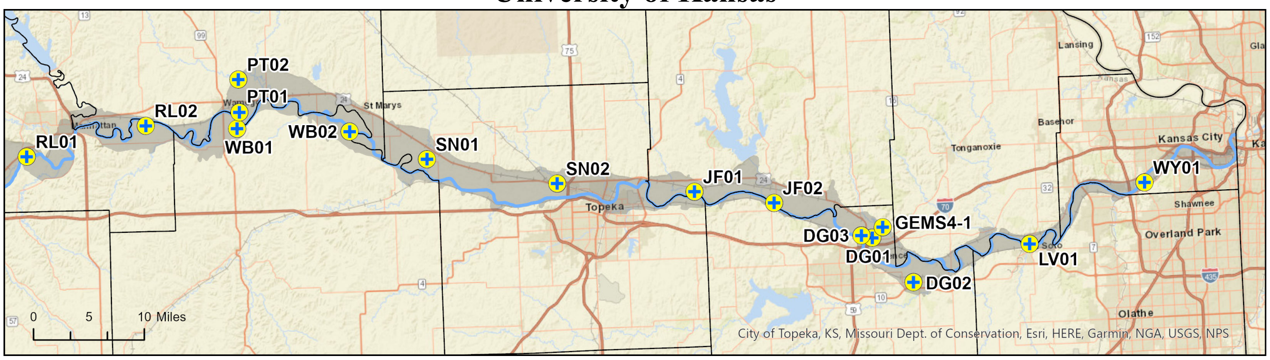
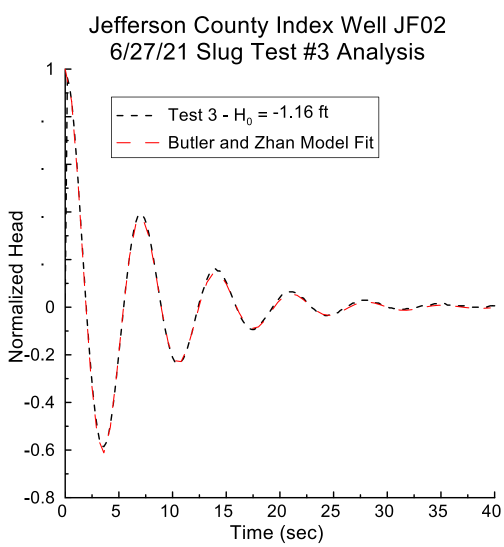
Kansas Geological Survey

Kansas River Alluvial Aquifer Index Well Program: June 2020 to May 2022 Report

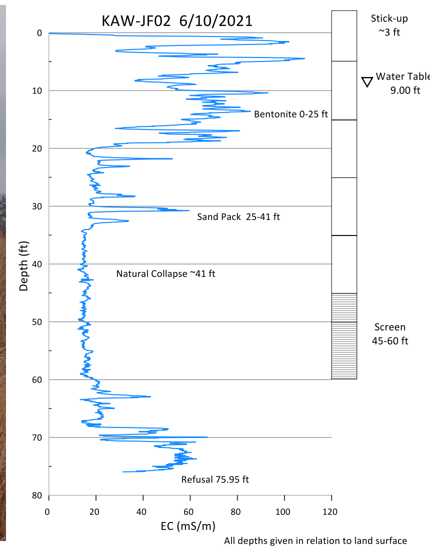
J. J. Butler, Jr., E. C. Reboulet, S. Knobbe, G. C. Bohling,
D. O. Whittemore, J. Voss, and B. B. Wilson
Kansas Geological Survey
University of Kansas



Kansas River Index Well Network – May 2022



Jefferson County Index Well 2
(JF02)



Kansas Geological Survey Open-File Report No. 2022-6
June 2022

GEOHYDROLOGY

KU Kansas Geological Survey
The University of Kansas

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

KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 2022-6

>>>>>>>>>> NOT FOR RESALE <<<<<<<<<<

Disclaimer

Acknowledgments

We are grateful for the support, assistance, and cooperation of the staff of the Kansas Water Office; past funding support by the U.S. Geological Survey's (USGS) National Groundwater Monitoring Network; cooperation of the Kansas Department of Agriculture, Division of Water Resources; and, especially, for the cooperation of the many landowners for making their properties available for installation of the wells. John Woods of the Kansas Geological Survey (KGS) prepared the report maps; Erin Seybold and Masoumeh Veisi of the KGS managed and analyzed, respectively, the water samples collected for the report; and Julie Tollefson of the KGS edited the report. Josh Olson of the Kansas Water Office provided instructive comments on the draft report. This project was funded by the State of Kansas Water Plan Fund.

Executive Summary

The Kansas River alluvial aquifer index well program is directed at developing a better understanding of the aquifer and its relationship to flow in the Kansas River. Projections indicate that the Kansas River corridor from Junction City to Kansas City will continue to be a major area of population and economic expansion in the coming decades and that groundwater will help fuel that expansion. Thus, we need to be able to reliably assess how water levels in the aquifer and the Kansas River will respond to increased groundwater pumping. The Kansas Legislature charged the Kansas Geological Survey (KGS) with improving our knowledge of the aquifer and its interactions with the Kansas River. A major focus of that effort has been on the establishment of a network of monitoring ("index") wells in the Kansas River alluvial aquifer (KRAA) that is patterned after the KGS index well network in the High Plains aquifer. A second major focus has been on improving understanding of KRAA hydrostratigraphy (the distribution of sediment types within the aquifer), a critical task for the modeling phase to follow this work. The Kansas River alluvial aquifer program is supported by the Kansas Water Office and has benefited from assistance from personnel of the Kansas Department of Agriculture, Division of Water Resources, and past funding support by the U.S. Geological Survey's National Groundwater Monitoring Network program.

The project began with the installation of a monitoring well near the Lawrence Airport in late summer 2017. The network now consists of 16 wells from west of Manhattan to just north of Lake Quivira in the Kansas City metropolitan area. Each well is equipped with a transducer for continuous monitoring of water levels, and the transducers are connected to telemetry equipment to allow real-time (hourly) viewing of well water levels on the KGS website (www.kgs.ku.edu/Hydro/KansasRiver/index.html). The vision of the program is that these wells will be monitored for the long term. The ultimate objective is to gather sufficient information through water-level monitoring and additional activities so that a groundwater model of the aquifer and its relationship to the Kansas River can be constructed and then improved over time.

This report provides a concise description of conditions as of May 2022. The report consists of a description of the five wells installed since the last program report (June 2020), an initial interpretation of the 14 well hydrographs that had been acquired as of May 2022, a discussion of the major efforts directed at developing a better understanding of site hydrostratigraphy, and a summary of additional activities that have been performed at the well sites since the last program report.

The major accomplishments of the KRAA index well program to date are as follows:

1. The network has been built from scratch and now consists of 16 wells spanning the length of the Kansas River corridor;
2. Telemetered data from all 16 wells are served on the KGS website;
3. We have initially analyzed hydrographs from 14 of the 16 wells and have begun to develop an understanding of the major mechanisms that produce water-level changes at each well and the relationship between the KRAA and the Kansas River and its tributaries. The river appears to be a gaining stream over most of its extent;
4. We completed a hydrostratigraphic analysis of the KRAA using 4,945 drillers' logs from the WWC-5 database;

5. We performed direct-push electrical conductivity logging to enhance understanding of KRAA hydrostratigraphy; logs were obtained at all 16 well sites and then an additional 23 logs were obtained as part of five transects in the KRAA;
6. We completed 68.35 miles of towed transient electromagnetic (tTEM) surveying in the KRAA to further enhance understanding of KRAA hydrostratigraphy;
7. We completed the analysis of groundwater samples from all 16 wells to serve as a benchmark for KRAA groundwater chemistry.

In summary, all major project activities have been completed. The focus of KGS activities in the KRAA will now shift to development of a groundwater model of the aquifer, network maintenance, and continued interpretation of well hydrographs, water chemistry, and aquifer hydrostratigraphy in support of modeling activities.

Table of Contents

List of Figures

List of Tables

1 Introduction and Background

The Kansas River corridor is projected to continue to be a major area of population and economic expansion in the coming decades, and pumping of groundwater from the Kansas River alluvial aquifer (KRAA) will undoubtedly increase to help support that expansion. Currently, we have insufficient information to reliably assess how water levels in the aquifer and the Kansas River will respond to increases in groundwater pumping. That information is essential for, among other things, management of groundwater storage in the aquifer in conjunction with management of reservoir system storage.

The Kansas Legislature charged the Kansas Geological Survey (KGS) with improving the understanding of the aquifer and its relationship to Kansas River flow and provided funding for the project through the Kansas Water Office. A major task of the project is the establishment of an index well network in the KRAA that is similar to the KGS index well network in the High Plains aquifer (Butler et al., 2021). The network that has now been established consists of 16 wells (15 installed as part of this project and one existing well) extending from upstream of Manhattan to the Kansas City metropolitan area; all wells are equipped for real-time monitoring of water levels. Five of these wells were installed with funding through the KGS participation in the USGS National Groundwater Monitoring Network Program (Wilson, 2019). All 16 wells are now in operation and provide continuous water-level records that are accessible in real time on the KGS website (www.kgs.ku.edu/Hydro/KansasRiver/index.html). Concurrent with the establishment of the well network was a series of additional activities. The primary focus of these activities was to obtain information about the hydrostratigraphic framework of the aquifer; other activities were directed at obtaining information about the hydraulic conductivity, water chemistry, and interactions between the KRAA and the Kansas River in the vicinity of each well. The ultimate objective of all project activities was to gather sufficient information through water-level monitoring and additional work so that a groundwater model of the aquifer and its relationship to the Kansas River and its tributaries can be constructed.

This report provides a concise description of conditions as of late spring 2022. The report consists of a description of the five wells installed since the last program report (Butler et al., 2020), an initial interpretation of the 14 well hydrographs that had been acquired as of May 2022, a discussion of the major efforts directed at developing a better understanding of site hydrostratigraphy, and a summary of additional activities that have been performed at the well sites since the 2020 program report.

2 Overview of Aquifer Characteristics

Whittemore et al. (2019) provide a description of the general characteristics of the KRAA from which the following is drawn. The aquifer is composed of the unconsolidated sediments that fill the Kansas River valley. These alluvial sediments can be more than 80 ft thick in the deepest areas. The underlying bedrock consists primarily of limestone and shale, although some short sections of the valley are underlain by sandstone. The sediments in the deeper part of the alluvial aquifer are generally coarse sand and gravel and are overlain by finer-grained deposits (sand, silt, and silty clay) (Davis and Carlson, 1952; Dufford, 1958; O'Connor, 1960, 1971). Where the alluvial deposits are of substantial thickness, the aquifer has a high transmissivity and can commonly yield more than 1,000 gallons per minute (gpm) to large-capacity vertical wells (Fader, 1974). The quality of the water is fresh, although it is hard due to groundwater flow passing through the calcareous bedrock underlying the aquifer and in the valley walls. High levels of iron and manganese occur in some portions of the alluvium as a result of chemically reducing conditions, probably generated by organic matter in sediment in buried meander cutoffs and overbank deposits (Whittemore et al., 2014).

3 Program History

The KRAA index well program began in late summer 2017 with the installation of a transducer- and telemetry-equipped well in Douglas County near the Lawrence Municipal Airport (Douglas County Index Well 1 [DG01]). This site was chosen so that we could build upon the 63-year record of monitoring from a previous well at the site. Over the next 4.75 years, 14 additional wells were installed and an existing well was converted to an index well. The current network consists of 16 wells. All wells are equipped with a transducer to measure the position of the water level every hour and with telemetry equipment so that the measurements can be transferred and viewed in real time on the KGS website. When possible, site locations were chosen, as with DG01, to build on previous monitoring efforts. In addition, when possible, an effort was made to site wells close to a USGS stream gage to develop a better understanding of the relationship between the river and the alluvial aquifer. The existing well that was incorporated into the network (GEMS4-1) is at the edge of the floodplain in Douglas County and was chosen to be part of a transect that runs from the river to the edge of the floodplain.

Figure 1 shows the 16 wells that make up the current network. The wells extend from west of Manhattan to the Kansas City metropolitan area. Two transects of three wells each were established, one just east of Wamego and the other north of Lawrence, to gather information about how the aquifer responds to changes in river stage at different distances from the river.

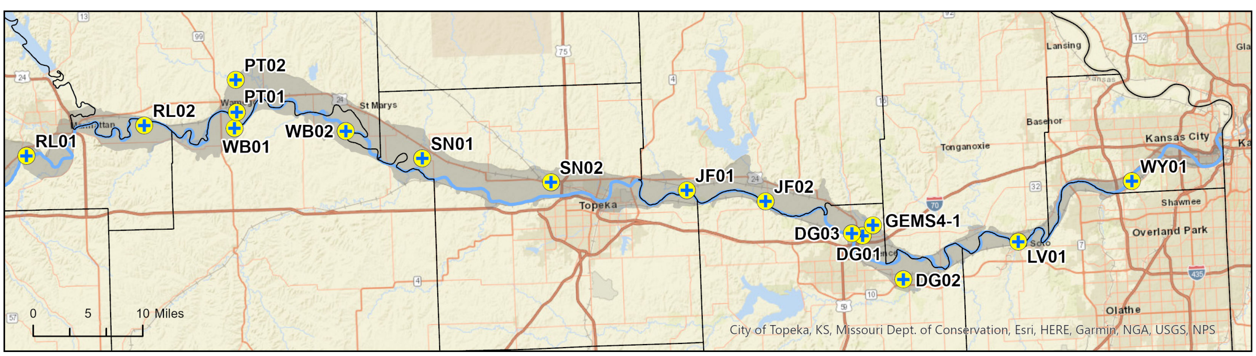


Figure 1. The Kansas River alluvial aquifer index well network as of May 2022. The shaded area is the extent of the aquifer.

Throughout the project, additional information was acquired at the well sites and elsewhere in the floodplain overlying the KRAA. Prior to well installation, a direct-push electrical conductivity (DPEC) log was obtained at the site so that well-construction details (e.g., screened interval) could be determined. Following installation, the well was developed, after which a water sample was obtained for chemical analysis and slug tests were performed to determine the transmissive characteristics of the aquifer in the vicinity of the well and to verify that the well was in good hydraulic connection with the aquifer. Moreover, the river stage was estimated opposite each index well so that the relationship between the

KRAA and the Kansas River could be determined at those locations. An additional 23 DPEC logs were obtained in transects west of Manhattan (near well RL01), east of Wamego, near well JF02, and east of Lawrence (south of the Kansas River). These additional logs were used in the evaluation of data obtained with the recently developed towed transient electromagnetic (tTEM) system for 3-D characterization of the shallow subsurface. The tTEM system obtains estimates of electrical conductivity (EC) by pulling a sensing unit across fields with an all-terrain vehicle. The DPEC and tTEM work were used to supplement the information from the existing drillers' logs in the KRAA as part of the hydrostratigraphic characterization phase of the project. Further details about all of the activities described in this paragraph are provided in section 5 and the appendix (section 8) of this report.

4 Overview of Index Well Sites and Monitoring Data

This section describes the installation of the five index wells completed since the 2020 report (Butler et al., 2020) and briefly discusses the hydrographs from 14 of the wells (monitoring equipment was installed in the final two wells shortly before the completion of this report). The duration of monitoring for the presented hydrographs ranges from 4.75 years of hourly measurements at the first installed well (DG01) to a little more than half a year at the most recently instrumented wells. The water-level data from the Kansas River network have very different characteristics from the data from the High Plains aquifer (HPA) index well network (Butler et al., 2021). In the HPA, the major drawdown in water level occurs during the summer when the aquifer is significantly stressed to provide water for irrigated agriculture. After cessation of irrigation pumping, water levels typically increase until the start of the next pumping season; other than in the eastern portions of the HPA in south-central Kansas, stream-aquifer interactions are negligible. In the KRAA, irrigation plays a more limited role than in the HPA, particularly in the eastern half of the network. In addition to irrigation pumping, which primarily occurs during the summer, the major mechanisms that produce changes in water level are precipitation recharge, stream-stage changes, and pumping for public water and industrial supplies, all of which can occur at any time during the year. As a result, the annual water-level change for an individual well is computed as the difference in the average water level from one year to the next, and not, as in the HPA network, from the difference in annual water-level measurements taken during the winter, three to four months after cessation of irrigation pumping.

The following subsections discuss the installation and characteristics of the five recently installed wells and the hydrographs from 14 of the 16 wells (all wells with at least one month of water-level monitoring). The wells are organized by their location with respect to Topeka; wells in and to the west of Topeka are in the western reach of the network, while those east of Topeka are in the eastern reach. Section 5 and the appendix (section 8) provide details about the methods used for well installation and for the subsequent water sampling and slug tests. Section 5.6 discusses the relationship between the Kansas River and the KRAA index wells. The Kansas River is also known as the “Kaw,” so aerial photos use that more succinct term for the Kansas River.

4.1 Western Reach — West of Manhattan to Topeka

Eight index wells are located in this reach of the KRAA (fig. 2). These wells were drilled between May 2018 and April 2022. Tables 1 and 2 summarize characteristics of the wells.

Table 1. Characteristics of the western wells in the KRAA index well network.

Site	Average 2021 WL elev. (ft)[a]	Average 2021 saturated thickness (ft)[a]	Bedrock depth (estimated ft below land surface)	Screened interval (ft below land surface)	2020 water use (ac-ft)[b]		
					1 mi radius	2 mi radius	5 mi radius
RL01	1,013.75	27.00	50.25	45–50	86.35[d]	217.90[e]	972.82[f]
RL02	980.51	18.71	37.2	27–37	31.58	621.93	3,371.49[g]
WB01	956.43	29.43	44[c]	22–37	199.12	809.29[h]	2,885.11[i]
WB02	923.06	62.26	84.2	60–80	394.27	1,347.82	4,513.11[j]
PT01	NA	NA	73.1	62–72	332.02[k]	1,332.87[l]	3512.17[m]
PT02	NA	NA	93.3	56–66	72.16	296.56	2,652.28[n]
SN01	905.99	24.49	46.5	36.5–46.5	240.96	856.01[o]	2,319.99[o]
SN02	868.68	40.18	71.5[c]	44–64	686.98[p]	1,206.02[q]	5,065.41[r]

[a] Averaging period is the full year unless stated otherwise:
WB02 7/30/21 – 12/31/21.
[b] Irrigation use unless noted
[c] Well did not reach bedrock, so value is the average of the two closest wells that reached bedrock.
[d] Includes 3.42 ac-ft of industrial water.
[e] Includes 67.55 ac-ft of industrial water.
[f] Includes 155.65 ac-ft of industrial, 141.19 ac-ft of municipal, and 328.03 ac-ft of other water.
[g] Includes 18.19 ac-ft of industrial and 1,715.56 ac-ft of municipal water.
[h] Includes 40.75 ac-ft of industrial, 116.84 ac-ft of municipal, and 1.58 ac-ft of stock water.
[i] Includes 40.75 ac-ft of industrial, 809.53 ac-ft of municipal, and 1.58 ac-ft of stock water.
[j] Includes 356.00 ac-ft of municipal and 388.16 ac-ft of other water.
[k] Includes 116.84 ac-ft of municipal and 1.58 ac-ft of stock water.
[l] Includes 575.93 ac-ft of municipal and 1.58 ac-ft of stock water.
[m] Includes 40.75 ac-ft of industrial, 1,111.10 ac-ft of municipal, and 11.18 ac-ft of stock water.
[n] Includes 40.75 ac-ft of industrial, 877.50 ac-ft of municipal, and 11.18 ac-ft of stock water.
[o] Includes 94.63 ac-ft of municipal water.
[p] Includes 2.19 ac-ft of industrial and 599.33 ac-ft of municipal water.
[q] Includes 19.60 ac-ft of industrial and 1,007.84 ac-ft of municipal water.
[r] Includes 2,730.29 ac-ft of industrial, 1818.22 ac-ft of municipal, and 23.76 ac-ft of other water.

Table 2. Additional characteristics of the western wells in the KRAA index well network.

Site	Distance from Kansas River (miles)	Width of floodplain (miles)[a]	Nearby weather station[b]	Nearby stream gage[c]	Nearby previous monitoring[d]		
					Nearby previous well?	Distance from index well (ft)	Monitoring period
RL01	0.20	1.86	Manhattan Airport	None	Yes	<300 ft[g]	9/65–12/83
RL02	0.36	2.91	None	None	Yes	<500 ft[g]	12/66–3/04
WB01	0.45	2.75	Wamego	06887500	Yes	<900 ft	6/66–3/04
WB02	0.01	3.65	None	06888350	No	NA	NA
PT01	0.55	2.88	Wamego	06887500	No	NA	NA
PT02	2.70	5.37	Wamego	06888300[e]	No	NA	NA
SN01	1.00	4.82	Rossville	06888700[f]	Yes	<500 ft[g]	6/78–3/04
SN02	1.20	2.55	None	06888990	Yes	<10 ft[g]	7/50–3/04

[a]Distance perpendicular to valley axis using the Kansas Biological Survey's FLDPLN (floodplain) model.
[b]Name of the weather station within 5 miles of well.
[c]USGS ID# of the stream gage within 5 miles of well.
[d]Within 2,000 ft of well.
[e]Stream gage is on Rock Creek near Louisville; well is adjacent to Rock Creek.
[f]Stream gage is on Cross Creek at Rossville; well is 0.40 miles from Cross Creek.
[g]Correction to the distance given in previous report (Butler et al., 2020).

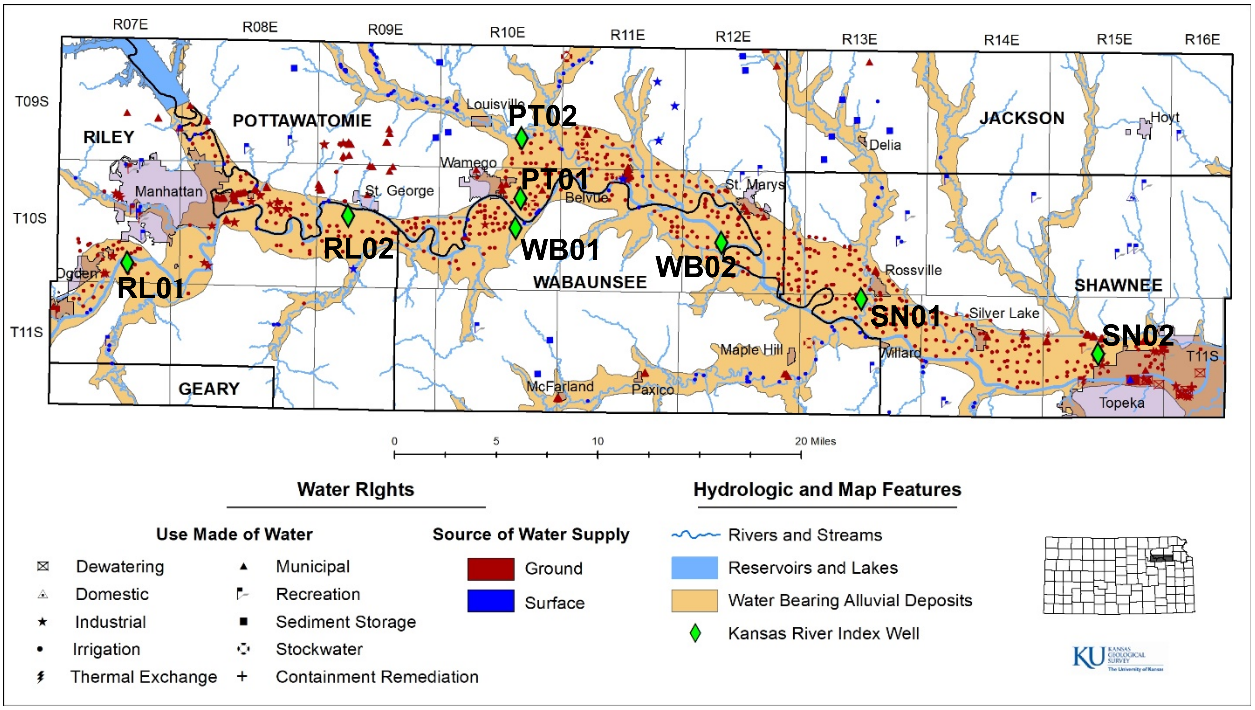


Figure 2. Map of index wells in the western reach of the KRAA network; data from these wells can be viewed in real time on the KGS website (http://www.kgs.ku.edu/Hydro/KansasRiver/index.html).

4.1.1 Riley County Index Well 1

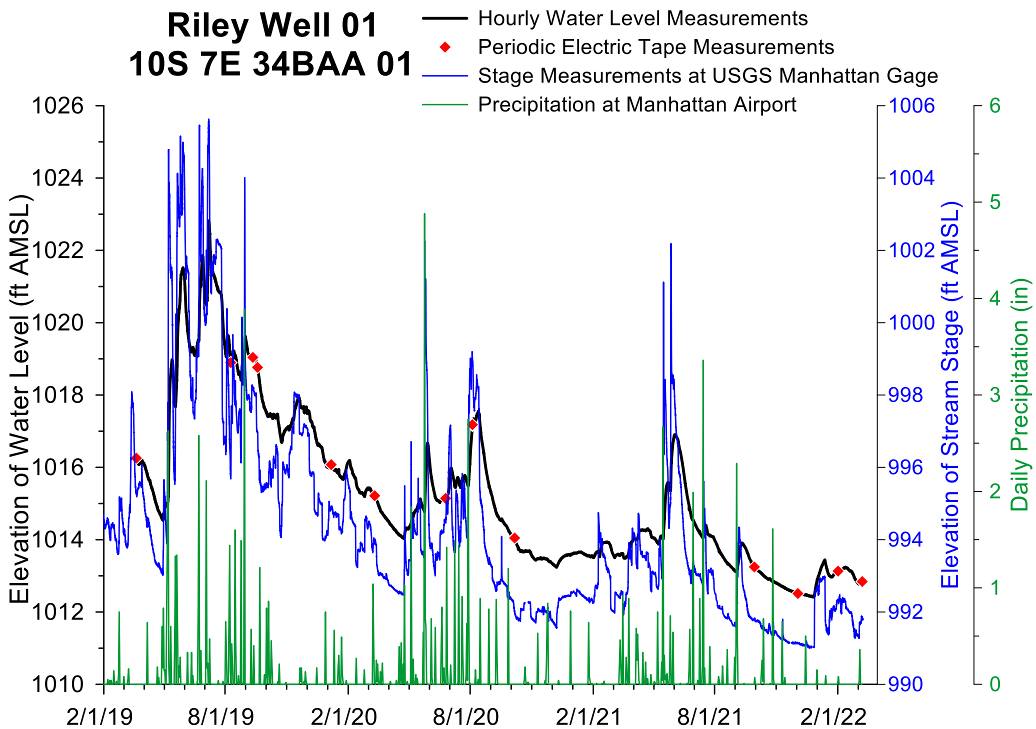


Figure 3. Riley County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/9/22. A water-level elevation of 1,016 ft corresponds to a depth to water of 21 ft below land surface (lsf). The top of the screen is 45 ft below lsf (elevation of 992 ft), and the bottom of the aquifer is 50.2 ft below lsf (elevation of 986.8 ft). The screen terminates 0.2 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. Manhattan Airport weather station is across the river from the well (less than 2 miles); Manhattan gage is 8 miles downstream from the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by changes in stream stage. The aquifer responds relatively rapidly to changes in stream stage, but responses are dampened with respect to those changes.
- Given the strong relationship with stream stage, it is difficult to discern the relationship between precipitation and water-level changes.
- The influence of nearby pumping wells is not discernible.
- Well does not appear to have a discernible response to changes in barometric pressure, which is consistent with the shallow depth to water and the sandy vadose zone (determined from DPEC logging).

4.1.2 Riley County Index Well 2

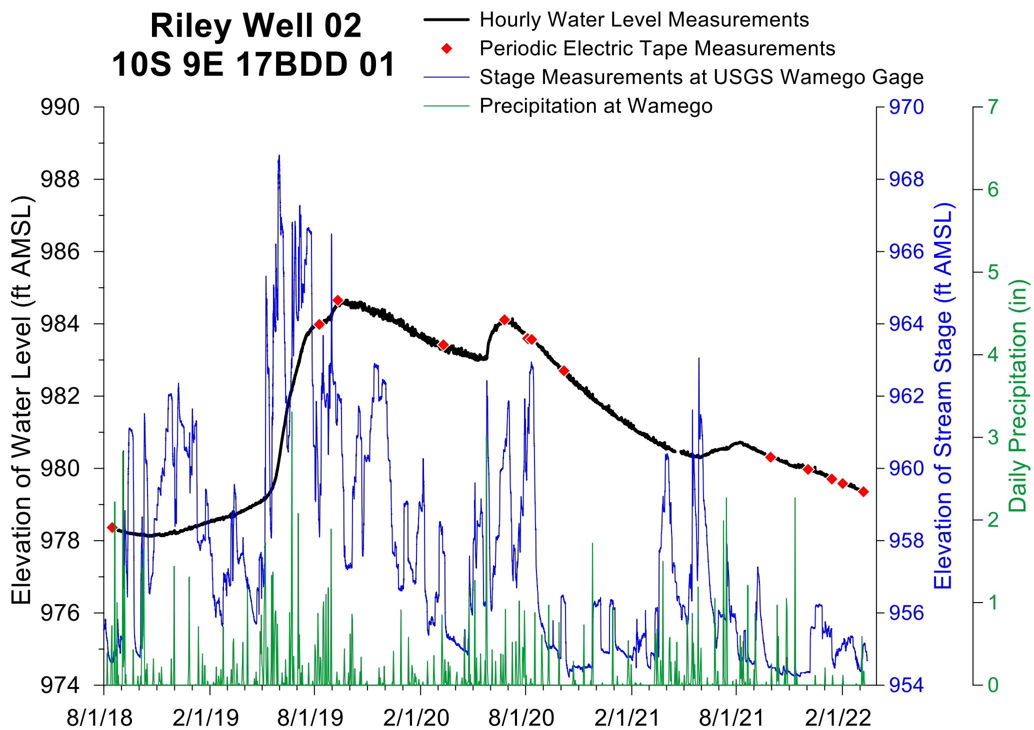


Figure 4. Riley County index well 2 hydrograph with stream stage and precipitation data—total data run to 3/9/22. A water-level elevation of 984 ft corresponds to a depth to water of 15 ft below land surface (lsf). The top of the screen is 27 ft below lsf (elevation of 972 ft), and the bottom of the aquifer is 37.2 ft below lsf (elevation of 961.8 ft). The screen terminates 0.2 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. Wamego gage is 10 miles downstream from the well. Precipitation measured at Wamego 4 W (USC00148563), approximately 4.2 miles to the northeast of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water levels exhibit a very muted and lagged response to stream-stage changes, despite being within 0.4 mi of the river. This indicates that there is a low-permeability interval limiting the connection between the river and the portion of the aquifer in the vicinity of the well.
- Water levels have an extremely muted response to precipitation, despite being within 20 ft of the land surface. This indicates a low permeability layer above the water table, which is consistent with the results of electrical conductivity logging.
- The influence of nearby pumping wells is difficult to discern, likely as a result of the very small water use within a 1 mi radius of the well.
- Water levels fluctuate more after slug tests on 9/18/19 (shortly after third electric tape measurement on plot), likely as a result of further well development produced by the slug tests. These small amplitude fluctuations appear to be produced by variations in barometric pressure.

4.1.3 Wabaunsee County Index Well 1

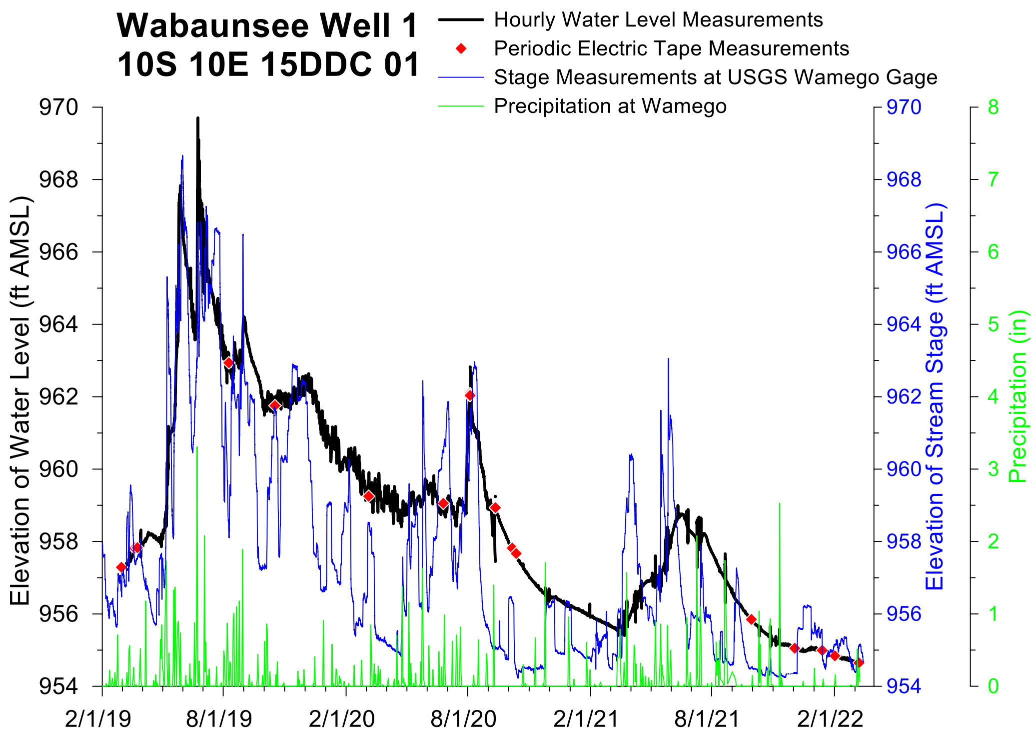


Figure 5. Wabaunsee County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/9/22. A water-level elevation of 960 ft corresponds to a depth to water of 11 ft below land surface (lsf). The top of the screen is 22 ft below lsf (elevation of 949 ft), and the bottom of the aquifer is estimated to be 44 ft below lsf (elevation of 927 ft). The screen terminates 7 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. Wamego gage is 2 miles upstream from the well. Precipitation measured at Wamego 4 (USC00148563), about 5.4 miles to the northwest of the well, until 3/25/20, and at Wamego 1.3 W (US1KSPT0044), about 3.3 miles to the northwest of the well from then on. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water levels respond to changes in stream stage and to precipitation; stream stage changes may be the primary driver of changes in water levels.
- Anomalous apparent water-level fluctuations occur in the first half of the record. These fluctuations are artifacts produced by water blocking the vent tube of the gauge transducer; transducer and cable were replaced and the anomalous fluctuations are not observed in the second half of the record.
- There is no indication of nearby groundwater pumping.

