ArkDSS Task 2.7.1
DRILLERS LOG DATABASE TECHNICAL MEMORANDUM - FINAL

To: Erin Wilson, Wilson Water Group
Cc: Kelley Thompson, Brian Macpherson, Bill Tyner
From: Matt Seitz, HRS Water Consultants, Inc.
Subject: Task 2.7.1 - Well Log Database Task
Date: June 5, 2019

INTRODUCTION

This memorandum documents the purpose, design, and contents of a hydrogeologic database prepared by HRS Water Consultants, Inc. (HRS) under the drillers log portion of ArkDSS Task 2.7. One goal of Task 2.7 was to collect hydrogeologic data from selected driller and pump installation reports, process the data, and import it into a relational database to allow database users to more easily map and analyze the extent, distribution, and permeability of the materials that comprise the alluvial aquifer in the H-I model area and the alluvial aquifer along Fountain Creek (Figure 1). A companion memorandum (Task 2.8 Unit Response Functions) documents the approach HRS used to delineate zones of groundwater accretion / depletion timing in the Arkansas River basin (Division 2).

A “drillers log” (also known as a “lithologic log” or “well construction report”) is a list of the depth intervals below ground and associated type of geologic material encountered during drilling. While drillers’ logs vary widely in accuracy and level of detail, they are often a valuable source of data when studying an aquifer or creating a groundwater model (Laton, 2009).

Along with technical details on the installed pumping equipment, a “pump installation report” contains information on the well’s tested pumping rate and the decline in water level after a given pumping time at that rate. This data can be used to estimate the aquifer property of “transmissivity[1]” and also provides a general indication of aquifer productivity.

Data from the driller’s logs and pump installation reports can be analyzed to estimate aquifer transmissivity and map aquifer thickness and extent. The data will be useful in possible future groundwater-related ArkDSS tasks such as creating a GIS raster coverage of Arkansas alluvial aquifer transmissivity for use in well depletion timing calculations (e.g., using the Glover equation). If created, the transmissivity grid is envisioned as being similar to a widely-used transmissivity grid of the South Platte

[1] Transmissivity: the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Higher transmissivity values generally correspond to higher maximum well pumping rates.

alluvial aquifer[2]. The data will also be helpful in delineating and assigning aquifer properties in a possible future groundwater model of the Arkansas alluvial aquifer.

Drillers' logs and pump installation reports are viewable (and are available as scanned .pdf downloads) from the Colorado Water Conservation Board (CWCB) / Colorado Division of Water Resources' (CDWR) well permit website.[3] While access to this well and pump information is very helpful in hydrogeologic studies, the reports' native format (scans of typed or handwritten notes downloaded on a well-by-well basis) does not lend itself to quickly analyzing, displaying, or modeling the geologic data from a large number of wells. The goal of the drillers log database is to capture data from selected wells and complete the time-consuming process of converting it into a format that can be more readily used for groundwater-related ArkDSS tasks and for other studies of the area. Database users can use HRS' interpreted permeability classifications to estimate aquifer properties or can prepare their own lithologic classifications and work products by reclassifying the drillers' log descriptions. Data exported from the database can be used to quickly complete geologic cross sections, three-dimensional visualizations, and to prepare groundwater model input.

APPROACH

The approach used to develop the database consists of these steps:

1. Filter Division 2 well permit application records by location and other attributes
2. Download .pdf files of filtered well records
3. Create a relational database
4. Enter scanned drillers log and pump installation data from .pdf files in the database
5. Assign wells a ground elevation using a digital elevation model (DEM)
6. Complete quality control checks of entered data
7. Classify drillers logs intervals into "hydrofacies" (i.e., group the numerous individual drillers logs descriptions into a limited number of classes of materials interpreted to have similar permeability)

HRS also used geologic modeling software (RockWorks™, RockWare, Golden, CO.) to create example cross sections and 3-D visualizations of the classified log data. Several of these visualizations are presented in the "Applications" section and these and additional RockWorks files are provided along with the relational database as a digital appendix (Appendix A) to this Technical Memorandum. The following approach subsections provide details on the above steps used to create the database.

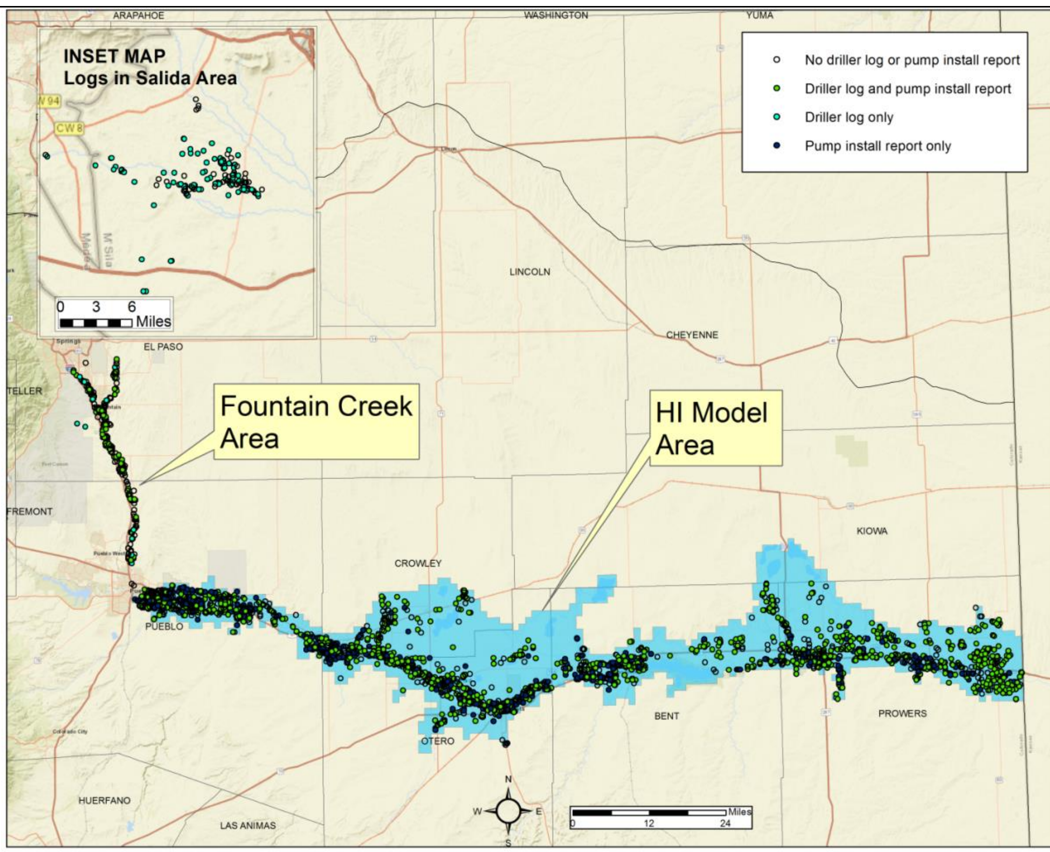
[2] Colorado Division of Water Resources GIS coverage: File: div1_gw_rasters.zip, raster: tgrid0309. https://www.colorado.gov/pacific/cdss/division-1-south-platte Division 1 Aquifer Grids (last updated 8/1/2011).
[3] https://dnrweb.state.co.us/cdss/WellPermits

Filter Well Records by Location and Attributes

The CWCB/CDWR well permit application GIS coverage includes XY coordinate pairs and other attribute data for well permit applications. In the October 2018 version of the GIS coverage, there were 108,439 well permit application records in Water Division 2 (the Arkansas River Basin). HRS used a series of filters to select a workable number of well permit application records that we judged more likely to have drillers' logs and pump installation reports in the area of interest. The filters HRS used were: 1.) well permit application is in Division 2, 2.) current status of well equal to "well constructed" or "well abandoned"[4], 3.) Well was within H-I model extent, 4.) Well was not reported to be in a bedrock aquifer, 5.) The primary reported well use was either commercial, industrial, irrigation, or municipal. These query criteria resulted in 3,000 selected well records within the H-I model area. As data from low-yield wells is not well-suited to estimating aquifer properties, HRS only entered pump installation data for wells with a reported pumping rate of greater than or equal to 50 gallons per minute (gpm).

