ground water

Methods Note/

A Geographic Data Model for Representing Ground Water Systems

by Gil Strassberg[1], David R. Maidment[2], and Norm L. Jones[3]

Abstract

The Arc Hydro ground water data model is a geographic data model for representing spatial and temporal ground water information within a geographic information system (GIS). The data model is a standardized representation of ground water systems within a spatial database that provides a public domain template for GIS users to store, document, and analyze commonly used spatial and temporal ground water data sets. This paper describes the data model framework, a simplified version of the complete ground water data model that includes two-dimensional and three-dimensional (3D) object classes for representing aquifers, wells, and borehole data, and the 3D geospatial context in which these data exist. The framework data model also includes tabular objects for representing temporal information such as water levels and water quality samples that are related with spatial features.

Introduction

Development of standardized geographic information systems (GIS) data sets for various classes of geospatial phenomena has been going on for more than a decade in the United States, and systematic descriptions of the surface water network (National Hydrography Dataset), land surface terrain (National Elevation Dataset), and land cover (National Land Cover Dataset) are available. Nationwide coverage of digital soil maps is available at 1:250,000 scale from the State Soil Geographic (STATSGO) database, and much of the nation has digital soil maps at 1:24,000 scale from the Soil Survey Geographic (SSURGO) database. Below the soil zone, however, there is no systematic geographic description of the subsurface. There are many reasons why this is so, including the fragmentation of geologic mapping and well stratigraphic databases among many state agencies and the need for models to infer hydrogeologic properties that are unobservable from the land surface. With advances in information technology, the availability of digital ground water data collected and distributed by federal, state, and local organizations is rapidly increasing. Many of these data sets have a spatial component, and GIS are becoming standard practice for managing and analyzing spatial ground water data sets. A variety of data models and standards have been developed for representing ground water information, including standards focused on describing site information (e.g., American Society of Testing and Materials 2004; Australian National Ground water Committee 1999; de Dreuzy et al. 2006), and for representing data in ground water simulation models (e.g., Steward and Bernard 2006; Gogu et al. 2001). Data models are also designed to support commercial software applications such as SiteFX, HydroGeo Analyst, and EQuIS, which are used for storing and visualizing ground water data. These software applications are based on relational database structures for archiving ground water data in tabular format and enable creation of reports and views of information, including extensions for creating spatial views of the data within GIS. The Arc Hydro ground water data model is distinct from these applications as it is designed specifically to handle geospatial data sets within a spatial database (geodatabase) framework.

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Data Model Design

Arc Hydro is a conceptual and technical design implemented within a geodatabase. The first Arc Hydro data model was designed for representing surface water systems (Maidment 2002) and included data structures for describing river networks, drainage areas, and related temporal information. Similar principles and conventions were used in the design of the ground water data model to allow for integration of the two data models. Although the logic of the data model can be implemented in different GIS software packages, the presented design implements object classes from the ArcGIS geodatabase model. The geodatabase is a repository of geographic information organized into geographic data sets built on top of relational database management systems (RDBMS) such as Microsoft Access, Oracle, or Microsoft SQL Server that are customized for storing spatial data structures. Thus, the geodatabase performs as any standard RDBMS with the addition of capabilities to store geospatial features. Geodatabase objects used in the ground water data model include features, feature classes, feature data sets, relationships, rasters, and raster catalogs. Features are spatial vector objects (e.g., points, lines, polygons, and multipatches) with attributes (fields) to describe their properties. Features are instances within a feature class, a collection of features with the same geometry type, attributes, and relationships (the feature-feature class hierarchy is equivalent to that of a row in a table). Relationships are objects that define associations between other object classes based on key fields (for example, a relationship can associate between an aquifer and a well). Raster data sets represent imaged, sampled, or interpolated data on a uniform rectangular grid, and raster catalogs are used for storing, indexing, and attributing raster data sets. A detailed description of the geodatabase model and object classes is provided by Zeiler (1999).

The ground water data model provides data structures for representing two-dimensional (2D) and three-dimensional (3D) hydrogeologic features (e.g., aquifers, wells, faults, cross sections, and volumes), objects for describing computational grids (cells and nodes) to represent inputs and outputs from simulation models, and objects for storing tabular or gridded temporal information such as water levels and water quality measurements. The description of the complete data model is beyond the scope of this paper; thus, we focus on presenting a "framework data model" that represents the most common features and data sets, and supports mapping and analysis of common ground water data within a GIS. Readers are referred to Strassberg (2005) for a complete description of the data model.

