LOCATION RESTRICTIONS DEMONSTRATION REPORT BOTTOM ASH IMPOUNDMENT

La Cygne Generating Station

Presented to:
Kansas City Power & Light Company
La Cygne Generating Station
La Cygne, Kansas

SCS ENGINEERS

27218131.04 | October 2018

8575 W 110th Street, Suite 100
Overland Park, Kansas 66210
913-681-0030

Table of Contents

1 INTRODUCTION AND PURPOSE

The Disposal of Coal Combustion Residuals (CCR) from Electric Utilities Final Rule (CCR Rule) 40 CFR 257.60 through 257.64 requires owner/operators of existing CCR units to make demonstrations in the event a unit is located in certain areas. The purpose of this report is to demonstrate whether the Bottom Ash Impoundment (Unit) at Kansas City Power & Light Company's (KCP&L) La Cygne Generating Station (La Cygne) is located in any of those areas; and, if so, to make certain demonstrations per the CCR Rule that will permit continued CCR disposal/management operations.

The Unit, which is an existing CCR surface impoundment, is located at the La Cygne Generating Station near La Cygne, Kansas, as indicated in **Figure 1**.

SCS Engineers (SCS) has reviewed the documents provided in Section 7 and completed site visit(s) to develop this report. This document provides demonstrations that documents if the Unit is located:

- with a base that is constructed no less than 5 feet above the upper limit of the uppermost aquifer (40 CFR §257.60);
- in wetlands (40 CFR §257.61);
- within 200 feet of the outermost damage zone of a fault which has been displaced in Holocene time (40 CFR §257.62);
- within a seismic impact zone (40 CFR §257.63); and
- in an unstable area (40 CFR §257.64).

The applicable CCR Rule requirement for each of the above is listed in the respective section in italics followed by an explanation of the review and determinations completed by SCS.

2 PLACEMENT ABOVE THE UPPERMOST AQUIFER (§257.60)

§257.60 (a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must be constructed with a base that is located no less than 1.52 meters (five feet) above the upper limit of the uppermost aquifer, or must demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including the seasonal high water table). The owner or operator must demonstrate by the dates specified in paragraph (c) of this section that the CCR unit meets the minimum requirements for placement above the uppermost aquifer.

SCS compared the location and elevation of the base of the Unit (approximately 842 feet MSL [mean sea level]) to the elevation of the upper limit of the uppermost aquifer by reviewing the site geology as characterized by AECOM in the Detailed Hydrogeologic Site Characterization Report (DSI) prepared in October 2017 (AECOM, 2017). Pertinent sections of this report have been provided in **Appendix A** summarizing and showing the location of the base of the Unit and the uppermost aquifer. As described in the investigation, the generalized geology underlying the Unit includes the following, from the surface down:

1. Fill consisting of rubble, slag, and clay
2. Native residual highly plastic clay (semi-confining to confining unit)
3. Unsaturated or relatively low-yielding shale (semi-confining to confining unit)
4. Saturated unweathered to highly weathered shale (Holdenville Shale) with relatively higher permeability (uppermost aquifer)
5. Relatively unweathered lower permeability shale with sparse limestone and coal units interbedded (lower confining bedrock unit)

The site Investigation completed by AECOM confirmed that unconsolidated deposits consisted of approximately 5 to 11 feet of rubble, slag and clay fill over a relatively thick residual highly plastic clay up to approximately 36 feet below ground surface (bgs). Unsaturated or relatively low-yielding shale was encountered below the unconsolidated residual clay material. This low-yielding primarily shale material transitioned into a saturated relatively higher permeability unweathered to highly weathered zone which is defined as the uppermost aquifer beneath the impoundment. The thickness of the aquifer is believed to be roughly 5 to 10 feet with the upper elevation approximately 813 feet MSL (above mean sea level) beneath the impoundment.

The aquifer appears locally confined or semi-confined by relatively lower permeability shale bedrock and residual highly plastic clay acting as an upper confining unit, and a relatively lower permeability primarily shale bedrock on the bottom. Although groundwater levels measured in the wells extend up and into the low permeability shale and clay, the groundwater level is believed to be representative of the potentiometric head and not the water table elevation. Groundwater was not encountered during drilling of the overlying clay or unsaturated shale bedrock.

The Bottom Ash Impoundment was constructed as an incised impoundment approximately 12 feet above the level of the lake. Based on cross-sections, the bottom elevation of the impoundment is estimated to be approximately 842 feet MSL. The report also identifies the uppermost aquifer as the basal unit immediately above the bedrock. A review of hydrostratigraphic cross sections and boring logs in the report indicate the maximum uppermost aquifer elevation of approximately 813 ft. MSL. Based on this review, the base of the Unit appears to be approximately 30 feet above the upper limit of the uppermost aquifer, therefore the base of the unit was constructed no less than five feet above the upper limit of the uppermost aquifer. Consequently, no additional demonstration is necessary.

3 WETLANDS (§257.61)

§257.61 (a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in wetlands, as defined in §232.2 of this chapter, unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that the CCR unit meets the requirements of paragraphs (a)(1) through (5) of this section."

A figure developed for this analysis is provided as **Figure 2**. A Certified Wetland Delineator with SCS visited the Unit on May 2, 2018 to determine if any areas within the boundaries of the Unit are potentially located in existing wetland areas as defined in 40 CFR §232.2. The areas reviewed are indicated on **Figure 2**. Based on this review, SCS determined the Unit is not located within a wetland area, as defined in 40 CFR §232.2. Consequently, no additional demonstration is necessary.

4 FAULT AREAS (§257.62)

§257.62 (a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located within 60 meters (200 feet) of the outermost damage zone of a fault that has had displacement in Holocene time unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that an alternative setback distance of less than 60 meters (200 feet) will prevent damage to the structural integrity of the CCR unit.

SCS compared the location of the Unit to the location of faults as shown in the United States Geologic Survey (USGS) Quaternary Faults and Folds Database for the United States. The nearest fault area is indicated on Figure 3. Based on this review, SCS determined the Unit is not located within 200 feet of the outermost damage zone of a fault that has had displacement in the Holocene time, the most recent portion of the Quaternary Age. Consequently, no additional demonstration is necessary.

5 SEISMIC IMPACT ZONES (§257.63)

§257.63 (a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in seismic impact zones unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that all structural components including liners, leachate collection and removal systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site.

SCS compared the location of the Unit to the location of seismic impact zones as defined in §257.53, as shown in the USGS map "Two Percent Probability of Exceedance in 50 Years Map of Peak Ground Acceleration". The location of the Unit in relation to the nearest seismic impact zones (i.e., in areas of at least 0.1 g as shown on the map in dark blue) are indicated on Figure 4. The Unit falls within the 0.04 g to 0.06g range of the map. Based on this review, SCS determined the Unit is not located within a seismic impact zone. Consequently, no additional demonstration is necessary.

6 UNSTABLE AREAS (§257.64)

§257.64 (a) An existing or new CCR landfill, existing or new CCR surface impoundment, or any lateral expansion of a CCR unit must not be located in an unstable area unless the owner or operator demonstrates by the dates specified in paragraph (d) of this section that recognized and generally accepted good engineering practices have been incorporated into the design of the CCR unit to ensure that the integrity of the structural components of the CCR unit will not be disrupted.

SCS evaluated the location of the Unit for the presence of on-site or local unstable areas as defined in §257.53. Evaluations of the conditions listed in §257.64 (b)(1) through (3) were evaluated and are discussed below. Based on this review, SCS determined the Unit is not located within an unstable area as defined in §257.53. Consequently, no additional demonstration is necessary.

257.64 (b) The owner or operator must consider all of the following factors, at a minimum, when determining whether an area is unstable:

6.1 UNSTABLE FACTORS CONSIDERED: DIFFERENTIAL SETTLING (§257.64(b)(1))

On-site or local soil conditions that may result in significant differential settling;

SCS has visited the site and evaluated site-specific reports detailing the conditions of the on-site and local soils for conditions that could result in significant differential settling. The Unit was characterized in the “Detailed Hydrogeologic Site Characterization Report, Bottom Ash Impoundment” (DSI) prepared by AECOM in October 2017. The Unit is located within the Osage Cuestas physiographic section (Kansas Geological Survey) of eastern Kansas. Soils in the area are generally residual fine grained soils overlying shale, limestone, and sandstone.

According to the DSI (AECOM, 2017), a varying thickness of natural soil and fill materials underlie the Unit. The natural soils vary from brown to gray, low to highly plastic clays (CH) and silty clays (CL) as defined by the Unified Soil Classification System (USCS). The majority of the soils are residual deposits formed from the weathering of the underlying bedrock, although some alluvial or colluvial soils may be present. The fill soils consist of rubble, slag, and clay varying in thickness from 5 to 11 feet. The unconsolidated deposits vary in thickness from 14 to 36 feet across the Unit location.

The bedrock near the Unit consists of shale, limestone, sandstone and minor coal, assigned to the Middle to Lower Pennsylvanian Age, Marmaton and Pleasanton Groups (KGS, 1969). These units are relatively typical of the cyclic sedimentary rock deposits present in the Midwest. Thicknesses of individual beds vary from thin coal “smuts” to beds as thick as three feet as per the FGD Geotechnical Data report (WCC, 1978).

Based on the geologic description above and a review of geotechnical data in the report(s), it is SCS’ professional opinion that the soils on site will not experience significant differential settlement. Pertinent sections of the 2017 AECOM report are provided in **Appendix B.1** describing the soils at and near the Unit. Based on this review, SCS determined the Unit is not located within an area with on-site or local soil conditions that may result in significant differential settling.

6.2 UNSTABLE FACTORS CONSIDERED: GEOLOGIC/GEOMORPHOLOGIC FEATURES (§257.64(b)(2))

On-site or local geologic or geomorphologic features; and

SCS has visited the Unit and evaluated published data and site-specific reports for the presence of on-site or local geologic and geomorphologic features, to include karst terrain, steep slopes, and sinkholes. Documents and websites reviewed include:

- KGS Earthquakes and Hazards (http://geokansas.ku.edu/sinkholes)
- Land Subsidence in Central Kansas Related to Salt Dissolution (http://www.kgs.ku.edu/Publications/Bulletins/214/index.html)
- Appendix D—Surface Sinkholes and Other Solution Features, Geologic History of Kansas (http://www.kgs.ku.edu/Publications/Bulletins/162/10_app_d.html)
- Digital engineering Aspects of Karst Map, Tobin and Weary, USGS Open-File Report 2004-1352 (pubs.usgs.gov/of/2004/1352/data/USA_karst.pdf)

Neither the Kansas Geologic Survey website nor published data indicate the presence of karst terrain, sinkholes, caves, or ground conditions that could cause a structural failure in the area of the Unit or region around the Unit. Available data indicates most sinkholes in Kansas are related to salt dissolution (central part of the state) and caves, natural bridges, underground drainage, and soil cracks that are located predominately in the western part of the state. Sinkholes related to human-made features are discussed in Section 6.3

SCS' visits to the Unit and a review of terrain at and near the Unit indicated no steep slopes, terrain features, or other local geologic or geomorphologic features that could feasibly result in an unstable condition. Pertinent documents and sections of documents reviewed are provided in **Appendix B.2**, and indicate the location of the Unit in relation to the known geologic or geomorphologic features nearest the Unit.

Based on this review, SCS determined the Unit is not located within an area with on-site or local geologic or geomorphologic features that would result in an unstable environment for the Unit. Additional demonstration(s) are not required.

6.3 UNSTABLE FACTORS CONSIDERED: HUMAN-MADE FEATURES OR EVENTS (§257.64(b)(3))

On-site or local human-made features or events (both surface and subsurface).

SCS has visited the Unit and evaluated published data and site-specific reports for the presence of on-site or local human-made features or events (both surface and subsurface), to include surface and subsurface mining, extensive withdrawal of oil and gas, steep slopes, and sources of rapid groundwater drawdown, in strata that could feasibly impact the Unit. Documents and websites reviewed include:

- AECOM (2017), Detailed Hydrogeologic Site Characterization Report, Bottom Ash Impoundment, La Cygne Generating Station.
- Woodward Clyde Consultants, Geotechnical Data for Bidders, New FGD Sludge Retention Dam – Stage 1, Volume 2, La Cygne Steam Electric Station, December 1978.
- Coal Resources of the Marmaton Group in Eastern Kansas, Walter H. Schoewe, 1955, Kansas Geological Survey Bulletin 114, Part 2.
- KGS - State Inspector of Coal Mines report, 1893.
- Kansas Mines (http://www.miningartifacts.org/Kansas-Mines.html)
- Interstate Technical Group on Abandoned Underground Mines Third Biennial Workshop, Mining History in Kansas, Lawrence L. Brady, KGS (https://www.fhwa.dot.gov/engineering/geotech/hazards/mine/workshops/kdot/kansas01.cfm#fig4)
- Coal Mining (http://geokansas.ku.edu/coal-mining)
- Mining in Kansas, Kansas Historical Society (https://www.kshs.org/index.php?url=kansapedia/mining-in-kansas/15603)
- Google Earth Aerial photographs
- State Inspector of Coal Mines, Sixth Annual Report, 1893, pp. 60-65
- State Labor Department, Mine Inspection Division Report, 1950-52, pg. 33
- Ebasco Services Incorporated, Foundation Investigation Plan and Sections, 1969, sheets G-549-550.
- Geotechnology, Inc. (2009), Drilling, Laboratory, Geophysical, and Pressuremeter Results, Environmental Retrofit Project, La Cygne Generating Station La Cygne, Kansas.

