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Mapping the Base of the High Plains Aquifer using Borehole Geophysical Logs and Airborne Electromagnetic Surveys in Western Nebraska

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The project scanned and reviewed data from 15,421 oil and gas well geophysical logs in 13 counties to delineate the base of aquifer and thickness of the High Plains Aquifer (HPA). The data and interpretations from this study can be used in a regional groundwater modeling effort that includes the Western Water Use Management Modeling (WWUMM) and the and the Cooperative Hydrology Study (COHYST) model. The area studied is in the Upper Platte River Basin. The Nebraska Department of Natural Resources (NeDNR) has designated most of the area as either overappropriated or fully appropriated, where groundwater is managed jointly by both local Natural Resources Districts and the NeDNR. Improved maps of the base of the aquifer can also help the Nebraska Oil and Gas Conservation Commission (NOGCC) in establishing minimum surface casing depths to protect groundwater when oil and gas wells are being drilled. Data from the scanned logs can also be used by the general public to explore for groundwater where the HPA is thin or absent and another aquifer may be present.

Geophysical Log Evaluation

Paper copies of the geophysical logs were transported by Conservation and Survey Division (CSD) staff from the Nebraska Subsurface Geology Archive in Lincoln, Nebraska to the NOGCC offices in Sidney, Nebraska, where they were scanned to tagged imaged file format (.tiff) images by NOGCC staff. Additionally, the NOGCC provided a shapefile of all the reported oil and gas wells. The shapefile contains a spatial location of each well, and an elevation of either the Kelly bushing, derrick floor, or ground surface. Initially, the reported surface elevation data was used; however, inconsistencies were discovered, and the surface elevation data for every geophysical well was subsequently replaced with a ground surface datum of the USGS 10-meter Digital Elevation Model dataset. The scanned .tiff images were also provided by NOGCC and were imported into Petra; Version 2014 software, licensed by IHS Markit. Each image was depth calibrated to the measured depth of 1,500 or 2,000 feet, cropped on each side to narrow the log for ease of visualization, and if necessary, straightened to correct for scanning inconsistencies. Depth calibration is necessary to orient the log by depth below the ground surface and to have consistent subsurface elevations between each well log.

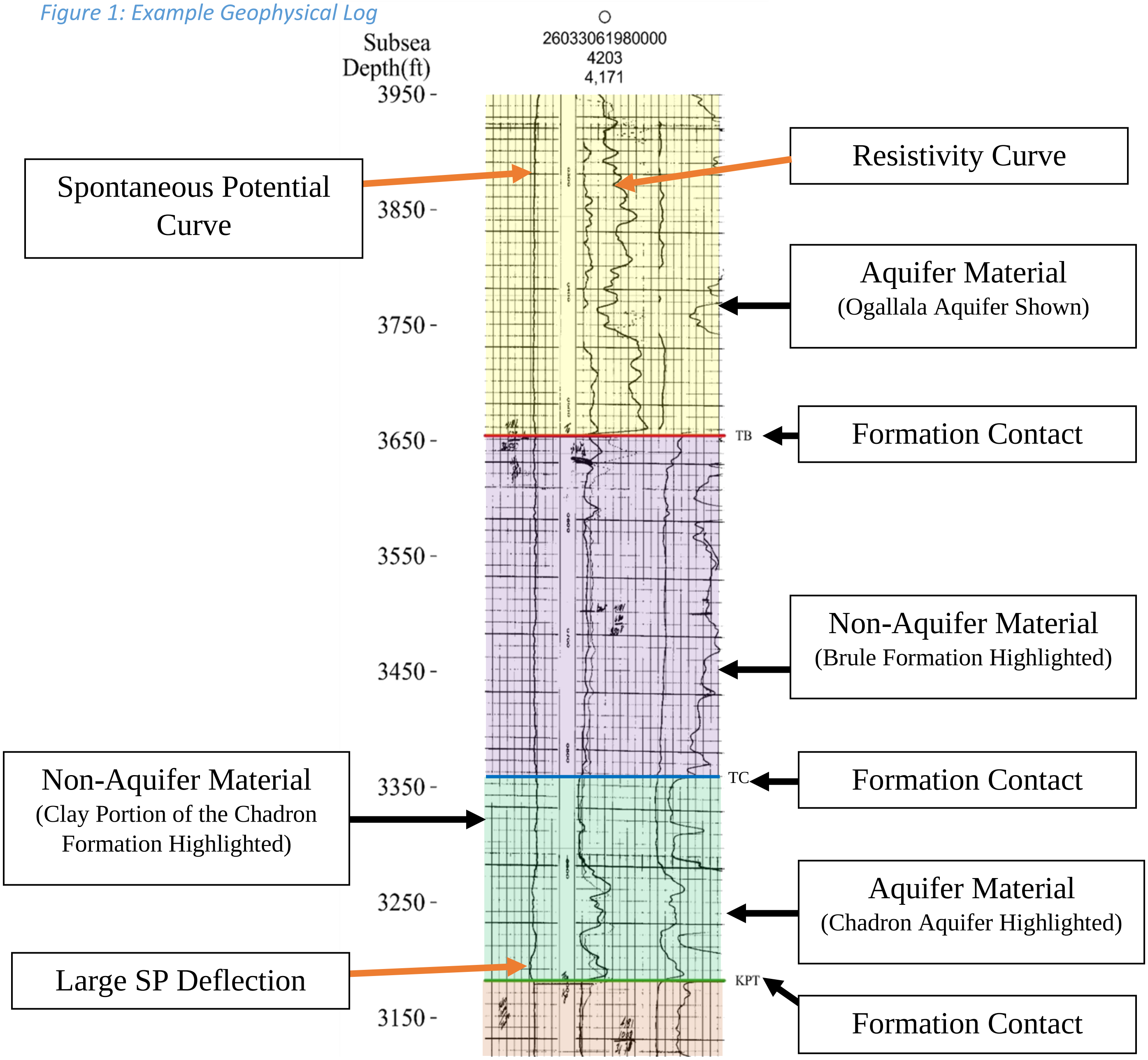
In addition to the archived CSD oil and gas geophysical logs, digital data from groundwater investigations conducted by CSD and the United States Geological Survey (USGS) were incorporated into the HIS Petra database. The CSD and USGS data included both geophysical logs from shallow test hole drilling programs and airborne electromagnetic surveys (AEM) from the USGS.

Each geophysical log image was examined by a geologist from CSD, Adaptive Resources, Inc. (ARI), or both to interpret whether the log provides valid information useful for the determination of the depth of the base of the HPA. Since oil companies only complete geophysical logs below the surface casing, only a subset of the NOGCC logs have data utilized in this study.

Borehole geophysical logs measure several different parameters. The most critical parameter for this study is resistivity that measures the ability of various formations to conduct electricity. Aquifer material, such as sand, gravel, and sandstone, are not good conductors of electricity and have higher resistivity values. Clays and shales conduct electricity and have lower resistivity values.

The spontaneous potential (SP curve) is also an important parameter that indicates the presence of permeability, which is the ability of formations to transmit fluid. Aquifer material is identified by higher resistivity and a deflection of the spontaneous potential curve. The deflection of the SP curve is very small in the aquifers that contain fresh water and larger in the aquifers that contain higher total dissolved solids (TDS). Figure 1 is a geophysical log with resistivity curve and spontaneous potential curves, illustrating the typical response in aquifer and non-aquifer material. The SP curve shows more deflection in the Chadron aquifer, which has a higher TDS value than the HPA.

Figure 1: Example Geophysical Log



Once the logs were obtained and calibrated, at least one geologist completed an initial evaluation of each log to determine if any aquifer material was present and completed initial hydrostratigraphic picks of formation/aquifer tops and bottoms. Hydrostratigraphic picks, in this report, represent the base of a single formation or multiple formations that are hydrologically connected to act as an aquifer like the HPA. The picks were categorized as either confident or questionable. Confident picks, similar to Figure 1 above, show a large, geophysically logged section of the HPA, resulting in a high level of confidence in the interpretation. A questionable pick is typically characterized by a geophysical log that displays a small amount of aquifer material. This situation creates uncertainty as to whether the aquifer material is part of the HPA, or another aquifer that may or may not be hydrologically connected to the HPA.

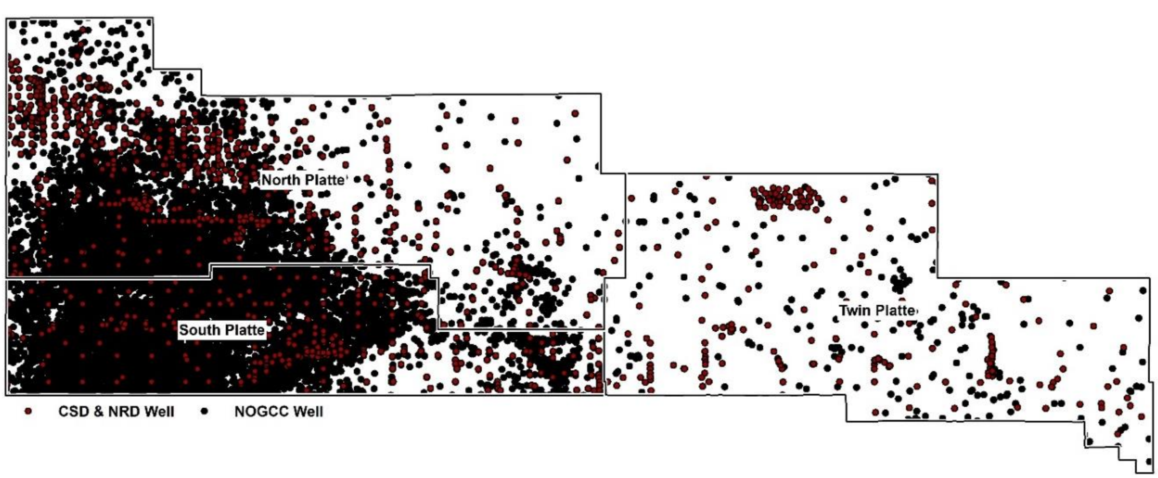
After the initial evaluation, two or more geologists completed a quality control evaluation on the accuracy of the hydrostratigraphic picks and the validity of the questionable picks. Structural cross sections, which depict the hydrostratigraphic contacts of the formations in two dimensions relative to sea level, were used as part of the evaluation to distinguish between the HPA and deeper, secondary aquifers. A third and final evaluation entailed finalizing the picks and was completed by three or more geologists. Additional structural cross sections were utilized as a part of this final evaluation. Table 1 provides statistics of the logs evaluated through this process.

Table 1: Geophysical Log Statistics

Category	Number of Logs
Total Logs Evaluated	15,421
CSD/NRD Logs Evaluated	987
Logs with High Plains Aquifer Information	2,902
SPNRD	2,097
NPNRD	779
TPNRD	26
Logs with Potential Aquifer Material	3,932

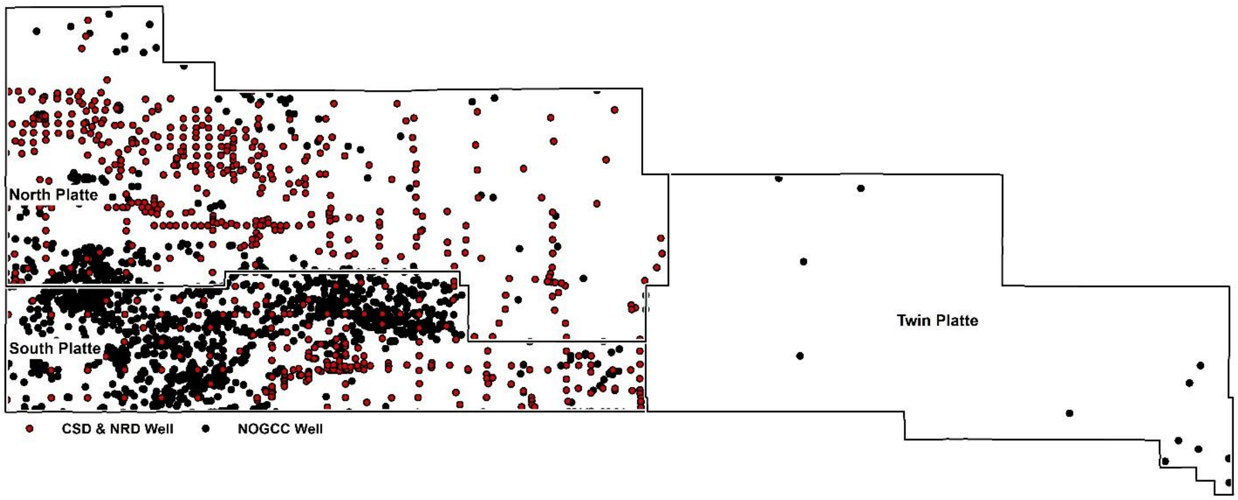
Map 1 shows the locations of the geophysical and CSD lithologic logs that were evaluated through this study.