4.1.4 Wabaunsee County Index Well 2

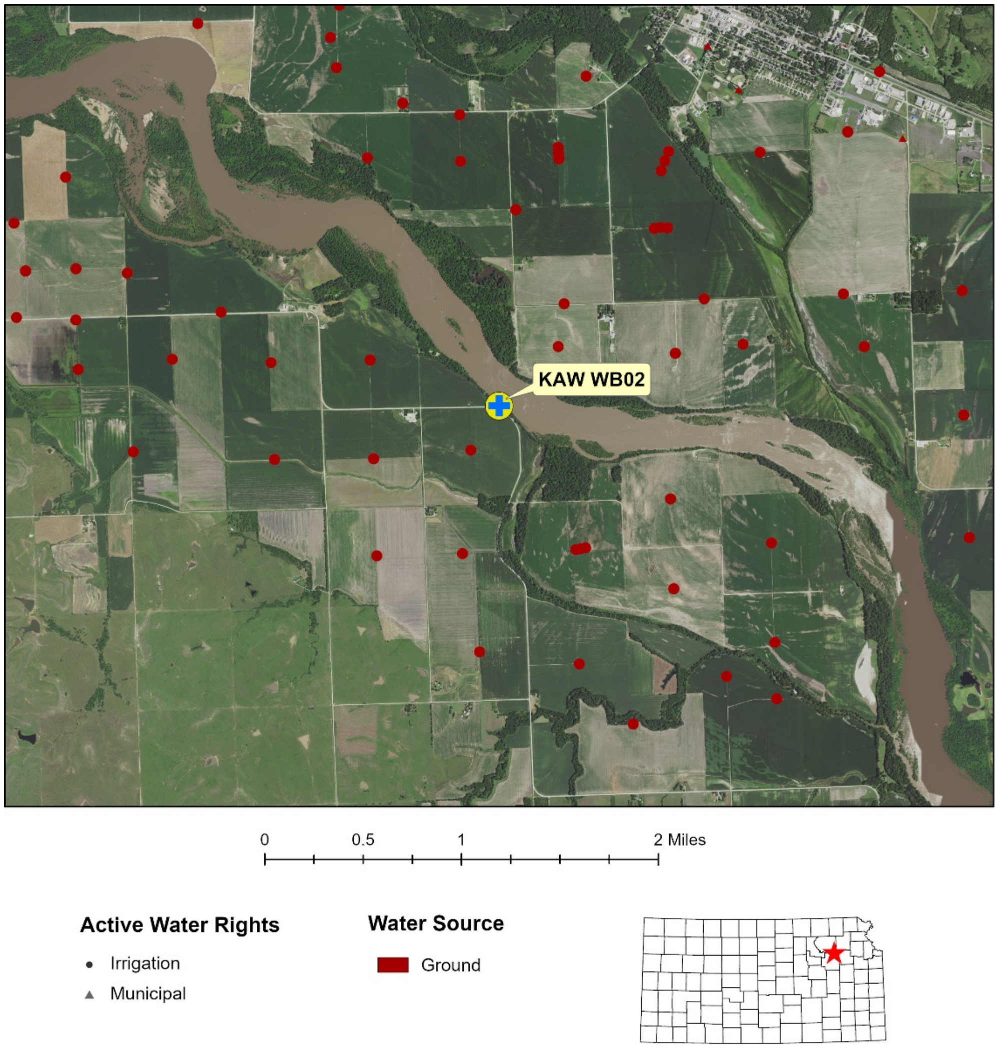


Figure 6. Aerial view of Wabaunsee County index well 2 (WB02) and nearby points of diversion. The city of St. Marys is about 2.4 miles to the northeast.

Figure 6 is an aerial view of the Wabaunsee County index well 2 site (T. 10 S., R. 12 E., 20ADD 01) at a scale that shows the site of the index well, the Kansas River, and nearby wells that have active water rights. The well was installed on 6/16/21 with a 20 ft screen terminating approximately 4 ft above the bottom of the aquifer. The aquifer consists of sand with a 6 ft silt lens (see appendix, section 8.3, for WWC-5 report and associated direct-push conductivity log). The well was developed (pumped 5.2 well volumes) on 6/23/21. Telemetry equipment and a sensor were installed and monitoring began on 7/30/21. Slug tests were performed on 6/27/21; test results indicate a good connection to the highly permeable aquifer with a hydraulic conductivity value of 243–324 ft/d. There is no record of previous monitoring within 2,000 ft of the index well; site was chosen to fill a gap in the network.

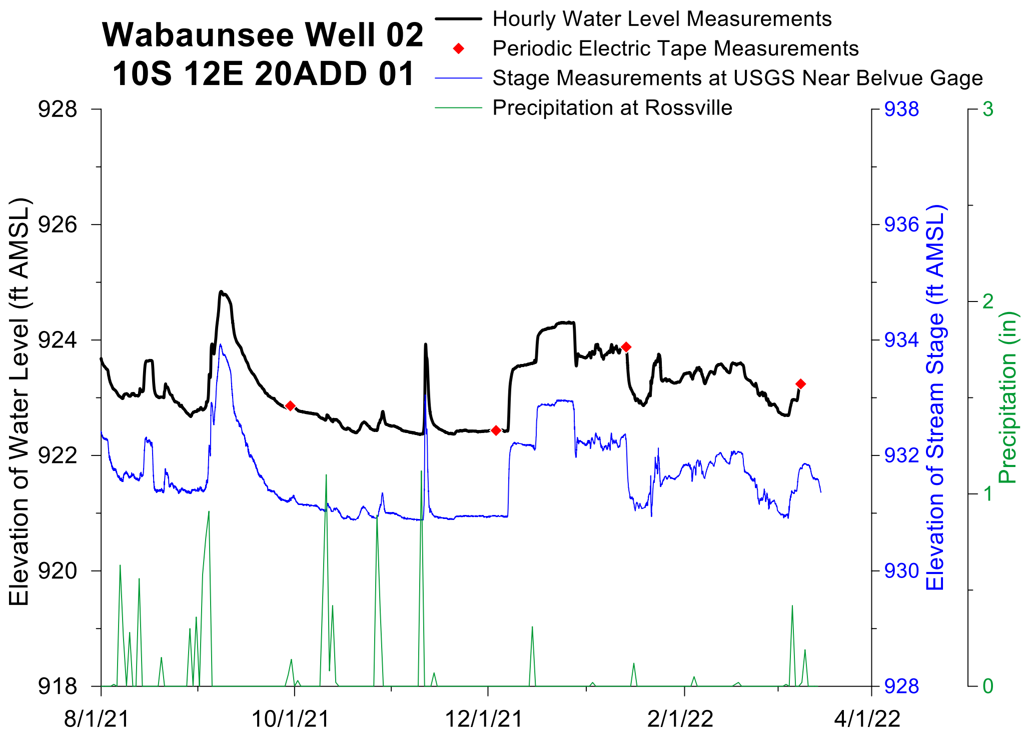


Figure 7. Wabaunsee County index well 2 hydrograph with stream stage and precipitation data—total data run to 3/9/22. A water-level elevation of 924 ft corresponds to a depth to water of 21 ft below land surface (lsf). The top of the screen is 60 ft below lsf (elevation of 885 ft), and the bottom of the aquifer is estimated to be 84.2 ft below lsf (elevation of 860.8 ft). The screen terminates 4.2 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. Gage near Belvue is 4.1 miles upstream from the well. Precipitation measured at Rossville, about 8 miles to the east-southeast of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by changes in stream stage.
- The effect of precipitation appears to be small.
- The effect of nearby pumping wells on water levels appears to be very small.
- Well response to barometric pressure is very small.

4.1.5 Pottawatomie County Index Well 1

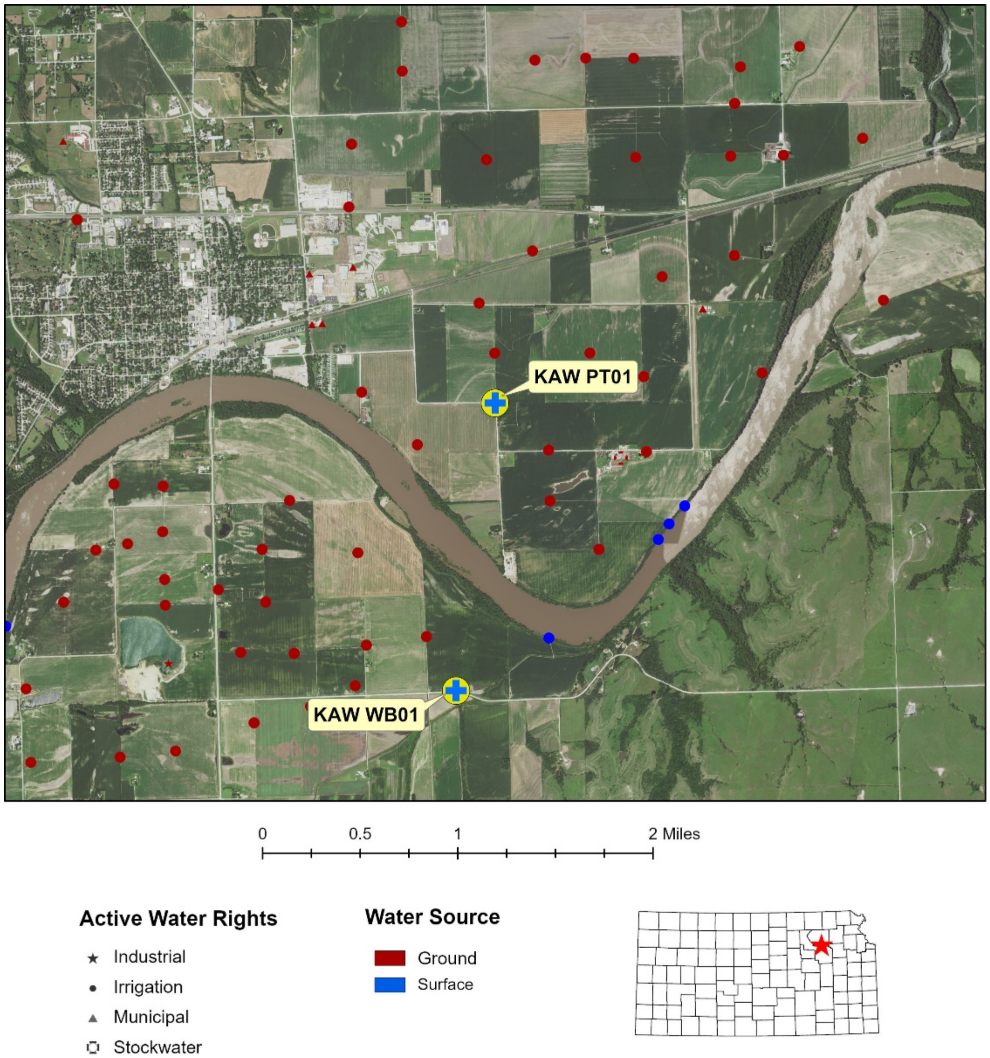


Figure 8. Aerial view of Pottawatomie County index well 1 (PT01), WB01 index well, and nearby points of diversion. The city of Wamego is to the west and northwest of the well.

Figure 8 is an aerial view of the Pottawatomie County index well 1 site (T. 10 S., R. 10 E., 10 ADD) at a scale that shows the site of the index well, the Kansas River, and nearby wells that have active water rights. The well was installed on 3/3/22 with a 10 ft screen terminating approximately 2 ft above the bottom of the aquifer. The aquifer consists of sand (see appendix, section 8.3, for WWC-5 report and associated direct-push conductivity log). The well was developed (pumped 6.0 well volumes) and sampled on 4/18/22. A sensor was placed in the well and monitoring began on 6/22/22. Slug tests were performed on 4/25/22; test results indicate an excellent connection to a highly permeable aquifer with a hydraulic conductivity value of 369–572 ft/d. There is no record of previous monitoring within 2,000 ft of the index well; site was chosen to complete a transect across the Kansas River valley east of Wamego.

4.1.6 Pottawatomie County Index Well 2

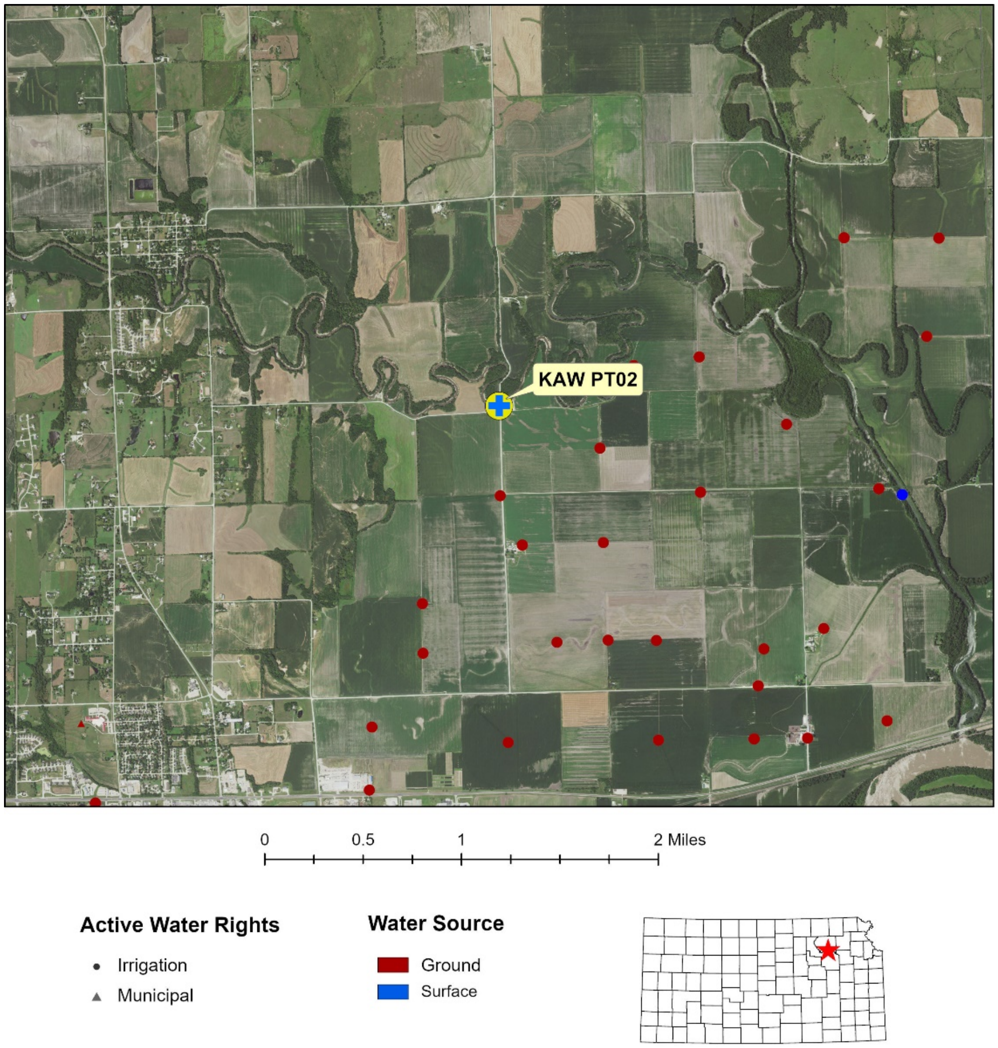


Figure 9. Aerial view of Pottawatomie County index well 2 (PT02) and nearby points of diversion. The city of Wamego is to the west and southwest of the well.

Figure 9 is an aerial view of the Pottawatomie County index well 2 site (T. 9 S., R. 10 E., 27 DAA) at a scale that shows the site of the index well and nearby wells that have active water rights. The well was installed on 4/8/22 with a 10 ft screen terminating approximately 27 ft above the bottom of the aquifer. The aquifer consists of sand with a thick clay layer near the water table and a few thin silt lenses (see appendix, section 8.3, for WWC-5 report and associated direct-push conductivity log). The well was developed (pumped 6.9 well volumes) and sampled on 4/18/22. Slug tests were performed on 4/25/22; test results indicate a good connection to the aquifer with a hydraulic conductivity value of 146–204 ft/d. A sensor was placed in the well and monitoring began on 6/22/22. There is no record of previous monitoring within 2,000 ft of the index well; site was chosen to complete a transect across the Kansas River valley east of Wamego.

4.1.7 Shawnee County Index Well 1

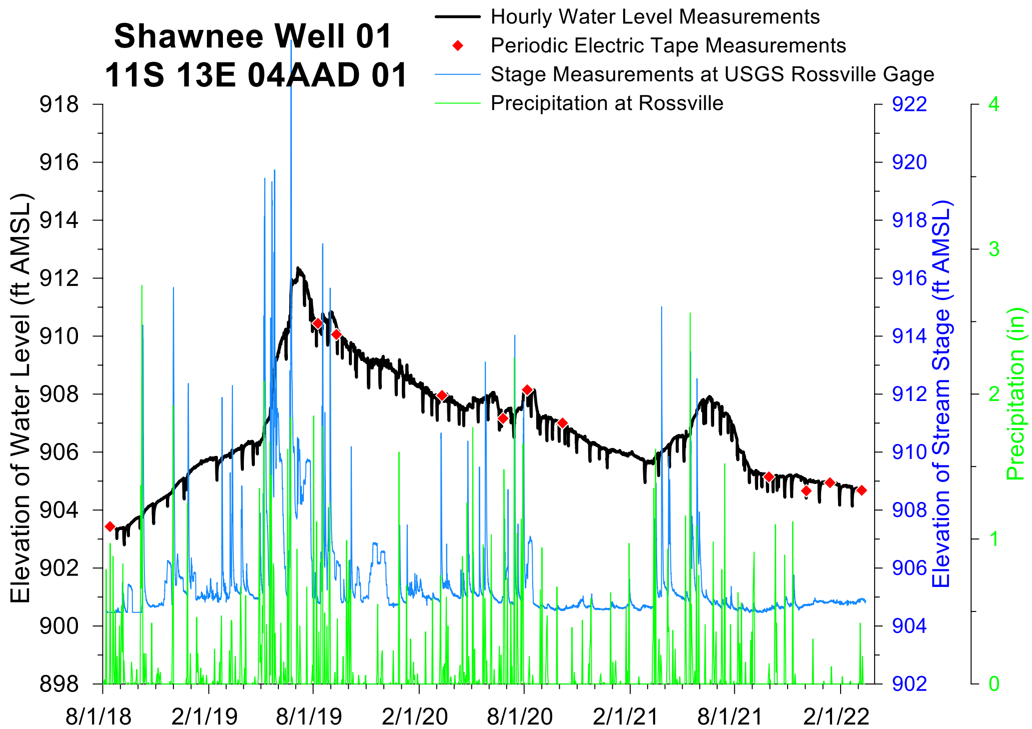


Figure 10. Shawnee County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/9/22. A water-level elevation of 908 ft corresponds to a depth to water of 20 ft below land surface (lsf). The top of the screen is 36.5 ft below lsf (elevation of 891.5 ft), and the bottom of the aquifer is 46.5 ft below lsf (elevation of 881.5 ft). The screen terminates at the bottom of the aquifer. Electric-tape measurements are in reasonable agreement with transducer. USGS gage is on Cross Creek at Rossville about 1 mile from well; there is no USGS gage on the Kansas River within 17 river miles of the well. The well is about 0.4 miles from Cross Creek and 1 mile from the Kansas River. Precipitation record from Rossville Mesonet Station slightly more than a mile from well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water levels appear to respond to both stream-stage changes and precipitation. Response to stream stage appears to be somewhat muted.
- Water levels fluctuate more after slug tests on 9/18/19 (shortly after third electric tape measurement on plot), likely as a result of further well development produced by the slug tests. Fluctuations appear to be driven by fluctuations in barometric pressure.
- A clear pumping signal can be observed on the graph, but pumping is not restricted to the growing season; periodic pumping occurs throughout the year. Water use within a 2 mi radius of the well is the highest of any of the wells in the western reach.
- The form of the water-level response to pumping indicates an unconfined aquifer, consistent with the DPEC log.

4.1.8 Shawnee County Index Well 2

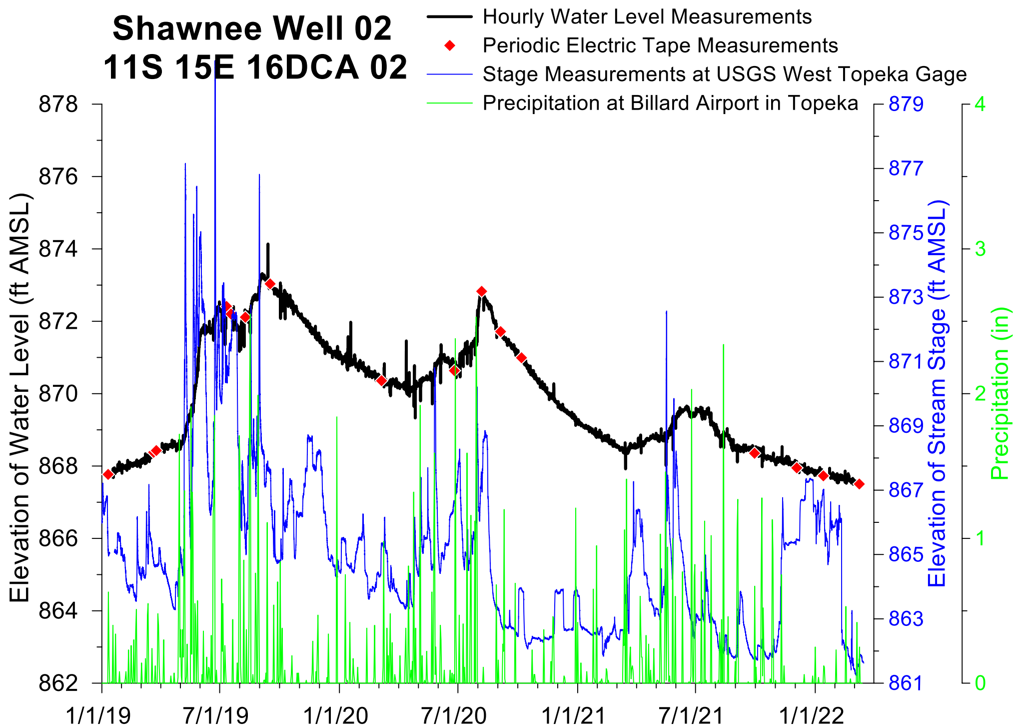


Figure 11. Shawnee County index well 2 hydrograph with stream stage and precipitation data—total data run to 3/9/22. A water-level elevation of 870 ft corresponds to a depth to water of 30 ft below land surface (lsf). The top of the screen is 44 ft below lsf (elevation of 856 ft), and the bottom of the aquifer is estimated to be 71.5 ft below lsf (elevation of 828.5 ft). The screen terminates 7.5 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. USGS gage is 3 miles downstream from well. Precipitation measured at Billard Airport, which is approximately 7 miles to the east of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water levels appear to respond to precipitation. Responses to stream-stage changes in the Kansas River are difficult to confirm. Soldier Creek is 0.6 miles to the north of the well but appears to have little impact on water levels.
- The spikes in the water-level record, which appear to be related to nearby rail and heavy truck traffic, indicate a confined aquifer (increased weight pressurizes pore water), a finding that is consistent with the electrical conductivity log.
- A pumping signal is small but discernible on the graph; periodic pumping occurs throughout the year.

4.2 Eastern Reach — East of Topeka to Kansas City

Eight index wells are located in this reach of the KRAA (fig. 12). The GEMS4-1 well, which is on the long-term Geohydrologic Experimental and Monitoring Site (GEMS), was drilled in 1990, while the seven other wells were drilled between August 2017 and June 2021. Tables 3 and 4 summarize characteristics of these eight wells.

Table 3. Characteristics of the eastern wells in the KRAA index well network.

Site	Average 2021 WL elev. (ft)[a]	Average 2021 saturated thickness (ft)[a]	Bedrock depth (estimated ft below land surface)	Screened interval (ft below land surface)	2020 water use (ac-ft)[b]		
					1 mi radius	2 mi radius	5 mi radius
JF01	841.2	25.9	46.7	33–43	173[c]	2,851[d]	3,554[e]
JF02	829.0	64.0	76	45–60	205[f]	577[g]	1,682[h]
DG01	816.0	50.0	68	46.5–66.5	143	1,609[i]	2,877[j]
GEMS4-1	808.9	53.9	70	39.5–69.5	398[k]	743[k]	2,650[l]
DG02	794.6	51.6	74	55–70	19	530[m]	2,265[n]
DG03	819.8	48.8	60[o]	29.5–44.5	141	1,087[p]	2,979[q]
LV01	760.9	41.1	66.2	45–65	5,792[r]	6,965[s]	9.696[t]
WY01	724.1	26.1	69	50–65	3,694[u]	3,788[v]	4,631[w]

[a] Averaging period is full year unless stated otherwise:
JF02 and DG03 8/3/21–12/31/21.
[b] Irrigation use unless noted.
[c] Includes 31 ac-ft of industrial water.
[d] Includes 2,467 ac-ft of industrial water.
[e] Includes 2,467 ac-ft of industrial, 243 ac-ft of municipal, and 45 ac-ft of recreational water.
[f] Includes 19 ac-ft of industrial and 70 ac-ft of municipal water.
[g] Includes 19 ac-ft of industrial and 240 ac-ft of municipal water.
[h] Includes 19 ac-ft of industrial, 547 ac-ft of municipal, and 45 ac-ft of recreational water.
[i] Includes 462 ac-ft of industrial and 702 ac-ft of municipal water.
[j] Includes 470 ac-ft of industrial, 1,268 ac-ft of municipal, 5 ac-ft of recreational, and 106 ac-ft of other water.
[k] Includes 10 ac-ft of industrial and 388 ac-ft of municipal water.
[l] Includes 470 ac-ft of industrial, 1,268 ac-ft of municipal, 5 ac-ft of recreational, and 106 ac-ft of other water.
[m] Includes 8 ac-ft of industrial and 503 ac-ft of municipal water.
[n] Includes 460 ac-ft of industrial, 1,067 ac-ft of municipal, and 106 ac-ft of other water.
[o] Depth to bedrock is suspect, we hit refusal at 51.7 feet, and the deepest nearby wells do not exceed 60 feet in depth (one driller calls the material producing refusal “hard river bottom”).
[p] Includes 702 ac-ft of municipal water.
[q] Includes 462 ac-ft of industrial, 1,268 ac-ft of municipal, 5 ac-ft of recreational, and 106 ac-ft of other water.
[r] Includes 4 ac-ft of industrial and 5,781 ac-ft of municipal water.
[s] Includes 8 ac-ft of industrial and 6,950 ac-ft of municipal water.
[t] Includes 35 ac-ft of industrial and 9,623 ac-ft of municipal water.
[u] Includes 3,694 ac-ft of municipal water.
[v] Includes 94 ac-ft of industrial and 3,694 ac-ft of municipal water.
[w] Includes 164 ac-ft of industrial, 3,694 ac-ft of municipal, and 773 ac-ft of other water.

Table 4. Additional characteristics of the eastern wells in the KRAA index well network.

Site	Distance from Kansas River (miles)	Width of floodplain (miles)[a]	Nearby weather station[b]	Nearby stream gage[c]	Nearby previous monitoring[d]		
					Nearby previous well?	Distance from index well (ft)	Monitoring Period
JF01	0.35	2.53	None	None	Yes	<350 ft[e]	6/66–3/04
JF02	0.21	2.16	Lecompton	06891000	No	NA	NA
DG01	0.84	3.10	Lawrence Airport	06891080	Yes	<30 ft	2/52–5/15
GEMS4-1	2.10	3.00	Lawrence Airport	06891080	No	NA	NA
DG02	1.61	3.55	Eudora	06891080	Yes	<30 ft	5/66–7/89
DG03	0.18	2.68	Lawrence Airport	06891080	Yes	175 ft 1,365 ft	5/66–3/75 6/66–12/83
LV01	0.20	2.12	None	06892350	No	NA	NA
WY01	0.09	1.10	Shawnee	06892518	Yes	<850 ft	3/67–12/99

[a]Distance perpendicular to the valley axis using the Kansas Biological Survey's FLDPLN (floodplain) model.
[b]Name of the weather station within 5 miles of well.
[c]USGS ID# of the stream gage within 5 miles of well.
[d]Within 2,000 ft of well.
[e]Correction to distance given in previous report (Butler et al., 2020).

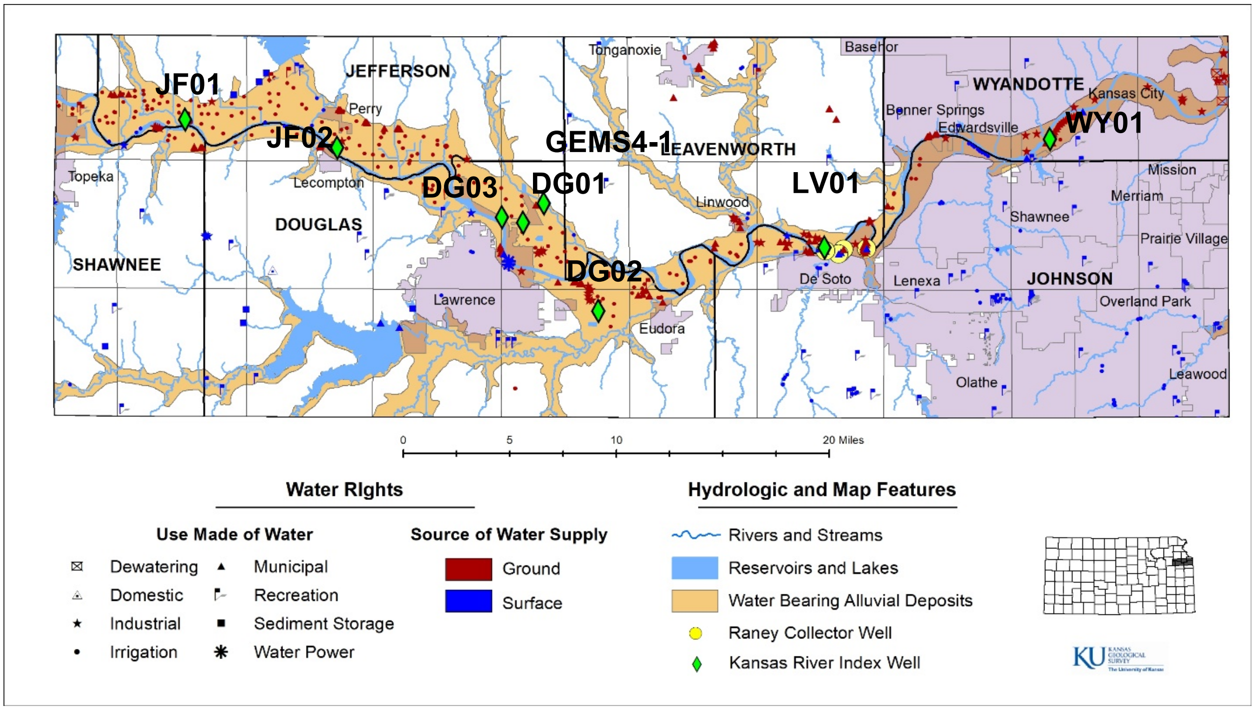


Figure 12. Map of index wells in the eastern reach of the KRAA network; data from these wells can be viewed in real time on the KGS website (http://www.kgs.ku.edu/Hydro/KansasRiver/index.html).