SCS reviewed the above historical records related to coal mining in the immediate vicinity of the Unit. Subsurface mining appears to have occurred on station property prior to the development of the generating station. Based on coal production data, the mines in the area are believed to be small and to have only served local trade (KGS, 1955). The exact location of each mine relative to the footprint of the Bottom Ash Impoundment cannot be determined from the KGS-provided information, some of which is dated before 1900; however, no mines were indicated in Section 33, Township 19 South, Range 25 East, where the Unit is in located.

The incised Bottom Ash Impoundment was constructed by excavating an area north of the plant and building internal separation berms with fill (slag). The Unit appears to be located on naturally occurring residual clay soils that weathered naturally from the underling bedrock. Thus, potential subsidence beneath the Unit would be unlikely given the subsurface conditions. Furthermore, discussions with KGS personnel regarding deep mining in the area did not indicate any issues with ground surface subsidence in the La Cygne area due to shaft mining or other causes.

SCS reviewed the available boring logs for the site, some of which encountered the Mulberry coal seam, and some of which may not have penetrated deep enough to encounter the coal seam. The boring logs from the 1969 plant investigation (Ebasco, 1969) indicated the presence of a 3- to 4-foot thick coal seam at approximately elevation 765 to 775 MSL. A cross section of borings in the turbine and building area indicated the lower coal seam in addition to a 1- to 6-foot thick coal seam at approximate elevation 820 MSL. None of the 1969 boring logs indicated voids in the bedrock, which would indicate the presence of previous mining activity. Borings drilled as part of the DSI (AECOM 2017) generally did not extend below elevation 800 MSL. The boring logs did not indicate the presence of any coal seams or voids. Borings drilled in 2009 (Geotechnology, 2009) for plant upgrades did not encounter coal seams above elevation 800 MSL. None of the 2009 borings penetrated deep enough to encounter the elevation 765 to 775 coal seam.

According to plant personnel, evidence of a mine collapse such as surface subsidence or unusual building settlement has not been observed on the generating station property or around the Unit.

SCS' review of the aerial photographs around the generating station showed indications of strip mining to the southeast of the station, ranging from approximately 1.6 miles to 5 miles from the Unit. The aerial photographs (Google Earth, 2014) confirm the presence of strip mining in the area; however none of the borings drilled for the ash impoundments or adjacent landfill reviewed by SCS indicated the presence of a heterogeneous backfill associated with strip mining.

SCS' internet search located a 1940 bulletin from the KGS titled "Oil and Gas in Linn County, Kansas". Plate 3 of Bulletin 30 is an Oil and Gas Exploration Map of Linn County. The map shows locations of wells drilled, various dry holes, oil wells, and oil wells with gas. No exploration or well drilling in the sections encompassing the generating station is indicated on the map.

Pertinent documents and sections of documents reviewed include soil boring data for La Cygne (Ebasco, 1969) and a table with the location of nearby coal mines (Schoewe, 1955), provided in **Appendix B.3.**

Based on this review, SCS determined that while the Unit is located in an area that was potentially mined for coal, the potential collapse of any underground mine is unlikely to have occurred, and if a collapse did occur, it would likely not affect the performance of the Unit's retaining structure. Furthermore, no evidence of steep slopes in the vicinity of the unit nor areas of rapid groundwater drawdown were identified. Therefore, it is SCS' opinion the Unit is not located within an area with on-site or local human-made features or events (both surface and subsurface) that could feasibly result in an unstable condition at the Unit. Additional demonstration(s) are not required.

7 REFERENCES

AECOM (2017), Detailed Hydrogeologic Site Characterization Report, CCR Landfill & Lower AQC Impoundment, La Cygne Generating Station.

AECOM (2017), Detailed Hydrogeologic Site Characterization Report, Bottom Ash Impoundment, La Cygne Generating Station.

Ebasco Services Incorporated (1969), Foundation Investigation Plan Set.

Geotechnology, Inc. (2009), Drilling, Laboratory, Geophysical, and Pressuremeter Results, Environmental Retrofit Project, La Cygne Generating Station La Cygne, Kansas.

Google Earth (2014), Aerial Photograph dated 10/20/2014.

Jewett, J.M., O'Connor, H.G., and Zeller, D.E., (1968), Stratigraphic Succession in Kansas – Pennsylvanian System. Kansas Geological Survey Bulletin 189.

Jewett, J.M., with Lee, Wallace and Keroher, R.P., (1940), Oil and Gas in Linn County, Kansas. Kansas Geological Survey Bulletin 30.

Kansas Geological Survey, (1969), Geologic Map of Linn County, Kansas.

Kansas Geological Society (1893), State Inspector of Coal Mines, Sixth Annual Report

Kansas State Labor Department (1950-52), Mine Inspection Division Report.

Physiographic Map of Kansas, http://www.kgs.ku.edu/Physio/physio.html.

Schoewe, Halter H., (1955), Coal Resources of the Marmaton Group in Eastern Kansas, Kansas Geological Survey Bulletin 114, Part 2.

URS (2005), Combined Supplemental Investigation and Groundwater Monitoring Report, KCP&L La Cygne Generating Station.

Woodward Clyde Consultants, (1978). Geotechnical Data for Bidders, New FGD Sludge Retention Dam – Stage 1, Volume 2, La Cygne Steam Electric Station.

USGS Maps: La Cygne, USGS US Topo 7.5 (1958) KS_La Cygne_511759_1958_24000_geo

Boicourt, USGS US Topo 7.5 (2015) KS_Boicourt_20151230_TM_geo

Boicourt, USGS US Topo 7.5 (1986) KS_Boicourt_801573_1986_24000_geo

8 QUALIFIED PROFESSIONAL ENGINEER CERTIFICATION (§§257.60(B), 257.61(B), 257.62(B), 257.63(B), 257.64(C))

The undersigned registered professional engineer is familiar with the requirements of the CCR Rule and has visited and examined the Unit and/or has supervised examination of the Unit and development of this report by appropriately qualified personnel. I hereby certify based on a review of available information and observations, that this report meets the requirements of paragraphs §§257.60(a), 257.61(a), 257.62(a), 257.63(a) and 257.64(a).

Professional Engineer: Company: Douglas L. Doerr, P.E.

SCS Engineers

PE Registration State: Kansas

Registration Number: 14136

Professional Engineer Seal:

Douglas L. Doerr

Digitally signed by Douglas L. Doerr
Date: 2018.10.17 16:01:14 -05'00'

DOUGLAS L. DOERR
LICENSED
14136
KANSAS
PROFESSIONAL ENGINEER

10-17-18

The undersigned registered professional geologist is familiar with the requirements of the CCR Rule and has visited and examined the Unit and/or has supervised examination of the Unit and development of this report by appropriately qualified personnel. I hereby certify based on a review of available information and observations, that this report meets the requirements of paragraphs §§257.60(a).

Professional Geologist: Company: John R. Rockhold, P.G.

SCS Engineers

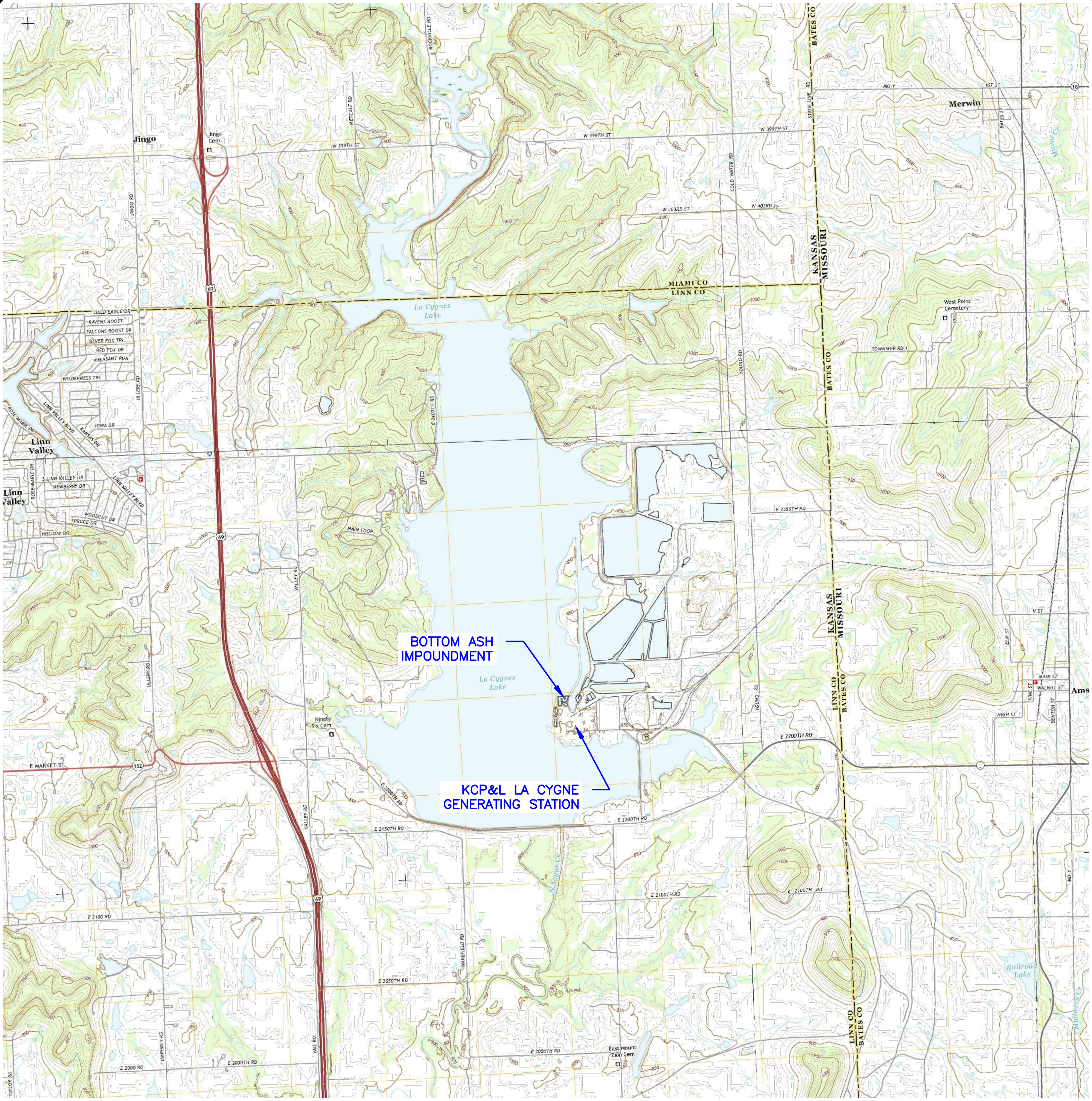
PG Registration State: Kansas

Registration Number: 0029

Professional Geologist Seal:

JOHN R. ROCKHOLD
LICENSED
29
10-17-18
KANSAS
PROFESSIONAL GEOLOGIST

FIGURES



5000 0 5000 10000

SCALE FEET

SOURCE:
2015 USGS MAP
NEW LANCASTER–KS, BOICOURT–KS, AMORET–MO, AND DREXEL–MO
7.5 MINUTE SERIES (TOPOGRAPHIC)

SCS ENGINEERS

8575 W. 110th St, STE. 100
Overland Park, Kansas 66210
PH. (913) 681-0030 eFAX. (913) 681-0012

FIGURE 1
SITE LOCATION MAP
KCP&L LA CYGNE GENERATING STATION - BOTTOM ASH IMPOUNDMENT
LA CYGNE, KANSAS

CHK. BY: DLD	DWN. BY: TGW	DSN. BY: TGW	PROJ. NO. 27218131.04
PROJ. MGR: DLD	DATE: 10/2018	CADD FILE: FIGURE 1_SITE MAP.DWG	DRAWING NO. 1

LEGEND:

AREAS THAT WERE FOUND NOT TO INCLUDE WETLANDS BASED ON REVIEW OF VEGETATION, SOIL TYPE, AND HYDROLOGIC CHARACTERISTICS.