HRS also selected 361 records within the Fountain Creek portion of the alluvial aquifer and 195 records in the Salida area. Figure 1 presents a map of the selected records.

Figure 1. Location of Wells (HI Model Area, Fountain Creek, Salida area)



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[4] Hydrobase field currstatus = "Well Constructed" or "Well Abandoned". All other HydroBase codes in the *currstatus* field are not expected to have drillers logs or pump installation reports.

Table 1. Summary of Available Data for Selected Records

Data type(s) available	Number of records
None: no driller log or pump installation report	1,386
Both drillers log and pump installation report	1,334
Drillers log only	135
Pump installation report only	701
Total:	3,556

Even after applying filters we judged would increase the likelihood finding data for the wells, about thirty-nine percent of the selected well records did not have either a driller's log or a pump installation report. HRS did not examine records for well permit applications where there was no indication that a well had been constructed and therefore no geologic or pumping information was likely to be available.

Download .pdf files of Well Records

HRS downloaded the scanned driller's log and pump installation reports on a well-by-well basis. Currently it is not possible to simultaneously download scanned documents from the well permit website for multiple wells. To speed up the download process, HRS created a URL hyperlink to the well permit website for each of the 3,556 well records by inserting each well's receipt number into a URL string.[5] The URL hyperlinks along with the well permit and applicant name were imported into a document download tracking spreadsheet. HRS data entry staff used the spreadsheet to access the scanned records and keep track of the data available for each well. The well permit number and applicant name were checked for agreement between the spreadsheet data and the online data for each well. The well records are uniquely identified by the value in the *Receipt*[6] field. Of the 3,556 well records, 2,747 also had a WDID[7] entered. Well pumping volumes (i.e., diversions) are tracked using a "WDID" number. In the future, it may be useful to compare the wells' historic diversions to the estimated aquifer properties in a given area to see if more productive areas of the alluvial aquifer are correlated with higher groundwater diversions.

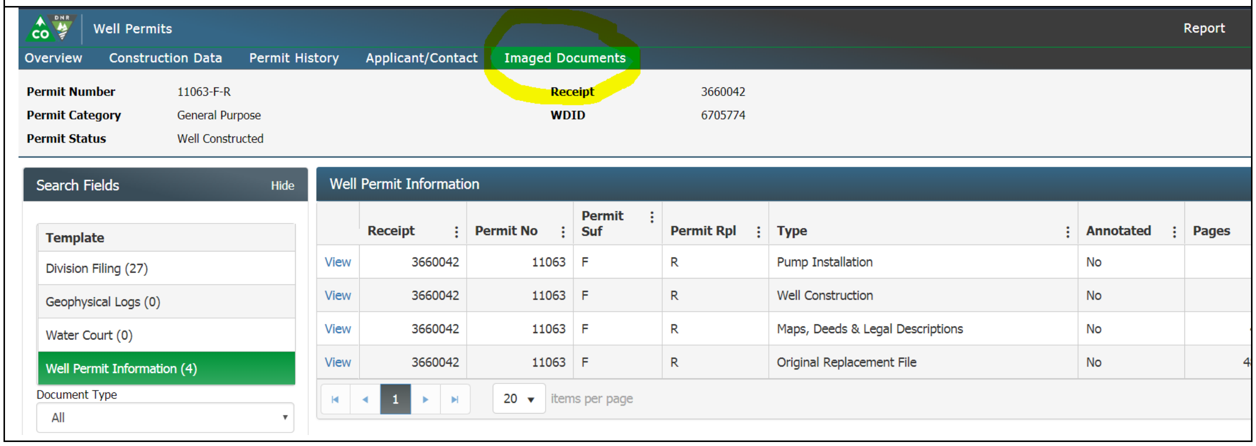
Figure 2 shows a screenshot of the webpage location of the scanned records of interest.

[5] The URL text string consists of the text "https://dnrweb.state.co.us/cdss/WellPermits/" with the wells Receipt number added to the end of the text. For example, the URL for a well with Receipt 3660042 is https://dnrweb.state.co.us/cdss/WellPermits/3660042

[6] Database field names are shown in italic font. Database table names are shown in all caps and bold font.

[7] A WDID is a CDWR-issued identification number for a water right.

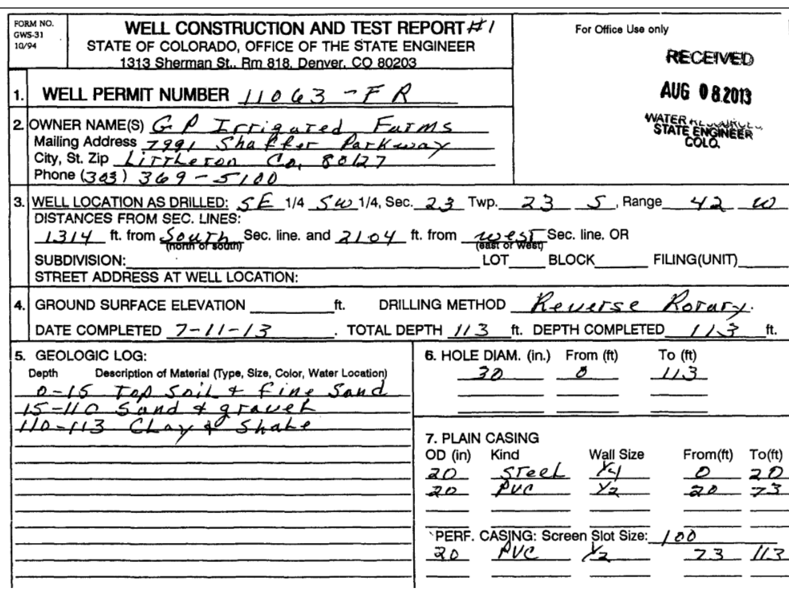
Figure 2. Screen shot of CWCB/CDWR Well Permit Website (Feb 2019)



The URL opens to a page that provides an overview of the subject well with tabs containing additional information. Clicking the "Imaged Documents" tab (highlighted in the above figure) brings up a list of the scanned documents for that well. Each scanned document has a hyperlink (labelled 'view') that opens the document for viewing and download. Typically drillers' logs are found in documents where document "Type" is either "Well Construction", "Original File", or "Original Replacement File". Pump installation reports are typically found where the document type is "Pump Installation", although this data is sometimes found in the Original File document. In some cases, a well's permit number has changed over time. In these cases, the scanned documents of interest may be associated with the earlier permit number and are not found on the 'Imaged Documents' tab. Viewing the documents referenced under an earlier permit number is completed by going to the 'Overview' tab (Figure 2) and clicking the link under 'Permit Associations'.

Figure 3 is a screenshot of an example drillers log accessed from the imaged documents tab.

Figure 3. Screen shot of Example Well Drillers Log (from Imaged Document 'view' link)



FORM NO. GWS-31 10/94

WELL CONSTRUCTION AND TEST REPORT #1
STATE OF COLORADO, OFFICE OF THE STATE ENGINEER
1313 Sherman St., Rm 818, Denver, CO 80203

For Office Use only

RECEIVED
AUG 08 2013
WATER RESOURCES STATE ENGINEER COLO.

