3-D aquifer characteristics analysis using a well database and GOCAD

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Abstract Using a water well database, called TANGRAM, well data are stored and their stratigraphic logs are translated into alphanumeric codes. Textural well data can be translated and imported into GOCAD (Geological Object Computer Aided Design), where a set of three-dimensional (3-D) special virtual objects is easily constructed. The wells are easily located on a DTM and are defined by marker levels which correspond to the different stratigraphic layers. A hydraulic conductivity and porosity value can be assigned to each stratigraphic layer of the wells. Using the 3-D grid GOCAD object, the hydraulic conductivity and porosity values are assigned to the grid nodes. In this way the aquifer characteristics distribution is calculated over the whole 3-D volume of the hydrogeological system.

Key words 3-D models; alluvial plain; aquifer characteristics; GOCAD; stratigraphic data; well database; wells

WORK STEPS

Three-dimensional (3-D) model applications are an important technique for groundwater resource management and planning. In particular hydrogeological models need to define the structure and the 3-D geometry reconstructions of aquifer texture variations and the hydraulic conductivity of the hydrogeological system. The recent developments of software packages, which allow several kinds of operation, permit improved model data entry from data stored in databases.

The creation of the international GOCAD consortium by ASGA (Association Scientifique pour la Geologie et ses Applications), Nancy, France, which has been recently joined by the CNR (Centro di Studio per la Geodinamica Alpina e Quaternaria, Sezione di Geologia Ambientale) of Milan, has greatly improved the use of a high-performance 3-D software system GOCAD, (Geological Object Computer Aided Design), designed specially for geological and hydrogeological reconstructions.

GOCAD is an integrated computer application that offers advanced technology in 3-D visualization, interpretation and geo-analysis to the earth scientist and engineers. The main advantage of GOCAD is its ability to integrate information from previously isolated sources (seismic, production data, geostatistical, simulations, etc.) and to unite them in a single 3-D view.
The aim of this first application is to combine a well database, GIS and GOCAD to link different hydrogeological data. The 3-D aquifer characteristics analysis is obtained through several steps: translating the stratigraphic well logs into alphanumeric codes; collecting and storing many well data in a database; converting the stored well data into GOCAD well objects; importing and quoting the well data in GOCAD, where marker levels define the different stratigraphic layers; the creation of a Pointset to detail 3-D surfaces representing the main structural features of the aquifer (Digital Terrain Model (DTM), aquifer bottom, water table); topographic and hydrogeological data are first integrated within a GIS and then translated and imported into GOCAD; attributing the hydrogeological parameters value to each stratigraphic levels (porosity and hydraulic conductivity); assigning the hydraulic conductivity and porosity values to the grid nodes. In this way the aquifer characteristics distribution is calculated for the whole 3-D space of the hydrogeological system.

STUDY AREA

The study area is located in the Po Plain (northern Italy) and it is characterized by a very high density of urban, industrial and agricultural activities: the Brescia provinces.

The hydrogeological system consists of fluvial and fluvio-glacial deposits, in which gravels and sands are texturally predominant, with local and discontinuous silty and clayey levels. From a hydrogeological point of view, the study area can be considered as an unconfined aquifer. The flux is mainly directed north–southward (Fig. 1).

In Brescia province, the alluvial plain is 1370 km$^2$ in extent and has 103 municipalities. In the area 415 public wells were identified and located, 342 of which have stratigraphic logs (Bonomi et al., 1997).

Fig. 1 The study area: Brescia province in northern Italy.
THE WELL DATABASE AND GOCAD WELL OBJECTS

The hydrogeological database used is a custom-built package called TANGRAM (Bonomi et al., 1995). This package can be used to store and display all data associated with water wells: administration, construction, stratigraphic, water level and hydro-chemical details. Its use allows the reconstruction of "layers" and their property distribution and these are the inputs for modelling in GIS.

The wells for which data are stored are referenced by geographic co-ordinates and stratigraphic logs. All well logs are translated into alphanumeric codes. The 415 wells stored in a database have been referenced by geographic co-ordinates (Fig. 1). Textural well data can be translated and imported into GOCAD. A conversion program has been developed to translate the "tangram file" into a "gocad file".

