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Database development and 3D modeling of textural variations in heterogeneous, unconsolidated aquifer media: Application to the Milan plain☆

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Abstract

The textural and hydrogeologic properties of loose deposits are closely connected to the sedimentary processes occurring in fluvial and glacio-fluvial systems. The proposed procedure combines geologic knowledge, coded well data logs stored in a hydrogeologic georeferenced database, geographic information system (GIS) and 3D calculation software to reconstruct the detailed distribution of the subsoil's hydrogeologic parameters. The calculations may apply to any subsoil part, bounded by one or more surfaces. This methodological approach may be applied to diverse investigation depths, vertical intervals detailed to varying extents, on a local or regional scale. Employing great quantities of well data logs, recorded in different ways and distributed across large areas, has enabled significant spatial sedimentologic reconstruction. Two groups of parameters were considered: textural (percentages of gravel, sand and clay) and hydrogeologic (hydraulic conductivity and porosity). In terms of sedimentology, the method reconstructs spatial heterogeneity both along cross-sections and for an entire user-defined volume to analyze the sediments' energy functions and their distribution; deposition rates are proportional to process intensity and distribution with time. In terms of hydrogeology, detailed 3D hydrogeologic structural data provide detailed input for hydrogeologic models in groundwater resource management and planning, such as for transport models.

Keywords: Stratigraphic data; Water wells; Hydrogeologic flow model; Hydrogeologic structural model

1. Introduction

Geologic processes and parameters are often expressed in a qualitative form, and converting them into a quantitative form may be difficult. The textural and hydrogeologic properties of loose deposits are closely connected to sedimentary processes occurring in alluvial and fluvial environments. A quantitative estimate becomes necessary in cases such as using hydrogeologic modeling to manage groundwater resources. Groundwater flow and travel time are dependent on stratigraphic architecture governed by competing processes that control the spatial and temporal distribution of accommodation and sediment supply (Edington and Poeter, 2006). Accommodation is the amount

☆This article presents a case study, in the province of Milan, where well data logs are processed to build a 3D reconstruction of aquifer characteristics and gain detailed hydrogeologic structural data as flux and transport model input.

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of space in which sediment may accumulate. The groundwater flow and transport models do not necessarily require a sedimentary basin model to be reconstructed, as they consider the deposits in hydrogeologic terms and identify them as a function of their defining parameters. However, as aquifers are heterogeneous in longitudinal and vertical directions, the consequences of spatial variability in aquifer properties are known to be a major limitation in using the models (Gòmez-Hernandez, 2003; Peck et al., 1988). Basin simulation includes spatial and temporal distribution of petrophysical parameters (Bitzer, 1999). It should also be kept in mind that transport behaviors, such as average fluxes and heads and overall plume movements, are well represented in upscaled models, and extreme flow and transport behaviors, such as early and late arrival times, local heads and velocities, are more strongly influenced by local discrete heterogeneities and are not well represented in upscaled systems (Scheibe and Yabusaki, 1998).

Furthermore, hydrogeologic flow models require parameters to be distributed in both space and depth. Generally, hydrogeologic investigations use geologic or seismic cross sections, field data and stratigraphic well data interpretations to determine parameters. Parameterization of aquifer materials is often achieved by assigning mean parameter values to hydrogeologic formations or to hydrostratigraphic units in the aquifers. These values are obtained by means such as pumping tests and field observations. This study's intent is to propose an improved definition of the spatial distribution of hydraulic conductivity and porosity based on differing percentages of heterogeneous materials, such as gravel, sand and clay, in fluvial and glacio-fluvial deposits. This objective can be achieved by quantitative three-dimensional (3D) processing of information in well logs, stored and codified in a hydrogeologic database. The well log data are often used to reconstruct the hydrogeologic sections, but the information is rarely translated into quantitative evaluations. This often has to do with its poor reliability and lack of homogeneity. This study shows that if they are analyzed in large quantities and over extensive areas, they will be considered a useful tool for investigation and quantitative parameterization.

2. Procedure

The proposed procedure evaluates the well logs, suggests a continuous and systematic method for storing the data, proposes a coding system for the stratigraphic descriptions and calculates the hydraulic conductivity distribution from the well logs as a function of 3D numerical modeling. The procedure links a computer-based hydrogeologic database to a 3D model through several steps.

The procedure is divided into three phases. The first phase is essential for making quantitative evaluations of the subsoil's textural and hydrogeologic characteristics. It entails collecting and organizing well data in a database. The second phase develops a hydrogeologic model in a heterogeneous unconsolidated aquifer medium. The aquifer medium is not tied to a schematic subdivision of the subsoil into aquifers and aquicludes, as it considers the spatial heterogeneity of textural variations and hydrogeologic parameters. Hydraulic conductivity, which is highly variable, is the most critical parameter controlling groundwater flow and contaminant transport. Small-scale heterogeneities in hydraulic conductivity distribution are highly important for contaminant transport modeling, as contaminants tend to move along pathways of higher conductivity and avoid areas of low conductivity (Zheng and Bennett, 1995). The final objective of the third phase is to create a hydrogeologic flux and transport model incorporating highly detailed hydrogeologic data. Though highly detailed hydrogeologic parameterization may not be necessary for a flow model, it becomes a major advantage in a transport model. Excessive detail about hydraulic conductivity and porosity may compromise the use and calibration of dispersivity values in a transport model. Dispersivity simulates the heterogeneity of an aquifer system, but it is only an artificial concept. Dispersion is currently understood to result primarily from groundwater flow through heterogeneous materials (Weaver et al., 1997) and many authors suggest that an advection–dispersion model can generally not simulate transport behavior observed in heterogeneous aquifers where there are these kinds of connected flow paths (Zheng and Gorelick, 2003).

In the first phase, the main features of the proposed database are as follows:

1. Systematic collection of all available well data logs, even those that seem useless; the data logs of greater depth are often used in traditional calculations. In fact, many other well logs, which are meaningless for a hydrogeological cross