Identification of Groundwater Recharge Areas Using Readily Available Data

Over the past decade the public has become more and more aware of problems with groundwater resources. Groundwater problems mostly concern the quantity and quality of the supply; therefore, the importance of recharge and the susceptibility of groundwater to contamination are of major interest. This paper describes data querying and subsequent mapping techniques used to establish groundwater recharge areas. Hydrogeologic characteristics that make recharge areas important to re-supplying groundwater also make these areas very susceptible to contamination. Readily available soil information and well log data were queried to define the distribution of surface soils and the materials underlying the soils horizon. In addition, the materials between the surface and the uppermost aquifer and the depth of the aquifer were also established. The water transmission characteristics (hydraulic conductivity) were used to determine rates at which water could travel from the surface to the uppermost aquifer. A five-part scale was established to facilitate the identification of areas that exhibited high recharge/susceptibility to contamination characteristics to those that exhibited low characteristics.

1.0 BACKGROUND

The Barrington Area Council of Governments (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:

- Barrington
- Lake Barrington
- Tower Lakes
- Barrington Hills
- North Barrington
- Cuba Township
- Deer Park
- South Barrington
- Barrington Township

Politically, BACOG's jurisdiction covers portions of four counties:

- Cook
- Kane
- Lake
- McHenry

All the BACOG members have independent governing bodies. The area is a unique regional community with a central business district and village atmosphere surrounded by semi-rural countryside residential areas and extensive acreage in wetlands, forest preserves, parks, agriculture. As a regional planning organization, BACOG's primary functions are to promote the regional comprehensive land use plan and protect environmental resources, for the greater good and preservation of the community.

Groundwater is the lifeblood of the BACOG area. Residents are dependent primarily on the shallow aquifer (the aquifer system that lies above bedrock), and within that, primarily the shallower layers of the shallow aquifer, for all water needs. Only the central "hub" village of Barrington, Tower Lakes, and small sections of the other communities offer public water or sewer. The countryside communities require well and septic systems that utilize the shallow aquifer and large lot zoning (one or more acres) that are necessary for proper functioning of those systems. With very few exceptions, public water is not offered or planned for the area, and only those areas currently served contain the infrastructure required for public utilities. Publicly provided water is metered, but most other water consumption is not measured or estimated. Any threat to the quantity or quality of water in the aquifers would threaten the community structure, the public health, safety and welfare, and the ability of families and businesses to survive.

Recognizing these concerns, in early January 2001 BACOG proposed to the member villages a study of groundwater resources. The Executive Board agreed and authorized the Water Resources Initiative (WRI) and the formation of a Water Resources Committee (WRC) to begin a study. The WRC is entirely staffed by volunteers and includes advisory members from the Illinois State Water Survey, the Lake County Health Department, and a private environmental consulting firm. In addition to representatives from all the BACOG villages and a number of county boards and townships, members also include representatives of conservation and community organizations. Under the direction of the BACOG Executive Director, the Water Resources Committee conducted its first meeting in April 2001, providing educational materials and presentations for its members for the first few months. The Committee began identification of local groundwater issues, data collection, research, and structuring of the project later that year. Since then work has continued through regular meetings of the committee and its five subcommittees.

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, will be 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).

Since the footprint of the communities that comprise the BACOG area is irregular, a boundary was drawn around the extent of the seven communities to establish the BACOG area for the purposes of this study. The extent of the BACOG area for the water project is approximately 175 square miles (Figure 1). A six-mile wide buffer was established around the BACOG area to identify the entire BACOG study area. This buffer zone was included to insure that the system characteristics at the border of the BACOG area can be established. The complete BACOG study area contains about 600 square miles.

The groundwater system in this study area includes the unconsolidated sand and gravel water-bearing units (aquifers) located in the glacial drift (material deposited by glaciers) as well as the uppermost bedrock immediately underlying the glacial drift. The bedrock unit is a Silurian dolomite/limestone and is located at 150 to 350 feet below the ground surface. One to five aquifers may be present at any given location within this study area (Meyer, 1998). These units may be interconnected or they may be separated by impermeable (aquicludes) or semi-permeable units (aquitards) of glacial till (fine materials deposited by glaciers). Therefore, these units may exhibit unconfined, semi-confined or confined hydraulic conditions.

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.

Since the interest of this study lies in the location and flow characteristics of water, geological formation descriptions, while of interest, are not required to define the shallow aquifer system. A numerical technique that is objective and compatible with computer analytical techniques was developed to determine the intermediate stratigraphy of the sub-area. As it turned out, the same technique could be used for establishing the entire sub-area stratigraphy between the bedrock surface and the ground surface including the basal aquifer.

2.0 STRATIGRAPHIC MAPPING

The materials composing the stratigraphic units in the sub-area are clay, sand, gravel and cobbles as mentioned before. Silt has not been included because when a geologist describes borehole soil samples, the difference between clay and silt cannot be discerned with the naked eye. The term “boulders” is commonly used in well log descriptions. Boulders are large rocks that would stop drilling operations. Since the well logs do not include notes saying that the boulders were drilled through, or that the borehole was relocated, it was assumed that the boulders were small enough to be pushed aside by continued drilling making the rocks small enough to be cobbles rather than boulders. Therefore, whenever the term “boulders” was encountered in a well log, “cobbles” was substituted.

