High Plains Aquifer Index Well Program: 2025 Annual Report

by

J. J. Butler, Jr., D. O. Whittemore, L. A. French, M. Billinger,

E. Reboulet, B. B. Wilson, and G. C. Bohling

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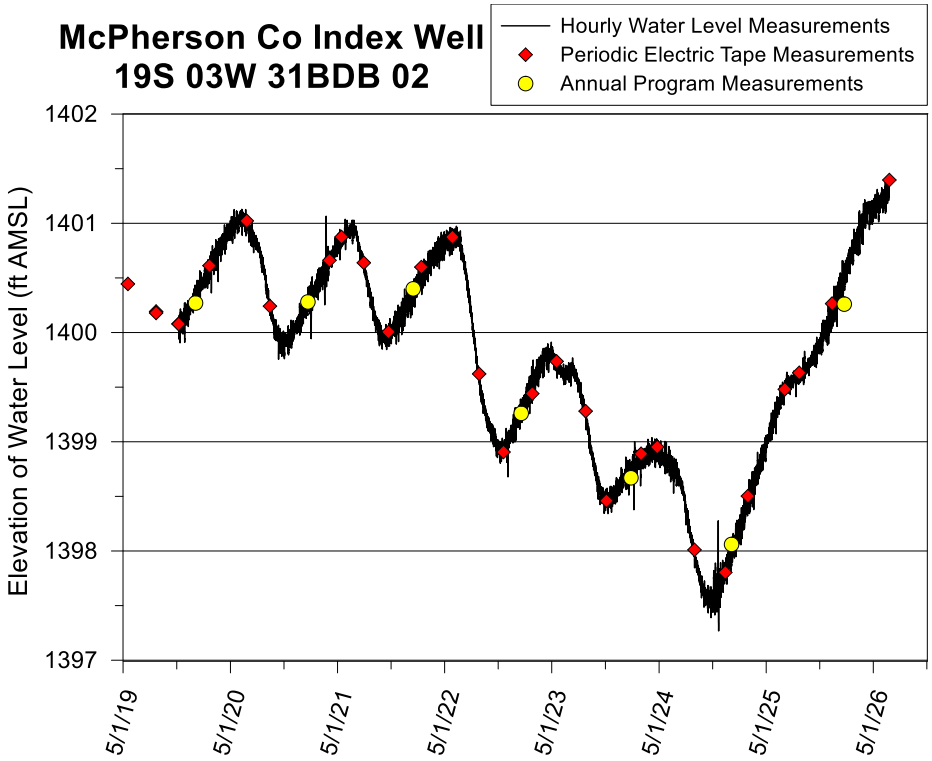
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Kansas Geological Survey

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J. J. Butler, Jr., D. O. Whittemore, L. A. French, M. Billinger, E. Reboulet, B. B. Wilson, and G. C. Bohling
Kansas Geological Survey
University of Kansas



Impact of Nearby Pumping Reductions at the McPherson County Index Well

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Acknowledgments

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Executive Summary

The index well program of the Kansas Geological Survey (KGS) is directed at developing improved approaches for measuring and interpreting hydrologic responses at the local scale (section to township) in the High Plains aquifer (HPA) in western and south-central Kansas. The program is supported by the Kansas Water Office (KWO) with Kansas Water Plan funding as a result of the agency's interest in and responsibility for long-term planning of groundwater resources in western and south-central Kansas. The Kansas Department of Agriculture, Division of Water Resources (DWR), provides assistance, as do the five Groundwater Management Districts (GMDs) and the Kansas State University Northwest Research-Extension Center (KSU-NWREC).

The project began with the installation of three monitoring ("index") wells in western Kansas in summer 2007. Each well has an integrated pressure transducer-datalogger unit for continuous monitoring of water levels that is connected to telemetry equipment to allow real-time viewing of well conditions on a publicly accessible website. Since late 2012, wells have been systematically added to the network. The index well network was enlarged in early June 2026 with the installation of a new well in GMD3. The network now consists of 34 wells with telemetry equipment and real-time data access from the KGS website and 6 wells without telemetry equipment (water-level data downloaded approximately quarterly and displayed on the KGS website). The vision of the index well program is that these wells, and others that will be added to the network over time, will be monitored for the long term. Shorter-term monitoring will be done at additional wells (expansion wells); two expansion wells are currently continuously monitored in GMD1. A major focus of the program is to use these data for the development of criteria or methods to evaluate the effectiveness of management strategies at the local scale in the HPA in western and south-central Kansas. These data also are used to develop a better understanding of the major mechanisms affecting water levels in the Kansas HPA. This improved understanding can then be incorporated into data analyses and numerical models to obtain a better picture of what the future holds for the aquifer.

This report provides a concise description of conditions as of early summer 2026. The majority of the report consists of an update and interpretation of the hydrographs for all of the index wells and the GMD1 expansion wells. In addition, the report presents a discussion of the relationships among precipitation (as characterized by radar data), annual water-level changes, and nearby water use at the three original index wells and three additional wells, and the implications of those relationships for efforts to moderate water-level declines by pumping reductions.

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

1. Water-level data collected using an integrated pressure transducer-datalogger unit provide a near-continuous record of great practical value that can help in the assessment of the continued viability of the HPA as a source of water for large-scale irrigation.
2. Interpretation of index well hydrographs enables important insights to be drawn concerning hydrogeologic conditions, the major mechanisms affecting water levels, and the long-term viability of the aquifer in the vicinity of the index wells. For example, there is little indication of episodic recharge at most index wells in the western Kansas HPA, but substantial water-level rises do occur in index wells relatively close to rivers in the south-central Kansas HPA as a result of large increases in river stage. Although seasonal pumping variations differ appreciably

depending on the proximity and hydraulic connection of index wells to pumping wells, the multi-year declines and fluctuations provide an improved understanding of changes observed from the annual water-level measurement program.

3. The annual water-level measurement data, in conjunction with reliable water-use data, can be used to evaluate the effect of management decisions on the township and larger scale using an approach developed from water-level responses collected as part of the index well program; this approach (Q_{stable}) is now widely used in the western Kansas HPA.
4. The standardized precipitation index and radar precipitation data are good indicators of the climatic conditions that drive HPA pumping in Kansas. In addition, these quantities can be used in precipitation versus water use relationships to identify changes in pumping produced by management decisions or storm-induced crop damage.

In addition to the concise descriptions in this report, these findings are discussed in previous program reports, KGS publications (Whittemore, Butler, and Wilson, 2023; Buchanan et al., 2023), and scientific journal articles resulting from program work (Butler, Stotler et al., 2013; Whittemore, Butler, and Wilson, 2016; Butler, Whittemore, Wilson et al., 2016, 2018; Butler, Bohling et al., 2020a,b; Bohling et al., 2021; Butler, Knobbe et al., 2021; Butler, Bohling et al., 2023; Whittemore, Butler, Bohling et al., 2023; Butler and Whittemore, 2024).

The focus of activities for the remainder of 2026 and the first half of 2027 will be on the continuation of monitoring at all program wells, continued analysis of hydrographs from all wells, incorporation of one or more wells into the network, and further assessment of the relationships among radar-determined precipitation, annual water-level change, and water use.

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1 Introduction and Background

Groundwater withdrawals in the Ogallala–High Plains aquifer (hereinafter, High Plains aquifer or HPA) in Kansas have resulted in large water-level declines that call into question the viability of the aquifer as a continuing resource for irrigated agriculture (Butler, Stotler et al., 2013; Buchanan et al., 2023; Butler, Bohling et al., 2023; Butler and Johnson, 2024). The index well program of the Kansas Geological Survey (KGS), which is a response to this condition, is directed at developing improved approaches for measuring and interpreting hydrologic responses in the HPA at the local (section to township) scale to aid in the development of management strategies. The study is supported by the Kansas Water Office (KWO) with Kansas Water Plan funding as a result of KWO's interest in and responsibility for long-term planning of groundwater resources in western and south-central Kansas. The Kansas Department of Agriculture, Division of Water Resources (DWR), provides assistance, as do all five Groundwater Management Districts (GMDs) and the Kansas State University Northwest Research-Extension Center (KSU-NWREC).

A major focus of the index well program is the development of methods for evaluating the effectiveness of management strategies at the local scale in a timely fashion. Changes in water level—or the rate at which the water level is changing—are considered the most direct and unequivocal measures of the effect of management strategies. Because of the economic, social, and environmental importance of water in western and south-central Kansas, the effects of modifications in patterns of water use need to be evaluated promptly and accurately. The program also has provided valuable information about the mechanisms that control changes in water levels in the vicinity of each well. That information, which is helpful for assessing the effect of management strategies at the local scale, also can provide a check on some of the assumptions incorporated in groundwater models developed for the Kansas HPA. The program thus aims to provide accurate and timely information that can complement and significantly enhance data provided by the annual water-level measurement program (hereinafter, annual program) that the KGS and DWR administer.

At the time of this report, monitoring data (hourly frequency) from up to 18 full recovery and pumping seasons and one additional ongoing pumping season have been obtained. With increasing data, the index well program has demonstrated the following:

1. Water-level data collected using an integrated pressure transducer-datalogger unit provide a near-continuous record of great practical value that can help in the assessment of the continued viability of the HPA as a source of water for large-scale irrigation.
2. Interpretation of index well hydrographs enables important practical insights to be drawn concerning hydrogeologic conditions, the major mechanisms affecting water levels, and the long-term viability of the aquifer in the vicinity of the index wells. For example, there is little indication of episodic recharge at the index wells in the western Kansas HPA, but substantial water-level rises do occur in index wells relatively close to rivers in the south-central Kansas HPA as a result of large increases in river stage. Although seasonal pumping variations differ appreciably depending on the proximity and hydraulic connection of index wells to pumping wells, the multi-year declines and fluctuations provide an improved understanding of changes observed from the annual program.

3. The annual program data, in conjunction with reliable water-use information, can be used to evaluate the effect of management decisions on the sub-county and larger scale using an approach developed from observed water-level responses as part of this program; this approach (Q_{stable}) is now widely used in the western Kansas HPA.
4. The standardized precipitation index and radar precipitation data are good indicators of the climatic conditions that drive pumping of the HPA in Kansas. In addition, this program has found that these quantities can be used in precipitation versus water use relationships to identify changes in pumping produced by management decisions or storm-induced crop damage.

The index well network was enlarged in the first half of 2026 by the installation of a new well in GMD3 (Sand Hills index well). Note that the term "index well" is used here to designate a dedicated, non-pumping well at which monitoring is anticipated to continue for many years. There are additional wells, designated here as "expansion wells," at which monitoring is not likely to continue over the long term because of constraints imposed by well depth (i.e., water level is anticipated to drop below the bottom of the well screen), logistics, or management issues. Both types of wells are considered here.

This report provides a concise description of conditions as of early summer 2026. The majority of the report consists of an update and interpretation of the hydrographs for all of the index wells and the GMD1 expansion wells. In addition, this report discusses the relationships among precipitation (as characterized by radar data), annual water-level changes, and nearby water use at the three original index wells and three additional wells and the implications of those relationships for efforts to moderate water-level declines with pumping reductions.

2 Program History

The index well program began in summer 2007 with the installation of three transducer- and telemetry-equipped wells, designed and sited to function as HPA monitoring wells (hereinafter, original index wells). One well was installed in each of the three western GMDs, with locations (stars in fig. 1) deliberately chosen to represent different water use and hydrogeologic conditions and to take advantage of related past or continuing studies. The original experimental design envisioned use of the index wells to anchor and calibrate the manual measurements of annual program wells in their vicinity, thus providing more consistency and confidence in the calculation of the water-table surface and its changes in those general areas. However, the scope of the project was quickly expanded to also focus on the mechanisms that control changes in water level in the vicinity of each well. Further information about the characteristics of the original sites and the experimental design can be found in previous annual reports (Young et al., 2007, 2008; Buddemeier et al., 2010).

The demonstrated value of continuous monitoring at the original three index wells led to a significant expansion of the index well network. In the spring of 2012, we started to explore adding a group of wells along the Kansas-Oklahoma border to the network. These wells were in four well nests originally installed by the U.S. Geological Survey (USGS; National Water-Quality Assessment [NAWQA] Project) in 1999 just north of the Oklahoma border. The USGS, which had not used these wells for more than a decade, agreed that the KGS could use the wells for both annual water-level measurements and continuous monitoring. The well nests are located in Seward, Stevens, and Morton counties (circles and

triangles along the Kansas-Oklahoma border in fig. 1—from east to west, Cimarron, Liberal, Hugoton, and Rolla sites). These monitoring locations were important additions to the index well network because they provide valuable information about responses in the areas of thick aquifer intervals in southernmost GMD3.

In early December 2012, we installed transducers in one well at each site and a barometer at the site near Hugoton. The two criteria used to select the well for monitoring at each site were 1) the nature of pumping-induced water-level responses determined from an examination of manual water-level data collected by the USGS in 1999 and 2000 (McMahon, 2001, fig. 8) and 2) the position of the well within the HPA (the objective was to have a well that would provide information about conditions in the main body of the HPA). All four of these wells were added to the annual water-level measurement network and, since January 2013, measured as part of the annual program.

In early August 2013, we placed transducers in one additional well each at the Hugoton and Liberal sites. In the third week of December 2013, working cooperatively with the USGS, we installed telemetry equipment at the Liberal and Hugoton sites and began to obtain real-time water-level data from the four monitored wells at those sites. The telemetry equipment remained in these wells until late summer 2017, when it was removed because of insufficient funds for the USGS to continue the real-time monitoring. Barometers were added to the Rolla and Cimarron sites in February 2014 and November 2015, respectively. The Rolla barometer was removed in early December 2015 because it appeared to be malfunctioning. The Hugoton site barometer was turned off by USGS personnel in November 2015 but was restarted in 2016. The Hugoton and Liberal sites were previously operated cooperatively by the KGS and USGS but, as of late summer 2017, are operated solely by the KGS. Telemetry equipment was added back to the Hugoton well in the main body of the HPA on April 25, 2019; telemetry equipment was added back to the Liberal well in the main body of the HPA on September 27, 2019. On December 26, 2018, the transducer at the additional Liberal index well (Liberal 160) failed. Given the limited information provided by that well since 2013, we decided to remove it from the index well program. In the fall of 2025, we placed an integrated pressure transducer-datalogger unit into the Hugoton 313 well where less-robust sensors had repeatedly failed. This well now has the same type of sensor as the other index wells in GMD3. Data from the Cimarron, Hugoton 313, and Rolla wells can be viewed up to the latest download on the KGS website.

In February 2014, the KGS and staff at the KSU-NWREC facility in Colby began to discuss adding the longtime manually measured well at that facility to the index well network. An integrated pressure transducer-datalogger unit was installed in the well in August 2014 shortly before the centennial celebration of the facility. Unlike at the other index wells, the datalogger uses the facility's wi-fi system to communicate with network servers housed at the KGS. In early February 2015, the facility completed running a power cable nearby and installing a wi-fi transmitter. The wi-fi system was successfully tested concurrent with the February 11, 2015, download. However, the integration of the wi-fi system with the transducer-datalogger unit proved challenging. On September 9, 2015, the integration was successfully completed. Continuous measurements are available on the KGS website.

In the spring of 2014, GMD5 expressed interest in expanding the index well program into its area. KGS and GMD5 staff worked together to identify a monitoring well that was drilled 20 years earlier by the KGS north of Belpre and just south of the Edwards-Pawnee county line (Belpre index well). The well

is in an area of groundwater-level declines that is of concern to the district. An integrated transducer-datalogger unit and telemetry equipment were installed in July 2014. As described in the 2014 report (Butler, Whittemore et al., 2015), the Belpre data transfers to the KGS network servers could not be automated because of limitations of the telemetry system vendor's website. After considerable efforts to resolve the problems, the decision was made to switch vendors in late summer of 2015. The data have been accessible from the KGS and GMD5 websites since September 18, 2015.

In 2012, collaboration with GMD4 began on the continuous monitoring of water levels at five observation wells within the Sheridan-6 (SD-6) Local Enhanced Management Area (LEMA). As described in previous reports (Butler, Whittemore et al., 2015; Butler, Whittemore, Reboulet et al., 2016), the records from the original sensors in these wells often had anomalous water-level spikes, primarily during the summer, that coincided with high temperatures in the datalogger housings. After the decision was made to incorporate these wells into the index well program, the existing monitoring equipment was replaced in the second half of 2015 and early 2016 with integrated pressure transducer-datalogger units that are similar to those used at all the other index wells. In late October 2016, telemetry equipment was added to the monitoring well located in the west-central portion of the SD-6 LEMA (Seegmiller index well). In mid-May 2021, telemetry equipment was added to the westernmost monitoring well in the SD-6 LEMA (Steiger index well). Real-time data from these two wells are now accessible from the KGS website. Data from the three other wells in the SD-6 LEMA (Baalman, Beckman, and Moss index wells) can be viewed up to the latest download on the KGS website.

In the spring of 2016, we further expanded the program by installing three new wells in Lane, Wallace, and Wichita counties in GMD1. Integrated pressure transducer-datalogger units were placed in the wells in mid-June 2016. Telemetry equipment was installed in the Wallace and Wichita index wells in late July 2016 and in the Lane index well in early September 2016. Real-time data from these wells are accessible from the KGS website.

In the summer of 2016, we converted an existing well on the Willis Water Technology Farm in southern Finney County in GMD3 to an index well. An integrated pressure transducer-datalogger unit and telemetry equipment were added to the well in late July 2016. Real-time data from this well are accessible on the KGS website.

In late fall of 2016, we further expanded the network by installing a new well in Sherman County southwest of Goodland in GMD4 (Sherman County index well). An integrated pressure transducer-datalogger unit and telemetry equipment were installed in the well in March 2017. Real-time data from this well are accessible on the KGS website.

In the summer of 2017, we converted a longtime manually measured well northwest of Garden City in western Finney County in GMD3 to an index well (Kearny-Finney index well). An integrated pressure transducer-datalogger unit and telemetry equipment were added to the well in mid-June 2017. Real-time data from this well are accessible on the KGS website.

In late spring of 2018, we converted an existing well at the KGS research site along the Arkansas River channel east of Larned in eastern Pawnee County in GMD5 to an index well (Larned index well). An integrated pressure transducer-datalogger unit and telemetry equipment were installed in late May 2018. Real-time data from this well are accessible on the KGS website.

In the summer of 2019, we converted four existing GMD2 monitoring wells located in McPherson, Harvey, Sedgwick, and Reno counties into index wells. Integrated pressure transducer-datalogger units and telemetry equipment were placed in the Mount Hope (Sedgwick County) and Pretty Prairie (Reno County) index wells on August 20, 2019. An integrated pressure transducer-datalogger unit and telemetry equipment were placed in the McPherson County index well on August 21, 2019. Telemetry equipment was installed in the Harvey County index well on August 21, 2019, and an integrated pressure transducer-datalogger unit was installed on September 26, 2019. In late summer 2020, we installed an integrated pressure transducer-datalogger unit and telemetry equipment in an existing GMD2 monitoring well located in Sedgwick County (Bentley index well, recording began on September 12, 2020). Real-time data from these five wells are accessible from the KGS website.

In the second half of 2021, we converted two existing GMD5 monitoring wells to index wells. On August 11, 2021, an integrated pressure transducer-datalogger unit and telemetry equipment were placed in the Trousdale index well in southeast Edwards County. On December 2, 2021, an integrated pressure transducer-datalogger unit and telemetry equipment were placed in the Rozel index well in western Pawnee County. Real-time data from these two wells are accessible from the KGS website.

In late winter to early spring of 2022, we converted existing wells in northeast Sherman County and northwest Wichita County to index wells (Sherman County 2 index well and Wichita County 2 index well, respectively). Integrated pressure transducer-datalogger units were placed in both wells on February 9, 2022. Telemetry equipment was added to the Sherman County 2 index well on April 12, 2022, and to the Wichita County 2 index well on April 13, 2022. Real-time data from these wells are accessible on the KGS website.

In the late summer and fall of 2022, we used funding from the USGS National Ground-Water Monitoring Network (NGWMN) and this program to drill two well nests in GMD3 (Ulysses and Satanta sites). Each nest consists of one well near the bottom of the HPA and one well in the underlying Dakota aquifer. Integrated pressure transducer-datalogger units were placed in both wells at the Ulysses site in western Grant County on March 8, 2023, and at the Satanta site in southwest Haskell County the following day. Telemetry equipment was added at both sites on March 22, 2023. Real-time data from these wells are accessible on the KGS website.

In the fall of 2023, we converted an existing monitoring well in Stafford County to an index well (St. John index well). An integrated pressure transducer-datalogger unit and telemetry equipment were placed in the well on November 9, 2023. In late spring of 2024, we converted an existing well in far southeastern Sherman County to an index well (Brownville index well). An integrated pressure transducer-datalogger unit and telemetry equipment were placed in the well on June 25, 2024. Real-time data from these wells are now accessible on the KGS website.

In the late fall of 2024 and late spring of 2025, we used funding from the USGS NGWMN and this program to drill two new index wells in GMD3 (Meade County index well) and GMD4 (Cheyenne County index well), respectively. An integrated pressure transducer-datalogger unit and telemetry equipment were placed in the Meade County well on February 25, 2025. An integrated pressure transducer-datalogger unit and telemetry equipment were placed in the Cheyenne County well on July 1, 2025. Real-time data from these wells are accessible on the KGS website.

In the fall of 2025, we placed an integrated pressure transducer-datalogger unit back into the Hugoton 313 well where less-robust sensors had repeatedly failed. This well now has the same type of sensor as the other index wells in GMD3 and real-time data from this well is accessible on the KGS website. In the late spring of 2026, we used internal KGS funding to drill a new index well in the sand hills south of Garden City (Sand Hills index well). An integrated pressure transducer-datalogger unit was placed in this well on August 18, 2026, and a telemetry unit will be added shortly. Real-time data should be accessible on the KGS website in fall 2026.

Figure 1 shows the index well network, which now encompasses 34 wells with telemetry equipment and real-time data access on the KGS website and 6 wells without telemetry equipment (data downloaded approximately quarterly and displayed on the KGS website). Most of these wells have been added to the annual water-level measurement network and are measured as part of the annual program. In addition, monitoring without telemetry equipment continues at two expansion wells in GMD1.

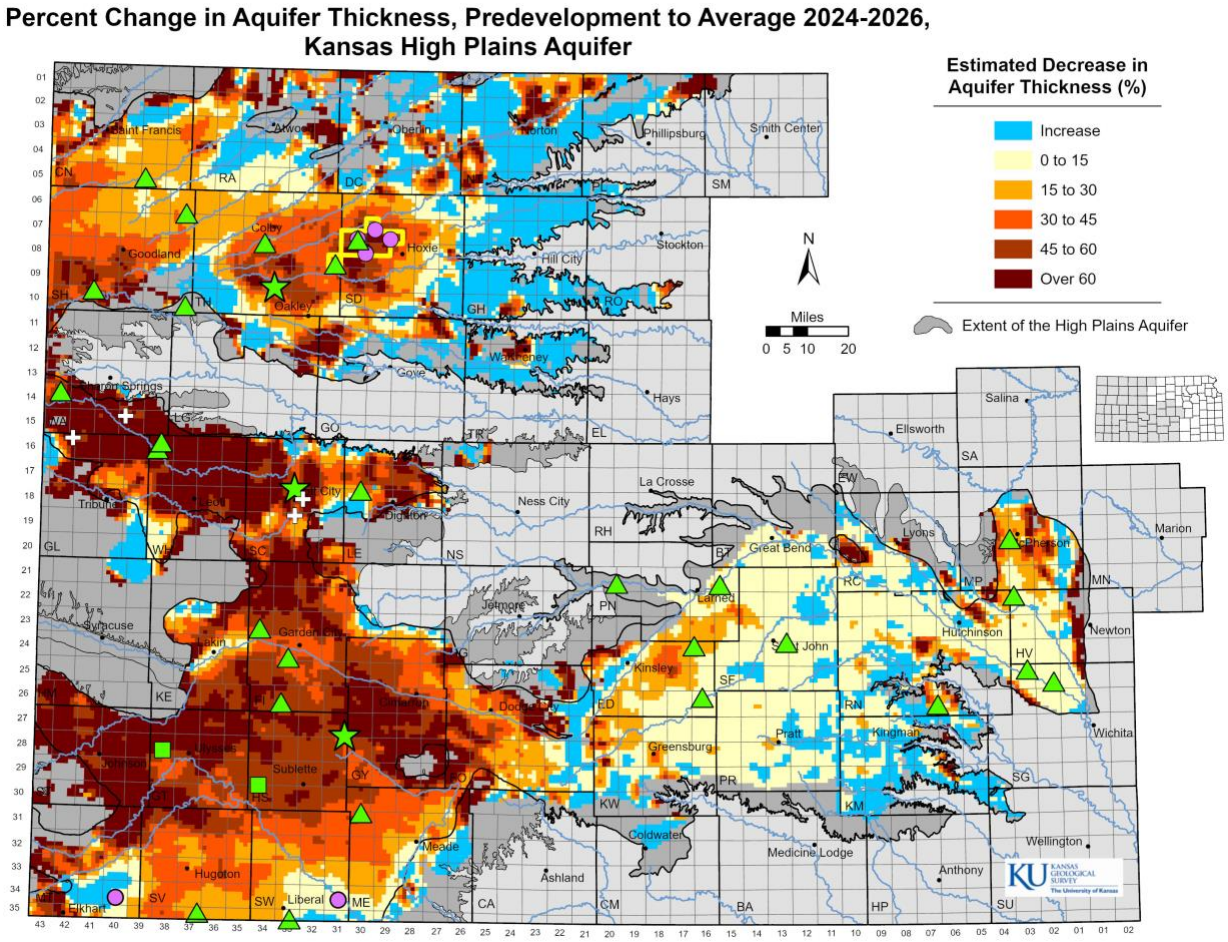


Figure 1. The Kansas portion of the High Plains aquifer, with aquifer and county boundaries shown. Each colored pixel represents one section (1 mi²), coded for the degree of groundwater depletion from the beginning of large-scale development to the average of conditions in 2024–2026. The green stars indicate the locations of the original three index well sites, the green triangles indicate additional telemetry-equipped wells, the green squares are the telemetry-equipped two-well nests (one well in the HPA and one in the Dakota aquifer), the purple circles are the index wells without telemetry equipment where data are downloaded quarterly, and the yellow polygon indicates the Sheridan-6 Local Enhanced Management Area. The white plus signs are the four expansion wells within GMD1.

