases can offer a large quantity of data, there are limitations to the distribution and quality of data they contain. Data coverage is focused in rural areas and may be patchy, concentrating particularly along roads. Many of the records are relatively shallow and rarely extend to bedrock, as the wells are generally drilled only to depths sufficient to penetrate productive aquifers. Data quality is a particular concern with water well databases as drillers do not always apply consistent terminology to describe sediment texture and the depth of textural changes may not be accurately recorded. In addition, well location may be difficult to establish for older records in the absence of GPS data. To reduce the number of erroneous data points incorporated into the 3D subsurface model, a water well database can be queried to isolate only the more reliable wells. For example, the Ontario water well database has two reliability codes assigned to each well; one is for the overall quality of the log, and the other is for the accuracy of the elevation measurement. The code is a value between 1 and 9 with a value of 1 representing low accuracy and 9 being highly accurate. It is important that only wells with reliability codes of 9 for both the overall quality and elevation accuracy be used to create the model.

In order to accurately identify texturally distinct stratigraphic units from a water well database, it is important to construct a number of cross sections through the study area using selected data points. These cross-sections should be closed whenever possible (i.e. start and end at the same well) in order to check that individual units are correctly identified and are laterally consistent. This is an essential step in the modeling process as incorrect stratigraphic classification of units can dramatically affect model output.

Once the selected data are organized in a database that is compatible with the modeling software, it is possible to run a model for basic applications using default settings to interpolate between data points (e.g. Rockworks v.2002 uses the inverse distance method of interpolation). In areas where there is some understanding of subsurface geological conditions, model output can be improved by changing the default settings to better reflect spatial trends. For example, if the area is thought to be underlain by features with some directional trends (such as buried valleys or shorelines) it is appropriate to run the model using the directional weighting or kriging algorithm. Cross-validation of the model output can be done by manually checking individual borehole records from selected sites in the study area.
This type of basic 3D subsurface modeling is most appropriate in areas underlain by relatively simple stratigraphy (Fig. 1A), essentially comprising of stacked planar tabular (“layer cake”) geologic units. The most common problem with relying on water well data as the only data source is the variable quality of input data and requires that erroneous points or ‘outliers’ are carefully identified and removed. Some modeling programs (e.g. Rockworks v.2002) contain algorithms that provide information specifically about data quality. These algorithms include ‘distance to point’ which identifies spatial locations of poor data coverage, and ‘trend residual’ which identifies extreme highs and lows within the dataset. These algorithms should be run on the dataset prior to the creation of a model. The major advantage of using a basic approach to subsurface modeling is that models can be produced relatively quickly.

INTEGRATED DATABASE TECHNIQUE

A more sophisticated form of 3D subsurface modeling involves the integration of a number of different data sources to create a more comprehensive database. This is recommended for study areas underlain by complex stratigraphy that include such features as unit pinch-outs, channels or irregular geometries (Fig. 1B). Subsurface geological data can be obtained from geotechnical reports from engineering and construction projects, the Ministry of Transportation, geological surveys and urban geology databases compiled by government agencies (e.g. the Urban Geology Database of Hamilton, Ontario). Data obtained from these sources often requires digitizing prior to integration into a master database that may already include water well data. The major limitations of these sources of data are that they have patchy and uneven distributions, and are focused predominantly along highways or in urbanized areas. If feasible, primary geological data collected from surface outcrops or boreholes are a valuable and reliable addition to such a database and may be weighted more heavily in some programs as ‘Golden Spikes’. A broad understanding of the geological history of the region can also greatly improve the delineation of stratigraphic units to be used in the model as textural units may either be combined or subdivided according to their depositional origin. This background geological knowledge can also be used to guide decisions regarding the choice of suitable algorithms with which to interpret the data. In Rockworks v.2002 algorithms include closest point, directional weighting, inverse distance, kriging, multiple linear regression, trend polynomial, triangulation, and hybrid algorithm. In situations where subsurface units show considerable spatial variability (Fig. 1B) multiple models should be created using a variety of algorithms in order to determine which one produces the most realistic representation of the subsurface stratigraphy. Manual checking of the model output with selected data points is also recommended to ensure consistency with the known geological history of the area.

APPLICATION OF MODEL FILTERS

The most sophisticated method of 3D subsurface modeling is necessary in areas underlain by complex stratigraphy that include significant geological boundaries such as major faults, escarpments, and lake basins (Fig. 1C). In order to effectively model the 3D subsurface stratigraphy in such situations, a variety of filtering procedures need to be implemented to allow more accurate extrapolation of data. The types of filters applied to the model are dependent on the nature of the boundaries and characteristics of the study area and include distance, grid, range, rounding, smoothing and polygon clip filters. For example, the polygon clip filter may be used to remove part of the study area, such as a lake basin where data are sparse or non-existent, from consideration by the model. Appropriate application of filters significantly increases the accuracy of the model output and improves the reliability of 3D models in areas where subsurface stratigraphy are affected by major geologic boundaries.
Figure 1. Schematic diagram showing types of data input and analysis required for different 3D subsurface modeling applications.