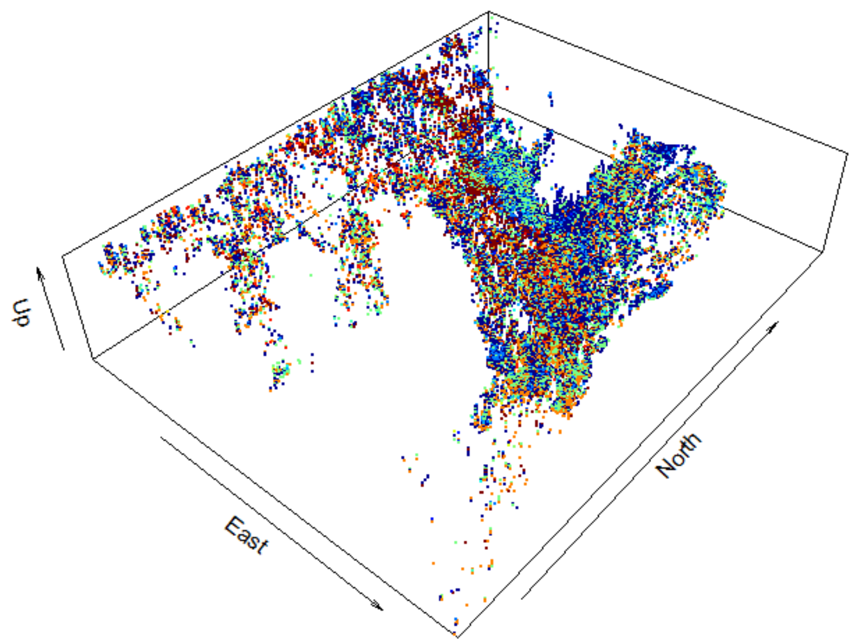
Kansas Geological Survey

Explanation of Quantitatively Interpreted Logs in the Kansas Geological Survey's WWC5 Database

Geoffrey Bohling, Brownie Wilson, Dana Adkins-Heljeson
Kansas Geological Survey
University of Kansas



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The University of Kansas

The University of Kansas, Lawrence, KS 66047 (785) 864-3965 www.kgs.ku.edu

Abstract

The Kansas Geological Survey (KGS) has long stored and served information from Kansas water well completion records in its WWC5 database. Composed primarily of records submitted by water well drillers, the database contains more than 280,000 records detailing construction and lithology information for freshwater well locations across the state. The LOGS table in this database contains near-verbatim transcriptions of the lithological logs — descriptions of the sediments and rocks encountered during drilling — contained in the forms. To date, approximately 197,500 logs statewide, containing descriptions of more than 1.3 million depth intervals, have been transcribed into this table. KGS investigators developed a process for quantitatively interpreting these logs and have been using the resulting information in the development of groundwater flow models for a number of years. We have recently added tables representing the initial steps of this quantification process to the WWC5 database to allow others to employ this information in their own studies. This report briefly explains these tables and how to access them. A companion report (in preparation) will present and document a series of scripts and programs that implement the steps used to produce these tables, along with additional processing steps, allowing others to customize the interpretation and processing of the logs.

Introduction

Since 1975, water well drillers in Kansas have been required under the Kansas Groundwater Exploration and Protection Act (KSA 82a-1201 et seq.) to submit forms containing information about completed water wells to the Kansas Department of Health and Environment. The Kansas Geological Survey is charged under the same state statute to archive and serve this information, which is done through the WWC5 (water well completion) database. Along with information regarding the well location, depth, construction details, etc., each water well completion form contains a lithologic log — a description of the sediments and rocks encountered during drilling.

WWC5 is a collection of tables stored in an Oracle relational database management system. The single-valued well characteristics (location, construction, etc.) are entered into the WELLS table and the lithologic logs are transcribed near-verbatim into the LOGS table. Both of these tables are updated continuously because of the continuing submission of new water well completion forms on top of a backlog of previously submitted forms that await processing. As of this writing, approximately 197,500 lithologic logs, containing descriptions of more than 1.3 million depth intervals, have been transcribed into the LOGS table. These logs are distributed across the state but are more strongly concentrated in the High Plains aquifer region of western and south-central Kansas, which has a significantly higher density of large capacity wells than does eastern Kansas (Figure 1). Water wells in eastern and north-central Kansas tend to be concentrated in the alluvial aquifers along river valleys.