1. WELL PERMIT NUMBER 11063-F R

2. OWNER NAME(S) G P Irrigated Farms
Mailing Address 7991 Shaffer Parkway
City, St. Zip Littleton Co. 80127
Phone (303) 369-5100

3. WELL LOCATION AS DRILLED: SE 1/4 SW 1/4, Sec. 23 Twp. 23 S, Range 42 W
DISTANCES FROM SEC. LINES:
1314 ft. from South (north or south) Sec. line. and 2104 ft. from West (east or west) Sec. line. OR
SUBDIVISION: ____ LOT ____ BLOCK ____ FILING(UNIT) ____
STREET ADDRESS AT WELL LOCATION:

4. GROUND SURFACE ELEVATION ____ ft. DRILLING METHOD Reverse Rotary
DATE COMPLETED 7-11-13 . TOTAL DEPTH 113 ft. DEPTH COMPLETED 113 ft.

5. GEOLOGIC LOG:

Depth	Description of Material (Type, Size, Color, Water Location)
0-15	Top soil + fine sand
15-110	Sand + gravel
110-113	Clay + Shale

6. HOLE DIAM. (in.)

HOLE DIAM. (in.)	From (ft)	To (ft)
30	0	113

7. PLAIN CASING

OD (in)	Kind	Wall Size	From(ft)	To(ft)
20	Steel	1/4	0	20
20	PVC	1/2	20	73

PERF. CASING: Screen Slot Size: 100

OD (in)	Kind	Wall Size	From(ft)	To(ft)
20	PVC	1/2	73	113

To manage the large number of downloaded pdf files, HRS created subfolders in MS Office Windows Explorer using a free program[8] that automatically creates and names folders using data contained in a user-created text file. Each of the 3,556 well records had a subfolder with an assigned name consisting of a counter (1,2,3, etc.) an underscore character, and the record's *Receipt* number[9]. The counter was added so that data entry staff could navigate more quickly to the correct download folder. Some wells had multiple downloaded documents in a single folder. As the database provided in Appendix A contains a URL link to the imaged documents and the data of interest have been entered as numbers and text, HRS did not include the downloaded pdf files in Appendix A; however, these files are available upon request.

Create a relational database

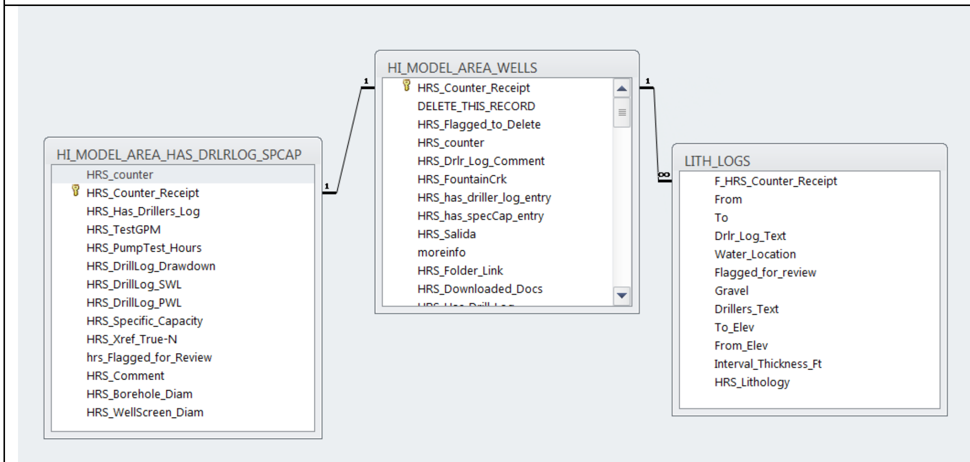
A relational database is an efficient means to enter, store, view, and process drillers' log data. HRS created the relational database in MS Access 2010™, however the tables that comprise the database can be easily imported into other database programs. The database has three tables linked together by a common unique identifier field used in Hydrobase (*Receipt*):

1. **HI_MODEL_AREA_WELLS** – This table contains the CDWR's well permit application database information for filtered wells in the study area as of October 2018. HRS added several new fields to this table which are identified by the prefix "HRS_" in the field name (see Appendix B). Each record (i.e., well) is uniquely identified by the *Receipt* field to be consistent with CDWR's Hydrobase identifier.
2. **LITH_LOGS** - This table contains information for each well that has a driller's log in the study area. Because a given well typically has more than one geologic interval reported on its driller's log, the **LITH_LOGS** table is joined to the **STUDY_AREA_WELLS** table using a "one-to-many" type database relationship. This table includes the verbatim drillers log text, the starting and ending interval depths in feet below ground level, and HRS' lithologic classification for that text (discussed later). Some drillers' logs also include a checkbox indicating that a given interval was a location of water; this information was entered using a yes/no checkbox in the database.
3. **HI_MODEL_AREA_HAS_DRLRLOG_SPCAP** – This table contains selected data entered by HRS from a scanned pump installation report or well construction report. The entered data include pumping rate, water level drawdown at that rate, and pumping water level. Records in the Fountain Creek alluvial aquifer also include borehole diameter and well screen diameter, two properties that HRS used to complete a more in-depth estimate of transmissivity in this area (see the ArkDSS Technical Memorandum for Task 2.8).

[8] Text2Folders.exe; https://www.softpedia.com/get/System/File-Management/Text-2-Folders.shtml

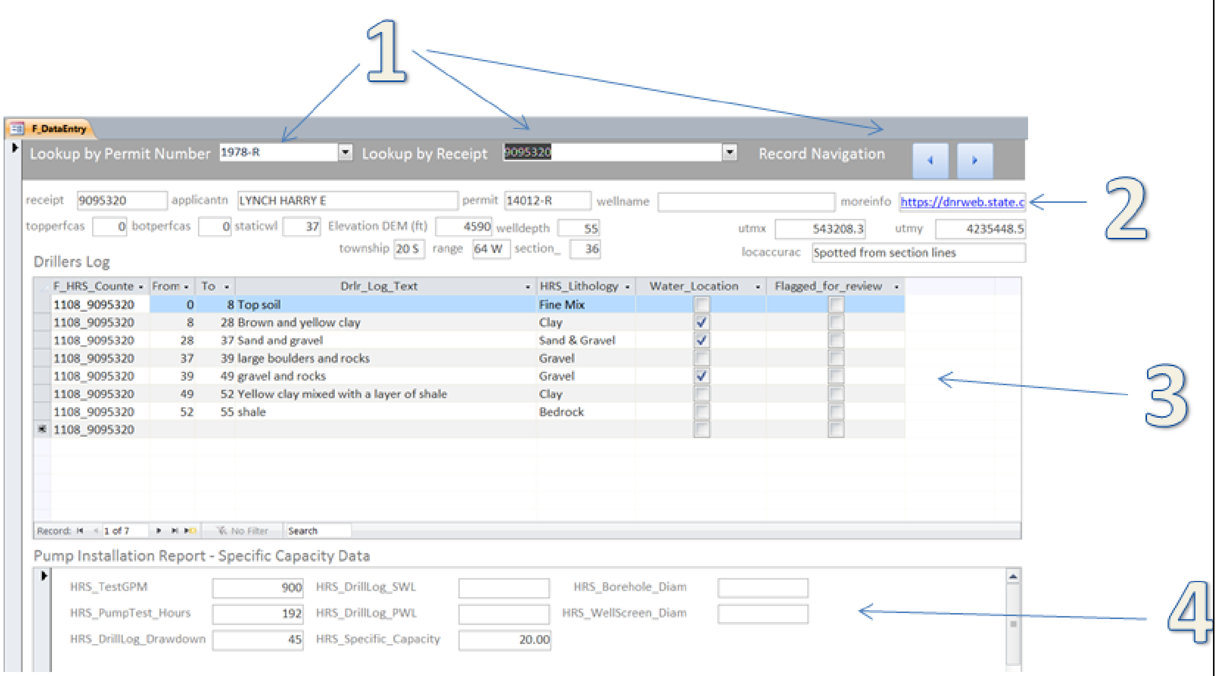
Appendix B is a data dictionary describing the data and data types for fields added by HRS. A data dictionary for the CDWR well permit application fields is available from CDWR.