4.2.1 Jefferson County Index Well 1

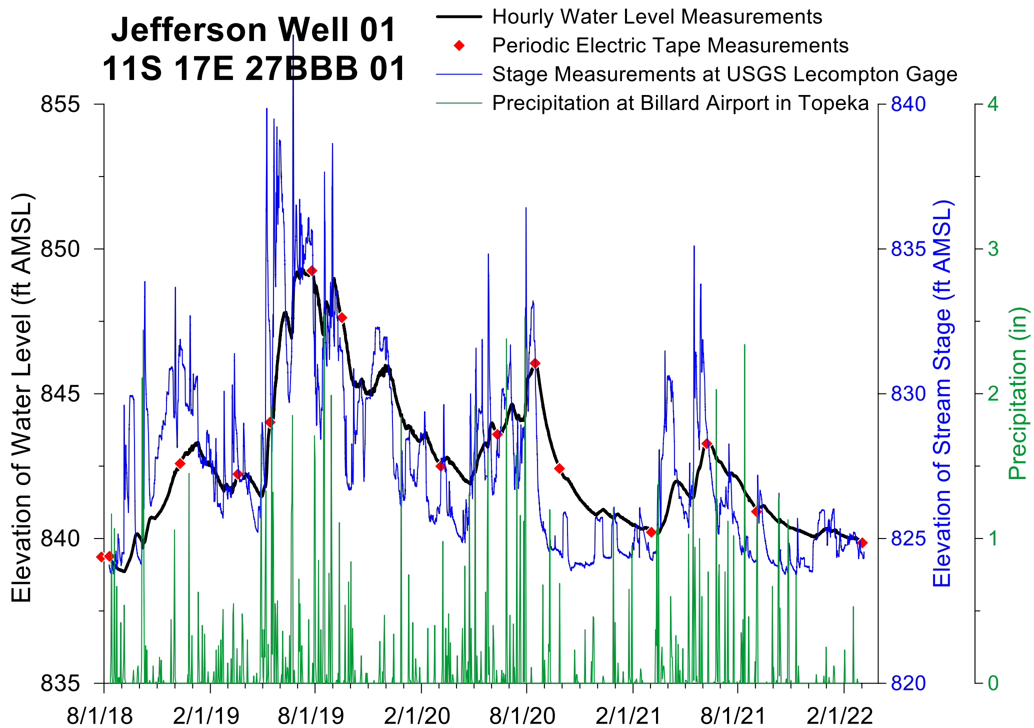


Figure 13. Jefferson County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/4/22. A water-level elevation of 845 ft corresponds to a depth to water of 17 ft below land surface (lsf). The top of the screen is 33 ft below lsf (elevation of 829 ft), and the bottom of the aquifer is 46.6 ft below lsf (elevation of 815.4 ft). The screen terminates 3.6 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. USGS gage is 9 miles downstream from well. Precipitation measured at Billard Airport, which is approximately 6 miles to the west of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by changes in stream stage, although the aquifer response to stream-stage changes is muted and shifted in time.
- Given the relationship between water levels and stream stage, it is difficult to discern the effect of precipitation.
- The effect of nearby pumping wells on water levels appears to be very small despite the amount of pumping in the area.
- Well response to barometric pressure appears to depend on position of water level. Responses below an elevation of 842 ft (20 ft below lsf) are difficult to discern; responses at higher elevations appear to be consistent with a confined aquifer.

4.2.2 Jefferson County Index Well 2

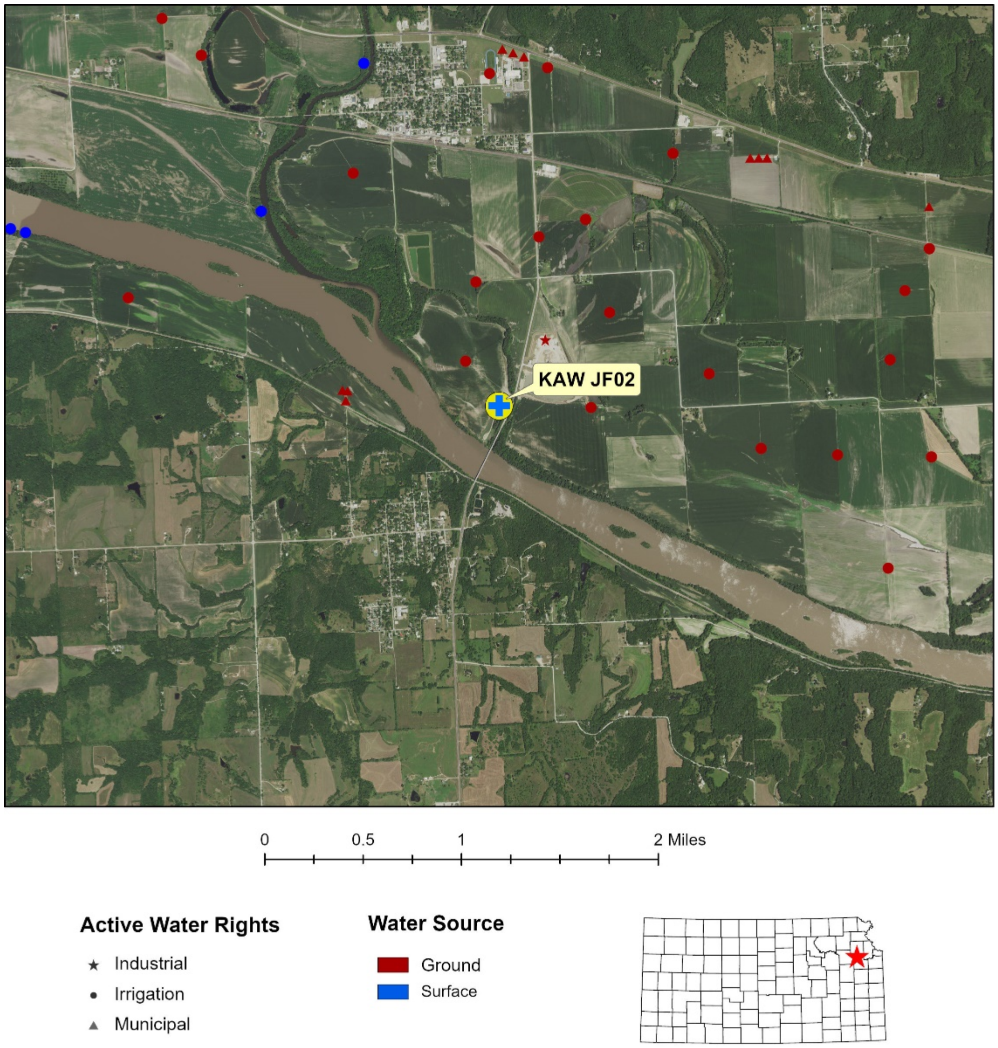


Figure 14. Aerial view of Jefferson County index well 2 (JF02) and nearby points of diversion. The town of Perry is about 1.6 miles to the north, and the town of Lecompton is about 0.7 miles to the southwest.

Figure 14 is an aerial view of the Jefferson County index well 2 site (T. 11 S., R. 18 E., 35 BCD 01) at a scale that shows the site of the index well, the Kansas River, and nearby wells that have active water rights. The well was installed on 6/10/21 with a 15 ft screen that terminates 16 ft above the bottom of the aquifer. The aquifer, which is overlain by clay and silt, consists of sand with minor silt lenses until 60 ft and then silty sand followed by silt until bedrock at 76.0 ft (see appendix, section 8.3, for WWC-5 report and associated direct-push electrical conductivity log). The well was developed (pumped 5.5 well volumes) on 6/22/21. Telemetry equipment was installed on 7/23/21; a sensor was installed and monitoring began on 8/3/21. Slug tests were performed on 6/27/21; test results indicate an excellent connection to a highly permeable aquifer with a hydraulic conductivity value of 221–354 ft/d. There is no record of previous monitoring within 2,000 ft of this site; site was chosen because of its proximity to the USGS stream gage at the Lecompton bridge.

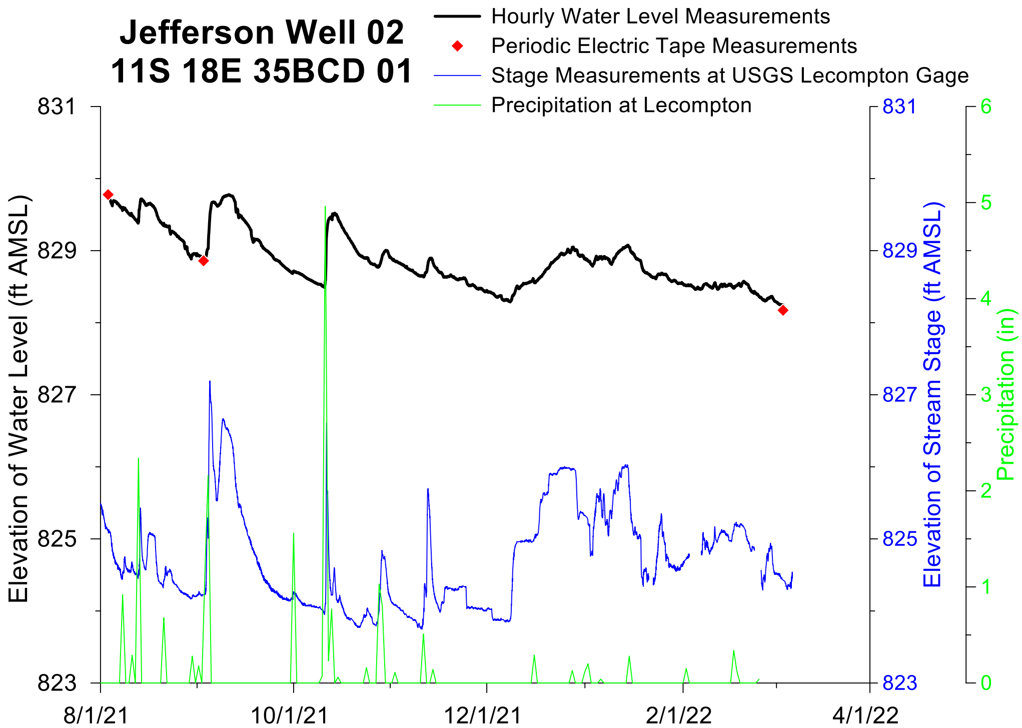


Figure 15. Jefferson County index well 2 hydrograph with stream stage and precipitation data—total data run to 3/4/22. A water-level elevation of 829 ft corresponds to a depth to water of 12 ft below land surface (lsf). The top of the screen is 45 ft below lsf (elevation of 796 ft), and the bottom of the aquifer is 76.0 ft below lsf (elevation of 765.0 ft). The screen terminates 16 ft above the bottom of the aquifer. Electric-tape measurements are in reasonable agreement with transducer. USGS gage is 0.2 miles from well. Precipitation measured at Lecompton, approximately 0.6 miles south of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by changes in stream stage.
- Given the relationship between water levels and stream stage, it is difficult to discern the effect of precipitation.
- The effect of nearby pumping wells on water levels appears to be small
- Well response to barometric pressure appears to be small.

4.2.3 Douglas County Index Well 1

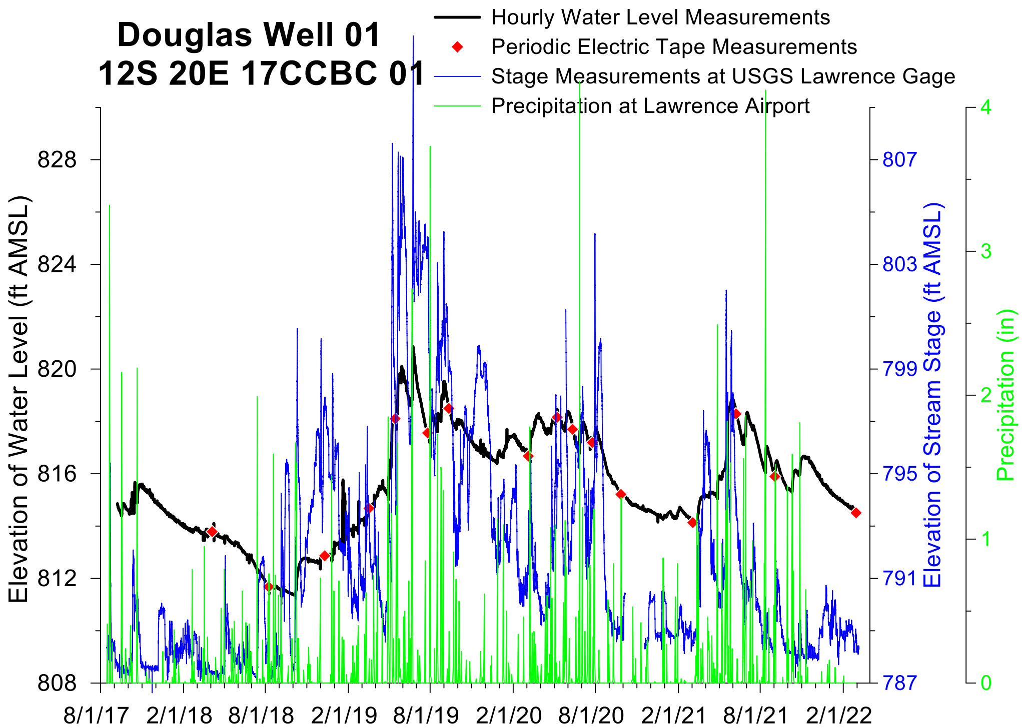


Figure 16. Douglas County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/1/22. A water-level elevation of 816 ft corresponds to a depth to water of 18 ft below land surface (lsf). The top of the screen is 46.5 ft below lsf (elevation of 787.5 ft), and the bottom of the aquifer is 67.5 ft below lsf (elevation of 766.5 ft). The screen terminates 1.0 ft above the bottom of the aquifer. Electric-tape measurements are in reasonable agreement with transducer. USGS gage is approximately 2 miles downstream from well, but the river is within 0.85 miles of the well upstream of the gage. Precipitation measured at Lawrence Municipal Airport, which is a short distance northeast of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by precipitation.
- Given the relationship between water levels and precipitation, it is difficult to discern the effect of stream-stage changes.
- The effect of nearby pumping wells on water levels appears to be very small, consistent with the relatively small amount of pumping within a mile of the well.
- Well response to barometric pressure appears to be consistent with a confined aquifer.

4.2.4 GEMS4-1 Index Well

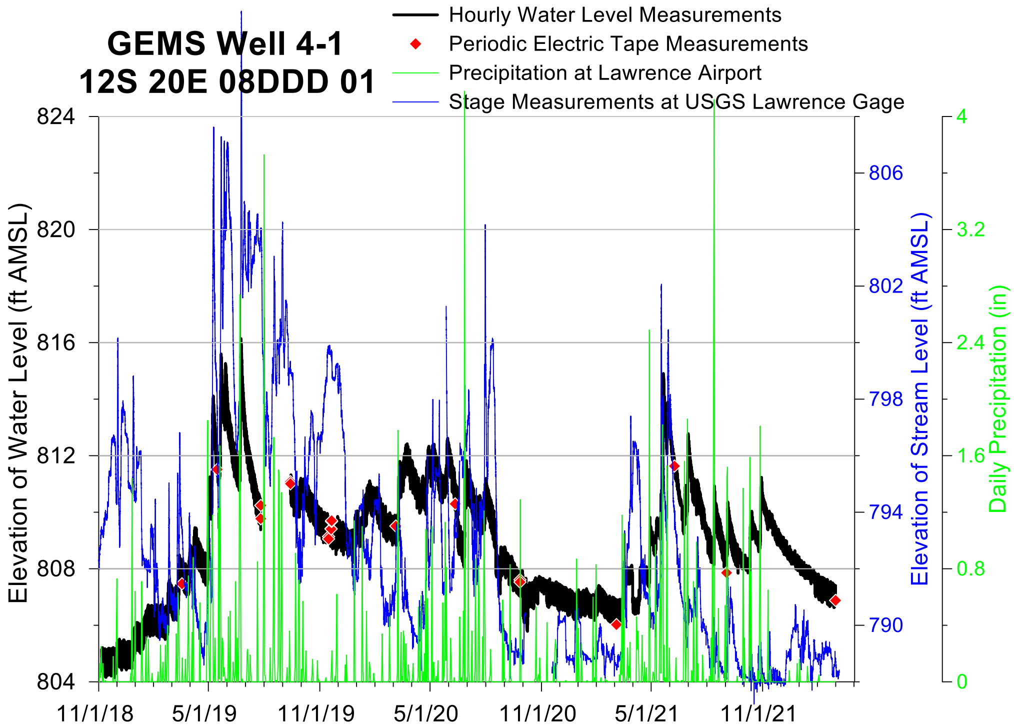


Figure 17. GEMS4-1 index well hydrograph with stream stage and precipitation data—total data run to 3/1/22. A water-level elevation of 810 ft corresponds to a depth to water of 15 ft below land surface (lsf). The top of the screen is 39.5 ft below lsf (elevation of 785.5 ft), and the bottom of the aquifer is 70.3 ft below lsf (elevation of 754.7 ft). The screen terminates less than 1 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. USGS gage is 3.2 miles from the well but the river is within 2.1 miles of the well upstream of the gage. Precipitation measured at Lawrence Municipal Airport, which is 0.9 miles southwest of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by precipitation.
- The band in the water-level record (approximately 1 ft in width) is created by nearby (≈0.2 miles to the west) supply wells for a rural water district turning on and off two to three times per day.
- The impact of stream-stage changes in the Kansas River appears to be very small. However, the role of a nearby stream, Mud Creek, has yet to be clarified.
- The form of the water-level responses to pumping indicates a confined aquifer, consistent with the DPEC log.

4.2.5 Douglas County Index Well 2

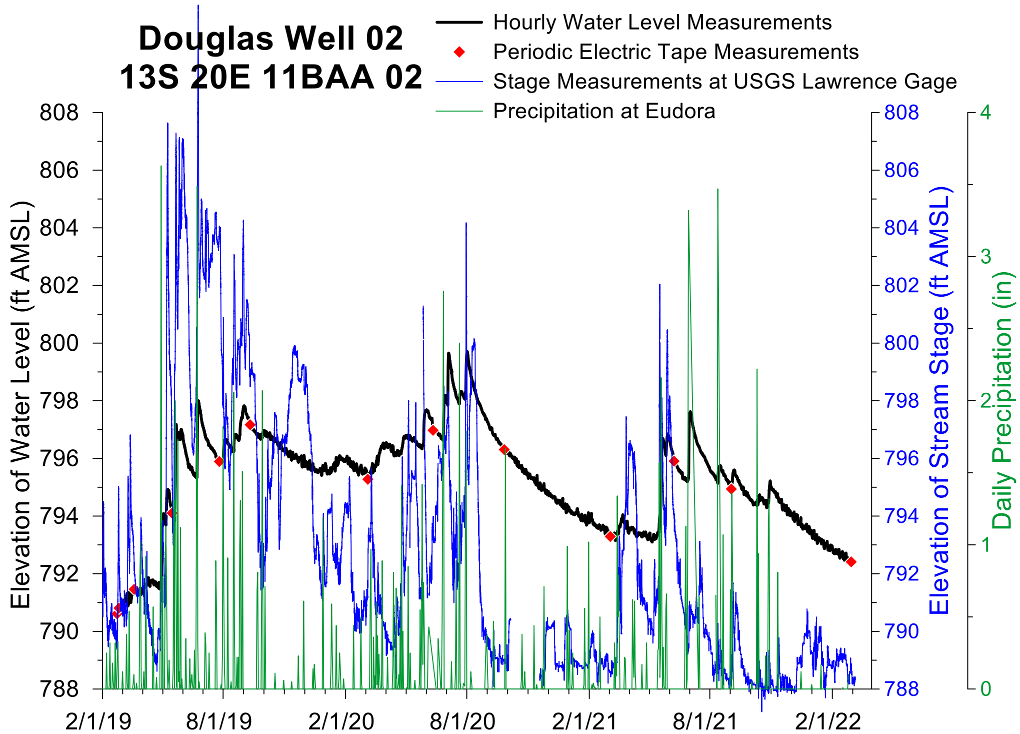


Figure 18. Douglas County index well 2 hydrograph with stream stage and precipitation data—total data run to 3/1/22. A water-level elevation of 796 ft corresponds to a depth to water of 21 ft below land surface (lsf). The top of the screen is 55 ft below lsf (elevation of 762 ft), and the bottom of the aquifer is 74 ft below lsf (elevation of 743 ft). The screen terminates 4 ft above the bottom of the aquifer. Electric-tape measurements are in good agreement with transducer. Well is 1.6 miles from the Kansas River channel, and the USGS gage is 3.5 miles upstream from that point. Well is 1.0 mile from the Wakarusa River channel. Precipitation measured at NOAA station in Eudora, which is 3.6 miles east of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by precipitation.
- Given the relationship between water levels and precipitation, it is difficult to discern the effect of stream-stage changes in either the Kansas or Wakarusa rivers.
- There is no detectable signal of nearby pumping, consistent with the lowest amount of pumping within a 2 mi radius for any of the network wells.
- Well response to barometric pressure appears to be consistent with a confined aquifer.

4.2.6 Douglas County Index Well 3

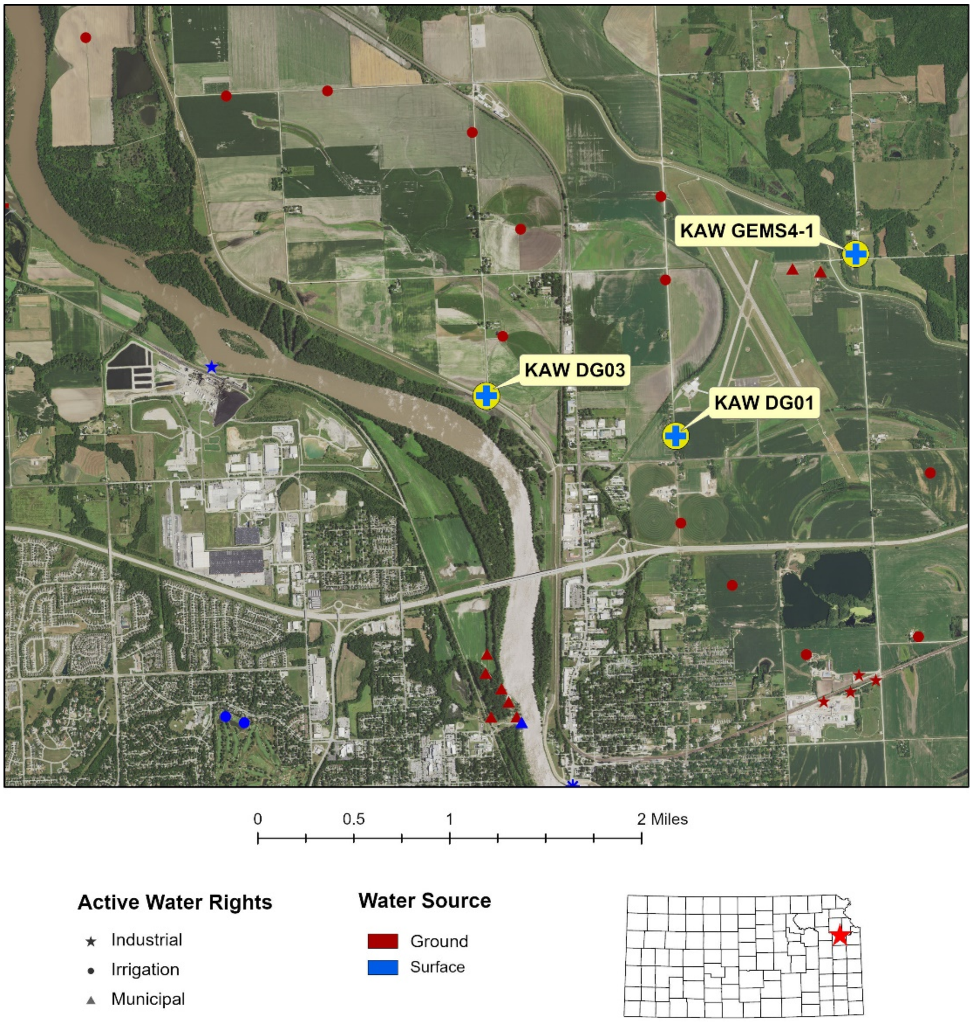


Figure 19. Aerial view of Douglas County index well 3 (DG03), DG01, and GEMS4-1 index wells and nearby points of diversion. The city of Lawrence is to the south.

Figure 19 is an aerial view of the Douglas County index well 3 site (T. 12 S., R. 19 E., 13 DAA 01) at a scale that shows the site of the index well, the DG01 and GEMS4-1 index wells, the Kansas River, and nearby wells that have active water rights. The well was installed on 6/4/21 with a 15 ft screen that terminates about 8 ft above the suspected bottom of the aquifer. The aquifer consists of sand with streaks of silty sand from 15 to 51.7 ft below land surface and is overlain by clay and silt (see the appendix, section 8.3, for WWC-5 report and associated direct-push electrical conductivity log). The well was developed on 6/23/21 by surging followed by pumping of 5.6 well volumes. Telemetry equipment was installed on 7/23/21; a sensor was installed and monitoring began on 8/3/21. Slug tests were performed on 6/27/21; test results indicate an excellent connection to a highly permeable aquifer with a hydraulic conductivity value of 168–234 ft/d. Previously, water levels were monitored from May 1966 to March 1975 at a well (USGS ID #390006095143701) 175 ft south of the index well (readings reported at intervals of less than a month to eventually quarterly) and from June 1966 to December 1983 at a well (USGS ID # 390032095143801) 1,365 ft north of the index well (readings reported at various intervals from June 1966 to December 1970 and then quarterly from 1971 on).

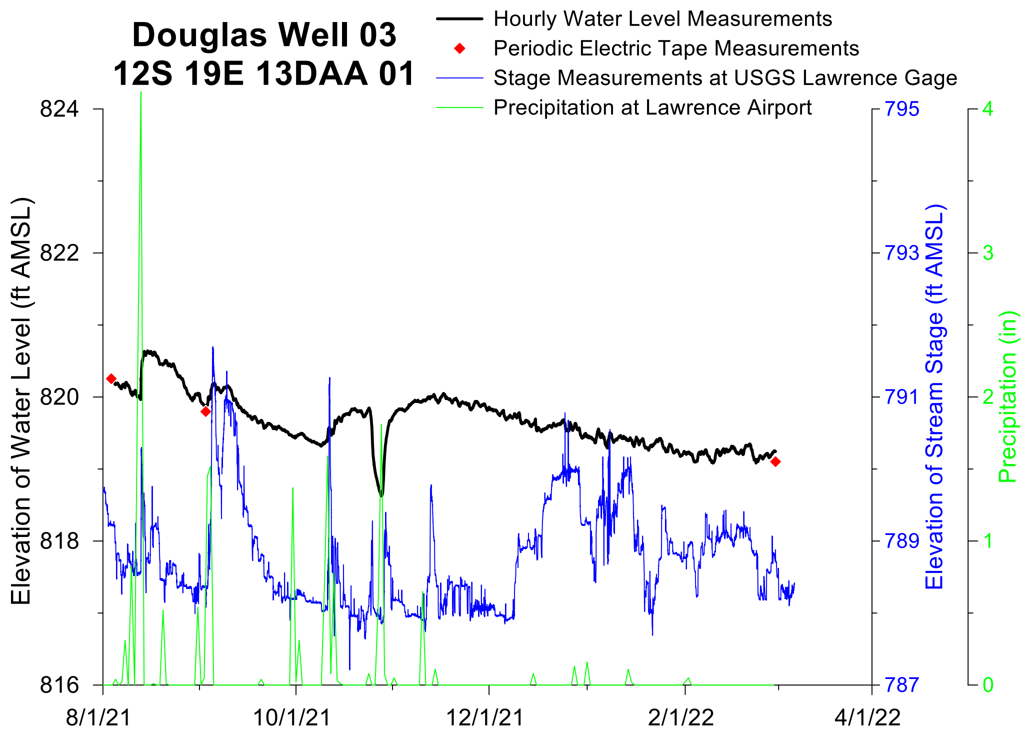


Figure 20. Douglas County index well 3 hydrograph with stream stage and precipitation data—total data run to 3/1/22. A water-level elevation of 820 ft corresponds to a depth to water of 11 ft below land surface (lsf). The top of the screen is 29 ft below lsf (elevation of 791 ft), and the apparent bottom of the aquifer is 51.7 ft below lsf (elevation of 768.3 ft). The screen terminates 7.7 ft above the apparent bottom of the aquifer. Electric-tape measurements are in reasonable agreement with transducer. USGS gage is approximately 2 miles downstream from well, but the river is within 0.18 miles of the well upstream of the gage. Precipitation measured at Lawrence Municipal Airport, which is 1.4 miles east of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- The record is too short during a relatively dry period to assess the major drivers of water-level changes.
- The impact of nearby pumping wells on water levels is clear from a pumping event in late October.
- Well response to barometric pressure appears to be consistent with a confined aquifer.

4.2.7 Leavenworth County Index Well 1

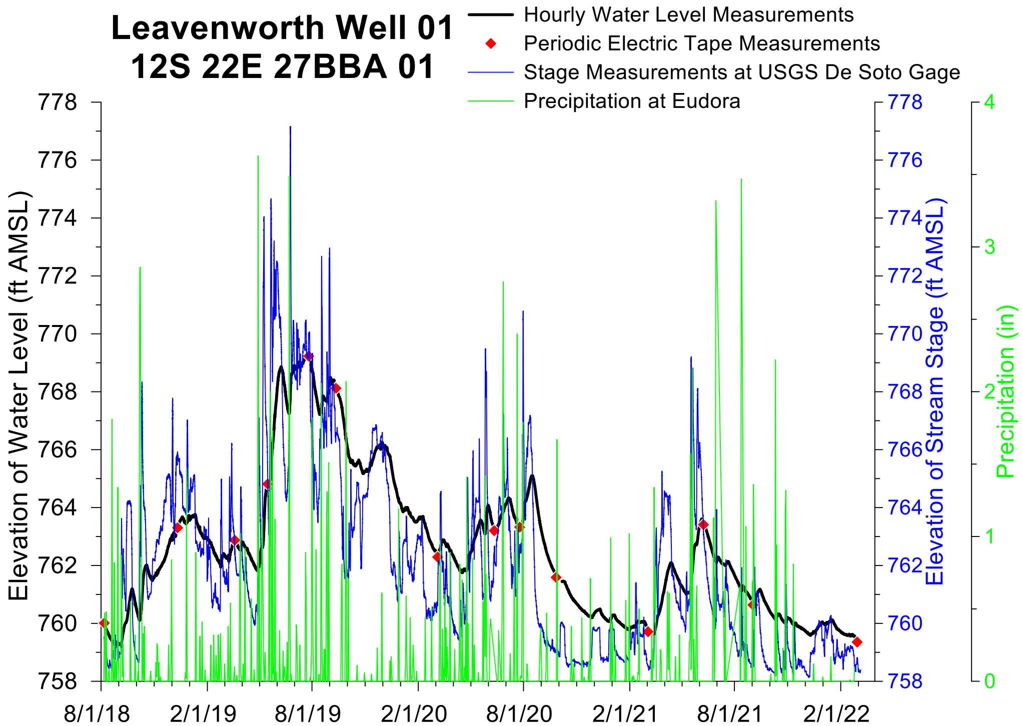


Figure 21. Leavenworth County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/1/22. A water-level elevation of 764 ft corresponds to a depth to water of 22 ft below land surface (lsf). The top of the screen is 45 ft below lsf (elevation of 741 ft), and the bottom of the aquifer is 66.1 ft below lsf (elevation of 719.9 ft). The screen terminates 1.1 ft above the bottom of the aquifer. Electric-tape measurements are in reasonable agreement with transducer. USGS gage is 0.2 miles upstream from the well. Precipitation measured at NOAA station in Eudora, which is 7.9 miles southwest of the well. Section 5.6 discusses the relationship between the index well and the Kansas River.

Major Points

- Water-level changes appear to be primarily driven by changes in stream stage, although there does appear to be a slight lag in the water-level response.
- The effect of precipitation appears to be small.
- The effect of nearby pumping wells on water levels appears to be very small despite the large amount of municipal pumping in the area (most on the opposite side of the river [south] from the index well). This may be an indication that most of the pumped water is being drawn from the river.
- Well response to barometric pressure is small.
- The relative changes in the elevation difference between the water level in the well and that in the river suggest that the general groundwater flow direction down the river valley shifted somewhat such that the component directed toward the river was greater after the high flows of mid-2019 than before.

4.2.8 Wyandotte County Index Well 1

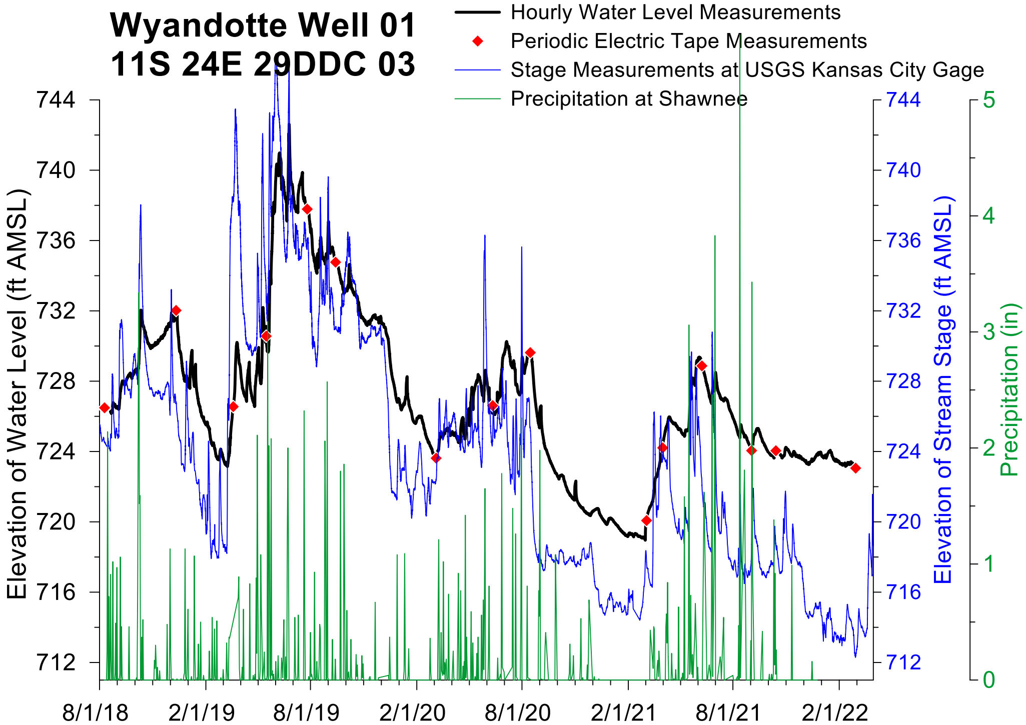


Figure 22. Wyandotte County index well 1 hydrograph with stream stage and precipitation data—total data run to 3/1/22. A water-level elevation of 732 ft corresponds to a depth to water of 35 ft below land surface (lsf). The top of the screen is 50 ft below lsf (elevation of 717 ft), and the bottom of the aquifer is 69 ft below lsf (elevation of 698 ft). The screen terminates 4 ft above the bottom of the aquifer. Electric-tape measurements are in reasonable agreement with transducer. USGS gage is approximately 11.6 miles downstream from the well. Precipitation measured at Shawnee, which is 3.75 miles south-southwest of the well. Section 5.6 discusses the relationship between the index well and the Kansas River. Note that the WYO1 plot in the 2020 project report (Butler et al., 2020) used an incorrect elevation for the USGS stream gage datum.