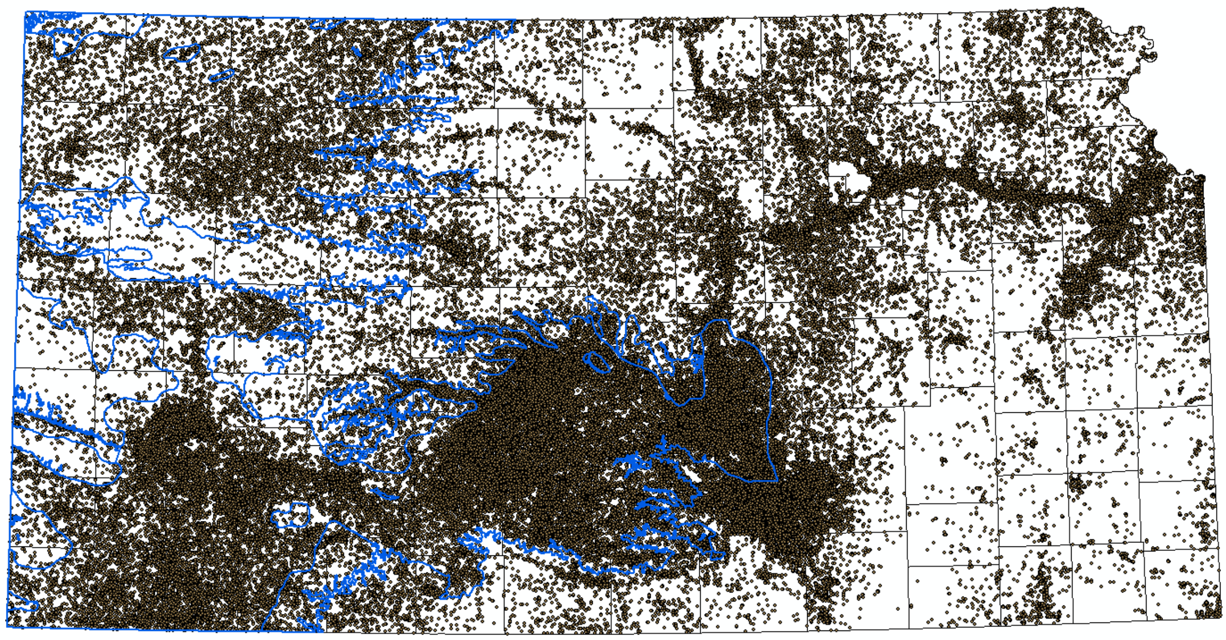

Figure 1. Locations of about 197,500 logs transcribed into the WWC5 LOGS table as of July 21, 2020. Blue outline represents extent of High Plains aquifer in Kansas.

Figure 2 shows an example lithologic log, as it appears on the water well completion form and as it appears in the LOGS table. This is a fairly atypical log with regard to the level of detail in depth and in the sediment descriptions. This log was provided by a particularly meticulous driller; most logs are much less detailed as there are no standards that submitted forms must meet. Though its level of detail is atypical, this log provides a good example of the subsequent processing steps due to its inclusion of several depth intervals containing a few distinct sediment types. It also illustrates some of the modifications made during the transcription process to try to provide more consistency among logs — for example, replacing "w/" with "with" and "strks" with "streaks." Note that scanned versions of the completion forms are included in the database so that the original version of all the submitted information is archived and publicly accessible through the WWC5 website (http://www.kgs.ku.edu/Magellan/WaterWell/index.html).