3 Overview of Index Well Sites and Monitoring Data

This section provides a brief discussion of the hydrographs from the 40 index wells and the four additional GMD1 expansion wells currently in operation. The duration of monitoring ranges from about 19 years of hourly measurements at the three original index wells to a little over a year at the Cheyenne County index well added in late spring of 2025. Although pumping occurs sporadically throughout the year, the major drawdown in water level in all of the wells occurs during the summer pumping season when the aquifer is stressed significantly for an extended period. For this study, the pumping season is defined as the period from the first sustained drawdown during the growing season (often, but not always, following the maximum recovered water level) to the first major increase in water level near the end of the growing season. The recovery season (period) is defined as the time between pumping seasons. Because water levels continue to increase throughout the recovery period at most of the index wells, the difference between water levels measured during the recovery period from one year to the next only provides a measure of the year-to-year change in still-recovering water levels. This year-to-year change in recovering water levels must be used cautiously by managers because it can be affected by a variety of factors that are unrelated to aquifer trends, such as the year-to-year variability in the time between the end of the irrigation season and the annual measurement. More importantly, it *does not* involve the final recovered water level—the elevation to which the water level would rise if the next pumping season did not interrupt recovery. While this final recovered water level would provide a reliable basis for managers to assess the effect of changes in water use, efforts to estimate this level through various extrapolation procedures have proven difficult because of the variety of mechanisms that can affect the recovery process (Stotler et al., 2011).

In the following subsections, the hydrograph and characteristics of each well are discussed. The wells are organized by the GMD in which they are located. In the interest of brevity, discussion of each well will be limited to one page. Further information can be found in previous reports and on the KGS website. In reports before 2017, two tables were presented for most wells: one provided information about the well hydrograph and the local water use, and the other provided comparisons between the manual annual program measurements and the transducer measurements. Those tables with data from all years of index well operation are online at www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml.

3.1 GMD1 Index Wells

Five index wells are located in GMD1 (fig. 2). The Scott County well was one of the original index wells drilled in 2007, whereas the Lane, Wallace, and Wichita County wells were drilled in the spring of 2016. The Wichita County 2 well was added to the network in early 2022 because the Wichita County index well showed little response to nearby pumping. Table 1 summarizes the characteristics of these five wells. Further details concerning these wells are given in the 2016 and 2021 annual reports (Butler, Whittemore et al., 2017; Butler et al., 2022) and the online appendices for this report (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml). Section 3.6.1 discusses the GMD1 expansion wells.

Table 1. Characteristics of the GMD1 index well sites.

Site	2026 WL elev. (ft)[a]	2026 Saturated thickness (ft)	Bedrock depth (estimated ft below land surface)	Screened interval (ft below land surface)	2025 Water Use (ac-ft)		
					1 mi radius circle	2 mi radius circle	5 mi radius circle
Lane	2,768.6	34.6	118	105–115	281	590	1,920[b]
Scott	2,823.6	79.4	223	215–225	555	1,641[c]	8,675[d]
Wallace	3,536.6	102.6	394	375–385	500[e]	2,527[e]	8,154[f]
Wichita	3,286.8	28.8	190	175–185	174	1,588	6,262[g]
Wichita 2	3,276.4	38.4	221	189–226	679	2,373	5,894[g]

[a] 2026 annual tape water-level measurements from WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/). Wichita 2 is not part of the annual measurement program; 2026 water-level measurement estimated from sensor data on 01/3/2026 from 0800 to 1700.

[b] Includes 10 ac-ft of municipal water and 1 ac-ft of non-irrigation stock water.

[c] Includes 20 ac-ft of non-irrigation stock water.

[d] Includes 2 ac-ft of industrial water, 829 ac-ft of municipal water, and 367 ac-ft of non-irrigation stock water.

[e] Includes 43 ac-ft of municipal water.

[f] Includes 43 ac-ft of municipal water and 3 ac-ft of non-irrigation stock water.

[g] Includes 41 ac-ft of non-irrigation stock water.

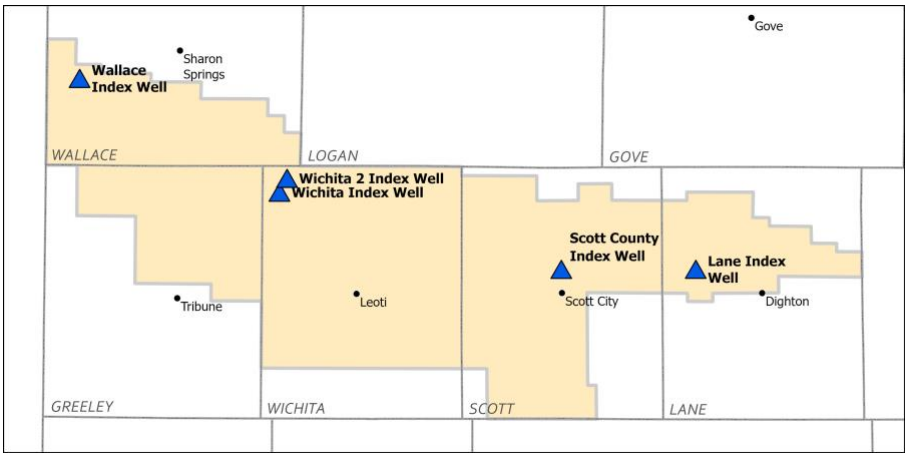


Figure 2. Map of index wells in GMD1; data from these wells can be viewed in real time on the KGS website (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml).

3.1.1 Lane County Index Well

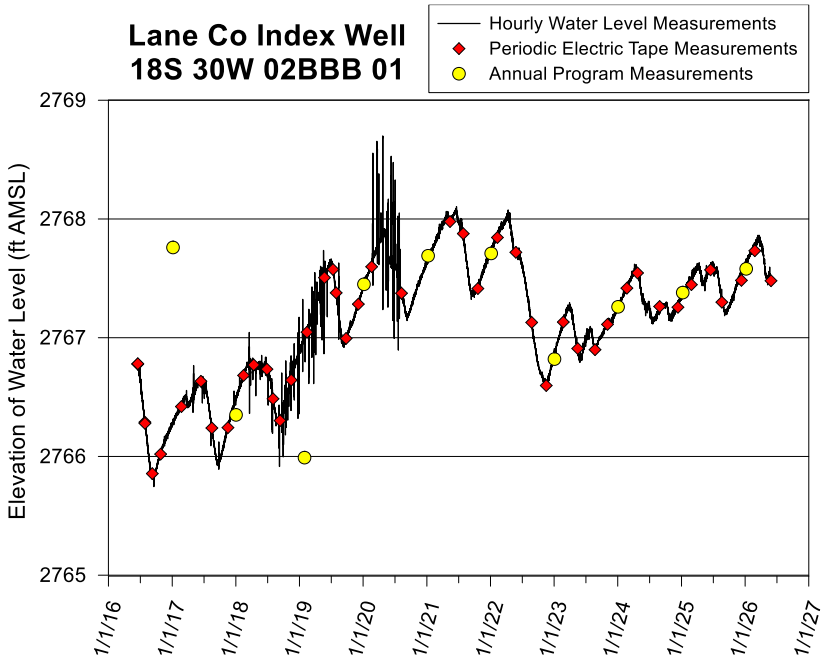


Figure 3. Lane County index well hydrograph—total data run to 5/29/26. A water-level elevation of 2,767 ft corresponds to a depth to water of 84 ft below land surface (lsf). The top of the screen is 105 ft below lsf (elevation of 2,746 ft), and the bottom of the aquifer is 118 ft below lsf (elevation of 2,733 ft). The screen terminates 3 ft above the bottom of the aquifer. The 2017 and 2019 annual water-level measurements appear to be in error. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct the drift noted in earlier annual reports.

Major Points

- Very small amplitude fluctuations superimposed on the water levels are likely an indication of a relatively shallow unconfined aquifer overlain by a vadose zone with high air permeability.
- The influence of individual nearby pumping wells is not discernible; the water-level response appears to be a response to regional, more distant pumping rather than a response to pumping at nearby wells as at most of the index wells (i.e., response is more integrated in nature).
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- Pumping for the 2024 irrigation season was largely paused from 7/23/24 to 10/7/24 after which pumping continued until 11/6/24 (the latest ending of the irrigation season since the start of monitoring). In contrast, the 2023 irrigation season ended on 8/25/23, the earliest ending of the irrigation season since the start of monitoring. The 2025 irrigation season ended in mid-September.
- Many short-duration spikes appear on the hydrograph until mid-summer 2020; we suspect the origin of the spikes is related to air expansion and contraction in the desiccant tube of the gauge pressure sensor (Cain et al., 2004), which was located by the telemetry box and exposed to sunlight. On 8/8/20, we replaced the telemetry system with a different vendor's system that did not expose the tubing to sunlight and the spikes disappeared.
- The 2025 total water use (5 mi radius centered on well) was the lowest of any of the index wells.

3.1.2 Scott County Index Well

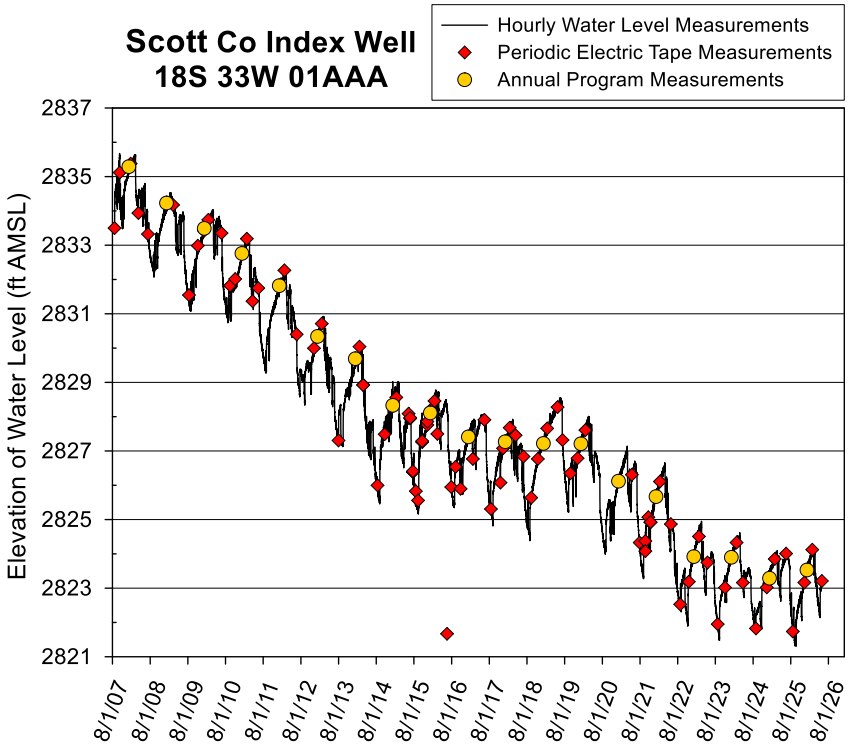


Figure 4. Scott County index well hydrograph—total data run to 5/29/26. A water-level elevation of 2,823 ft corresponds to a depth to water of 144.2 ft below lsf. The top of the screen is 215 ft below lsf (elevation of 2,752.2 ft), and the bottom of the aquifer is 223 ft below lsf (elevation of 2,744.2 ft). The screen terminates 2 ft below the bottom of the aquifer. Transducer data have been adjusted for change in position as described in a previous annual report (Butler, Whittemore, Reboulet et al., 2016). The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The hydrograph form, the relatively small change and rate of change in water level during each pumping and recovery season (despite at least two high-capacity pumping wells within approximately a half mile of the index well), and the fluctuations superimposed on the water levels are all indications of an unconfined aquifer.
- The effect of individual pumping wells is discernible, indicating that one or more pumping wells are in relatively close proximity to and in good hydraulic connection with the index well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The maximum water level has been below that of the preceding year for every year except 2019. The minimum water level for 2025 was the lowest of the monitoring period and 0.5 ft below that for 2024.
- Transducer readings are in good agreement with manual measurements after in-field calibration except for one electric-tape measurement that appears to be a transcription error.

3.1.3 Wallace County Index Well

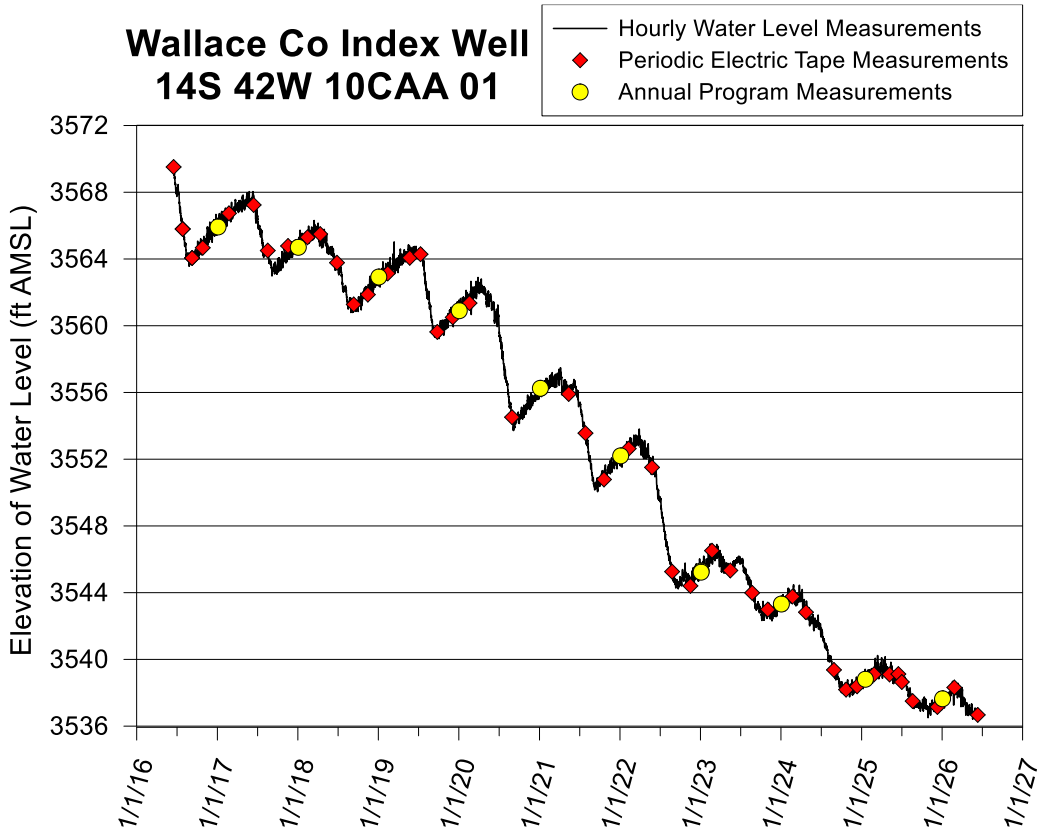


Figure 5. Wallace County index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,540 ft corresponds to a depth to water of 289 ft below lsf. The top of the screen is 375 ft below lsf (elevation of 3,454 ft), and the bottom of the aquifer is 394 ft below lsf (elevation of 3,435 ft). The screen terminates 9 ft above the bottom of the aquifer. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions with a relatively deep water table.
- The effect of individual pumping wells is discernible, indicating that one or more pumping wells are in relatively close proximity to and in good hydraulic connection with the index well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- Each year, the maximum and minimum water levels are below that of the preceding year, creating a downward stair-stepping pattern. The 2025 maximum water level was 28 ft below that of 2017 for an average decline rate of 3.5 ft/yr. The 2025 minimum water level was 1 ft below that of 2024.
- Transducer readings are in good agreement with manual measurements. Similar to the Lane County index well, many short-duration spikes appear on the hydrograph until mid-summer 2020. On 8/29/20, we replaced the telemetry system with a different vendor's system and the spikes disappeared.

3.1.4 Wichita County Index Well

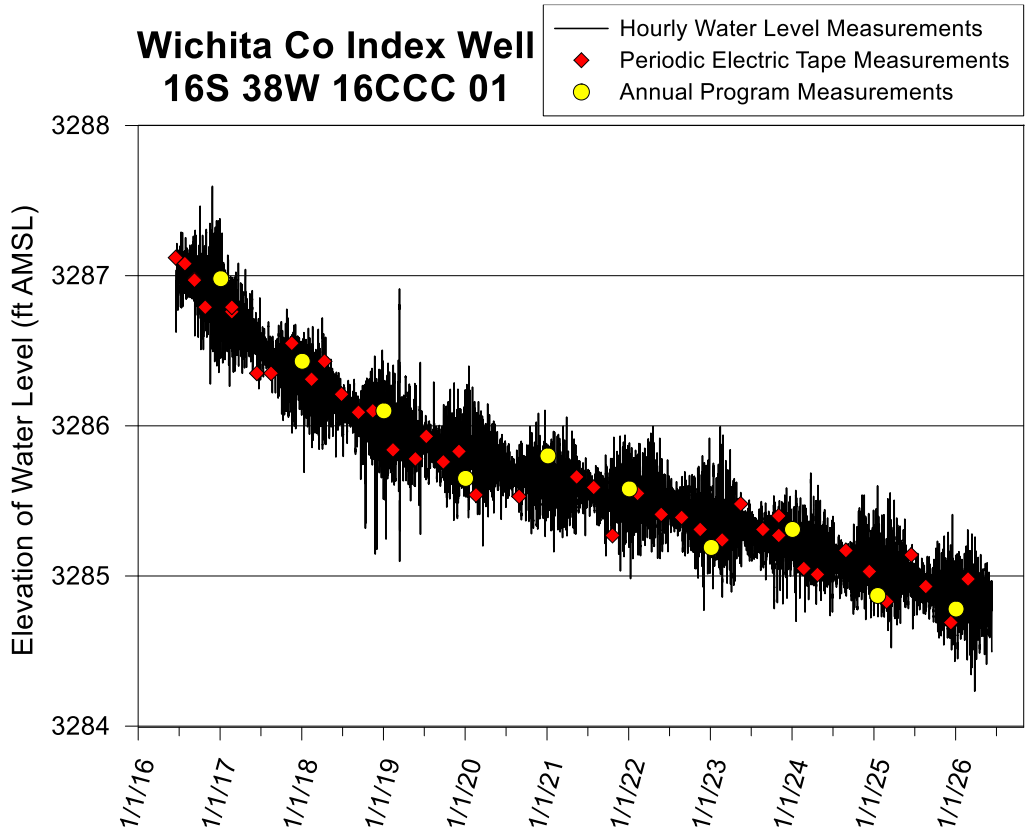


Figure 6. Wichita County index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,287 ft corresponds to a depth to water of 159 ft below lsf. The top of the screen is 175 ft below lsf (elevation of 3,271 ft), and the bottom of the aquifer is 190 ft below lsf (elevation of 3,256 ft). The screen terminates 5 ft above the bottom of the aquifer. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The amplitude of the fluctuations superimposed on the water levels are an indication of unconfined conditions; the seasonal variations in the amplitude are produced by seasonal changes in the range over which barometric pressure can vary (smaller range during the summer [Butler, Knobbe et al., 2021]).
- It is difficult to discern individual pumping and recovery seasons; cannot discern effect of individual wells cutting on and off.
- Water levels continue to drop throughout the monitoring period.
- Transducer readings are in good agreement with manual measurements after in-field calibration. Similar to the Lane County index well, short-duration spikes appear on the hydrograph until mid-summer 2020. On 8/29/20, we replaced the telemetry system with a different vendor's system and the spikes disappeared.

3.1.5 Wichita County 2 Index Well

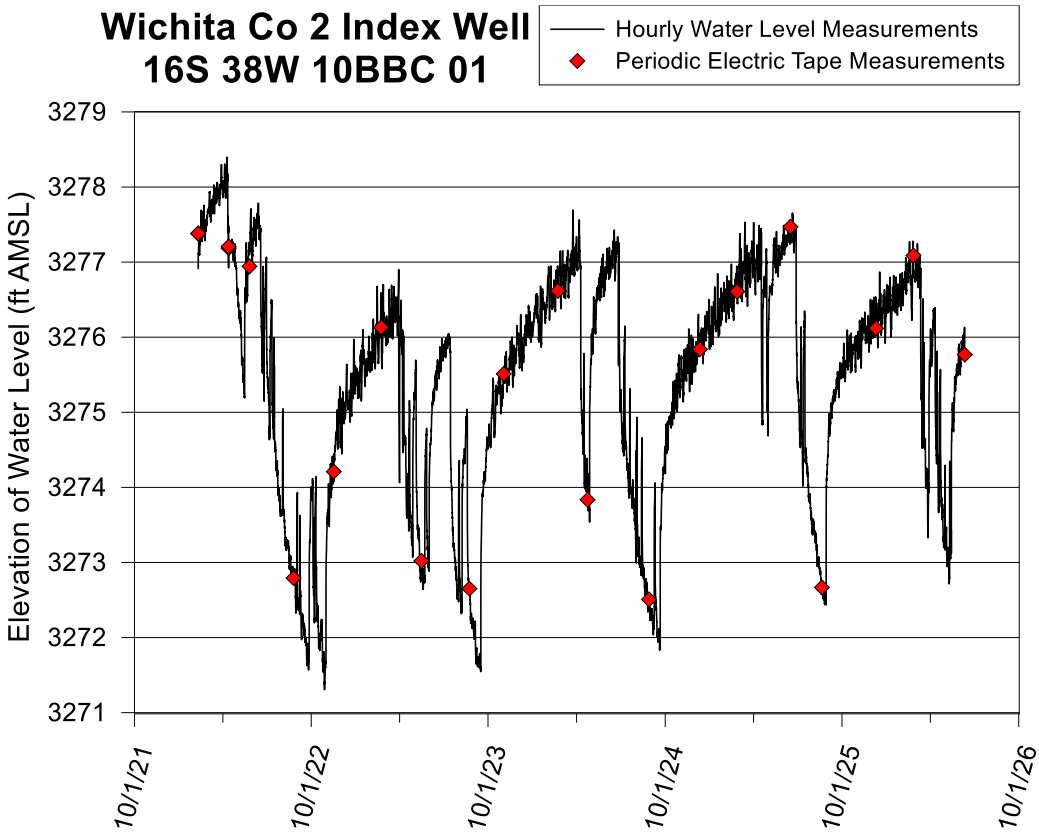


Figure 7. Wichita County 2 index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,277 ft corresponds to a depth to water of 182 ft below lsf. The top of the screen is 189 ft below lsf (elevation of 3,270 ft), and the screen extends to the bottom of the well. The aquifer bottom is estimated to be 221 ft below lsf (elevation of 3,238 ft); the well bottom is 226.2 ft below lsf. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The hydrograph form during the irrigation season and the relatively large fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions.
- The effect of individual pumping wells is discernible, indicating that one or more of the nearby pumping wells are in good hydraulic connection with the index well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- Despite the relatively close proximity (1.9 miles) to the Wichita County index well, the hydrographs of the two wells are dramatically different, indicating aquifer conditions change greatly over that distance.
- Transducer readings are in good agreement with manual measurements after in-field calibration.

3.2 GMD2 Index Wells

Five index wells are located in GMD2 (fig. 8); the most recent well (Bentley) was brought into the network in September 2020. Table 2 summarizes the characteristics of these wells. Further details concerning the Bentley well and the four other wells are given in the 2020 annual report (Butler, Whittemore et al., 2021) and the 2019 annual report (Butler, Whittemore et al., 2020), respectively. In addition, the online appendices for this report (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml) provide further details for all five wells.

Table 2. Characteristics of the GMD2 index well sites (water use is for irrigation unless noted otherwise).

Site	2026 WL elev. (ft)[a]	2026 Saturated thickness (ft)	Bedrock depth (estimated ft below land surface)	Screened interval (ft below land surface)	2025 Water Use (ac-ft)		
					1 mi radius circle	2 mi radius circle	5 mi radius circle
Bentley	1,371.9	206.9	216	23–33	647	2,309[b]	23,496[c]
Harvey	1,409.2	160.2	206	198–208	393	2,408[d]	10,936[e]
McPherson	1,400.5	90.5	184	139–183	188[f]	3,716[g]	7,034[h]
Mount Hope	1,408.3	158.6	173	163–173	634	1,977[i]	18,426[j]
Pretty Prairie	1,544.0	46.0	71	61–71	630[i]	2,184[k]	6,577[l]

[a] 2026 annual tape water-level measurements from WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/); Bentley is not part of the annual measurement program; 2026 water-level measurement estimated from sensor data on 1/2/26 from 0800 to 1700.

[b] Includes 254 ac-ft of municipal water.

[c] Includes 14,181 ac-ft of municipal water and 613 ac-ft of industrial water

[d] Includes 182 ac-ft of municipal water.

[e] Includes 2,638 ac-ft of municipal water and 135 ac-ft of non-irrigation recreation water.

[f] Includes 80 ac-ft of municipal water.

[g] Includes 2,780 ac-ft of industrial water, 211 ac-ft of municipal water, and 2 ac-ft of non-irrigation stock water.