Major Points

- Water-level changes appear to be primarily driven by changes in stream stage.
- The effect of municipal pumping wells very close to the index well is clear; numerous cusp-shaped features are indications of pumps turning on and off.
- The effect of precipitation appears to be small.
- Well response to barometric pressure is small.

5 Additional Project Activities

5.1 Water Sampling at KRAA Index Wells

Water samples were obtained at all 16 wells. After well development and the purging of several well volumes from the well (water was mostly sediment free), samples were collected from the well discharge while pumping continued. Two 250 ml sample bottles (one wide-mouth bottle and one narrow-mouth bottle) and caps were rinsed in the flowing stream of water three times. After the third rinse, the bottles were filled to minimize the head space of air. The narrow-mouth bottle was then capped, while the wide-mouth bottle was used to fill two 60 ml bottles using a syringe filter. As with the original sample bottles, these 60 ml bottles and the syringe used to fill them were rinsed three times with the sample water from the 250 ml wide-mouth bottle. After this initial rinse, the syringe was again filled with the raw sample water and a 0.45 µm filter was attached to it and the bottles were rinsed three times with filtered water. After the last rinse, the 60 ml bottles were filled with filtered sample water. One bottle was filled to the shoulder of the bottle and the other was filled to about the three-fourths point (45–50 ml). Once the three samples were collected (250 ml narrow-mouth bottle, the almost-full 60 ml bottle, and the three-quarters-full 60 ml bottle), they were labeled and placed in a cooler with a blue ice block for transport back to the KGS.

The collected samples were then analyzed in the KGS chemical laboratory. Cation concentrations were determined using an inductively coupled plasma spectrometer, and anion concentrations were measured by ion chromatography, except bicarbonate, which was determined using an automated titrimeter. Quality control included analyzing U.S. Geological Survey standard reference waters with the samples and calculating the charge balance error.

Data from the chemical analyses are available in an Excel workbook, "KGS 2020 to 2022 Chemical Analyses of Water Samples from KRAA Index Wells.xlsx," that accompanies this report on the project webpage (www.kgs.ku.edu/Hydro/KansasRiver/index.html).

5.2 Slug Testing at KRAA Index Wells

Slug tests were performed at all 16 wells using the pneumatic method for test initiation and the field guidelines outlined in Butler (2019). Each well was tested at least six times using different initial water-level displacements (H_0). Figure 23 shows the comparison of the six tests at well JF02; the figure is plotted in a normalized format (deviation of water level from static divided by H_0) to allow ready comparison between tests. All of the wells had similar agreement for their normalized plots.

The Aqtesolv software (HydroSOLVE, Inc., 2007) was used to obtain a hydraulic conductivity (K) estimate for the screened interval. The tests were analyzed using the Butler and Zhan model developed at the KGS. Although this model was developed for use in confined aquifers, it provides very reasonable estimates in unconfined aquifers as well (Butler, 2019). Given the agreement between tests performed with different initial displacements illustrated in fig. 23, only one test was selected for analysis at each well (typically the test with the largest H_0). The test was analyzed using maximum and minimum specific storage (S_s) and anisotropy ratios (vertical hydraulic conductivity over horizontal hydraulic conductivity) to allow the uncertainty about those aquifer properties to be incorporated into the analysis. Figure 24 illustrates the fit that was obtained at well JF02 for what were considered lower-bound specific storage ($7.6x10^{-7}$ ft^{-1}) and anisotropy ratio (0.1) estimates. Similar fits were obtained for all the parameter combinations used at well JF02. Similar fits were obtained at most of the wells. Table 5 can be used to determine the horizontal hydraulic conductivity ranges for the wells. The second and third columns define the range for an assumed isotropic aquifer (impact of uncertainty in S_s), and the third and fourth columns define the range resulting from the uncertainty in anisotropy. For example, the range for an assumed isotropic aquifer for well JF02 is 221-301 ft/d; the range incorporating uncertainty in both Ss and the anisotropy ratio is 221-354 ft/d.

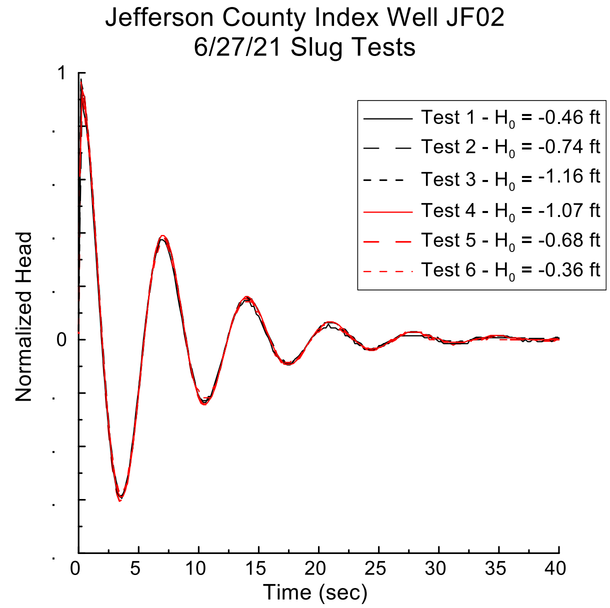


Figure 23. Normalized head (deviation from static/H_0) versus time since test began for the six slug tests performed at well JF02.

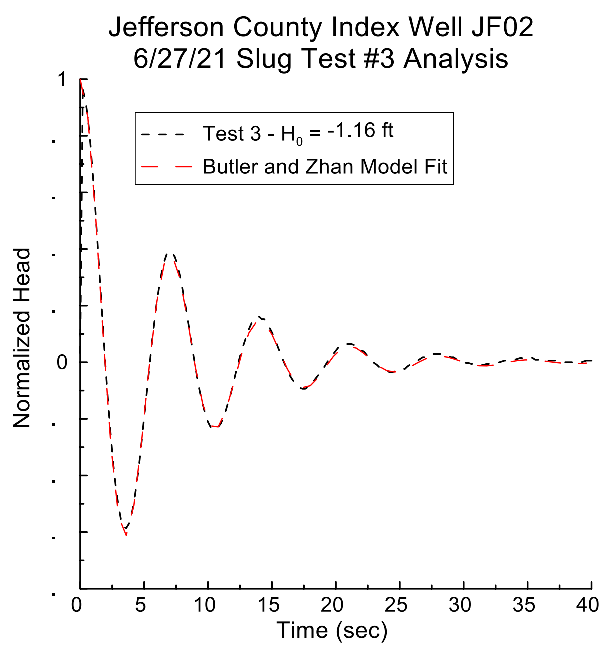


Figure 24. Fit of Butler and Zhan model to response data from slug test 3 at well JF02.

Table 5. Horizontal hydraulic conductivity values[a] of screened portion of KRAA wells.

Site	K (ft/d) Upper S_s[b]	K (ft/d) Lower S_s[c]	K (ft/d) Lower S_s with Anisotropy[d]
RL01	18.0[e]	19.7	23.9
RL02	389.1[f]	459.3	536.4
WB01	118.1[e]	146.7	162.1
WB02	243.4[e]	281.8	324.1
PT01	369.4	479.3	572.5
PT02	146.0[f]	167.6	203.7
SN01	180.1[e]	211.9	240.5
SN02	207.0	330.0	360.9
JF01	128.0[f]	160.4	184.7
JF02	220.8	300.8	354.3
DG01	186.3	298.9	329.1
GEMS4-1	73.5	137.8	142.4
DG02	102.4	159.4	179.8
DG03	168.0[f]	197.8	234.2
LV01	199.1[f]	264.4	269.7
WY01	258.2	375.3	425.2

[a] Estimated using the Butler-Zhan model for slug tests in high-K confined aquifers (Butler, 2019).
[b] Upper bound S_s is 2.5×10^{-4} /ft unless noted, anisotropy ratio is 1.0 in all cases.
[c] Lower bound S_s is 7.6×10^{-7}/ft and anisotropy ratio is 1.0 in all cases.
[d] Lower bound S_s is 7.6×10^{-7}/ft and anisotropy ratio is 0.1 in all cases.
[e] Upper bound S_s is 2.5×10^{-5}/ft.
[f] Upper bound S_s is 6.2×10^{-5}/ft.

5.3 Hydrostratigraphic Characterization of the Aquifer

An important component of project activities was the subsurface characterization of the KRAA. This section describes the development of two- and three-dimensional models of the sediment distribution (hydrostratigraphy) in the Kansas River valley based on lithologic descriptions from drillers' logs. These models will be a key input into the groundwater flow model of the KRAA to be created in the next phase of this project.

Since 1975, water well drillers in Kansas have been required to submit forms containing information regarding completed water wells (fig. 25) to the Kansas Department of Health and Environment. The Kansas Geological Survey is charged by statute with archiving this information and making it publicly available, which it does through the WWC-5 database (https://www.kgs.ku.edu/Magellan/WaterWell/index.html). Single-valued data for the wells, such as location, construction, driller name, etc., are stored in the WWC-5 WELLS table, and the corresponding sediment ("lithologic") logs are stored in the LOGS table. Transcription of the sediment logs into the LOGS table is a labor-intensive process that is ongoing across the state due to a backlog of submitted forms and continued submission of new forms. The analysis presented here is based on logs transcribed as of May 24, 2021, at which point a focused effort to transcribe all available logs within the Kansas River valley had been completed. This provided 5,183 logs containing sediment descriptions for a total of 28,877 depth intervals (fig. 26).

An initial step in the analysis was to create land and bedrock elevation surfaces, a process that called for introduction of a two-dimensional (2-D) grid that then was employed throughout the subsequent analysis. The western third of the valley, approximately, falls within UTM Zone 14N and the eastern two-thirds in UTM Zone 15N. We have performed the analysis using Zone 15N coordinates. The 2-D grid is defined over a rectangle encompassing the valley outline, with 968 cells in the X (west-east) direction, 208 in the Y (south-north) direction, and a cell spacing of 200 m (0.124 mile) in each direction. Of the 201,344 (968 x 208) cells, only 21,555 (10.7%) fall within the valley outline (cell center in valley); these cells define the "active" region for this study. We computed the land surface elevation for each grid cell as the average of LIDAR surface elevation measurements over the cell except where LIDAR is unavailable (Johnson County and Fort Riley), where we used USGS National Elevation Dataset (NED) elevations instead (fig. 27).

Each well was then assigned the surface elevation of the cell within which it (nominally) falls, a decision motivated by the uncertainty in the well location data. Although some well coordinates (latitude and longitude) are based on hand-held GPS measurements with accuracies of 50 feet or less, most (71%) have been computed from the legal (PLSS) location descriptions reported on the well completion forms and are thus subject to larger uncertainty due to the potentially coarse resolution and error-prone nature of such descriptions (Suchy, 2002). Taking these coordinates at face value and using them to extract elevations, point-wise, from the LIDAR or NED elevation data that have much higher spatial accuracies can lead to erroneous variation in the assigned well elevations. Given the essentially unresolvable uncertainty in the well locations, we have instead chosen to work at the grid cell level throughout the analysis, starting with assigning each well the average land surface elevation of its containing cell.

We examined the 5,183 logs and recorded the depth of bedrock in logs containing clear bedrock picks (e.g., shale or limestone underlying sand and/or gravel, as in fig. 25). Clear bedrock picks were identified in 1,264 logs, with the majority of the remaining 3,919 logs containing unconsolidated materials in all depth intervals ("non-bedrock logs"). We converted the picked bedrock depths to elevations by subtracting from the land surface elevation at the well and then performed a cross-validation analysis to identify outliers in the elevation data. The cross-validation procedure involves removing each data point in turn, interpolating elevations from nearby data points to the location of the withheld data point, and comparing the original and interpolated elevations. Through this process, we identified 53 of the bedrock elevations as outliers and removed them from the data set. Then we interpolated bedrock elevations from the remaining bedrock elevation data points to the locations of the 3,919 non-bedrock logs and identified 234 non-bedrock logs where the interpolated bedrock elevation was more than 10 feet above the bottom-of-log elevation, which was inconsistent with the expectation that bedrock should be at or below the bottom of such logs. We therefore added the bottom-of-log elevations for these 234 logs to the bedrock elevation dataset. After another round of cross-validation, we ended up with a final bedrock dataset containing 1,188 actual bedrock elevations and 216 bottom-of-log elevations from non-bedrock logs. We interpolated from these data points to create a bedrock elevation surface over the grid (fig. 28). Figure 29 shows the resulting sediment thickness (land surface minus bedrock elevation).

Before converting the logs into quantitative form, we filtered out logs with excessive depth interval thicknesses, as measured by the average interval thickness for each log, since this provides a simple but effective means to identify low quality logs. For this work, we have removed logs with average depth interval thicknesses greater than 34 feet (the 99th percentile of the average thickness distribution). After this, we removed excessively thick intervals (greater than 40 feet, the 99th percentile of the individual interval thickness distribution after removing logs with excessive average thicknesses) on an individual basis and also removed depth intervals containing terms describing artificial materials (asphalt, concrete, driveway gravel, etc.). This left 4,945 logs containing a total of 28,184 depth intervals. The map of the locations of these logs is essentially indistinguishable from fig. 26.

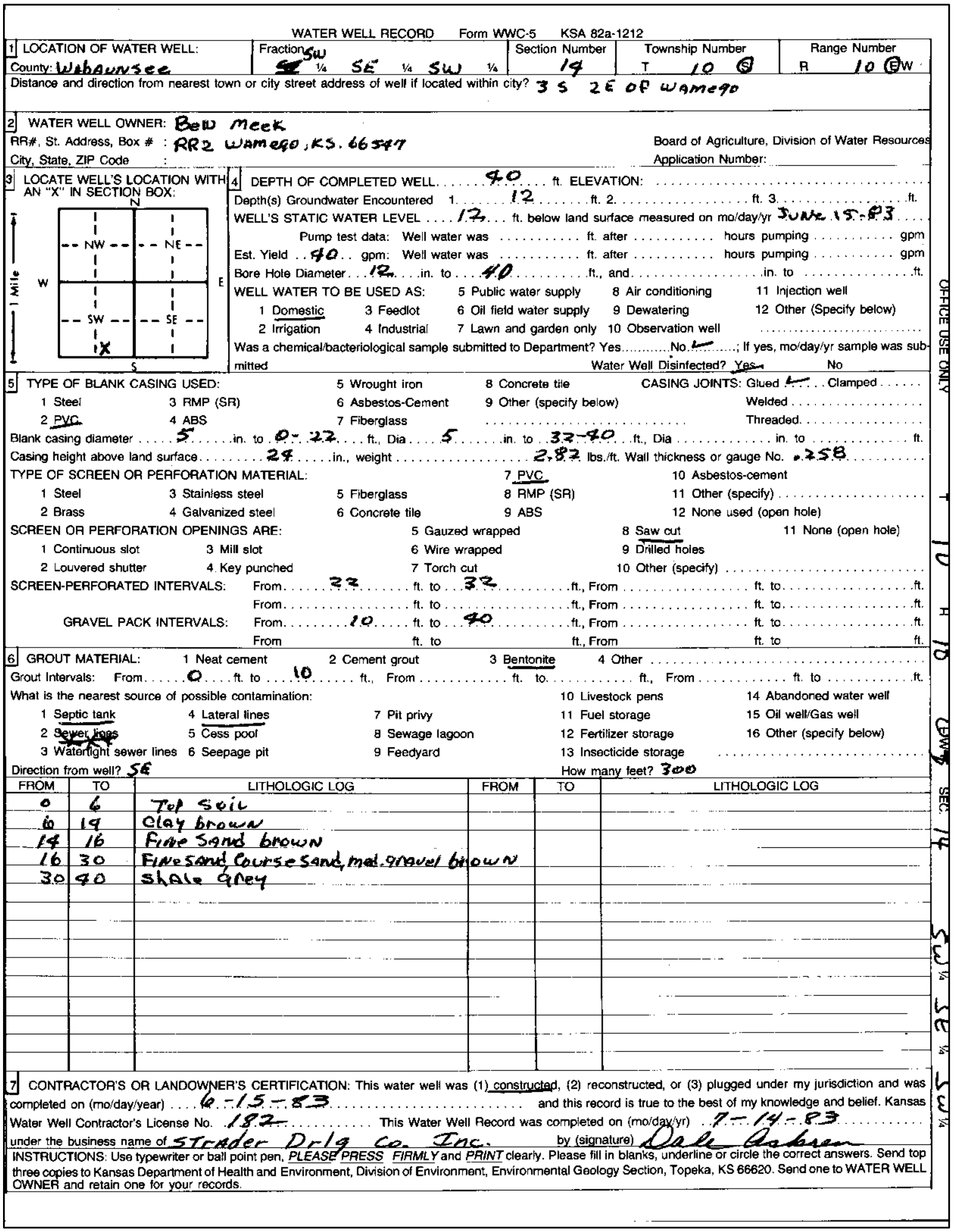
Logs were converted into quantitative form in two steps, standardization and categorization. Briefly, standardization means representing each sediment description in the logs in terms of percentages of a set of standardized lithologies – for example, the description "medium gravel, gray, and clay, gray" is represented as "60, 40 mg, c" meaning 60% medium gravel and 40% clay – and categorization means grouping the standardized lithologies into a smaller set of sediment categories and computing category proportions from the lithology percentages (Bohling et al., 2020). In addition, the categorization code converts the interval depths into elevations, creating a quantitative 3-D dataset in a common coordinate system. The standardization process uses a large translation table containing a standardized representation for each unique sediment description encountered in the logs, but development of this table is continuing. For the current project, more than 5,000 entries were added to the translation table to provide an essentially complete standardization of all depth intervals in the Kansas River valley.

This work employs a four-part categorization of the 71 standardized lithologies, representing predominantly 1: clays, 2: silts, 3: sands, and 4: gravels (table 6). Figure 30 shows the global proportions of the 71 standardized lithologies in the valley along with the four-part categorization. The 2-D and 3-D category proportion grids were then developed by 1) computing aggregated category proportions in all cells containing logs (footage of each category divided by the total footage of log in the cell) and assigning those aggregated proportions to the grid cell center, 2) interpolating each category proportion from the cells containing logs to the empty grid cells (those without logs), 3) smoothing each resulting proportion grid to reduce interpolation artifacts (bullseyes), and 4) renormalizing the four proportion values in each grid cell to sum to 1 (or 100%).

In 2-D, the results represent category proportions between bedrock and land surface (fig. 31). Figure 32 shows the percentage of coarse material (sand and gravel) between bedrock and land surface, together with the index well locations, and fig. 33 shows the dominant (majority) category.

The 3-D grid is the same as the 2-D grid, areally, with vertical grid node locations ranging from 627.5 to 1,137.5 feet above sea level in 5-foot increments (encompassing the minimum bedrock elevation and maximum land surface elevation in the valley). That results in a 968 x 208 x 103 grid, for a total of 20,738,432 cells, but only 247,055 (1.2%) of them are in the volume of interest (within the valley and between bedrock and land surface). Figure 34 shows the percentage of coarse materials in north-south cross sections at 12.5-mile (20.1-km) intervals from west to east along the valley, and fig. 35 shows a 3-D view of 35 north-south cross sections at 3.1-mile (5-km) intervals.

Figures 34 and 35 confirm the expectation that we should see fine (clay and silt) floodplain deposits overlying coarse (sand and gravel) channel deposits at most points in the valley. Since the thicknesses of the fine and coarse layers would be of interest in a number of applications, we have estimated the elevation of a bounding surface separating these two layers throughout the valley. This surface is a simplified and generalized version of the 50% coarse isosurface (the 3-D equivalent of a contour) computed from the 3-D grid of percentage coarse values. Figures 36 and 37 show the resulting fine and coarse layer thicknesses. Figures 38 and 39 show the north-south cross sections from the 3-D grid nearest to the selected (12 of the 16) index wells, together with the location of the index well and the bounding surface elevation along the section.


WATER WELL RECORD Form WWC-5 KSA 82a-1212

1 LOCATION OF WATER WELL: County: Wabaunsee | Fraction SW ¼ SE ¼ SW ¼ | Section Number 19 | Township Number T 10 S | Range Number R 10 E W

Distance and direction from nearest town or city street address of well if located within city? 3 S 2 E of Wamego

2 WATER WELL OWNER: Ben Meek
RR#, St. Address, Box # : RR2 Wamego, KS. 66547
City, State, ZIP Code :
Board of Agriculture, Division of Water Resources
Application Number:

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N, NW, NE, W, E, SW, SE, S, 1 Mile, X

4 DEPTH OF COMPLETED WELL 40 ft. ELEVATION:
Depth(s) Groundwater Encountered 1. 12 ft. 2. ft. 3. ft.
WELL'S STATIC WATER LEVEL 12 ft. below land surface measured on mo/day/yr June 15-83
Pump test data: Well water was ft. after hours pumping gpm
Est. Yield 40 gpm: Well water was ft. after hours pumping gpm
Bore Hole Diameter 12 in. to 40 ft., and in. to ft.
WELL WATER TO BE USED AS: 1 Domestic 2 Irrigation 3 Feedlot 4 Industrial 5 Public water supply 6 Oil field water supply 7 Lawn and garden only 8 Air conditioning 9 Dewatering 10 Observation well 11 Injection well 12 Other (Specify below)
Was a chemical/bacteriological sample submitted to Department? Yes No ✓; If yes, mo/day/yr sample was submitted
Water Well Disinfected? Yes ✓ No

5 TYPE OF BLANK CASING USED: 1 Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)
CASING JOINTS: Glued ✓ Clamped Welded Threaded
Blank casing diameter 5 in. to 0-22 ft., Dia 5 in. to 32-40 ft., Dia in. to ft.
Casing height above land surface 24 in., weight 2.87 lbs./ft. Wall thickness or gauge No. .258
TYPE OF SCREEN OR PERFORATION MATERIAL: 1 Steel 2 Brass 3 Stainless steel 4 Galvanized steel 5 Fiberglass 6 Concrete tile 7 PVC 8 RMP (SR) 9 ABS 10 Asbestos-cement 11 Other (specify) 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE: 1 Continuous slot 2 Louvered shutter 3 Mill slot 4 Key punched 5 Gauzed wrapped 6 Wire wrapped 7 Torch cut 8 Saw cut 9 Drilled holes 10 Other (specify) 11 None (open hole)
SCREEN-PERFORATED INTERVALS: From 22 ft. to 32 ft., From ft. to ft.
From ft. to ft., From ft. to ft.
GRAVEL PACK INTERVALS: From 10 ft. to 40 ft., From ft. to ft.
From ft. to ft., From ft. to ft.

6 GROUT MATERIAL: 1 Neat cement 2 Cement grout 3 Bentonite 4 Other
Grout Intervals: From 0 ft. to 10 ft., From ft. to ft., From ft. to ft.
What is the nearest source of possible contamination: 1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer storage 13 Insecticide storage 14 Abandoned water well 15 Oil well/Gas well 16 Other (specify below)
Direction from well? SE How many feet? 300

FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
0	6	Top Soil			
6	14	Clay brown			
14	16	Fine Sand brown			
16	30	Fine Sand, Course Sand, med. gravel brown			
30	40	shale grey			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 6-15-83 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 182 This Water Well Record was completed on (mo/day/yr) 7-14-83 under the business name of Strader Drlg Co. Inc. by (signature) Dale Aakren
INSTRUCTIONS: Use typewriter or ball point pen, PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Division of Environment, Environmental Geology Section, Topeka, KS 66620. Send one to WATER WELL OWNER and retain one for your records.

OFFICE USE ONLY T 10 R 10 E SEC. 19 SW ¼ SE ¼ SW ¼

Figure 25. Typical water well completion form from the Kansas River valley.

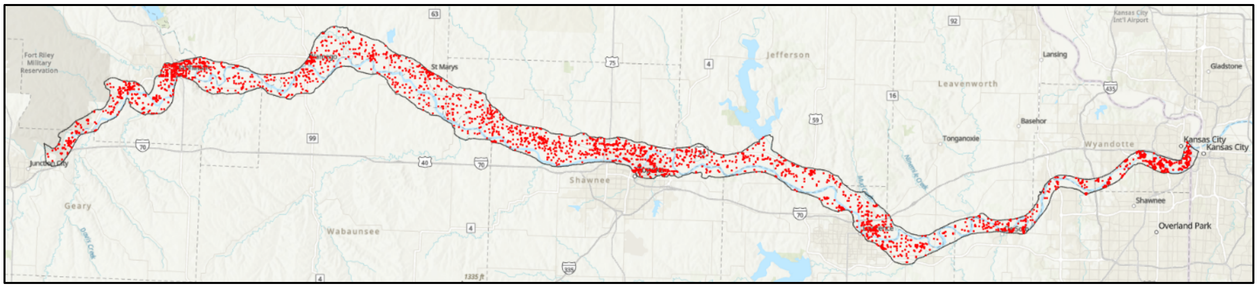


Figure 26. Locations of 5,183 water well drillers' logs in the Kansas River valley transcribed into the WWC-5 LOGS table as of May 24, 2021.

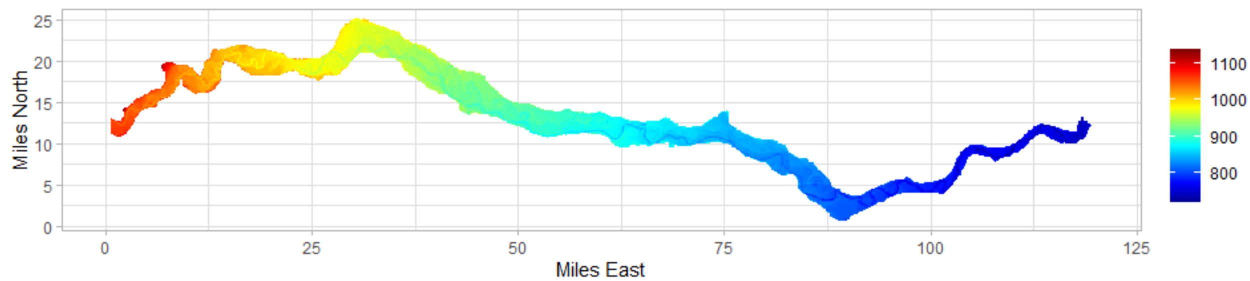


Figure 27. Land surface elevation (feet above sea level).

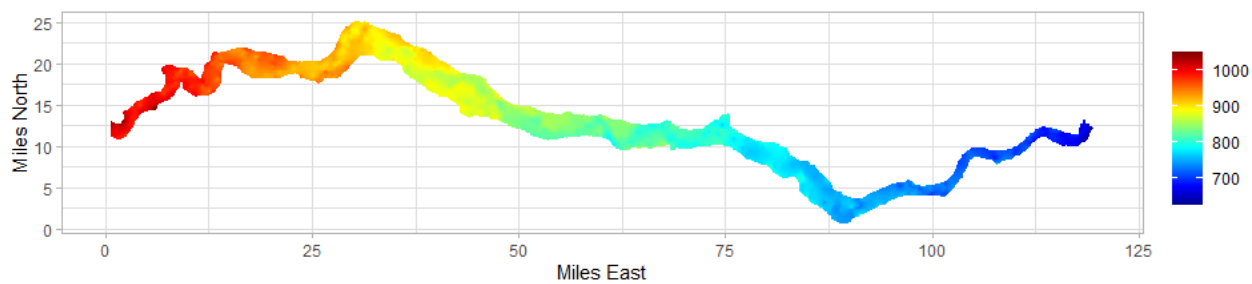


Figure 28. Interpolated bedrock elevation (feet above sea level).

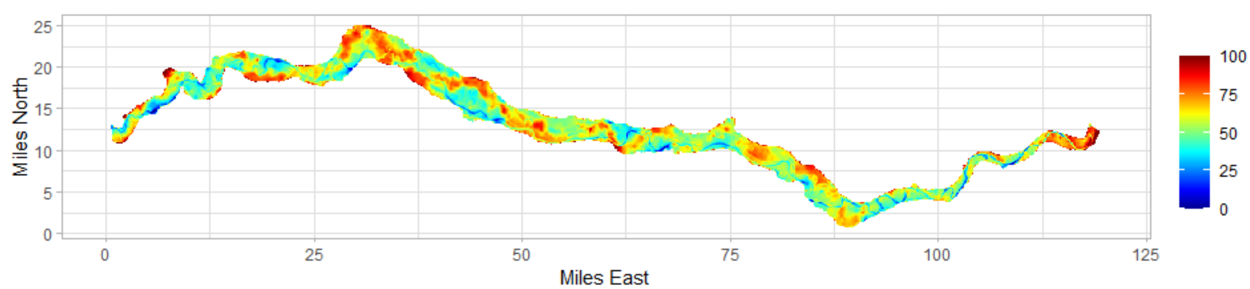


Figure 29. Sediment thickness (feet). The 128 values greater than 100 feet (0.6% of total, ranging up to 158 feet) are shown as 100 feet.

Table 6. Descriptions of 71 standardized lithologies, their codes, and assigned categories (1: clay, 2: silt, 3: sand, 4: gravel).

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

Table 6 (continued)

Description	**Code**	**Category**
unknown	u	2
cemented sand and/or gravel	cesd/cg	2
clayey sand	csnd	3
fine silty sand	fss	3
fine to medium silty sand	fmss	3
silty sand	ssnd	3
medium silty sand	mss	3
fine to coarse silty sand	fcrsss	3
medium to coarse silty sand	mcrsss	3
coarse silty sand	crsss	3
fine sand	fsnd	3
fine to medium sand	fmsnd	3
sand	snd	3
medium sand	msnd	3
fine to coarse sand	fcrssnd	3
fine to medium coarse sand	fmcrssnd	3
medium to coarse sand	mcrssnd	3
coarse sand	crssnd	3
clayey gravel	cg	4
silty gravel	sg	4
fine sand and gravel	fsdg	4
fine to medium sand and gravel	fmsdg	4
medium sand and gravel	msdg	4
sand and gravel	sdg	4
fine to coarse sand and gravel	fcrssdg	4
medium to coarse sand and gravel	mcrssdg	4
coarse sand and gravel	crssdg	4
fine to coarse sandy gravel	fcrssg	4
fine gravel	fg	4
fine to medium gravel	fmg	4
medium gravel	mg	4
gravel	g	4
fine to coarse gravel	fcrsg	4
medium to coarse gravel	mcrsg	4
coarse gravel	crsg	4

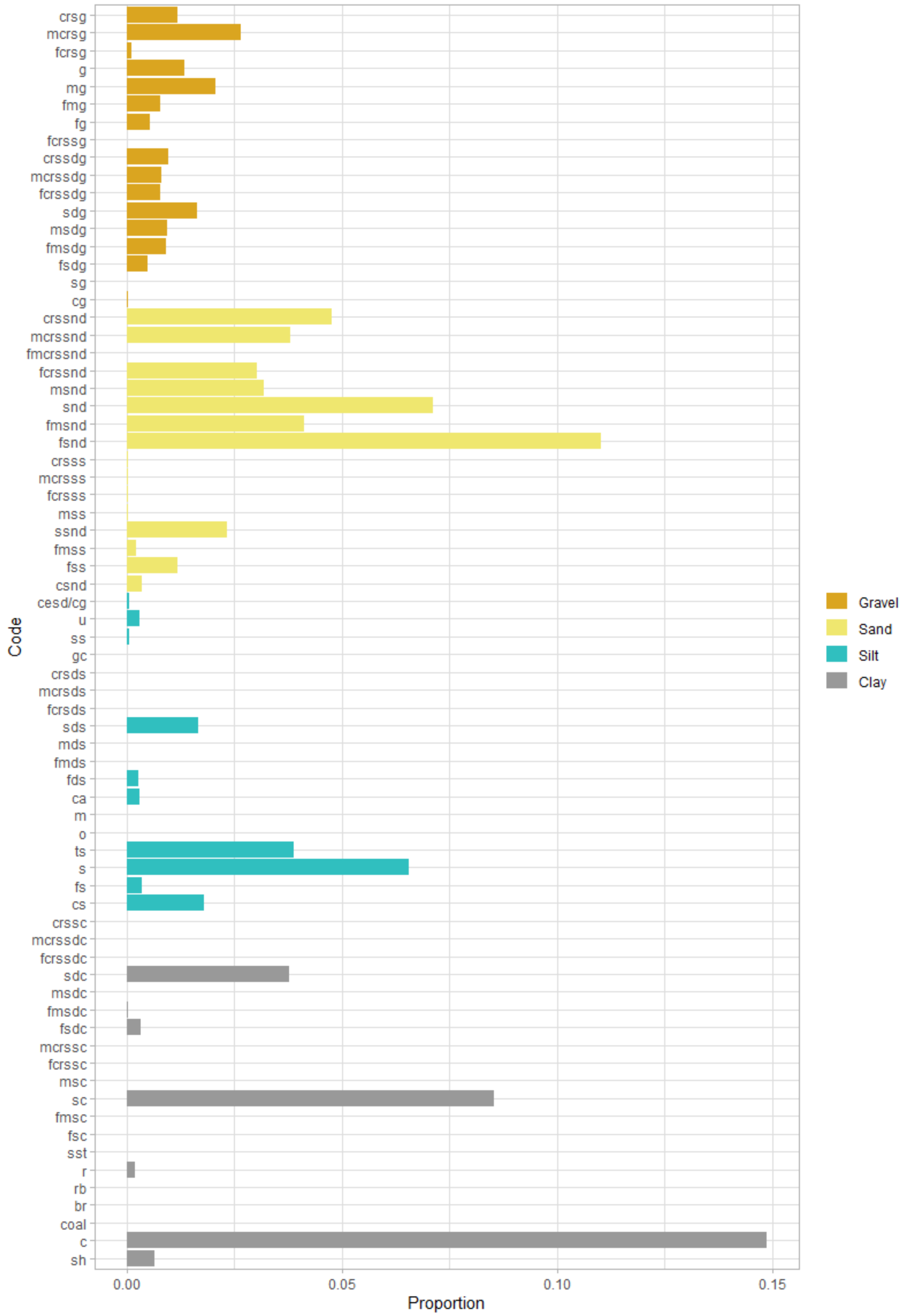


Figure 30. Proportions of 71 standardized lithologies (table 6) throughout the valley between bedrock and land surface. Category percentages are 1) clay: 28.4%, 2) silt: 15.2%, 3) sand: 41.1%, 4) gravel: 15.3%.