The INTERPRETED_LOGS table that we have recently added to the WWC5 schema is essentially a copy of the LOGS table with additional columns representing *standardized* and *categorized* versions of the logs. Standardization involves representing each sediment description in terms of percentages of one or more standardized lithology codes. Currently, there are 71 standardized codes. Categorization involves representing the logs in terms of percentages of five different *property* categories, representing a lumping of the 71 lithologies into groups that are expected to exhibit generally similar aquifer properties (such as hydraulic conductivity or specific yield). The next two sections of this report explain the standardization and categorization processes in more detail.

A) Original log (water well completion form)

FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	2	Surface	143	160	Clay & sandy clay w/caliche strks
2	5	Loess	160	183	Fine to some med sand w/clay lenses
5	11	Caliche w/sand strks	183	184.5	Flint
11	26	Fine sand w/caliche strks	184.5	195	Yellow ochre w/flintstone
26	30	Sand stone			
30	48	Sandstone w/clay & caliche strks			
48	73	Caliche & clay w/fine sand strks			
73	80	Fine to some med sand w/caliche & clay			
80	95	Fine sand			
95	143	Fine sand w/caliche & clay strks			

B) Transcribed log (WWC5 LOGS table)

Lithologic Log (Log data entered by KGS.)		
	From: 0 ft. **to** 2 ft.	Surface
	From: 2 ft. **to** 5 ft.	Loess
	From: 5 ft. **to** 11 ft.	Caliche with sand streaks
	From: 11 ft. **to** 26 ft.	Fine sand with caliche streaks
	From: 26 ft. **to** 30 ft.	Sandstone
	From: 30 ft. **to** 48 ft.	Sandstone with clay and caliche streaks
	From: 48 ft. **to** 73 ft.	Caliche and clay with fine sand streaks
	From: 73 ft. **to** 80 ft.	Fine to some medium sand with caliche and clay
	From: 80 ft. **to** 95 ft.	Fine sand
	From: 95 ft. **to** 143 ft.	Fine sand with caliche and clay streaks
	From: 143 ft. **to** 160 ft.	Clay and sandy clay with caliche streaks
	From: 160 ft. **to** 183 ft.	Fine to some medium sand with clay lenses
	From: 183 ft. **to** 184.5 ft.	Flint
	From: 184.5 ft. **to** 195 ft.	Yellow ochre with flint stone

Figure 2. An example lithologic log A) as it appears on the water well completion form and B) after transcription into the WWC5 LOGS table.

We conclude the introduction with a few notes:

1) The terms *standardization* and *categorization* are a little arbitrary; the corresponding processes could be described equally well using other terms (for example, *translation* and *lumping*, respectively). However, these are the terms we have chosen and have tried to use consistently in various reports on this work.

2) Currently, the INTERPRETED_LOGS table contains rows that represent only about 82% of the depth intervals contained in the LOGS table because a number of sediment descriptions have not yet been standardized. The next section discusses this issue in more detail.

3) A companion report (in preparation) will present and document a set of scripts and programs that implement the standardization and categorization processes, along with additional associated processing steps, allowing others to customize these processes to suit their own needs (for example, using a different set of standardized lithologies or a different categorization of the lithologies).

Standardization

Standardization is the process of mapping the near-verbatim sediment description for each logged depth interval, contained in the LOGS table, to one or more standardized lithology codes and the assignment of percentages associated with the standardized lithologies. For example, "brown sand with streaks of clay and a bit of gravel" might be represented as 70% snd (sand), 20% c (clay), and 10% g (gravel). This process uses a translation table that maps each unique sediment description into a standardized representation. The current translation table is included in the WWC5 database under the name TRANSLATION_TABLE. The translation table contains a list of unique sediment descriptions and, for each of those, a standardized representation. (The meaning of "unique" is discussed in the next paragraph.) The standardized representation consists of two columns containing comma-delimited lists, one specifying a set of percentages and the other specifying a corresponding set of lithology codes. The example given above would contain "70, 20, 10" in the percentages column and "snd, c, g" in the lithology codes column. The comma-delimited list approach allows flexibility in the representation of the descriptions, avoiding the need to set a fixed number of percentage and lithology code "slots" to use for the standardized representation of each description.