NOTES:

1. GOOGLE EARTH IMAGE DATED OCTOBER 2014.

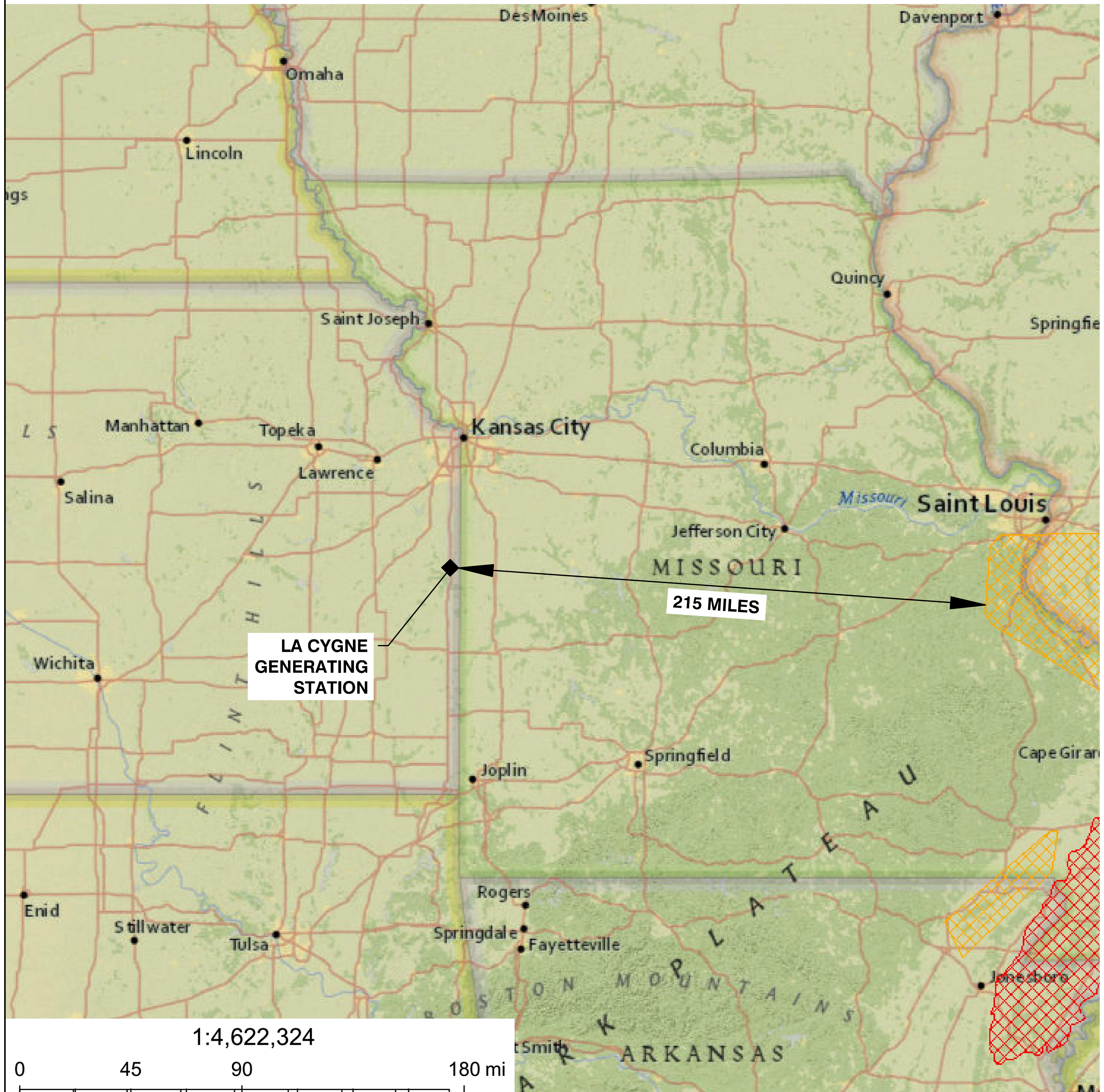
FIGURE 2
WETLANDS MAP

KCP&L LA CYGNE GENERATING STATION - BOTTOM ASH IMPOUNDMENT
LA CYGNE, KANSAS

SCS ENGINEERS
8575 W. 110th St. STE 100
Overland Park, Kansas 66210
PH. (913) 681-0030 eFAX. (913) 681-0012

CHK. BY: DLD	DWN. BY: TGW	DSN. BY: TGW	PROJ. NO. 27218131.04
PROJ. MGR: DLD	DATE: 10/2018	CADD FILE: FIGURE 2_WETLANDS.DWG	

USGS Quaternary Faults and Folds Database



7/5/2018, 9:50:24 AM

1:18,489,298

0 185 370 740 mi

0 287.5 575 1,150 km

Site Investigations

Quaternary Faults

historical (<150 years), well constrained location

historical (<150 years), moderately constrained location

historical (<150 years), inferred location

latest Quaternary (<15,000 years), well constrained location

Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

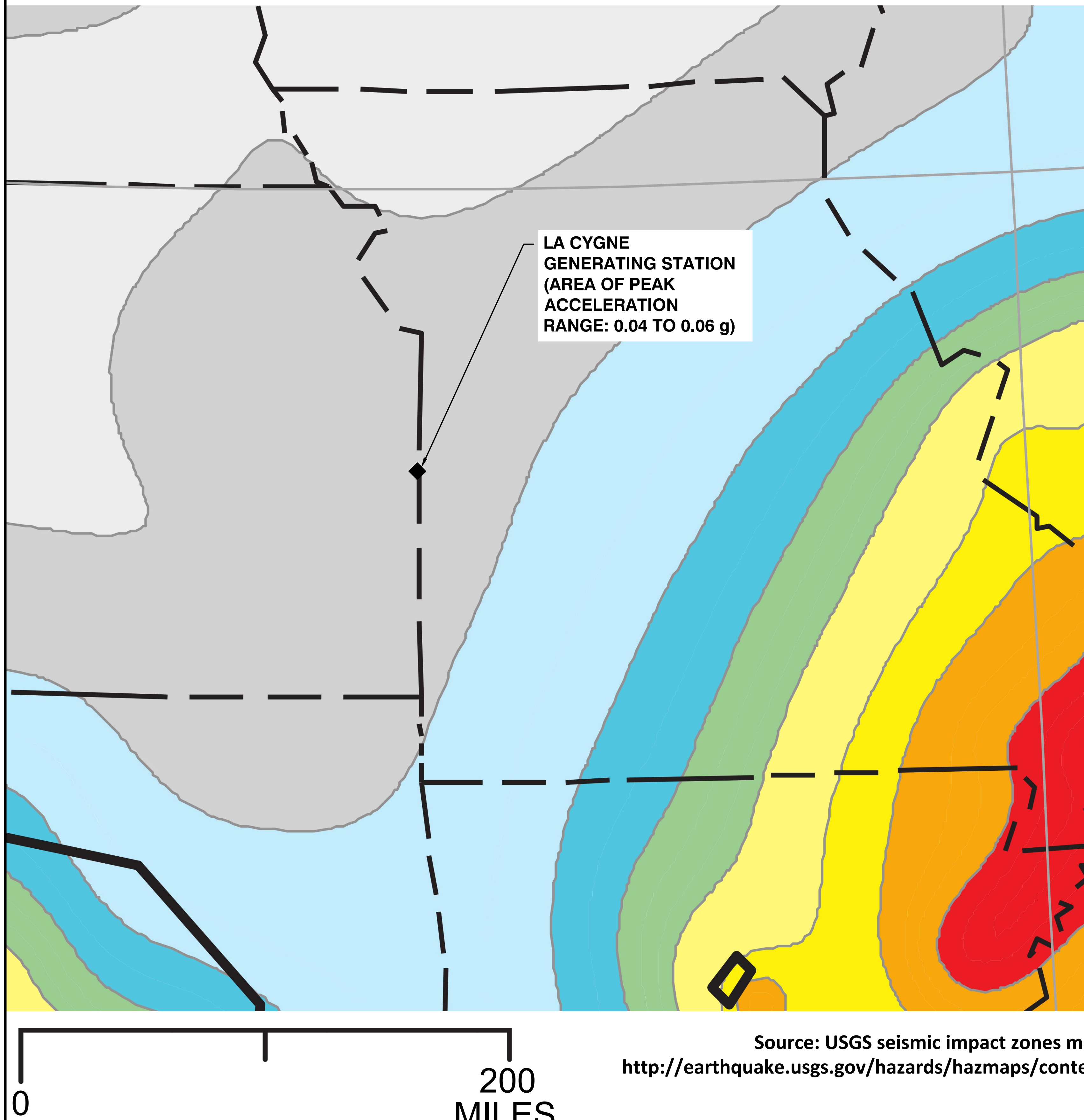
Source: USGS fault map - https://earthquake.usgs.gov/hazards/qfaults/

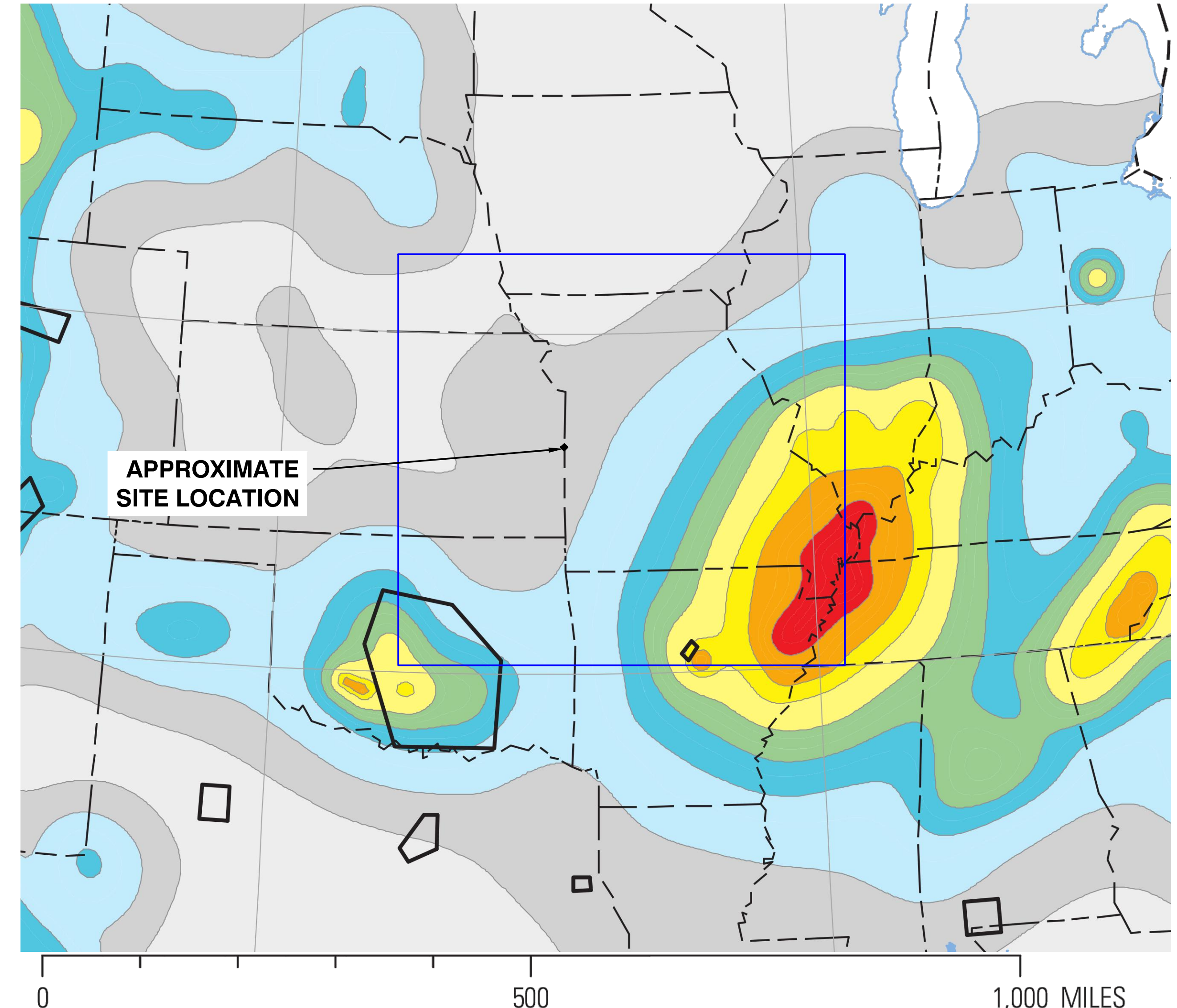
FIGURE 3
FAULT AREAS MAP
KCP&L LA CYGNE GENERATING STATION - BOTTOM ASH IMPOUNDMENT
LA CYGNE, KANSAS

SCS ENGINEERS
8575 W. 110th St. STE 100
Overland Park, Kansas 66210
PH. (913) 681-0030 eFAX. (913) 681-0012

CHK. BY: DLD	DWN. BY: TGW	DSN. BY: TGW	PROJ. NO. 27218131.04
PROJ. MGR: DLD	DATE: 10/2018	CADD FILE: FIGURE 3_FAULT AREAS.DWG	

Two-percent probability of exceedance in 50 years map of peak ground acceleration





EXPLANATION

Peak acceleration, expressed as a fraction of standard gravity (g)

0.8
0.4
0.3
0.2
0.14
0.1
0.06
0.04
0.02
0

Areas with suspected nontectonic earthquakes are not included.

Source: USGS seismic impact zones map (2014) - http://earthquake.usgs.gov/hazards/hazmaps/conterminous/index.php#2014

FIGURE 4
HORIZONTAL ACCELERATION MAP
KCP&L LA CYGNE GENERATING STATION - BOTTOM ASH IMPOUNDMENT
LA CYGNE, KANSAS

SCS ENGINEERS
8575 W. 110th St. STE 100
Overland Park, Kansas 66210
PH. (913) 681-0030 eFAX. (913) 681-0012

CHK. BY: DLD	DWN. BY: TGW	DSN. BY: TGW	PROJ. NO. 27218131.04
PROJ. MGR: DLD	DATE: 10/2018	CADD FILE: FIGURE 4_SEISMIC.DWG	

APPENDIX A

Placement Above the Uppermost Aquifer Supporting Information

- Portions of Detailed Hydrogeologic Site Characterization Report (AECOM 2017) during the desktop study. Three boring logs, B-15, B-27, and B-28, were drilled near the Site by Geotechnology in 2009. The location of the borings is provided on **Figure A.5.2, Appendix A**. The boring logs are included in **Appendix D.2**.