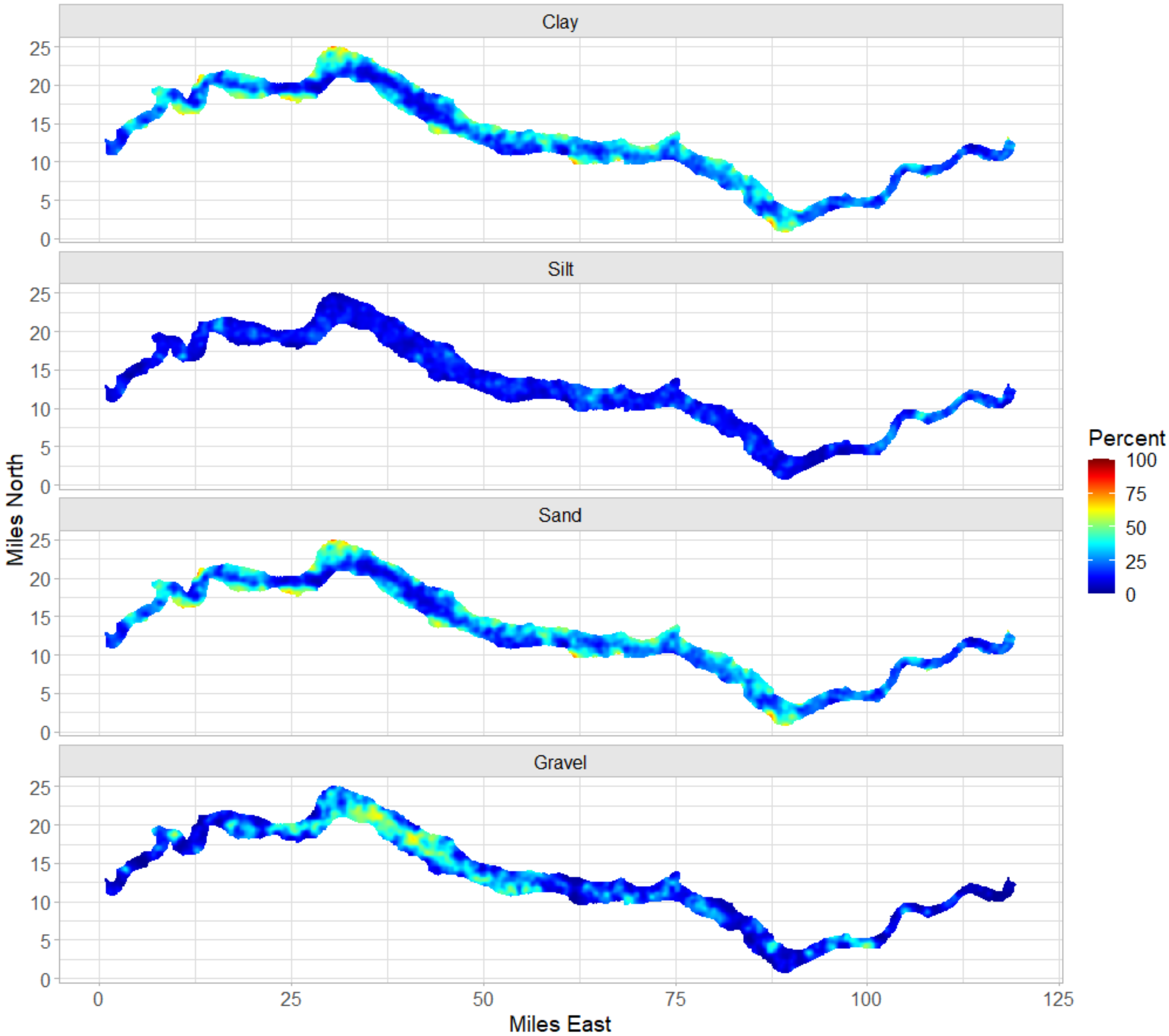


Figure 31. Category percentages between bedrock and land surface.

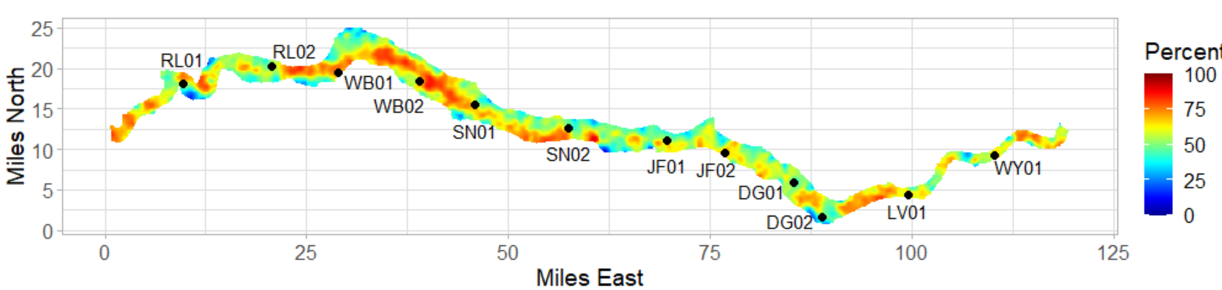


Figure 32. Percentage coarse materials (sand and gravel) between bedrock and land surface, with the selected (12 of 16) index well locations.

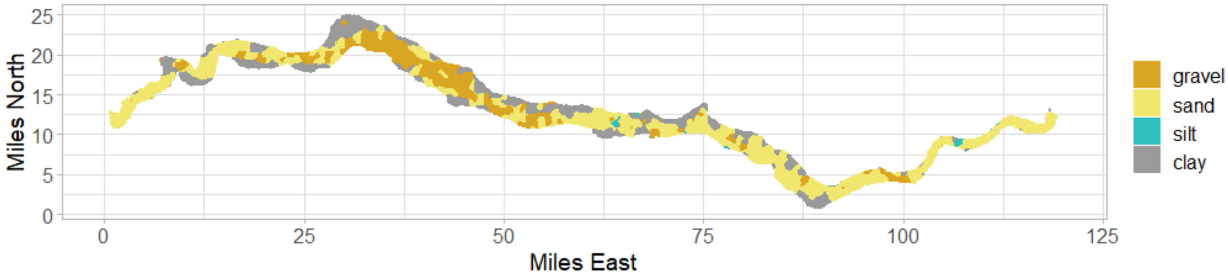


Figure 33. Dominant (majority) category between bedrock and land surface.

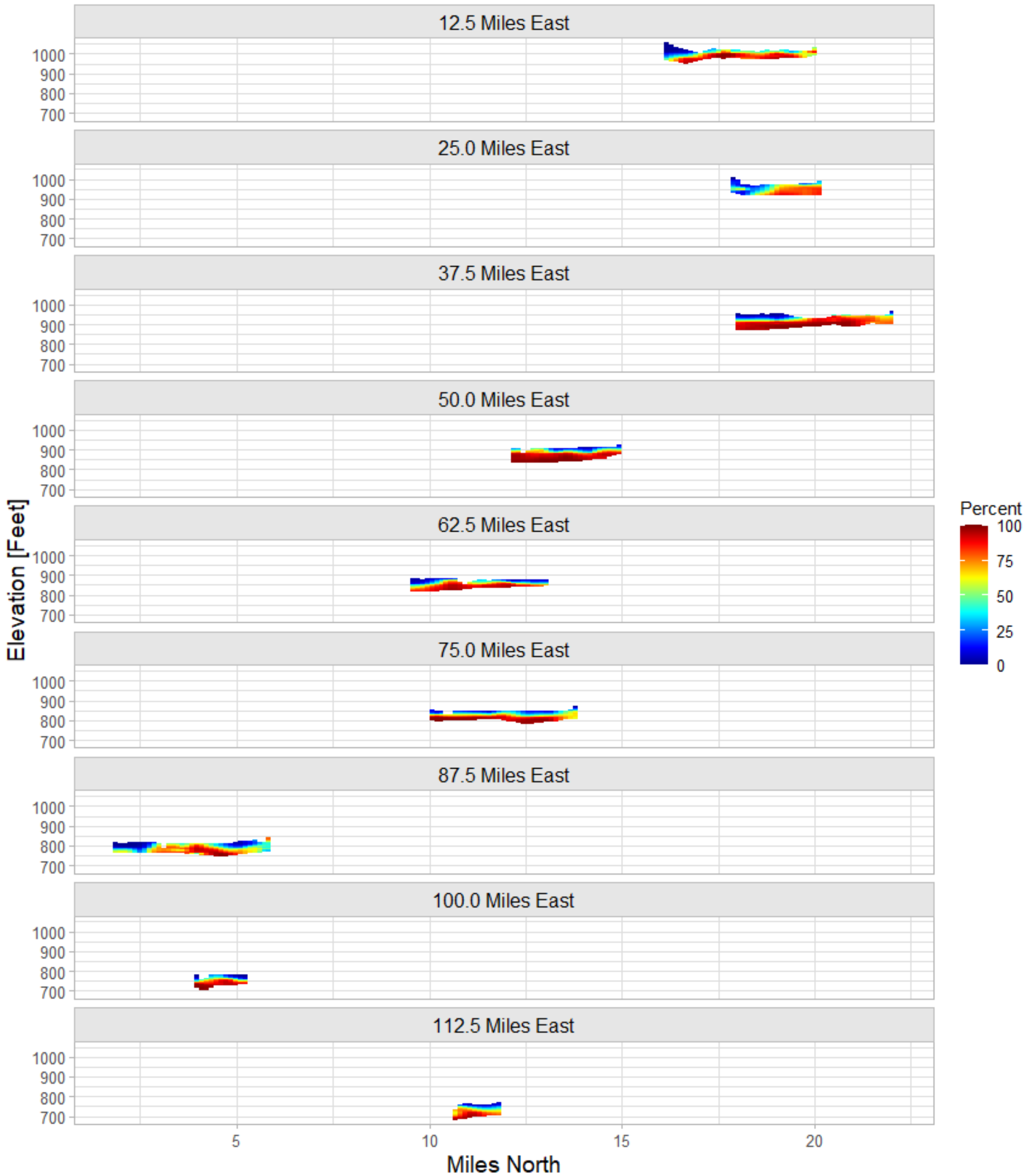


Figure 34. Percentage coarse materials (sand and gravel) in north-south cross sections at 12.5-mile (20.1-km) intervals from west to east along the valley (corresponding to the grid lines along the horizontal axis in figs. 27–29 and 31–33).

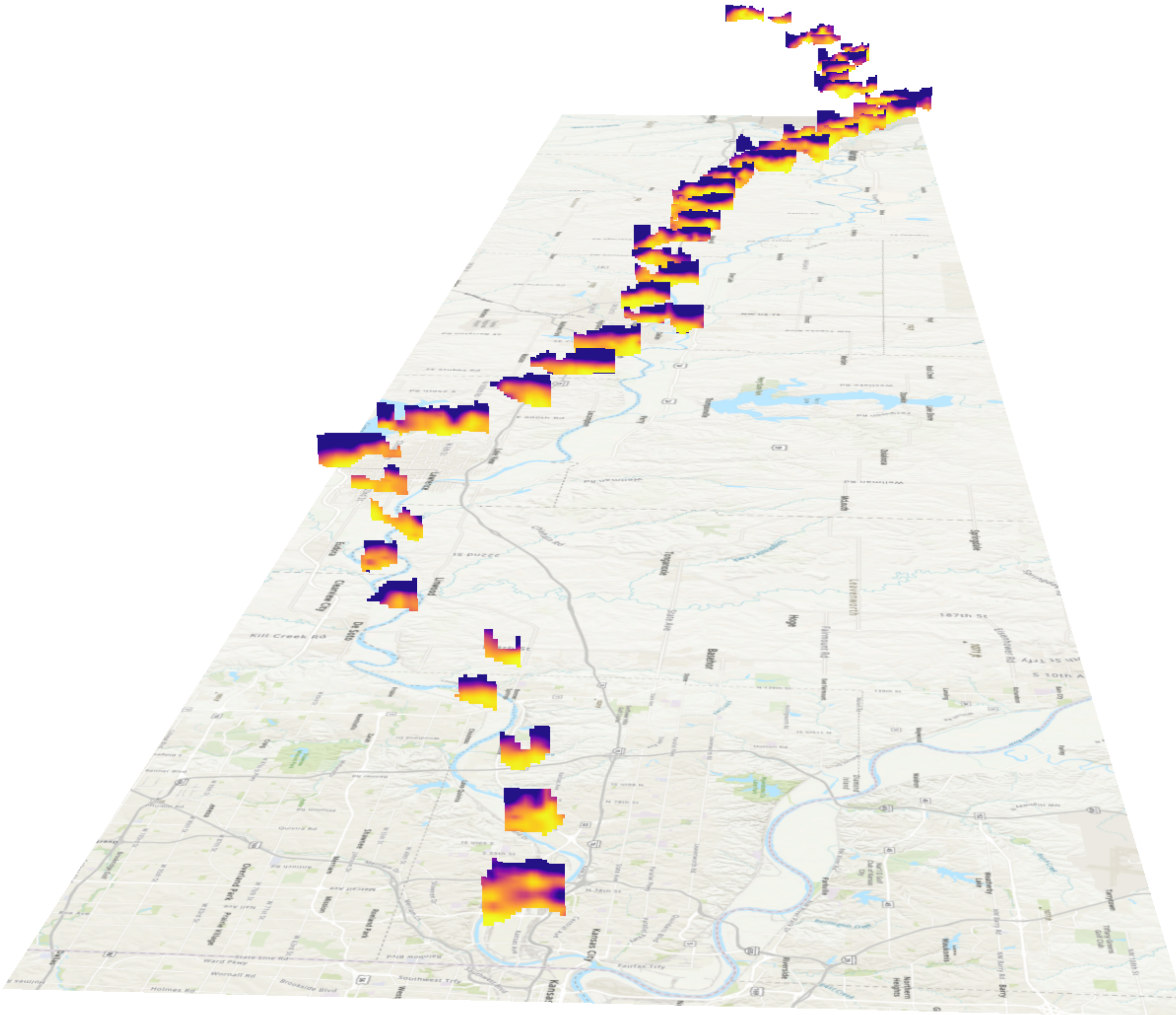


Figure 35. Percentage of coarse materials in 35 sections at 3.1-mile (5-km) intervals from west (top) to east (bottom) along the valley. Map extent is 120 miles east-west and 26 miles north-south.

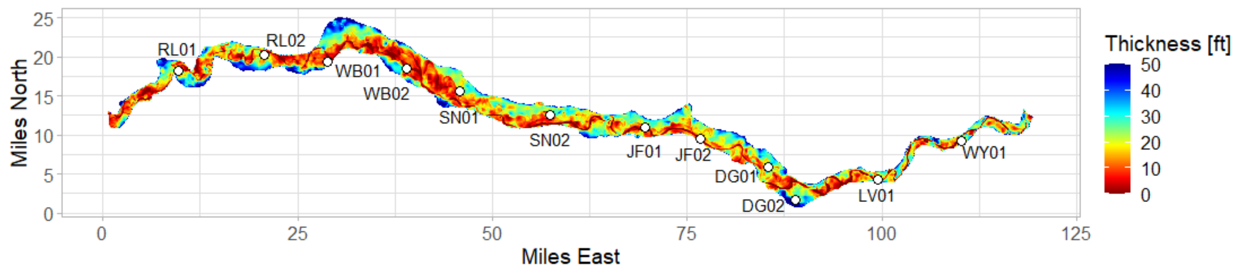


Figure 36. Fine layer thickness. The 474 values greater than 50 feet (2.2% of total, ranging up to 97 feet) are shown as 50 feet. Note that color scale is reversed relative to other figures.

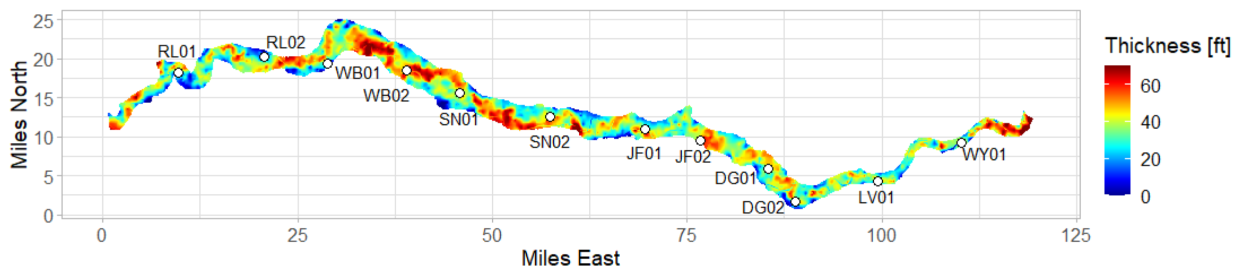


Figure 37. Coarse layer thickness. The 215 values greater than 70 feet (1.0% of total, ranging up to 116.5 feet) are shown as 70 feet.

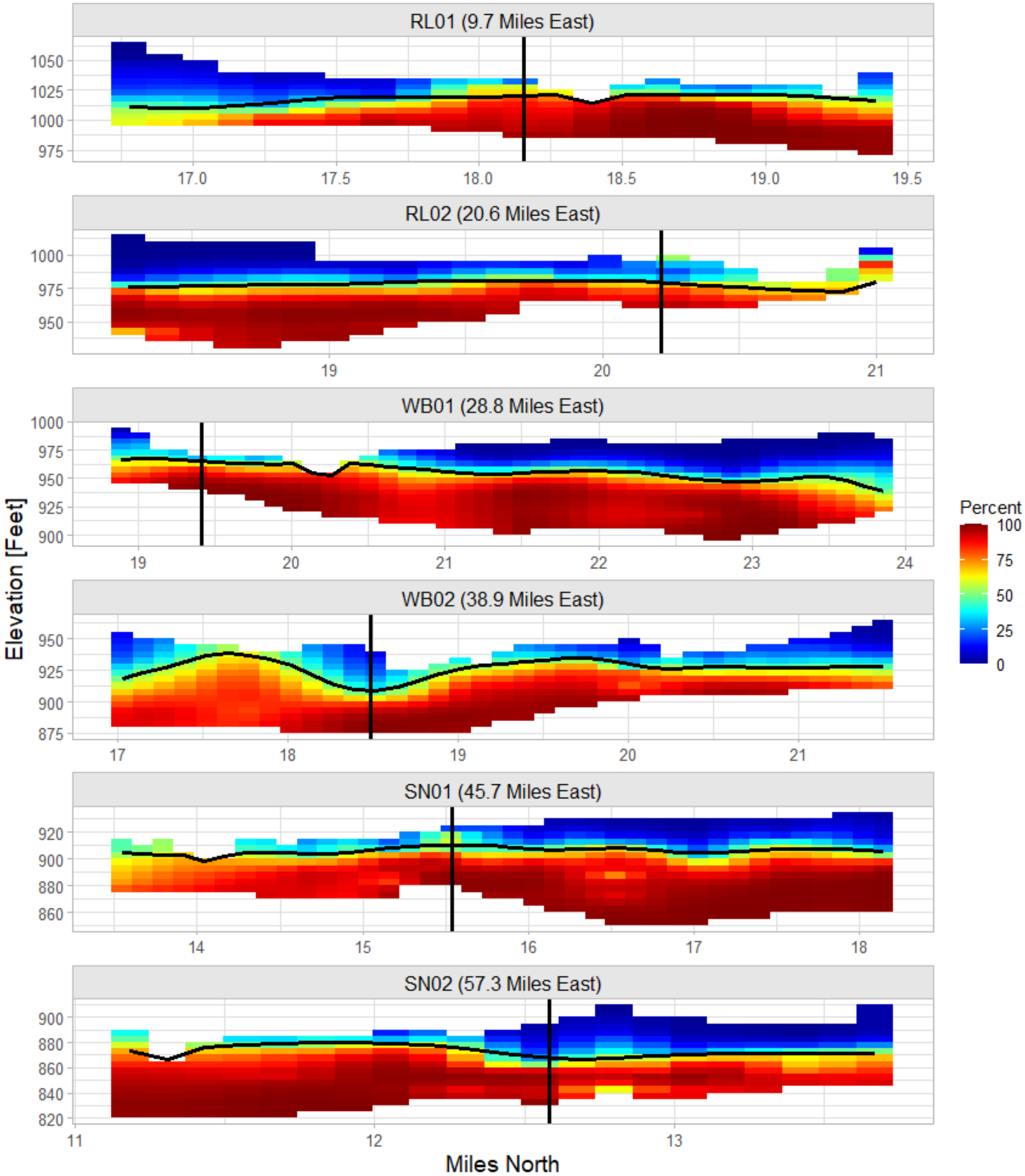


Figure 38. Percentage coarse in north-south cross sections of 3-D grid closest to six index wells in the western reach of the network. Vertical black line in each panel represents index well location, and black curve represents generalized bounding surface between fine and coarse layers. Note varying axis scales. Mileages in panel labels represent section locations. Distances between each index well and the corresponding cross section range from 33 to 305 feet.

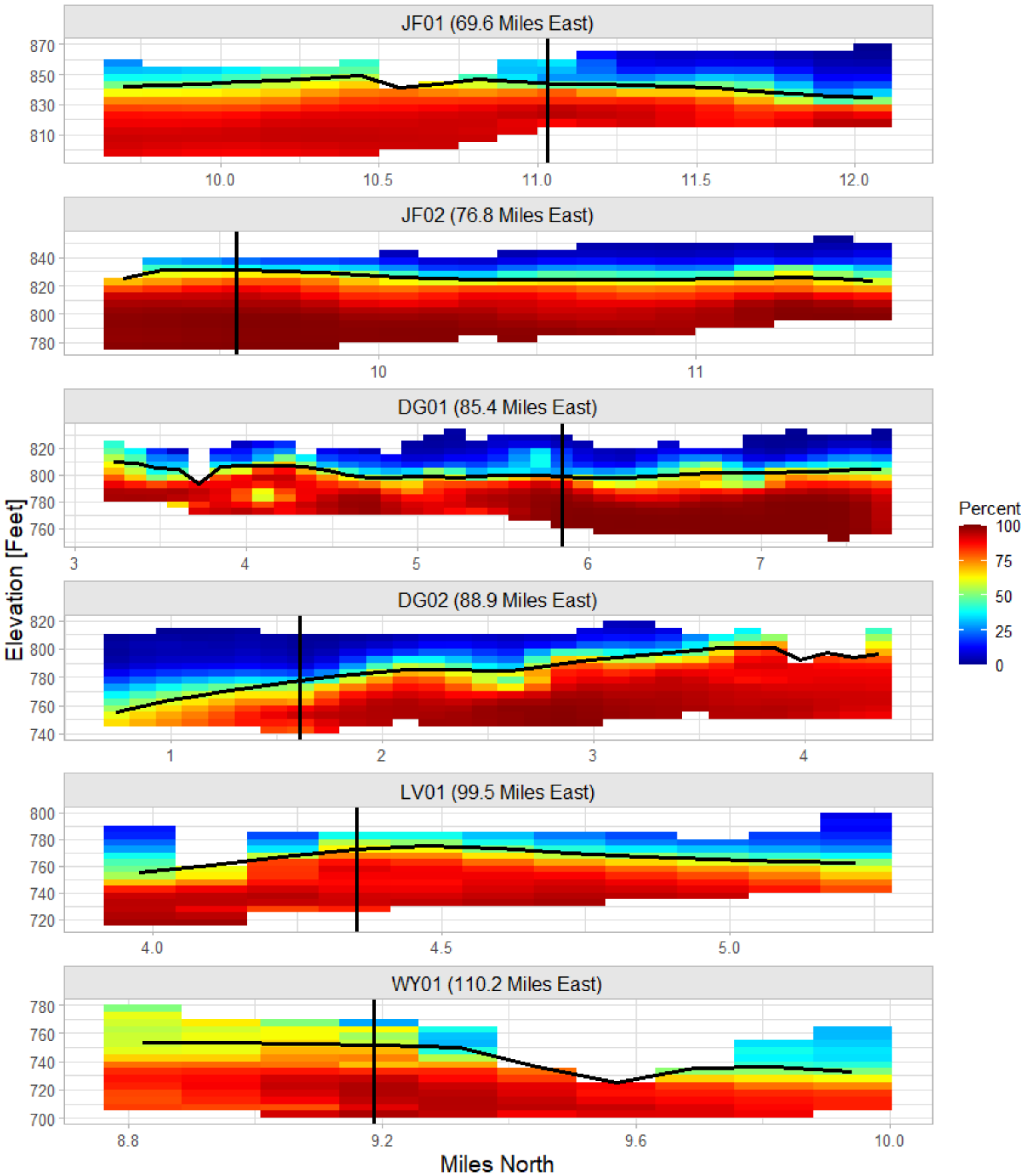


Figure 39. Percentage coarse in north-south cross sections of 3-D grid closest to six index wells in the eastern reach of the network. Vertical black line in each panel represents index well location, and black curve represents generalized bounding surface between fine and coarse layers. Note varying axis scales. Mileages in panel labels represent section locations. Distances between each index well and the corresponding cross section range from 55 to 323 feet.

5.4 Direct-Push Electrical Conductivity Logging in the KRAA

Along with the information from drillers' logs described in the previous section, additional hydrostratigraphic information was obtained via direct-push electrical conductivity (DPEC) logging (Schulmeister et al., 2003). This involves advancing small-diameter steel pipe with an electrical conductivity probe at its lower end from the surface to the bottom or near bottom of the aquifer to obtain high-resolution (≈0.05 ft) information about the hydrostratigraphy at the site and, in particular, the distribution of coarse materials (sands and gravels) versus fines (clays and silts).

DPEC logging was performed at the location of each of the 16 wells in the KRAA index well network. Plots of those records for the five wells installed during this reporting period are given in the appendix, section 8.3; the plots for the eleven other wells in the network are provided in the earlier project report (Butler et al., 2020).

An additional set of 23 DPEC logs was obtained during this reporting period to provide further information for hydrostratigraphic analyses. These logs were obtained as part of five DPEC transects in the Kansas River valley. Each transect was associated with one or more index wells. Three of the transects extended significant distances across the floodplain – these are the RL01 transect, the WB01–PT02 transect, and the DG02 transect. One of the transects was in a rather narrow portion of the floodplain (JF01 transect) and one consisted of relatively closely spaced logs (DG03 transect), so we were able to assess the continuity of subsurface structures. In all cases, the transects were associated with the tTEM geophysical surveys described in the next section.

Figure 40 is a Google Earth image of the RL01 transect showing the locations of the RL01 index well and the additional six DPEC logs obtained in that transect. The data for this and the other transects are provided as online Excel workbooks for this report (www.kgs.ku.edu/Hydro/KansasRiver/index.html). Each of the workbooks contains a Google Earth image with the locations of the wells and the transect followed by separate worksheets containing the DPEC data.

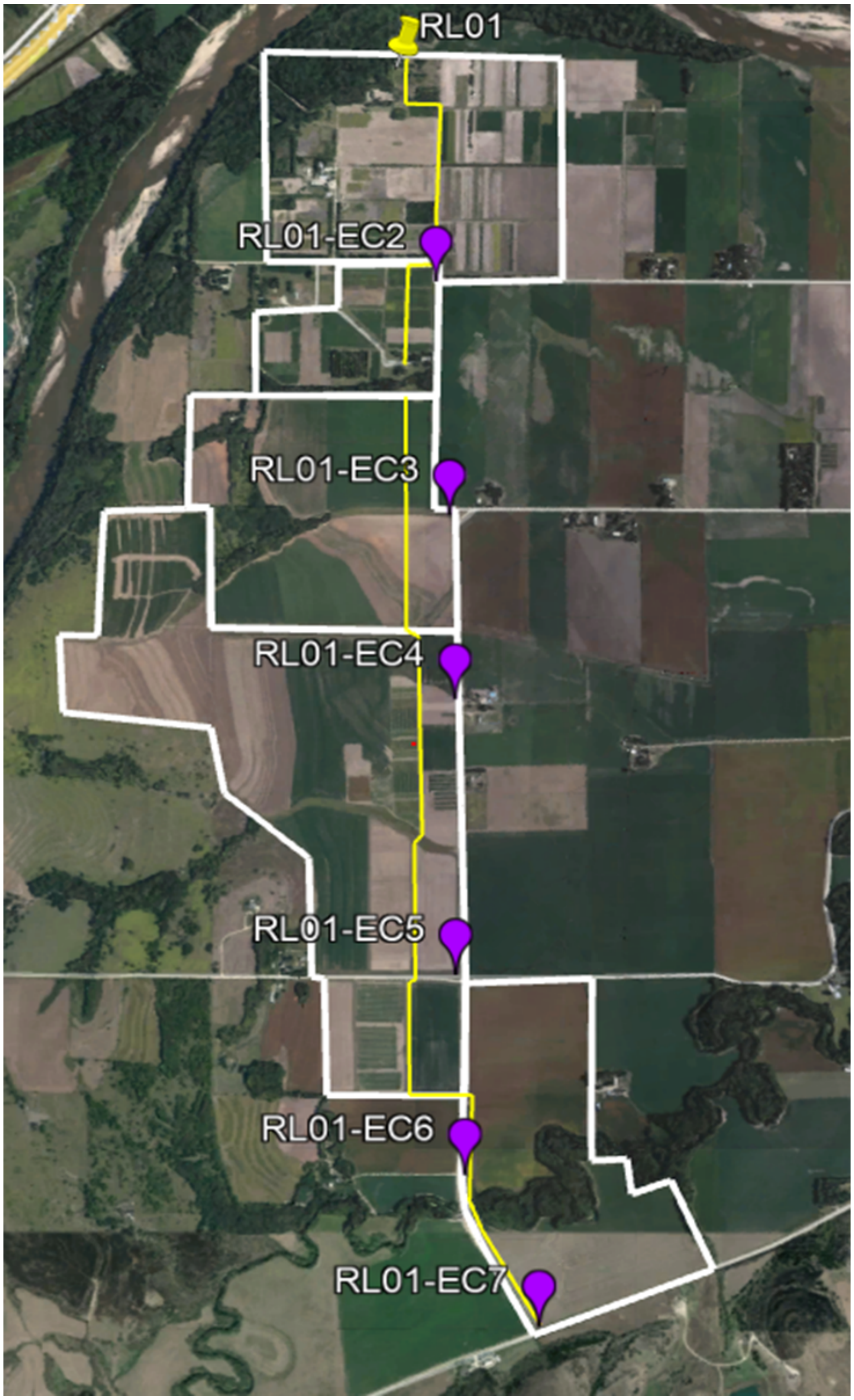


Figure 40. Aerial view of the RL01 DPEC transect consisting of the location of the DPEC log obtained at the RL01 index well and the six additional DPEC log locations. The white lines delineate the properties for which we had permission for tTEM surveys and DPEC logging; the yellow line was the original planned transect, but DPEC logging was done adjacent to roads for ease of access.

5.5 Towed Transient Electromagnetic (tTEM) Geophysical Survey of the KRAA

During the period of this report, the KGS worked with researchers at the Missouri University of Science and Technology (MST) to explore the potential of towed transient electromagnetic (tTEM) geophysical surveying to enhance understanding of the aquifer hydrostratigraphy.

The tTEM method is a recently developed approach that has great potential for describing aquifer hydrostratigraphy (Maurya et al., 2020). The surveys performed for this project involved dragging excitation and sensing units behind an all-terrain vehicle. The electromagnetic signals obtained during a survey are used to estimate the resistivity of subsurface units, which helped in determining material type and water saturation for this project. The benefit of using tTEM is the efficiency of the surveys; many line kilometers can be obtained in a matter of hours and less interpolation between data is required when compared to more traditional methods such as DPEC logging and the analysis of drillers' logs described in the previous two sections. A limitation of the tTEM equipment in this project was that it was not robust enough to apply in recently harvested corn fields, so application was limited to recently harvested soybean fields or fallowed fields. Thus, the areas in which it could be applied were limited.

Figure 41 shows the four areas in which the tTEM was applied for this project; a fifth area near DG03 was used for an initial assessment of the method. A total of 68.35 miles (110 kilometers) of survey lines were obtained in the four areas. In all cases, the method of Knight et al. (2018) was used to estimate the resistivity of the processed tTEM data. A report on the survey results is provided in the appendix (section 8.3).