When stratigraphic units are composed of materials of varying particle sizes (clay, sand, gravel, and cobbles), void spaces exist between particles. Collectively, the volume of void spaces of a stratigraphic unit is its porosity. Porosity is important because the void spaces are where the water is found. The smaller the particle size of the material composing a unit (such as a clay unit) the higher the porosity. On the other hand, the same characteristic of a clay unit gives it a low permeability. Permeability is the property of a soil that allows it to transmit water. A saturated clay unit holds a lot of water but water has difficulty flowing through it because of friction and the electrostatic forces associated with the soil particles. Closely related to permeability is hydraulic conductivity. Hydraulic conductivity is a measure of the ability of water to flow through a soil unit.

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 soil types present in the shallow aquifer system (Sanders, 1998).

Soil Material	**$\log_{10}$ K (cm/sec)**
Clay	-7.5
Silt	-5.0
Sand	-3.0
Gravel	1.0
Cobbles	3.0

Table 1 Average Hydraulic Conductivity (K) of Soil Materials

A technique called stack-unit mapping (ISGS, 1995 and Stumpf, Hansel and Burnhardt, 2004) was used to define the stratigraphy of the shallow aquifer system. Using this technique, the sub-area was divided into 20-foot vertical sections that extended from below bedrock and through the surface. For instance, the 680 to 700-foot layer or stack is a 20-foot layer extending over the entire sub-area at a level from 680 to 700 feet above mean sea level (AMSL). Twenty-foot layers above and below this layer are stacked together to depict the stratigraphy of the sub-area.

The distribution of the hydraulic conductivity of the soils within the layers is the characteristic that is used to define the stratigraphy. Within each layer, an average vertical hydraulic conductivity is determined for each well location. The average hydraulic conductivities are then contour mapped, creating a map showing the average distribution of soil hydraulic conductivities for the layer. This distribution represents the characteristics of the 20-foot layer. These layers are stacked together to yield the soil distribution of hydraulic conductivity of the entire sub-area.

Using the 680 to 700-foot layer as an example, the first task was to query all the wells in the sub-area bedrock wells database to identify and isolate the 680 to 700-foot layer for each well. The first step was to convert the top depth and bottom depth of each strata or formation to its elevation AMSL. The first query was set up to find all strata with a top elevation of greater than 680 feet and with a bottom elevation of less than 700 feet. As a result of this query, most strata selected did not have a top elevation of 700 feet and a bottom elevation of 680. For example, a more typical occurrence was 714 feet for a top elevation and 651 feet for a bottom elevation, for example. This meant that the soil material between elevations 714 and 651 feet was the same. Therefore, the next step was to change the elevations to 700 and 680 feet respectively.

Occasionally the query identified multiple strata occurring within a 20-foot interval, such as 709 to 694 feet for a top unit, followed by a unit from 694 to 687 feet, and a third unit 687 to 671 feet. In this case the 709 feet was changed to 700 feet and the 671 feet was changed to 680 feet resulting in a 20-foot layer having three sub-layers. Figure 2 is a portion of the spreadsheet used to determine the distribution of the soil hydraulic conductivity for the 680 to 700-foot stack. Column E contains the description of the formation as recorded in the well log for each location. Columns F and G record the top and bottom elevations for each formation. In most cases these are 700 and 680 feet respectively. Elevations other than these indicate wells that have sub-strata in the 20-foot interval from 680 to 700 feet.

The next query addressed the composition of the soils in each layer or sub-layer. As can be seen by reviewing Column G in Figure 2, most of the strata are made up of varying amounts of clay, sand, and gravel. Column G was queried using the terms clay, sand, and gravel individually or in combination to determine strata composition. The first term encountered in a description was placed in Column H, the second in Column I, and the third in Column J. Cobbles were rarely found; if found, they would be placed in Column K and information in subsequent columns would be shifted to the right.

After Columns H, I, and J were completed, the soil terms in each column were replaced with their respective average hydraulic conductivity value taken from Table 1. These values are shown in Figure 2. Average hydraulic conductivity values were calculated for strata having more than one soil in its composition and/or strata having sub-strata. Final strata hydraulic conductivity values are listed in Column L (Figure 2). For strata having only one soil type, the average hydraulic conductivity value was moved directly from Column H to Column L. All other strata required manipulation of the data to arrive at the average hydraulic conductivity for the strata.

Description	Interpretation
“equal” (“and” or x, y)	0.5x + 0.5y
3 “equal” components	0.3x + 0.3y + 0.3z
Adjective (such as, “sandy”)	0.4x + 0.6y
“with”	0.3x + 0.7y
“some”	0.2x + 0.8y
“trace”	0.1x + 0.9y
- where x, y, z are average Ks of included soils	

Table 2 Interpretations of Strata Descriptions Used to Calculate Average Ks

Table 2 is a summary of the interpretations of strata and sub-strata descriptions used to determine the average hydraulic conductivity of the strata or sub-strata in question. For instance, line 15 (Figure 2) describes the stratum as “sand & gravel.” Using the information from Tables 1 and 2, the calculation of the average hydraulic conductivity of the stratum would be:

$$K = 0.5(-3.00) + 0.5(1.00) = -1.00$$

This value was placed in Column L because it describes the entire stratum.
The average hydraulic conductivity of the stratum would be –1.00 cm/sec.

Line 17 describes a sub-stratum composed of three types of soil. The description is, “silty fine sand & clay, reddish.” The sub-stratum hydraulic conductivity would be calculated by:

$$K = 0.2(-5.00) + 0.3(-3.00) + 0.5(-7.50) = -5.65$$

In this example, there are three types of soil, but only two parts: silty sand and clay. Therefore, the stratum contains 50 percent silty sand (a 40/60 percent combination) and 50 percent clay.