There are no rules governing how drillers describe sediments and rocks, leading to considerable variety in the descriptions. Nevertheless, many descriptions are used frequently, so that the number of unique descriptions in the LOGS table is considerably less than the number of depth intervals described. Currently, the LOGS table contains approximately 171,000 unique descriptions, even though the number of depth intervals is more than 1.3 million. Part of the process of building up the translation table has been to count the frequency of occurrence of each unique description (the number of depth intervals in which that description occurs) to prioritize their translation. The list of unique descriptions is compiled after casting all descriptions to lowercase and trimming off leading and trailing white space. Table 1 shows example rows from the current translation table, sorted by decreasing frequency of occurrence of each description. Along with representing abundant sediment types, the descriptions that occur most frequently tend to be simple. At the other end of the spectrum, tens of thousands of descriptions each represent only a single depth interval; these tend to be very detailed — for example, "brown medium to coarse sand, lots of brown clay, to fine gravel and boulders."

Table 1. Example rows from the current translation table (which contains about 26,000 rows). The table is sorted in descending order of the number of depth intervals in which each description occurs. Table 3 contains the complete list of lithology codes.

Row Number	Description	Lithology Percentages	Lithology Codes	Number of Depth Intervals
1	clay	100	c	74,798
2	top soil	100	ts	51,605
3	fine sand	100	fsnd	33,457
4	brown clay	100	c	32,080
5	shale	100	sh	28,317
45	clay and caliche	60, 40	c, ca	2,528
53	fine sand and clay	60, 40	fsnd, c	1,847
89	clay and caliche with sand streaks	50, 40, 10	c, ca, snd	1,012
256	fine to medium sand and gravel 10% clay (loose)	90, 10	fmsdg, c	300
620	clay and caliche with traces of sand	50, 40, 10	c, ca, snd	111
1,501	silty clay, medium brown	100	sc	38
5,058	medium sand with fine clay layers	70, 30	msnd, c	6
4,773	silt, soft, pale yellowish brown, damp	100	s	7
8,855	shale - blue	100	sh	2
16,804	med. to lar. sand and gravel (lost circulation)	100	mcrssdg	1
23,150	gravel with caliche and sand and clay streaks, reddish brown, poorly sorted	50, 30, 10, 10	g, ca, snd, c	1

Building the translation table is a continuing and labor-intensive process because a standardized representation of each description has to be entered by hand. The current translation table contains ~26,000 entries, leaving a backlog of ~145,000 unique descriptions still to be translated. Nevertheless, the current translation table contains entries for the descriptions that occur most frequently and is sufficient to generate standardized representations for about 82% of the depth intervals in the LOGS table.

Building the translation table is a subjective process. The degree of subjectivity involved in assigning each standardized representation varies with the degree of ambiguity of the verbatim description, which can range from quite clear to highly ambiguous. Furthermore, the current translation table contains a number of inconsistencies (for example, descriptions of the form “A and B with streaks C” are probably represented several different ways in the table) and almost certainly contains some misinterpretations and outright errors. We are looking into approaches to automate this process to make it less labor intensive and more consistent. Nevertheless, it would be impossible to make the process completely objective or correct in any absolute sense.

Another shortcoming of the current approach to standardizing the logs is that each unique description is assigned the same standardized representation in all depth intervals in which it occurs, without regard to spatial context or vertical structure. This is a particular problem for terms that could apply to materials with varying degrees of lithification. For example, the translation table entry for "sandstone" represents it as 100% ss, where "ss" is meant to represent fully lithified sandstone. However, drillers sometimes use the term "sandstone" to describe partially cemented sand, which would be better represented using the standardized lithology code "cesd/cg" (cemented sand and/or gravel). Whether "ss" or "cesd/cg" is more appropriate can only be determined by assessing the description in a spatial context, looking at nearby intervals in the same log and possibly also neighboring logs.

