Groundwater Resource Planning – Defining the Shallow Aquifer System

Kurt O. Thomsen, Ph.D., P.G.
Janet L. Agnoletti
and
Connie L. Pokorny
Barrington Area Council of Governments

ABSTRACT

Over the past decade the public has become more and more concerned with water resources. As a proactive measure, the Barrington Area Council of Governments (BACOG), an association of villages and townships in far northwest suburban Chicago, is currently working on a project to establish water resource baseline conditions in their immediate and surrounding area. Under the direction of BACOG and a professional advisor, a committee of volunteers is conducting much of the work of this water resource initiative using data readily available for little or no cost.

To establish water resource baseline conditions using limited resources, BACOG developed a method to produce baseline hydrogeologic unit maps from readily available borehole log data using GIS querying techniques. Borehole strata descriptions were converted to numerical values by establishing the average hydraulic conductivity of the combined soils making up the stratum of interest. These hydraulic conductivity values were then used to assign each stratum to a hydrogeologic unit based on typical ranges of hydraulic conductivity for aquifers, aquitards and aquicludes. In this manner, the well log data were queried to describe the shallow aquifer system. The bedrock surface, basal aquifer and overlying stratigraphy were described. Aquifers, aquitards and aquicludes overlying the bedrock were defined and preliminary interrelationships were established. Analysis of the resulting information produced cross-sections in areas of interest and identification of potential recharge areas.

INTRODUCTION

The BACOG geographic area is located approximately 40 miles northwest of downtown Chicago in northeastern Illinois. BACOG is a regional planning organization comprised of seven member municipalities and two townships. Through the water resource initiative, BACOG will expand its base of knowledge, technical capacity, and data on water resources. Specific data on water conditions and water availability, rough mapping of the aquifers, estimates of current and projected water consumption, the potential for groundwater contamination, a network of private monitoring wells, and future monitoring against current conditions are all critical to the desired goals of sustainability of natural resources and balance with development. Geographic Information System (GIS) technology, a computer mapping and data management tool, is being utilized for data collection and analysis for the entire project. Project progress has been reported on a regular basis (Peters, Agnoletti and Thomsen, 2003; Agnoletti and Thomsen, 2003; Thomsen and Agnoletti, 2003; Thomsen and Agnoletti, 2004; and Agnoletti and

Thomsen, 2004). BACOG has been participating in a demonstration project with the Illinois Geological Survey (ISGS). The purpose of this project is to compare mapping techniques and various approaches for data analysis. A nine-section sub-area of the BACOG study area is being used for this purpose. The maps included in this paper were generated as part of this project.

DATA PREPARATION

All databases are different. Geologic databases are particularly extensive with regard to description of materials. If data are not standardized at the time of input, thousands of descriptors and definitions (including misspellings and mistakes) may exist in the geologic database presenting a serious problem for GIS applications or any database utility. Geologic databases created from well logs tend to have been built over long time periods, with data having been input by many different numbers of scientists and well drillers, or database technicians working from paper records. In addition, the nature of geologic data in itself, presents a challenge for standardization of materials. It is necessary for the best possible generalizations to be made in order to place materials into classifications. Without classifications, it is impossible to create maps for visual analysis.

Without question, large geologic databases must be standardized in order to make them useful for scientists and computer applications. It is important to note that many operations will need to be repeated a number of times in order to achieve standardization, and that all databases will have a unique set of circumstances. Once all operations are complete, some records will have to be dealt with individually in order to best categorize them. Some records will have to be discarded or changed to 'null' if the description does not have enough information, is too vague, or does not have any information.

The analyst may use Access, ArcGIS or a combination of both to complete all data procedures. It is recommended that Excel only be used when necessary, or for data conversion into Access. This is especially true if the database being manipulated has more than 65,000 records. Excel will cut the database off at this number and all data records beyond that number will be lost if the file is saved.

It is of most importance that the analysts familiarizes themselves with the data. With a database of more than 20,000 it may take up to a few days to become familiar with the many different terms used in the geologic description field. It is helpful to first create a summary table (and create additional tables many times throughout the standardization process) in Access or ArcGIS that lists each of the unique identifiers found in the description field, and the number of times each identifier appears in the database. This will help the technicians and analysts decide which terms are important, most frequently occurring, most often misspelled, and how much work and time it will take to standardize the database.

In the case of BACOG, over 15,000 unique terms were found in the geologic description field of the entire database. There are over 100,000 records in the database representing

about 25,000 wells. These numbers indicate that a great deal of standardization must be completed in order to make BACOG's database useful for mapping and analysis.

Ideally, the number of unique identifiers should be a manageable amount, based only on the materials that are considered important for analysis using hydraulic conductivity. A definitive possibility of unique identifiers should exist based on the chosen materials.

For example, BACOG has several terms for clay, which include kaolin, bentonite, and talc. It also includes green clay, blue clay, and brown clay, etc.

All of the above materials have the same average hydraulic conductivity values, and once they are identified the technician or analyst can record them in the database so that they are all one classification instead of seven separate classifications. Every time this is done, it will further eliminate the need for complicated querying procedures that will be highly prone to error due to the large amount of unique identifiers.

Once the analyst has become familiar with the terms in the database, confirms with the geologist or specialist what terms should be used and what terms will be lumped together as one (i.e. green clay will be changed to clay), then, the resulting terms are populated with corresponding average hydraulic conductivity values.

Once the unique identifiers have been established, the list of identifiers needs to be populated with average hydraulic conductivity and hydrogeologic unit information. When completed, these identifiers and associated information are used to populate the entire database.