Map 1: NOGCC Oil and Gas Well, CSD Test Hole, and Natural Resources District Monitor Well Locations



Map 2 shows the locations of the geophysical logs that were used to complete the interpretation of the base of the HPA surface.

Map 2: Locations of the NOGCC Oil and Gas Wells, CSD Test Holes, and Natural Resources District Monitor Well Geophysical Logs used in this study



To incorporate the USGS AEM data into the overall project, we obtained the information collected from the surveys completed throughout SPNRD and NPNRD. The data was obtained from Jared Abraham of Aqua Geo Frameworks, LLC, formerly of the USGS, who was the lead geophysicist for the USGS AEM projects. The information was provided as a text file, including the spatial location, depth interval, and the associated resistivity value for each depth at sample points along each flight path flown as part of the USGS efforts.

To incorporate the data, pseudo-wells were generated at the ground surface for each point along a flight path that contained resistivity values. The depth-interval resistivity data was then used to create pseudo-geophysical logs that could be imported into IHS Petra to assist in the interpretation of the base of the HPA. The data values were not modified or processed upon receipt by ARI; though an interpolation was applied to generate equal-depth-interval data, the calculated resistivity values were maintained at the original depths. The AEM data was not utilized in generating the base of the HPA surface interpretation, but rather in guiding the interpretation of local CSD, NOGCC, and NRD logs. The full depth of the pseudo-geophysical logs were used with the understanding that the confidence and resolution of the data would decrease with increasing depth and increasing depth intervals.

After reviewing multiple interpolation methods, a simple linear fill method was adopted for the generation of each pseudo-geophysical log. This method uses the upper resistivity value for an entire depth interval (top to base) until a new interval and resistivity is encountered. This was done from the ground surface to the total depth of investigation. This resulted in a relatively blocky pattern that was preferred in the interest of simplicity and to prevent any additional skew in the data from computer interpolation.

To reduce data processing and interpretation time, the AEM pseudo-geophysical logs were limited to one log approximately every 100 feet. Additionally, due to the blocky nature of the AEM data over large depth intervals, formation contacts were not interpreted individually for the entire project area. The pseudo-geophysical logs were used as a regional scale guide to check the base of HPA surface interpretation, especially in areas with few other data sources. Map 3 provides the locations of the USGS AEM data collected throughout the North Platte Natural Resources District and South Platte Natural Resources District (SPNRD). Figure 2 demonstrates an example of an AEM pseudo-geophysical log.

Map 3: USGS AEM Data Locations

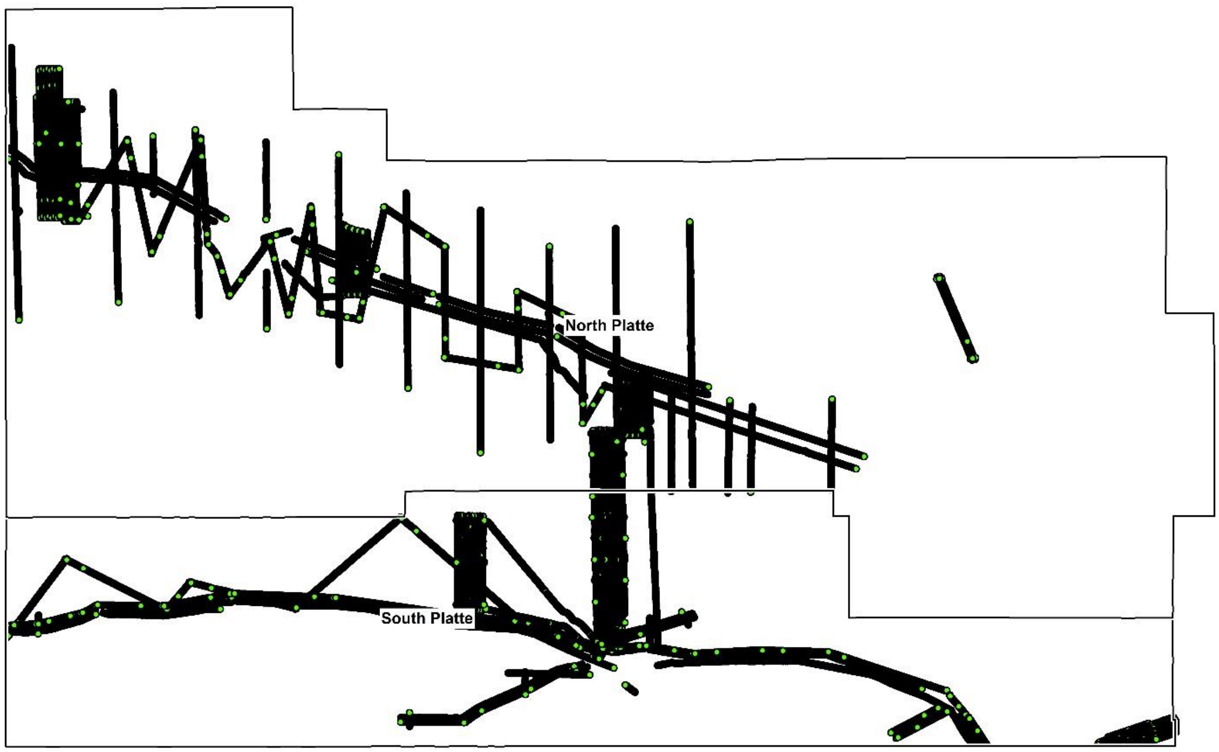
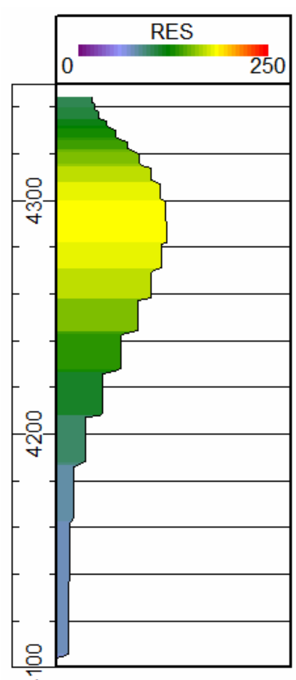


Figure 2: Pseudo AEM Geophysical Log



Regional Geology

The HPA in the study area consists of sediments of the Quaternary Alluvium, Neogene Ogallala Group, and the Neogene Arikaree Group. The Quaternary Alluvium is composed of sand and gravel deposited relatively recently (2.6 million to recent) along the streams and rivers of the study area. The alluvium is relatively thin and easily recognizable and rarely appears on oil and gas logs. The Neogene Ogallala Group is the most widespread and thickest unit of the HPA. The Ogallala Group consists of sand, gravel, sandstone, silt, interbedded caliche and paleosols (fossil soil zones). It is heterogeneous, and its aquifer characteristics can be very variable. The older Neogene Arikaree Group is found only in the western portion of the study area and consists of gray sandstones, some of which are tightly cemented. The Arikaree Group is difficult to distinguish from the Ogallala Group on geophysical logs. In most of the area, the Arikaree Group was removed by erosion before the deposition of the Ogallala Group.

Underlying the base of the HPA in the western study area are sediments of the upper part of the White River Group. The Sharps Formation and the Brule Formation are the two uppermost geologic formations in the White River Group. Both formations consist primarily of interbedded brown fine-grained siltstones and sandstones, which act as an aquitard. The contact between these two formations is not easy to distinguish on geophysical logs since they behave virtually the same hydrologically; therefore, the base of the HPA was labeled as the top of the Brule Formation on the logs. The Sharps Formation is likely only present in a relatively small part of Kimball and Banner counties. The Brule Formation acts as an aquifer where the formation is fractured at shallow depths or where there are localized deposits of sand and gravel in paleochannels. Since we are mapping the base of the HPA at depths typically greater than 100 feet, fractured Brule Formation was not studied.

The lower part of the White River Group consists of the Chadron Formation and the Chamberlain Pass Formation. The upper part of the Chadron Formation is a regional confining layer of interbedded, variegated (multicolored) bentonitic clay that is present through most of the area. The lower part of the Chadron Formation is a sand and gravel unit that occurs only in paleovalleys. The Chamberlain Pass Formation is also mostly a sand and gravel unit deposited in paleovalleys. Both aforementioned sand and gravel deposits are secondary aquifers with relatively poor water quality (Divine and Sibray, 2017) and are lumped together as the Chadron aquifer since they cannot be distinguished on logs.

Along the southern margin of the eastern part of the study area, erosion removed the entire White River Group prior to the deposition of the Ogallala Group, where the HPA rests directly on the Cretaceous Pierre shale. The Pierre Shale is typically impermeable and is considered a confining unit. In some areas, the HPA may rest directly on the lower White River Group sand and gravel that was deposited in the Chadron or Chamberlain Pass paleovalleys. It is possible that a small amount of water from the lower White River Group may discharge as subflow into the HPA. Detailed descriptions of the geologic units of the HPA and the underlying units are described in Swinehart et al. 1985. Generalized descriptions of the aquifers of Nebraska are provided in Korus and Joeckel (2011).

Interpretation Complexities

Oil and gas companies drill a large diameter hole, which is set with steel surface casing to protect freshwater groundwater sources before drilling deeper into the potential oil producing zones. The upper portion, protected by surface casing, typically is not logged, which creates a challenging interpretation in these areas where secondary aquifers may be present below the HPA at relatively shallow depths. This situation is present in Kimball and Cheyenne counties, where significant and highly productive sand and gravel lenses were deposited in paleochannels within the Brule Formation. Interpreting the geology in these areas is difficult unless a high density of wells or shallow test hole information is available in the local area. Figures 2 and 3 below illustrate two possible interpretations of the aquifer material just below the surface casing. In the first interpretation (Figure 2), the aquifer material is part of a deep HPA channel eroded into the Brule Formation. In the second interpretation (Figure 3), the aquifer material is an isolated Brule sand lens that is not part of the HPA.