Another example is line 12 that describes the stratum as “clay, blue, mixed with gravel.” The average hydraulic conductivity for this stratum would be:

$$K = 0.7(-7.50) + 0.3(1.00) = -4.95$$

This value was placed in Column K because it is the average hydraulic conductivity of a sub-stratum and is an intermediate calculation. A review of lines 11 through 13 indicates that the 20-foot stratum contains sub-strata having average hydraulic conductivities of -7.50, -4.95, and –7.50 respectively. The sub-strata average hydraulic conductivities are proportioned over the 20-foot layer as follows:

$$K = (((700-695)/20)*-7.50) + (((695-684)/20*-4.95)) + (((684-680)/20*-7.50)) = -6.10$$

The combined average hydraulic conductivities of the sub-strata yield an average hydraulic conductivity of the 680 to 700-foot layer of –6.10 cm/sec at the given location.

The values in Column L, combined with their respective well locations were used to create a contour map showing the distribution of the average soil hydraulic conductivity in the 680 to 700-foot layer across the sub-area (Figure 3). This distribution was modified to represent the hdrogeologic units (aquifer, aquitard, and aquiclude) using the information in Table 3 and is presented in Figure 4 (Sanders, 1998).

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

Table 3 Definition of Hydrologic Units Based on Average Hydraulic Conductivity

At this time, not all of the layers in the sub-area have been defined. Figure 5 is an example of stack-unit mapping using three layers that have been completed.

3.0 RECHARGE POTENTIAL

As mentioned earlier, the BACOG study area includes portions of four counties: Cook, Kane, Lake, and McHenry. Soil surveys have been conducted in all four counties by the Soil Conservation Service (now an entity of the Natural Resource Conservation Service (NRCS) of the U. S. Department of Agriculture (USDA)), (USDA, 1970, 1979a, 1979b, and 2002). These surveys identified, described, characterized, and mapped the soils of each county. This information was used in conjunction with stratigraphic information to establish recharge characteristics and identify important recharge areas.

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 in Section 3.0. 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, their hudrologic soil groups and the range of hydraulic conductivities for each group.

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. The resulting a map contained polygons of water transmission characteristics from high to low with intermediate levels of moderate high, moderate, and moderate low. This map became the basis for determining the recharge areas. Table 4 describes the characteristics of the recharge potential zones. Figure 6 is the distribution of the recharge hydraulic conductivity and Figure 7 shows the recharge potential zones.

Recharge Zones	**Log_{10} K (cm/sec)**
High	Greater than – 0.50
Moderate High	- 1.66 to – 0.50
Moderate	- 3.23 to – 1.65
Moderate Low	- 4.84 to – 3.22
Low	Less than – 4.84