Average Hydraulic Conductivity

As mentioned in above, average hydraulic conductivity will be used to represent each stratum listed in a given well log. In turn, it will be used to assign hydrogeologic units to the strata. The basic building blocks of shallow aquifer systems are clay, silt sand, gravel, cobbles and boulders.

Since hydraulic conductivity is a measurable numerical characteristic of soil material, it was decided to define the stratigraphy of the shallow aquifer system using this characteristic of the stratigraphic units. This numerical characteristic makes hydraulic conductivity ideal for analysis using computer analytical techniques. Table 1 lists the average hydraulic conductivity values for the basic soil types present in most shallow aquifer system (Sanders, 1998).

Soil Material	**Average Log_{10} K (cm/sec)**
Clay	-7.5
Silt	-5.0
Sand	-3.0
Gravel	1.0

Cobbles	3.0
Boulders	3.0

Table 1 Average Hydraulic Conductivity (K) of Soil Materials

Stratum Descriptions in Terms of Hydraulic Conductivity

Table 2 is a soil texture table commonly used by drillers to describe the composition of soil recovered form borehole soil samples for the purpose of creating a borehole or well log of the hole being drilled (Wilun and Starzcwski, 1972).

Term	Percent of Soil Composition
Major Soil Type (clay, sand, etc.)	50 to 60
“with”	20 to 35
“some”	10 to 20
“trace”	1 to 10

Table 2 Terms Used by Soil Engineers and Drillers to Describe Texture of Borehole Materials

Information in Table 2 was expanded to include addition terms commonly found in borehole soil descriptions. Table 3 is an expanded version of Table 2 presenting additional basic key words found in well logs and used to convert soil descriptions to representative average hydraulic conductivity values.

Use of Terms	Terms	Content	Proportion Factor
Nouns	clay, silt, sand, gravel cobbles & boulders	60%	6
Conjunctions	and, comma & hyphen	60%	6
Adjectives	clayey, silty, sandy, gravelly, cobbley, & bouldery	40%	4
Prepositions	in & with	30%	3
	few	20%	2
Adverbs	considerable, frequent & much	30%	3
	a bit, contain, containing, little, scattered, slightly, small amount, & some	20%	2
	isolated, occasional, & trace	10%	1

Table 3 Key Terms Used for Soil Description Conversions

Converting soil descriptions of the unique identifiers (Column A, Figure 3-1) into representative hydraulic conductivity values (Column O, Figure 3-1) is very similar to the diagramming of sentences that everyone was exposed to in grammar school. The main part of a description is the soil type, usually used as a noun or adjective. When used as a

noun by itself the soil will be the major component of the soil making up about 60 percent of the soil. If the soil is used as an adjective it makes up about 40 percent of the soil volume. Use of a conjunction such as "and," a comma, or a hyphen with nouns gives the nouns equal weight. Two nouns not separated by a comma or an "and" become an adjective and a noun respectively such as "clay gravel." "Clay gravel is equivalent to clayey gravel. If the soil is used with any of the prepositions or adverbs listed in Table 3 the contribution to the soil volume is equal the percents listed in the table.

If more than one noun is used in the descriptions then the terms are weighted using the proportion factors listed in Table 3.

MAPPING

Bedrock

The development of a bedrock topographic map is important in that it may show pre-glacial drainage patterns that can influence flow within the shallow aquifer system. Within these drainage patterns, coarse material is usually found making these areas some of the most productive for the placement of water wells. In addition, the types of bedrock encountered can also be shown and will indicate variation in downward seepage rates due to the variation of hydraulic conductivity of the material composing bedrock.

The bedrock well data for the sub-area were analyzed and queried as described above. The resulting bedrock elevation data were manipulated using kriging statistical analysis to generate a contour map depicting the topography of the bedrock surface (Figure 2).

In addition, a bedrock map showing the distribution of bedrock type can be created. The BACOG study area contains the beginning portion of the transition zone from Silurian Age dolomite/limestone to the older Ordovician age Maquoketa shale (Meyer, 1998), going from east to west. This information determines the variation in the seepage rate of the groundwater to the underlying bedrock, since the hydraulic conductivity of the dolomite/limestone is greater than that of the shale. The inflow to (or outflow from) the underlying bedrock component of the water balance is estimated using this and water level information.

No bedrock type map was prepared for the sub-area because the bedrock in the sub-area is all Silurian Age dolomite/limestone.

Basal Aquifer

The most productive region in terms of water production within the shallow aquifer system is the region located directly above bedrock. This region is composed of weathered and broken bedrock and combinations of sand and gravel and is referred to as the basal aquifer. This water-bearing unit is the most extensive in the BACOG study area and is present everywhere except for small portions of the area.

The bedrock well database, established when querying to develop the bedrock surface map, was queried to determine the elevation of the basal aquifer surface at each bedrock well location. This method uses approximately 350 points of data, i.e., all wells within the 9 square miles. The database was queried from the top down using descriptors such as clay, silt, and till. These descriptors were augmented by others that accounted for unique nouns and adjectives, misspelled words and abbreviations. The query was set up to find the bottom elevation of strata that contain the last occurrence of these descriptors before reaching bedrock. This was accomplished for every well in the database. At this point the querying process was the same as that described above for the bedrock topography map with the exception that different descriptors were used. After a final QA/QC check, a file was created containing the basal aquifer surface elevations for each well location referenced in the database. These data were used to develop a topographic map of the surface of the basal aquifer (Figure 3).