Figure 2: High Plains Aquifer Material Below the Surface Casing

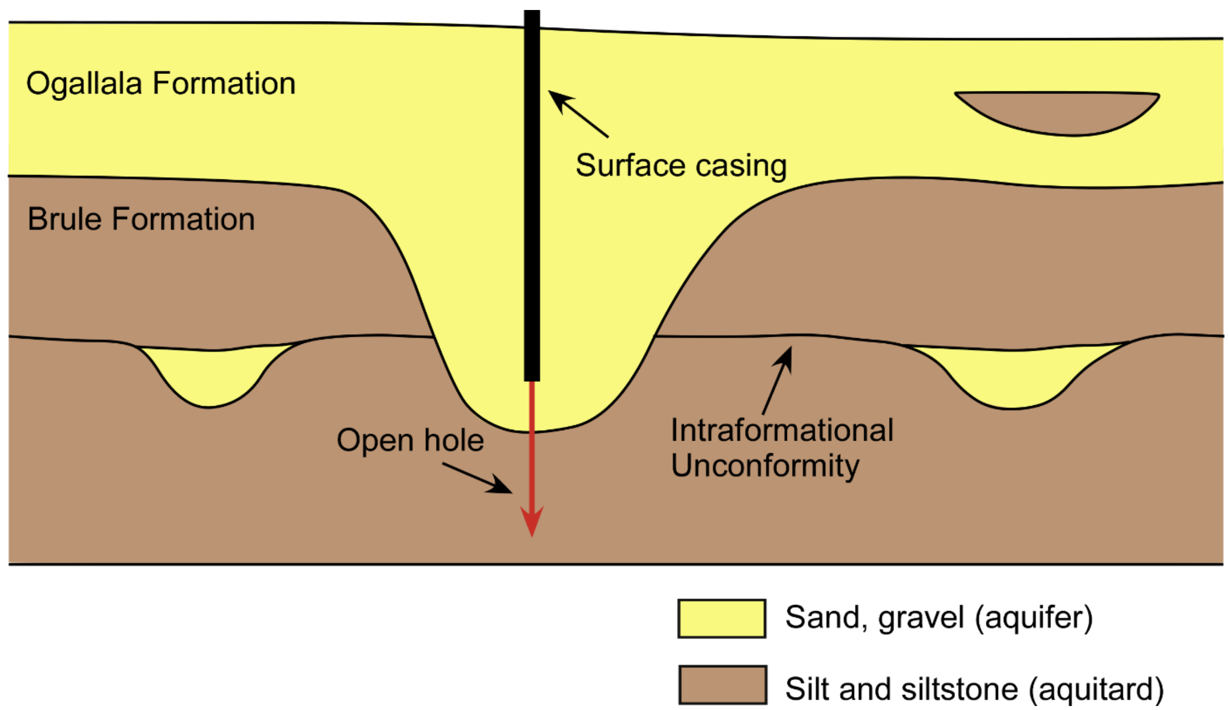
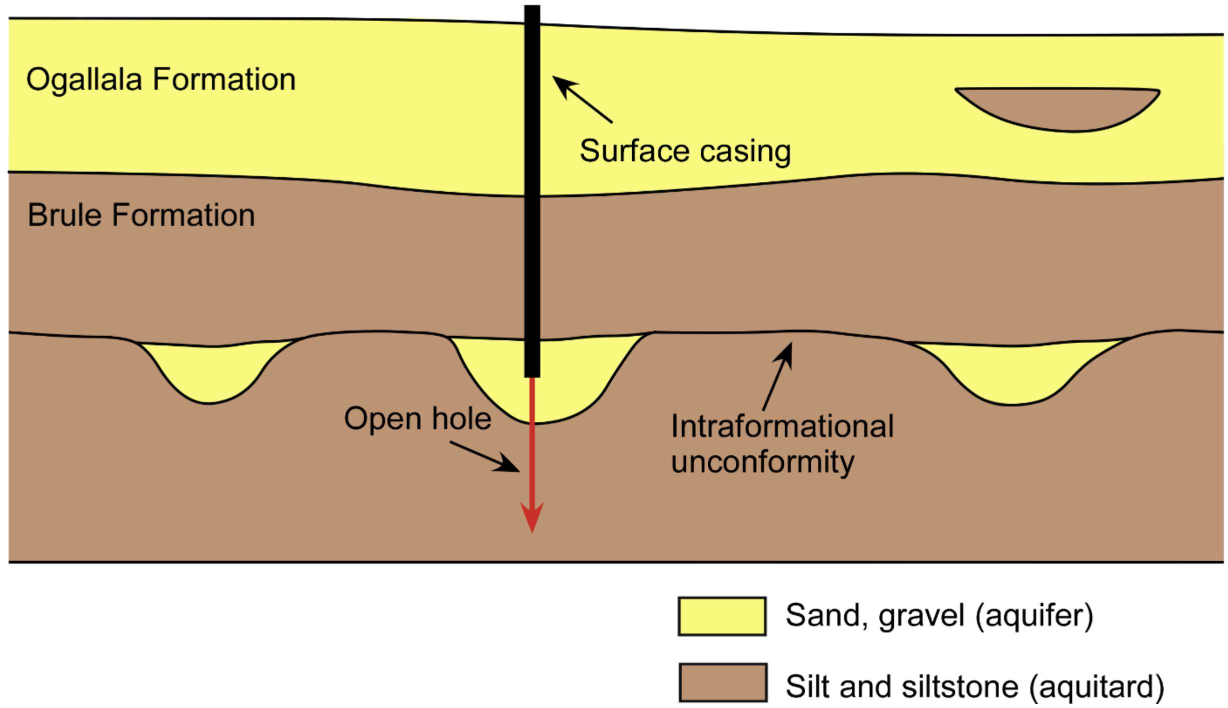


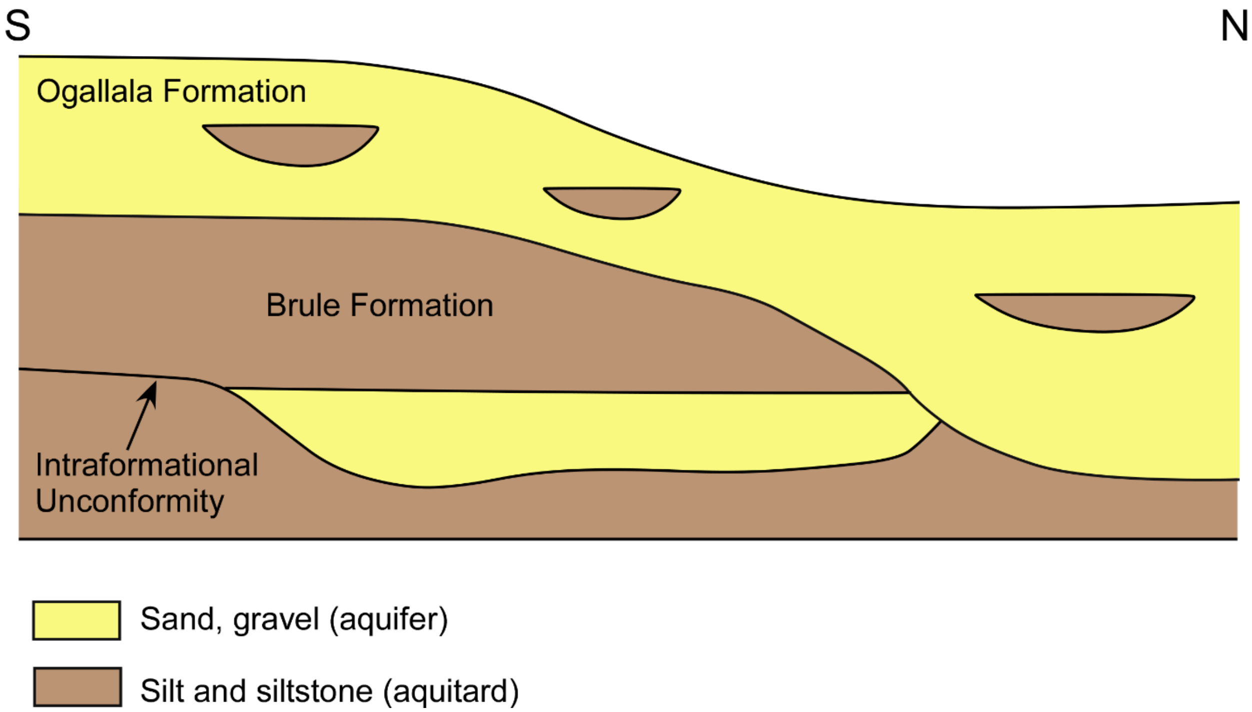
Figure 3: Isolated Brule Sand Lens Not Part of the High Plains Aquifer



In 2007, Steele et al. mapped a Brule paleochannel that was at least six miles long, ½ mile wide and up to 60 feet thick in an area with a high density of oil and gas logs. Geologic and geophysical logging completed during monitor well drilling in the area confirmed the presence of this Brule paleochannel. Similar narrow Brule Formation channel sands and gravels have been mapped on the surface south of the study area in northeastern Colorado, where the HPA has been removed by erosion (Scott, G. R., 1982). Chemical analysis from this study indicated that there were two basic types of water present. A sodium bicarbonate groundwater found in deeper, isolated lenses of Brule Formation sands had carbon 14 dates of 10,000 to 30,000 years before present. The other groundwater found in the study from the HPA contained calcium bicarbonate with age dates that ranged from the mid-1980s to the early 1990s. The water chemistry in the shallower Brule formation channel sands was intermediate between the two end members and similar to the water found at the base of the HPA. This would indicate that there was communication between the Brule paleochannel and the HPA. Test hole drilling by the University of Nebraska-Lincoln in 2016 at the High Plains Agricultural Lab also encountered a Brule paleochannel trending NE-SW near the base of the Ogallala formation (HPA). Unpublished chemical analysis of the water showed similar chemistry to the water found in the Brule paleochannel, sampled by Steele, et al., and to the water found at depth in the HPA.

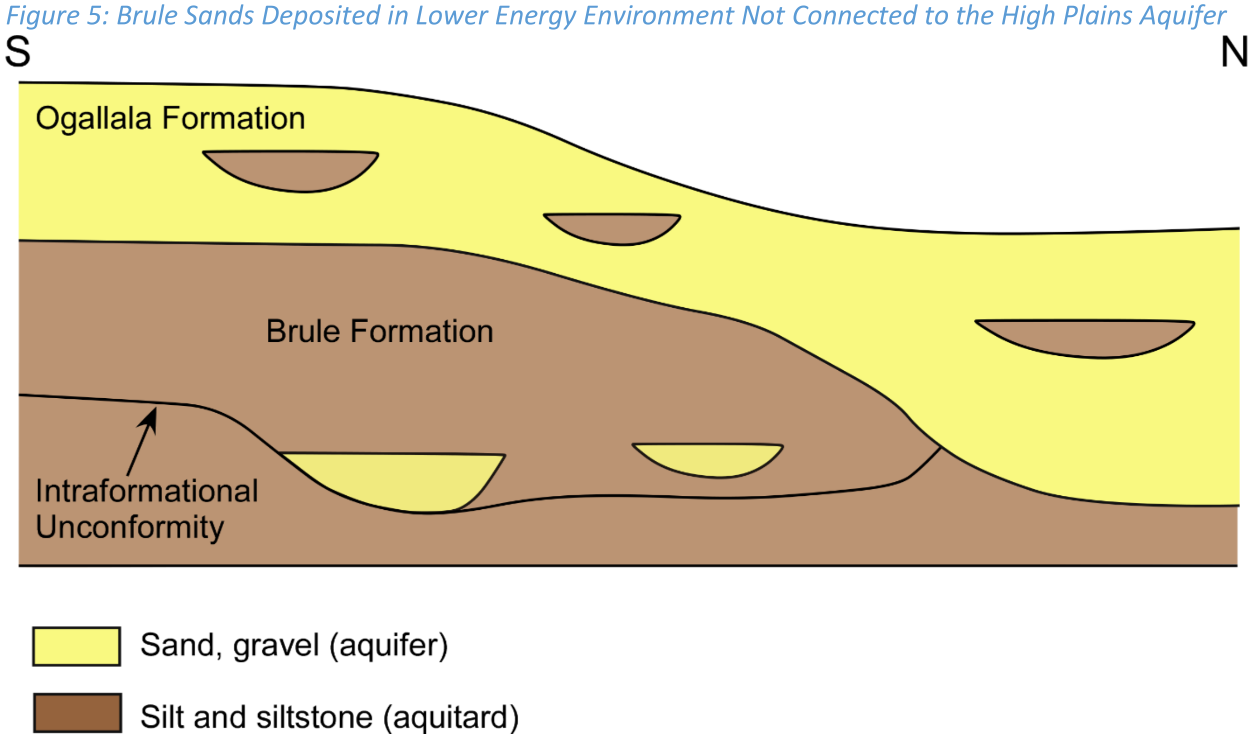
In Kimball and Cheyenne counties, there are numerous locations where it is difficult to determine if the aquifer material present was part of the Brule Formation or part of the Ogallala Formation (HPA). Based on a review of the Steele, et al. 2007 study, it is very likely that at least some of the Brule sands are hydraulically connected to the HPA. This is probably true of the thicker sands that were deposited in paleochannel sands near the top of the Brule Formation. Figure 4 shows an example of a Brule sand deposited in a high energy environment that is connected to the HPA.

Figure 4: Brule Sands Deposited in High Energy Environment and Connected to the High Plains Aquifer



There are likely some Brule sands that were deposited in a lower energy environment that may not be as thick or continuous and may not be connected to the HPA (see Figure 5).