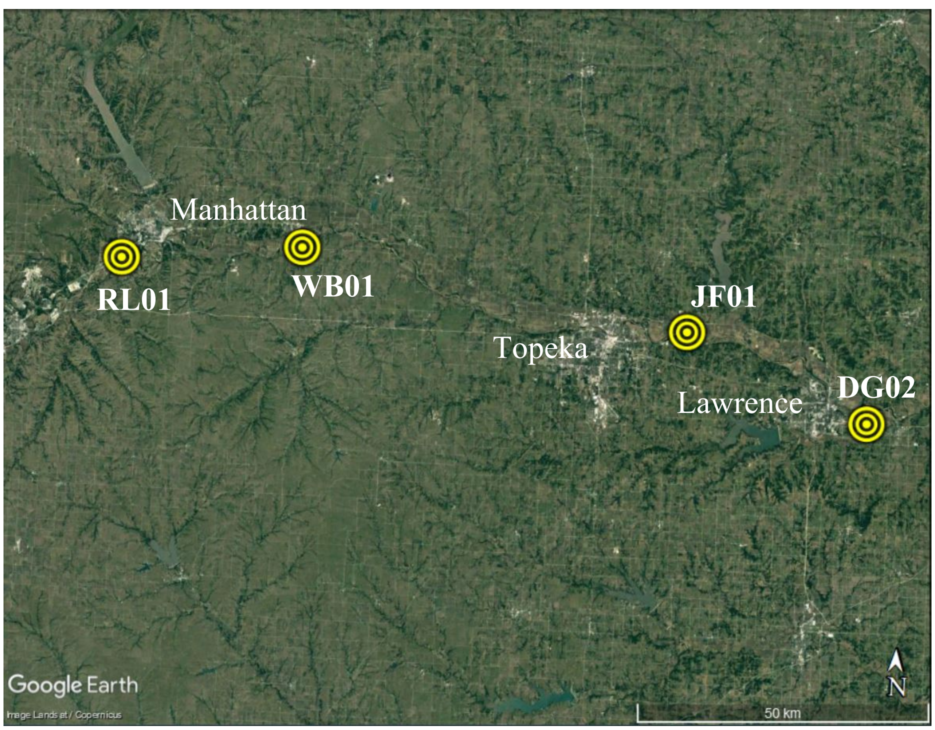


Figure 41. Aerial view of the locations of the four sites in the KRAA where tTEM surveys were performed.

5.6 Relationship Between the KRAA and the Kansas River

An important objective of this phase of the project was to assess the relationship between the Kansas River and the KRAA and how that changes in space and time. Two index wells (JF02 and LV01) are approximately 0.2 miles from USGS stream gaging stations, but the rest are at considerably greater distances. Thus, to assess the relationship, we first had to estimate the stream stage at the position of the index wells. This was done in a three-step process described in the following paragraphs.

The first step was to calculate the daily average stream stage at each gage. In most cases, this was part of the USGS data record at the gage. However, at some gages (e.g., Lake Quivira), daily average stream stage data were not available. In that case, we used the reported 15-minute stage data to compute a stage-discharge relationship for the gage. We then estimated the daily average stream stage at the gage from the daily average discharge over the period of record. The daily average stream stage elevation was then computed using the USGS gage datum for each station.

The second step was to calculate the slope in the stage elevation between adjacent gages. This was done using the reported stage for four periods: a high-flow event from mid-June to mid-July 2019, August 2019, February 2021, and a low-flow event in December 2021. We also computed an average slope for those four periods. Table 7 summarizes the results of the slope analysis, and fig. 42 shows the locations of the Kansas River gages, dams along the river, and the stage slope in August 2019. Table 7 also includes the slope calculated using each USGS gage datum for comparative purposes.

The third step was to compute the stage elevation opposite the index well. We used the average slope calculated between adjacent USGS gages (rightmost column in table 7) to estimate the river stage opposite an index well. Table 8 presents these results. Our primary emphasis is on the index wells within a quarter of a mile from the river (bolded rows in table 8).

The plots in section 4 can be redone to clarify the relationship between the river and the aquifer by adjusting the stream stage for the location of the index well. Figure 43 is an example of such a plot for well WB02. The plot reveals that the Kansas River is a gaining river in the vicinity of well WB02 during the entire monitoring period. Figures 44 and 45 present the results of table 8 for two periods to illustrate the relationship between the river and the aquifer for the index well network. Other than the interval of the river near WY01 and bank storage during very high peak flows, the river is a gaining reach for the locations and time periods assessed here. The findings at WY01 should be considered preliminary, as further work is required to fully account for the impact of the WaterOne low-head dam a short distance upstream of the well.

This initial analysis shows that the Kansas River is a gaining river over most of its extent. Further development of the KRAA could lead to a shifting of the relationship between the river and the aquifer with significant ramifications for the management of the combined river-aquifer resources. The continued monitoring of this relationship will be an important task for the future.

Table 7. Location of USGS stream gages and the calculated slope between gages.

Location of USGS Gage	Est RM[a]	USGS Gage Datum[b]	Slope (ft/mile) Gage Datum[c]	Slope (ft/mile) 6/16/19–7/15/19 High Flow Event[c]	Slope (ft/mile) Dec 2021 Low Flow Event[c]	Slope (ft/mile) Aug 2019[c]	Slope (ft/mile) Feb 2021[c]	Average Slope (ft/mile) based on the four flow periods[c]
at Fort Riley	170.6	1031.40						
at Manhattan	150.7	985.87	2.29	2.29	2.28	2.28	2.23	2.27
at Wamego	128.5	950.82	1.58	1.70	1.63	1.68	1.74	1.69
near Belvue[d]	116.9	925.70	2.17	2.00	1.97	1.95	1.97	1.98
at Topeka WP[e]	87.0	857.16	2.29	2.35	2.31	2.35	2.31	2.32
at Topeka	83.8	846.66	3.28	2.00	3.17	2.27	3.07	2.75
at Lecompton[f]	64.3	821.84	1.27	1.52	1.44	1.47	1.43	1.46
at Lawrence[g,h]	52.4	800.12	1.83	1.57	0.94	1.22	0.92	1.14
at Lawrence – below dam[h]	52.4	800.12	0	-13.56	-24.71	-18.61	-24.93	-21.07
at Desoto	30.8	753.87	2.14	1.78	1.38	1.48	1.37	1.51
near Lake Quivira[i]	14.8	727.22	1.67	1.33	1.34	1.60	1.38	1.35
at Kansas City	2	707.00	1.58	0.42	1.27	0.64	1.27	0.99

a—River miles (RM) estimated from Friends of the Kaw online maps (https://kansasriver.org/river-access-map/).
b—Sensor datum for USGS gages from the USGS website and personal communication with the USGS Water Science office in Lawrence. Gages are placed beneath the river bed for stability and are likely not buried to equal depths.
c—Calculated slope is for the distance between this gage and the nearest upstream one.
d—There is a low-head dam upstream of the Belvue gage.
e—There is a low-head dam/weir at the Topeka Water Plant (Topeka WP)
f—There is a low-head dam between Topeka and Lecompton
g—There is a low-head dam between Lecompton and Lawrence
h—For the Bowersock Dam at Lawrence, the USGS uses the same datum point for both the upstream and downstream gages. This produces negative stage heights below the dam (river stage is below gage datum).
i—There is a low-head dam at the Lake Quivira gage used for Water One water intake.

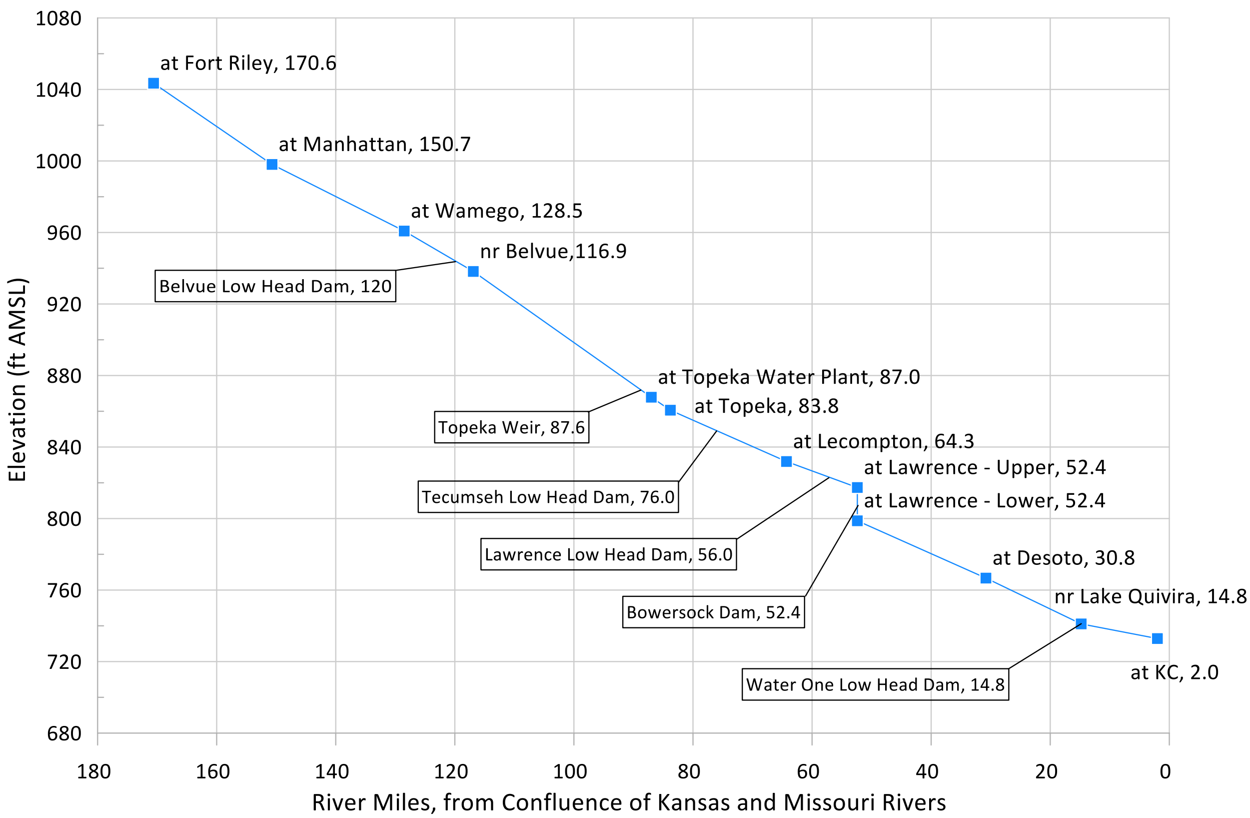


Figure 42. Location of USGS Kansas River gages (blue squares), dams along the river, and estimated river stage between gages (blue line) during August 2019.

Table 8. Location of KRAA index wells along the Kansas River and the calculated river stage[a] and well water-level elevation for four periods between June 2019 and December 2021 (wells PT02 and GEMS4-1 not included in table because of their distance [>2 mi] from the river).

KRAA Well ID[b]	Est RM[c]	Aug. 2019		Feb. 2021		High Flow 6/16/19–7/15/19		Low Flow Dec. 2021	
		Calculated River Elev.	Average Well Elev.	Calculated River Elev.	Average Well Elev.	Calculated River Elev.	Average Well Elev.	Calculated River Elev.	Average Well Elev.
RL01	**158.8**	**1016.45**		**1011.59**	**1011.83**	**1019.85**		**1009.55**	**1010.55**
RL02	137.75	976.44	980.03	970.21	976.99	979.44	978.62	970.65	975.92
PT01	127.3	958.79		952.31		961.19		952.73	
WB01	126.8	957.80	961.91	951.32	955.06	960.20	964.56	951.74	955.01
WB02	**112.8**	**927.72**		**922.53**		**930.32**		**922.93**	**923.63**
SN01	104.5	908.46	910.43	903.27	905.78	911.06	911.63	903.67	904.93
SN02	89.7	874.12	872.40	868.93	868.79	876.72	872.29	869.33	867.92
JF01	72.3	843.58	847.94	836.65	840.38	846.06	848.60	836.59	840.16
JF02	**64.3**	**831.90**		**824.97**		**834.38**		**824.91**	**825.65**
DG03	**54.4**	**819.64**		**816.32**		**817.95**		**816.04**	**815.64**
DG01	54.1	819.30	814.35	815.98	810.47	817.61	815.37	815.70	811.71
DG02	48.4	793.28	796.71	786.16	793.67	790.21	796.62	785.72	793.65
LV01	**30.6**	**762.40**	**767.82**	**758.79**	**759.98**	**763.66**	**768.45**	**759.00**	**759.80**
WY01	**13.6**	**744.36**	**735.19**	**732.67**	**719.23**	**748.49**	**738.87**	**732.79**	**723.58**

[a]Used the slopes from table 7.

[b]Bolded rows are wells within 0.25 miles of river.

[c]Used the closest point to river from well to establish the estimated river mile (RM) and calculate stage elevation.

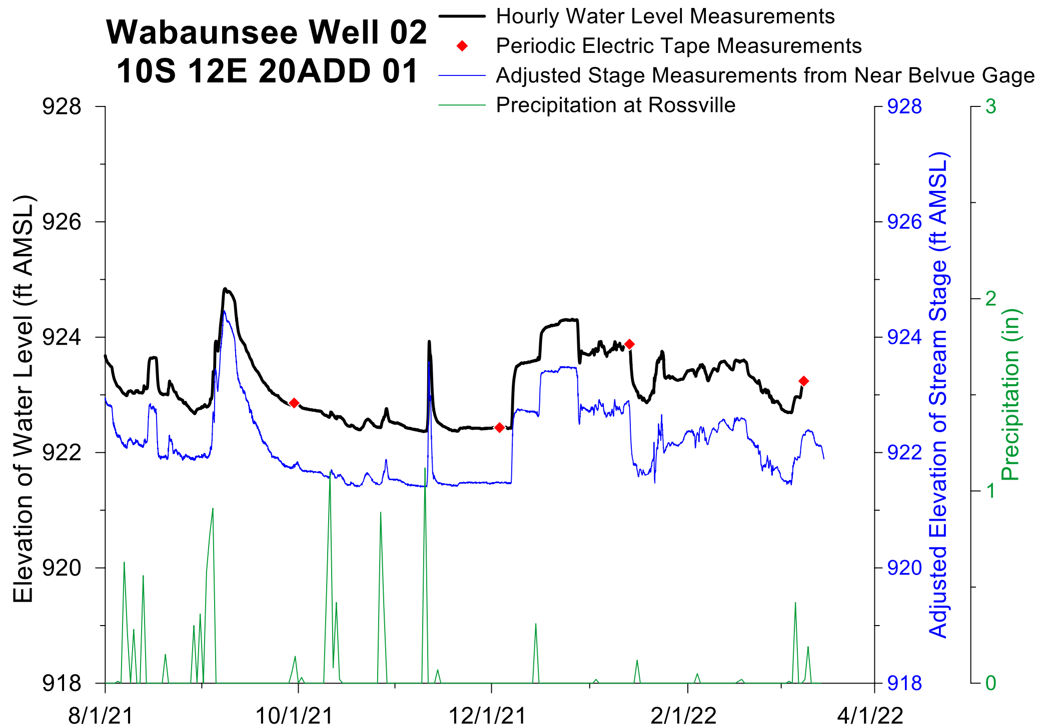


Figure 43. Revision of the Wabaunsee County index well 2 hydrograph with stream stage and precipitation data from fig. 7. Stream gage elevation from gage near Belvue (4.1 miles upstream) has been reduced by approximately 9.5 ft using the average slope in the rightmost column of table 7. Further details about Wabaunsee County index well 2 are provided in the caption for fig. 7.

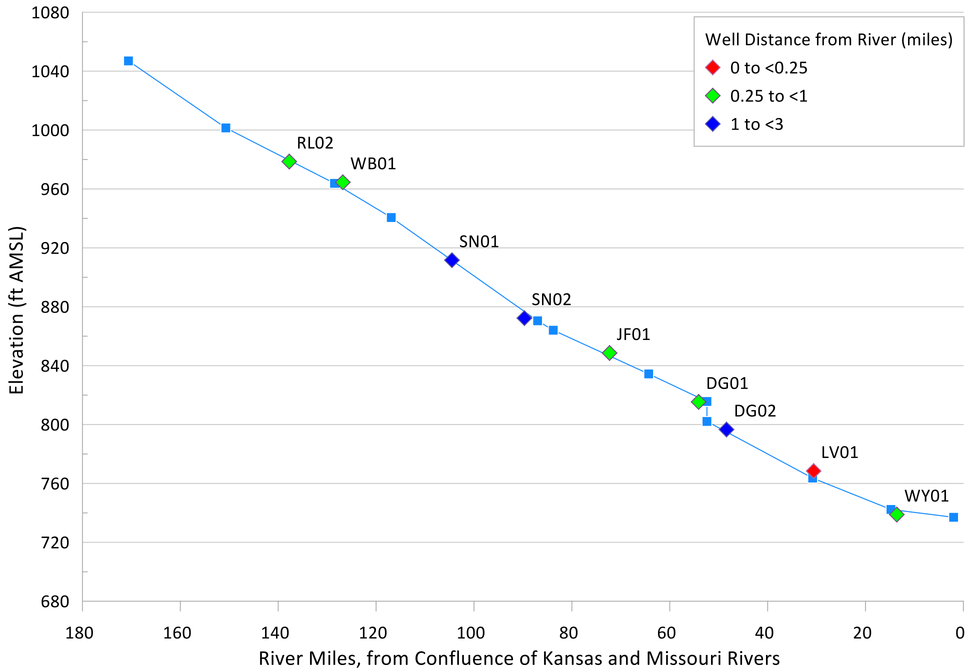


Figure 44. Plot of water-level elevation at KRAA index wells (diamonds), stage at USGS stream gages (blue squares), and the estimated river stage between gages (blue line) for the high-flow event in the Kansas River from June 16 to July 15, 2019.

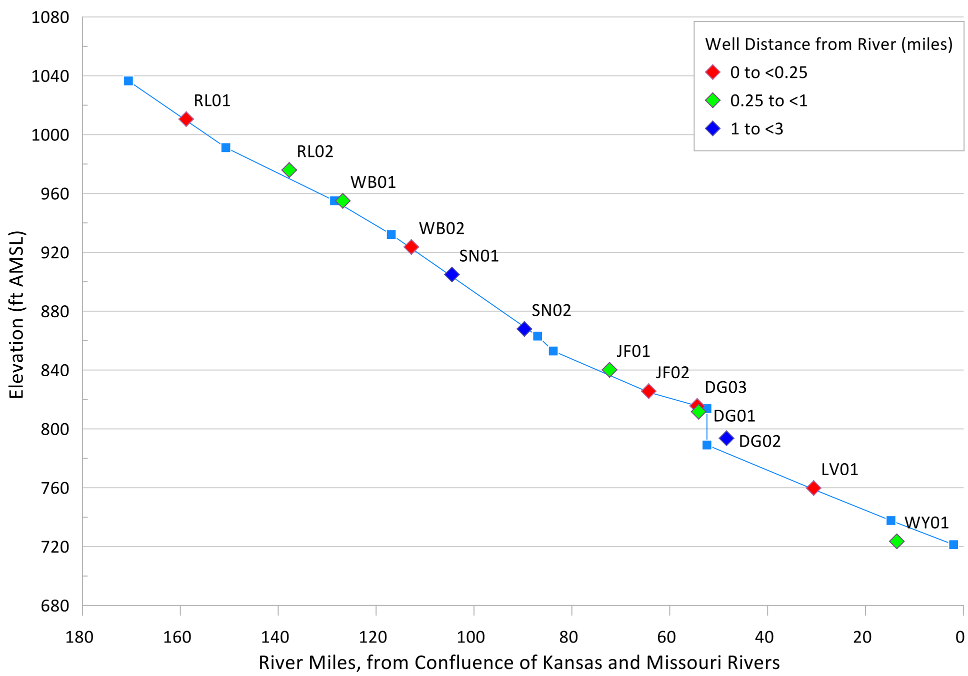


Figure 45. Plot of water-level elevation at KRAA index wells (diamonds), stage at USGS stream gages (blue squares), and the estimated river stage between gages (blue line) for the low-flow event in the Kansas River in December 2021.

6 Summary of Phase Two Accomplishments and Future Plans

6.1 Phase Two (June 2020 to May 2022) Accomplishments

- Selected five sites for new monitoring wells in the Kansas River corridor from just east of Wamego to just north of Lawrence.
- Obtained direct-push electrical conductivity (DPEC) logs at all five well sites; logs were used to understand site hydrostratigraphy and to select the screened intervals for each well.
- Drilled and constructed all five wells. Developed all five wells to ensure a good connection between the well and the aquifer; performed and analyzed slug tests at all five wells to confirm that connection.
- Installed sensors and telemetry equipment and initiated monitoring at all of the wells. Network now consists of 16 wells from west of Manhattan to near the junction with the Missouri River in Kansas City.
- Obtained and analyzed water samples from all 16 wells in the network; the results of these analyses will serve as benchmarks for future water sampling.
- Served telemetered data from all 16 wells on the KGS website in real time. Visited each well quarterly to take manual measurements of water levels and download data from sensors.
- Compared water-level responses to stream-stage changes and precipitation, and completed an initial interpretation of hydrographs from 14 of the 16 wells to help develop an understanding of the major mechanisms that produce water-level changes at each well and the relationship between the KRAA and the Kansas River and its tributaries. An initial analysis of the relationship between the KRAA and the Kansas River found that the river was a gaining stream over most of its extent.
- Completed a hydrostratigraphic analysis of the KRAA using 4,945 drillers' logs from the WWC-5 database.
- Performed five DPEC transects in the KRAA from west of Manhattan to east of Lawrence for a total of 23 DPEC logs.
- Performed towed transient electromagnetic (tTEM) geophysical surveys of the aquifer in four areas along the Kansas River floodplain – one west of Manhattan, one east of Wamego, one west of Perry, and one east of Lawrence. These surveys totaled 68.35 miles in length and enhanced understanding of the hydrostratigraphy of the aquifer; all were performed in the areas of the DPEC transects.

6.2 Planned Activities, 2022 and Beyond

- Create a groundwater model of the aquifer with a particular emphasis on its relationship to the Kansas River.
- Continue monitoring and processing water-level data from all wells in the network. Visit each well quarterly to take manual measurements of water levels and download data from sensors.

- Perform detailed analyses of hydrographs from all wells involved in the program to enhance understanding of the major drivers of water-level changes in the wells and the relationship between the KRAA and the Kansas River and its tributaries.
- Interpret groundwater chemistry at the index wells relative to that of the river based on distance from the river to assess water exchange and enhance understanding of stream-aquifer interactions.

7 References

Bohling, G. C., Wilson, B. B., and Adkins-Heljeson, D., 2020, Explanation of quantitatively interpreted logs in the Kansas Geological Survey's WWC5 database: Kansas Geological Survey Open-File Report 2020-13, 14 p., https://www.kgs.ku.edu/Publications/OFR/2020/OFR2020-13.pdf.

Butler, J. J., Jr., 2019, The Design, Performance, and Analysis of Slug Tests (2nd edition): Boca Raton, Florida, CRC Press, 266 p.

Butler, J. J., Jr., Reboulet, E. C., Knobbe, S., Whittemore, D. O., Wilson, B. B., and Bohling, G. C., 2020, Kansas River alluvial aquifer index well program: 2019 annual report: Kansas Geological Survey Open-File Report 2020-14, 54 p., http://www.kgs.ku.edu/Publications/OFR/2020/OFR2020-14.pdf.

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., and Bohling, G. C., 2021, High Plains aquifer index well program: 2020 annual report: Kansas Geological Survey Open-File Report 2021-8, 108 p., http://www.kgs.ku.edu/Publications/OFR/2021/OFR2021-8.pdf.

Davis, S. N., and Carlson, W. A., 1952, Geology and ground-water resources of the Kansas River valley between Lawrence and Topeka, Kansas: Kansas Geological Survey, Bulletin 96, pt. 5, p. 201–276, http://www.kgs.ku.edu/Publications/Bulletins/96_5/index.html.

Dufford, A. E., 1958, Quaternary geology and ground-water resources of Kansas River valley between Bonner Springs and Lawrence, Kansas: Kansas Geological Survey, Bulletin 130, pt. 1, p. 1–96, http://www.kgs.ku.edu/Publications/Bulletins/130_1/index.html.

Fader, S. W., 1974, Ground water in the Kansas River valley, Junction City to Kansas City, Kansas: Kansas Geological Survey, Bulletin 206, pt. 2, 12 p., http://www.kgs.ku.edu/Publications/Bulletins/206_2/index.html.

HydroSOLVE, Inc., 2007, AQTESOLV for Windows, Version 4.5.

Knight, R., Smith, R., Asch, T., Abraham, J., Cannia, J., Viezzoli, A., and Fogg, G., 2018, Mapping aquifer systems with airborne electromagnetics in the Central Valley of California: Groundwater, v. 56, no. 6, p. 893–908.

Liu, G., Butler, J. J., Jr., Reboulet, E. C., and Knobbe, S., 2012, Hydraulic conductivity profiling with direct-push methods: Grundwasser, v. 17, no. 1, p. 19–29, doi: 10.1007/s00767-011-0182-9.

Maurya, P. K., Christiansen, A. V., Pedersen, J., and Auken, E., 2020, High resolution 3D subsurface mapping using a towed transient electromagnetic system - tTEM: case studies: Near Surface Geophysics, v. 18, p. 249–259, https://doi.org/10.1002/nsg.12094.

O'Connor, H. G., 1960, Geology and ground-water resources of Douglas County, Kansas: Kansas Geological Survey, Bulletin 148, http://www.kgs.ku.edu/General/Geology/Douglas/index.html.

O'Connor, H. G, 1971, Geology and ground-water resources of Johnson County, northeastern Kansas: Kansas Geological Survey, Bulletin 203, http://www.kgs.ku.edu/General/Geology/Johnson/index.html.

Schulmeister, M. K., Butler, J. J., Jr., Healey, J. M., Zheng, L., Wysocki, D. A., and McCall, G. W., 2003, Direct-push electrical conductivity logging for high-resolution hydrostratigraphic characterization: Ground Water Monitoring and Remediation, v. 23, no. 3, p. 52–62.

Suchy, D. R., 2002, The Public Land Survey System in Kansas: Kansas Geological Survey Public Information Circular 20, 4 p., https://www.kgs.ku.edu/Publications/pic20/pic20_1.html.

Whittemore, D. O., Wilson, B. B., and Butler, J. J., Jr., 2014, Field trip guide, Groundwater resources of the alluvial aquifer system in the lower Kansas River valley: 59th Annual Midwest Ground Water Conference, Lawrence, Kansas, 31 p.

Whittemore, D. O., Wilson, B. B., and Butler, J. J., Jr., 2019, Kansas River alluvial aquifer: Water use and real-time monitoring: Kansas Geological Survey Open-File Report 2019-18, 30 p., http://www.kgs.ku.edu/Hydro/Publications/2019/OFR19_18/index.html.

Wilson, B. B., 2019, Maintenance of the Kansas Geological Survey's data services to the National Groundwater Monitoring Network and establishment of a trend well network in the Kansas River alluvial aquifer: Kansas Geological Survey Open-File Report 2019-17, 20 p., http://www.kgs.ku.edu/Hydro/Publications/2019/OFR19_17/index.html.

8 Appendix — Field Methods, Well Completion Reports, and Direct-Push Logs

8.1 Field Methods

8.1.1 Well Installation

All of the new wells for this project were installed with the KGS Geoprobe direct-push unit. Direct-push technology uses hydraulic rams supplemented with the vehicle weight to rapidly advance small-diameter pipe into the subsurface; material is not removed as in traditional drilling methods but is displaced to the side by the advancing pipe (Liu et al., 2012). The technology can be used for advancing small-diameter sensors to obtain high-resolution information about the subsurface as well as for well installation. In this work, it was used for both purposes. Once a site had been selected and landowner approval had been obtained, the KGS team advanced small-diameter pipe with an electrical conductivity probe (Schulmeister et al., 2003) at its lower end from the surface to the bottom or near bottom of the aquifer to obtain high-resolution (≈0.05 ft) information about the hydrostratigraphy at the site and, in particular, the distribution of coarse (sands and gravels) and fine (clays and silts) materials. The electrical conductivity log was then used to create the geologic log for the site and to select the screened interval for the well.

The well was installed by advancing larger diameter pipe with a plug at the lower end and overdrilling the hole created by the direct-push electrical conductivity logging. Upon reaching the bottom, a 2-inch PVC Sch. 40 well string (casing and screen) was put down the center of the pipe. The well string was then used to push the plug out the bottom of the direct-push pipe and the pipe was withdrawn while leaving the well string in place. The formation quickly collapsed against the screen and casing except in the upper portions of the hole. The annulus in the upper section was then filled with bentonite pellets to the land surface. A steel well protector was placed around the casing extending above the surface.

8.1.2 Well Development

The development procedure began by taking a water level and tagging the bottom of the well. The well volume was then determined from the height of the water column (0.163 gal/ft for 2 inch PVC). A 2-inch diameter surge block attached to lengths of ½-inch PVC was placed in the well screen and used to surge the well. The standard surging protocol for this project was 20 cycles of surging (up and down movement of surge block) for each 2½ to 3 ft section of screen. After surging was completed, the surge block was removed and a 12V plastic well sampling pump was placed in the well approximately 5 feet from the bottom of the well. The pump was connected to a 12V battery, and the pumped water was collected and measured in a 5-gallon bucket. Five to six well volumes were removed from the well as described in the main text.

8.2 Characterization of the Kansas River Alluvial Aquifer Using Towed Transient Electromagnetic (tTEM) Technology – Report prepared by Jonathon Voss of the Missouri University of Science and Technology as part of his M.S. work

Introduction

The Kansas Geological Survey (KGS) has interest in the characterization of the Kansas River alluvial aquifer system west of Kansas City due to the projected land development and the resulting expected increased groundwater demand. Typically, drillers' logs are used to characterize aquifer systems, but they provide only limited information and require much interpolation between log locations.

To characterize this aquifer system, drillers' logs, direct-push electrical conductivity (DPEC) logs, and towed transient electromagnetic (tTEM) surveys have been conducted. tTEM surveys use electromagnetic signals to estimate resistivity in subsurface layers, which can help determine sediment type and water saturation. The benefit of using tTEM is the efficiency of the surveys, which can cover many line kilometers in a matter of hours and requires less interpolation between data when compared to more traditional methods. DPEC logs were used to verify tTEM results, specifically the depth to bedrock. Drillers' logs are also used to compare resistivity data with lithology data, providing a high-resolution map of the subsurface.

Location

In total, four locations across the KRAA were surveyed, all associated with existing index wells. The total length of the combined surveys is 110 line-kilometers (68.35 miles). The locations were chosen based on their distance apart from one another to create a general structure of the aquifer from Manhattan to Lawrence. The site names are RL01 west of Manhattan, WB01 east of Wamego, JF01 east of Topeka, and DG02 east of Lawrence.

tTEM is very sensitive to electrical noise, such as that generated by power lines and transformer stations. The locations with the best quality data were RL01 and WB01, because of the absence of the electrical noise typically found in large towns or cities. The location with the most electrical noise was DG02, as the survey was conducted close to Lawrence, resulting in a larger amount of noise and more data being excluded from the analysis. The amount of data collected at each location depended on landowner approval, noise present, and ability of the tTEM device to be towed over certain ground conditions. WB01 provided an ample amount of data, while DG02 had a lower level of landowner approval and more difficult terrain. Figure 46 shows the survey locations.

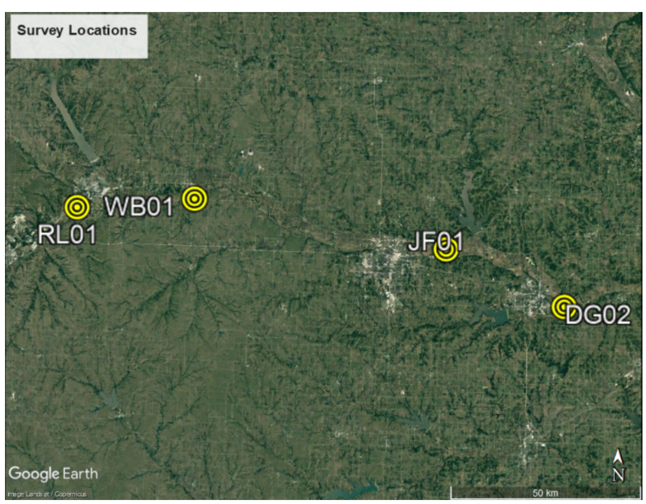


Figure 46. Survey locations.

Data Modeling & Interpretation

Models and Profiles

Once all the data were collected, editing and processing of the data began. The first step involved manually editing the raw data for noise from metallic or electrical objects. Electrical noise was commonly encountered in locations close to large towns, specifically in the Lawrence area. Once the noise was removed from the data, inversions of the tTEM data could be conducted to get the final resistivity results. Both spatially constrained inversions (SCI) and laterally constrained inversions (LCI) (see https://hgg.au.dk/software/aarhus-workbench/skyteminv) were performed using an initial inversion model of 40 ohm-meters (initial uniform value throughout the domain). The inversions of each location were completed successfully, with very low residuals for each location. The depth of investigation was determined to be at approximately 70 meters at the four locations, as the inversion would begin to converge back to the initial 40 ohm-meter model past this depth. The results of the LCI and SCI inversions are identical. SCI results were used for subsequent steps because of the ability to obtain 2-D sky view resistivity maps as well as the ease of exporting profile values for further analysis.

After the data analysis, a general 2-D profile was created for two of the four locations using the SCI inversion results. A profile of DG02 was not created as the data were too coarse and too irregularly distributed for a profile to be created; a profile of JF01 was not created because the data were limited and not perpendicular to the river. Figures 47–48 show the profile lines for RL01 and WB01. Sky views of the SCI results of each location are also shown in these figures from a depth of 30 to 31 meters, indicating bedrock at all locations for the RL01 profile at this depth but deeper aquifer materials for the WB01 profile. Figures 49 and 50 show sky views of DG02 and JF01. Sky view rasters at each location are available in 1-meter intervals from 0 to 70 meters. Figures 51 and 52 show corresponding 2-D profiles of RL01 and WB01.