Since both the bottom (bedrock topography) and the top (basal aquifer topography) of the basal aquifer were defined, the water storage capacity for the aquifer could be estimated by determining the thickness (isopach) of the aquifer. Establishing the thickness of the aquifer and multiplying it by the sub-area (9 square miles) would yield the volume of material contained in the aquifer.

3D Representation of the Shallow Aquifer System

Because of the vertical and areal variation in the distribution of the materials that make up the shallow aquifer system, defining the stratigraphy of the system is very difficult. Traditionally, known stratigraphic units are defined by relating unit characteristics to similar characteristics of materials encountered when drilling reference boreholes. Reference borehole information is related to nearby wells using well logs from the ISGS database (ISGS, 2001). Interpretation of the stratigraphy of an area is based on the use of descriptors and is very subjective. This type of analysis is not very compatible with analysis using computer techniques and is the reason for changing the well log data to a numerical format as described above.

A means to define the stratigraphy of the shallow aquifer system is imperative in order develop 3-dimensional capabilities for site-specific analyses. Several software packages are available that provide 3-dimensional presentations, but most have a limited value for conducting analyses for specific projects. Two techniques used to provide 3-dimensional capabilities for project use are stack mapping and the preparation of cross-sections.

Once the hydraulic conductivity of all strata have been estimated as described above and added to the database, the strata can be classified in terms of hydrogeologic units (aquifer, aquitard and aquiclude) using the relationships presented in Table 4.

Hydrogeologic Units	**Log_{10} K (cm/sec)**
Aquifer	Greater than –3.0
Aquitard	-5.0 to –3.0

Aquiclude	Less than –5.0

Table 4 Definition of Hydrologic Units Based on Average Hydraulic Conductivity

This information is used to create parallel maps showing the distribution of hydrogeologic units in a given interval (20 feet for example) from the ground surface to the bedrock. The average hydraulic conductivity is determined in the specified interval at each well location. A map is generated using these values for each interval and then stacked in order to represent the vertical distribution of hydrogeologic units in the area of interest. Figure 4 is the stack map representing the 9-section sub-area.

The same information used for stack mapping is also used for creating cross-sections. A cross-section relates the hydrogeologic units of a number of wells located along a straight line. Since the estimated strata hydrogeologic units are recorded in the database, well logs can be graphically represented in terms of hydrogeologic units such as shown in Figure 5. Relating these units can be very difficult because of the variability in the location of the hydrogeologic units both vertically and horizontally. Figure 6 is an example of a cross-section that has the interrelationship of the hydrogeologic units across its length completed.

Recharge and Aquifer Sensitivity

The characteristics that are optimal for aquifer recharge also make an aquifer susceptible to contamination. The U.S. Environmental Protection Agency defines aquifer sensitivity as groundwater contamination potential or aquifer sensitivity (U.S. EPA, 1993). According to Berg (Berg, 2001), aquifer sensitivity is the relative ease with which a contaminant of any kind applied on or near the land surface can migrate to an aquifer. Aquifer sensitivity is a function of the intrinsic characteristics of the geological materials but is not dependent on land use or contaminant characteristics. Aquifer vulnerability, however, focuses on the vertical migration of contaminants into the groundwater and is dependent on land-use management practices, contaminant characteristics, and aquifer sensitivity conditions. In general, aquifers at depth have a lower potential for becoming contaminated than do aquifers near or at the land surface.

Potential recharge areas are determined by establishing the water transmission characteristics of the topsoil and the underlying materials to a depth equal to the location of the uppermost aquifer material. This information is used to develop a map that depicts the distribution of relative water transmission rates into the soil to the first aquifer throughout the study area. These transmission rates are then ranked to indicate the areas that have high potential for recharge and those that have lesser potential for recharge.

In this study, the interest in recharge is twofold. First, the distribution of recharge characteristics within the study area is needed to make sound planning decisions. Recharge areas are important because precipitation enters and supplies the groundwater system through these areas. Any obstruction of these areas will prevent groundwater from being recharged. The characteristics of these areas that make them important to

refreshing groundwater also make them very susceptible as pathways for surface pollution to reach the groundwater.

Recharge areas have permeable topsoils and permeable materials (materials composed of sand, gravel or combinations of the two) underlying the topsoil. Non-recharge areas have impermeable topsoils and impermeable materials (materials composed of silt, clay or combinations of the two) underlying the topsoil. The majority of the well logs do not record drilling through the topsoil, but begin the record with the material underlying topsoil. For the purposes of this study the top five feet of a well log will be assumed to be the soil horizons (Westphal, 2004). The well log database was queried to determine the stratigraphy at each well location and identify the location of the uppermost aquifer using the techniques described above. An aquifer was defined as a permeable unit having a thickness of 10 feet or greater.

As mentioned above, electronic copies of soil maps for the BACOG study area were obtained from the local county offices of the NRCS. Included in this information was a description of each soil type encountered in the surveys. These soils were placed into seven classification groups by the Lake County Health Department (LCHD) (LCHD, 1997). LCHD uses this information to determine the loading capacity of the various soils for septic fields. The soils maps were recreated using the LCHD soil classification groups rather than the original soil codes.

The map containing the materials underlying the topsoil and the soils map were combined using the union feature of GIS to create new polygons having water transmission characteristics of both the soils and the underlying material. This resulted in a map containing polygons of water transmission characteristics from high to low with intermediate levels of moderate high, moderate, and moderate low.

The soil data were incorporated into the database for each well log. The revised well logs were then queried to determine the distance to the uppermost aquifer material greater than or equal to 10 feet. The hydraulic conductivity values were used to estimate a relative time of travel for recharging water to travel the determined distance. These values from each well in the sub-area were used to plot the estimated distribution of the recharge/aquifer sensitivity characteristics (Figure 7).