Figure 5: Brule Sands Deposited in Lower Energy Environment Not Connected to the High Plains Aquifer

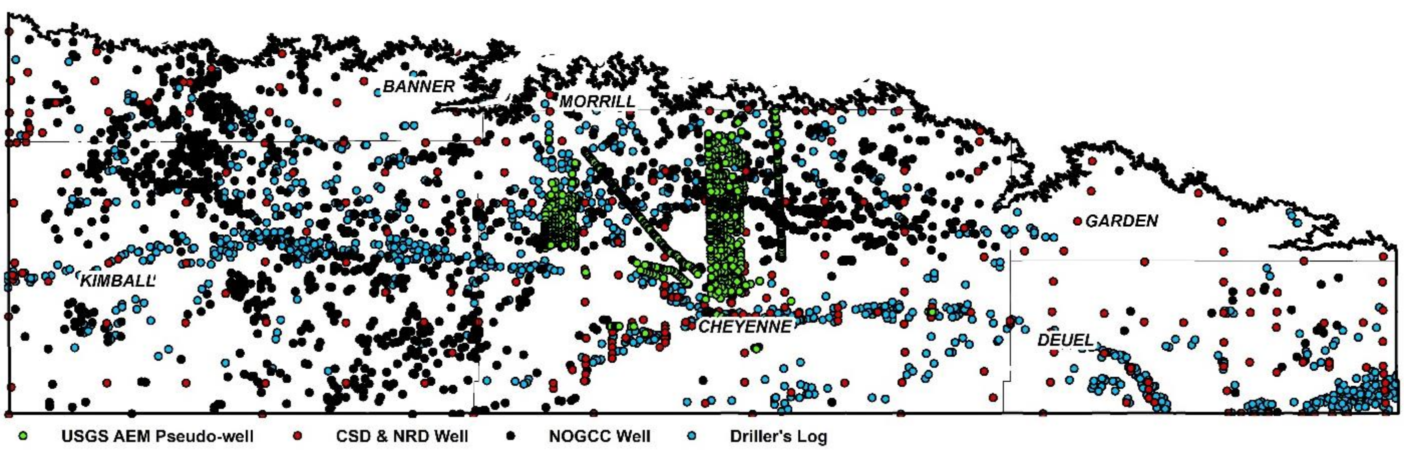


Base of the High Plains Aquifer Surface Interpretation Results

In the southern portion of the WWUMM area, a significant amount of data was available to produce a new interpretation of the base of the HPA, which will be used to improve the model's accuracy and continue to refine the groundwater pumping impacts on both streamflow and the aquifer. For more information on the WWUMM, refer to the following link: http://spnrd.org/Html/WWUM.html.

The surface interpretation extent includes Kimball, Cheyenne, Deuel, southern Banner, southern Morrill, and southern Garden Counties. The interpretation utilized the hydrostratigraphic picks from the NOGCC oil and gas well geophysical data, CSD geophysical log data, USGS geophysical log data, USGS AEM data, CSD lithologic log data, USGS lithologic log data, NRD monitor well lithologic data, and irrigation well drillers logs. Map 4 shows the location of all the information that was used to create the base of the HPA surface interpretation.

Map 4: Information Used to Create the Base of the High Plains Aquifer Surface Interpretation



The surface interpretation began with a computerized interpretation utilizing the ESRI ArcGIS "topo to raster" computer interpolation tool. This interpolation provides an unbiased interpretation of the data, which had the primary function of determining lows and highs created from the points. These points were reanalyzed in greater detail and, in some cases, were changed from confident to questionable. Additionally, the COHYST Hydrostratigraphic Units (Cannia et al., 2006) base of the HPA or COHYST Hydrostratigraphic Unit 7 surface was utilized as the initial interpretation which was modified by information gathered through this effort. Several iterations and additional structural cross sections were created to determine the final interpretation.

When the interpretation was close to being final, casing depth points were added where the interpreted contours were lower than the casing depths of surrounding wells that did not have aquifer material exposed. For the most part, the casing depths supported or nominally refined the contours. However, in some cases, the interpretation did not eliminate the data discrepancies. The surface interpretation considered all the confident and questionable data points; however, in specific instances, the interpreted contours do not match the point data.

These data points were not removed from the overall dataset so that future efforts to interpret the geology or hydrostratigraphy can utilize the data. Additionally, these points may be used as a location to drill test holes, collect geologic and geophysical data, and modify the interpretation completed through this effort.

Divine and Sibray, 2016, reported that the water quality of the Brule secondary aquifer is generally good. As a consequence, it was decided to include the thicker and more continuous aquifer material as part of the HPA, even though it is somewhat questionable. This is advisable because the NOGCC can use the base of the HPA surface interpretation for setting surface casing depths to protect water quality. The final base of the HPA surface interpretation within the WWUMM area shows similar characteristics to previous interpretations, with the exception of the significant deep channels. These deep channels can be the Ogallala Formation, the Brule Formation sands, or both. Typically, the Brule Formation sands are considered a secondary aquifer. However, in this study, at least some of these sands appear to be hydrostratigraphically connected to the HPA.

In Appendix A, Map 5 provides the base of the HPA surface elevation contours at 50-foot intervals.

Other Results and Datasets

For areas outside the base of HPA surface interpretation, this study provides datasets and shapefile(s) of all geologic and geophysical logs compiled and analyzed. This includes any additional points in North Platte Natural Resources District, Twin Platte Natural Resources District, and Central Platte Natural Resources District.

Included in Appendix B are five example cross sections that are representative of the numerous cross sections generated in Petra to interpret the geology and hydrostratigraphy used in determining the depth of the base of the HPA. These cross sections were first created in Petra before being further refined to better demonstrate the subsurface interpretation. This process was completed by exporting borehole data for each well or test hole to Stater 5, a subsurface visualization package developed by Golden Software. This data included surface elevation, measured depth of geological unit contacts, and geophysical log data. Geophysical logs were digitized from the raster image files (.tiff) in Petra for those boreholes that did not have digital LAS files available.

Cross Section 1 is a south to north section starting in Kimball County near the Colorado border and ending in Banner County. This cross section intersects the numerous channels cut down into the Sharps and the Brule Formations prior to the deposition of the Ogallala Group. These channels trend roughly west to east. Cross Sections 2a and 2b are two different interpretations of a single west to east section in Kimball county. Multiple interpretations in this situation are possible due to the complex geology and the lack of data from oil and gas geophysical logs in the portion that is covered by surface casing, which isn't logged. Cross Section 3 is a south to north section through Cheyenne County just west of Sidney. This cross section intersects two different Brule sands deposited in two paleo-channels trending roughly west to east. The southern paleo-channel is about ½ mile wide and 6 miles long with a maximum depth of 60 feet. This Brule sand is fairly well defined by oil and gas logs and by drilling conducted by CSD and the USGS for the South Platte Natural Resources District in 2003. Cross Section 4 is a south to north section through a west to east trending Ogallala channel in eastern Cheyenne County. The Chadron aquifer is also present in the northern part of the section.

Recommendations

In order to fully understand the hydrogeologic framework of the HPA in Kimball and Cheyenne counties, it is recommended that additional test hole drilling is conducted using the maps and information generated from this study. Installing monitor wells, sampling for chemical analysis, and age dating are also recommended in order to understand the interconnection of the Brule Formation sands and the HPA in Cheyenne and Kimball counties.

The current interpretation is sound; however, with large datasets like these, additional refinement is warranted. It is recommended that the South Platte Natural Resources District pursue a subsequent grant with the Nebraska Environmental Trust to continue to refine the base of the HPA surface interpretation to create the most robust understanding of the local geology and hydrostratigraphy possible for their groundwater planning efforts.

Additional investigation and analysis of deeper secondary aquifers is also recommended. This includes the Brule Formation sand aquifers, Chadron Formation aquifer, Lance and Fox Hills Formations aquifer, and the Upper Pierre Formation Transitional Zone aquifer. In the future, as groundwater resources continue to be heavily utilized, these secondary aquifers will become much more important for sources of drinking water and livestock water. To understand the water resources available within these aquifers, a similar geophysical log evaluation, creation of structural cross sections, surface interpretations, test hole drilling, and water quality and quantity monitoring are necessary.

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APPENDIX A

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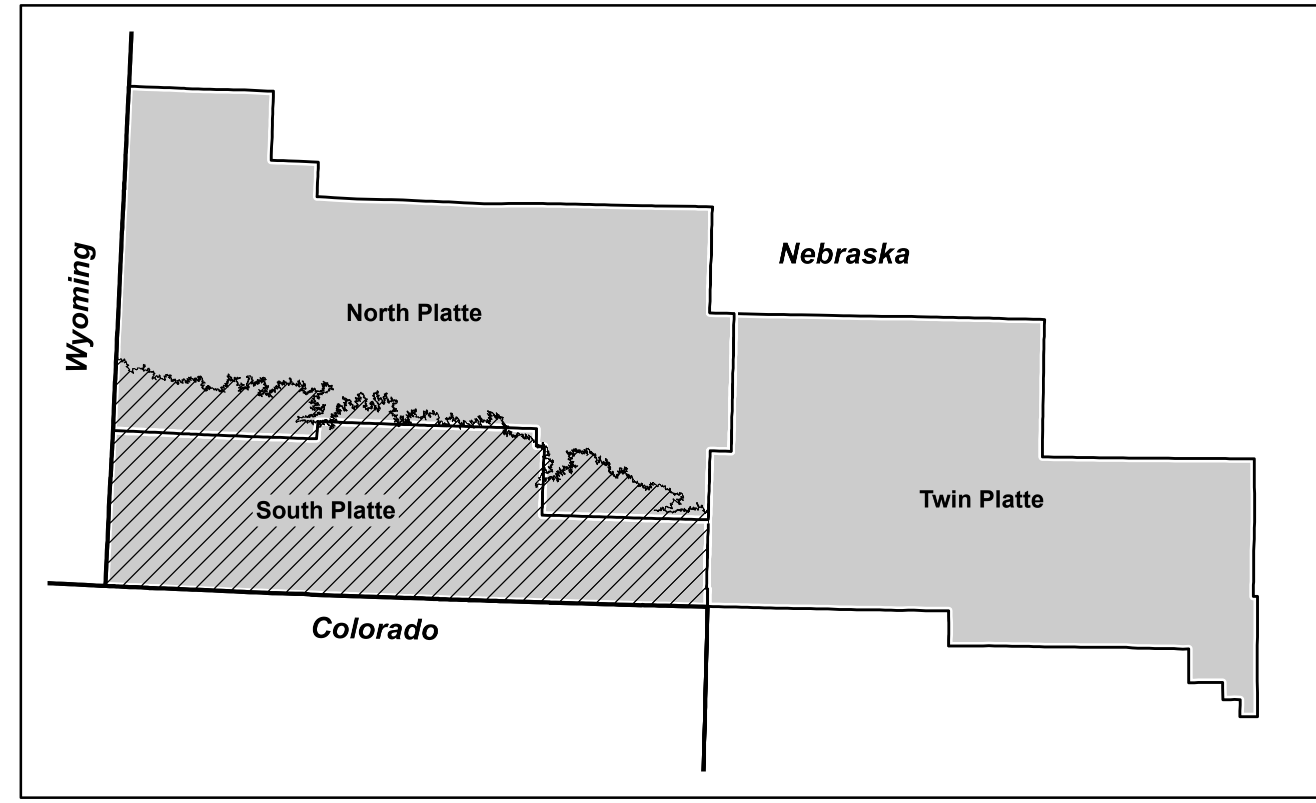
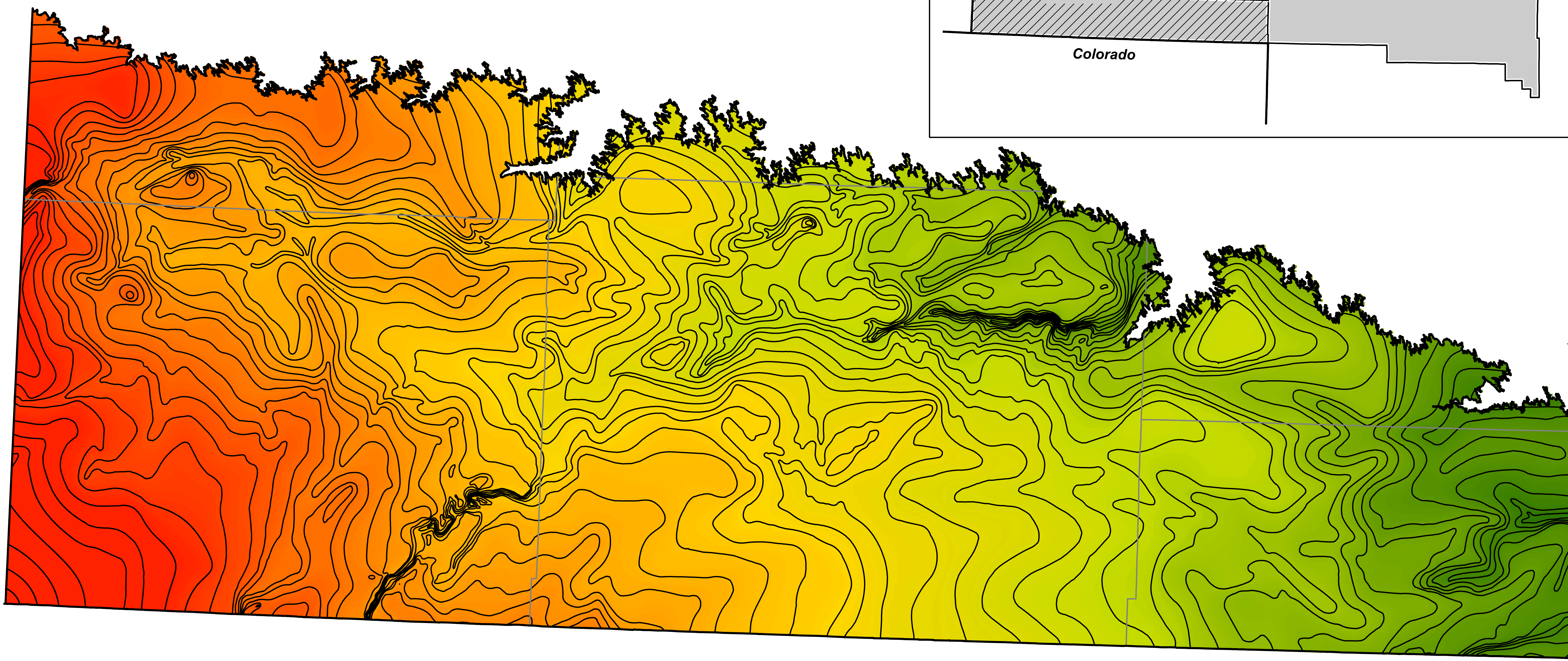
INTERPRETED SURFACE OF THE BASE OF THE HIGH PLAINS AQUIFER, SOUTHERN PANHANDLE OF NEBRASKA