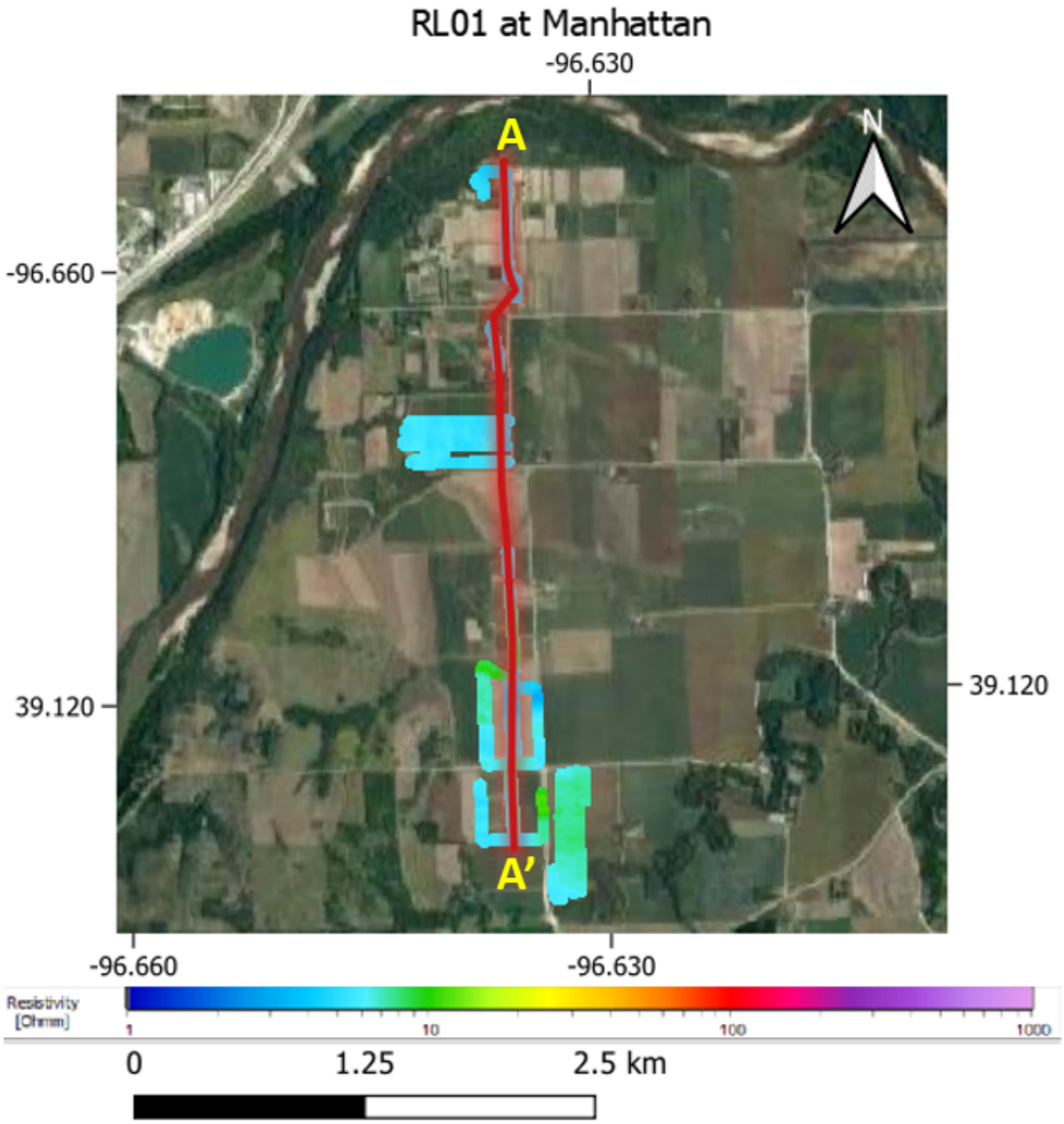


Figure 47. RL01 sky view results at 30–31 meter depth with 2-D cross section.

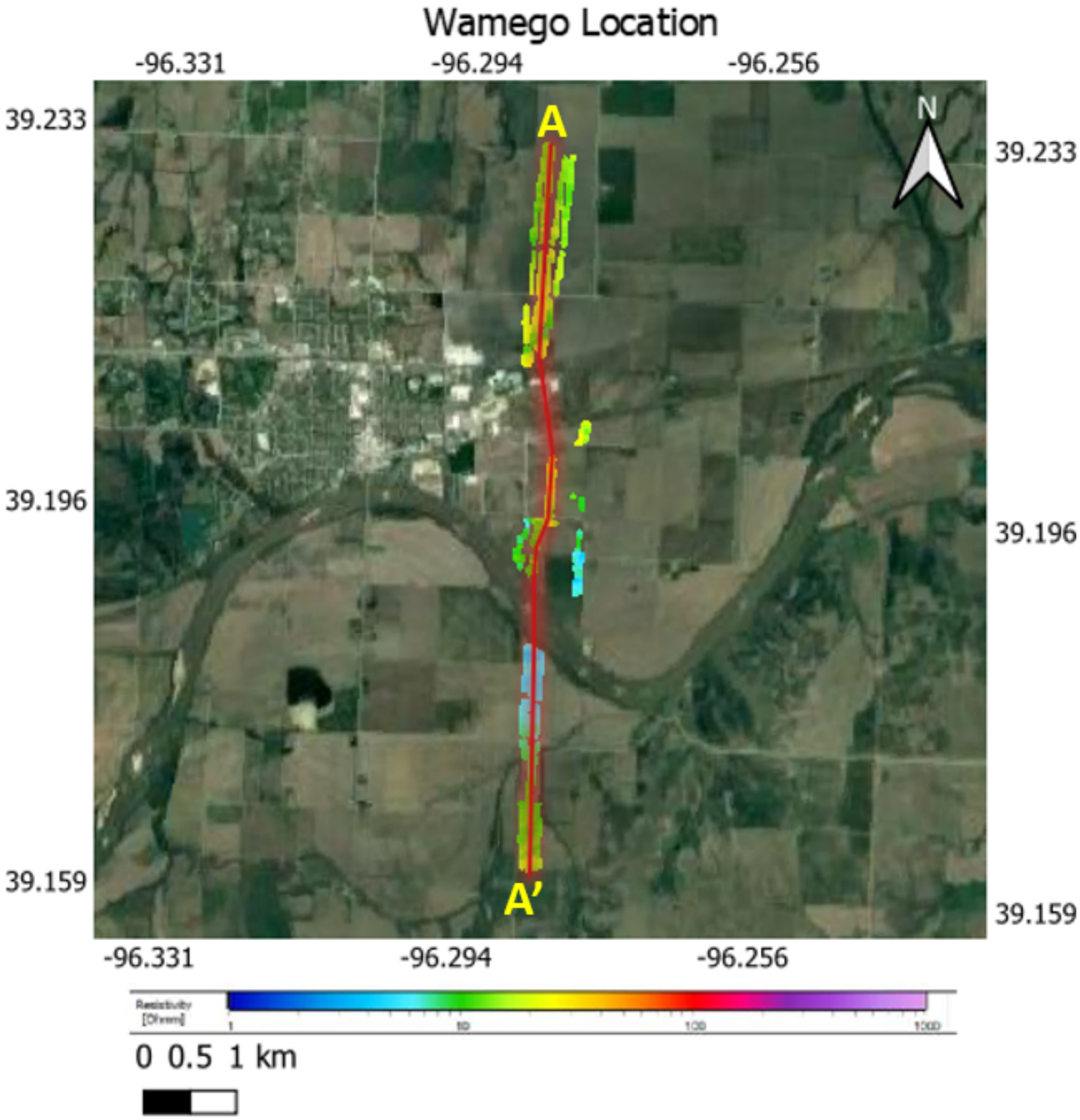


Figure 48. WB01 sky view results at 30–31 meter depth with 2-D cross section.

Figure 49. JF01 sky view results at 30–31 meter depth.

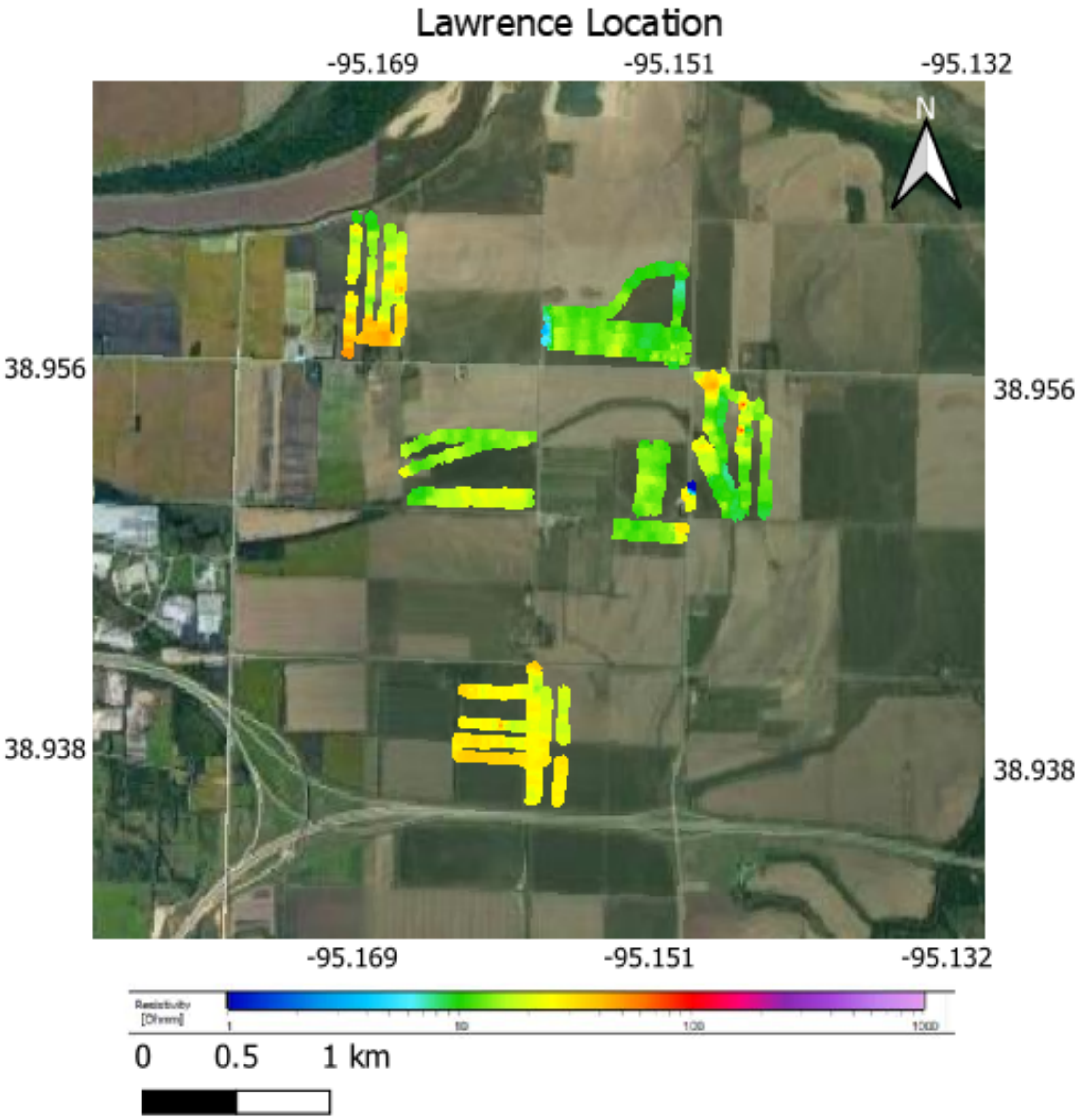


Figure 50. DG02 sky view results at 30–31 meter depth.

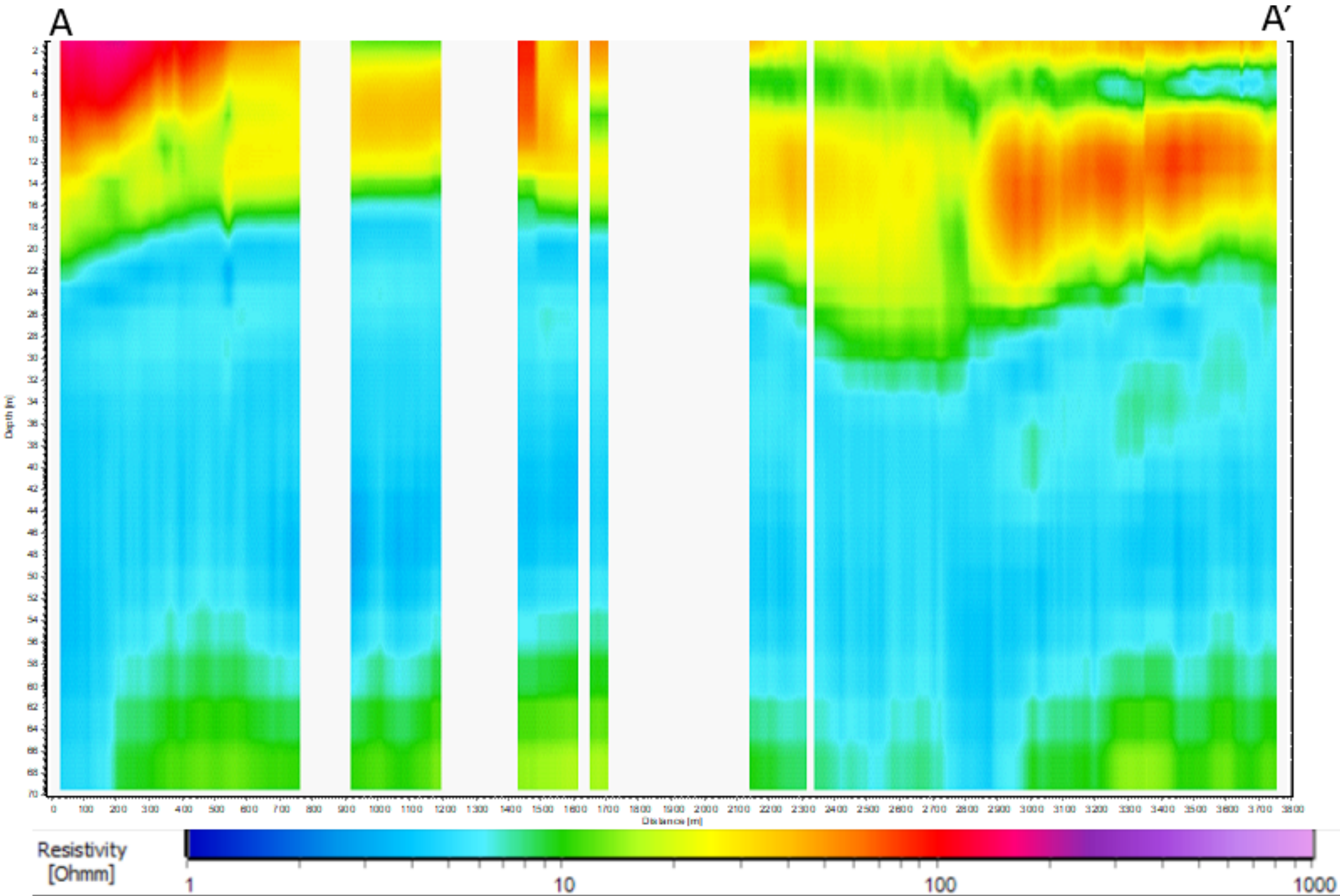


Figure 51. RL01 2-D resistivity profile.

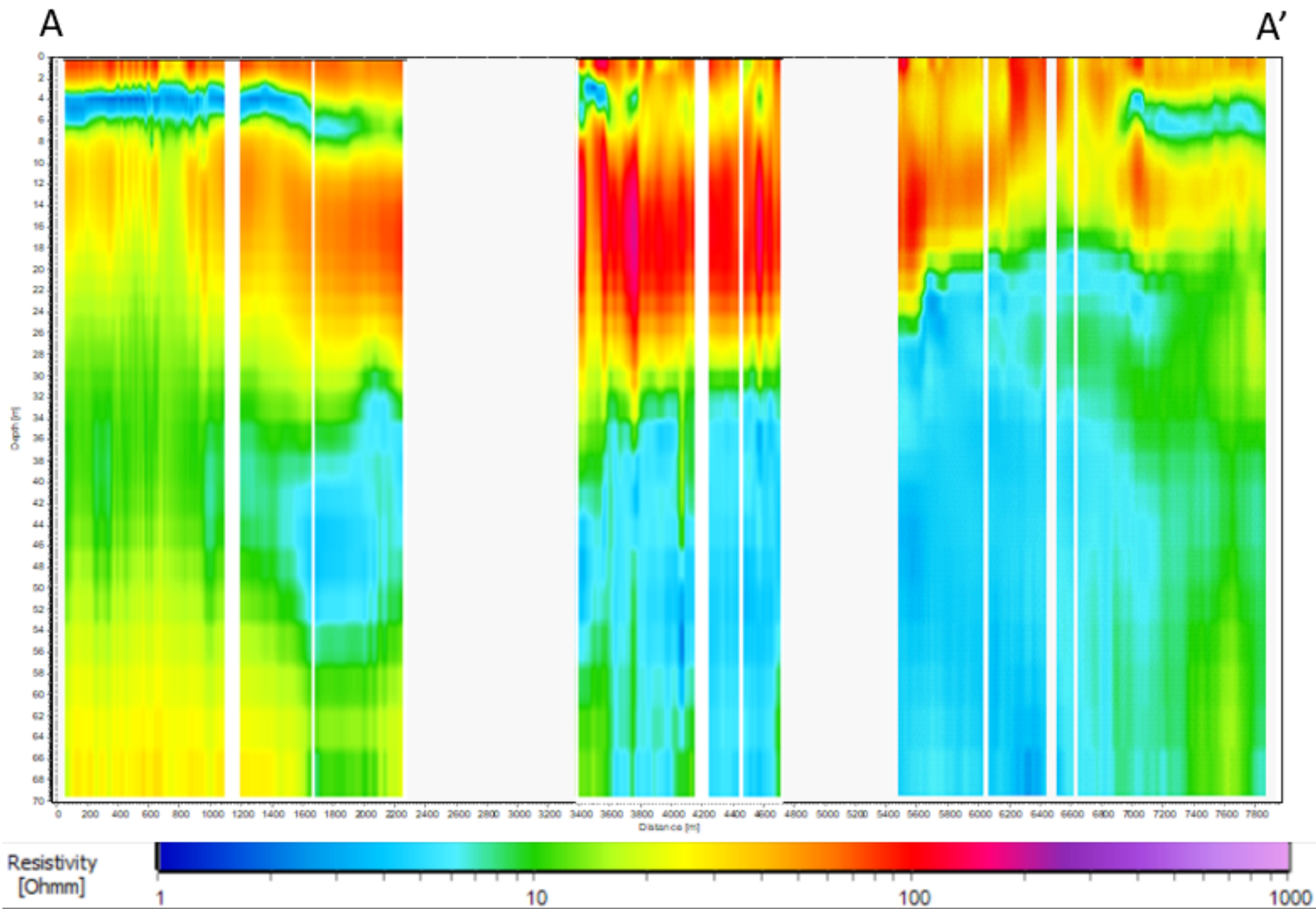
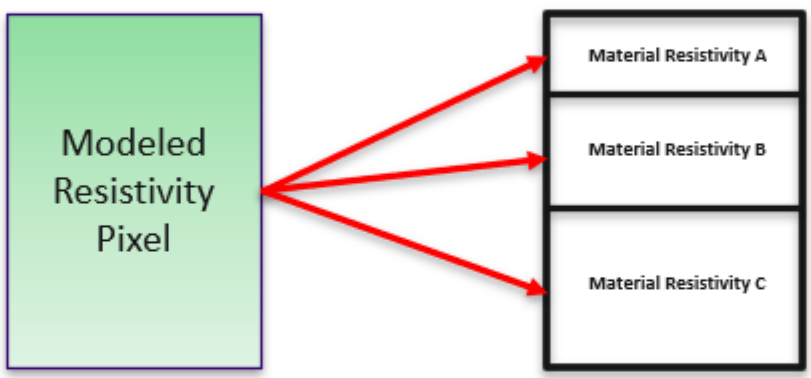


Figure 52. WB01 2-D resistivity profile.

Resistivity-Lithology Relationship

The resistivity-lithology relationship was determined using a method utilized in Knight et al. (2018) that employs systems of equations to solve for the resistivity of each user-defined lithology type. After examining 31 drillers' logs in the vicinity of the tTEM surveys, we selected three lithology types: fine-grained (clay), mixed-grained, and coarse-grained (sand and gravel) materials. All data used for interpretation were from below the water table; the position of the water table was determined from the water levels in the index wells associated with each profile. The resistivity-lithology method involved taking a modeled resistivity pixel nearest to a lithology log and breaking the lithology log into ratios based on lithology type. Figure 53 depicts this process, where ρ_{AEM} represents the resistivity value of a modeled resistivity pixel, t_{AEM} is the total thickness of a modeled resistivity pixel, $t_{a,b,c}$ is the thickness of each lithology type within that modeled resistivity pixel, and $\rho_{a,b,c}$ are the unknown resistivity values for the lithology types. The result was the equation given in fig. 53 with one known (resistivity pixel value) and three unknowns (resistivity values of lithology types). This process was completed for all 31 lithology logs, producing a large system of equations, each of which had one known and three unknown values. The resistivity values for the lithology types were determined using the bootstrapping method described in Knight et al. (2018). To ensure a normal distribution of data, bootstrapping was conducted 1,000 times, taking 100 samples with replacement from the system of equations and then solving for the resistivity of each lithology type each time. Table 9 displays the average and range of the bootstrap analysis found for each lithology type.



$$\rho_{\mathrm{AEM}} = \left(\left(\frac{t_{\mathrm{sg}}}{t_{\mathrm{AEM}}}\right)\left(\frac{1}{\rho_{\mathrm{sg}}}\right) + \left(\frac{t_{\mathrm{mixed}}}{t_{\mathrm{AEM}}}\right)\left(\frac{1}{\rho_{mixed}}\right) + \left(\frac{t_{\mathrm{clay}}}{t_{\mathrm{AEM}}}\right)\left(\frac{1}{\rho_{\mathrm{clay}}}\right)\right)^{-1}$$

Figure 53. Resistivity-lithology transform method.

Table 9. Resistivity-lithology relationship.

Lithology Type	Minimum Resistivity (Ohm-Meter)	Maximum Resistivity (Ohm-Meter)	Median Resistivity (Ohm-Meter)
Fine Grained	13	39	22
Mixed Grained	24	52	35
Coarse Grained	38	67	52

From the analysis, we concluded that below the water table, any value from 0 to 39 ohm-meters is fine-grained material with some overlap of mixed-grained materials at the higher values in this range (any value below 24 ohm-meters can be considered clay with high confidence). Values of 24 to 52 ohm-meters are mixed grained, with some overlap of fine-grained materials at the lower end of this range and overlap of coarse-grained materials in the upper end of this range. Coarse-grained material resistivity values are from 38 ohm-meters to the maximum resistivities found below the water table (any value above 52 ohm-meters can be considered coarse-grained material with high confidence). Typically, trends can be seen from the transitions of resistivities to deduce the lithology type from the resistivity profiles shown in Figures 51 and 52. This approach was used to generate the sky view rasters in figs. 47–50.

Depth to Bedrock

Depth to bedrock was determined using well logs, DPEC logs, tTEM results, and an interpolated depth to bedrock raster created by Geoff Bohling at the KGS. The DPEC log refusal depth offered in-situ readings of the depth to bedrock. Using the tTEM results along with the lithology of the bedrock recorded in well logs, we found in the 2-D profiles that the depth to bedrock at most locations appears at 15 to 20 meters below the land surface as a low resistivity unit with a wavy undulating bedrock. From the lithology logs in the area, the bedrock is a shale layer with thin interbedded limestone layers. tTEM is sensitive to conductive material. When there are thin high resistivity layers, tTEM can miss mapping these layers. No limestone layers appeared in the results, which is to be expected when the limestone layers are recorded to be very thin in the lithology reports. The DPEC log readings do not exactly align with the tTEM results in the area because of the extremely high vertical resolution of the DPEC logs of 0.02 meters (Schulmeister et al., 2003). The transition from unconsolidated material to bedrock typically takes 1–2 tTEM pixels varying 1–3 meters in thickness. This transition distance increases with depth. These results have been confirmed with the bedrock raster created from well logs.

Results & Discussion

From the data modeling and interpretation section, we conclude that the typical structure of the KRAA is an unconsolidated alluvial system with grain size of the material increasing near the Kansas River in the most recent deposits. This trend can be seen in the WB01 cross section, where data were collected on both sides of the river. All locations appear to be bounded by a shale dominant bedrock. Near the water table, there is a thin fine-grained layer, particularly in areas away from the river. There is a hint of that layer close to the river, which could act as a semi-confining layer and diminish surface water-groundwater interaction. However, the hydrograph in fig. 5 indicates that there is a reasonable interaction between the Kansas River and the KRAA in the vicinity of WB01.

Comparing tTEM results with DPEC log results proved difficult in an alluvial setting. The tTEM results provide a broad lateral average of resistivity that enables the general geologic structure of the subsurface to be defined, while the DPEC logs provide excellent vertical resolution at specific locations. Figure 54, which is from Schulmeister et al. (2003), depicts the very fine vertical resolution and interpolated horizontal structure from DPEC logs in the KRAA. Many small units can be detected in the vertical, but the lateral extent of those units often may be limited. Comparing the tTEM profiles to this cross section, we observe that there are not nearly as many small defined units in the tTEM profiles, but the general structure of the dominant geologic units can be detected.

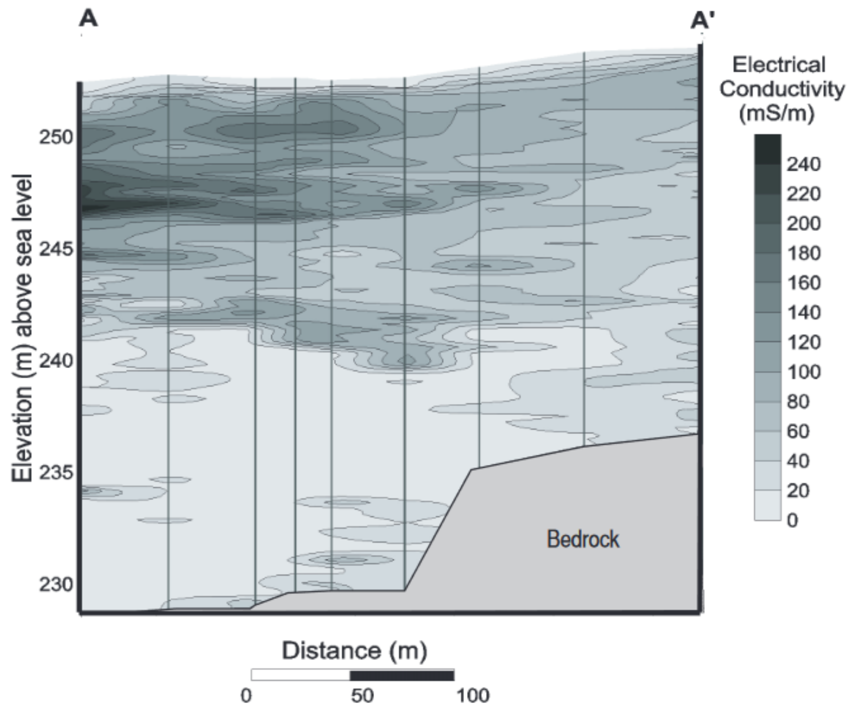


Figure 54. Electrical conductivity cross section of the KRAA near GEMS4-1 obtained using direct-push electrical conductivity logging (from Schulmeister et al., 2003). Vertical lines indicate the positions of DPEC logs.

Conclusion

Using tTEM to characterize the KRAA proved to be successful in defining large geologic structures in the unconfined alluvial deposits and in mapping depth to bedrock and bedrock shape. The efficiency of tTEM surveys and their spatial resolution shows that tTEM is a promising new method for characterizing the subsurface when used in coordination with nearby lithology logs. Reproducing the resistivity-lithology transform method in Knight et al. (2018) at this location allowed for the subsurface geology to be interpreted at a large scale and the general geometry of the KRAA to be defined.

8.3 Well Completion Reports and Direct-Push Electrical Conductivity Logs

This section contains the well completion (WWC-5) reports and the corresponding direct-push electrical conductivity logs for each of the five wells installed during this reporting period. The well order is as in the report (WB02, PT01, PT02, JF02, DG03).

Wabaunsee County Index Well 2 – WWC-5 Form

WATER WELL RECORD Form WWC-5

Division of Water Resources App. No. [ ] Well ID KAW-WB02

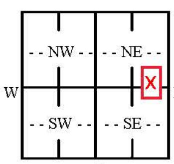
■ Original Record ☐ Correction ☐ Change in Well Use

1 LOCATION OF WATER WELL: County: Wabaunsee
Fraction: SE ¼ SE ¼ NE ¼ ¼
Section Number: 20
Township Number: T 10 S
Range Number: R 12 ■ E ☐ W

2 WELL OWNER: Last Name: First:
Business: kANSAS GEOLOGICAL SURVEY
Address: 1930 Constant Ave
Address:
City: Lawrence State: KS ZIP: 66047

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☐
Turkey Creek Rd, 2075 feet east of Eagle Nest Rd

3 LOCATE WELL WITH "X" IN SECTION BOX:



4 DEPTH OF COMPLETED WELL: 80 ft.
Depth(s) Groundwater Encountered: 1) 20 ft.
2) .... ft. 3) .... ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 19.67 ft.
☐ below land surface, measured on (mo-day-yr) 06-16-21
☐ above land surface, measured on (mo-day-yr) ....
Pump test data: Well water was .... ft.
after .... hours pumping .... gpm
Well water was .... ft.
after .... hours pumping .... gpm
Estimated Yield: .... gpm
Bore Hole Diameter: 3.25 in. to 80 ft. and
1.5 in. to 84.2 ft.

5 Latitude: 39.16594 (decimal degrees)
Longitude: -96.09387 (decimal degrees)
Horizontal Datum: ■ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☐ GPS (unit make/model: ....)
(WAAS enabled? ☐ Yes ☐ No)
☐ Land Survey ☐ Topographic Map
■ Online Mapper: Google Earth Pro

6 Elevation: 945 ft. ■ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map
☐ Other Google Earth Pro

7 WELL WATER TO BE USED AS:
1. Domestic:
☐ Household
☐ Lawn & Garden
☐ Livestock
2. ☐ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ....
6. ☐ Dewatering: how many wells? ....
7. ☐ Aquifer Recharge: well ID ....
8. ■ Monitoring: well ID KAW-WB02
9. Environmental Remediation: well ID ....
☐ Air Sparge ☐ Soil Vapor Extraction
☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ....
11. Test Hole: well ID ....
☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? ....
a) Closed Loop ☐ Horizontal ☐ Vertical
b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ....

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ■ No If yes, date sample was submitted: ....
Water well disinfected? ☐ Yes ■ No

8 TYPE OF CASING USED: ☐ Steel ■ PVC ☐ Other .... CASING JOINTS: ☐ Glued ☐ Clamped ☐ Welded ■ Threaded
Casing diameter 2 in. to 80 ft., Diameter .... in. to .... ft., Diameter .... in. to .... ft.
Casing height above land surface 36 in. Weight 0.698 lbs./ft. Wall thickness or gauge No. 0.154 in
TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☐ Stainless Steel ☐ Fiberglass ■ PVC ☐ Other (Specify) ....
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ■ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) ....
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☐ Saw Cut ☐ None (Open Hole)
SCREEN-PERFORATED INTERVALS: From 60 ft. to 80 ft., From .... ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From 22.5 ft. to 80 ft., From .... ft. to .... ft., From .... ft. to .... ft.

9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ■ Bentonite ☐ Other ....
Grout Intervals: From 0 ft. to 22.5 ft., From .... ft. to .... ft., From .... ft. to .... ft.
Nearest source of possible contamination:
☐ Septic Tank ☐ Lateral Lines ☐ Pit Privy ☐ Livestock Pens ☐ Insecticide Storage
☐ Sewer Lines ☐ Cess Pool ☐ Sewage Lagoon ☐ Fuel Storage ☐ Abandoned Water Well
☐ Watertight Sewer Lines ☐ Seepage Pit ☐ Feedyard ☐ Fertilizer Storage ☐ Oil Well/Gas Well
■ Other (Specify) Kansas River
Direction from well? North Distance from well? 70 ft.