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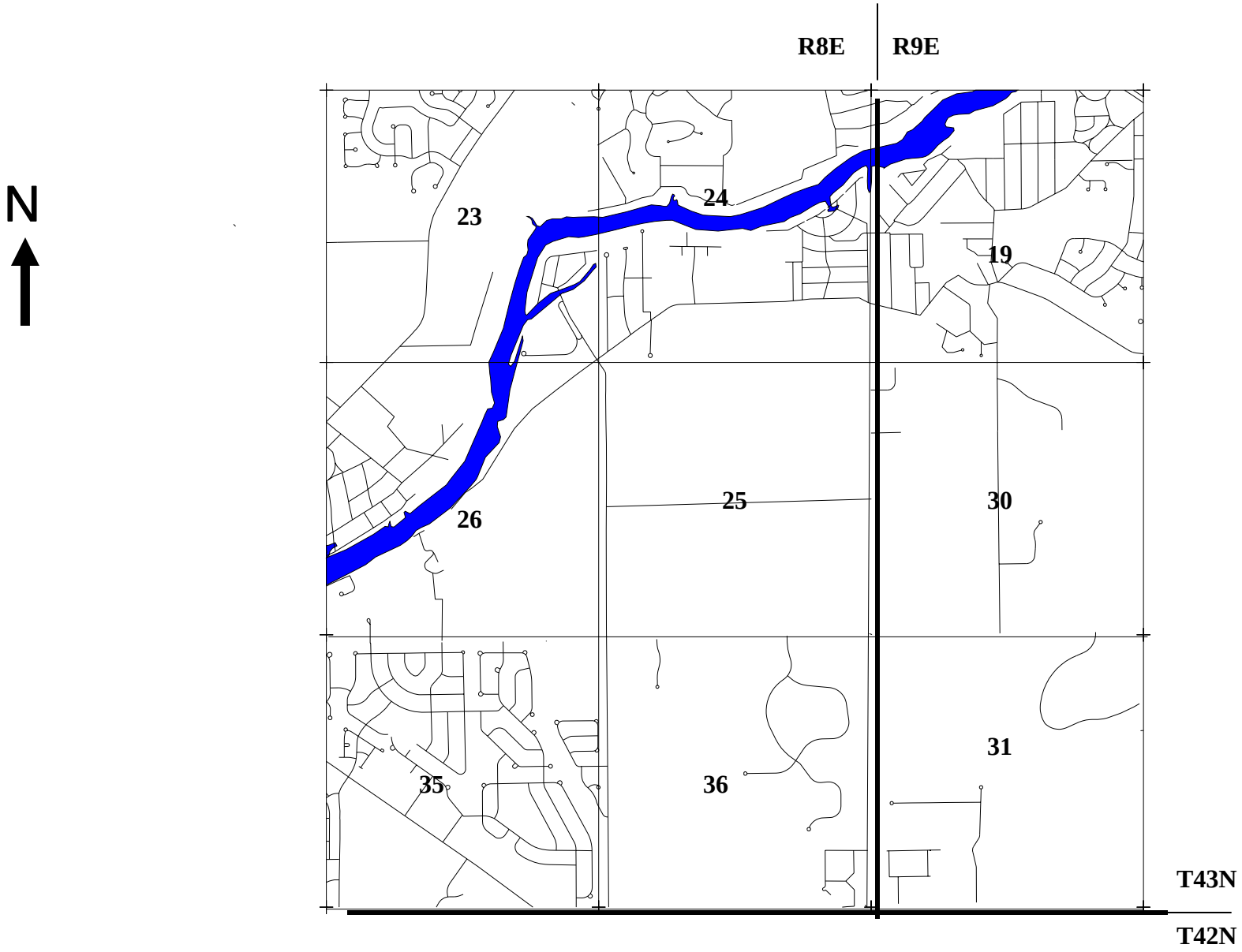