In KGS projects involving regional-scale aquifer modeling, we generally aggregate the information from the categorized logs within model cells (areas with dimensions of one-quarter to a few miles on a side and tens to hundreds of feet thick). Averaging over this scale will tend to reduce the effect of inconsistencies or errors in the translation table. In our experience, the "big picture" results obtained in this fashion seem to make geological sense, especially at multiple-township to sub-county scales. End users interested in characterizing smaller areas in more detail are advised to develop a customized translation table for their particular project. To that end, the standardization script described in the companion report (in preparation) essentially compiles a project-specific translation table, containing all the translation table entries actually used in processing a particular set of logs, ordered by frequency of occurrence within that set of logs (along with compiling the set of descriptions that still need to be translated). For a small area, this project-specific translation table will likely be significantly smaller than the original table, making it easier to check for quality and consistency. In addition, users are also encouraged to examine and revise the resulting standardized logs to better account for spatial context.

Table 2 shows the example log (Figure 2) with the standardized representations added. Although the assigned lithology percentages and codes provide a reasonable representation of the log overall, this example demonstrates some of the shortcomings discussed above. 1) There is perhaps some inconsistency in the representation of intervals with three distinct sediment types. 2) Two depth intervals, from 143 to 160 feet and 184.5 to 195 feet, are missing because their descriptions have not yet been translated. 3) It is likely that the "sandstone" from 26 to 30 feet should really be represented as "cesd/cg" rather than "ss" given the occurrence of "sandstone" with clay and caliche streaks in the next interval down, an association that strongly implies that the "sandstone" is actually cemented sand rather than fully lithified sandstone, along with the occurrence of caliche streaks in the interval above. Nevertheless, these minor flaws probably make little difference when this information is aggregated with that from nearby logs. For a smaller-scale study, an investigator might want to revise some of the standardized representations before moving to the next step of the process, categorization.

Table 2. Example log (Figure 2) with standardized representations (lithology percentages and codes) of each description added.

Top Depth	Bottom Depth	Description	Lithology Percentages	Lithology Codes
0	2	surface	100	ts
2	5	loess	100	s
5	11	caliche with sand streaks	80, 20	ca, snd
11	26	fine sand with caliche streaks	80, 20	fsnd, ca
26	30	sandstone	100	ss
30	48	sandstone with clay and caliche streaks	50, 30, 20	cesd/cg, c, ca
48	73	caliche and clay with fine sand streaks	50, 40, 10	ca, c, fsnd
73	80	fine to some medium sand with caliche and clay	50, 30, 20	fmsnd, ca, c
80	95	fine sand	100	fsnd
95	143	fine sand with caliche and clay streaks	50, 30, 20	fsnd, ca, c
160	183	fine to some medium sand with clay lenses	70, 30	fmsnd, c
183	184.5	flint	100	r

Categorization

Categorization is the process of converting the standardized lithology proportions in each logged interval into proportions of material in a smaller number of sediment categories. KGS modeling projects have used a set of 71 standardized lithologies and mapped them into five to eight categories, grouped according to expected ranges of aquifer properties (e.g., hydraulic conductivity or specific yield). The starting point for most of these projects has been the five-part categorization that is represented in the LITHOLOGY_CODES table in the WWC5 database. This table (shown in Table 3) contains the list of 71 standardized lithology codes, a brief description of the meaning of each code, and a number between 1 and 5 representing the category to which each lithology is assigned, with the category numbers representing a general ordering from fine- to coarse-grained (or low- to high-permeability) materials.

Table 3. WWC5 LITHOLOGY_CODES table.