[h] Includes 3,351 ac-ft of industrial water, 221 ac-ft of municipal water, 2 ac-ft of non-irrigation stock water, 119 ac-ft of non-irrigation recreation water, and 67 ac-ft of other water.

[i] Includes 16 ac-ft of non-irrigation recreation water.

[j] Includes 6,713 ac-ft of municipal water, 9 ac-ft of domestic water, 11 ac-ft of industrial water, 180 ac-ft of other water, and 629 ac-ft of non-irrigation recreation water.

[k] Includes 3 ac-ft of municipal water.

[l] Includes 66 ac-ft of municipal water.

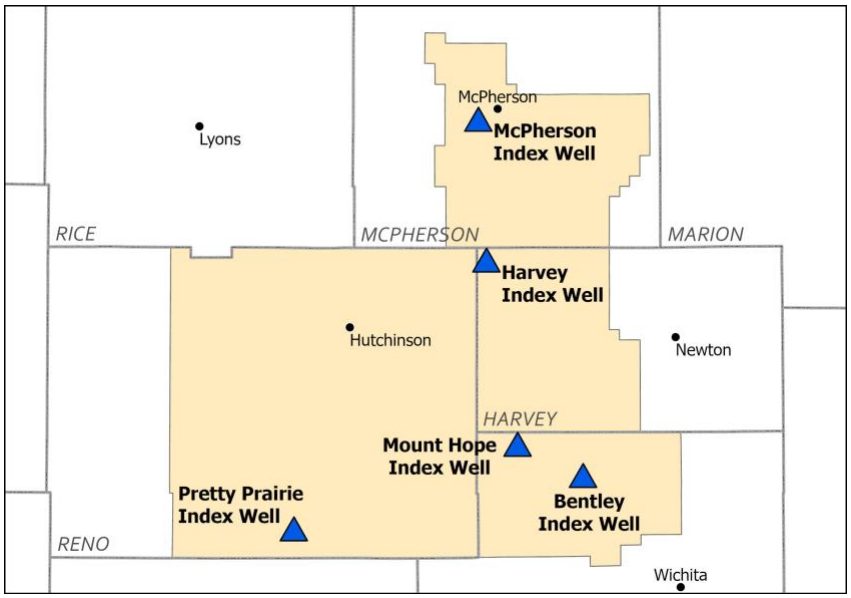


Figure 8. Map of index wells in GMD2; data from these wells can be viewed in real time on the KGS website (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml).

3.2.1 Bentley Index Well

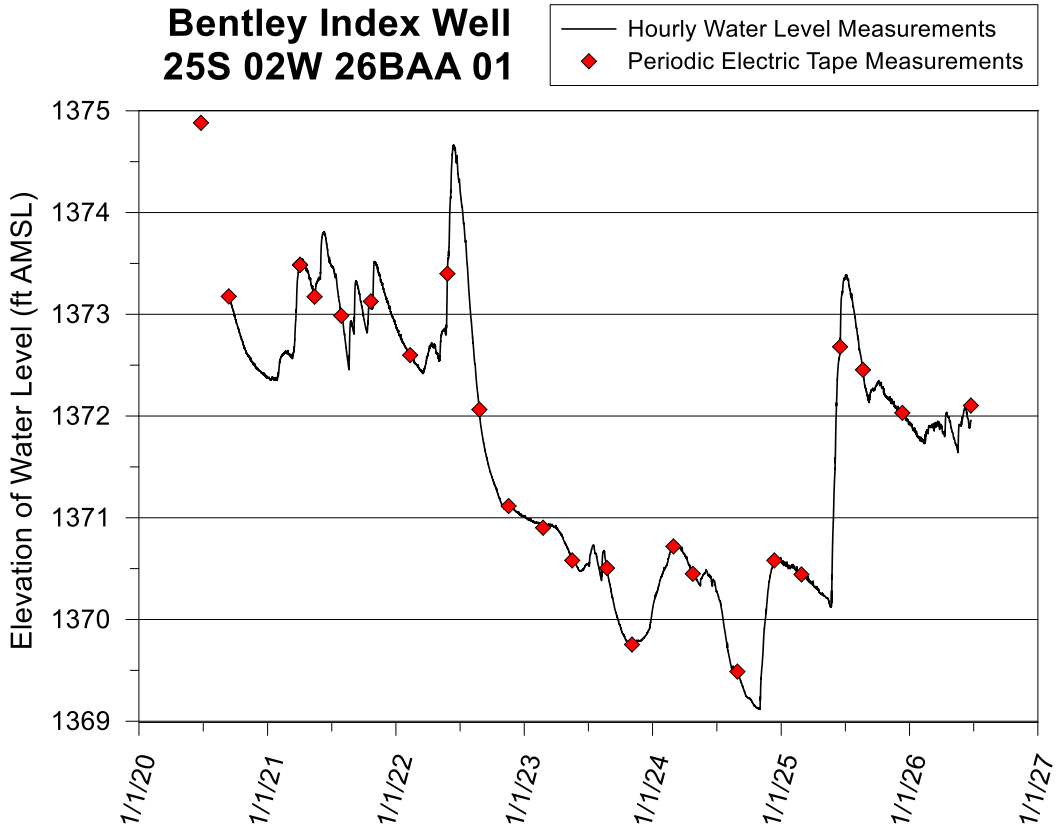


Figure 9. Bentley index well hydrograph—total data run to 6/24/26. A water-level elevation of 1,373 ft corresponds to a depth to water of 8 ft below lsf. The top of the 10 ft screen is 23 ft below lsf (elevation of 1,358 ft). The bottom of the aquifer is approximately 216 ft below lsf (elevation of 1,165 ft), and the bottom of the well is 33 ft below lsf (elevation of 1,348 ft). The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The hydrograph shows a small response to barometric pressure fluctuations as would be expected for shallow unconfined conditions.
- Large, rapid rises are likely produced by stage changes in the nearby Arkansas River and precipitation recharge. For example, a river flow peak at Maize occurred on 5/26/22.
- The large decline in the latter part of 2022 is primarily related to the substantial decrease in river flow after mid-June due to the drought.
- There is little indication of nearby pumping activity, which is likely due to the well location above the screened interval of the many nearby pumping wells.
- Transducer readings are in good agreement with manual measurements after in-field calibration.
- The 2025 municipal water use (5 mi radius centered on well) was the highest among the index wells.

3.2.2 Harvey County Index Well

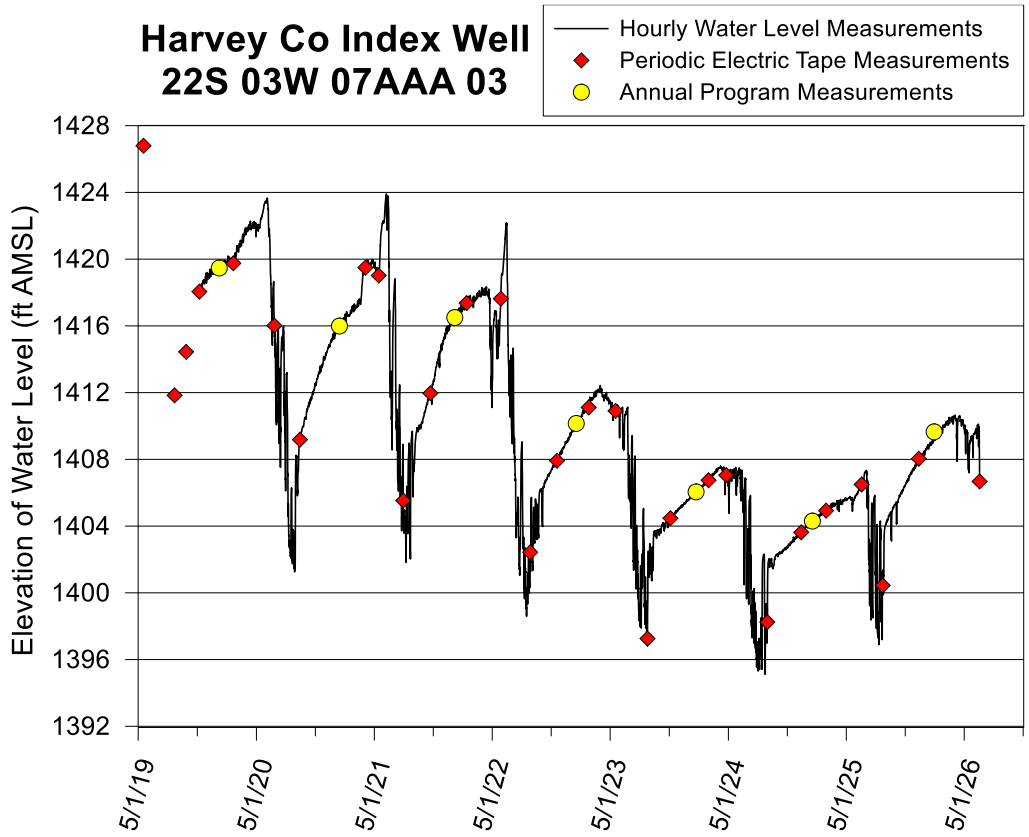


Figure 10. Harvey County index well hydrograph—total data run to 6/17/26. A water-level elevation of 1,408 ft corresponds to a depth to water of 47 ft below lsf. The top of the 10 ft screen is 198 ft below lsf (elevation of 1,257 ft), and the bottom of the aquifer is 206 ft below lsf (elevation of 1,249 ft). The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The hydrograph form (response to nearby pumping) indicates confined conditions.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- Abrupt rises in water level during the recovery period are likely produced by precipitation.
- The linear responses during the 2022–2023, 2023–2024, 2024–2025, and, to a lesser extent, 2025–2026 recovery periods indicate little precipitation and a steady rate of recharge during those periods. The difference in slopes of the linear responses indicates that the rate of recharge differs among the three recovery periods.
- The agreement between manual measurements and the transducer appears good.

3.2.3 McPherson County Index Well

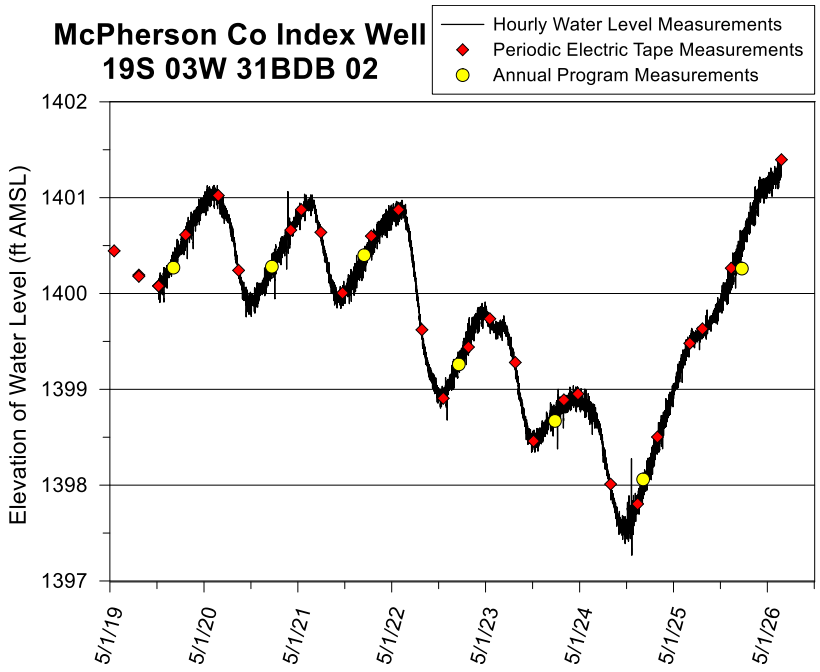


Figure 11. McPherson County index well hydrograph—total data run to 6/24/26. A water-level elevation of 1,400 ft corresponds to a depth to water of 94 ft below lsf. The top of the 44 ft screen is 139 ft below lsf (elevation of 1,355 ft), and the bottom of the screen is 183 ft below lsf (elevation of 1,311 ft). The bottom of the aquifer is 1 ft below the bottom of the screen (1,310 ft). We have yet to identify the mechanisms producing the infrequent anomalous spikes. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to correct for sensor drift.

Major Points

- The relatively small amplitude fluctuations superimposed on the water levels hint at confined conditions.
- The impact of individual wells turning on and off is difficult to discern.
- After the end of the irrigation season, water levels continue to recover until the start of the next irrigation season (water levels never stabilize).
- Transducer readings are in good agreement with manual measurements after in-field calibration.
- The lack of water-level rises similar to those seen in the other GMD2 index wells in late March 2021 and late May 2022 indicates that overlying clay layers are shielding the screened interval from short-term effects of recharge.
- Unlike at most of the index wells, where irrigation use dominates, industrial and municipal use is significant at the McPherson County index well.
- The 2024 minimum water level was the lowest observed during the monitoring period; the water level has risen approximately 4.0 ft since then as the result of a dramatic decrease (> 1,200 ac-ft) in annual municipal water use within one mile of the index well between 2024 and 2025.

3.2.4 Mount Hope Index Well

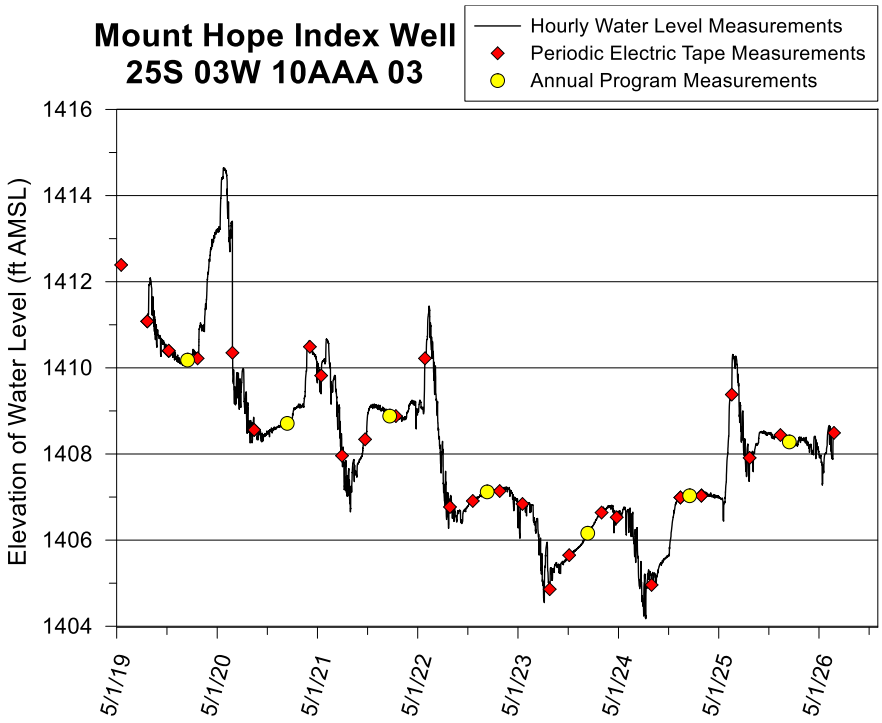


Figure 12. Mount Hope index well hydrograph—total data run to 6/24/26. A water-level elevation of 1,410 ft corresponds to a depth to water of 11.4 ft below lsf. The top of the 10 ft screen is 163 ft below lsf (elevation of 1,258.4 ft), and the bottom of the aquifer is 173 ft below lsf (elevation of 1,248.4 ft). The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to correct for sensor drift. Note that the data from 3/15/20 to 6/3/20, which had been reported as missing in previous reports, are uncalibrated.

Major Points

- The abrupt rise in water level shortly after instrumentation was installed in the well in 2019 and the decline after that are likely produced by stage changes in the nearby Arkansas River. Other abrupt rises and falls appear to be a combination of stage changes in the Arkansas River and recharge from precipitation and flow in the nearby creek about 0.3 mi to the southwest.
- The effect of individual wells turning on and off is clearly visible on the hydrograph, indicating pumping wells in good hydraulic connection with the index well.
- Due to drought conditions, the hydrograph from mid-June 2022 to late spring 2024 is dramatically different from that of the other years. No significant flow peaks occurred in the nearby Arkansas River during this period.
- Transducer readings are in good agreement with manual measurements after in-field calibration.
- The 2025 municipal water use (5 mi radii centered on well) was the second highest of any of the index wells.

3.2.5 Pretty Prairie Index Well

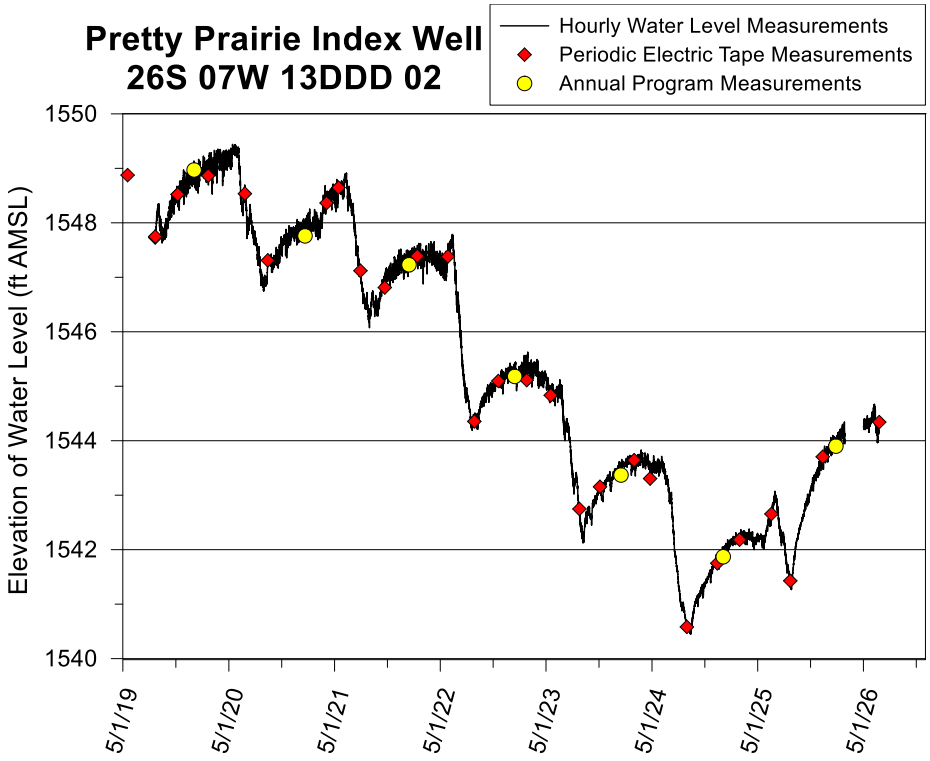


Figure 13. Pretty Prairie index well hydrograph—total data run to 6/24/26. A water-level elevation of 1,542 ft corresponds to a depth to water of 27 ft below lsf. The top of the 10 ft screen is 61 ft below lsf (elevation of 1,508 ft), and the bottom of the screen and aquifer is 71 ft below lsf (elevation of 1,498 ft). Lack of data between 2/26/26 and 5/1/26 was a result of datalogger malfunctioning. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to correct for sensor drift.

Major Points

- The relatively large amplitude fluctuations superimposed on the water levels indicate unconfined conditions.
- The effect of individual wells turning on and off is visible on the hydrograph.
- After the end of the irrigation season, water levels continue to recover until stabilizing in late January; water-level rises after that time appear to be driven by precipitation.
- Each year until 2025, the maximum and minimum water levels were below that of the preceding year, creating a downward stair-stepping pattern. The water level fell 7.1 ft between 1/1/2020 and 1/1/2025 for an average decline rate of 1.4 ft/yr. The water level has risen 2.4 ft since 1/1/2025. Precipitation in this area during 2025 was 25–50% above normal.
- Transducer readings are in good agreement with manual measurements after in-field calibration.

3.3 GMD3 Index Wells

Fourteen index wells are in GMD3 (fig. 14). The Haskell index well was one of the original 2007 index wells; monitoring began at the Cimarron, Hugoton, Liberal, and Rolla well sites in 2012–2013, at the Willis Water Technology Farm index well in the summer of 2016, at the Kearny-Finney County index well in the summer of 2017, at the Satanta and Ulysses well nests in late winter of 2023, at the Meade County index well in late winter of 2025, and at the Sand Hills index well in late summer of 2026. Table 3 summarizes characteristics of 12 of these wells (only the deeper well is listed for the Hugoton site; the Sand Hills index well will be included in next year's report). Further details concerning these wells are given in the 2016, 2022, and 2024 annual reports (Butler, Whittemore et al., 2017; Butler, Whittemore et al., 2023; Butler et al., 2025), and the online appendices for this report (www.kgs.ku.edu/HighPlains/OHP/index_program/ index.shtml).

Table 3. Characteristics of the GMD3 index well sites (water use is for irrigation unless noted otherwise).

Site	2026 WL elev. (ft)[a]	2026 Saturated thickness (ft)	Bedrock depth (ft below land surface)[b]	Screened interval (ft below land surface)[b]	2025 Water Use (ac-ft)		
					1 mi radius circle	2 mi radius circle	5 mi radius circle
Cimarron 210	2,473.96	289.96	345	200–210	3	3	8,263[c]
Haskell	2,509.94	105.14	433	420–430	397	4,954[d]	29,717[e]
Hugoton 495	2,881.64	416.64	635	485–495	531	2,590	38,551[f]
Kearny-Finney	2,765.31	164.29[g]	360[g]	70–266[h]	2,011	5,988	37,437[i]
Liberal 436	2,647.10	399.89	576	426–436	0	1,515[j,k]	30,824[l,m]
Meade	2,507.87	204.87	457	420–460	1,112	3,631	23,654
Rolla 366	3,183.50	207.50	399	356–366	338[n]	1,236[o]	9,125[p]
Satanta – HPA	2,603.01	143.01	520	500–520	100	2,763	19,392[q]
Satanta – Dakota	2,600.25	250.25	630*	600–620			
Ulysses – HPA	2,858.75	193.75	445	425–445	1,016	2,608	11,319[r]
Ulysses – Dakota	2775.08	241.08	576*	560–580			
Willis Tech Farm	2,614.15	176.15	502	262–482	469	4,293[s]	29,008[t]

[a] 2026 annual tape water-level measurements from WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/).
[b] Measurements for the Cimarron, Hugoton, Liberal, and Rolla wells from table 2 in McMahon (2001).
[c] Includes 10 ac-ft of non-irrigation stock water.
[d] Includes 2 ac-ft of industrial water and 9 ac-ft of municipal water.
[e] Includes 2 ac-ft of industrial water, 9 ac-ft of municipal water, and 11 ac-ft of non-irrigation stock water.
[f] Includes estimates of water use in Oklahoma based on "permitted" quantities of 17,989 ac-ft.
[g] Based on logs of nearby wells to bedrock.
[h] Measurements estimated from borehole camera log; screen is filled with sediment from 266 to 300 ft.
[i] Includes 44 ac-ft of industrial water, 233 ac-ft of municipal water, and 612 ac-ft of non-irrigation stock water.
[j] Includes estimates of water use in Oklahoma based on "permitted" quantities of 675 ac-ft.
[k] Includes 718 ac-ft of municipal water for the city of Liberal.
[l] Includes estimates of water use in Oklahoma based on "permitted" quantities of 20,909 ac-ft.
[m] Includes 2,962 ac-ft of industrial water, 3,161 ac-ft of municipal water, 27 ac-ft of recreational water, and 399 ac-ft of non-irrigation stock water.

[n] Includes 32 ac-ft of non-irrigation stock water.
[o] Includes 95 ac-ft of non-irrigation stock water.
[p] Includes 266 ac-ft of non-irrigation stock water and 70 ac-ft of municipal water.
[q] Includes 240 ac-ft of municipal water and 356 ac-ft of non-irrigation stock water.
[r] Includes 58 ac-ft of industrial water and 767 ac-ft of municipal water.
[s] Includes 7 ac-ft of non-irrigation stock water.
[t] Includes 888 ac-ft of industrial water and 7 ac-ft of non-irrigation stock water.
* Bottom of Dakota aquifer, not bedrock depth.

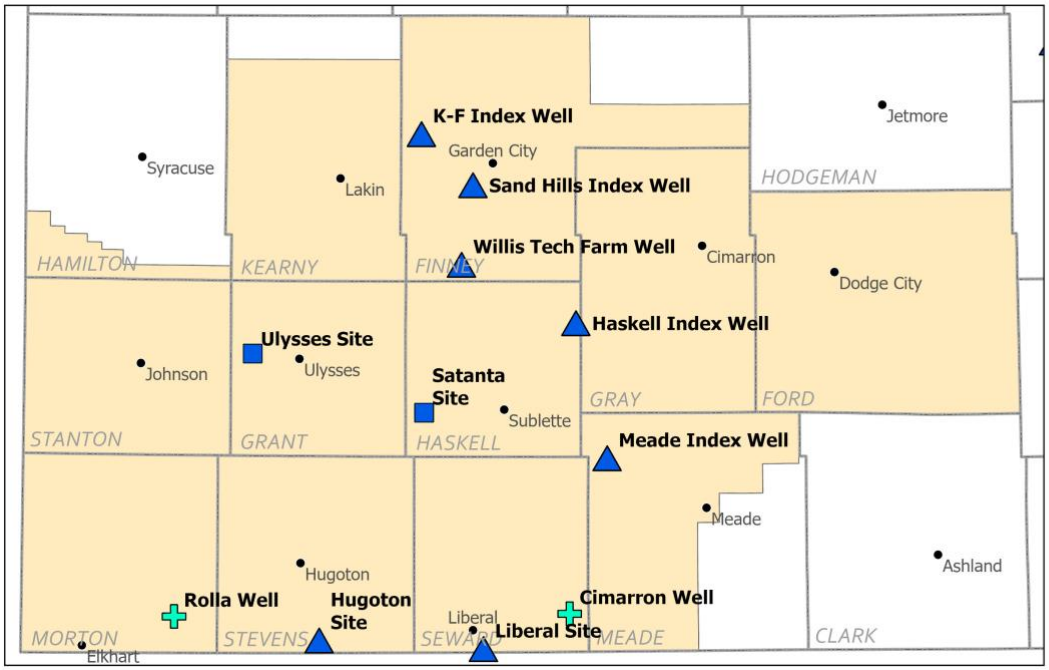


Figure 14. Map of index well sites in GMD3. Triangles and squares designate wells with telemetry equipment, whereas plus signs designate wells without telemetry equipment. Data from wells with telemetry equipment can be viewed in real time on the KGS website (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml); data from wells without telemetry equipment are periodically downloaded (typically quarterly) and posted on the KGS website. The Ulysses and Satanta sites each have one well near the bottom of the HPA and one well in the underlying Dakota aquifer; both wells at each site have telemetry equipment. The Hugoton site has one well with telemetry equipment and one well without; the well with telemetry equipment is located in the main body of the HPA. K-F = Kearny-Finney.