Figure 1 ISGS/BACOG Demonstration Area

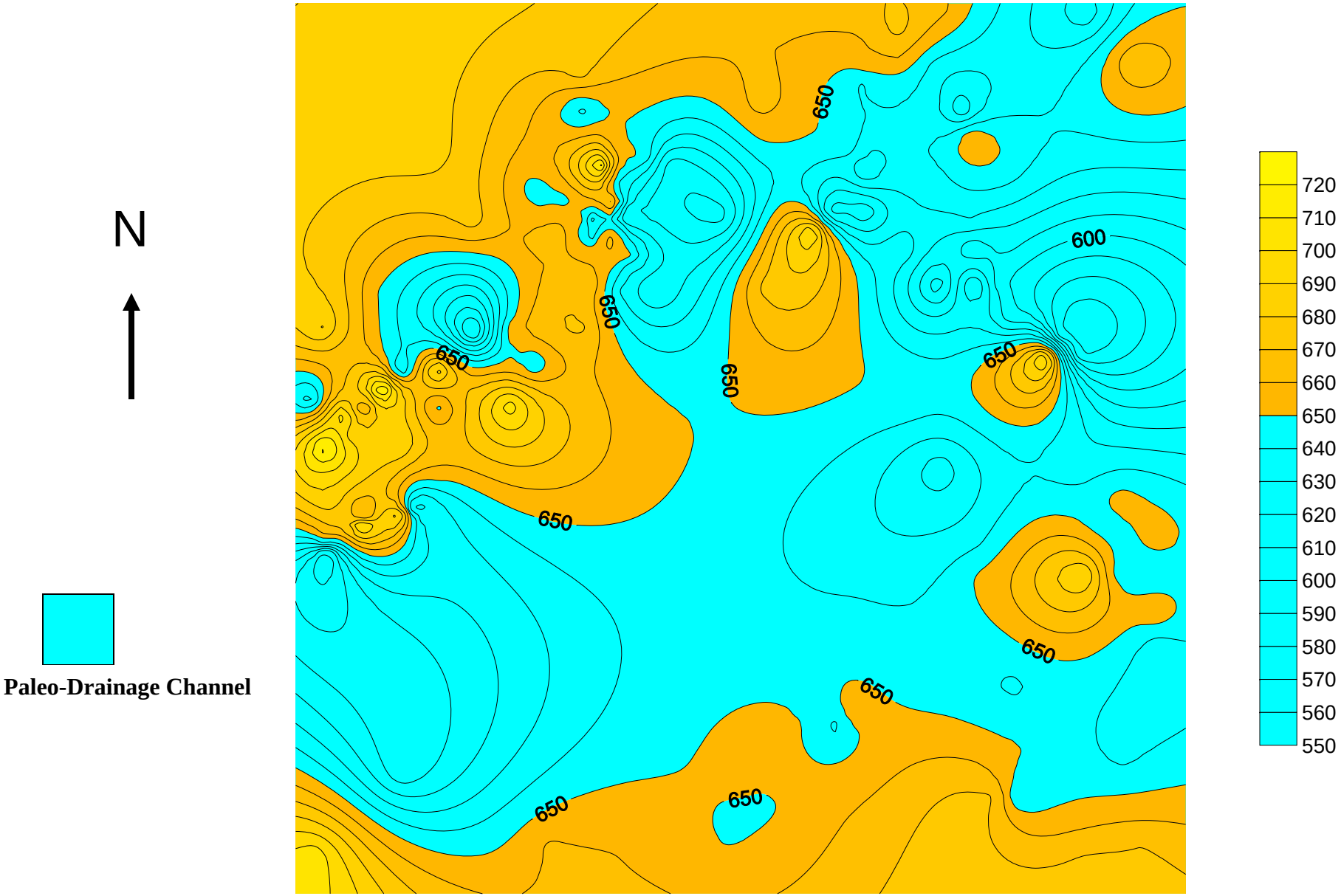

Figure 2 Bedrock Topography Showing Possible Paleo-Drainage Channel

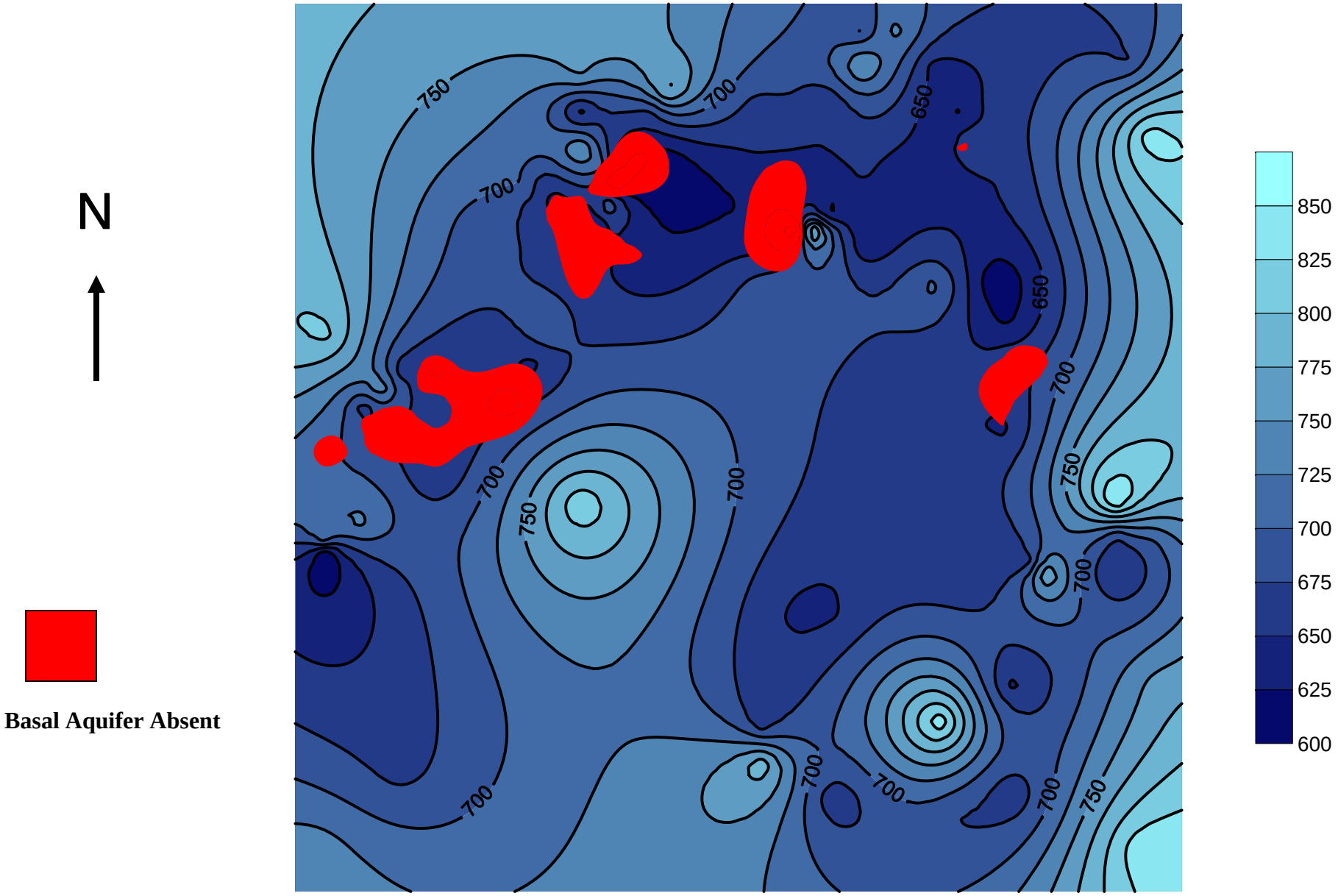