LITHOLOGY_CODE	DESCRIPTION	CATEGORY
sh	shale	1
c	clay	1
coal	coal	1
br	bedrock	1
rb	red bed	1
r	rock	1
sst	siltstone	1
fsc	fine silty clay	2
fmsc	fine to medium silty clay	2
sc	silty clay	2
msc	medium silty clay	2
fcrssc	fine to coarse silty clay	2
mcrssc	medium to coarse silty clay	2
fsdc	fine sandy clay	2
fmsdc	fine to medium sandy clay	2
msdc	medium sandy clay	2
sdc	sandy clay	2
fcrssdc	fine to coarse sandy clay	2
mcrssdc	medium to coarse sandy clay	2
crssc	coarse sandy clay	2
cs	clayey silt	2
fs	fine silt	2
s	silt	2
ts	top soil	2
o	overburden	2
m	marl	2
ca	calcified material (limestone/caliche)	2
fds	fine sandy silt	3
fmds	fine to medium sandy silt	3
mds	medium sandy silt	3
sds	sandy silt	3
fcrsds	fine to coarse sandy silt	3
mcrsds	medium to coarse sandy silt	3
crsds	coarse sandy silt	3
gc	gravelly clay	3
ss	sandstone	3
csnd	clayey sand	3

Table 3. WWC5 LITHOLOGY_CODES table (continued).

LITHOLOGY_CODE	DESCRIPTION	CATEGORY
fss	fine silty sand	3
fmss	fine to medium silty sand	3
ssnd	silty sand	3
mss	medium silty sand	3
fcrsss	fine to coarse silty sand	3
mcrsss	medium to coarse sandy silt	3
crsss	coarse silty sand	3
u	unknown	3
cesd/cg	cemented sand and/or gravel	3
fsnd	fine sand	3
fmsnd	fine to medium sand	3
snd	sand	4
msnd	medium sand	4
fcrssnd	fine to coarse sand	4
fmcrssnd	fine to medium coarse sand	4
mcrssnd	medium to coarse sand	4
crssnd	coarse sand	4
cg	clayey gravel	4
sg	silty gravel	4
fsdg	fine sand and gravel	5
fmsdg	fine to medium sand and gravel	5
msdg	medium sand and gravel	5
sdg	sand and gravel	5
fcrssdg	fine to coarse sand and gravel	5
mcrssdg	medium to coarse sand and gravel	5
crssdg	coarse sand and gravel	5
fcrssg	fine to coarse sandy gravel	5
fg	fine gravel	5
fmg	fine to medium gravel	5
mg	medium gravel	5
g	gravel	5
fcrsg	fine to coarse gravel	5
mcrsg	medium to coarse gravel	5
crsg	coarse gravel	5

The category proportions in each depth interval are computed by summing the proportions of the standardized lithologies by category, as specified in the LITHOLOGY_CODES table. In the example log (Table 2), the fine sand interval from 80 to 95 feet will end up being 100% category 3, since fine sand (fsnd) falls in category 3 (Table 3). The interval from 30 to 48 feet described as “sandstone with clay and caliche streaks” has been assigned a standardized representation of 50% cesd/cg (“sandstone” interpreted as cemented sand), 30% c (clay), and 20% ca (caliche). Since c falls in category 1, ca in category 2, and cesd/cg in category 3, this interval is 30% category 1, 20% category 2, and 50% category 3. However, if the final material listed had been, for example, silty sand (ssnd) instead of caliche, the interval would have been 30% category 1 and 70% category 3, since ssnd and cesd/cg both fall in category 3.

The INTERPRETED_LOGS Table

The INTERPRETED_LOGS table in the WWC5 database contains the information from the LOGS table (interval depths and near-verbatim descriptions, along with well and depth interval ID) plus columns that contain the results of the standardization and categorization processes, two columns that represent summary measures of the category proportions, and columns that contain well coordinate information. As mentioned above, the INTERPRETED_LOGS table currently contains rows for about 82% of the depth intervals in the LOGS table, those whose descriptions match entries in the TRANSLATION_TABLE. Table 4 contains an abbreviated version of the example log (Figure 2) as it appears in the INTERPRETED_LOGS table.

The first two columns in the INTERPRETED_LOGS table, WELL_ID and INTERVAL_ID, are pointers to the primary keys in the WELLS and LOGS tables, each of which is named INPUT_SEQ_NUMBER in its respective table. That is, INTERPRETED_LOGS::WELL_ID points to WELLS::INPUT_SEQ_NUMBER (the unique identifier for each well) and INTERPRETED_LOGS::INTERVAL_ID points to LOGS::INPUT_SEQ_NUMBER (the unique identifier for each depth interval).