Table 4 Recharge Potential Zones

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Figures

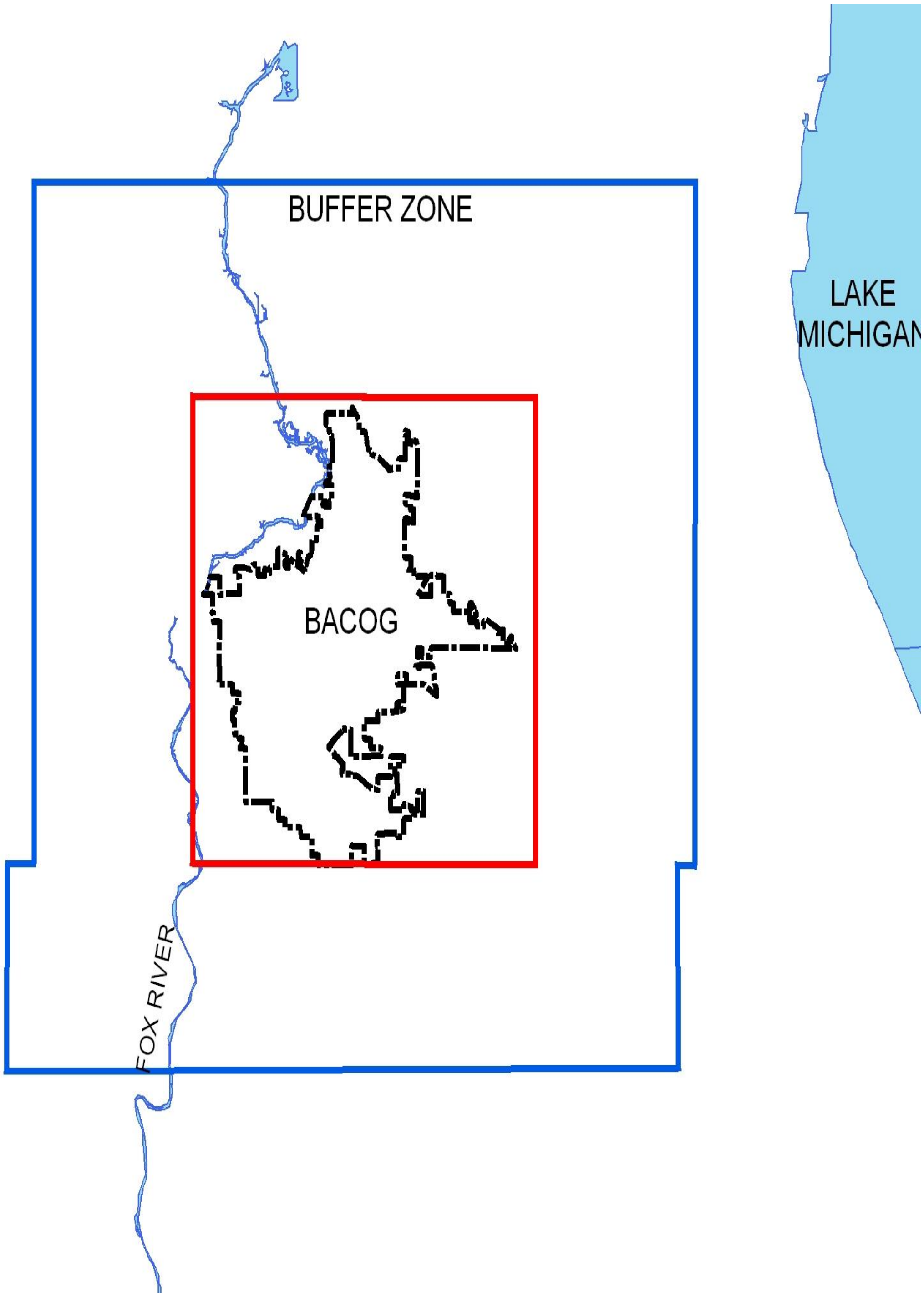
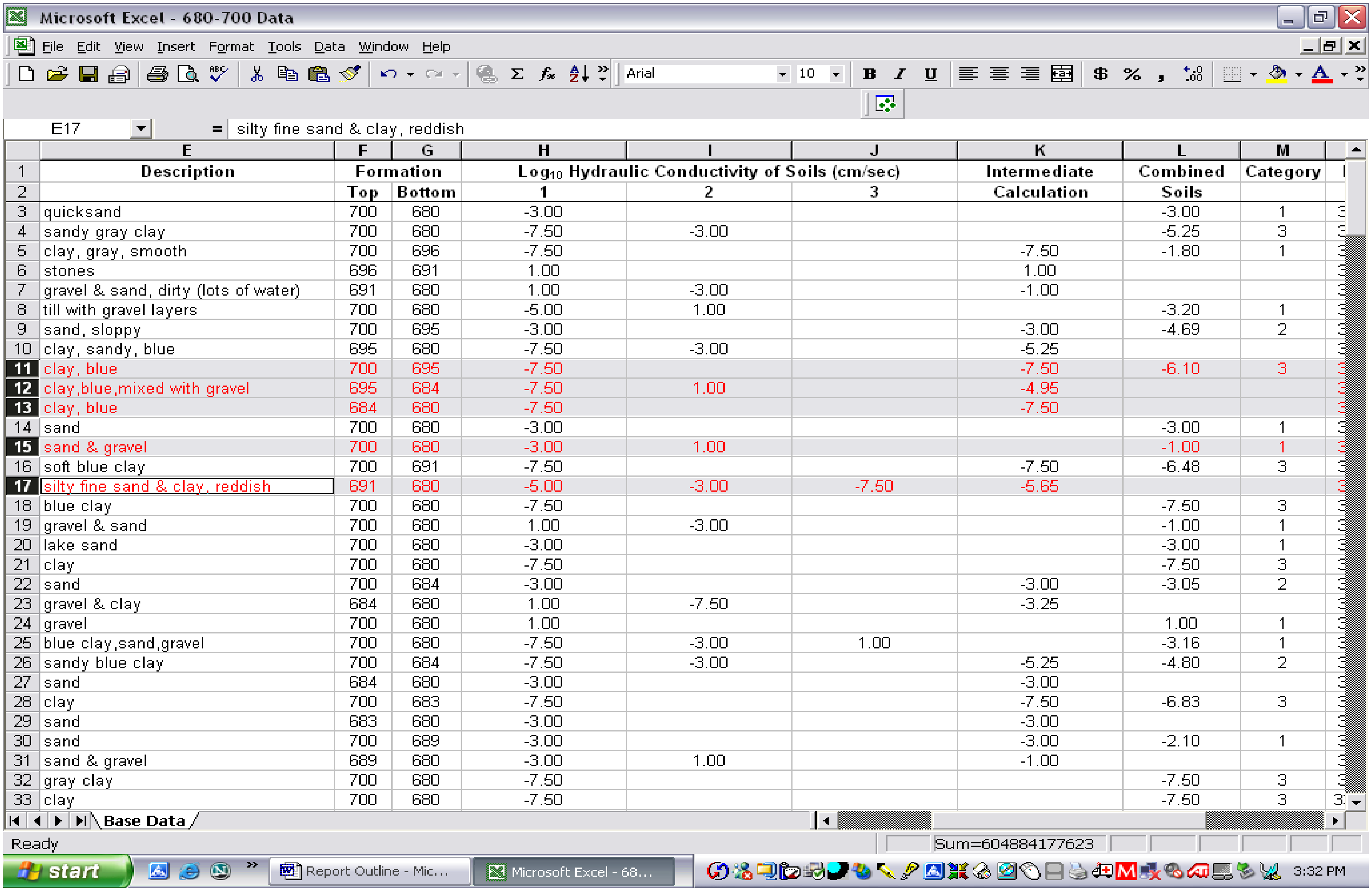