3.3.1 Cimarron 210 Index Well

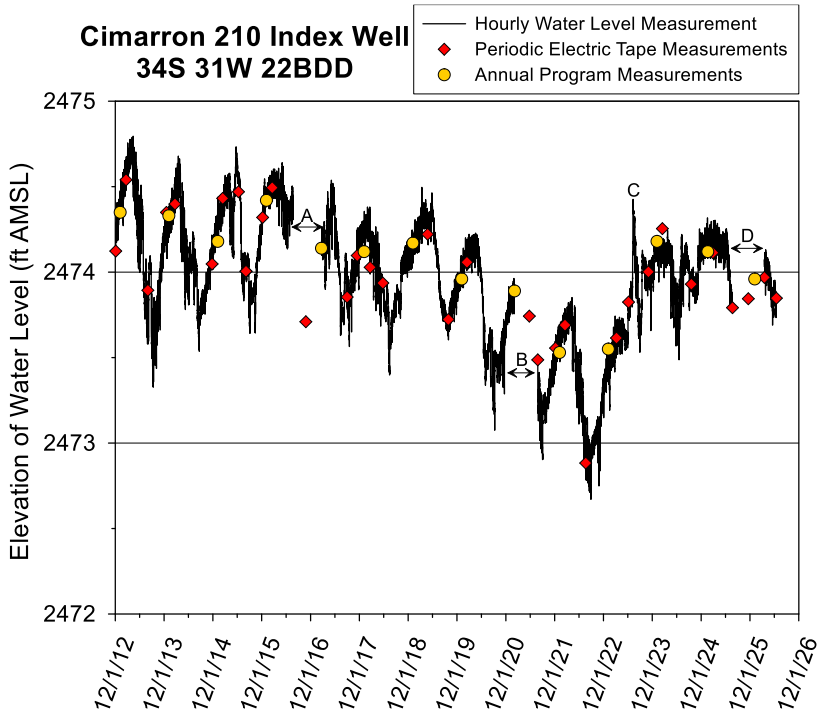


Figure 15. Cimarron 210 index well hydrograph—total data run to 6/16/26. A water-level elevation of 2,474 ft corresponds to a depth to water of 55 ft below lsf. The top of the 10 ft screen is 200 ft below lsf (elevation of 2,329 ft), and the bottom of the aquifer is 345 ft below lsf (elevation of 2,184 ft); A-D defined in text.

Major Points

- The hydrograph form and small response to pumping, despite a nearby (within 0.3 mi) irrigation well, indicate unconfined conditions.
- Relatively small (less than 0.2 ft) fluctuations superimposed on the water levels, particularly evident during the recovery periods, indicate an unconfined aquifer with a relatively shallow depth to water.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- Sensor failure produced gaps (A [7/22/16–2/22/17] and B [2/3/21–7/27/21]) in hydrograph record.
- Water-level rise in early July 2023 (C) appears to be an episodic recharge event. This well is the only one in GMD3 with definitive examples of episodic recharge and only the second index well in western Kansas with such examples (SD-6 Steiger index well in GMD4 is the other). In this case, the shallow depth to water and flow in the nearby Cimarron River likely play important roles.
- Inadvertent cessation of monitoring and failure to check sensor operation produced gap (D [7/23/25-3/18/26]) in hydrograph record.
- The 2025 water use within a 2 mi radius of the well was the lowest among the index wells.
- Water level has declined 2.0 ft since January 2000 (decline rate of less than 0.1 ft/yr); see 2016 annual report (Butler, Whittemore et al., 2017) for further details.
- Transducer readings are in good agreement with manual measurements.

3.3.2 Haskell County Index Well

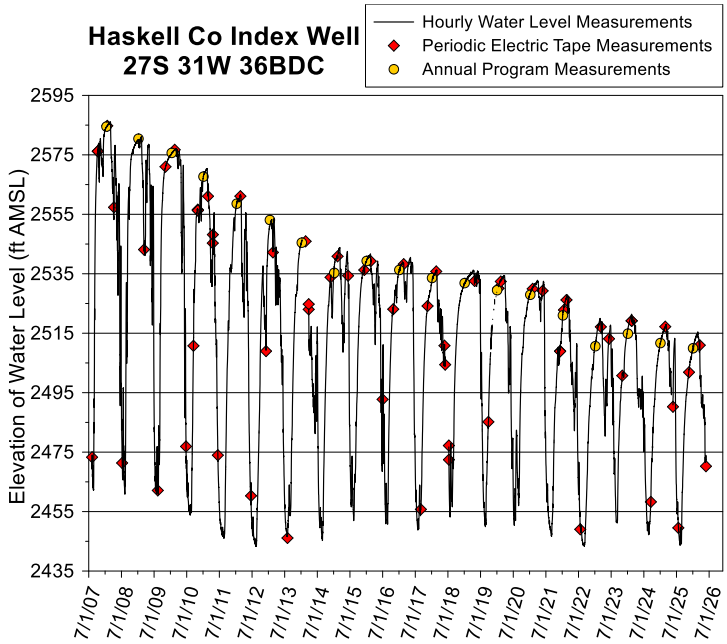


Figure 16. Haskell County index well hydrograph—total data run to 5/26/26. A water-level elevation of 2,455 ft corresponds to a depth to water of 382.8 ft below lsf. The top of the screen is 420 ft below lsf (elevation of 2,417.8 ft), and the bottom of the aquifer is 433 ft below lsf (elevation of 2,404.8 ft). The screen terminates 3 ft above the bottom of the aquifer. A sensor failure produced a break in monitoring from January to March 2014; a damaged cable produced a break in monitoring from early June to mid-July 2018; a malfunctioning sensor began producing many spurious values on 10/17/19 and was replaced on 1/16/20—only the sensor values deemed reasonable are plotted during that three-month period. A sensor failure produced a break in monitoring from 5/7/25 to 5/22/25.

Major Points

- The hydrograph form and large response (70–120 ft) to pumping, despite the closest high-capacity well being about 0.5 mi away, indicate a confined aquifer. After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- An increase in the minimum water-level elevation and a large decrease in the rate of decline of the maximum recovered water level after 2013 were produced by court-ordered early (2013 and 2014) cessation of pumping at two nearby irrigation wells and complete (after 2014) cessation of pumping at those wells and three additional nearby irrigation wells. Recent (2020–2022) increases in the rate of decline of both the maximum recovered water level and the minimum water level were likely produced by more pumping in response to drier conditions than in the 2015–2019 period. The court-ordered cessation has now been canceled, leading to greater pumping in 2026.
- The 2026 maximum recovered water level at the time of this report is the lowest since the start of monitoring (2007) at the well and approximately 70.7 ft below the maximum recovered water level of 2008.
- The 2026 minimum water level will be the lowest since the start of monitoring by at least 6 ft.
- Transducer readings are in reasonable agreement with manual measurements.

3.3.3 Hugoton Site

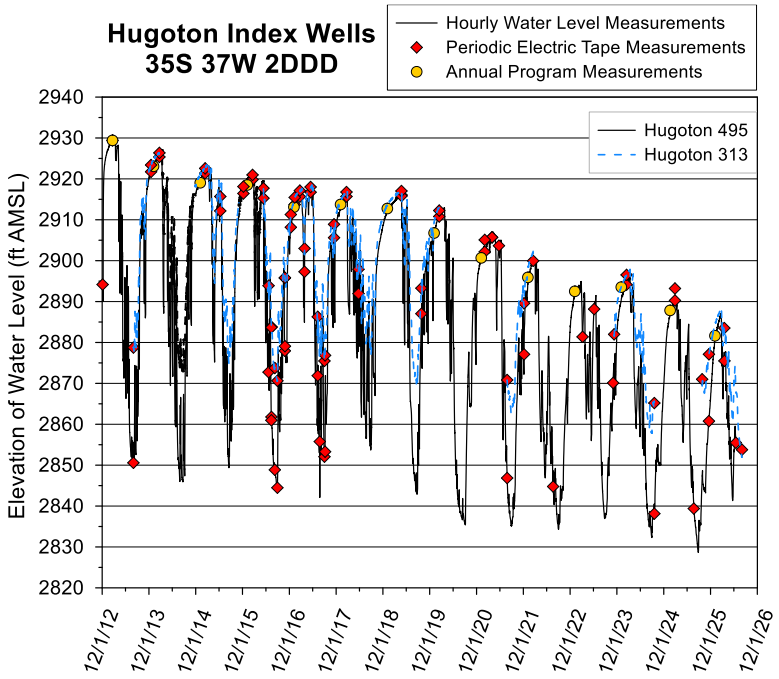


Figure 17. Hydrographs of Hugoton index wells—total data run to 6/16/26 for Hugoton 495 well. A water-level elevation of 2,900 ft corresponds to a depth to water of 200 ft below lsf. For the Hugoton 495 well, the top of the 10 ft screen is 485 ft below lsf (elevation of 2,615 ft). For the Hugoton 313 well, the top of the 10 ft screen is 303 ft below lsf (elevation of 2,797 ft). Bottom of the aquifer is 635 ft below lsf (elevation of 2,465 ft). Three-hour downward spike (13–15 ft drop) on 7/26/17 in the Hugoton 495 well is associated with transducer movement and considered spurious. Sensor failed in Hugoton 313 on 5/19/20 but, because of pandemic-limited travel, the failure was not recognized until 2/2/21. Sensor was replaced on 7/27/21 and failed again on 2/15/22; sensor was replaced on 11/9/23. Sensor failed again on 9/18/24; sensor and cable were replaced on 9/26/25. Hugoton 313 is not on telemetry and data are downloaded quarterly.

Major Points

- Two wells are monitored in a four-well nest.
- Large rapid drops and rises of water level following commencement and cessation of pumping, respectively, are indicative of confined conditions in both monitored intervals.
- Hydrographs indicate both intervals are affected by the same pumping stresses; the larger response in Hugoton 495 shows that interval is more heavily stressed, while the elevation difference between the water levels indicates that pumping has induced downward flow from the shallower interval.
- After the end of the irrigation season, water levels continue to recover until the start of the next season at both wells (water levels never stabilize).
- The water level in Hugoton 495 has declined 88.4 ft since January 2000 (decline rate of 3.4 ft/yr); see 2016 annual report (Butler, Whittemore et al., 2017) for further details.
- The 2025 minimum water level is the lowest since the start of monitoring (2012) at the Hugoton 495 index well.
- Transducer readings are in good agreement with manual measurements.

3.3.4 Kearny-Finney Index Well

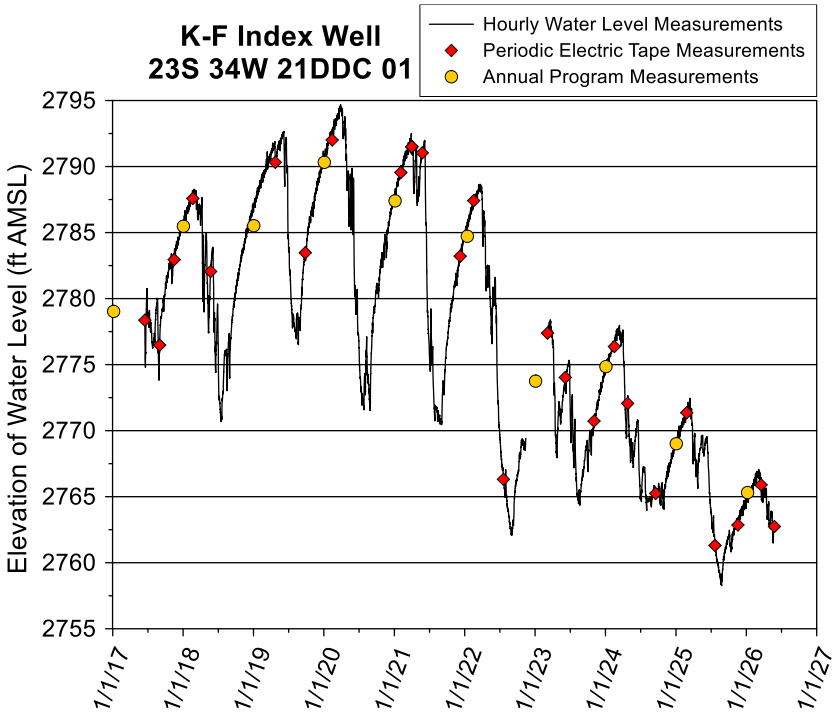


Figure 18. Kearny-Finney (K-F) index well hydrograph—total data run to 5/26/26. A water-level elevation of 2,775 ft corresponds to a depth to water of 186 ft below lsf. Nominal bottom of well is 300 ft below lsf (elevation of 2,661 ft), but the well is currently filled with sediments to 266 ft below lsf (elevation of 2,695 ft). Monitoring ceased on 11/13/22 after mice chewed through most of the sensor cable; cable was replaced and monitoring resumed on 3/6/23.

Major Points

- Relatively large amplitude fluctuations superimposed on the water levels are an indication of unconfined conditions.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The annual water-level elevation measurement has declined 72.9 ft since January 2008 (-4.1 ft/yr).
- Minimum water-level elevation for 2025 was the lowest since the start of monitoring.
- The 2025 total water use (1 mi, 2 mi, and 5 mi radii centered on well) was the highest among the index wells. Virtually all of the pumping was for irrigation (100%, 100%, and 97.4%, respectively).
- Transducer readings are in relatively good agreement with electric-tape measurements; 2019 annual measurement appears to be in error.

3.3.5 Liberal 436 Index Well

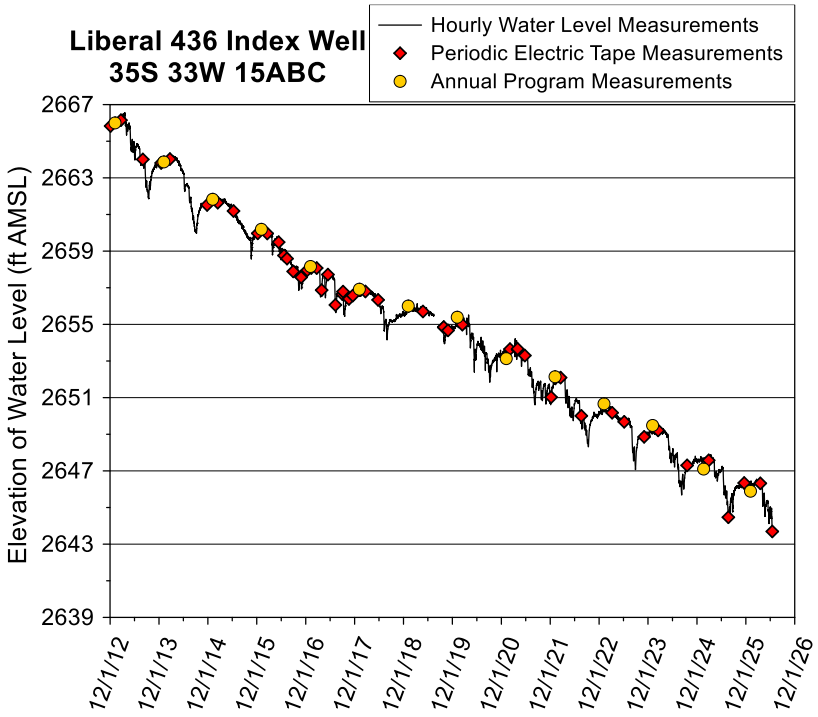


Figure 19. Liberal 436 index well hydrograph—total data run to 6/16/26. A water-level elevation of 2,647 ft corresponds to a depth to water of 174 ft below lsf. The top of the 10 ft screen is 426 ft below lsf (elevation of 2,395 ft). Sensor failed on July 6, 2019; a new sensor was installed on September 27, 2019.

Major Points

- One well is monitored in a four-well nest. Formerly, Liberal 160 well also was monitored, but that stopped on 12/26/18 as the monitoring provided very limited information.
- The hydrograph form and the relatively small (less than 0.35 ft) amplitude fluctuations superimposed on water levels indicate confined conditions.
- After the end of the irrigation season, water levels recover to a near-stable value that is generally well below the level at the start of the pumping season; this pattern is an indication of limited lateral flow to the well (see Butler, Knobbe et al., 2021).
- The water level in Liberal 436 (annual measurement) has dropped every year since January 2000, creating a downward stair-stepping pattern, for a total decline of 37.1 ft (rate of 1.4 ft/yr).
- The 2025 total water use (1 mi radius centered on well) was the lowest among the index wells; 2025 municipal water use (2 mi radius centered on well) was the second highest of any of the index wells.
- Transducer readings are in good agreement with electric-tape measurements, but annual program measurements appear to have greater error over the last several years.

3.3.6 Meade County Index Well

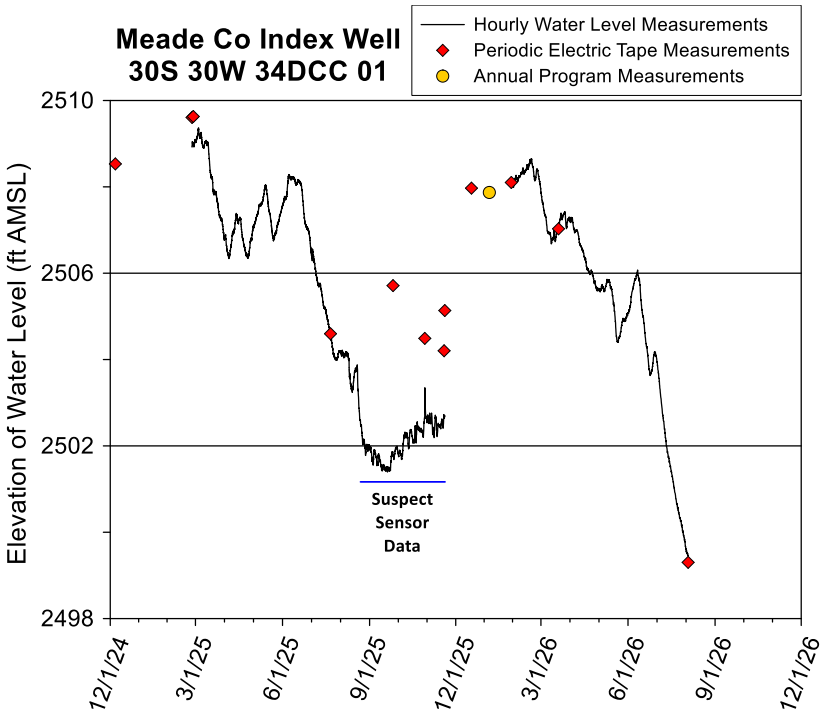


Figure 20. Meade County index well hydrograph—total data run to 8/03/26. A water-level elevation of 2,508 ft corresponds to a depth to water of 249 ft below lsf. The top of the 40 ft screen is 420 ft below lsf (elevation of 2,337 ft). The bottom of the well is 457 ft below lsf (elevation of 2,300 ft); the base of the aquifer is 454 ft below lsf (elevation of 2,303 ft). Sensor began to fail sometime after the 7/21/25 manual measurement. Sensor and cable were replaced on 1/28/26.

Major Points

- Further monitoring is needed to assess hydraulic conditions in the screened interval.
- It is difficult to distinguish the impact of nearby wells turning on and off.
- Based on manual measurements at a nearby well (T30S R30W 28 ABB 01), the water level has dropped 122.4 ft since 1/16/80 (2.7 ft/yr) and 22.6 ft in the last decade (2.3 ft/yr).
- After replacement of the sensor and cable on 1/28/26, the manual measurements have been in good agreement with the transducer reading.

3.3.7 Rolla 366 Index Well

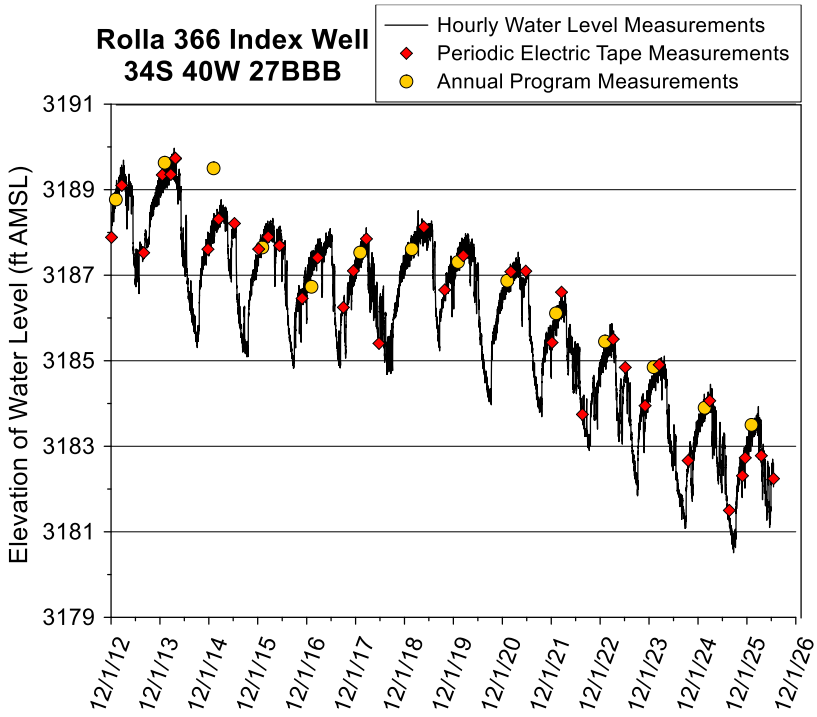


Figure 21. Rolla 366 index well hydrograph—total data run to 6/17/26. A water-level elevation of 3,185 ft corresponds to a depth to water of 190 ft below lsf. The top of the 10 ft screen is 356 ft below lsf (elevation of 3,019 ft), and the bottom of the aquifer is 399 ft below lsf (elevation of 2,976 ft). Note the suspect 2015 annual program measurement.

Major Points

- The hydrograph form and the relatively large (up to 0.7 ft) amplitude fluctuations superimposed on water levels indicate unconfined conditions.
- The effect of individual wells turning on and off is clearly visible on the hydrograph, indicating that pumping wells are in relatively close proximity to and in good hydraulic connection with the index well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The minimum water-level elevation in 2025 was the lowest since monitoring began in late 2012.
- The water level (annual measurement) has declined 13.5 ft since January 2000 (decline rate of 0.5 ft/yr).
- Transducer readings are in good agreement with electric-tape measurements but in poorer agreement with some of the annual measurements.

3.3.8 Sand Hills Index Well

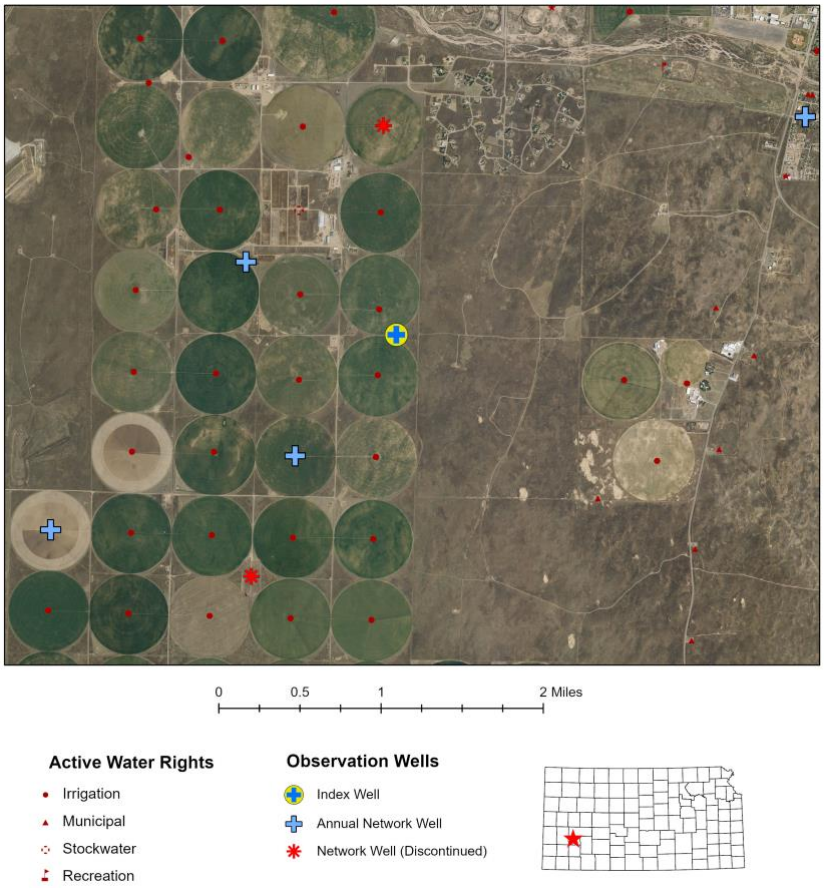


Figure 22. Aerial view of the Sand Hills index well, nearby annual program wells, and points of diversion.