Hydrogeology of Western Nebraska,
Project completion Report: Map 5





Map Elements

Interpreted Area   County   Contour (ft)

0   4.25   8.5   17   25.5   34 Miles

Elevation

5000   4600   4200   3800   3400   3000

APPENDIX B

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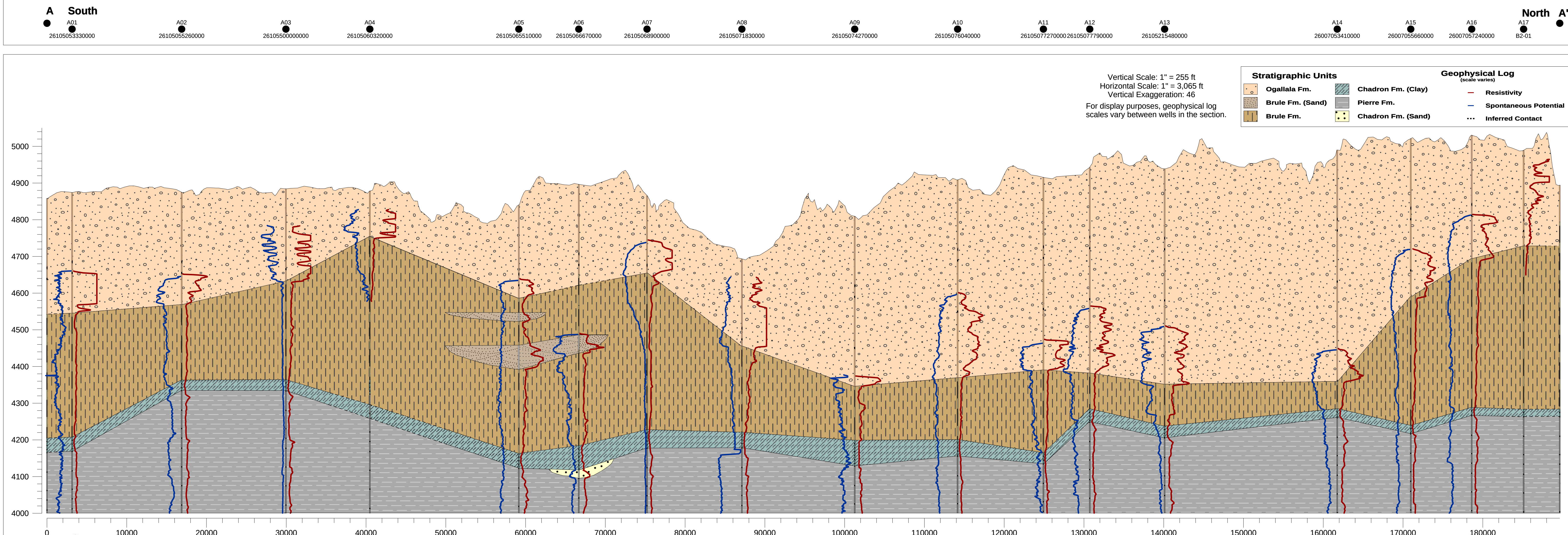
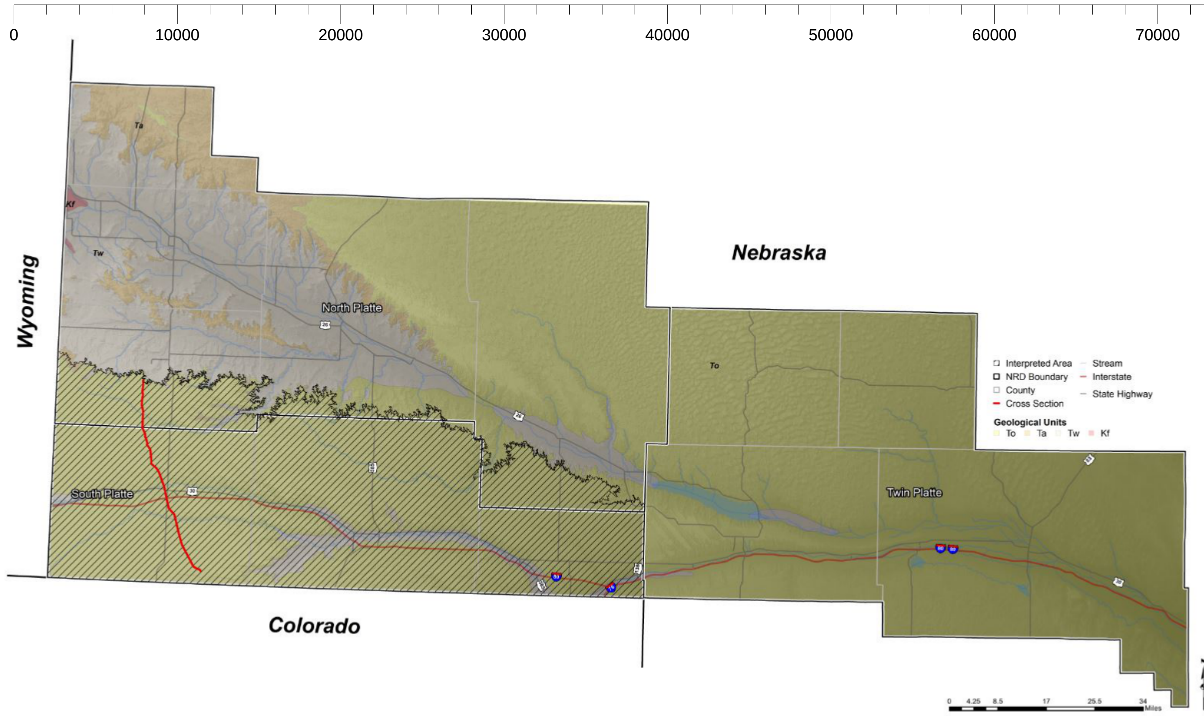
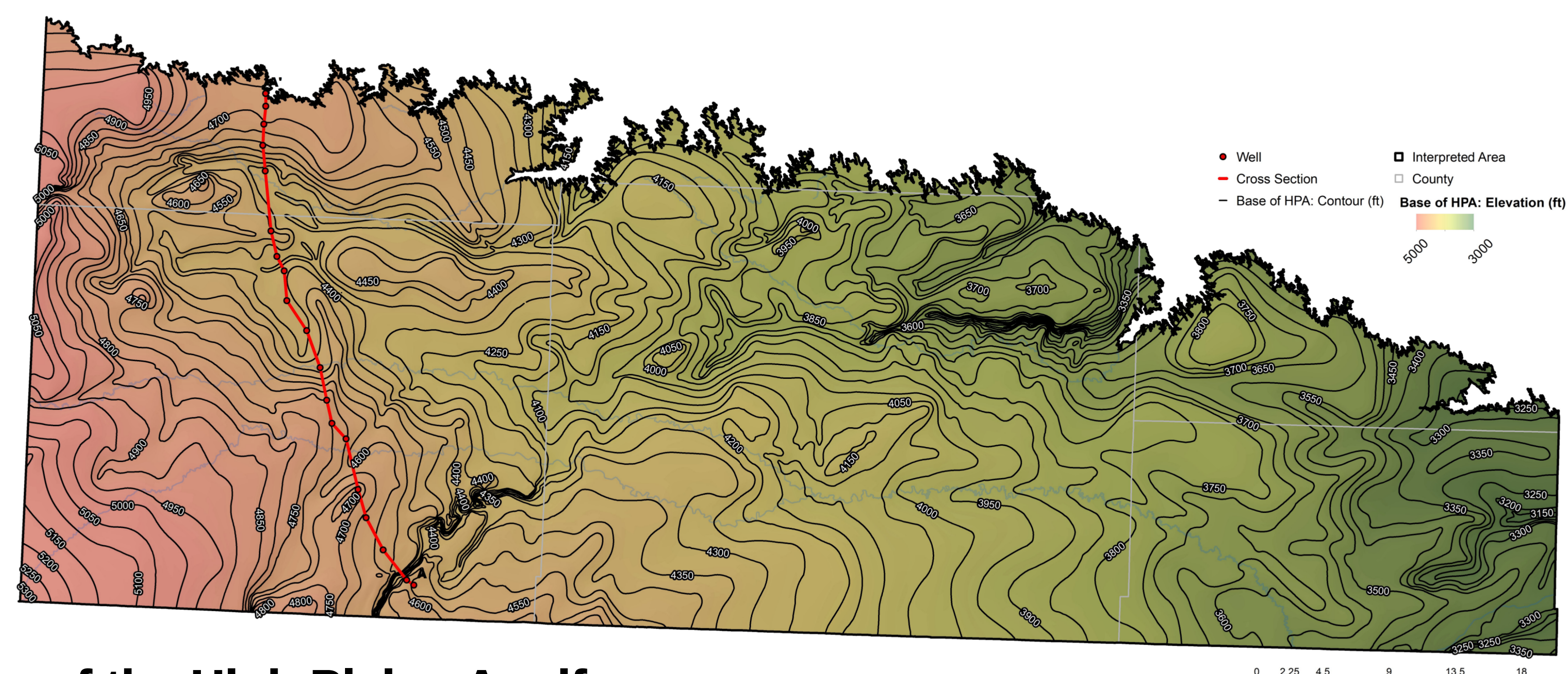
Cross Section 1: A-A'







Geologicic Cross Section of the High Plains Aquifer, Southern Panhandle of Nebraska