Figure 1 BACOG Study Area



E17 = silty fine sand & clay, reddish

	E	F	G	H	I	J	K	L	M
1	**Description**	**Formation**		**Log$_{10}$ Hydraulic Conductivity of Soils (cm/sec)**			**Intermediate**	**Combined**	**Category**
2		**Top**	**Bottom**	**1**	**2**	**3**	**Calculation**	**Soils**	
3	quicksand	700	680	-3.00				-3.00	1
4	sandy gray clay	700	680	-7.50	-3.00			-5.25	3
5	clay, gray, smooth	700	696	-7.50			-7.50	-1.80	1
6	stones	696	691	1.00			1.00		
7	gravel & sand, dirty (lots of water)	691	680	1.00	-3.00		-1.00		
8	till with gravel layers	700	680	-5.00	1.00			-3.20	1
9	sand, sloppy	700	695	-3.00			-3.00	-4.69	2
10	clay, sandy, blue	695	680	-7.50	-3.00		-5.25		
11	clay, blue	700	695	-7.50			-7.50	-6.10	3
12	clay,blue,mixed with gravel	695	684	-7.50	1.00		-4.95		
13	clay, blue	684	680	-7.50			-7.50		
14	sand	700	680	-3.00				-3.00	1
15	sand & gravel	700	680	-3.00	1.00			-1.00	1
16	soft blue clay	700	691	-7.50			-7.50	-6.48	3
17	silty fine sand & clay, reddish	691	680	-5.00	-3.00	-7.50	-5.65		
18	blue clay	700	680	-7.50				-7.50	3
19	gravel & sand	700	680	1.00	-3.00			-1.00	1
20	lake sand	700	680	-3.00				-3.00	1
21	clay	700	680	-7.50				-7.50	3
22	sand	700	684	-3.00			-3.00	-3.05	2
23	gravel & clay	684	680	1.00	-7.50		-3.25		
24	gravel	700	680	1.00				1.00	1
25	blue clay,sand,gravel	700	680	-7.50	-3.00	1.00		-3.16	1
26	sandy blue clay	700	684	-7.50	-3.00		-5.25	-4.80	2
27	sand	684	680	-3.00			-3.00		
28	clay	700	683	-7.50			-7.50	-6.83	3
29	sand	683	680	-3.00			-3.00		
30	sand	700	689	-3.00			-3.00	-2.10	1
31	sand & gravel	689	680	-3.00	1.00		-1.00		
32	gray clay	700	680	-7.50				-7.50	3
33	clay	700	680	-7.50				-7.50	3