Figure 22 is an aerial view of the Sand Hills index well site (T. 24 S., R. 33 W., 27 DDC) at a scale that shows the site of the new index well, four additional annual program wells, and wells with active water rights. The WWC-5 form (drillers' log) for this well is in the appendix.

An integrated pressure-transducer and datalogger unit was installed on 8/18/26, and a telemetry unit will be installed in fall 2026. This well will become part of the annual cooperative network program.

3.3.9 Satanta Site

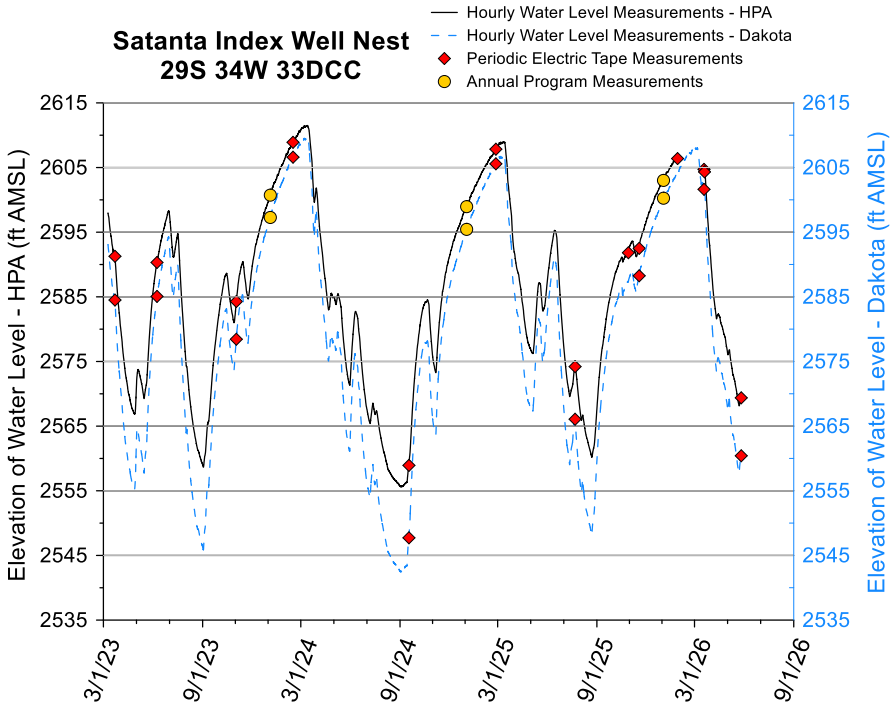


Figure 23. Satanta site hydrographs—total data run to 5/26/26. A water-level elevation of 2,575 ft corresponds to a depth to water of 405 ft below lsf. The top of the 20 ft screen in the HPA is 500 ft below lsf (elevation of 2,480 ft), and the top of the 20 ft screen in the Dakota is 600 ft below lsf (elevation of 2,380 ft). The bottom of the HPA is estimated to be at 520 ft below lsf (elevation of 2,460 ft); a 20-ft bentonite seal was placed in the annular space at 530–550 ft (just below the HPA-Dakota boundary). The well log indicates that the screened intervals in the HPA (sandy clay) and the Dakota (yellowish clay) are in lower permeability sediment. Break in HPA monitoring from 1/28/26 to 3/17/26 was due to mice eating through most of the cable.

Major Points

- The HPA and Dakota hydrographs are approximately parallel with one another, with the Dakota appearing to have larger drawdown in response to nearby pumping. All indications are that the bentonite seal has isolated the two screened intervals. Nearby pumping wells are likely screened in both aquifers.
- The hydrograph form and the relatively small (less than 0.35 ft) amplitude fluctuations superimposed on water levels indicate confined conditions in both wells.
- Transducer readings are in good agreement with manual measurements.
- The water pumped from the HPA well on 9/14/22 was fresh; total dissolved solids (TDS) concentration in samples collected at two different pumping times was 691 mg/L (both times), and chloride and sulfate concentrations were 104–109 mg/L and 203 mg/L (both times), respectively. The water pumped from the Dakota well was slightly saline; TDS concentrations were 1,442–1,572 mg/L, and the chloride and sulfate concentrations were 530–640 mg/L and 207–216 mg/L, respectively.

3.3.10 Ulysses Site

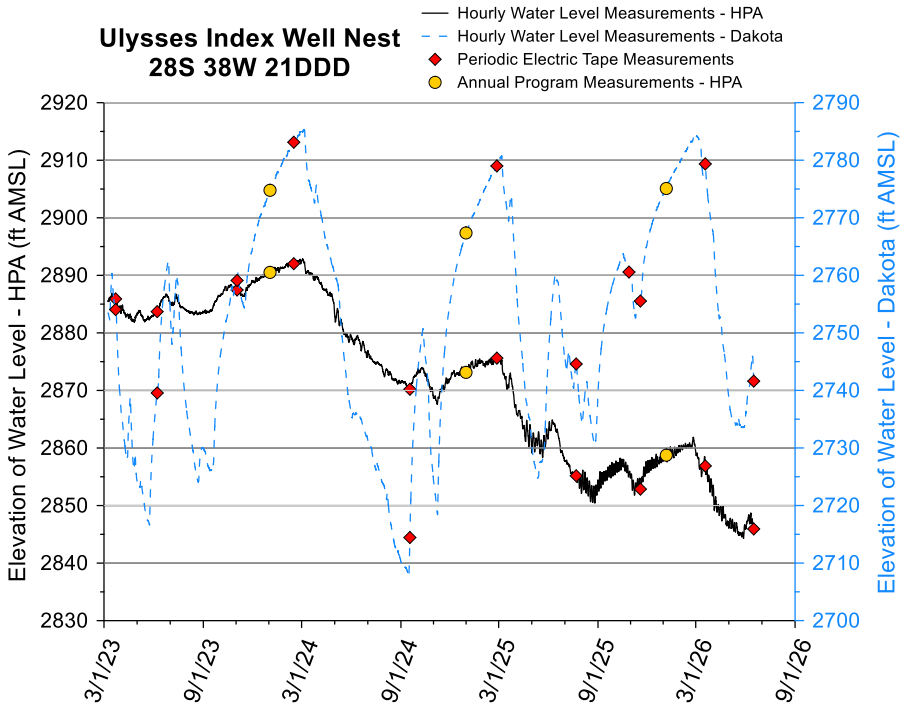


Figure 24. Ulysses site hydrographs—total data run to 6/16/26. A water-level elevation of 2,860 ft in the HPA well corresponds to a depth to water of 250 ft below lsf; a water-level elevation of 2,750 ft in the Dakota well corresponds to a depth to water of 360 ft below lsf. The top of the 20 ft screen in the HPA is 425 ft below lsf (elevation of 2,685 ft), and the top of the 20 ft screen in the Dakota is 560 ft below lsf (elevation of 2,550 ft). The bottom of the HPA is estimated to be at 445 ft below lsf (elevation of 2,665 ft); a 14-ft bentonite seal was placed in the annular space at 450–464 ft just below the HPA-Dakota boundary. The well log indicates that the screened intervals in both the HPA (fine to medium sand) and the Dakota (sandstone) appear to be in relatively good aquifer material.

Major Points

- The HPA and Dakota hydrographs display similar responses to pumping, with the Dakota well having much larger drawdown in response to nearby pumping. All indications are that the bentonite seal has isolated the two screened intervals. Some nearby pumping wells appear to be screened in both the Dakota and the HPA.
- High-frequency fluctuations in the HPA well from the spring of 2025 onward appear to be a product of nearby intermittent pumping.
- Transducer readings are in reasonable agreement with manual measurements.
- The water pumped from the HPA well on 11/12/22 was fresh (but nearly slightly saline); TDS concentrations collected at three different pumping times were 861–1,009 mg/L, and chloride and sulfate concentrations were 412–525 mg/L and 253–277 mg/L, respectively. The water pumped from the Dakota well was slightly saline; TDS concentrations collected at three different pumping times were 1,289–1,892 mg/L, and the chloride and sulfate concentrations were 794–1,249 mg/L and 182–206 mg/L, respectively. Concentrations decreased in consecutive samples from the Dakota well, suggesting that fresher water might have been drawn downward from the HPA, as also indicated by the hydrograph during the irrigation pumping season.

3.3.11 Willis Water Technology Farm Index Well

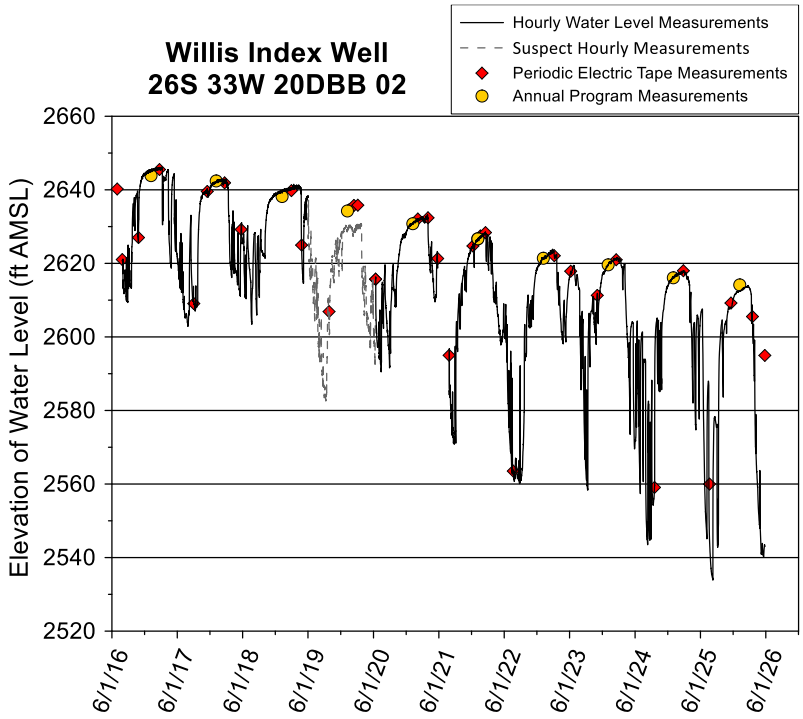


Figure 25. Willis Water Technology Farm index well hydrograph—total data run to 5/26/26. A water-level elevation of 2,620 ft corresponds to a depth to water of 320 ft below lsf. The top of the 220 ft screen is 262 ft below lsf (elevation of 2,678 ft), and the bottom of the aquifer is 502 ft below lsf (elevation of 2,438 ft). The first electric-tape measurement was taken before continuous monitoring began. The lack of agreement between manual and transducer measurements from September 2019 to June 2020 is a result of a miscalibrated transducer (dashed line indicates transducer data during this period). Telemetry ceased operating on 2/9/21 due to cable damage, and sensor ceased operating on 5/25/21; repaired cable and sensor were installed on 7/28/21.

Major Points

- The relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the latter stages of the recovery period, indicate unconfined conditions.
- The effect of wells turning on and off is clearly visible on the hydrograph, indicating pumping wells are in relatively close proximity to and in good hydraulic connection with the index well.
- Each year, the maximum recovered water level is below that of the preceding year, creating a downward stair-stepping pattern. Some years, water levels recover to a near stable value, while in other years, the recovery continues until the start of the next irrigation season. Water level has fallen 28.3 ft since January 2018, a rate of decline of approximately 3.5 ft/year. The minimum water level for 2025 was the lowest since the start of monitoring in 2016, and for 2026 it will be a number of feet lower. The water table appears to be moving into less transmissive materials as the declines during the pumping season in the last three years are larger than earlier despite the much lower pumping volumes.
- Transducer readings are in good agreement with manual measurements except for the 2017 and 2019 annual measurements, the 7/21/25 and 5/26/26 periodic etape measurements, and from February 2019 to June 2020 (period of use of miscalibrated transducer – see fig. 25 caption).

3.4 GMD4 Index Wells

Eleven index wells are located in GMD4 (fig. 26), eight of which have telemetry equipment that allows real-time viewing of data. The Thomas County index well was one of the original 2007 index wells and had telemetry capabilities from the start. Monitoring with telemetry began at the Colby, Seegmiller Sheridan-6 (SD-6) LEMA, Sherman County, Steiger SD-6 LEMA, and Sherman County 2 index wells in 2015, 2016, 2017, 2021, and 2022, respectively. The Brownville and Cheyenne County index wells began operating in June 2024 and July 2025, respectively. Table 4 summarizes characteristics of these wells. Further details concerning these wells are given in the 2016, 2021, and 2024 annual reports (Butler, Whittemore et al., 2017; Butler et al., 2022; Butler et al., 2025), and the online appendices for this report (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml).

Table 4. Characteristics of the GMD4 index well sites (water use is for irrigation unless noted otherwise).

Site	2026 WL elev. (ft)[a]	2026 Saturated thickness (ft)	Bedrock depth (estimated ft below land surface)	Screened interval (ft below land surface)	2025 Water Use (ac-ft)		
					1 mi radius circle	2 mi radius circle	5 mi radius circle
Brownville	3,209.2	110.2	260	202–262	713	2,031[b]	3,551[c]
Cheyenne	3,340.1	124.1	247	205-245	659	2,435	7,378
Colby	3,019.8	92.8[d]	250–300	156–175	472[e]	2,161[f]	10,132[g]
SD-6 Baalman	2,700.1	69.1	262	260–270	694	2,795	16,539[h]
SD-6 Beckman[i]	2,672.6[i]	[j]	[j]	[j]	1,084	3,598[k]	15,155[l]
SD-6 Moss[i]	2,617.7[i]	47.7	243	205–245	453	2,942	15,102[m]
SD-6 Seegmiller	2,729.3	65.3	265	225–265	958	3,815	18,673[n]
SD-6 Steiger	2,840.7	56.7	177	145–185	230	1,188[o]	11,329[p]
Sherman	3,609.0	139.0	323	310–320	1,185	2,553	9,454[q]
Sherman 2[i]	3,262.5[i]	113.5	275	240–280	253	1,915	10,365[r]
Thomas	2,966.5	63.1	284	274–284	785	2,283	10,443

[a] 2026 annual tape water-level measurements from WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/).
[b] Includes 1 ac-ft of non-irrigation stock water.
[c] Includes 29 ac-ft of non-irrigation stock water.
[d] Based on bedrock depth of 250 ft below lsf.
[e] Includes 276 ac-ft of municipal water.
[f] Includes 1,220 ac-ft of municipal water and 329 ac-ft of other water.
[g] Includes 1,375 ac-ft of municipal water, 329 ac-ft of other water, and 15 ac-ft of non-irrigation stock water.
[h] Includes 851 ac-ft of non-irrigation stock water.
[i] Not an annually measured index well; 2026 water-level measurements estimated from sensor data on 1/2/2026 from 0800 to 1700 at Moss and Sherman 2; 12/9/2025 etape measurement used at Beckman because sensor battery failed.
[j] Well construction information not available.
[k] Includes 282 ac-ft of non-irrigation stock water.
[l] Includes 794 ac-ft of non-irrigation stock water.
[m] Includes 679 ac-ft of non-irrigation stock water, 1 ac-ft of industrial water, and 352 ac-ft of municipal water.
[n] Includes 614 ac-ft of non-irrigation stock water.
[o] Includes 51 ac-ft of non-irrigation stock water.
[p] Includes 68 ac-ft of non-irrigation stock water and 6 ac-ft of recreational water.
[q] Includes 102 ac-ft of recreational water.
[r] Includes 144 ac-ft of non-irrigation stock water.

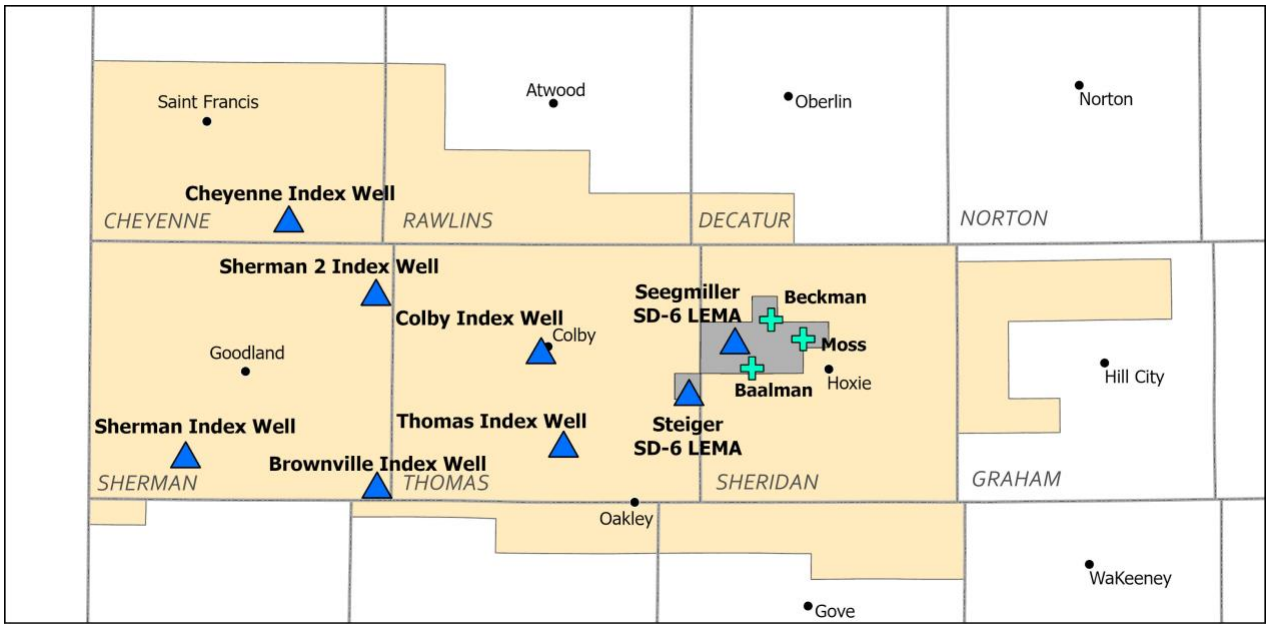


Figure 26. Map of index wells in GMD4. Triangles designate wells with telemetry equipment, and plus signs designate wells without telemetry equipment. Data from wells with telemetry equipment can be viewed in real time on the KGS website (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml); data from wells without telemetry equipment are periodically downloaded (typically quarterly) and posted on the KGS website. Gray shaded area is the Sheridan-6 LEMA.

3.4.1 Brownville Index Well

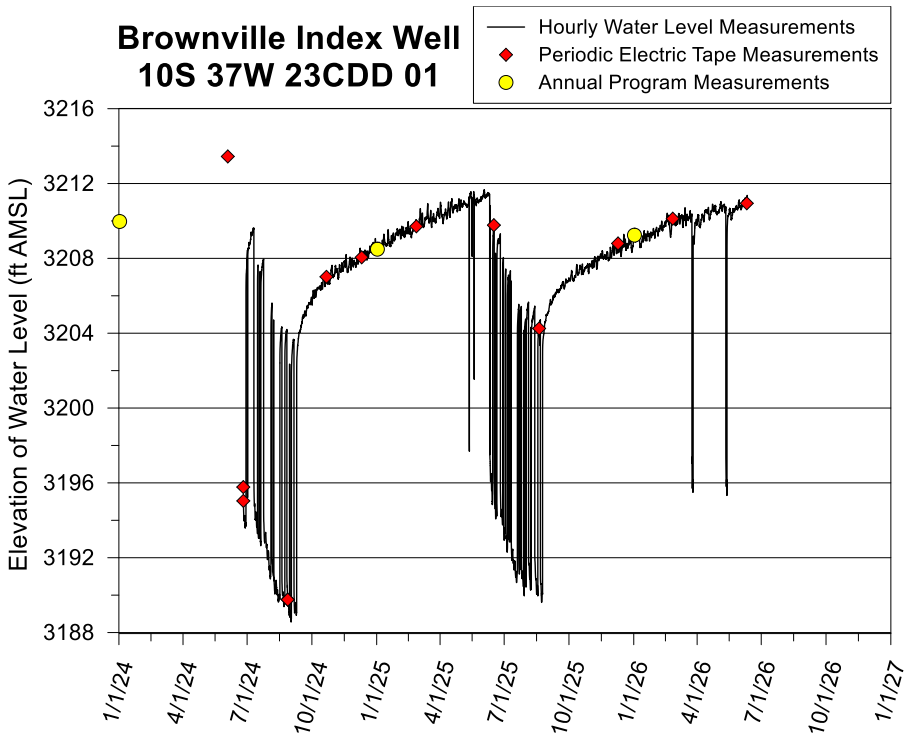


Figure 27. Brownville index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,208 ft corresponds to a depth to water of 151 ft below lsf. The top of the 60 ft screen is 202 ft below lsf (elevation of 3,157 ft), and the bottom of the aquifer is 260 ft below lsf (elevation of 3,099 ft). There is a 2 ft sump below the bottom of the aquifer.

Major Points

- The hydrograph form and the relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions.
- The effect of individual wells turning on and off is clearly visible, indicating pumping wells are in relatively close proximity to and in good hydraulic connection with the index well (closest irrigation well is within a few hundred feet of the index well).
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The 2025 total water use (5 mi radius centered on well) was the second lowest of all index wells.
- Transducer readings are in good agreement with manual measurements.
- Prior to the start of hourly monitoring, the annual measurements revealed an 8.9 ft increase in water level between 2017 and 2021, which is the largest increase observed in any index well in western Kansas. Unlike the Steiger index well, which had a large increase (greater than 7.5 ft in 2018 and 2019) but then declined to near starting conditions over the next two years, the Brownville index well has declined only 3.1 ft since 2021.

3.4.2 Cheyenne County Index Well

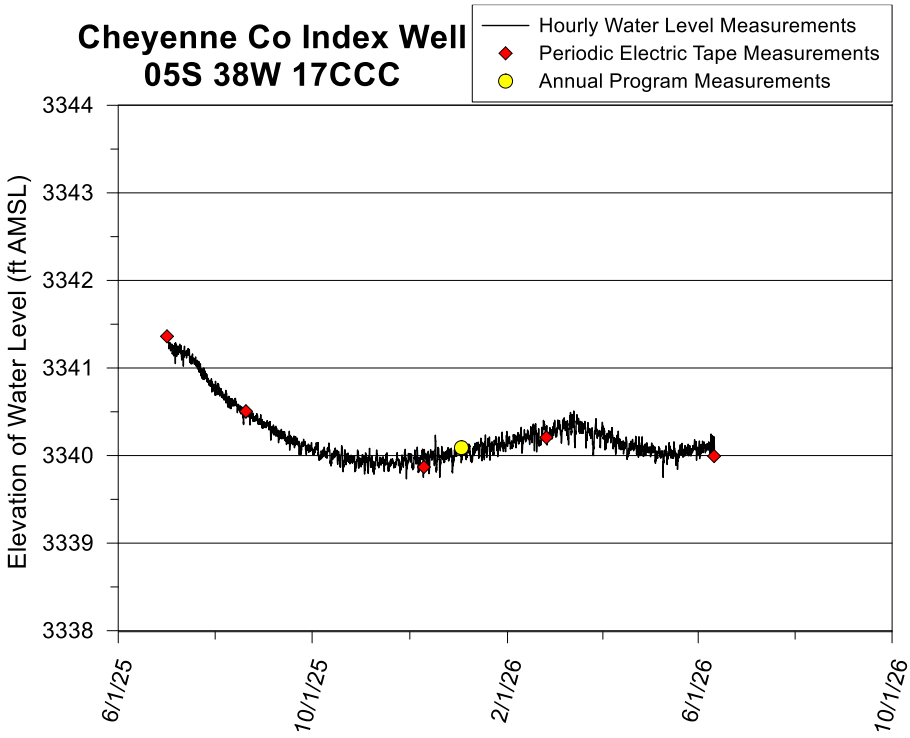


Figure 28. Cheyenne County index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,340 ft corresponds to a depth to water of 123 ft below lsf. The top of the 40 ft screen is 205 ft below lsf (elevation of 3,258 ft), and the bottom of the aquifer is 247 ft below lsf (elevation of 3,216 ft).

Major Points

- Further monitoring is needed to assess hydraulic conditions in the screened interval.
- The influence of individual nearby pumping wells is not discernible; water-level response appears to be a product of regional, more distant pumping.
- The low-amplitude and high-frequency undulations observed throughout the record are likely produced by a nearby domestic well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize). Except for domestic wells, all of the water pumped within five miles of the index well is used for irrigated agriculture.
- Transducer readings are in good agreement with manual measurements.