Hydrogeology of Western Nebraska, Project Completion Report: Cross Section 1

Thaddeus Kuntz, Steven Sibray, Joseph Reedy, Jason Yuill, & Doug Hallum

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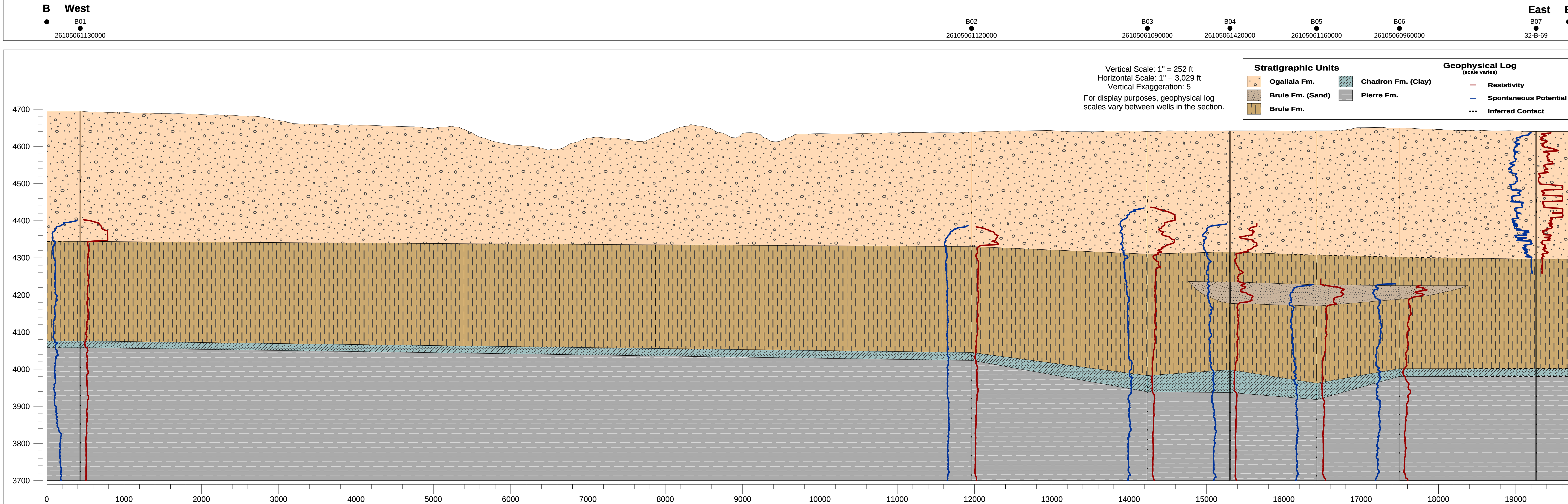
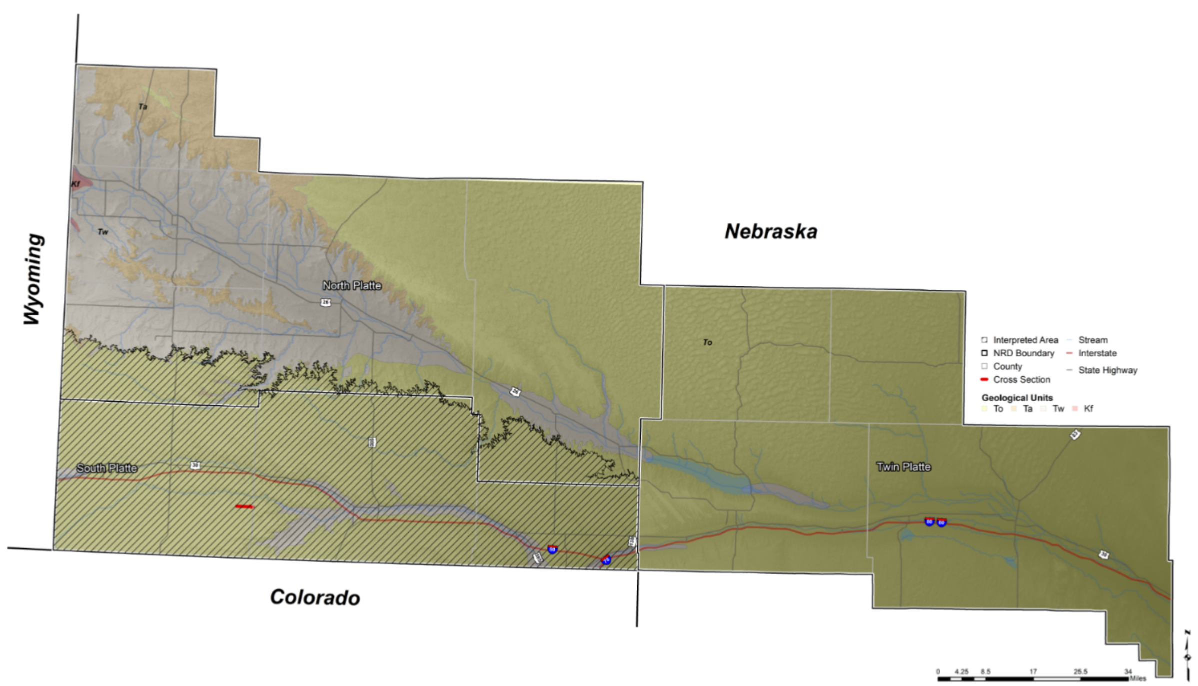
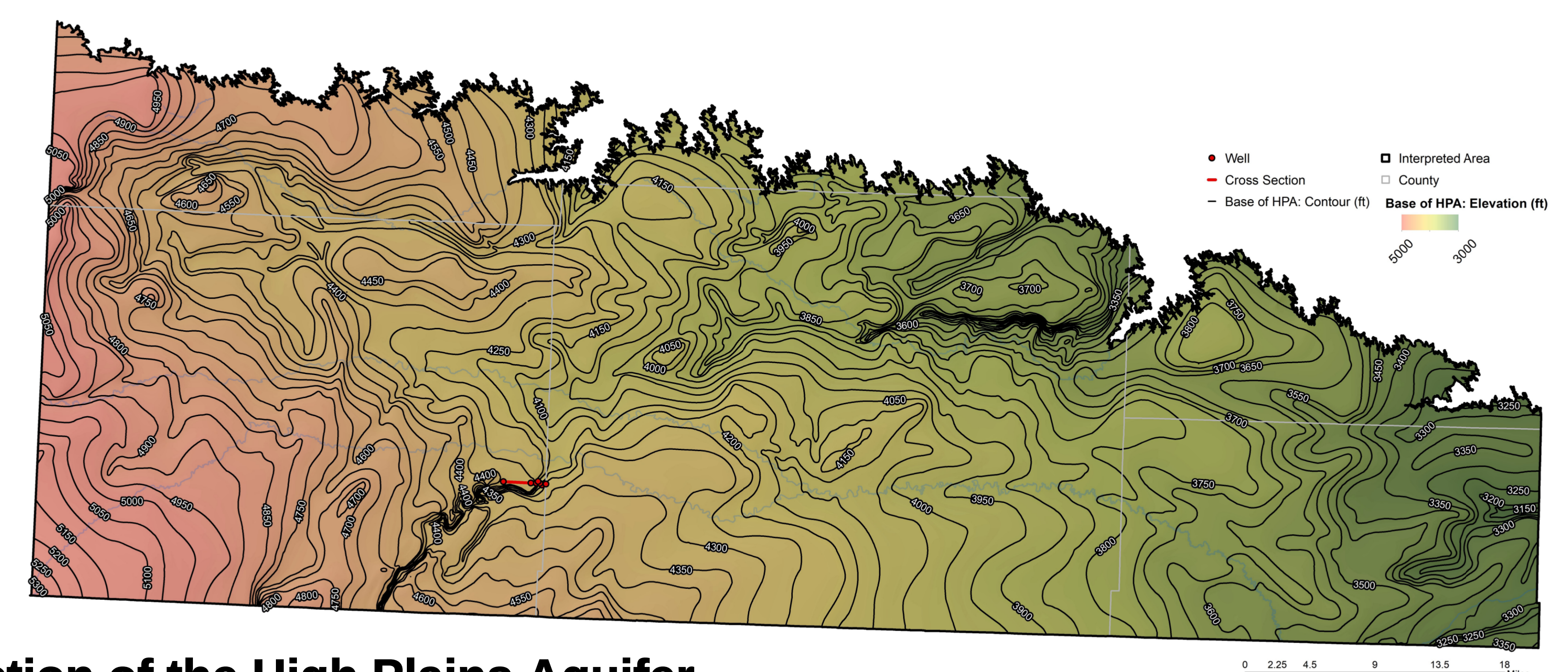
Cross Section 2a: B-B'







Geologicic Cross Section of the High Plains Aquifer, Southern Panhandle of Nebraska