The framework data model (Figure 1) represents common data sets such as aquifer units from aquifer maps, and well-related data such as stratigraphy, water levels and water quality samples commonly stored in ground water databases. The framework data model also provides spatial classes for representing the 3D geospatial context of the information.

Aquifer is a polygon feature class for representing aquifer boundaries and zones within them, such as an

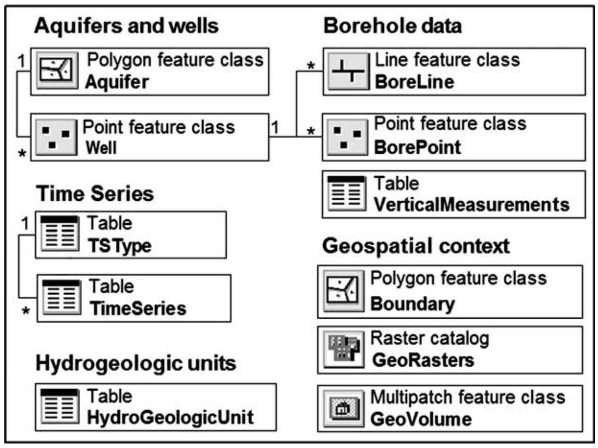

Figure 1. Schematic view of the framework data model. Boxes represent object classes, and the lines connecting the objects represent relationships (the annotation 1 to * represents a one-to-many relationship). Symbols within the boxes illustrate the data type and geometry (point, line, polygon, multipatch, raster catalog, and table).

outcrop or downdip area, which are commonly presented in aquifer maps. Wells are represented as 2D point features in the Well feature class with attributes to describe properties such as the well type, land surface elevation, and depth. Vertical borehole data related to the well features are represented as tabular data in the VerticalMeasurements table or as spatial features (either point or interval) in the BorePoint and BoreLine classes, which are 3D point and line feature classes. The Aquifer, Well, BoreLine, and BorePoint features are connected through relationship classes (Figure 2). The first relationship associates the AquiferID attribute of Well features with the HydroID of an Aquifer feature. This is a one-to-many relationship where an aquifer is associated with one or more wells. Two relationships associate between Wells, BorePoints, and BoreLines based on the HydroID attribute of Well features and the WellID attribute of BoreLine and BorePoint features. These are also one-to-many relationships where a Well feature is associated with one or more BorePoints and BoreLines. HydroID is a key attribute in the Arc Hydro data model. It is an integer identifier assigned to all features in the data model and is unique across the geodatabase. The HydroID is used to identify features and establish relationships within the geodatabase (see Maidment [2002] for more details on populating and managing the HydroID).

The advantage of representing data within a GIS is the ability to display and analyze information within geospatial context. Within GIS, information from various sources is assimilated and can be viewed and analyzed based on spatial relationships. To visualize 3D information stored in the Well, BorePoint, and BoreLine classes, it is important to establish a 3D geospatial context, which is established by the Boundary, GeoRasters, and GeoVolume classes (Figure 3). Boundary is a polygon feature class that represents an area of interest within the subsurface. The boundary can be natural (e.g., watershed overlying an aquifer) or artificial (e.g., extent of a simulation

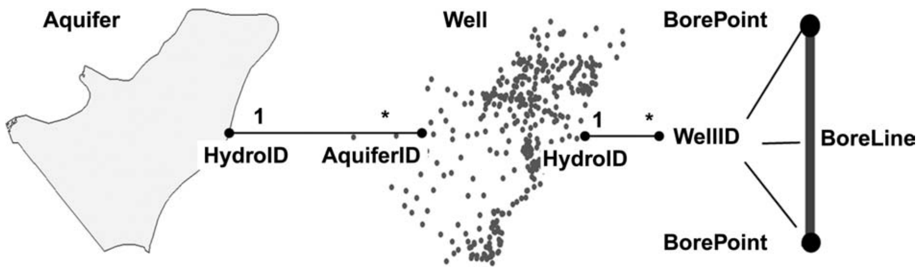

Figure 2. Relationships between Aquifers, Wells, BorePoints, and BoreLines. Well features have an AquiferID attribute that relates to the HydroID of an Aquifer feature. The WellID attribute of BorePoint and BoreLine features relates to the HydroID of a Well feature.

model or experimental ground water site). GeoRasters is a raster catalog containing gridded surfaces. These surfaces can describe land surface topography, top and bottom elevations of hydrogeologic units, and the spatial distribution of physical properties (e.g., specific yield, transmissivity) within hydrogeologic units. GeoVolume is a multipatch feature class for representing 3D volume features within the subsurface.