3.4.3 Colby Index Well

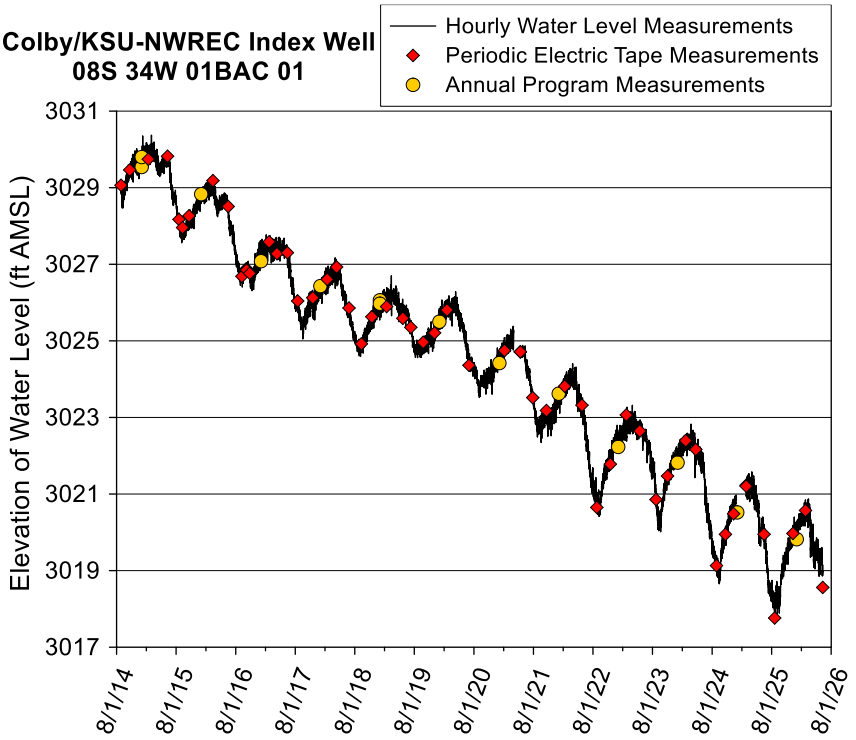


Figure 29. Colby index well hydrograph—total data run to 6/10/26. A water-level elevation of 3,021 ft corresponds to a depth to water of 156 ft below lsf. Total depth of the well is 175 ft below lsf (elevation of 3,002 ft). The screened interval extends from 156 to 175 ft below lsf. The base of the aquifer is estimated to be 250–300 ft below lsf (Butler, Whittemore et al., 2017). Sensor failed on 4/1/21 and was replaced on 5/12/21; sensor failed on 12/27/24 and was replaced on 2/25/25.

Major Points

- The relatively large amplitude fluctuations superimposed on the water-level record indicate unconfined conditions.
- After the end of the irrigation season, water levels continue to recover until the start of the next season; apparent stabilization of water levels in late winter and early spring of 2017 appears to be a product of nearby pumping.
- The maximum recovered water level has declined each year during the monitoring period, giving a distinct stair-step character to the hydrograph.
- Based on annual water-level measurements, the water level has declined approximately 0.9 ft/yr over the monitoring period (since January 2015) and a total of 43.1 ft since January 1948. The declines in 2022 and 2024 were the largest during the monitoring period.
- The 2025 municipal water use (1 mi radius centered on well) was the highest of any of the index wells.
- Transducer readings are in good agreement with manual measurements.

3.4.4 SD-6 Baalman Index Well

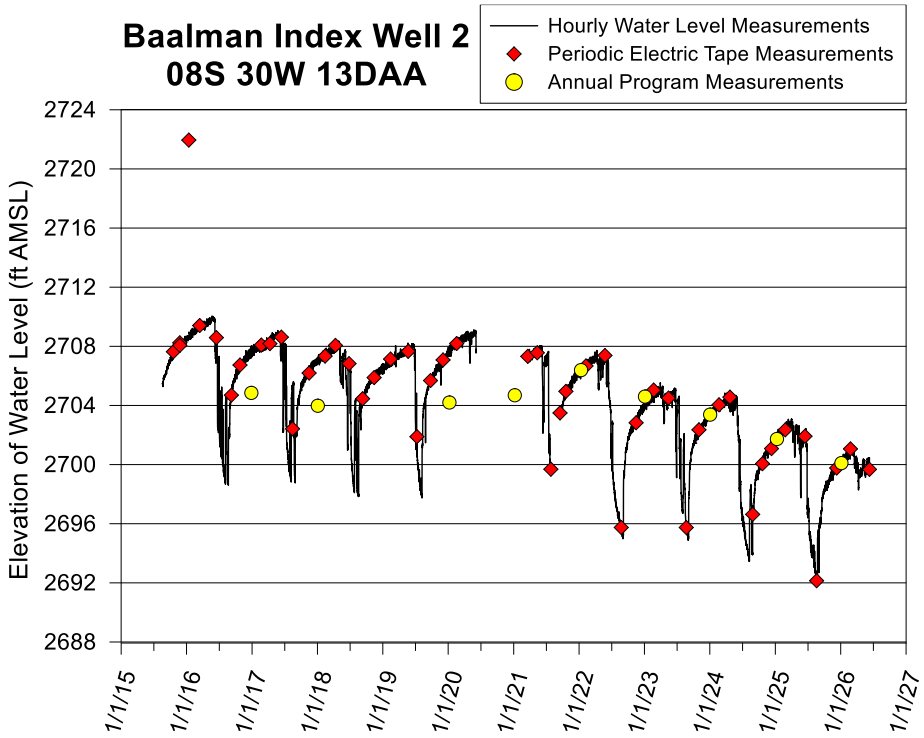


Figure 30. Baalman index well hydrograph—total data run to 6/10/26. A water-level elevation of 2,700 ft corresponds to a depth to water of 193 ft below lsf. The top of the 10 ft screen is 260 ft below lsf (elevation of 2,633 ft), and the bottom of the aquifer is 262 ft below lsf (elevation of 2,631 ft). The difference between the electric-tape and transducer measurements in January 2016 was caused by a malfunctioning electric tape. Sensor failed on 6/5/20 but, because of the pandemic and the lack of telemetry, the failure was not recognized until 2/4/21; a new sensor was installed on 3/20/21. Sensor was removed on 7/27/21 because of faulty cable. New sensor and cable installed on 9/16/21.

Major Points

- The hydrograph form and the relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions.
- The effect of individual wells turning on and off is clearly visible, indicating pumping wells are in relatively close proximity to and in good hydraulic connection with the index well.
- The maximum water level in 2025 was the lowest during the monitoring period, and the minimum water level in 2025 was far lower than previous minima during the monitoring period.
- In 2025, the water use per irrigated acre in the vicinity of the Baalman index well (2 mi radius) was 0.88 ft (10.6 in.)/acre. Since the establishment of the LEMA in 2013, the average annual water use per irrigated acre for this same area has been approximately 0.76 ft (9.2 in.)/acre.
- Transducer readings are in good agreement with periodic electric-tape measurements, except for the January 2016 measurement, but in poor agreement with early annual program measurements that may have been mistakenly taken in the previous Baalman well.

3.4.5 SD-6 Beckman Index Well

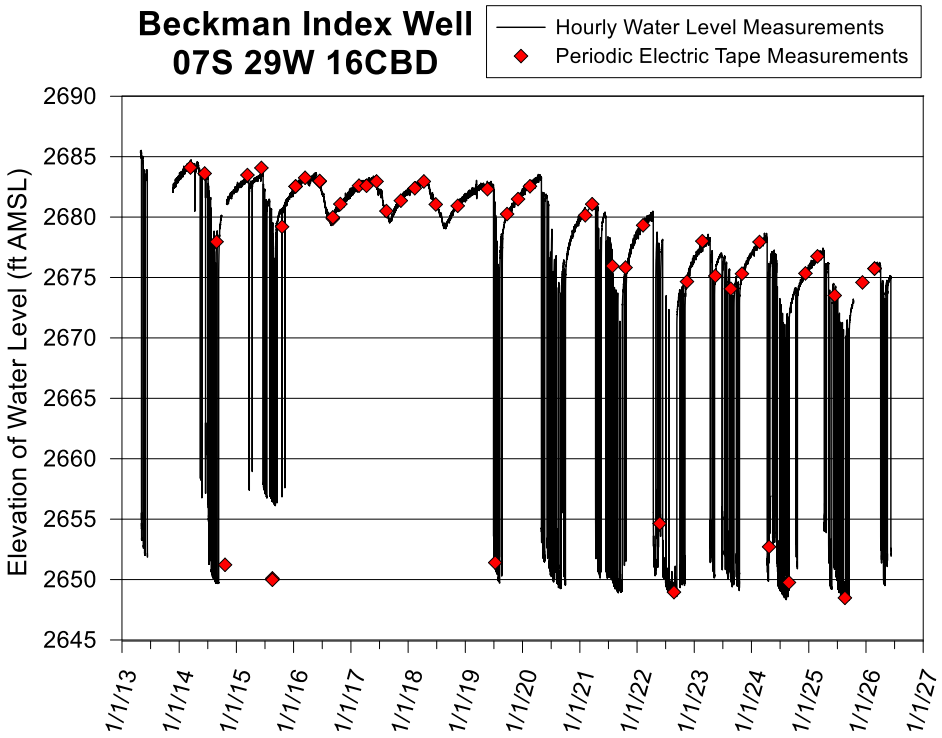


Figure 31. Beckman index well hydrograph—total data run to 6/10/26. A water-level elevation of 2,680 ft corresponds to a depth to water of 195 ft below lsf. The data gaps in 2013 and 2014 were caused by datalogger battery problems. The difference between the electric-tape measurement in the summer of 2015 and the hourly measurements is thought to be caused by a change in transducer calibration specifications associated with the resumption of monitoring in late October 2014. Measurements affected by datalogger overheating (mid-summer 2015 and earlier) are not displayed. Sensor failed on 2/4/21 and was replaced during site visit on 3/20/21. Sensor battery failed on 10/14/25 and a new sensor was installed on 2/24/26.

Major Points

- In 2025, the irrigation well adjacent to the Beckman index well was pumped for the seventh time in the last seven irrigation seasons and the tenth time since the establishment of the SD-6 LEMA.
- The hydrograph form and the relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- In 2025, the water use per irrigated acre in the vicinity of the Beckman index well (2 mi radius) was 0.89 ft (10.6 in.)/acre, the fourth highest since the SD-6 LEMA was established. Since the establishment of the LEMA, the average annual water use per irrigated acre for this same area has been approximately 0.77 ft (9.2 in.)/acre.
- Transducer readings are in good agreement with manual measurements in the latter half of the monitoring period.

3.4.6 SD-6 Moss Index Well

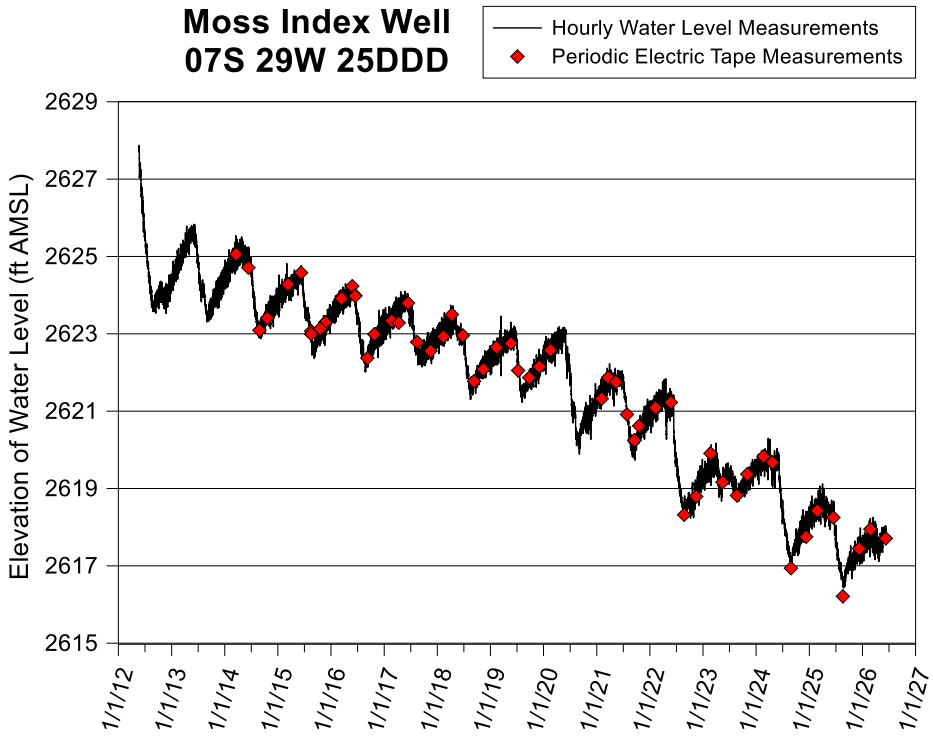


Figure 32. SD-6 Moss index well hydrograph—total data run to 6/10/26. A water-level elevation of 2,621 ft corresponds to a depth to water of 192 ft below lsf. The top of the 40 ft screen is 205 ft below lsf (elevation of 2,608 ft), and the bottom of the aquifer is 243 ft below lsf (elevation of 2,570 ft). Measurements affected by datalogger overheating (mid-summer 2015 and earlier) are not displayed.

Major Points

- The relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The minimum water-level elevation in 2025 was the lowest of the monitoring period. The hydrograph displays a downward stepping pattern most years.
- In 2025, the water use per irrigated acre in the vicinity of the Moss index well (2 mi radius) was 0.87 ft (10.5 in.)/acre. Since the establishment of the LEMA, the average annual water use per irrigated acre for this same area has been approximately 0.87 ft (10.4 in.)/acre.
- Transducer readings are in good agreement with manual measurements.

3.4.7 SD-6 Seegmiller Index Well

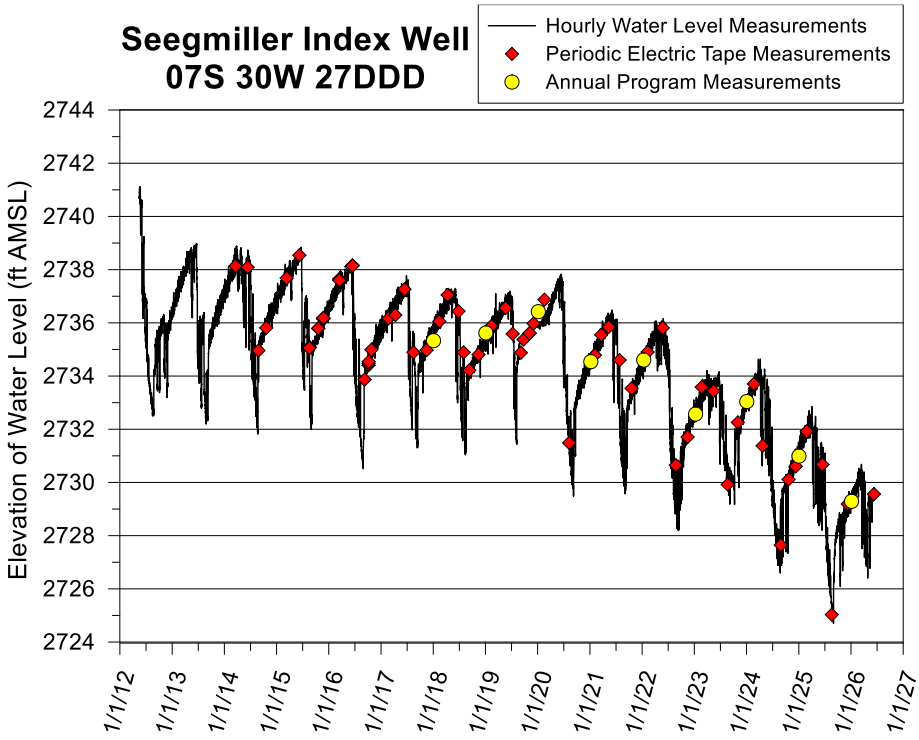


Figure 33. SD-6 Seegmiller index well hydrograph—total data run to 6/10/26. A water-level elevation of 2,730 ft corresponds to a depth to water of 199 ft below lsf. The top of the 40 ft screen is 225 ft below lsf (elevation of 2,704 ft), and the bottom of the aquifer is 265 ft below lsf (elevation of 2,664 ft). Measurements affected by datalogger overheating (mid-summer 2015 and earlier) are not displayed.

Major Points

- The hydrograph form and the relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, indicate unconfined conditions.
- The effect of individual wells turning on and off is clearly visible on the hydrograph, indicating pumping wells in relatively close proximity to and in good hydraulic connection with the index well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The minimum water-level elevation for 2025 is 1.9 ft below that of 2024, which had been the lowest observed during the monitoring period.
- In 2025, the water use per irrigated acre in the vicinity of the Seegmiller index well (2 mi radius) was 0.94 ft (11.2 in.)/acre, the third largest since the SD-6 LEMA was established (2020 and 2022 were larger, and 2024 was slightly lower). Since the establishment of the LEMA, the average annual water use per irrigated acre for this same area has been approximately 0.77 ft (9.2 in.)/acre.
- Transducer readings are in good agreement with manual measurements.

3.4.8 SD-6 Steiger Index Well

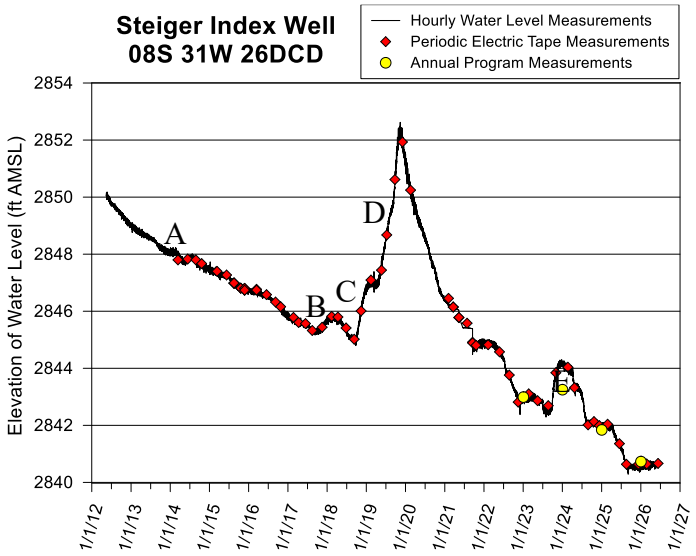


Figure 34. SD-6 Steiger index well hydrograph—total data run to 6/10/26. A water-level elevation of 2,842 ft corresponds to a depth to water of 119 ft below lsf. The top of the 40 ft screen is 145 ft below lsf (elevation of 2,816 ft), and the bottom of the aquifer is 177 ft below lsf (elevation of 2,784 ft). A–E defined in text. Measurements affected by datalogger overheating (mid-summer 2015 and earlier) are not displayed.

Major Points

- The fluctuations superimposed on the water levels are an indication of unconfined conditions but are of smaller magnitude than the other index wells in GMD4; this small magnitude typically indicates a relatively shallow depth to water.
- It is difficult to discern individual pumping seasons. The humps and troughs observed in the hydrograph at points marked A–E are likely related to a series of episodic recharge events and not pumping. The Steiger index well is located near an impoundment behind a small dam over an ephemeral stream channel; the impoundment appears to serve as a site of focused recharge.
- The effect of individual wells cutting on and off is difficult to discern.
- Except for a short decline early in the 2019 irrigation season, water levels rose continuously from the end of the 2018 pumping season to November 2019. This rise (greater than 7.5 ft) is one of only two definitive examples of episodic recharge that we have observed in the western Kansas index wells. The sharp decline since the peak in November 2019 indicates that the recharge was likely a localized event (i.e., water flows laterally to areas that did not receive the recharge) associated with the nearby impoundment (Butler, Knobbe et al., 2021). Comparison of the rise in water level with area rainfall indicates that the recharge pulse appears to have taken a little over a year to reach the water table.
- In 2025, the water use per irrigated acre in the vicinity of the Steiger index well (2 mi radius) was 0.92 ft (11.0 in.)/acre. Since the establishment of the LEMA, the average annual water use per irrigated acre for this same area has been approximately 0.86 ft (10.3 in.)/acre.
- Transducer readings are in good agreement with manual measurements except for the 2024 annual measurement, which appears to be in error.

3.4.9 Sherman County Index Well

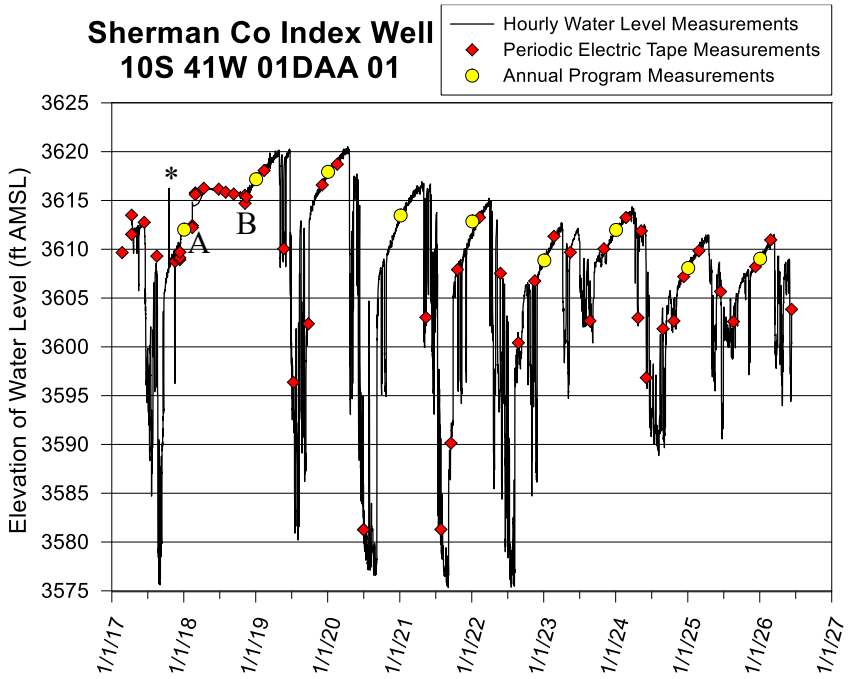


Figure 35. Sherman County index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,610 ft corresponds to a depth to water of 183 ft below lsf. The top of the 10 ft screen is 310 ft below lsf (elevation of 3,483 ft), and the bottom of the aquifer is 323 ft below lsf (elevation of 3,470 ft). The well has a 10 ft sump that extends to 330 ft below lsf. The asterisk indicates a single spurious reading; A and B are defined in text.

Major Points

- The hydrograph form and the relatively large amplitude fluctuations superimposed on the water levels, particularly evident during the recovery period, indicate unconfined conditions.
- The effect of individual wells turning on and off is clearly visible on the hydrograph, indicating pumping wells in relatively close proximity to and in good hydraulic connection with the index well.
- The well was not developed immediately after installation because of extreme cold. As a result, the screened interval gradually filled with fine-grained sediments. During the period from 2/13/18 (A on plot) to 11/7/18 (B on plot), the screened interval appears to have been in poor hydraulic connection with the aquifer. Well development on 11/7/18 (B) reestablished the hydraulic connections between the well and the aquifer (Butler, Knobbe et al., 2021).
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The minimum water-level elevation for 2025 was 1.8 ft higher than that of 2024 and was the second highest since the well was developed (B), generally reflecting less pumping in the area during 2025.
- Agreement between transducer readings and manual measurements varied over the monitoring period; agreement appears good after a new sensor was installed on 2/13/18 (A).
- The 2025 total water use (1 mi radius centered on well) was the second highest of any of the index wells; all of the pumping was for irrigation.

3.4.10 Sherman County 2 Index Well

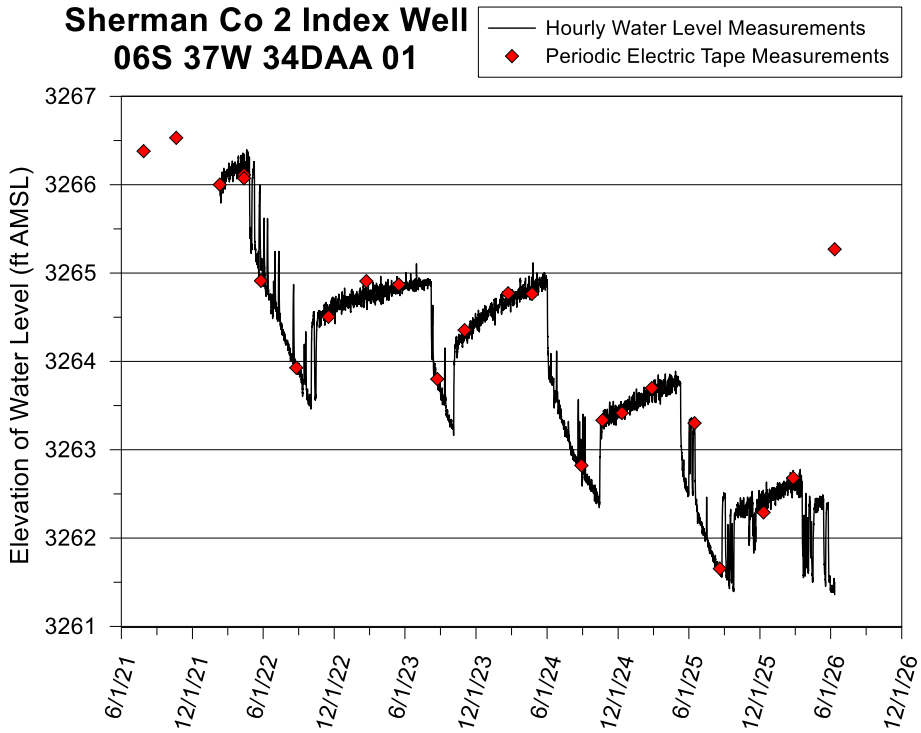


Figure 36. Sherman County 2 index well hydrograph—total data run to 6/11/26. A water-level elevation of 3,262 ft corresponds to a depth to water of 162 ft below lsf. The top of the 40 ft screen is 240 ft below lsf (elevation of 3,184 ft). The bottom of the aquifer is estimated to be 275 ft below lsf (elevation of 3,149 ft), and the bottom of the well is 276.3 ft below lsf (well appears to have 3.7 ft of material in the bottom; lower 5 ft of screen appear to be below the bottom of the aquifer). The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The hydrograph form during the irrigation season and the relatively large fluctuations superimposed on the water levels, particularly evident during the recovery period, are an indication of unconfined conditions.
- The effect of individual pumping wells is discernible, indicating that one or more of the nearby pumping wells are in good hydraulic connection with the index well.
- The linear form of the water-level decline during the 2022 and 2023 irrigation seasons is an indication of a laterally bounded system (Butler, Stotler et al., 2013). This could be produced by aquifer heterogeneity or nearby pumping wells.
- The minimum water-level elevation has declined each year during the monitoring period, giving a distinct stair-step character to the hydrograph.
- After in-field calibration, transducer readings are in good agreement with manual measurements since shortly after start of monitoring. The 6/11/2026 etape measurement appears to be in error.