1.4.1 Stratigraphy

A varying thickness of natural soil and some fill underlie the Station. In the Unified Soil Classification System (USCS), the natural soils vary from brown to gray, low to highly plastic clays (CH), silty clays (CL) and sandy clays (SC) with some discrete poorly graded sand beds or lenses (SP). The majority of the soils are residual deposits formed from the weathering of the underlying bedrock, although some alluvial or colluvial soils may be present. These unconsolidated deposits vary from 18- to 36-ft. in thickness at the boring locations overlying bedrock comprised of primarily shale with some thin sandstone and limestone units.

The shallow bedrock underlying the unconsolidated deposits is a stratigraphically and lithologically complex set of units that are transitional between the lower Pleasanton and upper Marmaton Groups of the Pennsylvanian System with a combined thickness of these units reported between 50- and 80-ft. The Pleasanton and Marmaton Groups are described as predominantly shale with some sandstone and limestone. Both shale and sandstone strata outcrop at various locations within the Station, generally along intermittent drainage ditches. Less frequently, discontinuous and localized limestone strata were observed at a few locations within the Station (Woodward-Clyde, 1978). Lateral facies changes and vertical gradational changes are common. Correlation of units between boreholes is somewhat limited since drilling methods used generally did not provide undisturbed samples resulting in shale units that are similar in appearance. However, the presence of a limestone unit in several borings potentially suggests the top of the Lenapah Formation (URS, 2005).

The elevation of top of bedrock surface underlying the Site is presented on **Figure A.7, Appendix A**. The contours shown were developed using site-specific boring information augmented with pre-plant topography as shown on **Figure A.4, Appendix A**. The bedrock surface reasonably parallels the pre-plant topography, which indicates the presence of a former west-flowing stream channel south of the Upper AQC Impoundment located below the CCR Landfill and Lower AQC Impoundment. The bedrock itself consists of primarily shale with sparse limestone and coal units interbedded. The upper most bedrock is generally weathered at the contact with the overlying unconsolidated deposits which decreases with depth until reaching competent bedrock. The shale observations from the investigation borings were primarily brown to grayish brown in color. The apparent absence of black and/or olive green shale in many of the borings may be due to an actual "pinching out" of the bed, or the inability to distinguish the cuttings from this thin shale unit from the cuttings of the other shales since most of the wells were drilled using auger or rotary methods. The investigation was originally designed to auger through the soils and shallow bedrock and to core the deeper unweathered bedrock. The structural configuration of the Station is such that the bedrock units have a general northeast strike and an average northwest dip of 0.34° or 31-ft/mile (URS, 2005).

1.4.2 Hydrogeologic Setting

The uppermost water-bearing zone at the Station is in the shale members of the Holdenville Shale in the upper Marmaton Group. The majority of the groundwater monitoring wells are screened in the Holdenville. In borings at the Station, the Holdenville is identified as a moderate to highly weathered shale with many calcareous and sandy zones and varying from brown and weathered to gray and unweathered. The Holdenville overlies the Lenapah Formation in the Marmaton Group.

Several of the groundwater monitoring wells appear to be installed into the upper few feet of one of the limestone members (Idenbro or Norfleet) of the Lenapah Formation. As described in the boring logs, this limestone is hard, dense, dark gray limestone immediately below the Holdenville. This limestone was not encountered in most of the borings on the Station; however, in many cases the stratigraphic position of this limestone is marked by zones with thin limestone stringers or very calcareous shales rather than a distinct limestone bed. In borings that clearly

During the 2015 Site Investigation, excluding SB series soil boring (SB-106), all of the borings encountered shale bedrock at elevations ranging from 831- to 815-ft. msl. Bedrock was cored in one of the borings (MW-901A).

3.2.4 Groundwater Conditions

As stated previously in Section 1.4.2, the uppermost water-bearing zone at the Site is typically encountered within the Holdenville Shale in the upper Marmaton Group. The majority of the groundwater monitoring wells are screened within this formation. The lithologic characteristics of this formation were described in the 2015 Site Investigation as a moderate to highly weathered shale with many calcareous and sandy zones and varying from brown and weathered to gray and unweathered.

The 2015 Site Investigation by AECOM confirmed the uppermost water-bearing zone at the Site is in a zone of saturated unweathered to highly weathered shale within the Holdenville Shale. For the purposes of the CCR Rule, this is the water-bearing unit that has been defined as the aquifer at the Site, as discussed in Section 3.3.2. During the groundwater monitoring sampling events, water levels from monitoring wells around the Site were measured by AECOM. These data were used to assess the magnitude and direction of the hydraulic gradient at the Site, and are presented on the potentiometric maps in **Appendix A.6**. Analysis of the potentiometric surface indicates typical groundwater flow beneath the Bottom Ash Pond is generally west to west-northwest toward La Cygne Lake. The water levels were monitored approximately every other month from June 2016 to June 2017 in each well at the Site. The seasonal variations of the groundwater elevations range from 841.74-ft. to 845.34-ft. from June 2016 to June 2017 at the Site. The table and chart of the water level measurements in the wells selected for the potentiometric maps over this period of time are included in **Table 2** and **Chart 1**, **Appendix C**. The calculations for hydraulic gradient for the water level readings from June 2016 to June 2017 are included in **Appendix C**. The average hydraulic gradient is approximately -0.0071 from generally southeast to northwest.

Well testing to assess the hydraulic characteristics of the Site monitoring wells was not performed. Previous testing conducted in monitoring wells in the vicinity estimated a hydraulic conductivity range of 6.3 x 10^{-05} cm/sec to 1.0 x 10^{-04} cm/sec (URS, 2002). However, indirect measurements of well response in the monitoring wells installed at the Site indicate the typical hydraulic conductivity for a well installed in this area is near or somewhat less than the low end of this Station-wide range.

3.3 Site-Specific Technical Information (40 CFR 257.91(b))

The site-specific technical information required by 40 CFR 257.91(b) is summarized in the sections below. The information has been divided into sections based on the requirements of the CCR Rule in order to characterize the overlying geologic units, the uppermost aquifer, and the confining unit defining the lower boundary of the uppermost aquifer.

3.3.1 Overlying Geologic Units

The material overlying the aquifer at the Site consists of unconsolidated overburden materials and the unsaturated shale bedrock above the water-bearing zone within the Holdenville Shale.

The overburden is mostly stiff to very stiff, low to highly plastic clay and some surficial fill material at several locations across the Site. The thickness of the clay ranged from 18- to 36-ft. at the boring locations advanced in 2015, depending on the ground surface elevation and the thickness of the overlying fill. The thickness and composition of the unconsolidated deposits is generally consistent with the findings from previous investigations as discussed in Section 1.5.2. The vertical hydraulic conductivity of the clay unit was measured by conducting falling head permeability laboratory tests from representative samples collected within the clay unit from boring SB-106. The results of these tests indicated a hydraulic conductivity range of 6.5 x 10^{-09} to 7.4 x 10^{-09} cm/sec. None of the boring logs from the 2015 investigation noted encountering water during drilling.

The unsaturated bedrock consists of the shale below the overburden and above the saturated zone. These rocks are dominated by shales but may also include limited limestone units as described in Section 3.2.3 above.

The low hydraulic conductivity of the overburden materials and unsaturated shale bedrock in conjunction with absence of observed groundwater during drilling indicates that the overlying residual clays and silty clays and the unsaturated bedrock act as upper confining layer.

3.3.2 Aquifer Characterization

Based on the field investigation activities, the uppermost aquifer at the Site was determined to consist of a saturated unweathered to highly weathered zone within the Holdenville Shale. The uppermost aquifer was identified through installation and testing of piezometer clusters at multiple locations. Although all of the piezometers were low-yielding, the piezometers that intercepted the most productive zones were selected as most closely satisfying the definition of the uppermost aquifer. The aquifer appears locally semi-confined to confined by the low permeability clay and unsaturated shale bedrock in the overlying geologic units as well as the shale units in the underlying bedrock.

The CSM presented in **Figure E.5**, **Appendix E** illustrates the definition of the uppermost aquifer for the unit. The thickness of the uppermost aquifer is believed to be roughly 5- to 10-ft. thick, based on evaluations of the boring logs and water level measurements collected from the piezometer cluster. The top of the uppermost aquifer is at approximately 813-ft. msl across the Site as shown in **Figure E.5**, **Appendix E**.

The calculated seepage velocity (flow rate) of the aquifer ranges from about 8.9 x 10^{-06} to 1.4 x 10^{-05} cm/sec. Calculations of the seepage velocity are included in **Appendix C**. The hydraulic conductivity of the aquifer was not assessed in 2015, instead deferring to the results from hydraulic testing of select monitoring wells in 2002, as discussed in Section 1.4.2. The results of these tests are presented in **Appendix G** and indicate a hydraulic conductivity range for the uppermost aquifer between approximately 6.3 x 10^{-05} cm/sec to 1.0 x 10^{-04} cm/sec. However, these values are not consistent with the low yield experienced in sampling most of the wells across the Site, suggesting that the true hydraulic conductivity of the water-bearing zone may be a significantly lower value. Representative values of total porosity for shale range from 0.0 to 0.10 (0% to 10%) based on literature values after Walton, 1988 and Domenico and Schwartz, 1990. The effective porosity is approximated to be 0.05 (5%) by specific yield for shale bedrock after Walton, 1970.

3.3.3 Lower Boundary Confining Geologic Unit

The 2015 Site Investigation indicated that the saturated unweathered to highly weathered zone within the Holdenville Shale acts as the uppermost aquifer at the Site as shown on **Figure E.6**, **Appendix E**. This unit is likely confined by the underlying unweathered shale of the Holdenville Formation, the Nenapah Limestone (where present) and the Nowata Shale in the Marmaton Group. Due to the dominance of fine-grained lithologies and thinness of the several carbonate rock units, very little groundwater is obtained from the Marmaton Group. Most wells in Linn County are completed in either the lower Pawnee Limestone and the Altamont Shale which underlies the above mentioned Nowata Shale (Seevers, 1969).

The hydraulic conductivity, porosity, and effective porosity ranges of the shale are 1 x 10^{-11} to 2 x 10^{-07} cm/sec, 0 - 10%, and 0.5 - 5%, respectively, based on literature values for the shale after Walton 1970, Walton, 1988, and Domenico and Schwartz, 1990.

3.3.4 Characteristics of Geologic Units

A summary table including the hydraulic conductivities of each geologic unit encountered during the field investigation activities at the Site is included in **Table 3-1**. The data presented in **Table 3-1** was obtained using the following methods:

APPENDIX B

Unstable Areas Supporting Information

APPENDIX B.1

Portions of Previous Reports

Portions of Detailed Hydrogeologic Site Characterization Report (AECOM, 2017)

Portions of Geotechnical Data for Bidders (WCC, 1978) operated in two areas, the northwest and southeast, separated by a roadway berm and hydraulically connected by a series of culverts. The unit, as a whole, has a surface water area of approximately 1.5 acres at the normal operating level of 848.2-ft. mean sea level (msl).

Influent to the Site consists of sluiced CCR and stormwater runoff from the immediate vicinity of the impoundment and a small area of upstream plant facilities. CCR is currently sluiced into the southeast portion of the Site from Unit 2 for initial particle settling. After dewatering is complete, material is loaded and transported for beneficial use or disposal at the CCR Landfill. Excess water is discharged via a permitted outfall to the discharge canal. Therefore, the storage capacity of the impoundment does not change significantly from year to year (AECOM, 2016).

Water discharges from the northwest portion of the Site through five 12-inch diameter steel pipes and one 30-inch diameter high density polyethylene pipe located at the east side of the impoundment. Water flows through the outlet pipes which daylight on the exterior slope, then through the permitted National Pollutant Discharge Elimination System (NDPES) outfall into the discharge canal.

1.3 Regional Geology and Hydrogeology

1.3.1 Geomorphology

The Station is located within the Osage Plains physiographic section, which is included within the larger Central Lowland province of the Interior Plains physiographic division (Adamski et al, 1995). The area is defined by gently rolling hills, with typically soft shale bedrock interbedded with sandstones and limestones characterized by a series of east-facing escarpments that indicate the presence of more resistant bedrock units (typically limestone) in the surficial rocks. Local surface topographic relief at the Station is typically less than 250-ft. msl with the greatest relief occurring where major streams incise the underlying rocks (Fenneman, 1938, Imes and Emmett, 1994). Local surface topography of the Site is relatively flat (**Figure A.4**, **Appendix A**). The local topography at the Site is highest in the northeast portion of the Site near MW-902 (852.07-ft. msl at ground surface) and the topography is lowest in the south portion of the Site near MW-905 (851.04-ft. msl at ground surface). The locations of MW-902 and MW-905 are shown on **Figure A.5.2**, **Appendix A**.

The regional drainage pattern is generally dendritic and associated with the larger Lower Marais de Cygnes Watershed (USDA, 2008), whose major water source is the Marais des Cygne River, which flows southeasterly approximately 5 miles south of the Station (Kansas Water Office (KWO), 2009). Elm Creek and Sugar Creek, tributaries of the Marais de Cygne River, flow into La Cygne Lake adjacent to the Station (**Figure A.1**, **Appendix A**).