Figure 3 Basal Aquifer Topography Showing Areas Where Basal Aquifer is Absent

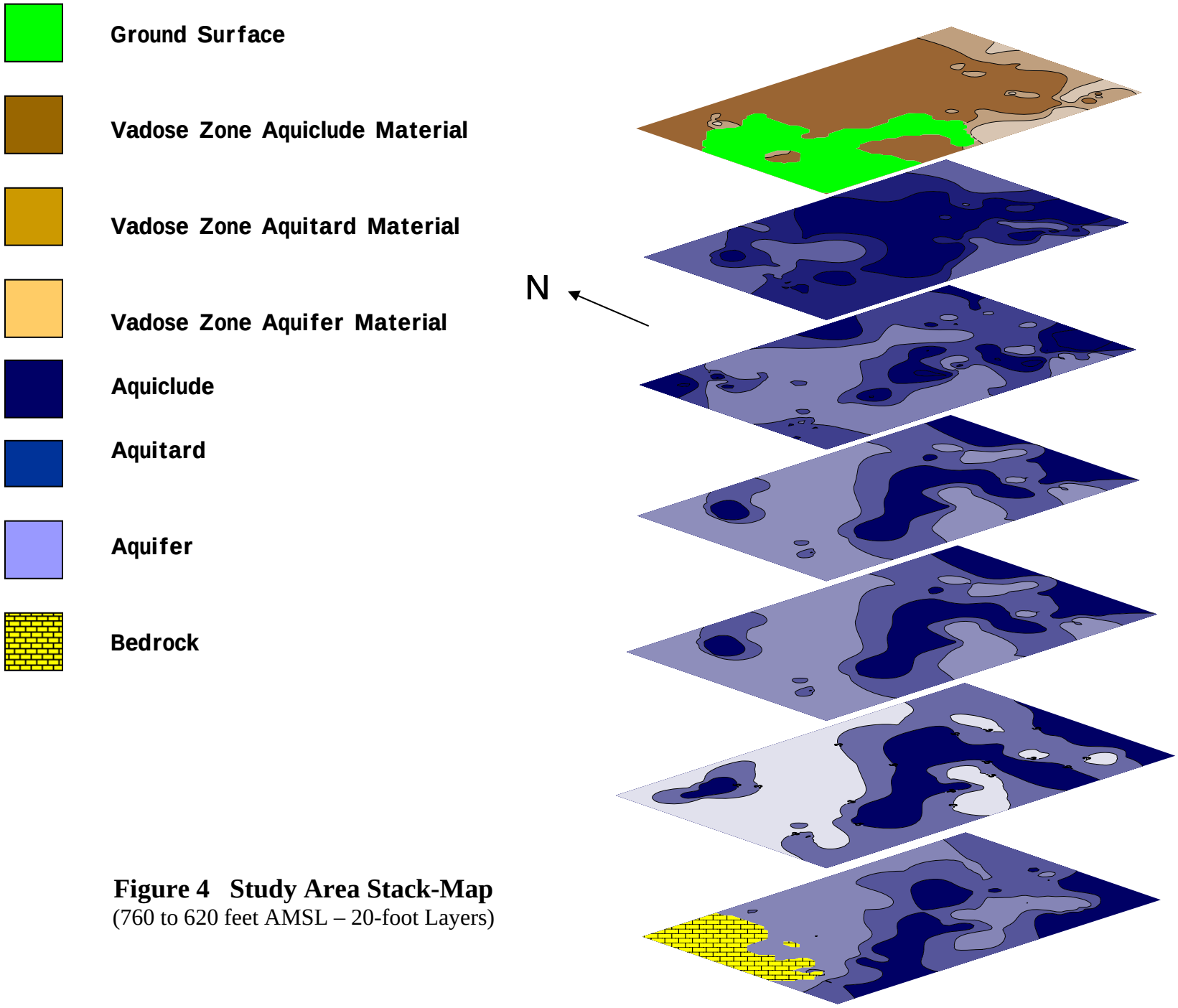

Figure 4 Study Area Stack-Map
(760 to 620 feet AMSL – 20-foot Layers)