The next two columns in the INTERPRETED_LOGS table contain summary measures of the category percentages, namely the dominant and the average category for each depth interval. The dominant category is the category with the highest percentage in each depth interval (using the lowest-numbered category in case of a tie). The average category is the proportion-weighted average category number, $1 \cdot p_1 + 2 \cdot p_2 + 3 \cdot p_3 + 4 \cdot p_4 + 5 \cdot p_5$, where p_i represents the proportion of category i in decimal form (between 0 and 1). The average category number can be thought of as a surrogate aquifer property; the spatial distribution of any property whose value increases (or decreases) with increasing category number will look similar to the spatial distribution of average category number. This provides a means of visualizing aquifer

Table 4. Example log (Figure 2) as it appears in the INTERPRETED_LOGS table, except that the columns containing the well and depth interval IDs, verbatim descriptions, and well coordinates have been dropped from this display and column names have been modified and abbreviated. The columns "% Cat 1" through "% Cat 5" are the percentages of the five categories. The dominant category is the category with the highest percentage in each depth interval (lowest numbered category in case of a tie) and the average category is the proportion-weighted average category number (see text).

Top Depth	Bottom Depth	Lithology Percentages	Lithology Codes	% Cat 1	% Cat 2	% Cat 3	% Cat 4	% Cat 5	Dominant Category	Average Category
0	2	100	ts	0	100	0	0	0	2	2.0
2	5	100	s	0	100	0	0	0	2	2.0
5	11	80, 20	ca, snd	0	80	0	20	0	2	2.4
11	26	80, 20	fsnd, ca	0	20	80	0	0	3	2.8
26	30	100	ss	0	0	100	0	0	3	3.0
30	48	50, 30, 20	cesd/cg, c, ca	30	20	50	0	0	3	2.2
48	73	50, 40, 10	ca, c, fsnd	40	50	10	0	0	2	1.7
73	80	50, 30, 20	fmsnd, ca, c	20	30	50	0	0	3	2.3
80	95	100	fsnd	0	0	100	0	0	3	3.0
95	143	50, 30, 20	fsnd, ca, c	20	30	50	0	0	3	2.3
160	183	70, 30	fmsnd, c	30	0	70	0	0	3	2.4
183	184.5	100	r	100	0	0	0	0	1	1.0