The GOCAD well objects are easily constructed 3-D special virtual objects. Each marker corresponds to the bottom of the stratigraphic levels along the path. They are different for the name and the colour. The name is linked to the alphanumeric code stored in the database and the same colour corresponds to the same code (Fig. 2(a), i.e. C, vegetal soil; 4, sand; 6, gravel; A, clay; 9 silt; etc.).

3-D SURFACES

A Pointset object in GOCAD is a set of discrete points and it is the simplest type of object. From Pointset, the 3-D surfaces of the geometrical aquifer characteristics are calculated: DTM, aquifer bottom (Fig. 2(b)) and water table. The wells are easily located on the DTM and aquifer base and the relationship between surfaces and wells may be analysed. The wells are defined by marker levels, which correspond to the different stratigraphic layers (Fig. 2(c)). Different surfaces, joining the markers, can be elaborate and they can be shown in a movie-surface slicing plane.

PROPERTY VALUE AND THE 3-D AQUIFER CHARACTERISTICS

A hydraulic conductivity and porosity value have been assigned to each stratigraphic code layer of the wells. These values are included in the database file. The conversion program created translates the porosity and the hydraulic conductivity values into a well curve section, inside the GOCAD well object. Each stratigraphic level has the same property value at all its depths. Markers define the bottom level.

The GOCAD interpolation engine is the Discrete Smooth Interpolator (DSI) (Mallet, 1992, 1997). The DSI has two built-in objectives: to make elements like one another (to smooth) and to change things as little as possible (to remain the same). DSI is an iterative process. Using the 3-D Sgrid GOCAD object, the hydraulic conductivity and porosity values are assigned to the grid nodes. In Sgrid the nodes are: 102 along Y(u), 105 along X(v), and 56 along Z(w). There are 577 720 cells and each one has a size of 500 m x 500 m x 2 m. The Sgrid is then modelled between the DTM and aquifer bottom (Fig. 2(b)). The cells are parallel to the bottom aquifer and cut in relation to the DTM, and the number is of course less (278 248).
Fig. 2 (a) Well object markers; the character is the first database code: i.e. C, vegetal soil; 4, gravel; 6, gravel; A, clay; 9, silt. (b) Sgrid calculated according to DTM and aquifer bottom. The height scale is per 50. (c) DTM, aquifer bottom and wells with stratigraphic markers. North is on the left; the height scale is per 50. (d) 3-D porosity distribution calculated with the Sgrid. The height scale is per 50. (e) North–south sections inside the Sgrid. (f) East–west sections inside the Sgrid.
Thus the aquifer characteristics distribution is calculated over the whole 3-D volume of the hydrogeological system. Figure 2(d) shows an example of the porosity distribution. Many 3-D sections are analysed to evaluate the distribution (Fig. 2(e and f)). Easy functions allow extraction of only the volume of the investigated value, or of all the node values located on sections parallel to the topographic or bottom surface.

FINAL REMARKS

This paper presents a first application of the 3-D reconstruction of the hydrogeological parameters of the subsurface in an alluvial plain region. Stratigraphic well data are often considered just as simple descriptions of the well logs. Using a hydrogeological database in a GIS framework, well-data are stored, referenced by geographic co-ordinates and the stratigraphic logs are translated into alphanumeric codes.

Many different studies need the definition of the aquifer texture variations and permeability: aquifer vulnerability analysis (Aller et al., 1985; Cavallin & Giuliano, 1992; Bondesan et al., 1994); hydrogeological modelling (Bonomi & Cavallin, 1997); contamination of groundwater (Rao et al., 1985), etc. The focus of the model in fact is the reconstruction of the textural and hydrogeological characteristics of the subsurface between two different surfaces (DTM and aquifer bottom) and the definition of the geometry related to the main aquifer and aquitard. The application has developed some specific new techniques: a link between a hydrogeological database and GOCAD; and a link between GIS and GOCAD. Future applications of this model, after further refinement, will include 3-D aquifer vulnerability analysis, 3-D flux and transport hydrogeological models, and 3-D pollution models.

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