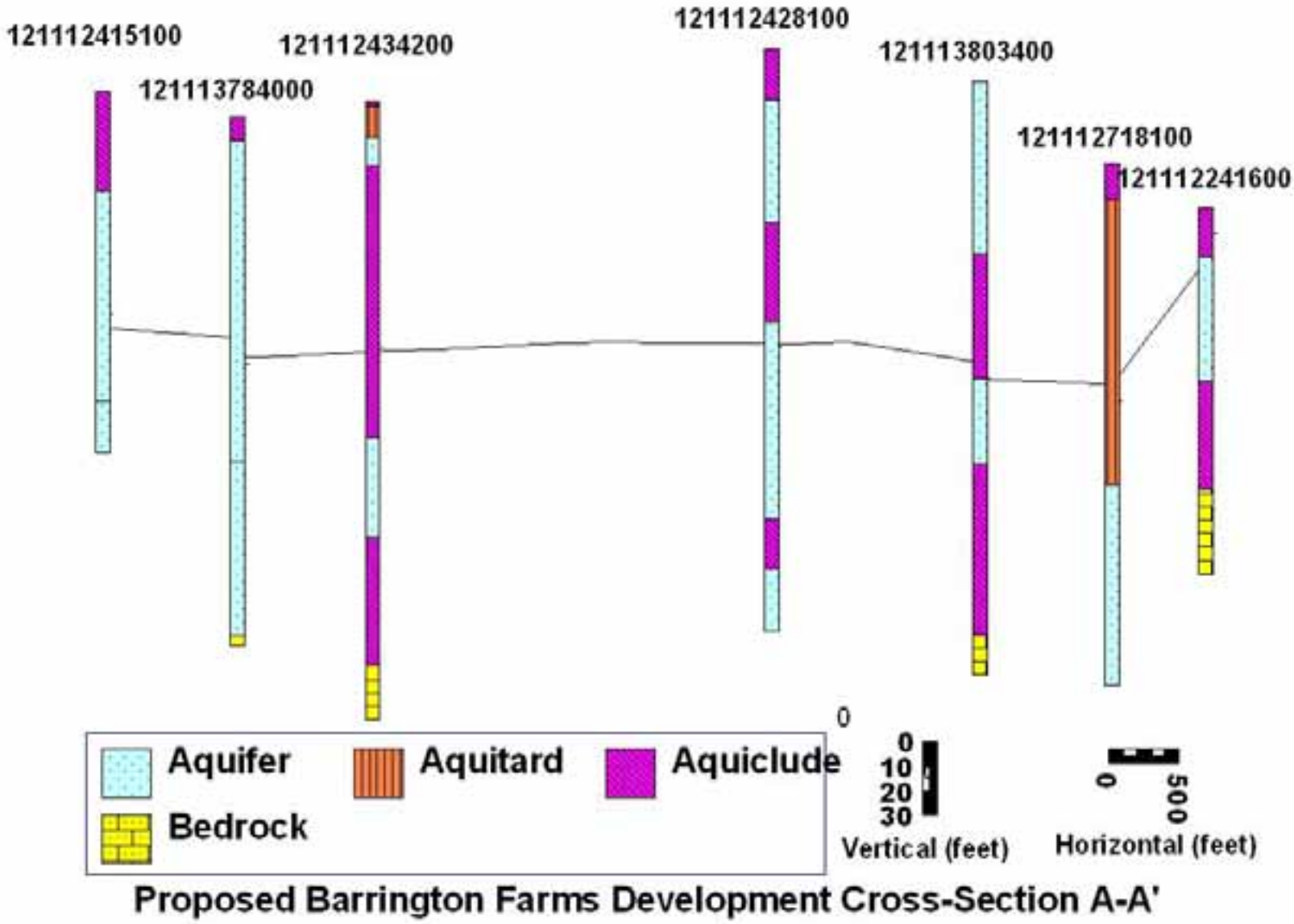

Figure 5 Example of a Cross-Section Used in a Site Specific Study

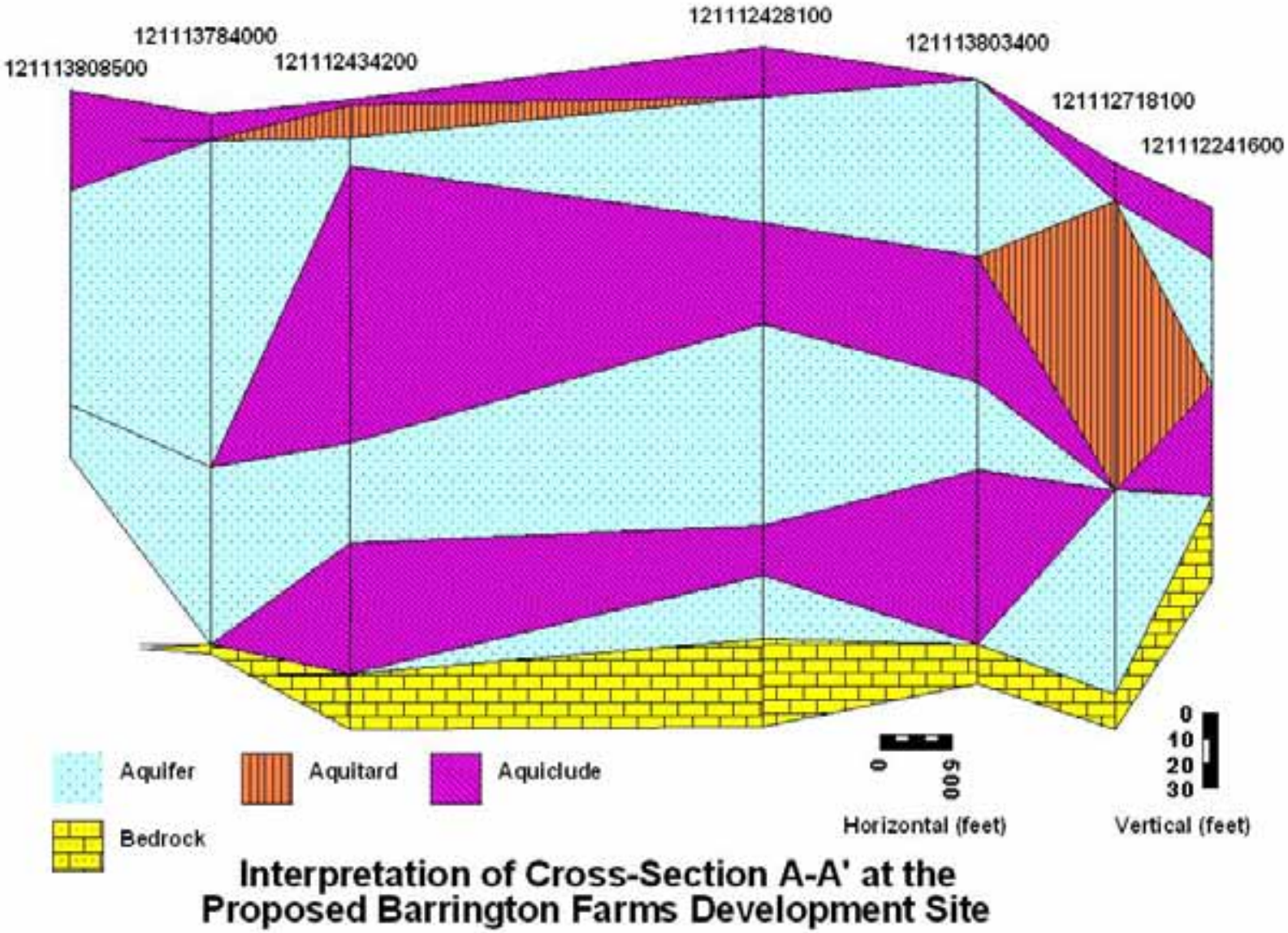

Figure 6 Example of a