Fig 4. Relational Database Design



The database includes a form (F_DataEntry) that automatically opens when opening the database in MS Access. The form allows the database user to easily view, enter, and edit data from multiple related database tables. Figure 5 presents a screenshot of the form and notes some of its features.

Fig 5. Database Form View

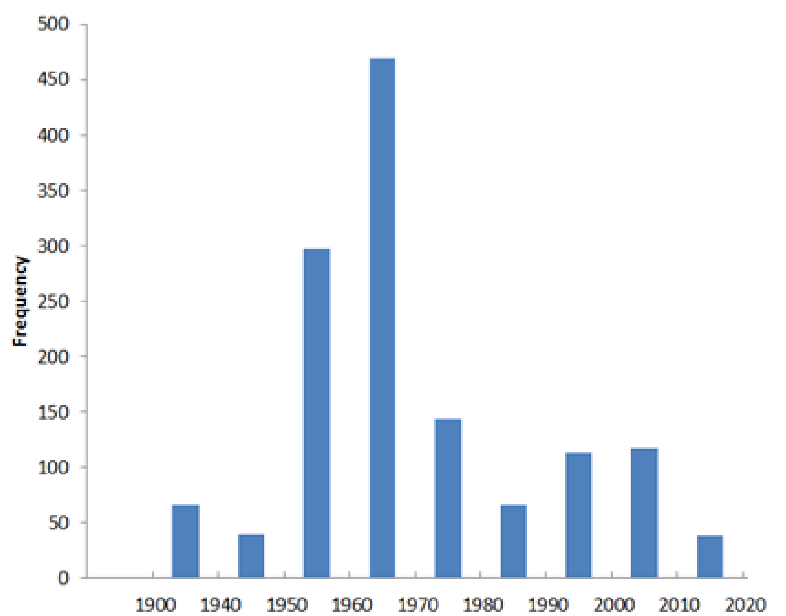


The features annotated in Figure 5 are: (1) Dropdown boxes that allow the user to pull up a well record by entering its permit number or receipt number; (2) Selected fields from the CDWR well records; the '*moreinfo*' field is a hyperlink to view CWCB/CDWR well permit website for the well and view imaged documents. Data in this section are from the **HI_MODEL_AREA_WELLS** table. (3) Driller's log text and depth interval ranges, and HRS' lithologic classification for the interval. Data is from the **LITH_LOGS** table. (4) Selected fields from the table **HI_MODEL_AREA_HAS_DRLRLOG_SPCAP**. The field *HRS_Specific_Capacity* contains the well's calculated specific capacity and the fields used in the calculation (i.e., the ratio of its pumping rate in gallons per minute to the drop in water level in feet at that pumping rate).

Enter drillers log and pump installation data in database

HRS examined 3,556 well records on the well permit website and, for records where a scanned log existed (1,469 wells), manually entered the drillers' logs into the database. The data entry process consisted of using the database form shown in Figure 5 to manually type in the data from the scanned pdf files. During data entry, HRS data entry staff marked a checkbox if the scanned records were illegible or had some other issue to review during the quality control (QC) process. There are 7,380 individual lithologic intervals entered in the database and a total of 135,000 feet of logged geologic material. Logs for redrilled wells were often only available for the originally drilled well. Often for redrilled wells the scanned document actually used for data entry was downloaded using a link to an earlier "cross referenced' well permit number (see link under Overview | Permit Associations | Associated Permit(s) section of well permit website). As shown in Figure 6, most of the wells with driller's logs in the database were drilled in the 1960s.

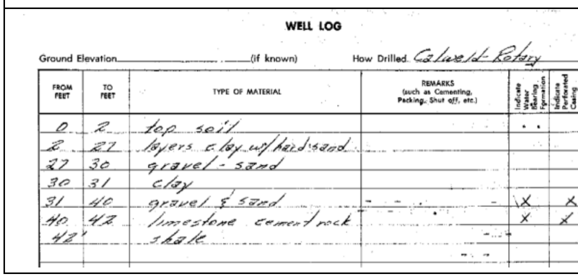
Figure 6. Well Construction Year Range for Wells in with Drillers Log in Database



Assuming a rough cost to mobilize a rig, drill, and document a 100-foot deep alluvial aquifer test hole of $1,500, we estimate the cost to collect the well log data compiled in the database to be close to two million dollars. As noted in the journal *Groundwater* by Dunkle et al (2016), “these types of reports [driller’s logs] are usually the largest available subsurface data source and are available with little or no cost to the hydrogeologist.”

The forms used to record drillers’ logs and pumping information have changed over the years. Some versions of the form have a checkbox indicating “water location” for a given geologic interval. Depending on the drilling method and experience of the driller, the more productive water-yielding portions of a planned well can be ascertained by the driller during drilling. When present, this information was entered using a checkbox field (*Water_Location*) in the ***LITH_LOGS*** table. Figures 7a and 7b show versions of drillers log forms from two example years.

Figure 7a. Example Drillers Log (circa 1965)

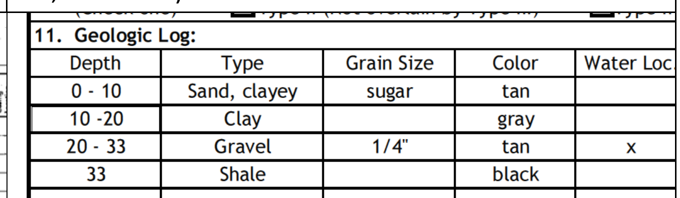


WELL LOG

Ground Elevation ______ (if known) How Drilled Calweld-Rotary

FROM FEET	TO FEET	TYPE OF MATERIAL	REMARKS (such as Cementing, Packing, Shut off, etc.)	Indicate Water Bearing Formation	Indicate Perforated Casing
0	2	top soil			
2	27	layers clay w/ hard sand			
27	30	gravel - sand			
30	31	clay			
31	40	gravel & sand		x	x
40	42	limestone cement rock		x	x
42'		shale			

Figure 7b. Example Drillers Log (current form GWS-31, Feb 2017)



11. Geologic Log:

Depth	Type	Grain Size	Color	Water Loc.
0 - 10	Sand, clayey	sugar	tan	
10 -20	Clay		gray	
20 - 33	Gravel	1/4"	tan	x
33	Shale		black	

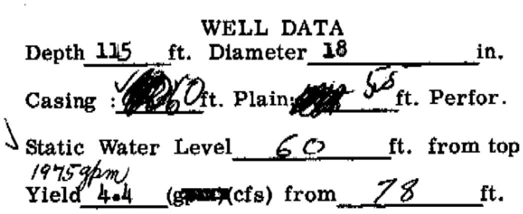
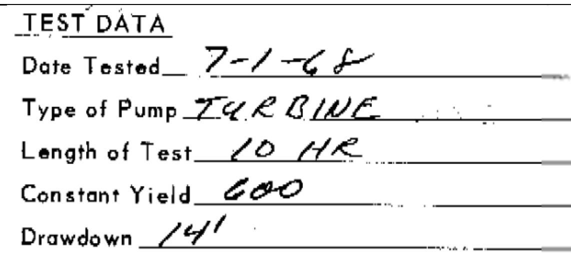
The current version of the form (Figure 7b) is a “fillable” pdf file with boxes that can be directly typed in; while now this data is often typed in by the person completing the form, each entered value has not been combined in to a larger table with discrete fields for all text and numbers. CDWR’s Hydrogeological Services branch is currently working on a new version of the Well Construction Form that allows the user to type driller log information into individual fields that will be linked to the Hydrobase record for that well. This change will greatly speed up visualization and analysis of future drillers’ logs. CDWR is also currently working to digitally enter a State-wide set of several hundred scanned drillers logs[10] using a process similar to the one detailed in this memorandum.