Figure 2 Example of Stack-Unit Map Calculations

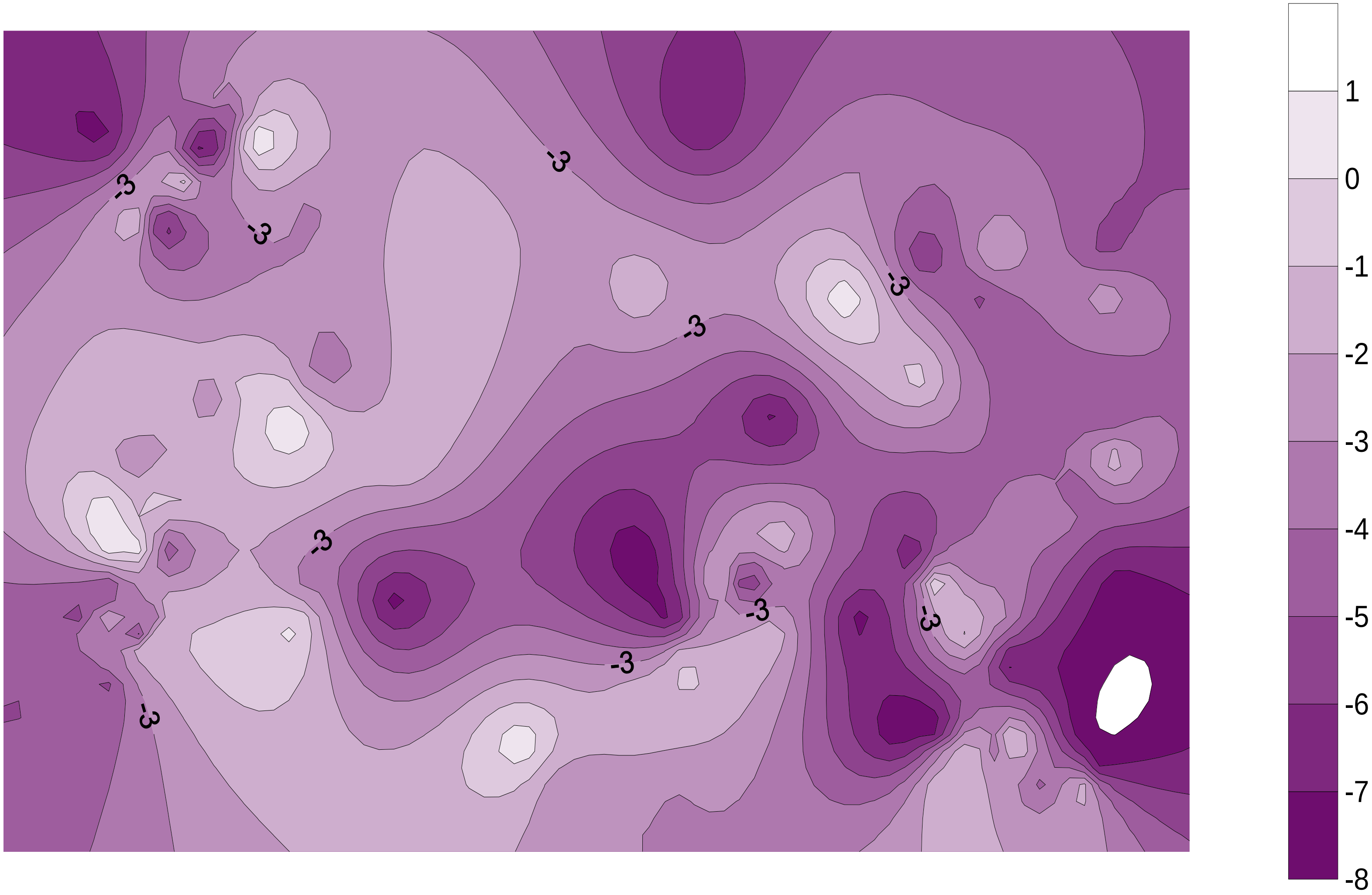
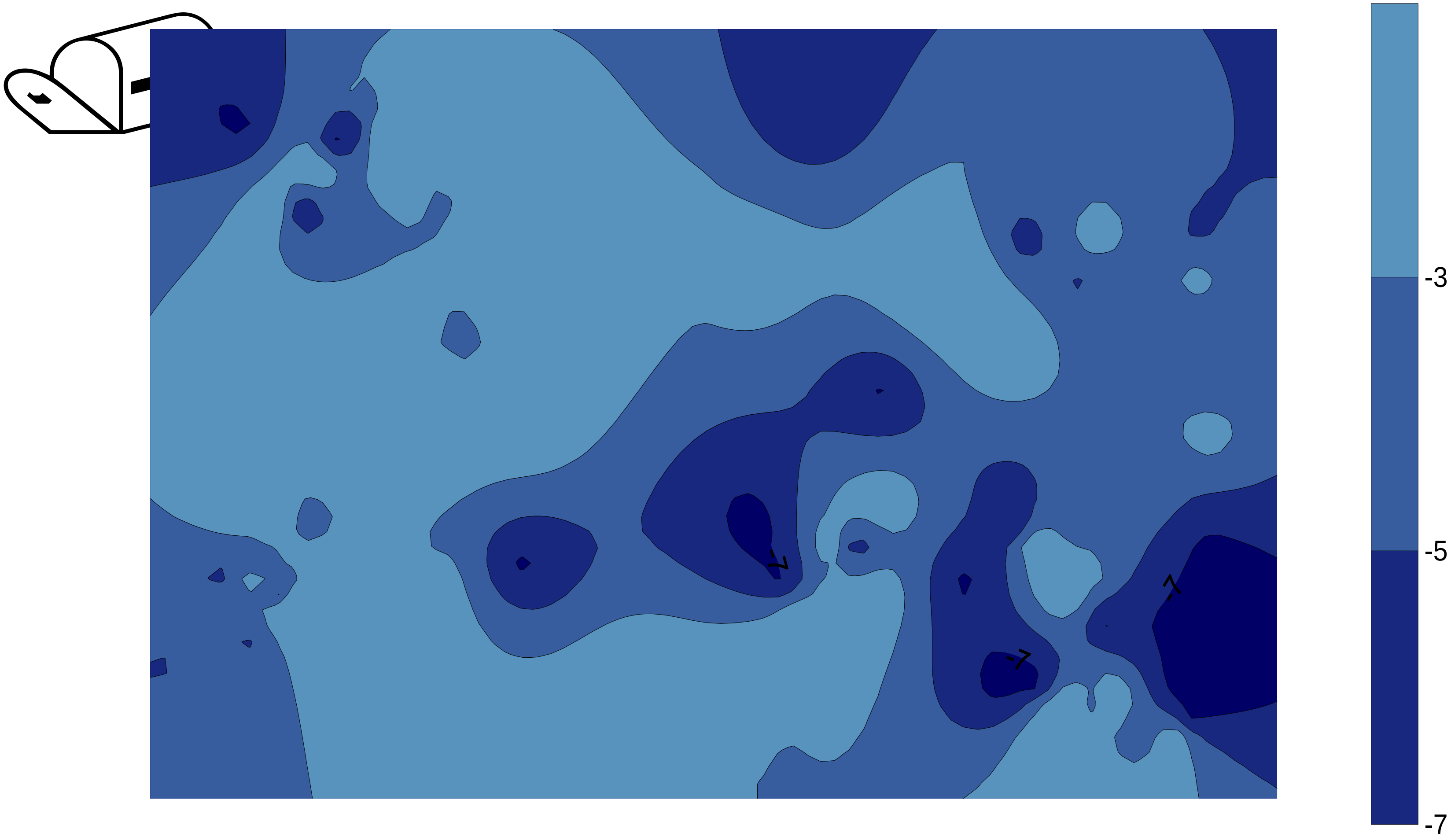


FIgure 3   Distribution of Average Hydraulic Conductivity in the 680 to 700 – Foot Layer


-7
-7
-7
-3
-5
-7

Aquifer

Aquitard

Aquiclude

Figure 4 Hydrogeologic Units Based on Distribution of Average Hydraulic Conductivity