Hydrogeology of Western Nebraska, Project Completion Report: Cross Section 2a

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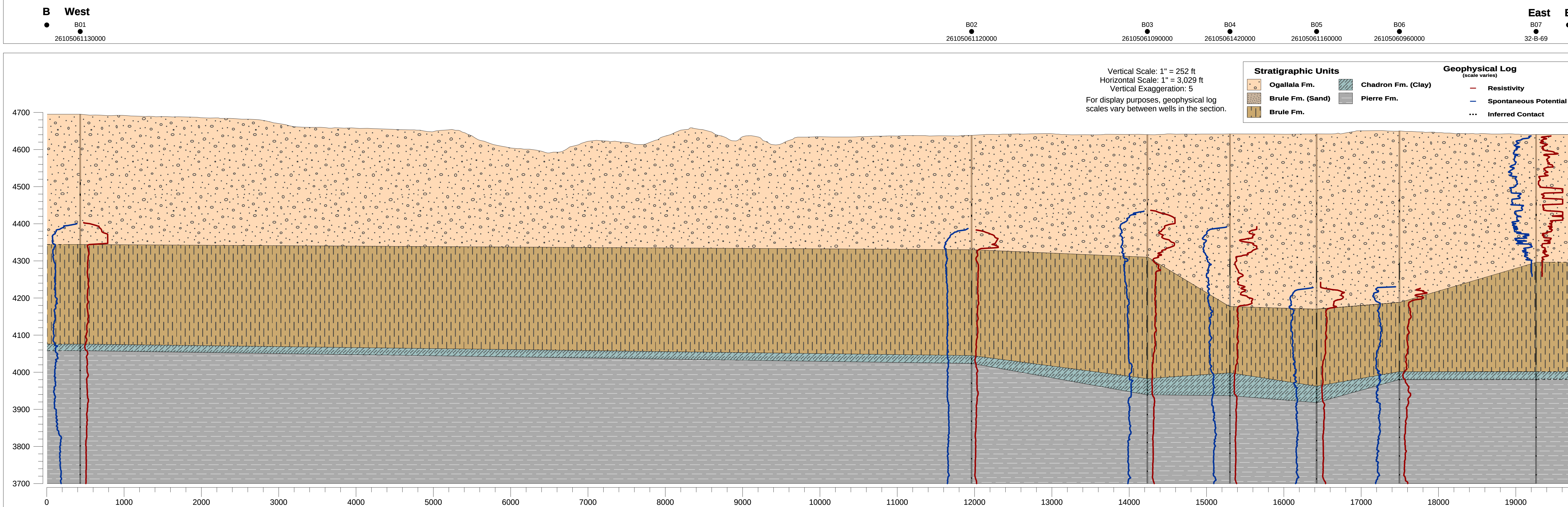
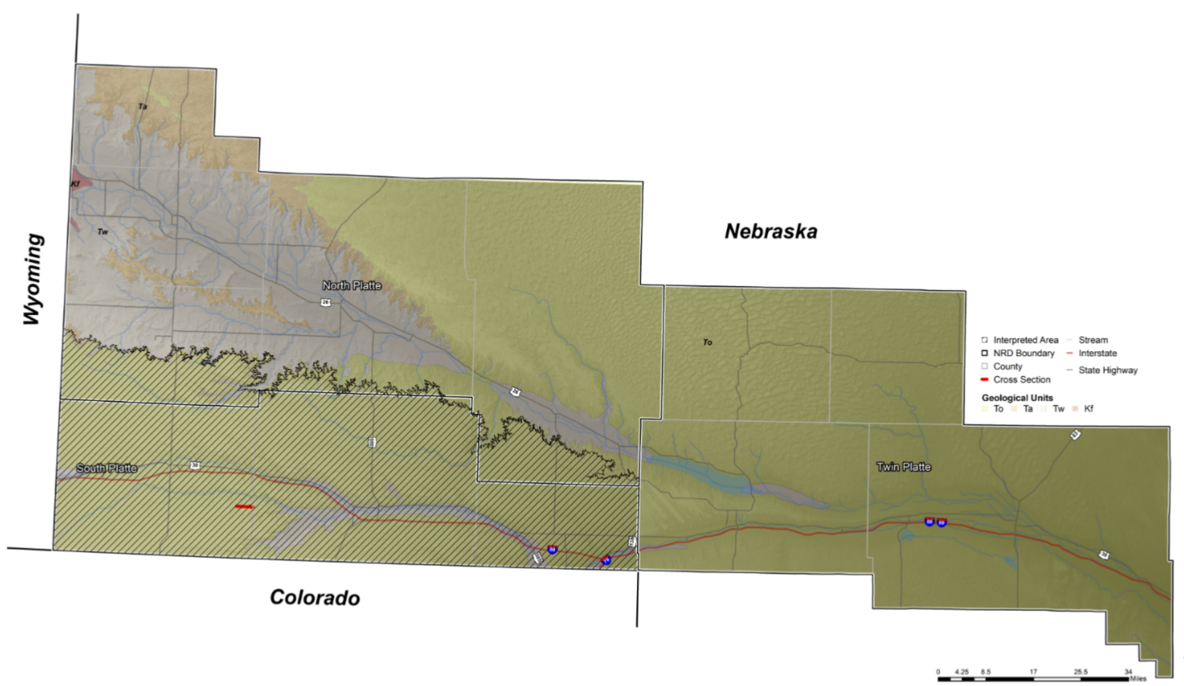
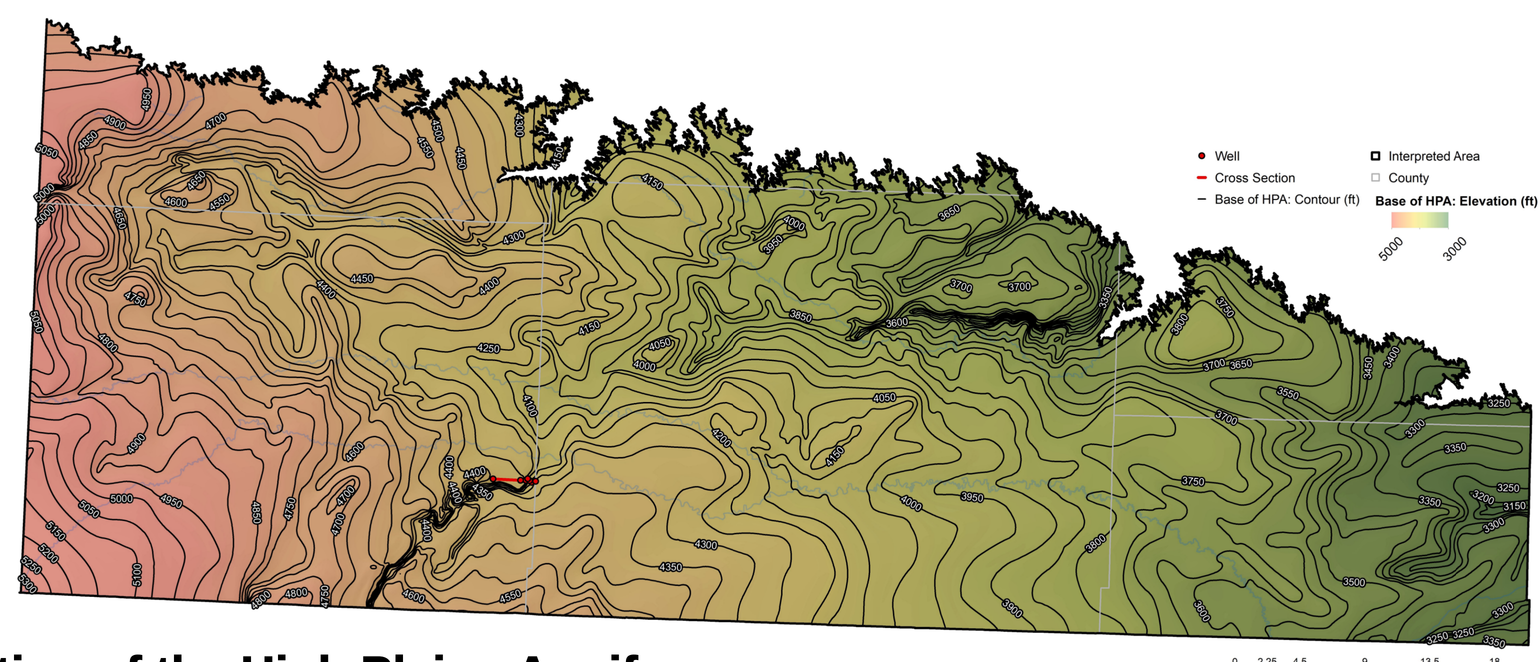
Cross Section 2b: B-B'







Geologicic Cross Section of the High Plains Aquifer, Southern Panhandle of Nebraska

Hydrogeology of Western Nebraska, Project Completion Report: Cross Section 2a

Thaddeus Kuntz, Steven Sibray, Joseph Reedy, Jason Yuill, & Doug Hallum

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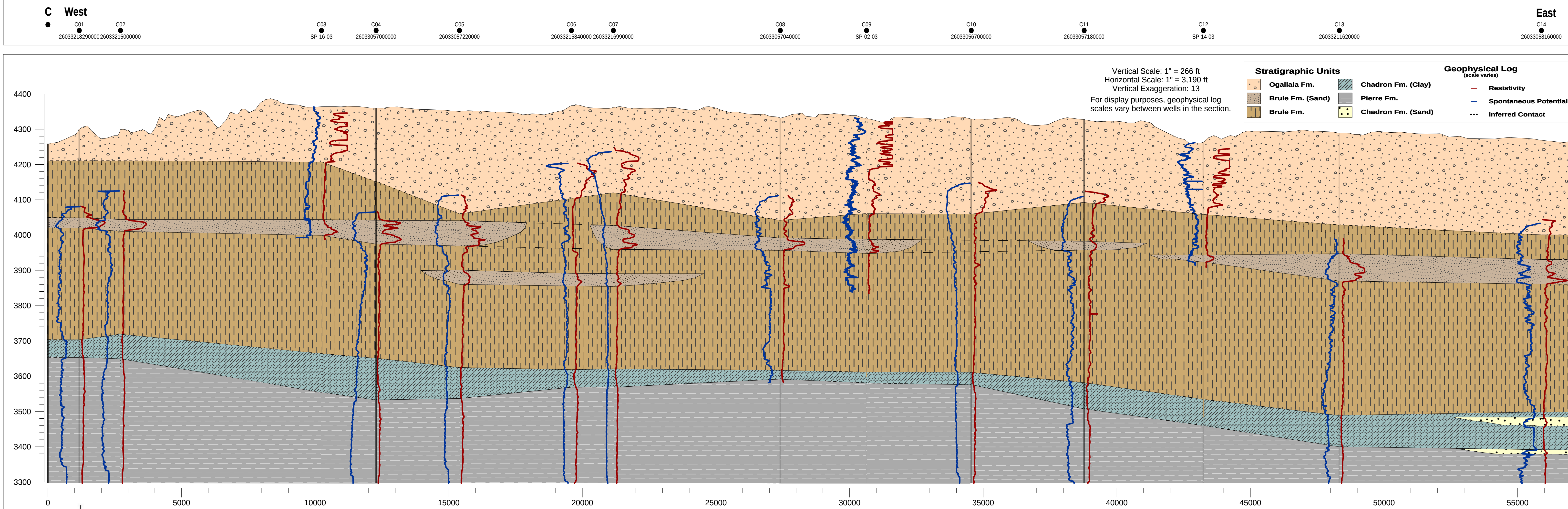
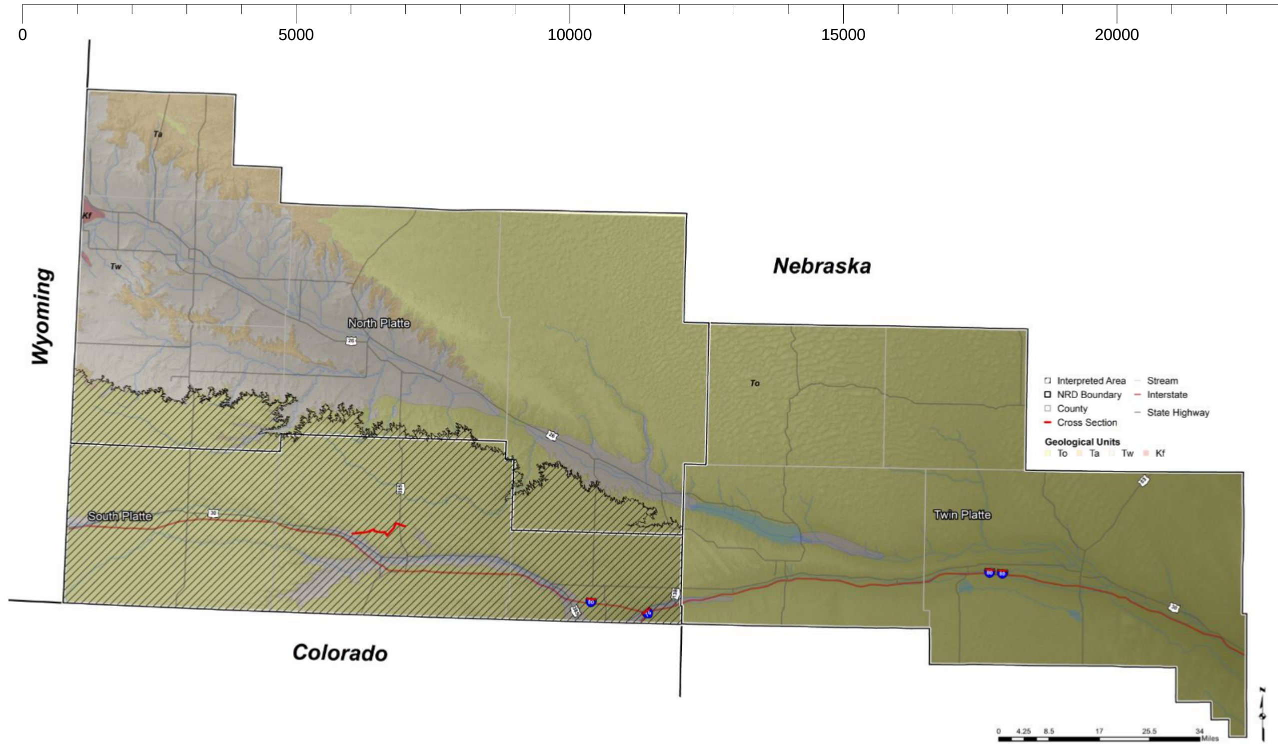
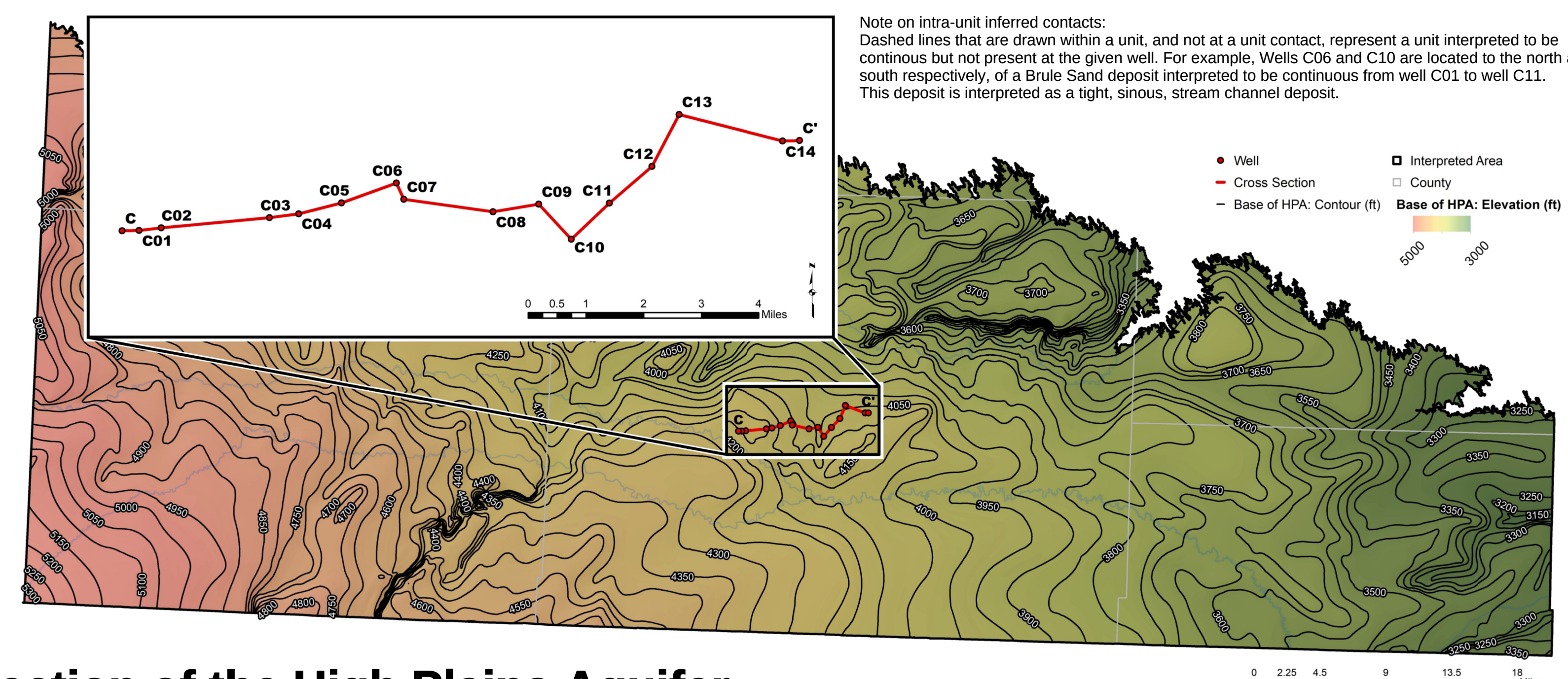
Cross Section 3: C-C'