1.3.2 Geology

1.3.2.1 Surficial Soils

The United States Department of Agriculture, (USDA) Soil Conservation Service has produced a soil map of this area (USDA, 2017), which is provided as **Figure B.1, Appendix B**. The dominant near surface soils underlying the Site are mapped as the Kenoma Silt Loam. The Kenoma Silt Loam is described as “deep, gently sloping, moderately well-drained”, and is found on slopes and knolls.

1.3.2.2 Bedrock

The bedrock near the Station consists of shale, limestone, sandstone and minor coal, assigned to the Middle to Upper Pennsylvanian Age, Marmaton and Pleasanton Groups (KGS, 1969). These units are relatively typical of the cyclic sedimentary rock deposits present in the Midwest. Thickness of individual beds varies from thin coal “smuts” to beds as thick as thirty feet, with lateral variations occurring in many locations (Jewett et al, 1968). A during the desktop study. Three boring logs, B-15, B-27, and B-28, were drilled near the Site by Geotechnology in 2009. The location of the borings is provided on **Figure A.5.2, Appendix A**. The boring logs are included in **Appendix D.2**.

1.4.1 Stratigraphy

A varying thickness of natural soil and some fill underlie the Station. In the Unified Soil Classification System (USCS), the natural soils vary from brown to gray, low to highly plastic clays (CH), silty clays (CL) and sandy clays (SC) with some discrete poorly graded sand beds or lenses (SP). The majority of the soils are residual deposits formed from the weathering of the underlying bedrock, although some alluvial or colluvial soils may be present. These unconsolidated deposits vary from 18- to 36-ft. in thickness at the boring locations overlying bedrock comprised of primarily shale with some thin sandstone and limestone units.

The shallow bedrock underlying the unconsolidated deposits is a stratigraphically and lithologically complex set of units that are transitional between the lower Pleasanton and upper Marmaton Groups of the Pennsylvanian System with a combined thickness of these units reported between 50- and 80-ft. The Pleasanton and Marmaton Groups are described as predominantly shale with some sandstone and limestone. Both shale and sandstone strata outcrop at various locations within the Station, generally along intermittent drainage ditches. Less frequently, discontinuous and localized limestone strata were observed at a few locations within the Station (Woodward-Clyde, 1978). Lateral facies changes and vertical gradational changes are common. Correlation of units between boreholes is somewhat limited since drilling methods used generally did not provide undisturbed samples resulting in shale units that are similar in appearance. However, the presence of a limestone unit in several borings potentially suggests the top of the Lenapah Formation (URS, 2005).

The elevation of top of bedrock surface underlying the Site is presented on **Figure A.7, Appendix A**. The contours shown were developed using site-specific boring information augmented with pre-plant topography as shown on **Figure A.4, Appendix A**. The bedrock surface reasonably parallels the pre-plant topography, which indicates the presence of a former west-flowing stream channel south of the Upper AQC Impoundment located below the CCR Landfill and Lower AQC Impoundment. The bedrock itself consists of primarily shale with sparse limestone and coal units interbedded. The upper most bedrock is generally weathered at the contact with the overlying unconsolidated deposits which decreases with depth until reaching competent bedrock. The shale observations from the investigation borings were primarily brown to grayish brown in color. The apparent absence of black and/or olive green shale in many of the borings may be due to an actual “pinching out” of the bed, or the inability to distinguish the cuttings from this thin shale unit from the cuttings of the other shales since most of the wells were drilled using auger or rotary methods. The investigation was originally designed to auger through the soils and shallow bedrock and to core the deeper unweathered bedrock. The structural configuration of the Station is such that the bedrock units have a general northeast strike and an average northwest dip of 0.34° or 31-ft/mile (URS, 2005).

1.4.2 Hydrogeologic Setting

The uppermost water-bearing zone at the Station is in the shale members of the Holdenville Shale in the upper Marmaton Group. The majority of the groundwater monitoring wells are screened in the Holdenville. In borings at the Station, the Holdenville is identified as a moderate to highly weathered shale with many calcareous and sandy zones and varying from brown and weathered to gray and unweathered. The Holdenville overlies the Lenapah Formation in the Marmaton Group.

Several of the groundwater monitoring wells appear to be installed into the upper few feet of one of the limestone members (Idenbro or Norfleet) of the Lenapah Formation. As described in the boring logs, this limestone is hard, dense, dark gray limestone immediately below the Holdenville. This limestone was not encountered in most of the borings on the Station; however, in many cases the stratigraphic position of this limestone is marked by zones with thin limestone stringers or very calcareous shales rather than a distinct limestone bed. In borings that clearly slotted pipe to a level approximately 2 ft above the topmost slot. Next, bentonite pellets were placed in the annulus forming an impermeable plug approximately 3 ft thick. The remaining length of the annulus was grouted using a cement-bentonite grout. A vented cap was placed on the top of the riser. The riser extends above ground approximately 3 ft at each location. All water level readings were referenced to the surveyed elevation at the top of the risers. A diagram showing typical observation well construction is included as Figure A-12.

REGIONAL GEOLOGY

The regional geology of the site was obtained from a review of the available geologic literature relevant to the site. A listing of the geologic literature reviewed is provided in the Bibliography.

The portion of eastern Kansas including the site lies in the Osage Cuestas section of the Osage Plains Physiographic Subprovince, a part of the Central Lowland Physiographic Province, Figure A-2. The Osage Cuestas are composed of a subparallel series of northeast-southwest trending, eastward facing escarpments, or cuestas. The valleys between the ridges are generally flat to gently rolling. The cuestas are invariably underlain by resistant Pennsylvanian age limestones; whereas, the intervening valleys are underlain by more easily eroded Pennsylvanian age shales, sandstones and siltstones. These rock units, composed of strata of the Pennsylvanian System of the Upper Paleozoic, normally dip to the west and northwest off the Ozark Dome in Missouri at approximately 20 ft per mile (less than 1 percent). They are designated sequentially

APPENDIX B.2

Geologic/Geomorphologic Features Documentation

Appendix D—Surface Sinkholes and Other Solution Features, Geologic History of Kansas

SEE STATE MAP AT END OF DOCUMENT FOR COUNTY CODES

Geologic History of Kansas

Prev Page--Structural Nomenclature || Next Page--Earthquakes in Kansas

Appendices, continued

Appendix D--Surface Sinkholes and Other Solution Features

From Merriam and Mann, 1957.

CA

Ashland Basin (Ashland-Englewood Basin)--The Ashland Basin in southern Clark County, southwestern Kansas, forms a large topographic depression. It is a coalescing sinkhole (Frye, 1942). The depression probably was caused by solution of Permian salt and gypsum, which occur less than 1,000 feet below the surface (Frye, 1950; Jewett, 1951; Smith, 1940).

This large sinkhole is as much as 12 miles wide and 500 feet below the general level of the High Plains (Schoewe, 1949). The walls are Permian redbeds capped by Ogallala (Pliocene). The basin is dissected and drained by Cimarron River. As much as 100 feet of late Pleistocene fill has been deposited in the depression. Frye (1950) dated its subsidence as mid-Pleistocene to late Pleistocene and believed that solution is directly related to faults that formed in Pleistocene time in the area.

CA

Big Basin and Little Basin--Two sinkholes in western Clark County are well known; the larger, Big Basin (Pl. 26A), is located just west of the smaller, Little Basin, which contains within its boundaries a picturesque and smaller sinkhole known as St. Jacob's Well (Pl. 26B).

Big Basin is situated in sec. 24 and 25, T. 32 S., R. 25 W. The sinkhole is subcircular and approximately one mile in diameter. The floor is relatively flat and 125 to 150 feet below the rim. Small depressions or sags, often retaining water, occur on the floor of the basin. The wall of the sinkhole is still essentially vertical although slightly dissected. Permian, Cretaceous, and Tertiary rocks crop out in the wall of the basin. Its formation probably occurred from several hundred to a few thousand years ago (Smith, 1940).

Little Basin is about one-third mile east of Big Basin. The floor is 35 feet below the rim level. Although Little Basin is shallower than Big Basin, the two sinkholes are believed to be the same age. St. Jacob's Well, a relatively recent sinkhole, is on the floor of Little Basin. The water which is retained in this smaller sinkhole forms an "oasis" in the semiarid country.

Both Big and Little Basins are believed to be due to solution of the underlying soluble Permian beds.

CR

Cherokee County Sinkholes--Sinkholes are observable where rocks of Mississippian age crop out in some areas of southeastern Kansas. All known sinkholes in Cherokee County are attributed to solution of the thick Mississippian limestone in post-Cherokee time, as well as recently. Howe (1956) reported that Pennsylvanian strata are commonly faulted in older sinkholes because the collapse of caverns in the Mississippian limestone occurred after consolidation of overlying sediments. Some faults have a throw of as much as 6 feet. Pyrite and marcasite are common along fault planes.

Nine recent sinkholes were described by Pierce and Courtier (1937). Old sinkholes dated as post-lower Cherokee are exposed in four of the recent sinkholes.

Two of the recent sinkholes subsided about 1905. One is located in the SW sec. 34, T. 32 S., R. 25 E.; the other is in the NW sec. 28, T. 33 S., R. 25 E. Both sinkholes are elliptical, 75 to 125 feet across, and 30 or more feet deep. Their walls are nearly vertical.

Two more sinkholes are in the W2 sec. 34, T. 32 S., R. 25 E. The earlier sinkhole was formed in 1911. A few years prior to 1911 a sag, about 14 feet in diameter, appeared in a corn field, but no water was retained in the depression. In 1911 a larger hole suddenly appeared in the area of the former sag. The wall was vertical and extended down 72 feet; water was present in the bottom. In 1933 the north rim sank approximately 20 feet. The second sinkhole in sec. 34 formed in 1922 and was a shallow depression about 10 feet in diameter.

Two other shallow sinkholes, about 10 feet in diameter, are located in the NE sec. 9, T. 32 S., R. 25 E.; one formed about 1921 and the other in 1929. Another sinkhole in the NE sec. 34, T. 32 S., R. 25 E., was reported to have formed in 1911 or 1912; it was filled prior to 1937, and no further data on it are available. In 1924 cracks appeared in the soil in the E2 sec. 9, T. 32 S., R. 25 E. The area of soil cracks subsided in 1929 to form a vertical-walled, elliptical sinkhole, 75 to 125 feet across and 30 feet deep.

HM

Coolidge Sink--On December 18, 1926, a hole suddenly appeared in the ground 15 miles south of Coolidge, Hamilton County (NE sec. 22, T. 25 S., R. 43 W.). On July 1, 1930, the sinkhole was reported to be about 60 feet in diameter and 40 feet deep (Bass, 1931). It was circular with a steep and undercut wall; the floor sloped at a low angle toward the center of the depression. Three sets of crevices encircled the structure.

By August 8, 1930, the sinkhole had enlarged to a diameter of 104 feet and increased in depth to 68 feet (Bass, 1931). The material in which the sinkhole was formed was homogeneous silt; no stratified rock could be seen in the hole. Smith reported that in 1940 water filled the hole to within 10 feet of the surface and that the wall had slumped so that no overhang was visible. The depression had increased in size to 150 by 200 feet in 1941 and had elongated from its original circular shape, engulfing a nearby country road. It also had filled with water to within 15 feet of the rim (McLaughlin, 1943).

Bass attributed the sinkhole to solution and formation of a cavern with subsequent collapse of the roof. He reported that bedrock dips at 5' toward the sinkhole, indicating that the entire area of recent subsidence may be part of a larger and older sinkhole. Landes (1931) studied the area and determined that Graneros Shale was exposed below the rim. From this, Landes decided that the original cavern must have been formed in either salt or gypsum in the Permian section. Smith found that this sinkhole is but one of a linear series and suggested that they occur along a post-Ogallala fault.

ME

Meade Salt Sink--Sudden sinking of a circular area 150 to 200 feet across took place sometime between the 3rd and 18th of March 1879, in Meade County, 1 1/2 miles southeast of Meade. The sinkhole is on the east side of Crooked Creek, just east of the Crooked Creek Fault. The Great Salt Well, as it was called at the time of formation, engulfed a portion of the "Jones and Plummer Trail," an often-used wagon road and cattle trail (Cragin, 1884). Mudge (1879) stated that by the 18th of March It was 60 feet deep and had a circumference of 610 feet; It was nearly circular with a perpendicular wall. Saline water filled the hole to within 17 feet of the land surface. The depth of the water ranged from 15 to 27 feet at the edge to 42 feet at the center. Water finally rose to within 14 feet of the ground surface.

Sod cracks formed on the rim around the sinkhole. They were 5 to 15 feet deep and 1 to 10 inches wide. The more distant cracks were 126 feet from the hole.

Mudge (1879) stated that 1 bushel of salt was recovered for every 43 gallons of water, about a 7 percent concentration. At one time salt was produced commercially from the well.

Presently the sinkhole is filling with sediment. In the last few years the sinkhole has been completely dry (W. H. Schoewe, personal communication).