Cross-Section Used in a Site Specific Study

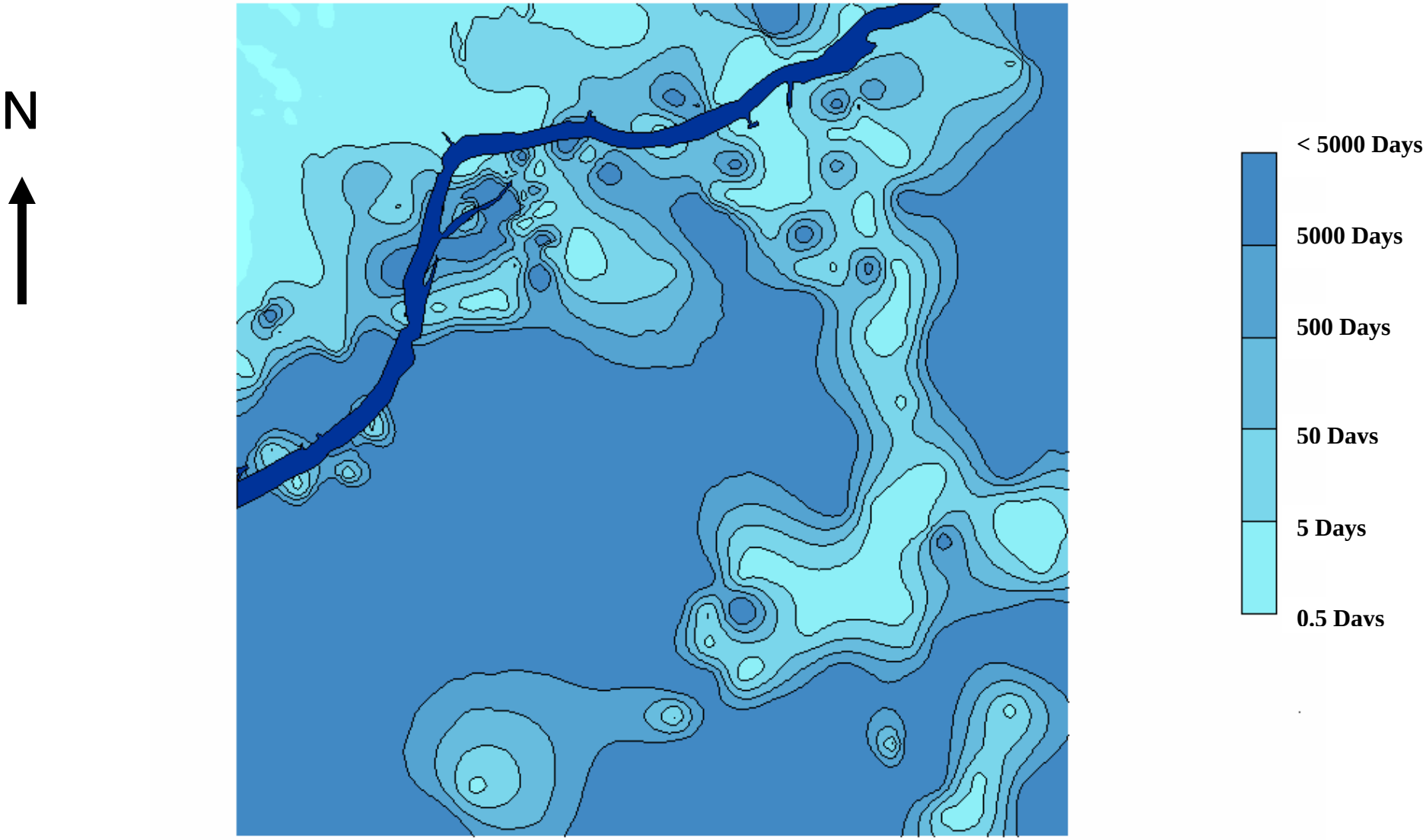

Figure 7 Estimated Relative Time-of-Travel for Recharging Water to Reach Uppermost Aquifer Material