HRS entered specific capacity data for a total of 2,035 wells, primarily in the H-I Model area and the Fountain Creek arm of the Arkansas River alluvial aquifer. Entry of the data needed to calculate specific capacity and estimate transmissivity included training data entry staff on the varying names and methods of reporting the data used over the years by pump installers. In the example pump installer forms shown Figures 8a and 8b below, pump installation forms may report some combination of static water level (swl), pumping water level (pwl), drawdown (pwl minus swl), pumping time, and pumping rate.

[10] K. Donegan, Senior Hydrogeologist, CDWR; personal communication, February 2019. Driller’s logs planned for entry are from Colorado wells that are part of the United States Geological Survey’s National Ground-Water Monitoring Network (NGWMN).

In unconfined alluvial aquifers, transmissivity (T) can be approximated as[11]:

*Equation 1. T (gpd/ft) = (specific capacity in gpm per foot of drawdown) * 1500*

Figure 8a. Specific Capacity Data: Example 1	Figure 8b. Specific Capacity Data: Example 2
 WELL DATA Depth 115 ft. Diameter 18 in. Casing : [redacted] ft. Plain [redacted] 58 ft. Perfor. Static Water Level 60 ft. from top 1975 gpm Yield 4.4 (g[redacted](cfs) from 78 ft.	 TEST DATA Date Tested 7-1-68 Type of Pump TURBINE Length of Test 10 HR Constant Yield 600 Drawdown 14'
Specific capacity = 1975 gpm / (78 ft – 60 ft) = 110 gpm / foot drawdown Approximate T = 110 * 1500 = 165,000 gpd/ft	Specific capacity = 600 gpm /14 ft = 43 gpm foot drawdown Approximate T = 43 * 1500 = 64,500 gpd/ft

HRS limited specific capacity calculations to wells with a reported test rate of greater than or equal to fifty gpm. Wells with reported test rates below fifty gpm are assumed to not induce enough of a hydraulic stress on the aquifer to result in reasonably accurate results.

There is a more rigorous ASTM method[12] for calculating transmissivity from specific capacity and well construction data than shown in Equation 1. In addition to specific capacity, the ASTM method requires correcting the observed drawdown based on aquifer thickness, and entering pumping duration and well casing diameter. As detailed in the Task 2.8 ArkDSS Technical Memorandum on Unit Response Functions (URFs), HRS completed this method for selected wells in the Fountain Creek alluvial aquifer to improve the quantification of URFs in this area. While not included in the current scope, the more detailed ASTM method could also be completed for the specific capacity data entered in the H-I Model area by entering the additional required fields. As with the specific capacity data, the additional fields used in the ASTM method are contained in the **HI_MODEL_AREA_HAS_DRLRLOG_SPCAP** table.

Quality Control of Entered Data

HRS completed several QC checks of the drillers log and pump installation report data including:

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[11] Driscoll, Fletcher, PhD., 1986. “Groundwater and Wells”. 2nd edition.

[12] ASTM D5472 / D5472M – 14: Standard Test Method for Determining Specific Capacity and Estimating Transmissivity at the Control Well

- Flagged drillers logs that were difficult to read or illegible[13];
- Checked reported intervals on drillers logs for gaps or overlapping geologic footage intervals;
- Reviewed a subset of records entered by data entry staff and compared for agreement to the original scanned documents;
- Set a unique identifier field in the database *Receipt* for each well record. Enforced referential integrity in database software to prevent entry of data in the related tables with no associated *Receipt* in the HI_MODEL_AREA_WELLS table (Figure 4).

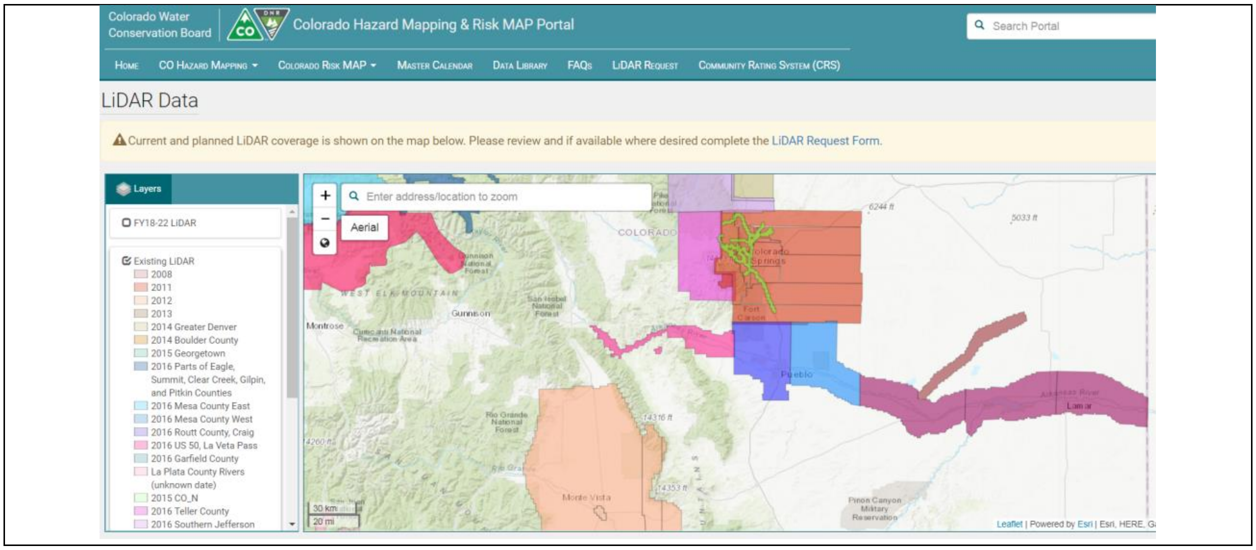
Assign Wells a Ground Elevation using a Digital Elevation Model (DEM):

As many records in the well permit database do not include ground level elevation, HRS used the United States Geological Survey's (USGS) Bulk Point Query Service (V.20)[14] to calculate the estimated ground level elevation at each well. The Bulk Point Query Service queries the USGS' 1/3 arc second digital elevation model (DEM) to estimate an elevation at each input XY location. The published vertical accuracy at the 95% confidence level within the conterminous United States is 3.04 meters. The accuracy of the estimated elevation depends in part on the accuracy of the XY coordinates for each well. Approximately fifty percent of the wells in the database have XY coordinates located only to the centroid of a quarter-quarter section (i.e., the well location is assigned to be the center of 40-acre parcel, but the actual well location may be anywhere within the qtr-qtr). The remaining wells are located more precisely, either by footage calls from PLSS section line measurements or user-supplied GPS coordinates. The wells with more precise XY coordinates are more likely to have an accurate DEM elevation. Elevation values were not calculated for the 197 well records in the Salida area as HRS' example cross sections focused on the H-I model area.

Portions of Division 2 (Figure 9) have higher resolution LiDAR topographic maps available via the CWCB's Colorado Hazard Mapping and Risk MAP Portal.[15] Division 2 LiDAR coverages include most of the mainstem of the Arkansas River and most of the HI-model area.

Figure 9. Current extent of LiDAR Coverage in Southeast Colorado

[13] Notes are in "HI_MODEL_AREA_WELLS" table and "HRS_Drlr_Log_Comment" field. Flagged intervals are in LITH_LOGS table and "Flagged_for_Review" field.
[14] https://viewer.nationalmap.gov/apps/bulk_pqs/
[15] http://www.coloradohazardmapping.com/lidar



HRS used the USGS' 1/3 arc sec DEM to estimate well elevations rather than the LiDAR coverages as the additional precision of the LiDAR data is not needed for the current uses of the well data (i.e., example cross sections and well borehole visualizations). The 1/3 arc sec DEM also provides a consistent method to estimate elevations across all of Division 2 and does not require downloading the very large LiDAR coverages. The LiDAR data may be helpful in possible future ArkDSS groundwater modeling tasks such as providing input to the MODFLOW Streamflow Routing Package and refining depth to groundwater maps and related groundwater evapotranspiration values.