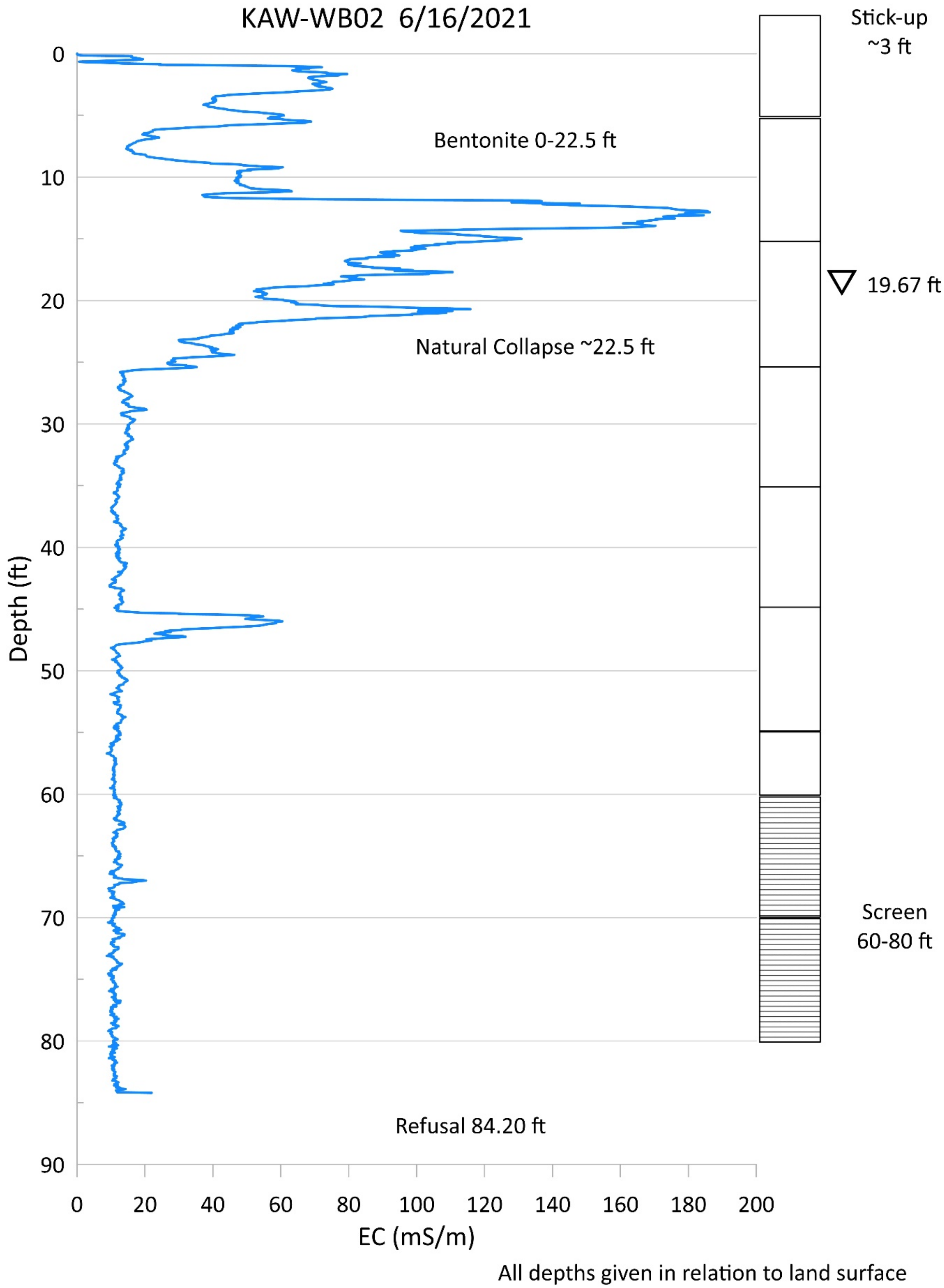
10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	5.6	Soil with silt lenses			
5.6	9	Sand			
9	11.6	Silt			
11.6	14.2	Clay			
14.2	21.5	Silt with clay			
21.5	25.6	Silt			
25.6	45.1	Sand			
41.5	47.8	Silt			
47.8	83.9	Sand			

Notes:
See Attached Electrical Conductivity Log

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ■ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 06-16-2021 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. .... This Water Well Record was completed on (mo-day-year) .... under the business name of Kansas Geological Survey Signature ....

Mail 1 white copy along with a fee of $5.00 for each constructed well to: Kansas Department of Health and Environment, Bureau of Water, GWTS Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Mail one to Water Well Owner and retain one for your records. Telephone 785-296-5524.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212 **Revised 7/10/2015**

Wabaunsee County Index Well 2 – Electrical Conductivity Log and Well Construction



Pottawatomie County Index Well 1 – WWC-5 Form

WATER WELL RECORD Form WWC-5

■ Original Record ☐ Correction ☐ Change in Well Use

Division of Water Resources App. No. ______ Well ID KAW-PT01

1 LOCATION OF WATER WELL: County: Pottawatomie | Fraction: SE ¼ SE ¼ NE ¼ ¼ | Section Number: 10 | Township Number: T 10 S | Range Number: R 10 ■ E ☐ W

2 WELL OWNER: Last Name: First:
Business: kANSAS GEOLOGICAL SURVEY
Address: 1930 Constant Ave
Address:
City: Lawrence State: KS ZIP: 66047

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☐
Dutch Mill Rd, 0.25 miles north of River Bend Rd

3 LOCATE WELL WITH "X" IN SECTION BOX:

N; NW, NE (X), SW, SE; W, E; S; |----------1 mile---------|

4 DEPTH OF COMPLETED WELL: 72 ft.
Depth(s) Groundwater Encountered: 1) 22 ft. 2) .... ft. 3) .... ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 22.8 ft.
■ below land surface, measured on (mo-day-yr) 03-03-22
☐ above land surface, measured on (mo-day-yr) ....
Pump test data: Well water was .... ft. after .... hours pumping .... gpm
Well water was .... ft. after .... hours pumping .... gpm
Estimated Yield: .... gpm
Bore Hole Diameter: 3.25 in. to 72 ft. and 1.5 in. to 73.9 ft.

5 Latitude: 39.19545 (decimal degrees)
Longitude: -96.27808 (decimal degrees)
Horizontal Datum: ■ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☐ GPS (unit make/model: ....) (WAAS enabled? ☐ Yes ☐ No)
☐ Land Survey ☐ Topographic Map
■ Online Mapper: Google Earth Pro

6 Elevation: 976 ft. ■ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map ☐ Other Google Earth Pro

7 WELL WATER TO BE USED AS:

1. Domestic: ☐ Household ☐ Lawn & Garden ☐ Livestock
2. ☐ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ....
6. ☐ Dewatering: how many wells? ....
7. ☐ Aquifer Recharge: well ID ....
8. ■ Monitoring: well ID KAW-PT01
9. Environmental Remediation: well ID .... ☐ Air Sparge ☐ Soil Vapor Extraction ☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ....
11. Test Hole: well ID .... ☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? .... a) Closed Loop ☐ Horizontal ☐ Vertical b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ....

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ■ No If yes, date sample was submitted: ....
Water well disinfected? ☐ Yes ■ No

8 TYPE OF CASING USED: ☐ Steel ■ PVC ☐ Other .... CASING JOINTS: ☐ Glued ☐ Clamped ☐ Welded ■ Threaded
Casing diameter 2 in. to .... ft., Diameter .... in. to .... ft., Diameter .... in. to .... ft.
Casing height above land surface 36 in. Weight 0.698 lbs./ft. Wall thickness or gauge No. 0.154 in

TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☐ Stainless Steel ☐ Fiberglass ■ PVC ☐ Other (Specify) ....
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ■ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) ....
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☐ Saw Cut ☐ None (Open Hole)

SCREEN-PERFORATED INTERVALS: From 62 ft. to 72 ft., From .... ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From 24 ft. to 72 ft., From .... ft. to .... ft., From .... ft. to .... ft.

9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ■ Bentonite ☐ Other ....
Grout Intervals: From 0 ft. to 24 ft., From .... ft. to .... ft., From .... ft. to .... ft.

Nearest source of possible contamination:
■ Septic Tank ☐ Lateral Lines ☐ Pit Privy ☐ Livestock Pens ☐ Insecticide Storage
☐ Sewer Lines ☐ Cess Pool ☐ Sewage Lagoon ☐ Fuel Storage ☐ Abandoned Water Well
☐ Watertight Sewer Lines ☐ Seepage Pit ☐ Feedyard ☐ Fertilizer Storage ☐ Oil Well/Gas Well
☐ Other (Specify) ....
Direction from well? South Distance from well? 600 ft.

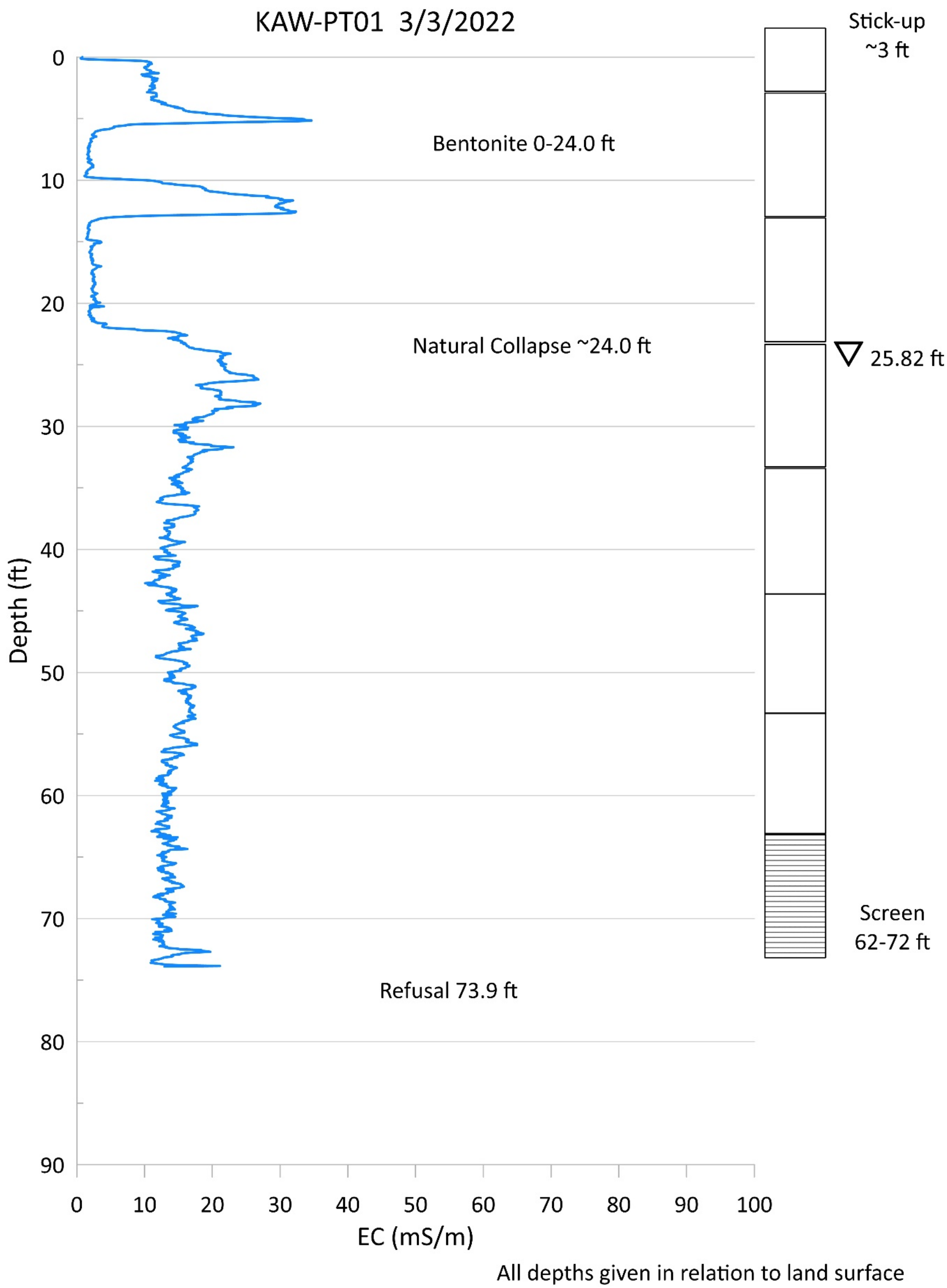
10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	4	Sandy Soil			
4	5	Sand with Silt			
5	10	Sand			
10	13	Sand with Silt			
13	73.9	Sand			

Notes: See Attached Electrical Conductivity Log

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ■ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 03-03-2022 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. .... This Water Well Record was completed on (mo-day-year) .... under the business name of Kansas Geological Survey .... Signature ....

Mail 1 white copy along with a fee of $5.00 for each constructed well to: Kansas Department of Health and Environment, Bureau of Water, GWTS Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Mail one to Water Well Owner and retain one for your records. Telephone 785-296-5524.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212 **Revised 7/10/2015**

Pottawatomie County Index Well 1 – Electrical Conductivity Log and Well Construction



Pottawatomie County Index Well 2 – WWC-5 Form

WATER WELL RECORD Form WWC-5

Division of Water Resources App. No. ______ Well ID KAW-PT02

☒ Original Record ☐ Correction ☐ Change in Well Use

1 LOCATION OF WATER WELL: County: Pottawatomie	Fraction: NE ¼ NE ¼ SE ¼ ¼	Section Number: 27	Township Number: T 9 S	Range Number: R 10 ☒ E ☐ W

2 WELL OWNER: Last Name: First:
Business: kANSAS GEOLOGICAL SURVEY
Address: 1930 Constant Ave
Address:
City: Lawrence State: KS ZIP: 66047

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☐
150 feet north of intersection of Military Camp Rd and Louis Vieux Rd, West side of road before bridge

3 LOCATE WELL WITH "X" IN SECTION BOX:
N / NW, NE, SW, SE / W, E / S — X in SE quarter, east edge
|----------1 mile---------|

4 DEPTH OF COMPLETED WELL: 66 ft.
Depth(s) Groundwater Encountered: 1) 40 ft. 2) ...... ft. 3) ...... ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 39.3 ft.
☒ below land surface, measured on (mo-day-yr) 04-08-22
☐ above land surface, measured on (mo-day-yr) ......
Pump test data: Well water was ...... ft. after ...... hours pumping ...... gpm
Well water was ...... ft. after ...... hours pumping ...... gpm
Estimated Yield: ...... gpm
Bore Hole Diameter: 3.25 in. to 66 ft. and 1.5 in. to 93.3 ft.

5 Latitude: 39.23830 (decimal degrees)
Longitude: -96.27808 (decimal degrees)
Horizontal Datum: ☒ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☐ GPS (unit make/model: ......) (WAAS enabled? ☐ Yes ☐ No)
☐ Land Survey ☐ Topographic Map
☒ Online Mapper: Google Earth Pro

6 Elevation: 988 ft. ☒ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map ☐ Other Google Earth Pro

7 WELL WATER TO BE USED AS:
1. Domestic: ☐ Household ☐ Lawn & Garden ☐ Livestock
2. ☐ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ......
6. ☐ Dewatering: how many wells? ......
7. ☐ Aquifer Recharge: well ID ......
8. ☒ Monitoring: well ID KAW-PT02
9. Environmental Remediation: well ID ...... ☐ Air Sparge ☐ Soil Vapor Extraction ☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ......
11. Test Hole: well ID ...... ☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? ...... a) Closed Loop ☐ Horizontal ☐ Vertical b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ......

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ☒ No If yes, date sample was submitted: ......
Water well disinfected? ☐ Yes ☒ No

8 TYPE OF CASING USED: ☐ Steel ☒ PVC ☐ Other ...... CASING JOINTS: ☐ Glued ☐ Clamped ☐ Welded ☒ Threaded
Casing diameter 2 in. to ...... ft., Diameter ...... in. to ...... ft., Diameter ...... in. to ...... ft.
Casing height above land surface 36 in. Weight 0.698 lbs./ft. Wall thickness or gauge No. 0.154 in
TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☐ Stainless Steel ☐ Fiberglass ☒ PVC ☐ Other (Specify) ......
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ☒ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) ......
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☐ Saw Cut ☐ None (Open Hole)
SCREEN-PERFORATED INTERVALS: From 56 ft. to 66 ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.
GRAVEL PACK INTERVALS: From 35 ft. to 66 ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.

9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ☒ Bentonite ☐ Other ......
Grout Intervals: From 0 ft. to 35 ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.
Nearest source of possible contamination:
☐ Septic Tank ☐ Lateral Lines ☐ Pit Privy ☐ Livestock Pens ☐ Insecticide Storage
☐ Sewer Lines ☐ Cess Pool ☐ Sewage Lagoon ☒ Fuel Storage ☐ Abandoned Water Well
☐ Watertight Sewer Lines ☐ Seepage Pit ☐ Feedyard ☐ Fertilizer Storage ☐ Oil Well/Gas Well
☒ Other (Specify) Farm Implement Storage and Shop
Direction from well? East Distance from well? 250 ft.

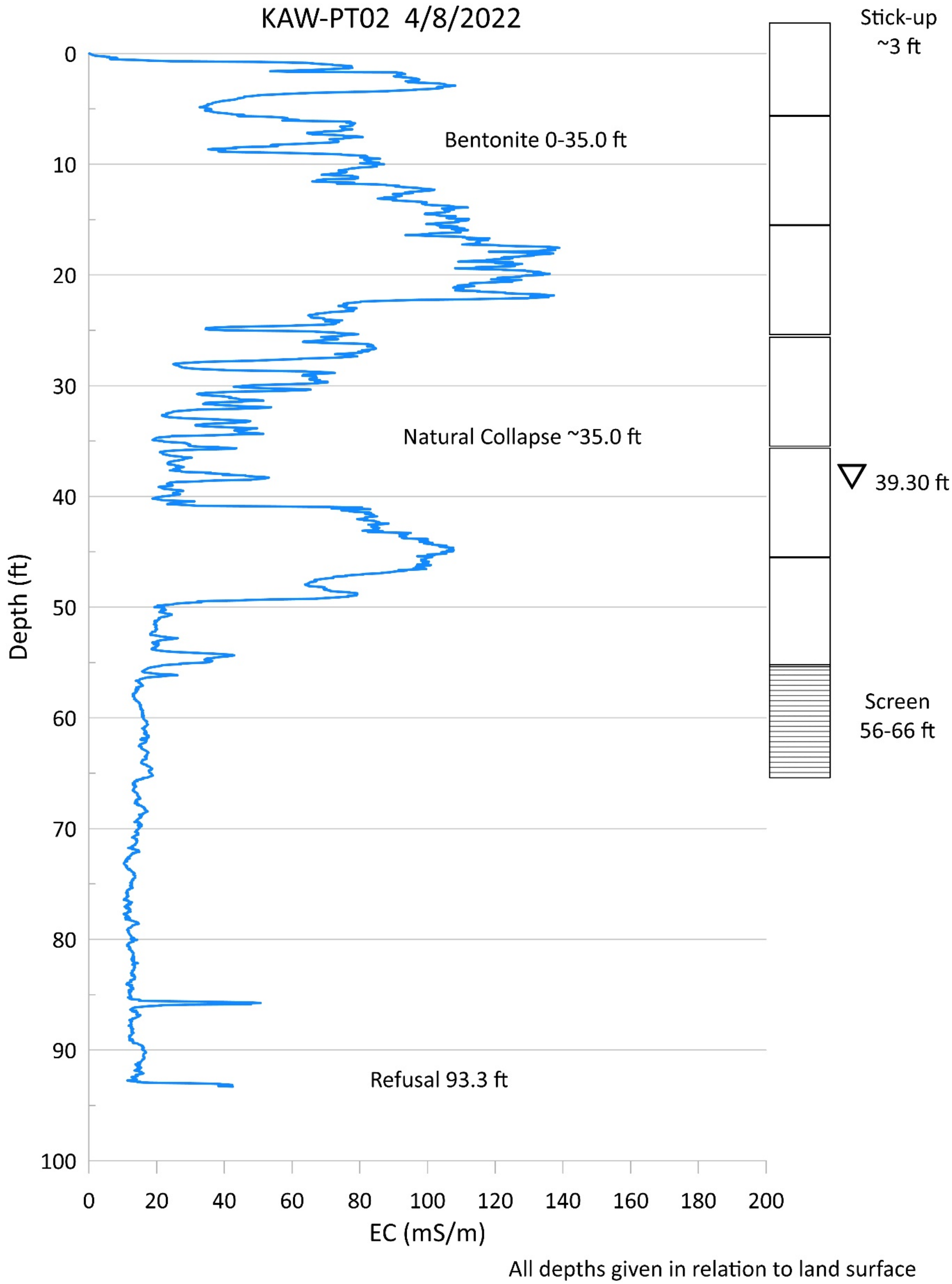
10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	3.5	Silty lay Soil	87	93	Sand
3.5	11.5	Silt and Clay	93	93.3	Bedrock
11.5	22.5	Clay			
22.5	30	Silt and Clay			
30	41	Silt with Sand Streaks			
41	49.5	Clay			
49.5	56.5	Sand with Silt			
56.5	86	Sand			
86	87	Silt Lens			

Notes:
See Attached Electrical Conductivity Log

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ☒ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 04-08-2022 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. ...... This Water Well Record was completed on (mo-day-year) 04-20-2022 under the business name of Kansas Geological Survey Signature ......

Mail 1 white copy along with a fee of $5.00 for each constructed well to: Kansas Department of Health and Environment, Bureau of Water, GWTS Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Mail one to Water Well Owner and retain one for your records. Telephone 785-296-5524.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212 **Revised 7/10/2015**

Pottawatomie County Index Well 2 – Electrical Conductivity Log and Well Construction



Jefferson County Index Well 2 – WWC-5 Form

WATER WELL RECORD Form WWC-5 Division of Water Resources App. No. [ ] Well ID: KAW-JF02

■ Original Record ☐ Correction ☐ Change in Well Use

1 LOCATION OF WATER WELL: County: Jefferson | Fraction: SW ¼ NW ¼ SE ¼ NW ¼ | Section Number: 35 | Township Number: T 11 S | Range Number: R 18 ■ E ☐ W

2 WELL OWNER: Last Name: First:
Business: kANSAS GEOLOGICAL SURVEY
Address: 1930 Constant Ave
Address:
City: Lawrence State: KS ZIP: 66047

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☐
Lecompton Rising Sun River Access, Lecompton Rd (1029), 3695 feet south of 12th St

3 LOCATE WELL WITH "X" IN SECTION BOX:
N
- - NW - - X | - - NE - -
W E
- - SW - - | - - SE - -
S
|----------1 mile---------|

4 DEPTH OF COMPLETED WELL: 60 ft.
Depth(s) Groundwater Encountered: 1) 9.0 ft.
2) ……… ft. 3) ……… ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 9.0 ft.
■ below land surface, measured on (mo-day-yr) 06-10-21
☐ above land surface, measured on (mo-day-yr) ……
Pump test data: Well water was ……… ft.
after……… hours pumping ……… gpm
Well water was ……… ft.
after……… hours pumping ……… gpm
Estimated Yield: ……… gpm
Bore Hole Diameter: 3.25 in. to 60 ft. and
1.5 in. to 76 ft.

5 Latitude: 39.05301 (decimal degrees)
Longitude: -95.38627 (decimal degrees)
Horizontal Datum: ■ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☐ GPS (unit make/model: ………)
(WAAS enabled? ☐ Yes ☐ No)
☐ Land Survey ☐ Topographic Map
■ Online Mapper: Google Earth Pro

6 Elevation: 838 ft. ■ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map
☐ Other Google Earth Pro

7 WELL WATER TO BE USED AS:
1. Domestic: ☐ Household ☐ Lawn & Garden ☐ Livestock
2. ☐ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ……
6. ☐ Dewatering: how many wells? ……
7. ☐ Aquifer Recharge: well ID ……
8. ■ Monitoring: well ID KAW-JF02
9. Environmental Remediation: well ID …… ☐ Air Sparge ☐ Soil Vapor Extraction ☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ……
11. Test Hole: well ID …… ☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? …… a) Closed Loop ☐ Horizontal ☐ Vertical b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ……

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ■ No If yes, date sample was submitted: ……
Water well disinfected? ☐ Yes ■ No

8 TYPE OF CASING USED: ☐ Steel ■ PVC ☐ Other ……… CASING JOINTS: ☐ Glued ☐ Clamped ☐ Welded ■ Threaded
Casing diameter 2 in. to ……… ft., Diameter ……… in. to ……… ft., Diameter ……… in. to ……… ft.
Casing height above land surface 30.96 in. Weight 0.698 lbs./ft. Wall thickness or gauge No. 0.154 in
TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☐ Stainless Steel ☐ Fiberglass ■ PVC ☐ Other (Specify) ………
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ■ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) ………
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☐ Saw Cut ☐ None (Open Hole)
SCREEN-PERFORATED INTERVALS: From 45 ft. to 60 ft., From ……… ft. to ……… ft., From ……… ft. to ……… ft.
GRAVEL PACK INTERVALS: From 25 ft. to 60 ft., From ……… ft. to ……… ft., From ……… ft. to ……… ft.

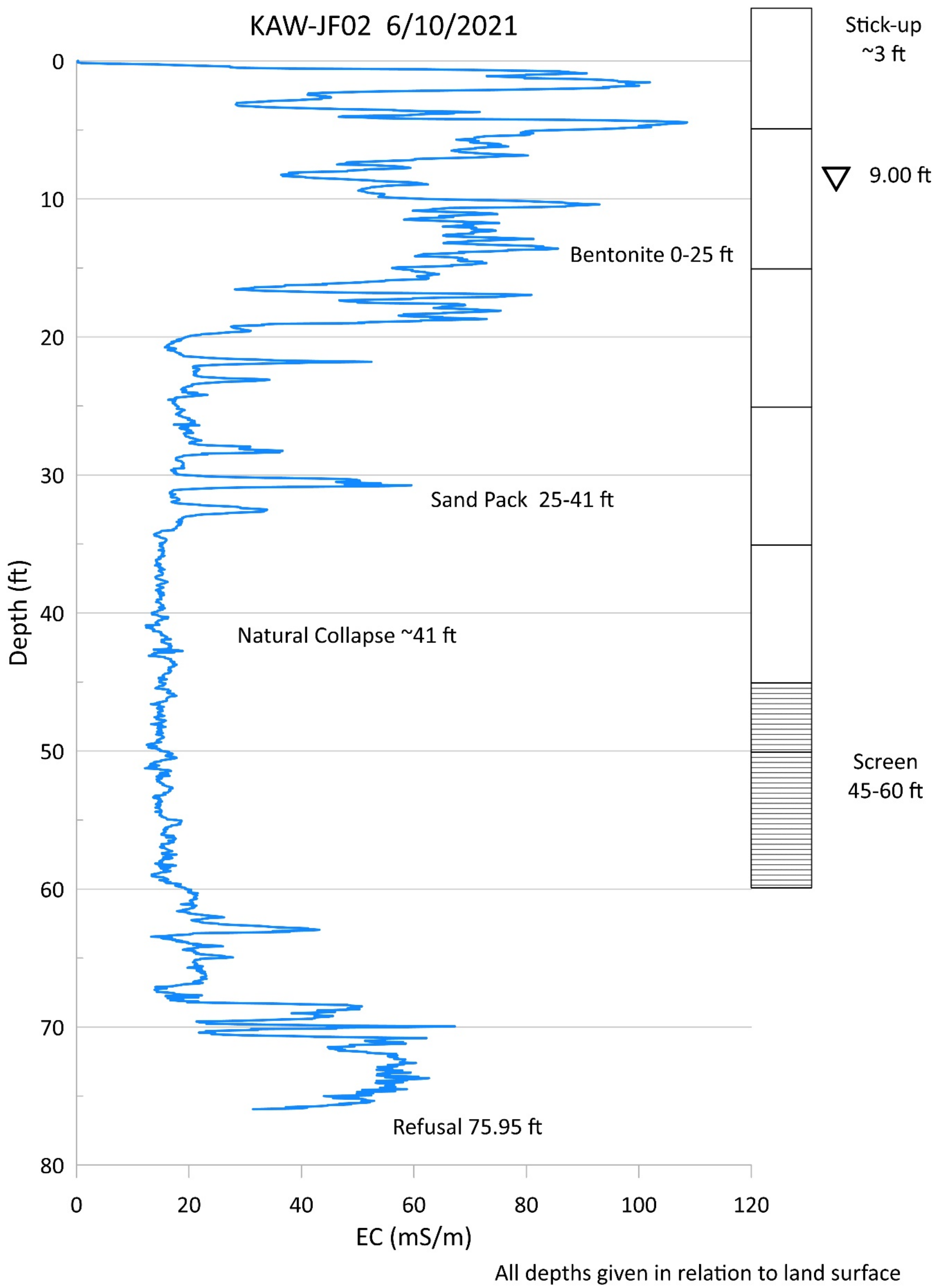
9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ■ Bentonite ☐ Other ………
Grout Intervals: From 0 ft. to 25 ft., From ……… ft. to ……… ft., From ……… ft. to ……… ft.
Nearest source of possible contamination:
☐ Septic Tank ☐ Lateral Lines ☐ Pit Privy ☐ Livestock Pens ☐ Insecticide Storage
☐ Sewer Lines ☐ Cess Pool ☐ Sewage Lagoon ☐ Fuel Storage ☐ Abandoned Water Well
☐ Watertight Sewer Lines ☐ Seepage Pit ☐ Feedyard ☐ Fertilizer Storage ☐ Oil Well/Gas Well
■ Other (Specify) Kansas River
Direction from well? Southwest Distance from well? 1070 ft.

10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	5	Soil with silt lens			
7	19	Silt with minor sand			
19	34	Sand with silt lenses			
34	60	Sand			
60	70	Silty sand with silt lenses			
70	76	Silt			
			Notes: See Attached Electrical Conductivity Log		

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ■ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 06-10-2021 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. ……… This Water Well Record was completed on (mo-day-year) ……… under the business name of Kansas Geological Survey ……… Signature ………

Mail 1 white copy along with a fee of $5.00 for each constructed well to: Kansas Department of Health and Environment, Bureau of Water, GWTS Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Mail one to Water Well Owner and retain one for your records. Telephone 785-296-5524.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212 **Revised 7/10/2015**

Jefferson County Index Well 2 – Electrical Conductivity Log and Well Construction



Douglas County Index Well 3 – WWC-5 Form

WATER WELL RECORD Form WWC-5

Division of Water Resources App. No. ______ Well ID: KAW-DG03

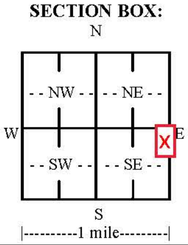
■ Original Record ☐ Correction ☐ Change in Well Use

1 LOCATION OF WATER WELL: County: Douglas | Fraction: NE ¼ NE ¼ SE ¼ ¼ | Section Number: 13 | Township Number: T 12 S | Range Number: R 19 ■ E ☐ W

2 WELL OWNER: Last Name: First:
Business: kANSAS GEOLOGICAL SURVEY
Address: 1930 Constant Ave
Address:
City: Lawrence State: KS ZIP: 66047

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☐
E 1400 Rd, 0.60 miles south of N 1900 Rd.

3 LOCATE WELL WITH "X" IN SECTION BOX:



4 DEPTH OF COMPLETED WELL: 44 ft.
Depth(s) Groundwater Encountered: 1) 10 ft. 2) ………… ft. 3) ………… ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 8.21 ft.
■ below land surface, measured on (mo-day-yr) 6/4/21
☐ above land surface, measured on (mo-day-yr) …………
Pump test data: Well water was ………… ft. after………. hours pumping ………… gpm
Well water was ………… ft. after………. hours pumping ………… gpm
Estimated Yield: ………..gpm
Bore Hole Diameter: 3.25 in. to 44 ft. and 1.5 in. to 51.7 ft.

5 Latitude: 39.00643 (decimal degrees)
Longitude: -95.24198 (decimal degrees)
Horizontal Datum: ■ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☐ GPS (unit make/model: ……………………) (WAAS enabled? ☐ Yes ☐ No)
☐ Land Survey ☐ Topographic Map
■ Online Mapper: Google Earth Pro

6 Elevation: 827 ft. ■ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map ☐ Other Google Earth Pro

7 WELL WATER TO BE USED AS:
1. Domestic: ☐ Household ☐ Lawn & Garden ☐ Livestock
2. ☐ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ……………
6. ☐ Dewatering: how many wells? ……………
7. ☐ Aquifer Recharge: well ID ……………
8. ■ Monitoring: well ID KAW-DG03
9. Environmental Remediation: well ID …………… ☐ Air Sparge ☐ Soil Vapor Extraction ☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ……………
11. Test Hole: well ID …………… ☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? …………… a) Closed Loop ☐ Horizontal ☐ Vertical b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ……………

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ■ No If yes, date sample was submitted: ……………
Water well disinfected? ☐ Yes ■ No

8 TYPE OF CASING USED: ☐ Steel ■ PVC ☐ Other ………… CASING JOINTS: ☐ Glued ☐ Clamped ☐ Welded ■ Threaded
Casing diameter 2 in. to 44 ft., Diameter ………… in. to ………… ft., Diameter ………… in. to ………… ft.
Casing height above land surface 33.96 in. Weight 0.698 lbs./ft. Wall thickness or gauge No. 0.154 in
TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☐ Stainless Steel ☐ Fiberglass ■ PVC ☐ Other (Specify) …………
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ■ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) …………
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☐ Saw Cut ☐ None (Open Hole)
SCREEN-PERFORATED INTERVALS: From 29 ft. to 44 ft., From ………… ft. to ………… ft., From ………… ft. to ………… ft.
GRAVEL PACK INTERVALS: From 15 ft. to 44 ft., From ………… ft. to ………… ft., From ………… ft. to ………… ft.

9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ■ Bentonite ☐ Other …………
Grout Intervals: From 0 ft. to 15 ft., From ………… ft. to ………… ft., From ………… ft. to ………… ft.
Nearest source of possible contamination:
☐ Septic Tank ☐ Lateral Lines ☐ Pit Privy ☐ Livestock Pens ☐ Insecticide Storage
☐ Sewer Lines ☐ Cess Pool ☐ Sewage Lagoon ☐ Fuel Storage ☐ Abandoned Water Well
☐ Watertight Sewer Lines ☐ Seepage Pit ☐ Feedyard ☐ Fertilizer Storage ☐ Oil Well/Gas Well
■ Other (Specify) Railroad Tracks
Direction from well? East Distance from well? 1960 ft.

10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	4	Soil			
4	5.25	Silt with Sand			
5.25	6.75	Clay			
6.75	14.0	Sandy Silt			
14.0	29.9	Sand			
29.9	30.5	Silty Sand			
30.5	39.4	Sand	**Notes:**		
39.4	41.5	Silty Sand	See Attached Electrical Conductivity Log		
41.5	44.0	Sand			

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ■ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 6/4/21 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. ………… This Water Well Record was completed on (mo-day-year) ………… under the business name of Kansas Geological Survey Signature …………

Mail 1 white copy along with a fee of $5.00 for each constructed well to: Kansas Department of Health and Environment, Bureau of Water, GWTS Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Mail one to Water Well Owner and retain one for your records. Telephone 785-296-5524.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212 **Revised 7/10/2015**

Douglas County Index Well 3 – Electrical Conductivity Log and Well Construction