Note on intra-unit inferred contacts:
Dashed lines that are drawn within a unit, and not at a unit contact, represent a unit interpreted to be continous but not present at the given well. For example, Wells C06 and C10 are located to the north and south respectively, of a Brule Sand deposit interpreted to be continuous from well C01 to well C11.
This deposit is interpreted as a tight, sinous, stream channel deposit.

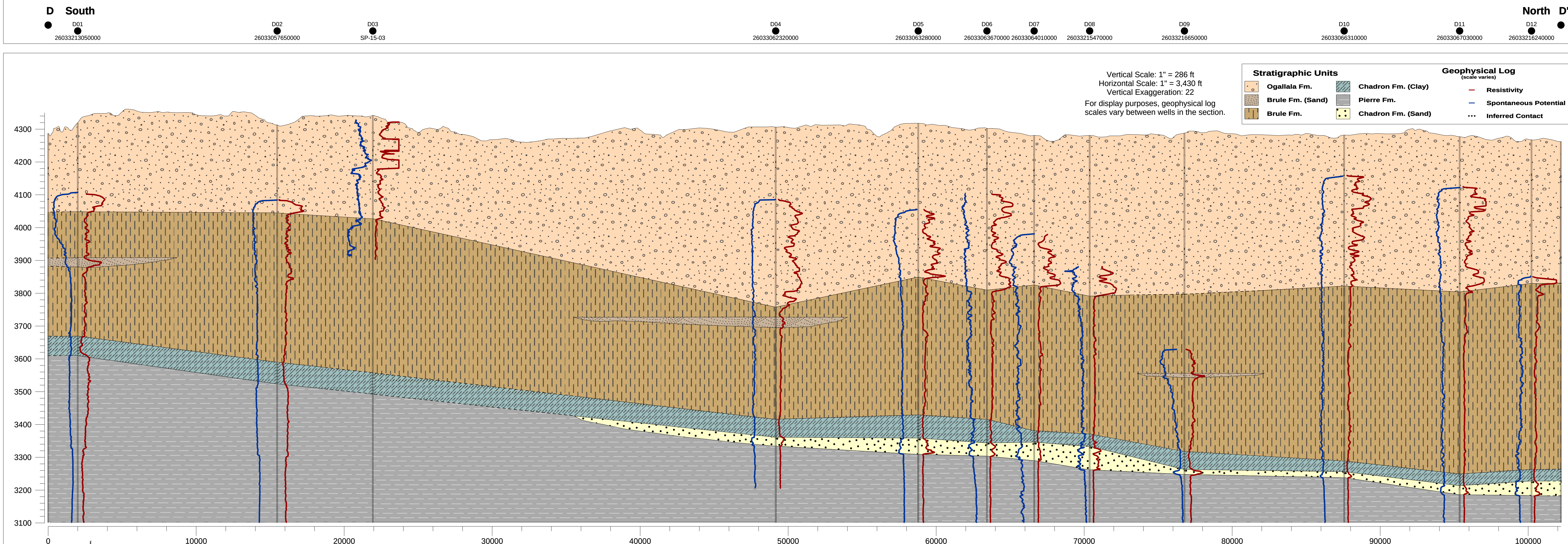


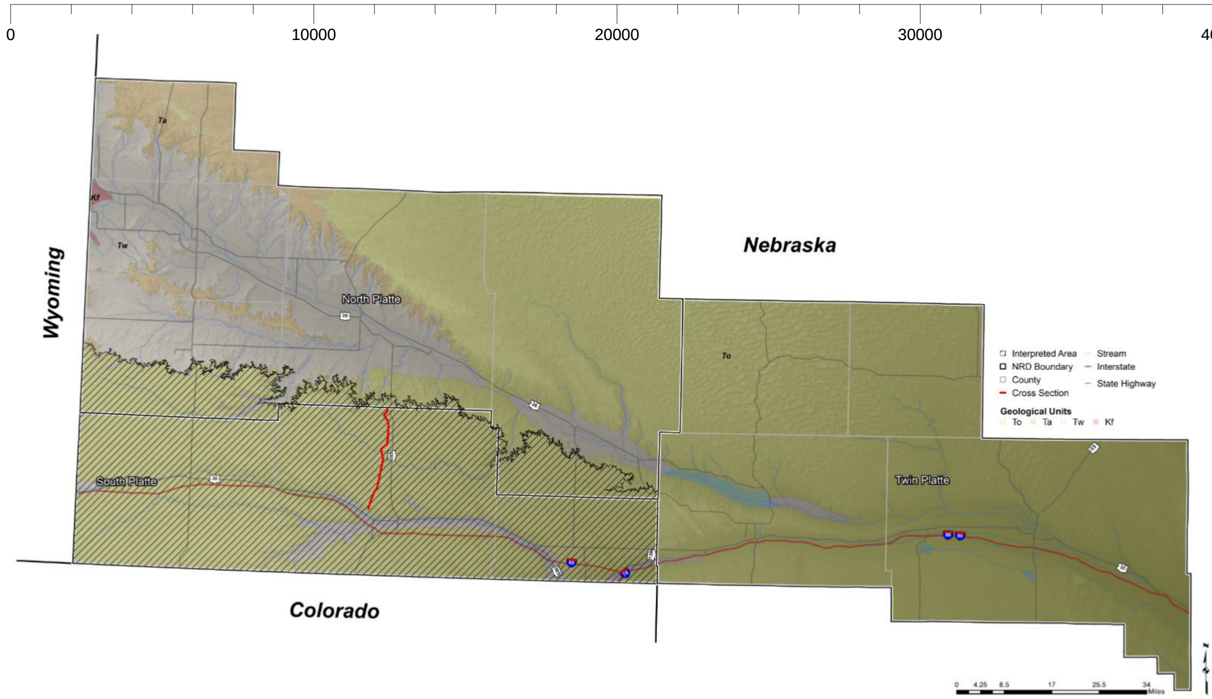
Geologicic Cross Section of the High Plains Aquifer, Southern Panhandle of Nebraska

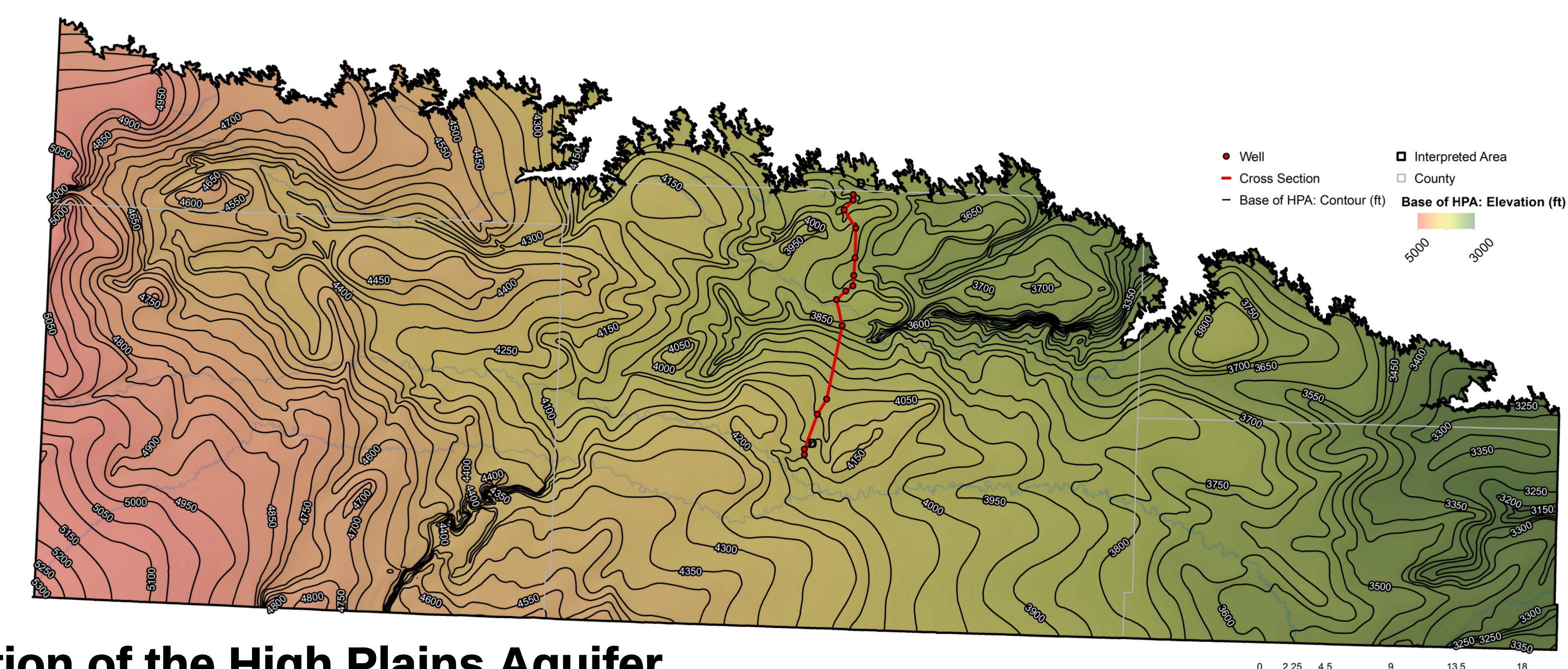
Hydrogeology of Western Nebraska, Project Completion Report: Cross Section 3

Thaddeus Kuntz, Steven Sibray, Joseph Reedy, Jason Yuill, & Doug Hallum

Cross Section 4: D-D'







Geologicic Cross Section of the High Plains Aquifer, Southern Panhandle of Nebraska

Hydrogeology of Western Nebraska, Project Completion Report: Cross Section 4

Thaddeus Kuntz, Steven Sibray, Joseph Reedy, Jason Yuill, & Doug Hallum

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