Classify Drillers Logs into Hydrofacies

Driller's log data typically comprise the largest (and sometimes only) source of subsurface information for a study area. Compared to completing a new regional test drilling program, compiling and analyzing drillers' logs is inexpensive. It takes geologic judgment and interpretation, however, to process and aggregate this data into a coherent conceptual model and useful set of geologic classifications with similar hydraulic characteristics. A key step in aggregating the myriad descriptions found on drillers' logs into information useful for hydrologic studies is to define a set of lithologic classifications of importance to hydrogeologic characteristics of the geologic layers, sometimes referred to as "hydrofacies" (Dunkle et al, 2011). The distribution and sorting of grain sizes in an alluvial sediment influences its water-transmitting properties (Faunt et al, 2009). Uniform-size coarse grained materials are associated with higher hydraulic conductivity whereas fine grained and/or poorly sorted materials (i.e., a wide range of grain sizes) are correlated with lower hydraulic conductivity. HRS reviewed reports of Arkansas alluvial aquifer properties and created six lithologic classifications or hydrofacies for the alluvial aquifer area shown in Figure 1.

Table 2. Hydrofacies Classifications and Preliminary Assigned Hydraulic Conductivity Values

Hydrofacies Name	**Example Drillers Log Text assigned to Hydrofacies**	**Assigned Hydrofacies Hydraulic Conductivity (K)**
Clay	Clay, silt, loess, adobe, gumbo, dobbie, bentonite	10^{-3} feet / day

Fine Mix	Soil, clay and sand, sand and clay layers, top soil, brown sandy clay	1 feet / day
Sand	Sand, fine sand, coarse sand, water sand, quick sand, sugar sand	100 feet /day
Sand and Gravel	Sand and gravel, sand and rock, sand and boulders, gravel and sand	500 feet / day
Gravel	Gravel, coarse gravel, boulders, water gravel, rocks and boulders	1,000 feet / day
Bedrock	Shale, limestone, sandy shale, black shale, blue shale, Dakota, sandrock, clay and shale	0 feet /day

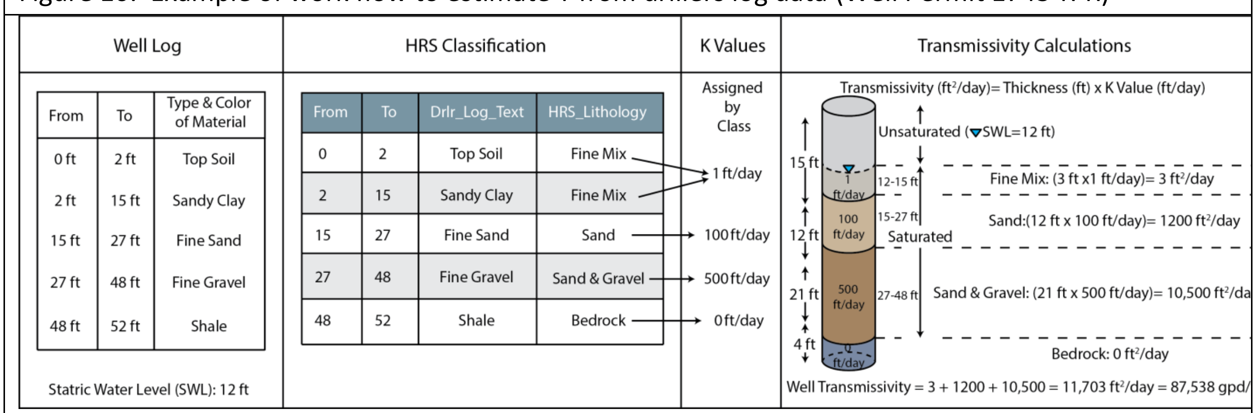
We believe these six classes provide a reasonable balance between honoring the level of detail found on drillers' logs with the need to simplify and aggregate this data into a set of geologic classes with similar hydraulic characteristics that are within the expected range of values for the study area. Entering the drillers' logs into the database format allows the database user to quickly come up with their own classifications and assignment of hydraulic conductivity.

This classification scheme and assignment of hydraulic conductivity (or one created by the database user) can be used to estimate transmissivity. Transmissivity (in units of ft^2/day) is equal to hydraulic conductivity (in units of feet/day) multiplied by saturated thickness (in units of feet).

Equation 2. Transmissivity (ft^2/day) = (Hydraulic Conductivity, ft/day) * (saturated thickness, ft)

Estimating transmissivity for the multiple geologic layers in a drillers log is simply a matter of adding the T values for each layer. Figure 10 shows an example of the process that can be used to estimate T by prorating the estimated T values of the saturated portions of classified layers.

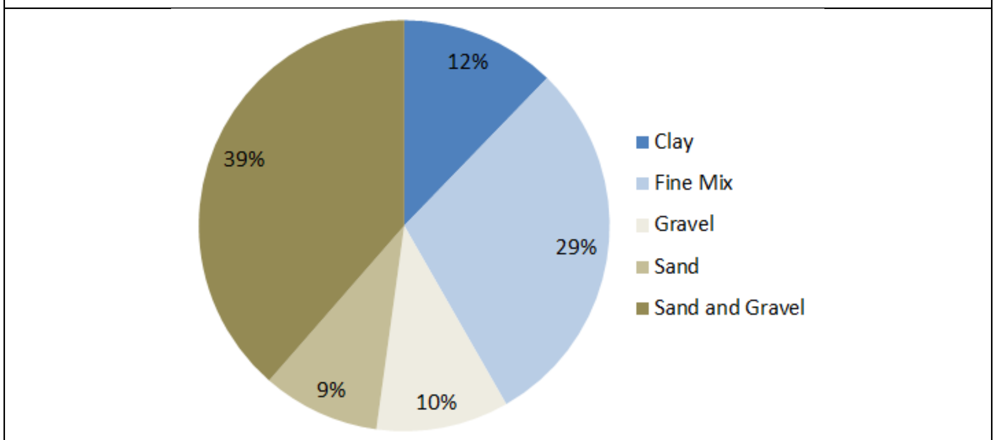
Figure 10. Example of work flow to estimate T from drillers log data (Well Permit 1743-R-R)



Drillers' logs vary widely in quality, with some logs providing a lot of accurate detail whereas other logs are more generalized. As noted by Faunt et al (2009) regarding a USGS study that included an 8,500 well drillers' log database in the Central Valley of California, "This study relies heavily on lithologic data from drillers' logs, which are frequently assumed to be poor sources of lithologic information. However, a number of previous studies in Central Valley have shown their utility if carefully used." In the ArkDSS well database there are bound to be cases where a given drillers log description (e.g., "sand") should have been more accurately reported as something else (e.g. "silty sand with clay streaks"). Despite the inherent differences in the descriptive language and level of detail in the logs, it is clear that, when analyzed together, the logs provide a valuable source of subsurface data in a large and often data-scarce study area.