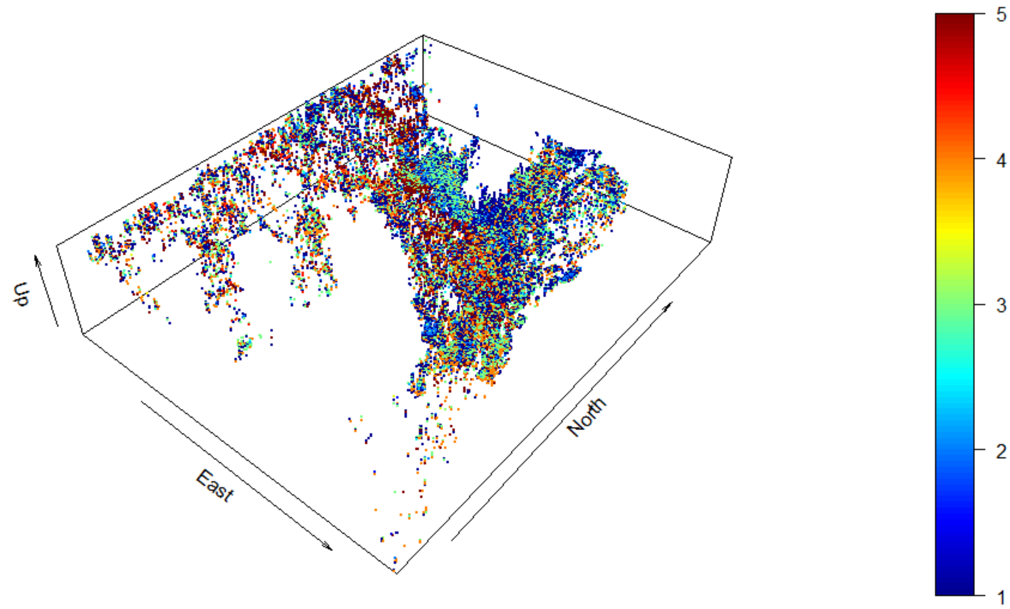

Figure 3. Proportion-weighted average category number in WWC5 logs in the High Plains aquifer in Groundwater Management District 2 (plus adjacent alluvial aquifers). Higher numbers represent coarser (more permeable) sediments. The region is 64 miles west to east, 82 miles south to north, and 620 feet in vertical extent.

characteristics in a general sense without having to explicitly assign property values to each category. As an example, Figure 3 is a three-dimensional display of average category number in Groundwater Management District 2 in south-central Kansas.

The final five columns of the INTERPRETED_LOGS table contain information regarding the well coordinates, required to place the log data in 3D space. These five columns are longitude and latitude referenced to North American Datum 1983 (NAD83_LONGITUDE and NAD83_LATITUDE), the corresponding X (east) and Y (north) coordinates (meters) in the Zone 14N Universal Transverse Mercator projection referenced to North American Datum 1983 (UTM_X_ZONE14 and UTM_Y_ZONE14), and the land surface elevation extracted from a U.S. Geological Survey digital elevation model at each well location (NED_ELEV). UTM Zone 14N covers most, but not all, of Kansas; approximately the eastern fifth of the state is in Zone 15N and a very small portion of the state, within a few miles of the western border, is in Zone 13N. Nevertheless, the Zone 14N projection provides sufficiently accurate projected coordinates throughout the state and is used for all wells in the INTERPRETED_LOGS table for the sake of consistency. The land surface elevations are required to convert the logged interval depths to elevations in order to place the data from multiple logs in a common coordinate system. (The data points shown in Figure 3 are plotted at the middle elevation of each depth interval.)

An important proviso regarding the coordinate information is that the majority of the well latitude and longitude values have been computed from Public Land Survey System ("legal") descriptions of the well locations and so are subject to varying degrees of inaccuracy, depending on the level of detail in the PLSS description (Suchy, 2002; Gagnon and Look, 2008). Well location inaccuracy contributes to inaccuracy in the assigned land surface elevation (NED_ELEV) values, since the land surface elevations at the nominal and actual well locations will generally differ to some extent. Consequently, there will generally be some inaccuracy in both the lateral and vertical placement of the log data.

Accessing the Tables

A periodically updated static version of the INTERPRETED_LOGS table and its supporting tables (TRANSLATION_TABLE and LITHOLOGY_CODES) can be downloaded from the WWC5 web page, http://www.kgs.ku.edu/Magellan/WaterWell/index.html. Links on that page, under the "Interpreted Logs" heading, point to csv (comma-separated value) files containing the three tables, with file names intepreted_logs.csv, translation_table.csv, and lithology_codes.csv. These are ASCII (text) files with the fields (columns) separated by commas, and with double-quotation marks surrounding any text fields that contain commas (to prevent these commas from being interpreted as delimiters). This format is convenient for import into a number of software packages, such as Excel and R. The processing scripts described in the companion report (in preparation) include a script for converting csv files into the tab-delimited text format used by the rest of the scripts. (Conversion also could be accomplished by opening the csv files in Excel and then exporting them as tab-delimited text files.)

Subsequent Processing Steps

Two- or three-dimensional grids representing the spatial distributions of aquifer properties serve as key inputs to groundwater flow models. Programs described in the companion report (in preparation) implement the steps required to compute such grids from the category proportion data in the INTERPRETED_LOGS table, namely interpolation of category proportions to all model grid cells and computation of aquifer property grids from the resulting proportion grids.

References

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Suchy, D. R., 2002, The Public Land Survey System in Kansas: Kansas Geological Survey, Public Information Circular 20, http://www.kgs.ku.edu/Publications/pic20/pic20_1.html.