Mudge (1879) thought that a cavern had been formed in the Dakota Formation, softer material having been washed out by subterranean water, causing subsequent caving. Johnson (1901), Smith (1940), and Frye (1942) suggested that the cavern formed in underlying Permian salt beds and that overlying rocks collapsed. Frye (1942) pointed out that the shallowest soluble rock is in Permian redbeds several hundred feet below the present water table. He believed that Pliocene faulting provided the necessary openings for water to have access to soluble beds in the Permian and the faulting therefore controlled development of solution caverns; the period of sinkhole formation thus has been limited to post-Pliocene time.

MC **Mitchell County Sink**--An unusual type of sinkhole developed in Mitchell County in 1927. Subsidence in the form of a trench in loess, 200 feet long, 75 feet wide, and 18 feet deep, necessitated moving a farm house. Landes (1932) reported that flat discoidal pebbles of the Fort Hays Limestone, derived from nearby outcrops, are found in loess at the level of the trench floor. He believed that solution of limestone pebbles formed a small cave in the loess, that erosion by circulating ground water enlarged the cave, and that the result was collapse of the overlying loess and formation of a sinkhole. A second collapsed cave 40 feet long was formed in 1931 at right angles to the main trench.

ME **Jones Ranch Sink**--The Jones Ranch Sink, 8 miles southeast of Meade, forms a large topographic depression in Meade County (T. 32 and 33 S., R. 27 W.). The sinkhole is subcircular, 3 miles in diameter, and controls a centripetal drainage pattern. It is dissected and partly filled with sediment. Exposed bedrock dips slightly into the sinkhole. Its origin is attributed to solution and collapse (Smith, 1940; Frye, 1942; Jewett, 1951). From the molluscan fauna which it contains, Frye and Leonard (1952) dated the fill as early Wisconsinan. They pointed out that isolated features such as this are dated either by fossils or by intersection of lines of dissection.

WA **Old Maid's Pool**--This sinkhole is northwest of Sharon Springs in Wallace County (sec. 30, T. 12 S., R. 40 W.). Moore (1926b) described it as 80 feet in maximum depth and three-eighths of a mile in diameter. It holds a small lake 300 feet wide, although in 1962 it was dry. The hole is circular, and the wall is moderately dissected. Pierre Shale is exposed on the south side of the basin (Elias, 1931).

BU **Potwin Sink**--A sinkhole which occurred suddenly near Potwin has been described by Gordon (1938). The hole, located in the SE sec. 24, T. 24 S., R. 3 E., Butler County, was formed on the afternoon of September 22, 1937. It was 90 feet by 150 feet, elongated in an east-west direction, and about 45 feet deep. Water filled the hole to within 15 feet of the rim. The unstratified loam of the wall of the sinkhole was perpendicular. It was estimated that approximately 500,000 cubic feet of material was involved in the subsidence. The rim was estimated to be about 35 feet below base of the Herington Limestone. Gordon believed that solution had taken place in the Fort Riley Limestone about 75 feet below base of the sinkhole and that sudden collapse of the cavern roof resulted in the sinkhole.

Two older partly filled sinkholes are found in the vicinity of the Potwin Sink.

WA **Smoky Basin Cave-in**--A sudden subsidence which took place near Smoky Hill River about 5 miles east of Sharon Springs on March 9, 1926, attracted nationwide attention. The sinkhole (sec. 33 and 34, T. 13 S., R. 39 W., Wallace County) had a diameter of about 50 feet. By March 11 it had increased in size to about 125 by 250 feet, giving it an irregular elliptical shape (Moore, 1926b). By April 13 its dimensions had increased to 150 by 290 feet, and still later to about 250 feet north-south by 350 feet cast-west. The wall was vertical down to the water level, 165 to 170 feet below the lip. Water was 50 feet deep in the center of the hole. Moore (1926a) estimated the total depth of the sinkhole to be 300 to 350 feet and the amount of material involved to be approximately 1 1/2 million cubic feet. Pierre Shale is exposed in the wall of the sinkhole, and the Niobrara Formation is exposed a short distance east of the area.

Moore (1926a) suggested that because of its size and the large amount of material involved, the sinkhole was due to roof collapse into a cavity of considerable size in chalk in the upper part of the Niobrara. Chalk was dissolved by eastward-moving ground water, which entered the formation at the outcrop farther west.

Russell (1929) discarded Moore's idea of solution of the Niobrara and postulated instead that the sinkhole was the indirect result of structural deformation. He thought there was too much shale in the Niobrara to be dissolved for cavern formation, and he found no evidence that the formation carried water. The clue to the origin of the sinkhole, he believed, lies in the structure of the region, because in nearby counties there are many faults which were formed during pre-Ogallala and post-Ogallala deformation. He believed that cavities, strong enough to resist pressures for a long time, occurred along faults, ultimately collapsing as did the Smoky Basin Cave-in. Many previously formed sinkholes probably have been obliterated by erosion and deposition so that only recent ones are evident. Russell reported a fault having a throw of 50 feet in the north wall of the cave-in.

Elias (1930) was of the opinion that the theory of collapse or subsidence along fault voids is unsound. He suggested that the fault may have aided indirectly in the cave-in by permitting surface water to descend underground and gain access to underlying chalk, causing subsequent solution in the Niobrara Formation.

RL **Flint Hills Sinkholes**--Hay (1896) described numerous sinkholes on upland areas of the Flint Hills in the Fort Riley Military Reservation, Riley County. Although not large, deep, nor spectacular, they are described here because they are representative of the common upland type in Kansas.

These sinkholes range in diameter from 30 to 50 feet and. in depth from 8 to 10 feet. All are roughly circular or oval in shape. Hay counted as many as 42 individual sinkholes in 1 square mile. Most individual sinkholes do not retain water. One of the larger sinkholes in the area contains five smaller ones in its floor. Upland sinkholes on the Fort Riley Reservation have been formed by solution and subsidence of the Fort Riley Limestone, which lies near the surface in the region. The Fort Riley is readily soluble and exhibits well-defined jointing.

Similar sinkholes have been reported in Wabaunsee County by Savage (1881) and in Morris County by W. R. Atkinson (personal communication), Hay (1896), and Schoewe (1949). Small, circular, shallow sinkholes due to solution of the Fort Riley Limestone also occur in Cowley County (Bass, 1929) and Butler County (Fath, 1921).

Other Solution Features--Commonly associated with sinkhole development in Kansas are caves, natural bridges, underground drainage, and soil cracks. These related features are prominent mainly in the western part of the state. For the most part they are small and do not form a major part of the physiography.

Lee and Payne (1944) described an interesting occurrence of cave deposits in Mississippian rocks found in the subsurface of the McLouth gas and oil field, in Jefferson and Leavenworth counties. Pennsylvanian deposits occur in the caves, which were found at depths of as much as 150 feet below the top of the Mississippian.

Davis (1955) described in detail three small caves in the Stanton Limestone (Pennsylvanian) in Wilson and Montgomery counties.

Caves, presumably In the Fort Riley Limestone (Permian), have been mentioned by Savage (1881) as occurring in Wabaunsee County. Stalactites and stalagmites occur in the caves. W. R. Atkinson (personal communication) reported the occurrence of caves in the Fort Riley Limestone in southwestern Morris County. Caves in this part of the geologic section are usually low and narrow but long.

Solution of gypsum in the Blaine Formation (Permian) has resulted in many small sinks, caves, and natural bridges in Barber and Comanche counties. Caves in this area and adjoining portion of Oklahoma are commonly called "The Bat Caves." These caverns have been described in detail by Twente (1955). Grimsley and Bailey (1899) described a gypsum cave on Cave Creek, 4 miles west of Evansville, known as Big Gypsum cave. A stream entered from the west of the 100-foot cave and left by an east opening.

The largest and best known natural bridge in Kansas spanned Bear Creek at a point 7 miles south of Sun City in Barber County (Pl. 26C). The bridge, 12 feet high, 55 feet long, and 35 feet wide, collapsed late in 1961 (D. J. Malone, personal communication). Many other small natural bridges occur in this part of the state, but they are not as well known as the Sun City Natural Bridge. Such bridges have also formed by solution of Permian gypsum.

The absence of surface drainage courses may indicate subterranean water courses In soluble rocks. In the Bird City area in Cheyenne County, there is an absence of drainage channels. In western Kansas, White Woman Creek offers an excellent example of subsurface water drainage. The stream enters the state in Greeley County and flows east across Wichita County into western Scott County, where the surface water course disappears. No re-entry to the surface is known. The point at which the stream disappears is a short distance west of the Modoc Basin.

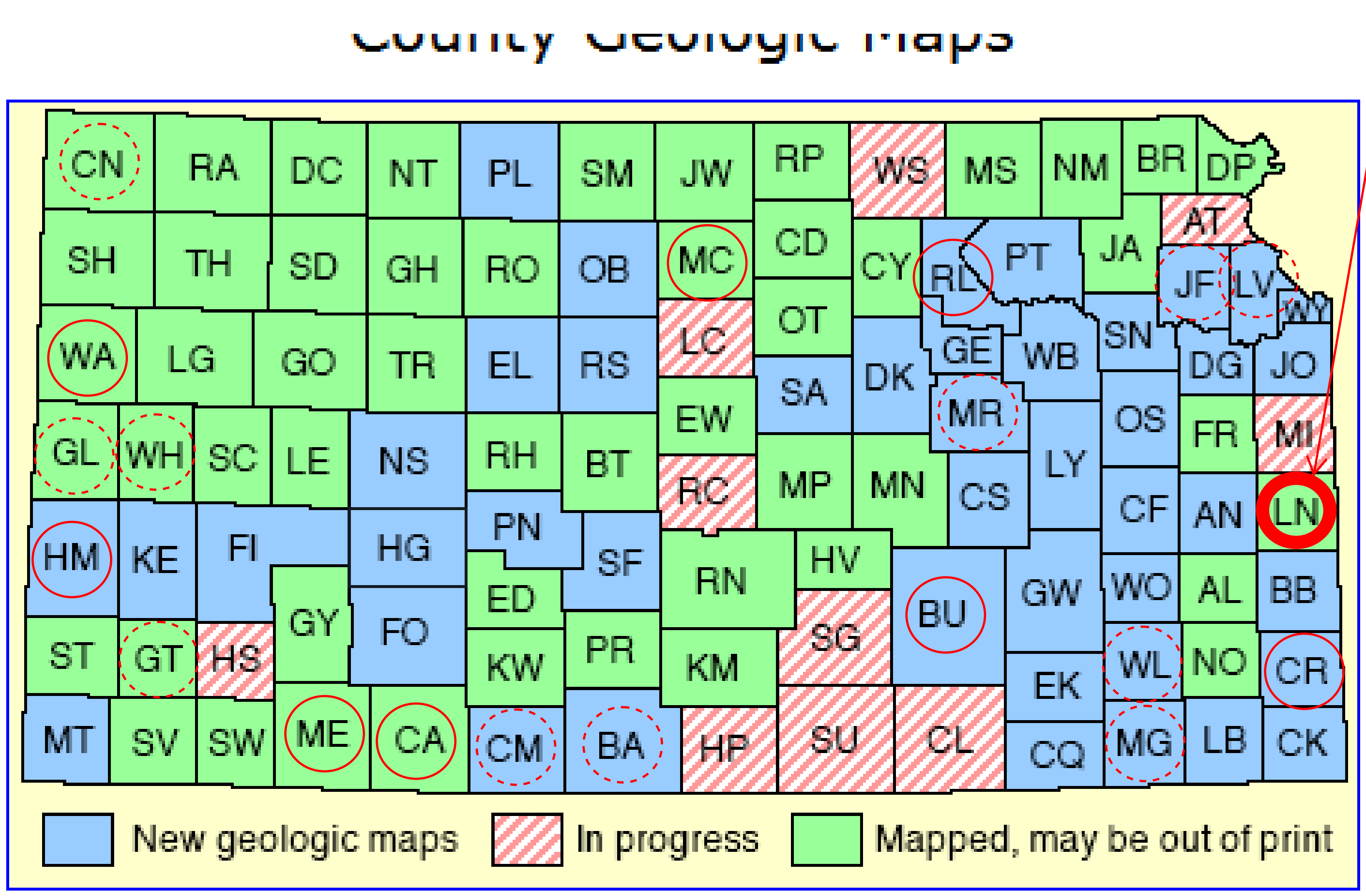
McLaughlin (1946) mentioned the area of the Bear Creek depression, where Bear Creek crosses the northwestern corner of Grant County. In places, drainage consists of a series of sinkholes and short intermittent streams, indicating underground water channels. In southern Kearny County, surface expression of the Bear Creek drainage ends abruptly. Many other small streams, especially in Wichita, Scott, Kearny, Finney, Grant, and Haskell counties, flow for short distances on the surface and then disappear underground.

Prev Page--Structural Nomenclature || Next Page--Earthquakes in Kansas

County key for counties discussed above. Note that Linn County was not discussed above.