For wells drilled in alluvium, the depth to bedrock reported on a given driller's log is an important and relatively clear cut data point that is likely more reliable than other portions of the description. It follows that bedrock contour maps and alluvial aquifer boundary maps have a higher degree of confidence compared to less obvious changes in relative percentages of logged alluvial aquifer materials such as sand, clay, silt, and gravel. Consolidated bedrock, such as shale, sandstone, limestone, and granite is much harder than the loose sand, gravel, clay, and silt that comprise the Arkansas River alluvial aquifer. Some drillers' logs do not report depth to bedrock, but instead have their deepest logged geologic interval listed as an alluvial material (e.g., sand). In these cases, the lowest alluvial depth value can either be treated as a minimum alluvial thickness, or, depending on a review of the surrounding wells, could be interpreted to represent the depth to bedrock based on the assumption that most high capacity alluvial wells (i.e., non-domestic use wells) are drilled through the entire alluvial saturated thickness in order to maximize well yield and the driller stopped when contacting bedrock but did not note it in the log. The percentage of fine grained material such as silt and clay that is mixed in with more permeable alluvial material such as sand is an important factor that dramatically impacts hydraulic conductivity. As opposed to correctly noting depth to bedrock during drilling, however, accurately noting silt content is much more difficult to quantify during drilling.

Figure 11. Geologic classification as a percent of total logged footage of alluvial (i.e., non-bedrock) materials.



Two layers described as "sand", for instance, may have very different hydraulic conductivity values if one has even two or three percent more silt or fine grained materials than the other. This subtle distinction in silt content is very difficult to make, particularly in the field during drilling. When possible, the drillers log-derived transmissivity estimates should be compared to nearby aquifer test or specific capacity test derived values. If a groundwater model or alluvial aquifer transmissivity grid is created in the future, we recommend this step be completed to assess and possibly revise the general hydraulic conductivity values in Table 2 to better reflect nearby aquifer test data. As shown in Figure 11, clay and clay sand mixes ("Clay and "Fine mix" classifications) account for forty-one percent of the total footage of non-bedrock materials entered in the database.

To assign the driller's log descriptions to a hydrofacies, HRS queried the database and exported all 1,821 unique text strings along with a count of the total number of times that exact text string was entered. Figure 12 shows the most frequently occurring drillers log text strings along with HRS' classification. HRS used a series of 'if' statements in the exported spreadsheet of the unique log text (excerpt shown in Fig 12) to automate assignment of hydrofacies classes to the more common descriptions (e.g., shale, sand and gravel, clay, etc.). Many descriptions, however, occurred only once or a just a few times. These less frequent text entries were assigned to a hydrofacies on a case-by-case basis.

All classifications relied on geologic interpretation based on the regional alluvial aquifer geology. Some logs were entered for deeper bedrock wells that met the well permit query criteria discussed earlier. After assigning each unique driller's log text string to a hydrofacies, the **LITH_LOGS** table in the database was updated by importing the spreadsheet and joining the classified spreadsheet table (by matching drillers log text) to the **LITH_LOGS** table and updating the database field *HRS_Class_Update* to the value in the spreadsheet table. HRS did not remove logs that contradicted surrounding data (i.e. we did not remove possible "outlier" logs) or remove logs that in our judgement appeared to be of low quality. Faunt et al (2009) suggest that logs should be screened on the basis of the degree of detail in the log and the spatial accuracy of the well location. Wells that are located to only quarter-quarter PLSS accuracy in the database will be spatially overlapping if two or more such wells are in the same quarter-quarter (i.e., both wells will be plotted in the center of the quarter-quarter). These duplicate coordinate sites were not removed from the database, but were removed to create the data visualizations. Where wells are mapped as spatially coincident, geologic interpretation is needed to assess which driller's log is more accurate and should be used for that location. Future work with the data including visualization, cross sections, and model layer construction may include adding new records and removing logs that are deemed less reliable.

Figure 12. Selected drillers log text strings sorted by frequency

Drlr_Log_Text	CountOfDrlr_Log_Text	HRS_Class_Update
Shale	867	Bedrock
Sand and gravel	598	Sand & Gravel
Clay	597	Clay
Top soil	316	Fine Mix
Sand	294	Sand
sandy clay	219	Fine Mix
gravel	160	Gravel
Fine sand	134	Sand
blue shale	122	Bedrock
top soil and clay	105	Fine Mix
Soil	93	Fine Mix
earth	86	Fine Mix
sandstone	70	Bedrock
Black Shale	70	Bedrock
Topsoil	62	Fine Mix
sand and clay	56	Fine Mix
Yellow Clay	55	Clay
Brown Clay	46	Clay
Sand gravel	45	Sand & Gravel

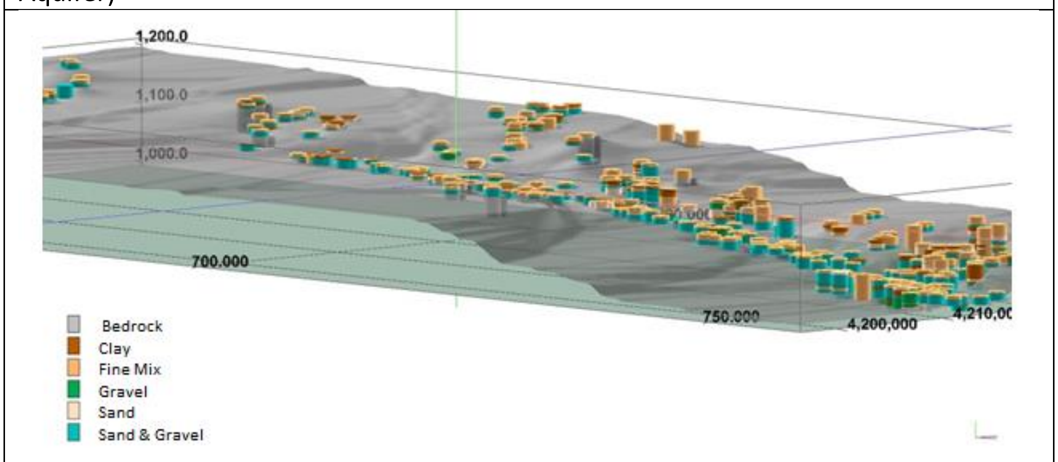
Applications

The database format is designed to quickly allow the user to query, process, and export drillers' log and specific capacity data to geologic visualization, GIS, or groundwater modeling software. Data sets of this type are often used to create:

- 3-D visualizations of lithology
- Geologic cross sections
- Solids models (for import to groundwater models)
- Zone maps or contour maps of aquifer hydraulic characteristics
- Bedrock contour maps or aquifer layer maps for groundwater modeling
- Saturated thickness maps

Figure 13 presents an example borehole 3D diagram created by exporting data from the database to geologic modeling software (Rockworks™, Rockware, Golden, CO.). The example Rockware files are included in Appendix A. The borehole visualization and cross sections are presented as preliminary examples to show possible uses of the database and are not scoped or intended as final ArkDSS deliverables.

Figure 13. Example Borehole Diagram (looking SE to NE along Arkansas River Alluvial Aquifer)



The fill color for each borehole interval corresponds to one of HRS' six lithologic classifications. Because the wells are very shallow compared to the large extent of the study area, it is difficult to discern trends in borehole materials at the regional scale shown in Figure 13, even with a large vertical exaggeration. Within the visualization software, however, the user can zoom into the areas of interest and better examine trends in lithology.

Once the borehole data is imported, the user can quickly create geologic cross sections by simply selecting the desired group of wells to include in the cross section. Figure 14a presents an example cross section (D-D') that parallels the Arkansas River northwest of La Junta.