3.4.11 Thomas County Index Well

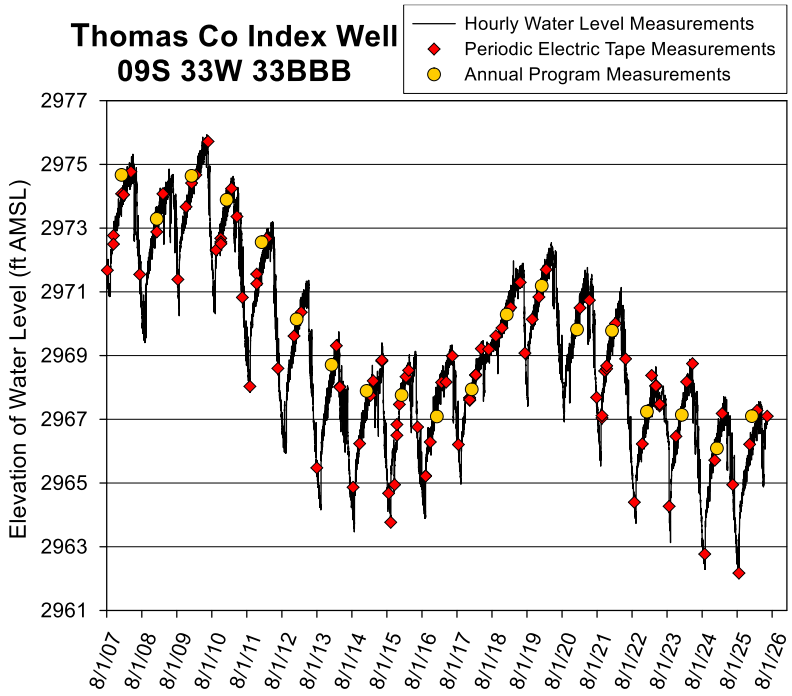


Figure 37. Thomas County index well hydrograph—total data run to 6/10/26. A water-level elevation of 2,967 ft corresponds to a depth to water of 220.4 ft below lsf. The top of the screen is 274 ft below lsf (elevation of 2,913.4 ft), and the bottom of the aquifer is 284 ft below lsf (elevation of 2,903.4 ft). The screen terminates at the bottom of the aquifer. No water-level data are available from 10/28/17 to 12/11/17 because of sensor failure. The in-field calibration approach described in Butler, Knobbe et al. (2021) has been applied to the transducer data to correct for sensor drift.

Major Points

- The hydrograph form, the relatively small change and rate of change in water level during each pumping and recovery season (despite eight high-capacity pumping wells within a mile of the index well), and the relatively large amplitude fluctuations superimposed on water levels indicate unconfined conditions.
- The effect of individual wells turning on and off is clearly visible on the hydrograph, indicating pumping wells in relatively close proximity to and in good hydraulic connection with the index well.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize).
- The minimum water level in 2025 was 0.3 ft lower than that in 2024, which had been the lowest since monitoring started in 2007.
- The 2018 water use (2 mi radius) was the lowest for the monitoring period because pumping stopped after a hailstorm in late spring 2018 destroyed crops in the vicinity of the index well; the next lowest water use was 2019 (wettest year during the monitoring period), when use was 1.9 times greater than that in 2018.
- Transducer readings are in good agreement with manual measurements after in-field calibration.

3.5 GMD5 Index Wells

Five index wells, all of which have telemetry equipment that allows real-time viewing of data, are in GMD5 (fig. 38). Table 5 summarizes characteristics of these wells. Further details concerning the Belpre and Larned wells are given in the 2016 (Butler, Whittemore et al., 2017) and 2018 (Butler et al., 2019) annual reports, respectively; information about the Rozel and Trousdale wells is provided in the 2021 annual report (Butler et al., 2022); and information about the St. John well is provided in the 2023 annual report (Butler et al., 2024). Further information about all wells is given in the online appendices for this report (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml).

Table 5. Characteristics of the GMD5 index well sites (water use is for irrigation unless noted otherwise).

Site	2026 WL elev. (ft)[a]	2026 Saturated thickness (ft)	Bedrock depth (ft below land surface)	Screened interval (ft below land surface)	2025 Water Use (ac-ft)		
					1 mi radius circle	2 mi radius circle	5 mi radius circle
Belpre	2,040.45	135.4–160.4[b]	175–200[b]	89–109	838	2,589	14,471[c]
Larned	1,942.42	58.1	71	66–71	299[d]	2,454[e]	14,603[f]
Rozel	2,037.97	78.5[b]	125.5[b]	40–59 109–129	318	2,344	8,383[g]
St. John	1868.65	112.6[b]	142[b]	65–75	263	1,032	7,575[h]
Trousdale	2,047.76	103.0[b]	140[b]	47–57	847	3,361[i]	19,492[j]

[a] 2026 annual tape water-level measurements from WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/).

[b] Well not drilled to bedrock; depth to bedrock estimated from nearby well logs.

[c] Includes 9 ac-ft of municipal water.

[d] Includes 7 ac-ft of industrial water.

[e] Includes 138 ac-ft of non-irrigation stock water and 7 ac-ft of industrial water.

[f] Includes 257 ac-ft of non-irrigation stock water, 288 ac-ft of municipal water, and 7 ac-ft of industrial water.

[g] Includes 42 ac-ft of municipal water and 1 ac-ft of non-irrigation stock water.

[h] Includes 105 ac-ft of municipal water, 11 ac-ft of recreation water, 2 ac-ft of industrial water, 1 ac-ft of non-irrigation stock water, and 2 ac-ft of other use water.

[i] Includes 5 ac-ft of non-irrigation stock water.

[j] Includes 17 ac-ft of industrial water and 6 ac-ft of non-irrigation stock water.

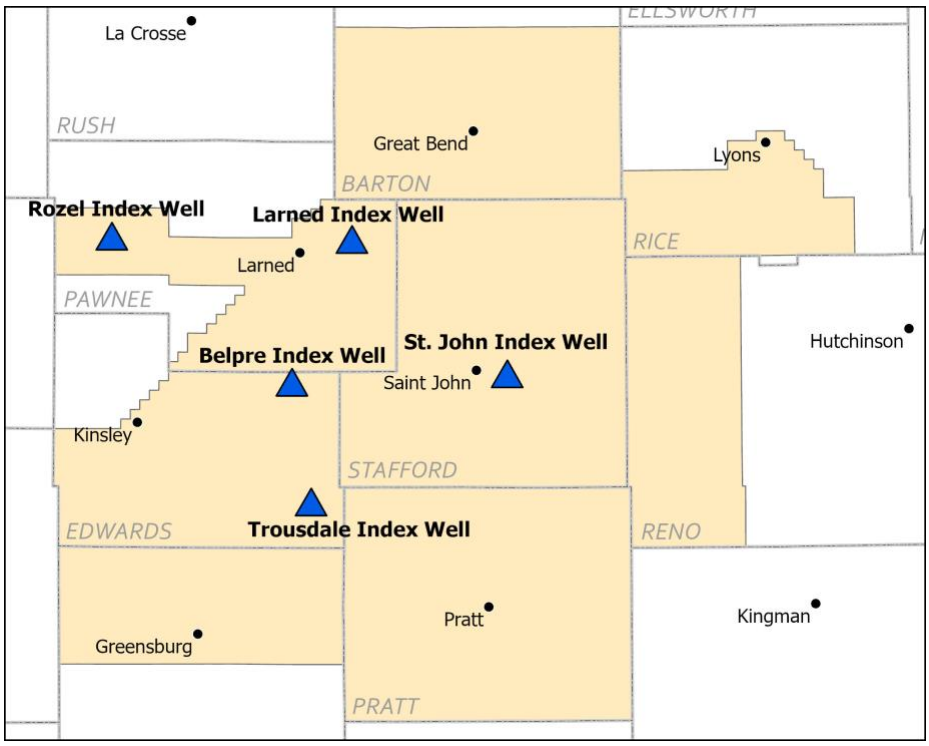


Figure 38. Map of index wells in GMD5. Data from all five wells can be viewed in real time on the KGS website (www.kgs.ku.edu/HighPlains/OHP/index_program/index.shtml).

3.5.1 Belpre Index Well

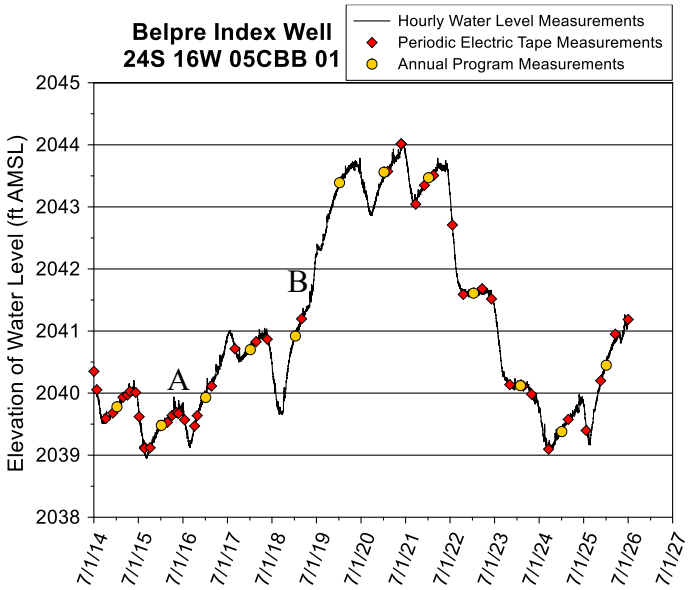


Figure 39. Belpre index well hydrograph—total data run to 7/1/26. A water-level elevation of 2,040 ft corresponds to a depth to water of 40 ft below lsf. The top of the 20 ft screen is 89 ft below lsf (elevation of 1,991 ft), and the bottom of the screen is 109 ft below lsf (elevation of 1,971 ft). The base of the aquifer is estimated to be 175–200 ft below lsf (elevation of 1,905–1,880 ft). A and B defined in text.

Major Points

- Small amplitude fluctuations superimposed on water levels indicate unconfined conditions with a relatively shallow depth to water.
- The effect of individual pumping wells cutting on and off is difficult to discern; the water-level response to pumping appears to be more integrated than at most of the index wells. Given the proximity of nearby pumping wells, this indicates that those wells are extracting water from intervals that are not in good hydraulic connection with the Belpre well, which apparently is screened below the interval used by most of the irrigation wells in the area.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize). The rise was very small and virtually non-existent after the end of the 2022 and 2023 irrigation seasons, respectively, because of drought conditions. This is an indication that vertical recharge is the primary driver of water-level rises at the well.
- The numerous upward spikes, such as marked by A, are local recharge events dissipated by lateral and vertical flow (Butler, Knobbe et al., 2021). Kinks in the plot, such as marked by B, were produced by regional recharge events from widespread precipitation.
- The water level has declined 10.1 ft since January 1988 (decline rate of 0.3 ft/yr) but 0 ft since January 2014.
- Transducer readings are generally in good agreement with manual measurements.

3.5.2 Larned Index Well

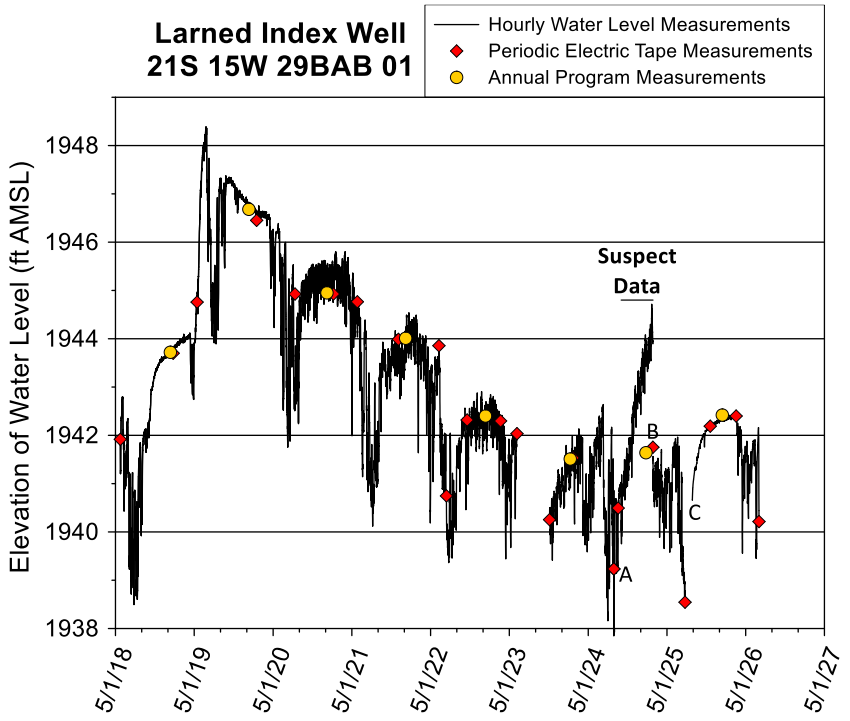


Figure 40. Larned index well hydrograph—total data run to 7/1/26. A water-level elevation of 1,942 ft corresponds to a depth to water of 13.3 ft below lsf. The top of the 5 ft screen is 66 ft below lsf (elevation of 1,889.3 ft), and the bottom of the screen, which is at the base of the aquifer, is 71 ft below lsf (elevation of 1,884.3 ft). Break in monitoring from 6/5/23 to 11/3/23 because of cable and transducer problems. A new transducer was installed on 8/27/24 (A) but malfunctioned and produced erroneous readings (e.g., 2.28 ft above 1/23/25 annual measurement). This transducer was replaced on 2/24/25 (B), but the readings were still noisy. Finally, on 8/6/25 (C), the transducer and cable were replaced, and the cabling was simplified. The noise level returned to pre-summer 2020 conditions.

Major Points

- Hydrograph form and small amplitude fluctuations superimposed on water levels (until the summer of 2020) indicate confined conditions. Much larger amplitude fluctuations after 7/16/20 were introduced by faulty monitoring and telemetry equipment. After a number of unsuccessful tries, the monitoring equipment was replaced and the telemetry system was reconfigured on 8/6/25.
- The effect of individual wells turning on and off is clearly visible on the hydrograph, indicating pumping wells in good hydraulic connection with the index well.
- The rapid increase in water level in May and June 2019 was produced by large flow events in the nearby Arkansas River (maximum discharge reached 5,720 ft^3/s with a stage increase greater than 9.9 ft at the end of May). The river was dry for over three months before this large flow.
- After the end of the 2018 irrigation season, water levels continued to recover until the start of the next season. After the end of the 2019 irrigation season, water levels continued to decline until near the start of the 2020 irrigation season. Water levels appeared to stabilize after the 2020–2022 and 2025 irrigation seasons, an indication of limited lateral flow to this portion of the aquifer. The 2022 recovery also may be affected by distant pumping in response to drought conditions. The 2023 recovery continued until the start of the 2024 irrigation season.

3.5.3 Rozel Index Well

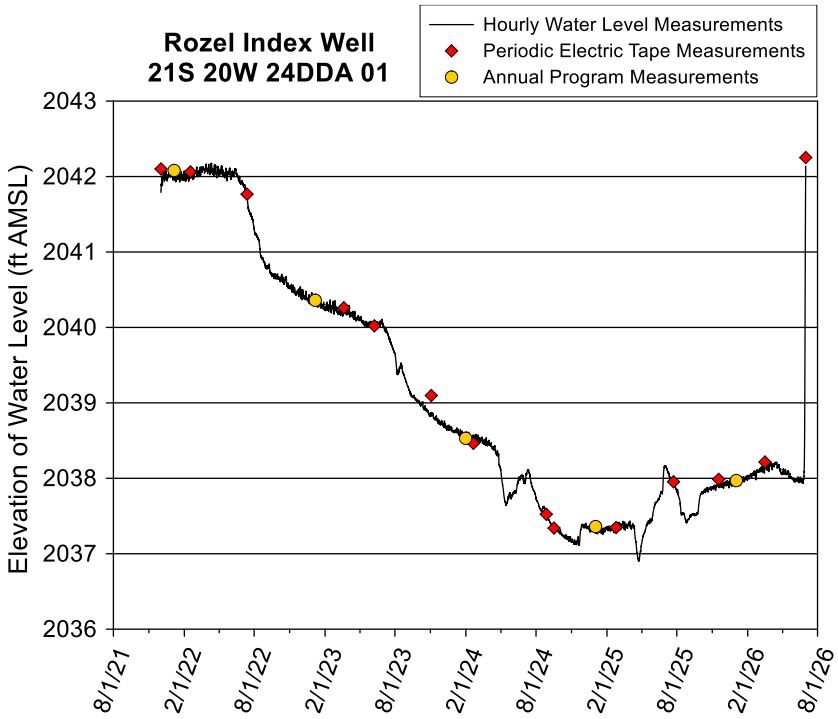


Figure 41. Rozel index well hydrograph—total data run to 7/1/26. A water-level elevation of 2,039 ft corresponds to a depth to water of 46 ft below lsf. Because a WWC5 form does not appear to have been filed for this well, there are no well construction details. A camera survey found that the screen started at 40 ft below land surface and ended at a sand plug at 59 ft (elevation of 2,026 ft).

Major Points

- The effect of individual pumping wells cutting on and off is difficult to discern; there appears to be a more integrated response to pumping.
- Water levels appeared to stabilize after the 2021 and 2024 irrigation seasons but continued to decrease after the 2022 and 2023 irrigation seasons. Drainage to the Pawnee River during years of low rainfall may be the reason for decreases during the 2022 and 2023 recovery periods.
- Water levels rose dramatically after a series of intense late June 2026 rainstorms. The stage of the Pawnee River at the Rozel gauge rose about 17 ft in three days.
- Based on annual program measurement, water levels have fallen 5.2 ft since late December 1984 for an average decline rate of 0.1 ft/yr. The decline rate between spring 2022 and spring 2025 was many times higher.
- Transducer readings are in good agreement with manual measurements except for one electric-tape measurement.

3.5.4 St. John Index Well

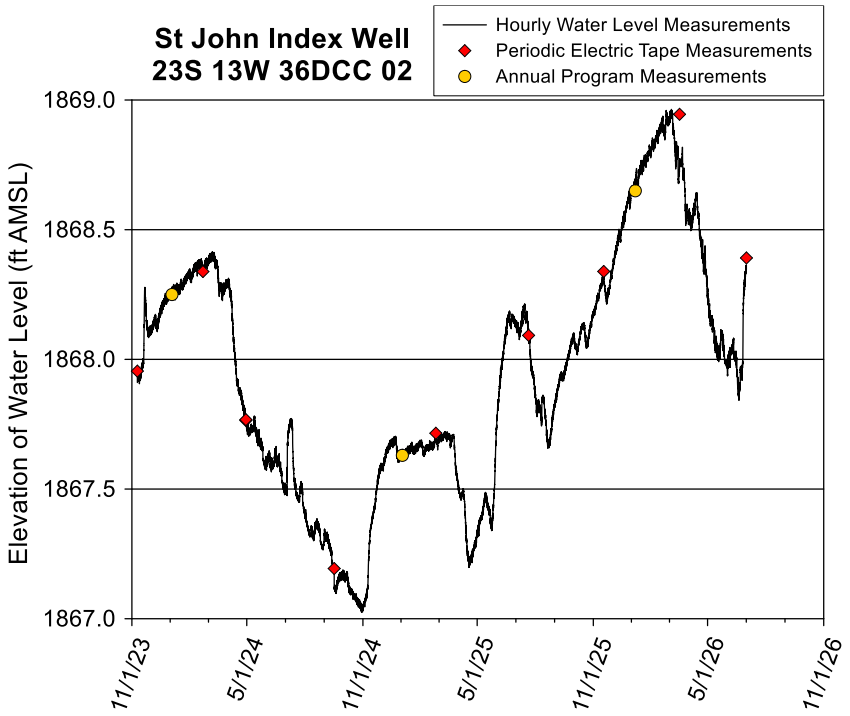


Figure 42. St. John index well hydrograph—total data run to 7/1/26. A water-level elevation of 1,868 ft corresponds to a depth to water of 30 ft below lsf. The top of the 10 ft screen is 65 ft below lsf (elevation of 1,833 ft). The bottom of the well is 75 ft below lsf (elevation of 1,823 ft); the base of the aquifer is 142 ft below lsf (elevation of 1,756 ft).

Major Points

- Although the effect of individual high-capacity wells cutting on and off is observable at certain times, the water-level response tends to be more integrated than at most other index wells. Recharge events are observable on the hydrograph (e.g., response to late June 2026 rainfall and to rainfall 25–50% above normal in 2025).
- Hydrograph form indicates unconfined conditions.
- The low-amplitude and high-frequency undulations observed throughout the record are likely produced by a nearby domestic well.
- Based on manual measurements, the water level has dropped 5.6 ft since 1/1/80 (0.1 ft/yr) and 2.0 ft in the last decade (0.2 ft/yr).
- Transducer readings are in good agreement with manual measurements.

3.5.5 Trousdale Index Well

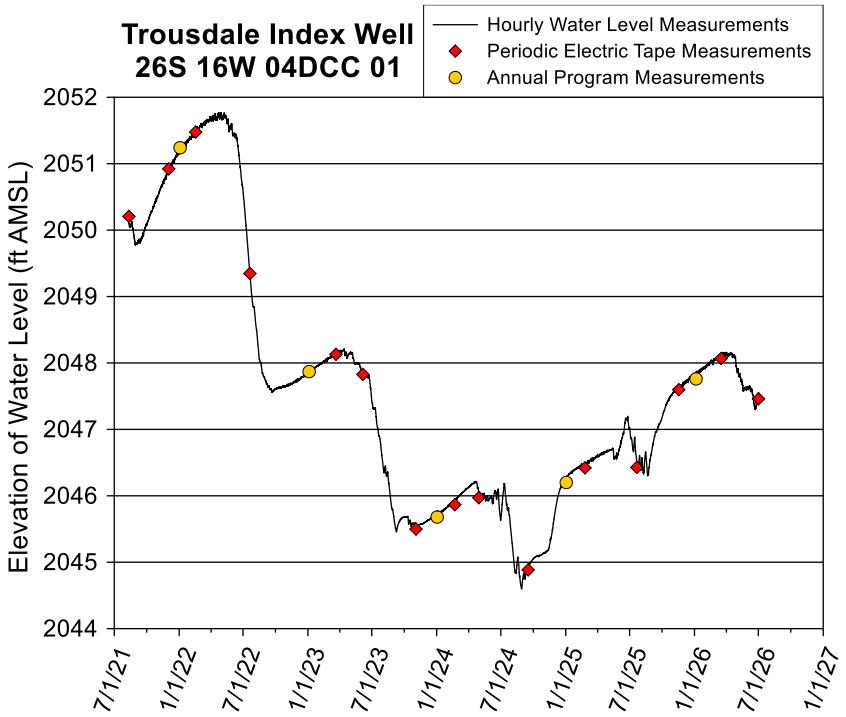


Figure 43. Trousdale index well hydrograph—total data run to 7/1/26. A water-level elevation of 2,046 ft corresponds to a depth to water of 38.8 ft below lsf. The top of the 10 ft screen is 47 ft below lsf (elevation of 2,037.8 ft). The bottom of the well is 57 ft below lsf (elevation of 2,027.8 ft); the base of the aquifer is at least 80 ft below the bottom of the well.

Major Points

- The effect of individual wells cutting on and off is difficult to discern, as the water-level response tends to be more integrated than at most other index wells. Recharge events are observable on the hydrograph. Further monitoring is needed to assess hydraulic conditions in the screened interval.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels never stabilize). The recovery after the end of the 2022 and 2023 irrigation seasons was much smaller than that after the other irrigation seasons because of drought conditions. The apparent stabilization of water levels in the spring of 2022 is likely a product of regional pumping.
- Based on annual program measurements, the water level has fallen 10.6 ft since January 2001 for a decline rate of 0.4 ft/yr. The water level rose 2.1 ft in the last two years because of greater precipitation (about 50% above normal rainfall in 2025). These are the first annual increases at the well since monitoring started.
- Transducer readings are in good agreement with manual measurements for the first 18 months of monitoring, but the agreement is lessening. This is an indication that the transducer needs to be recalibrated.

3.6 Expansion Wells

3.6.1 GMD1 Expansion Wells

Four expansion wells (SC-8 and wells 3–5) are now operating in GMD1 (table 6 and fig. 44). Originally, seven expansion wells were identified in GMD1, but the value of the information obtained from two of the wells (wells 2 and 6) did not merit continued participation in the index well program. In April of 2025, the owner of expansion well 1 decided to use that well for another purpose. As a result, monitoring equipment was removed and expansion well 1 is no longer part of the index well program. Monitoring at expansion well SC-8 (a former USGS recorder well) began in February 2012, monitoring at expansion wells 1 through 5 (existing wells; all but wells 4 and 5 were previously used for irrigation) began in late January 2017, and monitoring at expansion well 6 began in April 2018. The SC-8 well and wells 1–3 and 6 are part of the annual program. The expansion wells are not expected to be permanently monitored; sensors may be moved to other wells or continuous monitoring may be replaced by quarterly or annual measurements after sensors fail. We have had sensors fail at five of the seven sites. As a result, we now only continuously monitor expansion wells SC-8 and 4, while expansion wells 3 and 5 are measured quarterly. Expansion wells 1, 2, and 6 are measured only as part of the annual program. The barometer that had been a short distance below land surface at expansion well 3 has been moved to the Wichita County 2 index well. Additional information about the expansion wells can be found in Butler, Whittemore et al. (2017) and on the webpage for the GMD1 continuous monitoring wells expansion project (http://www.kgs.ku.edu/HighPlains/OHP/gmd_net/index.html).