Kansas Geological Survey, Geologic History of Kansas
Comments to webadmin@kgs.ku.edu
Web version April 2006. Original publication date Dec. 1963.
URL=http://www.kgs.ku.edu/Publications/Bulletins/162/10_app_d.html

LA CYGNE STATION



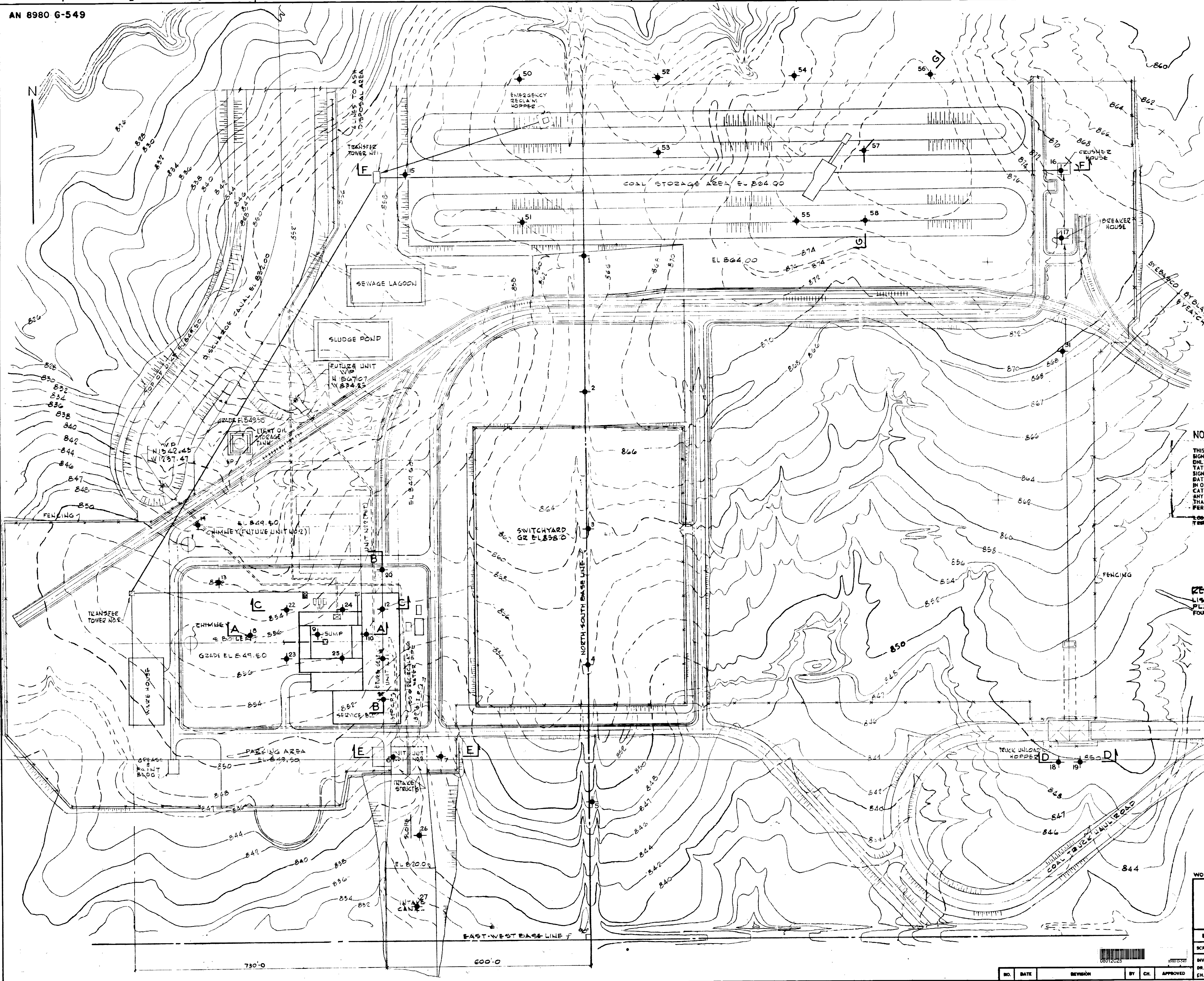
APPENDIX B.3

Human-made Features or Events Documentation

Ebasco Cross Sections from 1969

KGS Publication 114, Part 2, Coal Resources of the Marmaton Group in Eastern Kansas

AN 8980 G-549



BORING LOCATIONS

NO.	N-S	E-W	REMARKS
1	2010N	0	NOT TAKEN
2	1610N	0	NOT TAKEN
3	1210N	10E	
4	810N	0	NOT TAKEN
5	410N	10E	
6	544N	570W	
7	544N	430W	
8	904N	980W	
9	904N	790W	
10	904N	650W	
11	834N	600W	
12	974N	600W	
13	1054N	1080W	
14	1224N	1140W	
15	2250N	520W	
16	2250N	1400E	
17	2050N	1400E	
18	510N	1375E	
19	510N	1425E	
20	1094N	600W	
21	714N	600W	
22	974N	880W	
23	834N	880W	
24	974N	720W	
25	834N	720W	
26	310N	500W	
27	110N	510W	
28	190S	550W	NOT SHOWN ON DWG.
29	490S	650W	" " " "
30	790S	750W	" " " "
31	1710N	1400E	
50	2530N	180W	
51	2110N	180W	
52	2530N	220E	
53	2310N	220E	
54	2530N	620E	
55	2110N	620E	
56	2530N	1020E	
57	2310N	820E	
58	2110N	820E	
A	USED FOR WATER		LOCATION UNKNOWN
B	LEVEL DETERMI-		" "
C	NATION		" "

NOTES:

THIS DRAWING HAS BEEN PREPARED FOR THE USE OF DESIGN PERSONNEL OF EBASCO SERVICES INCORPORATED ONLY. INFORMATION CONTAINED HEREON IS AN INTERPRETATION OF THE ORIGINAL LOGS OF THE BORINGS FOR DESIGN PURPOSES ONLY AND MAY OR MAY NOT BE COMPLETE. DATA NOT PERTINENT TO DESIGN PURPOSES OR AVAILABLE IN OTHER REPORTS OR DATA SHEETS MAY NOT BE INDICATED HEREON.

ANY PERSON USING THIS DRAWING FOR ANY PURPOSE OTHER THAN THE ABOVE SHOULD REQUEST TO EXAMINE AND REFER TO THE ORIGINAL LOGS AND DATA SHEETS.

LOGS BASED ON BORINGS AND TESTS MADE BY GENERAL TESTING LABORATORIES IN LATE 1968 AND EARLY 1969.

REFERENCE DRAWINGS

LIST OF DRAWINGS ---------- A-160
PLANT SITE TOPOGRAPHY & LOCATION PLAN -- G-543
FOUNDATION INVESTIGATION - SECTION ---- G-550

WORK THIS DWG WITH DWG AN 8980 G 550

KANSAS CITY POWER & LIGHT COMPANY
KANSAS GAS AND ELECTRIC COMPANY
LA CYGNE STEAM ELECTRIC COMPANY
1973-840MW (NET) INSTALLATION - UNIT NO.1

FOUNDATION INVESTIGATION PLAN

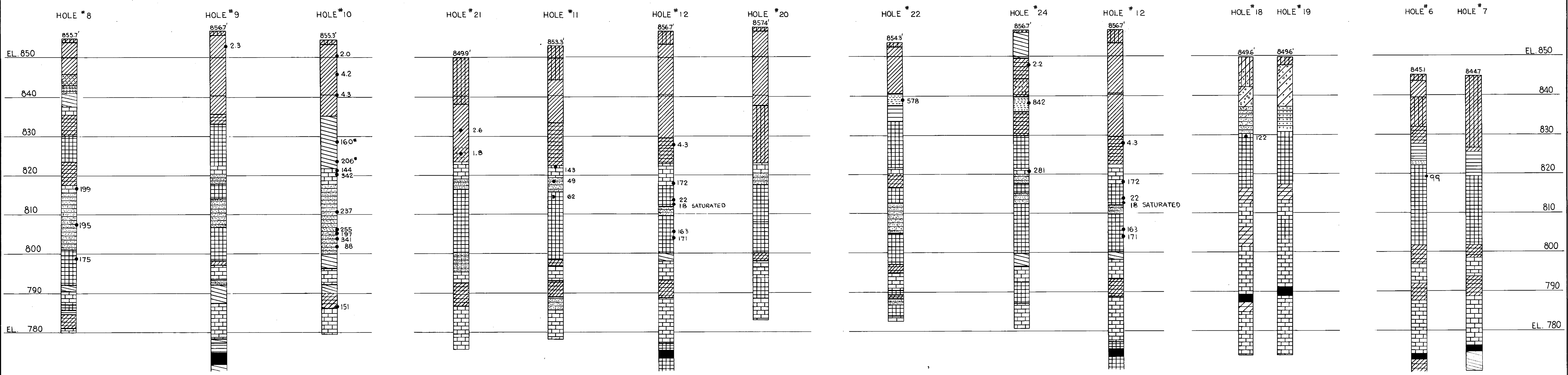
EBASCO SERVICES INCORPORATED NEW YORK

SCALE 1:100	APPROVED	DATE 6/13/69	
DIV. C-H	A. A. Ferlito	AN 8980	
DR. TRAINOR		G-549	
CH. HANNA			

NO.	DATE	REVISION	BY	CH.	APPROVED

8980 G-549

AN 8980 G-550



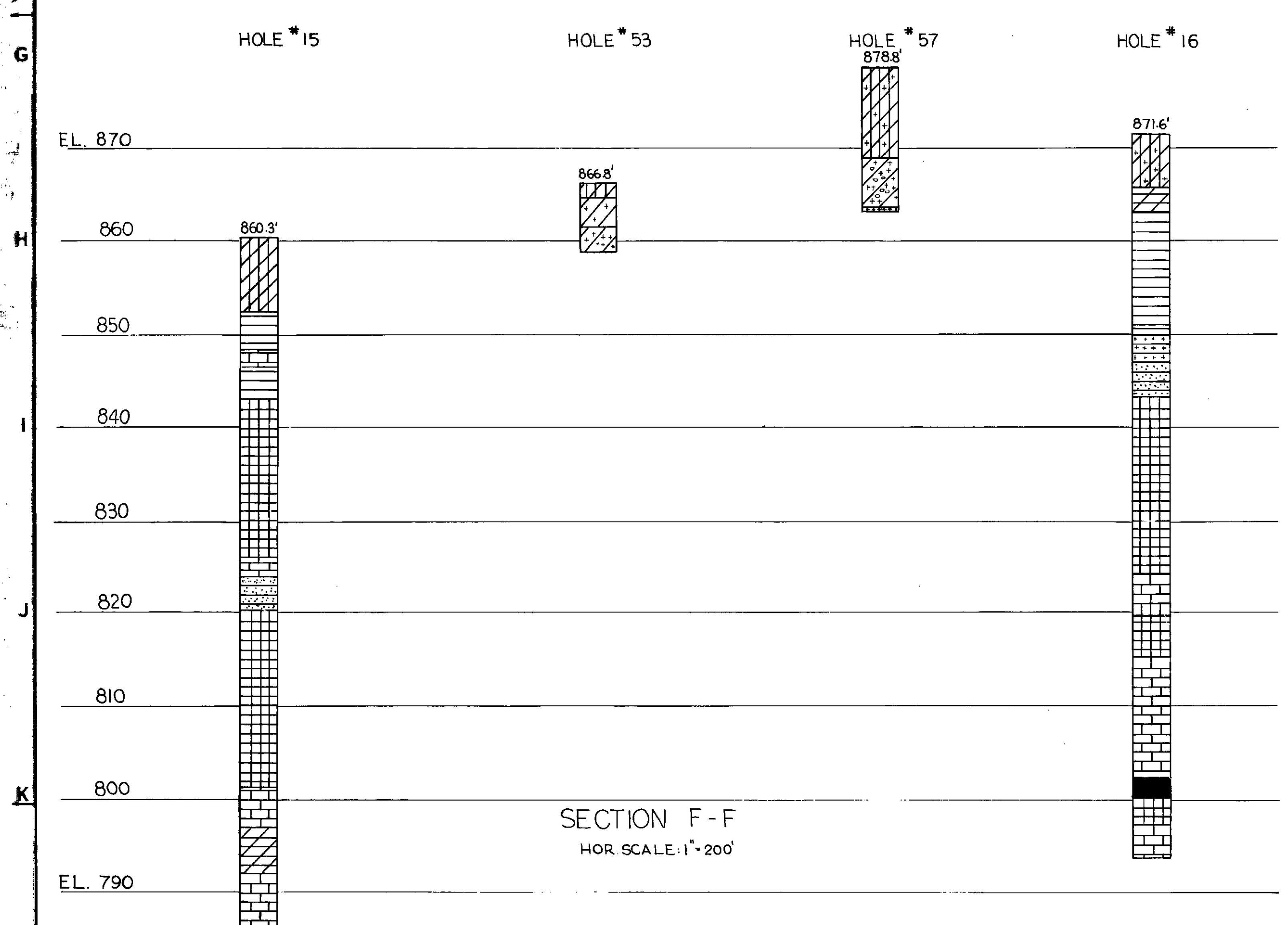
SECTION A-A
HOR. SCALE: 1"=50'

SECTION B-B
HOR. SCALE: 1"=50'