Figure 14a. Map View of Cross Section D-D’ – Arkansas Alluvial Aquifer northwest of La Junta

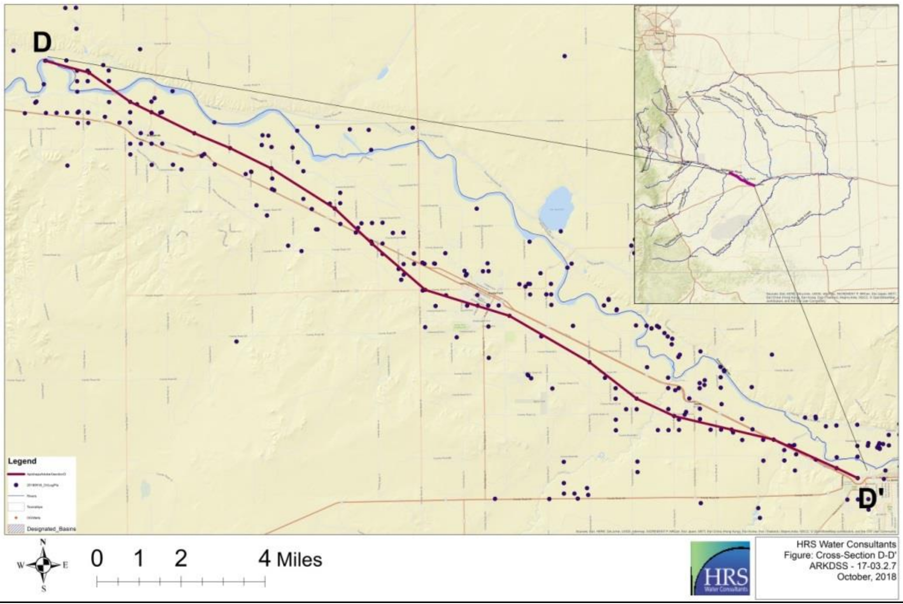
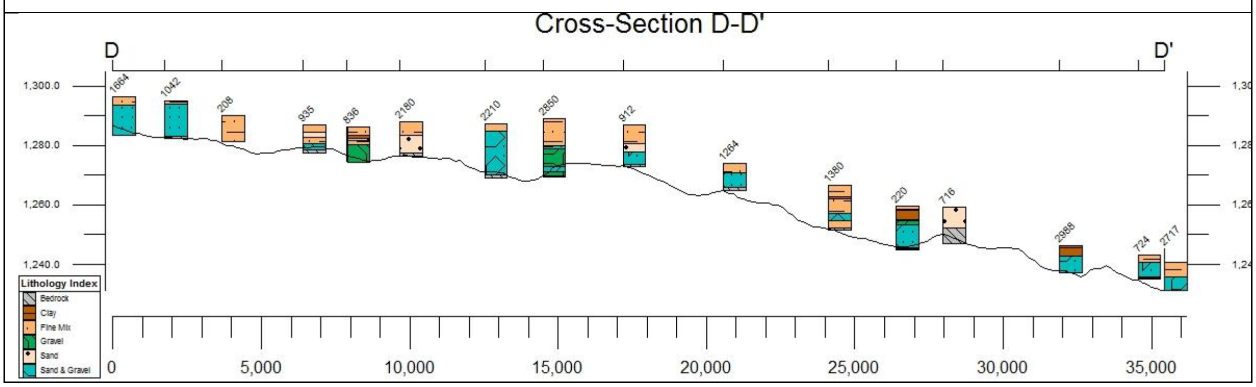
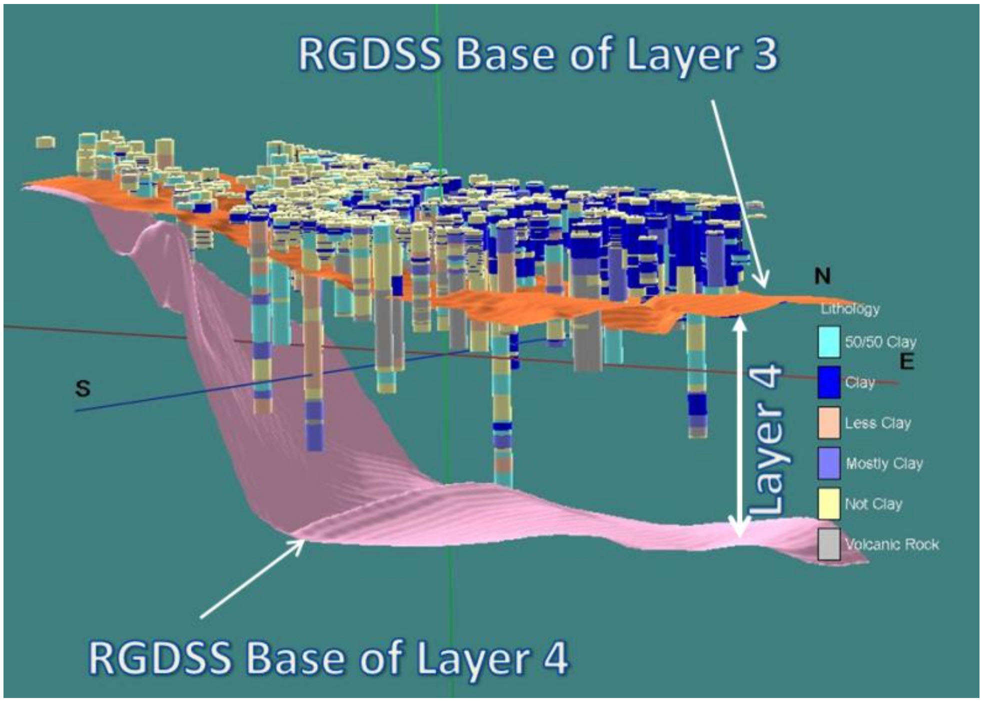


Figure 14b. Example Cross Section D-D’ (xyz units in meters)



While beyond the scope of Task 2.7, the well data can also be used to create a solids model or aquifer layer maps for import into groundwater modeling software. Figure 15 below presents an example aquifer layering maps from the CWCB/CDWR’s Rio Grande Decision Support System (RGDSS) for and area near La Jara, Colorado in the San Luis Valley.

Figure 15. Example of borehole and groundwater model layering (RGDSS)



Dunkel et al (2016) present a process to create solids models and interpolated aquifer hydraulic conductivity for an area with multiple geologic strata that can be assigned to model layers. Often a model of an unconfined alluvial aquifer (such as the Arkansas River alluvial aquifer) is a single layer model and the only bounding surfaces that are defined are ground level and the bedrock surface. For single layer models, the transmissivity estimates derived from specific capacity data and the drillers' logs process shown in Figure 11 are either contoured across the single layer or are used to subdivide the model area into zones of similar aquifer properties.

Summary

The ArkDSS Task 2.7.1 drillers log database contains a large amount of information that can be used to visualize, interpret, and analyze hydrogeologic conditions in the Arkansas River alluvial aquifer and Fountain Creek arm of alluvial aquifer. Prior to the creation of this database, this information was generally only available as scanned handwritten notes and could not be readily processed and mapped across large areas.

This database will be useful in completing envisioned future ArkDSS groundwater tasks such as preparing a GIS coverage of aquifer transmissivity, refining the alluvial aquifer boundary, and preparing a bedrock elevation contour surface for use in a numerical groundwater model or other hydrogeologic study.

References

ASTM D5472 / D5472M – 14: Standard Test Method for Determining Specific Capacity and Estimating Transmissivity at the Control Well.

Driscoll, Fletcher, PhD., 1986. “Groundwater and Wells”. 2nd edition.

Dunkle, K. M., Anderson, M. P. and Hart, D. (2016), New Ways of Using Well Construction Reports for Hydrostratigraphic Analyses. Groundwater, 54: 126–130. doi:10.1111/gwat.12326
Giffin C. L. (2011) USGS Lidar Point Cloud (LPC) CO_San-Luis-Valley_2011.

Faunt, Claudia C., Belitz, Kenneth, Hanson, Randall T. October, 2009. “Development of a three-dimensional model of sedimentary texture in valley-fill deposits of Central Valley, California, USA.” Hydrogeology Journal (2010) 18: p 625-649.

Laton, R. 2009. Boring Logs – What’s Important and What’s Not: A Scientific Viewpoint. National Ground Water Research and Educational Foundation William A. McEllhiney Distinguished Lecture Series in Water Well Technology.