Spatial occurrences of hydrogeologic units can take a variety of forms and can be represented with different data structures within the geodatabase. For example, a hydrogeologic unit can be described by an Aquifer polygon, stratigraphy along a borehole stored as BorePoints or BoreLines, surfaces representing the top and bottom of the unit stored as GeoRasters, or as a volume object in the GeoVolume feature class. Conceptually, all these instances describe the same hydrogeologic unit but the spatial representation varies. The HydroGeologicUnit table provides the means to store descriptive attributes (e.g., texture, name, code) of hydrogeologic units within the ground water data model and enables the connection between the conceptual definition of the unit and its spatial occurrences. Each row in the table defines a conceptual hydrogeologic unit and is assigned a unique hydrogeologic unit identifier (HGUID), and attributing spatial objects with the same HGUID provides a linkage between different spatial instances of the same conceptual unit.

Tabular temporal data such as water levels and water quality samples are stored in the TimeSeries and TSType tables, following the conventions and data structures from the surface water data model described by Maidment (2002). The TSType table defines the type of the time series by describing the variable, its units, the source of data, and so on. The TimeSeries table is a store of time series values indexed by date and time, and a reference to a spatial feature. Temporal data are mapped by relating the time series data with spatial features in the data model (e.g., Wells, BorePoints) to create 2D or 3D temporal-spatial views.

Discussion

The focus of the framework data model is to represent basic ground water features and data sets and support common mapping and analysis procedures. As much of ground water data are gathered from wells, it is important to establish classes for representing wells and borehole data. For representing wells and associated borehole data and how they relate with specific aquifers, the framework includes the Aquifer, Well, BorePoint, and BoreLine feature classes and the VerticalMeasurements table. Relationships established in the framework provide logical connectivity between these features and enable querying the geodatabase and performing logical operations based on these associations. For example, one could select an aquifer feature from a map and through the relationships retrieve wells related with it and then query for any vertical data related with this set of wells. BorePoints and BoreLines are created from the vertical data to visualize 3D features such as hydrostratigraphy intervals along boreholes, sampling ports in multilevel sampling wells, and the location of well screens.

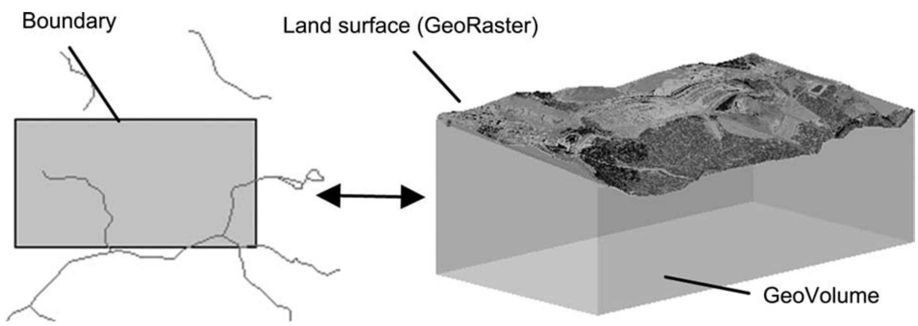

Figure 3. Objects representing a 3D geospatial context. Boundary represents the horizontal extent of an area of interest, GeoRasters represent gridded surfaces such as a digital elevation model, and GeoVolume represents a volume within the subsurface.

An important aspect of this research is the demonstration of GIS capabilities to represent the 3D nature of the subsurface and describing hydrogeologic information in the form of 3D geospatial objects. The need for 3D representation of subsurface information has been emphasized in the past (e.g., Turner 1989, 2000). While it is possible to store and view 3D data within a GIS, it is important to note the limitation of current GIS in analysis of 3D data. Currently, GIS software packages are strong in 3D data presentation and support navigation, animation, and data exploration (Zlatanova et al. 2002), but spatial operations are not commonly supported, limiting many analyses done in GIS to 2D data. Keeping these limitations in mind, the data model is designed with 3D classes that provide a more realistic representation of ground water features and better describe reality. With progress in the 3D capabilities of GIS, these classes will provide a better point of departure for spatial analyses. Readers are referred to Strassberg (2005) for a detailed description of the full ground water data model and examples applications.

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