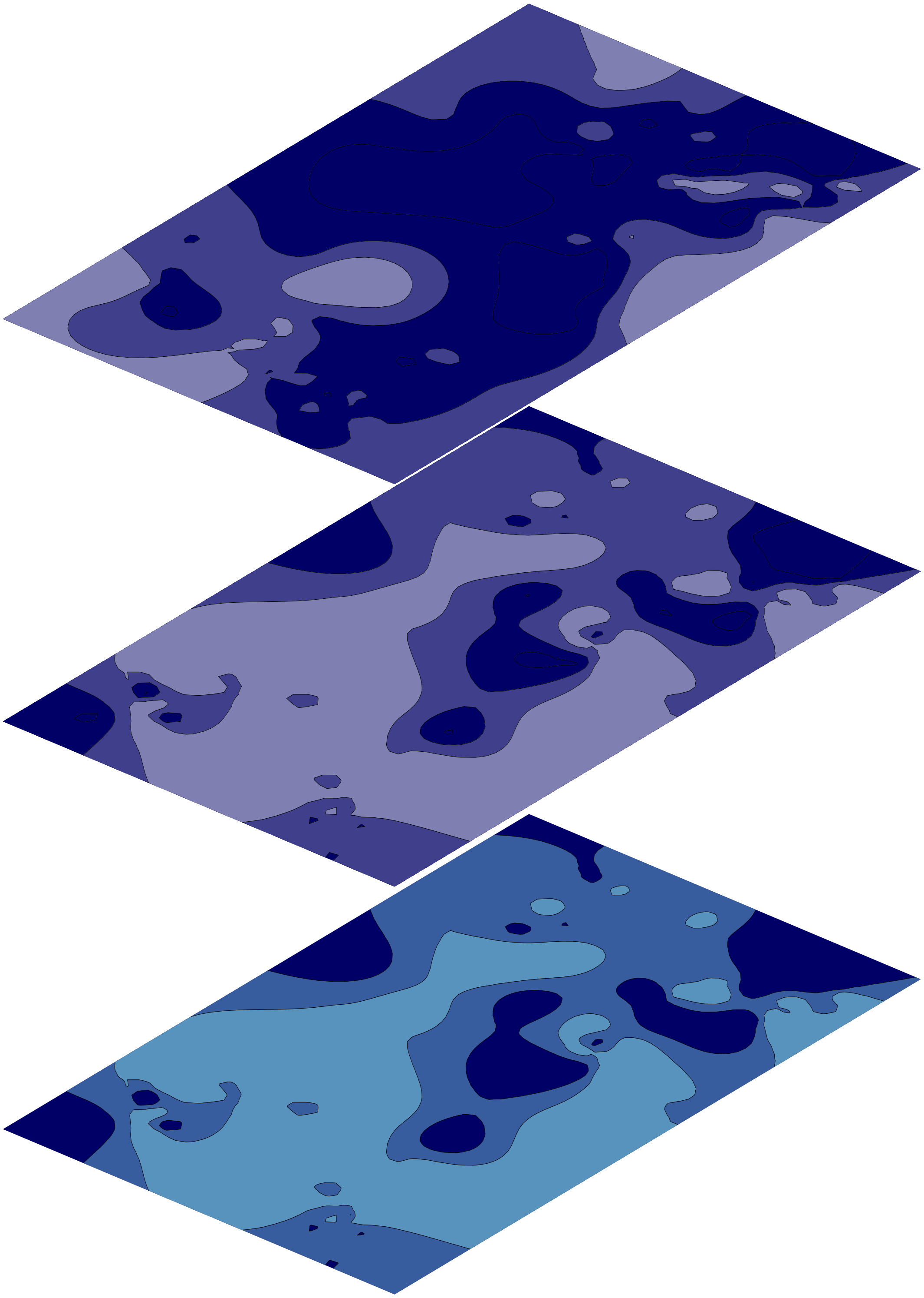


Figure 5 Partial Sub-Area Stack-Unit Map
(From Top: 740 to 720 Feet; 720 to 700 Feet; 700 to 680 Feet)