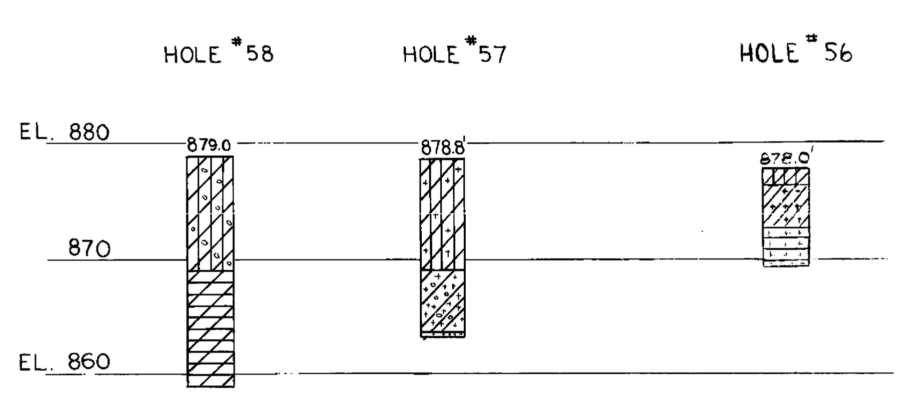
SECTION C-C
HOR. SCALE: 1"=50'

SECTION D-D
HOR. SCALE: 1"=50'

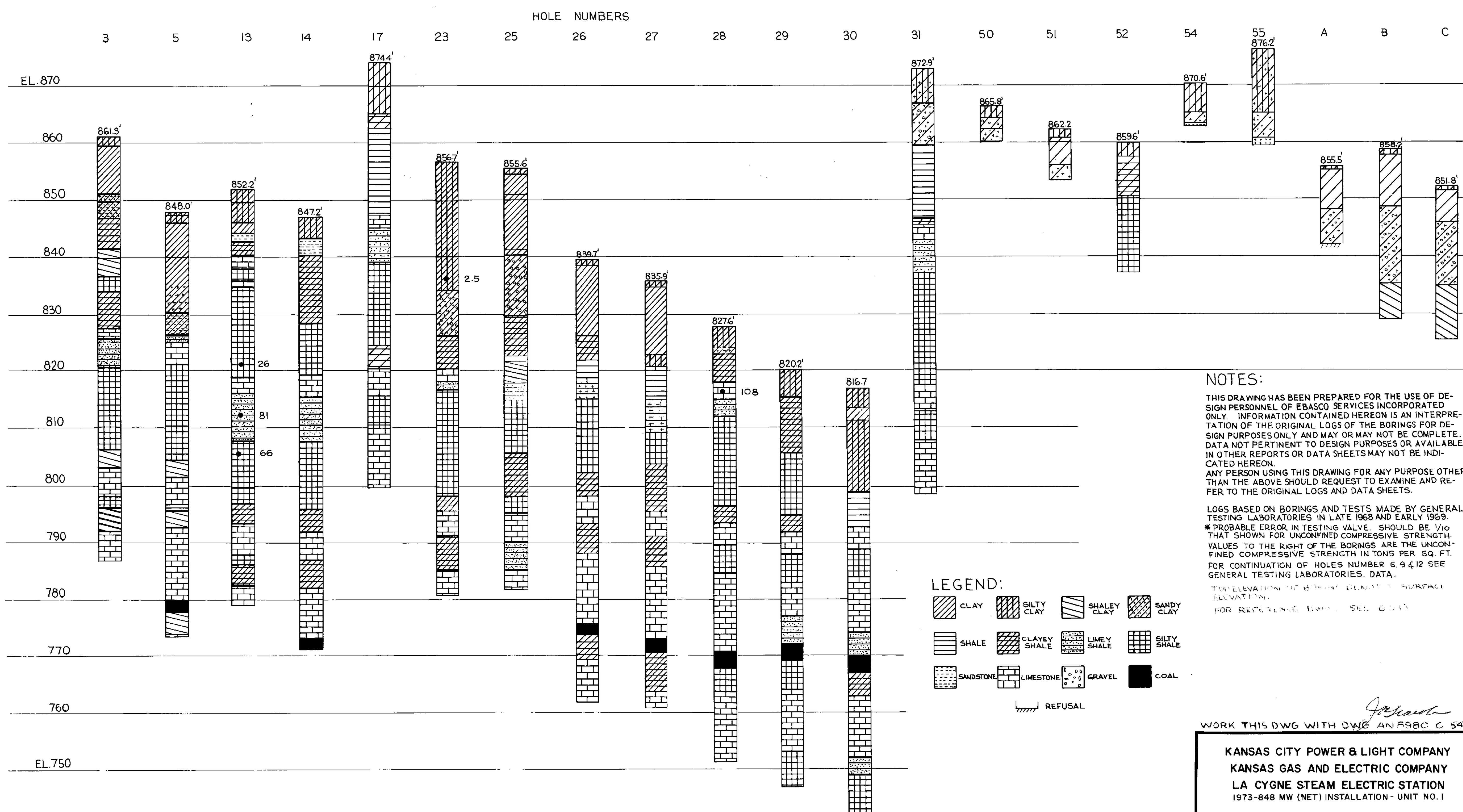
SECTION E-E
HOR. SCALE: 1"=100'



SECTION F-F
HOR. SCALE: 1"=200'



SECTION G-G
HOR. SCALE: 1"=100'



MISCELLANEOUS BORINGS

NOTES:

THIS DRAWING HAS BEEN PREPARED FOR THE USE OF DESIGN PERSONNEL OF EBASCO SERVICES INCORPORATED ONLY. INFORMATION CONTAINED HEREON IS AN INTERPRETATION OF THE ORIGINAL LOGS OF THE BORINGS FOR DESIGN PURPOSES ONLY AND MAY OR MAY NOT BE COMPLETE. DATA NOT PERTINENT TO DESIGN PURPOSES OR AVAILABLE IN OTHER REPORTS OR DATA SHEETS MAY NOT BE INDICATED HEREON.
ANY PERSON USING THIS DRAWING FOR ANY PURPOSE OTHER THAN THE ABOVE SHOULD REQUEST TO EXAMINE AND REFER TO THE ORIGINAL LOGS AND DATA SHEETS.

LOGS BASED ON BORINGS AND TESTS MADE BY GENERAL TESTING LABORATORIES IN LATE 1968 AND EARLY 1969.
* PROBABLE ERROR IN TESTING VALVE. SHOULD BE 1/10 THAT SHOWN FOR UNCONFINED COMPRESSIVE STRENGTH.
VALUES TO THE RIGHT OF THE BORINGS ARE THE UNCONFINED COMPRESSIVE STRENGTH IN TONS PER SQ. FT.
FOR CONTINUATION OF HOLES NUMBER 6, 9 & 12 SEE GENERAL TESTING LABORATORIES. DATA.

TOP ELEVATION OF BORING [illegible] SURFACE ELEVATION.
FOR REFERENCE [illegible]

LEGEND:

CLAY, SILTY CLAY, SHALEY CLAY, SANDY CLAY, SHALE, CLAYEY SHALE, LIMEY SHALE, SILTY SHALE, SANDSTONE, LIMESTONE, GRAVEL, COAL, REFUSAL

WORK THIS DWG WITH DWG AN 8980 G 549

KANSAS CITY POWER & LIGHT COMPANY
KANSAS GAS AND ELECTRIC COMPANY
LA CYGNE STEAM ELECTRIC STATION
1973-848 MW (NET) INSTALLATION - UNIT NO. 1

FOUNDATION INVESTIGATION - SECTIONS

EBASCO SERVICES INCORPORATED NEW YORK

SCALE VERT. 1"=10' HOR. AS NOTED	APPROVED	DATE	
DIV. C H			AN 8980 G-550
DR. L. DORN			
CH. HANNA			

NO.	DATE	REVISION	BY	CH.	APPROVED

08012110

8980 G-550

BORING NUMBER
3
20
12
9
24
23
8
25
10
22
11
13
21
5
14
28
29
30
T
B
QU TSF
861.3
857.4
856.7
856.7
856.7
856.7
855.7
855.6
855.3
854.3
853.3
852.2
849.9
848.0
847.2
827.6
820.2
816.7
HIGH POINT PLANT PAVING
EL 850.0
NORMAL LAKE LEVEL
EL 840.0
860'
850'
840'
830'
820'
810'
800'
790'
780'
770'
760'
750'
740'
730'
720'
710'
2.3
2.2
2.0
4.2
4.3
842 (NEW)
578 (NEW)
2.5
4.5
160*
208*
144
342
281
172
198
145
49
62
26
81
66
82 TSF
(18 TSF)
102
170
195
237
(NEW)
235
197
341 (NEW)
88 (NEW)
175
151
108
172
154
219
116
LEGEND
SILTY CLAY
CLAY
CLAYEY SHALE
GROUND WATER
COAL
SILTY SHALE
LIMEY SHALE
LIMESTONE
SANDSTONE
SHALEY CLAY
SHALE
SANDY CLAY
GRAVEL
T. INDICATES BORINGS IN TURBINE AREA.
B. INDICATES BORINGS IN BOILER AREA
SCALE 1:10
GENERAL TESTING LABORATORIES INC.
★ PROBABLE ERROR IN TESTING VALVE SHOULD BE 1/10 THAT SHOWN FOR UNCONFINED COMPRESSION

Bradley-Vernon mine shaft was sunk. According to Mudge (Gray, 1878, p. 87) coal was mined at Boicourt as early as 1872, for from 1873 to 1877, a total of 167 cars of coal of 18 tons capacity each was shipped from Boicourt on the Missouri River, Fort Scott, and Gulf Railroad. Gray (1875, p. 319) mentions the sinking of a mine shaft to a depth of 90 feet and encountering a coal seam measuring 40 inches in thickness. Traces of these early mines are no longer to be seen unless the mines were located at the sites of the more recent mines of the 1890's and 1910's.

Production--Except for the reference (Gray, 1878, p. 87) to the 167 cars of coal shipped from Boicourt between 1873 and 1877 the only coal production figures published by the Kansas coal mine inspectors are those shown in Table 19. A minimum production, therefore, of 31,698 tons plus 3,006 tons shipped between 1873-1877 or 34,704 tons of coal may be assigned to the Boicourt mining district.

Table 19--Coal production in the Boicourt coal-mining district, Linn County, Kansas.

Year	Bradley-Vernon mine, tons	Boicourt Coal Co. mine, tons	Total
1893	18,873		18,873
1894			
1895	11,037		11,037
1906		1,150	1,150
1913		208	208
1914		215	215
1915		215	215
Total	**29,910**	**1,788**	**31,698**

Reserves--The measured coal reserve area of the Boicourt coal-mining district comprises 1.1 square miles. On the basis of 34 inches as the average thickness of the coal seam, 3,590,400 tons of coal originally underlay the district. Subtracting from this amount approximately 35,000 tons known to have been mined leaves thus a measured reserve of 3,555,400 tons of coal (Table 14). As for the other mining districts in Linn County, the indicated and inferred coal reserves are best considered in relation to the county as a whole.

North Sugar Creek Coal-mining District

The North Sugar Creek coal-mining district is along North Sugar Creek in the northeastern part of Linn County 5 to 8 miles east and southeast of LaCygne. The mines are all in R. 25 E., 10 mines being in T. 19 S., and 16 in T. 20 S. All the mines except 2 small strip pits are underground mines, none of which was in operation in 1953. As in the other mining districts, some of the mines changed ownership and consequently changed names. In most cases it is impossible to tell from the published records which mines operated under more than one name. Reports of the State coal mine inspectors record 33 mines, although field evidence for only 26 mines is to be found in the district. Data pertaining to the mines of this district are given in Table 20.

Table 20--Mulberry coal mines, North Sugar Creek coal-mining district, Linn County, Kansas.

Name	Location	Depth to coal, feet	Thickness of coal, inches	Type of mine
Jarred	NW 35-19-25E	86		Underground
Henry McNabb	NW cor. SW 35-19-25E	72		Underground
Vantyle	NW SW SW 35-19-25E	90	36-42	Underground
Vantyle	SW cor. SW 35-19-25E	65	36-42	Underground
Max Cerise Cox	NW 34-19-25E			Underground
C. Good	SW cor. 34-19-25E	40		Underground
Pinkert-Hall	SE SW 34-19-25E			Underground
	N. line SE 34-19-25E			Underground
	N. line SE 34-19-25E			Underground
	NE cor. SW 33-19-25E			Underground
Ben Good	NW. cor. 2-20-25E			Underground
Hall-Charlie Good	SE cor. NW NW 2-20-25E	50	48	Underground
King	NE cor. 3-20-25E	60-65		Underground
Berry-Vantyle	NE cor. NW 3-20-25E			Underground
	NW cor. 3-20-25E			Underground
	E. line NW 2-20-25E			Underground
	SE cor. NW SW 8-20-25E			Underground
	NE cor. NE SW 8-20-25E			Underground
Schirard	SE cor. NE SW 8-20-25E			Underground
	S. line NE SW 8-20-25E			Underground
	NE cor. SW SW 8-20-25E			Underground
	NW cor. NW SE 8-20-25E			Underground
	NE cor. NW SE 8-20-25E			Underground
Rucker	SW 9-20-25E	15		Strip
Gage	NW cor. 16-20-25E	15		Underground
	W. line SW 16-20-25E			Underground

The coal lies at depths ranging from 15 to 90 feet and is 3 to 4 feet thick. The two small strip mines reported are farmyard pits no more than 200 feet long and less than 50 feet wide with overburdens of about 15 feet. Because of the location close to drainageways, the coal is of poor quality and consequently was not exploited to any appreciable extent. The last mine in the district to operate was the Shirley slope in the SE cor. NE SW sec. 18, T. 22 S., R. 25 E. This mine ceased mining coal at the close of the 1951 mining season. All the mines served local trade.