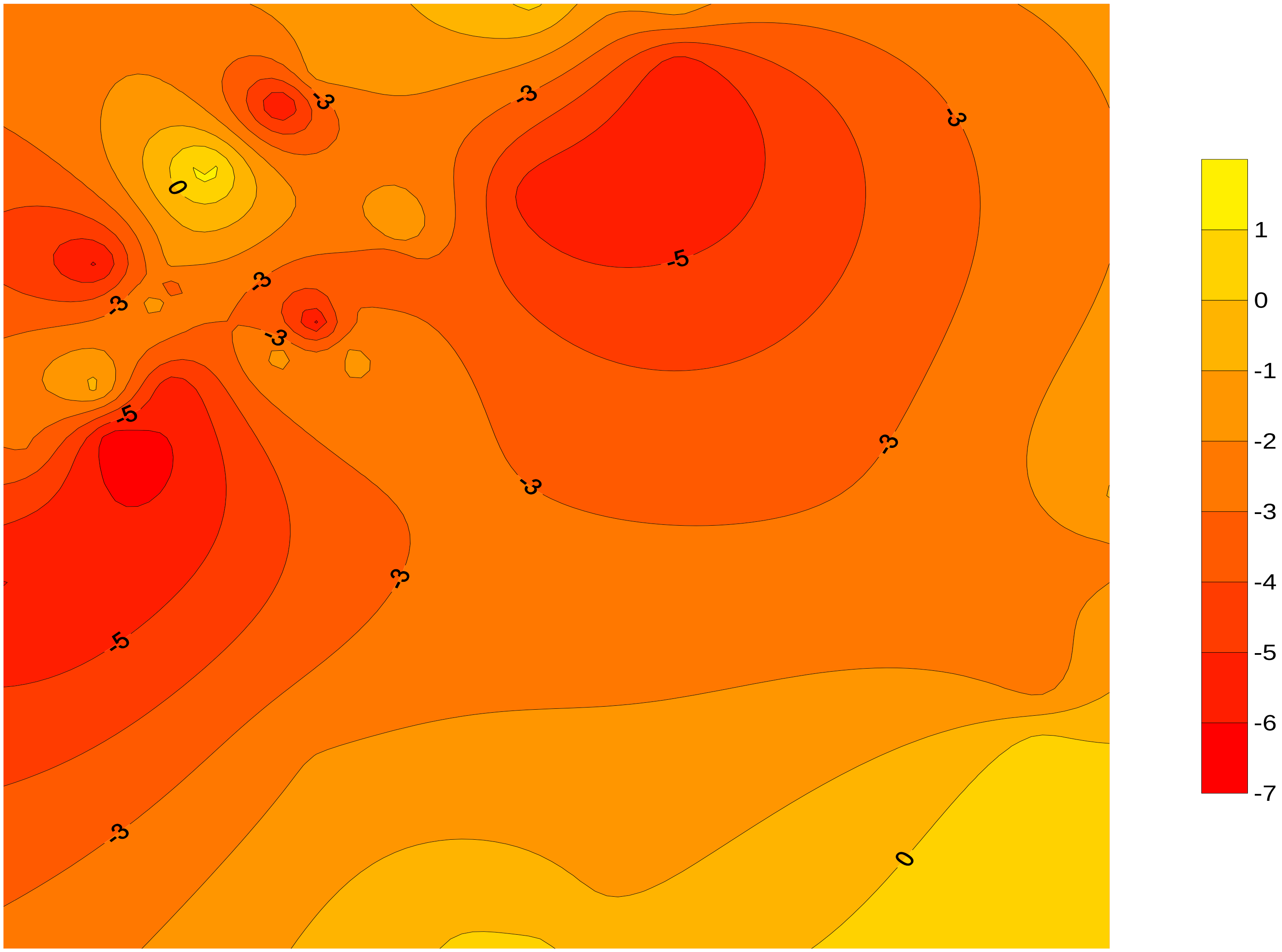


Figure 6 Distribution of Recharge Average Hydraulic Conductivity

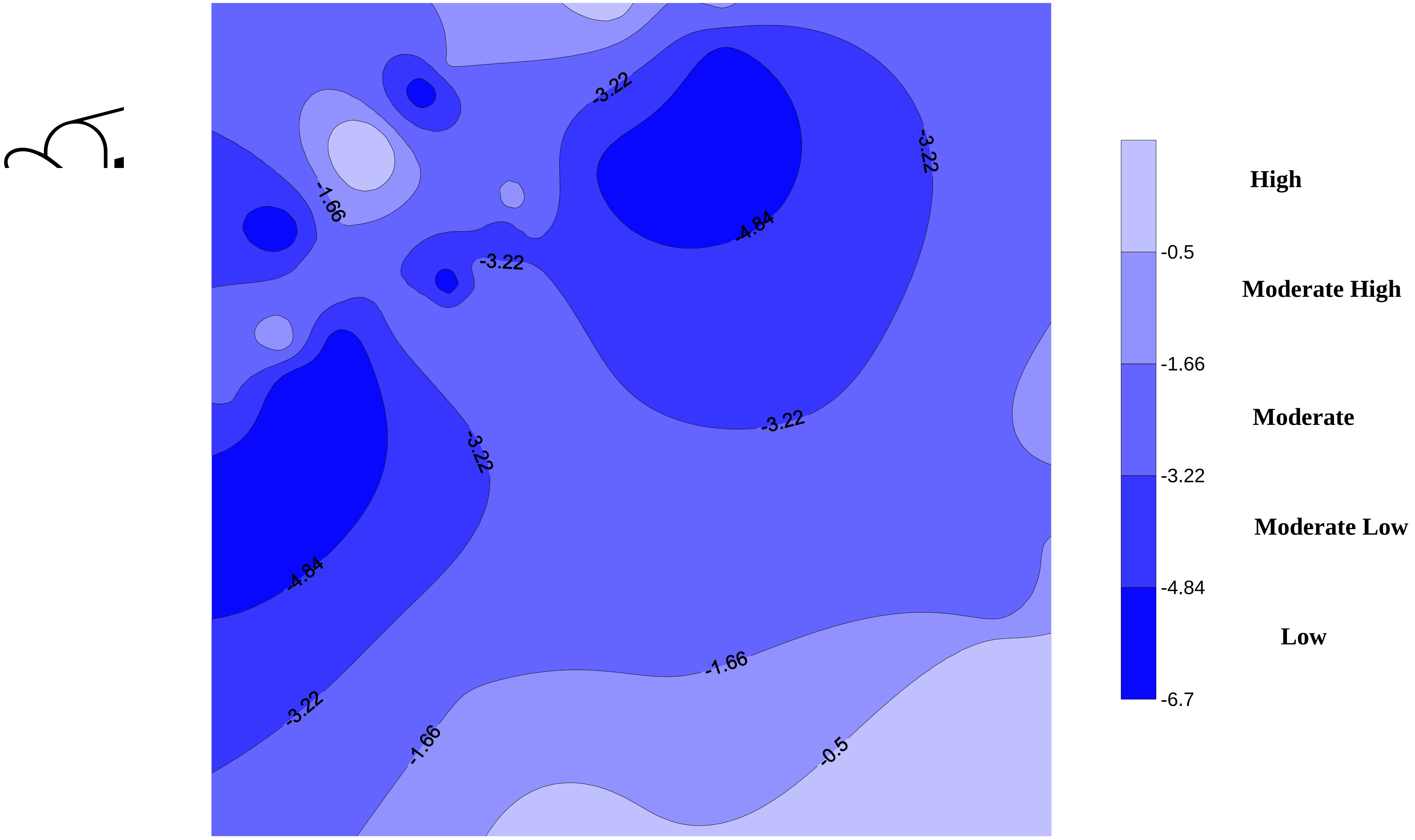


Figure 7 Recharge Potential Zones