Table 6. Characteristics of the GMD1 expansion well sites (water use is for irrigation unless noted otherwise).

Site	2026 WL elev. (ft)[a]	2026 Saturated thickness (ft)[b]	Bedrock depth (estimated ft below land surface)[b]	Screened interval (ft below land surface)	2025 Water Use (ac-ft)		
					1 mi radius circle	2 mi radius circle	5 mi radius circle
SC-8	2,846.3	83.3	174	[c]	305	963	6,307[d]
Site 3	3,423.5	20.5	220	[c]	26	716	7,239[e]
Site 4	3,534.5[f]	[g]	[g]	[c]	158	1,458	3,757[h]
Site 5	2,835.2[i]	24.2	158	[c]	156	1,426[j]	5,945[k]

[a] 2026 annual tape water-level measurements from WIZARD database (https://geohydro.kgs.ku.edu/geohydro/wizard/).
[b] Wells did not have WWC5 forms, so values are estimated from nearby wells with WWC5 forms.
[c] Information on screened interval not available for any of the wells.
[d] Includes 829 ac-ft of municipal water, 2 ac-ft of industrial water, and 325 ac-ft of non-irrigation stock water.
[e] Includes 17 ac-ft of municipal water and 57 ac-ft of non-irrigation stock water.
[f] Not an annually measured index well; 2026 water-level measurements estimated from sensor data on 01/5/2026 from 0800 to 1700.
[g] Lack of agreement among nearby WWC5 forms prevented estimation.
[h] Includes 695 ac-ft of non-irrigation stock water.
[i] Not an annually measured index well; water-level measurement from 2/25/2026 manual measurement.
[j] Includes 384 ac-ft of municipal water, 13 ac-ft of non-irrigation stock water, and 2 ac-ft of industrial water.
[k] Includes 829 ac-ft of municipal water, 202 ac-ft of non-irrigation stock water, and 2 ac-ft of industrial water.

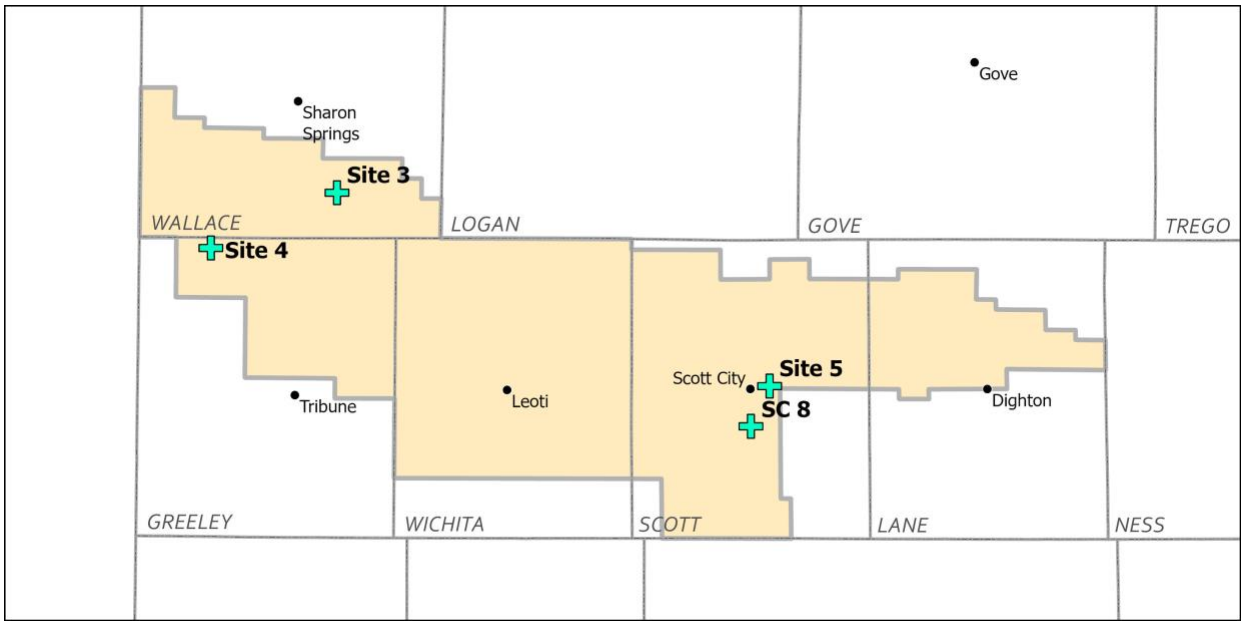


Figure 44. Map of GMD1 expansion wells.

3.6.1.1 SC-8 Site – Scott County

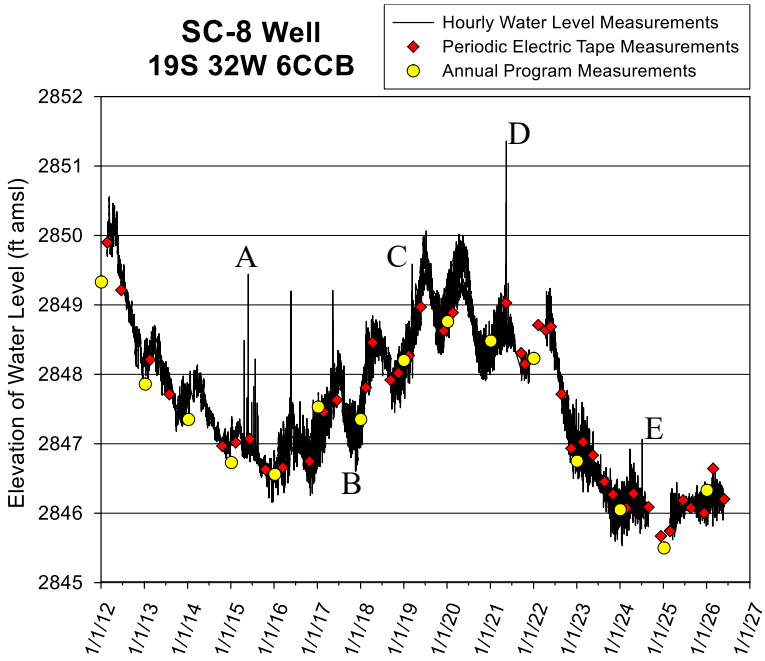


Figure 45. SC-8 well hydrograph—total data run to 5/29/26. A water-level elevation of 2,847 ft corresponds to a depth to water of 90 ft below lsf. Bottom of well is approximately 102 ft below lsf (elevation of 2,835 ft). Transducer measurements have been adjusted from earlier reports for an incorrect offset parameter (Butler, Whittemore et al., 2017). Transducer measurements were corrected for a sudden 4.9 ft apparent drop in water level on 7/11/19 and a sudden 4.7 ft apparent rise in water level on 9/25/19. Monitoring was temporarily suspended from 7/28/21 to 9/17/21, 11/26/21 to 4/13/22, and 8/28/24 to 12/11/24 due to sensor failures. A more robust sensor was placed in the well on 2/26/25. A–E defined in text.

Major Points

- The relatively large amplitude fluctuations superimposed on the water levels are an indication of unconfined conditions.
- The large number of upward spikes in the water level, such as the one marked by A, are associated with rainfall events and are likely produced by storm runoff flowing into the well; the added water dissipates quickly through lateral flow to the aquifer (Butler, Whittemore et al., 2017). On 8/15/17 (B), GMD1 staff sealed openings in the casing at the land surface; only two large spikes (D, E) that can be attributed to runoff flowing down the well have been recorded since that time.
- A bomb cyclone produced the 3/13/19 (C) spike (Butler, Knobbe et al., 2021).
- The overall rise in water level from late 2015 to 2020, the largest during the monitoring period, is explained by the well location in White Woman Basin, a closed surface drainage basin at the end of White Woman Creek. The period 2015–2019 was the wettest series of years since 2005, and flow from the creek into the basin provided recharge.
- Transducer readings are generally in good agreement with manual measurements.

3.6.1.2 Expansion Site 3 – Wallace County

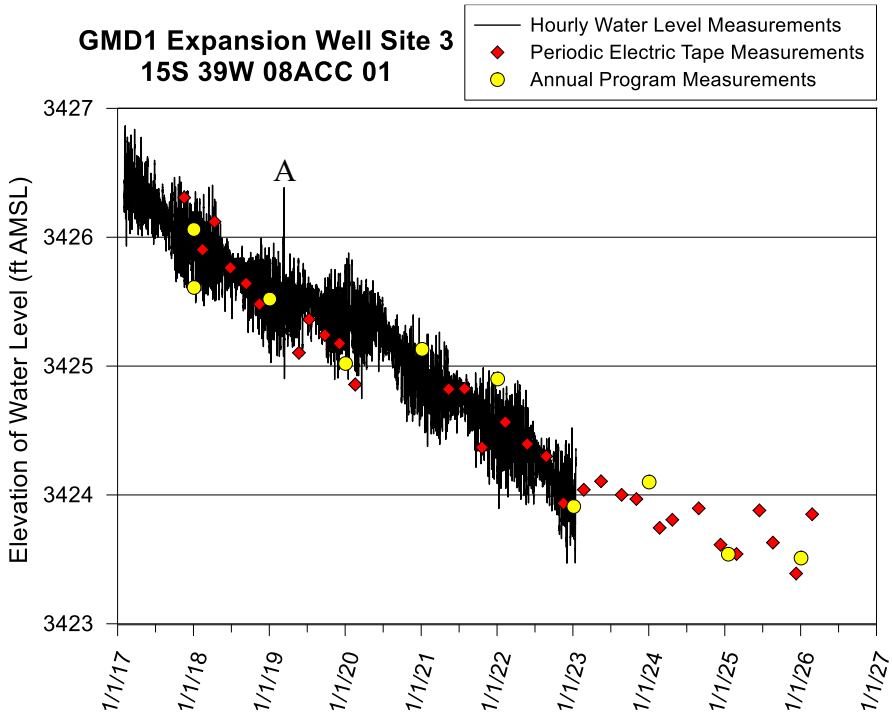


Figure 46. GMD1 Expansion Site 3 well hydrograph—total data run to 2/25/26. A water-level elevation of 3,424 ft corresponds to a depth to water of 199 ft below lsf. Bottom of well is 219.9 ft below lsf (elevation of 3,403.1 ft). A defined in text.

Major Points

- Relatively large amplitude fluctuations superimposed on the water levels are an indication of an unconfined aquifer. The seasonal variations in the amplitude are produced by seasonal changes in the range over which barometric pressure can vary with a smaller range during the summer (Butler, Knobbe et al., 2021).
- It is difficult to discern pumping and recovery seasons and the effect of individual wells cutting on and off.
- The water level has declined 79.5 ft since 1964 (1.3 ft/yr) and 4.0 ft since 2016 (0.4 ft/yr). The decline rate diminished in 2019 because of a lower level of pumping due to wet conditions. The decline rate increased in 2020 with more pumping due to much drier conditions.
- A bomb cyclone produced the 3/13/19 (A) water-level spike (Butler, Knobbe et al., 2021).
- Transducer readings are generally in good agreement with manual measurements.
- There appeared to be little justification for continuous monitoring at this well, so the sensor was removed from the well after the battery died on 1/15/23. The well is now measured quarterly.

3.6.1.3 Expansion Site 4 – Greeley County

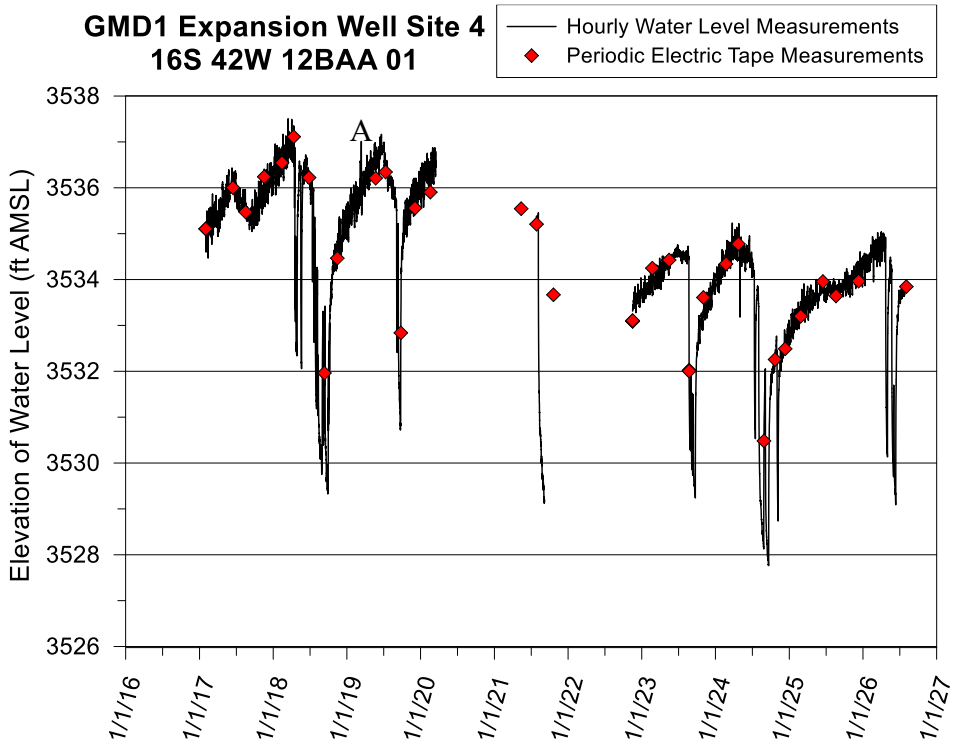


Figure 47. GMD1 Expansion Site 4 well hydrograph—total data run to 8/3/26, hourly measurements to 3/17/20, from 7/28/21 to 9/5/21, and from 11/16/22 on. A water-level elevation of 3,535 ft corresponds to a depth to water of 238 ft below lsf. Bottom of well is 264.5 ft below lsf (elevation of 3,508.5 ft). A defined in text.

Major Points

- Hydrograph form and relatively large amplitude fluctuations superimposed on the water levels are an indication of an unconfined aquifer.
- Little nearby pumping occurred in the 2017 and 2025 irrigation seasons, but more happened in other years. The effect of one or more nearby individual wells cutting on and off is clearly seen in the 2018–2019 and 2023–2024 irrigation seasons.
- After the end of the irrigation season, water levels continue to recover until the start of the next season (water levels do not stabilize).
- A bomb cyclone produced the 3/13/19 (A) water-level spike (Butler, Knobbe et al., 2021).
- The transducer failed on 3/17/20, most likely because of a water leak. The pandemic limited travel, so the failure was not recognized until 5/13/21; the sensor was removed from the well and replaced on 7/28/21. That sensor then failed on 9/9/21. A new, more robust sensor was placed in the well on 11/16/22.
- Sensor readings are in reasonable agreement with manual measurements.

3.6.1.4 Expansion Site 5 – Scott County

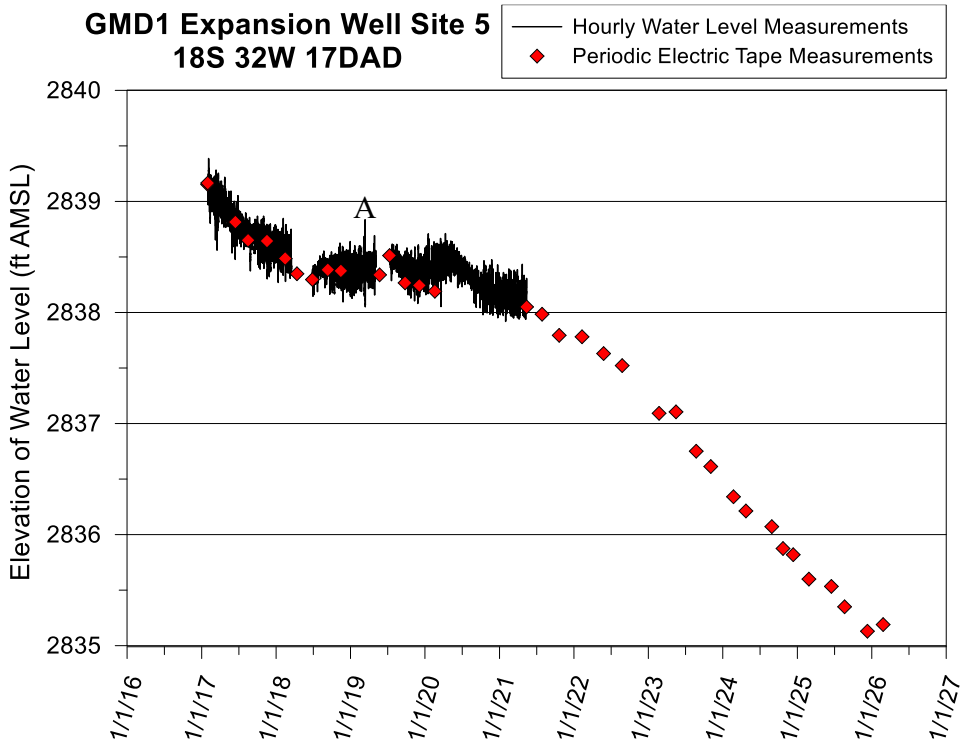


Figure 48. GMD1 Expansion Site 5 well hydrograph—total data run to 2/25/26. A water-level elevation of 2,838 ft corresponds to a depth to water of 131 ft below lsf. Elevation of well bottom is not known. A defined in text.

Major Points

- Moderate amplitude fluctuations superimposed on the water levels are an indication of an unconfined aquifer. The seasonal variations in the amplitude are produced by seasonal changes in the range over which barometric pressure can vary with a smaller range during the summer (Butler, Knobbe et al., 2021).
- It is difficult to discern the effect of individual wells cutting on and off.
- The battery of the transducer-datalogger unit died on 3/17/18 and was restarted on 6/28/18. The unit stopped functioning again on 5/5/19 and was removed from the well on 5/23/19. It was cleaned, evaluated in the lab, and reinstalled on 7/11/19.
- The water level in the well has dropped 4.0 ft since January 2017; the water level at a nearby annual well (T. 18 S., R. 32 W., 17ABA 02) has fallen 3.6 ft since 2016 (0.4 ft/yr) and 36.5 ft since 1981 (0.8 ft/yr).
- A bomb cyclone produced the 3/13/19 (A) water-level spike (Butler, Knobbe et al., 2021).
- Transducer readings generally were in good agreement with manual measurements.
- There appeared to be little justification for continuous monitoring at this well, so the sensor was removed from the well on 5/13/21 and the well is now measured quarterly.

3.6.2 Thomas County Expansion Wells

As the index well program continues to expand, we must periodically examine the value of continuing to monitor expansion wells. In late 2017, we decided that the information gained from the expansion wells in the vicinity of the Thomas County index well was insufficient to justify continued monitoring. We therefore ceased monitoring at wells TH7, TH9, TH10, and TH11. See Butler, Whittemore et al. (2017) and earlier reports for a discussion of the hydrographs from those wells.

3.6.3 Haskell County Expansion Wells

We examined the hydrographs from wells in the vicinity of the Haskell well in 2010 and 2017 (Buddemeier et al., 2010; Butler, Whittemore et al., 2017). In both analyses, we found hydrographs that indicated some wells are screened in isolated aquifer compartments. The relatively rapid recovery after cessation of irrigation pumping, lack of response to nearby pumping, and step changes in water level across the pumping periods were determined to be diagnostic indicators of an aquifer unit that is surrounded by low permeability materials (Butler, Stotler et al., 2013). The major finding of the 2017 assessment of the Haskell County expansion wells was that the permeable interval at the bottom of the HPA in the vicinity of the Haskell index well does not appear to be continuous. This lack of continuity is likely partly responsible for the large drawdowns observed during the pumping season at the Haskell index well.

We will reassess the Haskell County expansion wells in a future report.

4 Relationships Among Water-Level Changes, Water Use, and Climatic Conditions

4.1 Introduction

The measurement and interpretation of water-level changes at the index wells have provided an improved understanding of hydrologic responses at the local scale (section to township) in the Kansas HPA. In addition, the interpretation of water-level responses at these wells has helped to enhance understanding of the relationships among water-level change, water use (groundwater pumping), and changes in climatic conditions at both local and GMD scales.

The main driver of water-level declines in the HPA is the amount of water pumped for irrigation. The major drivers for irrigation water use are the type of crop, the additional water needed for crop growth above that provided by precipitation, and the irrigated area. In addition to the amount of precipitation, its timing relative to crop stage is important. If the number of irrigation wells, the average mix of crops, and the irrigated area remain relatively constant and the aquifer transmissivity is not near the lower limit for an irrigation well, then the main factor influencing annual pumping is meteorological conditions.

Since 2007, the number of water-right permitted wells (mainly irrigation wells) in the three western GMDs has remained nearly constant. The increase in the number of points of diversion (wells) from 2007 to 2025 ranged from less than 0.5% of the current total for GMDs 1 and 3 to 2.1% for GMD4**.** Thus, for close to two decades, the main driver of water-level changes in the HPA in western Kansas has been the amount of pumping from each well.

The main driver of water-level recovery after an irrigation pumping season is the net inflow (Butler, Bohling et al., 2023). The components of net inflow are described in previous index well reports. Variations in irrigation water use across the HPA are primarily a function of the acreage of irrigated fields, crop type, climatic conditions, and the irrigation application rate. Of these, the climatic conditions generally had the greatest influence over the last few decades because the irrigated acreage, crop type, and application rate have not changed substantially over most of the HPA in Kansas. The most significant exception is in the Sheridan-6 LEMA, where the crop type and application rate have been altered the last 13 years, relative to practices for similar climatic conditions before the establishment of the LEMA, to achieve true water savings. These changes are being implemented in other LEMAs in GMDs 1 and 4 as well as in Water Conservation Areas (WCAs) in these and other GMDs. Water savings have been apparent for the last several years in GMD1, especially in Wichita County.

The relationships among pumping, water-level changes, and meteorological conditions are explored further in the following sections. The index well program has been the primary driver for improving our understanding of these relationships, which has led to development of additional approaches for better assessing the properties and behavior of the HPA, especially in stressed areas. That understanding and those approaches are essential for providing a sound scientific foundation for management of the groundwater resources of the Kansas HPA. The relationship between pumping and precipitation also is explored in a journal article that developed out of work for the index well project (Whittemore, Butler, Bohling et al., 2023).

4.2 Annual Winter Water-Level Measurements

Annual winter groundwater levels have been measured in a network of irrigation and other well types in the Kansas HPA for many decades. Before 1997, the USGS and DWR measured the water levels. Starting in January 1997, the KGS took over administrative responsibilities of the annual program with DWR continuing to provide its measurements. The KGS then developed standardized procedures, software, and equipment for measurement, acquisition, and transfer of the data to a relational database (WIZARD). The KGS and DWR now measure water levels in a network of about 1,400 wells (mainly irrigation wells) across the HPA. These measurements typically are made in late December and early January.

4.3 Radar Precipitation

Radar precipitation has been found to be a good indicator of the climatic conditions that drive pumping and thus water-level changes in the Kansas HPA (Whittemore, Butler, and Wilson, 2015; Whittemore, Butler, Wilson, and Woods, 2015; Whittemore, Butler, Bohling et al., 2023). The National Weather Service (NWS) provides spatial images and data coverages of radar precipitation for the United States (available by enabling *Precipitation Estimate* on the map page at https://water.noaa.gov/). The NWS radar precipitation data are adjusted using data from a network of precipitation gauges. A brief description of the observation methods that apply to the general Kansas region was included in a previous project report (Butler, Whittemore et al., 2015). Coverages for radar precipitation are available from the NWS beginning in 2005.

We use radar precipitation as the primary metric for characterizing climatic conditions in the Kansas HPA (we also use station-based precipitation data called PRISM for certain applications). Figure 49 shows an image from the NWS website of the percent of normal annual precipitation during 2025. The data have a spatial resolution of approximately 4x4 km; the pixel size as measured from the data for western Kansas is 2.57 mi north-south and 2.58 mi west-east.

Precipitation in 2025 was above average over much of the GMDs and substantially above average in parts of them (between 125% and 200% of normal). Some areas of GMDs 3 and 4 had slightly below normal rainfall, particularly the northwestern part of Sheridan County in GMD4 and southwestern sections and some northern counties in GMD3. Precipitation was also above normal in 2024 in the three western GMDs but near normal in GMD5 and below normal (75–90% of normal) to near normal in GMD2. The map reveals that substantial spatial variation in precipitation existed within the GMDs; the precipitation ranged from 150–200% above normal to 10–25% below normal in 2025.

The mean spatial radar precipitation for January–September, which covers the extended irrigation season (Whittemore, Butler, Bohling et al., 2023), ranged widely during 2005–2025 (fig. 50). The 2025 precipitation was above average and close to the same (21–23 in.) for GMDs 1, 3, and 4 while substantially above average for GMDs 2 and 5 (31–34 in.).

The nine-month Standardized Precipitation Index (SPI) for October covers the extended irrigation season and was found to correlate well with water-level change and water use for the GMDs (Whittemore, Butler, and Wilson, 2016). The 2025 values of this SPI for Kansas climatic divisions 1, 4, 7, and 8, which include GMDs 4, 1, 3, and 2 and 5, respectively, are 0.23, 0.75, 0.95, and 1.64, respectively, in comparison to -0.58, -0.31, -0.12, and -0.62 for 2024. An SPI value of zero plus or minus 1 represents average conditions whereas values above 1 or below -1 indicate wet or dry conditions, respectively.

Therefore, the 2025 climate for the irrigation season was within the normal range for GMDs 1, 3, and 4 and in the category of very wet for GMDs 2 and 5. The 2025 SPI values indicate that the climate for the 2025 irrigation season was wetter than in 2024 for all five GMDs. The greatest change was for GMDs 2 and 5, where the SPI value increased by 2.26 from 2024 to 2025.

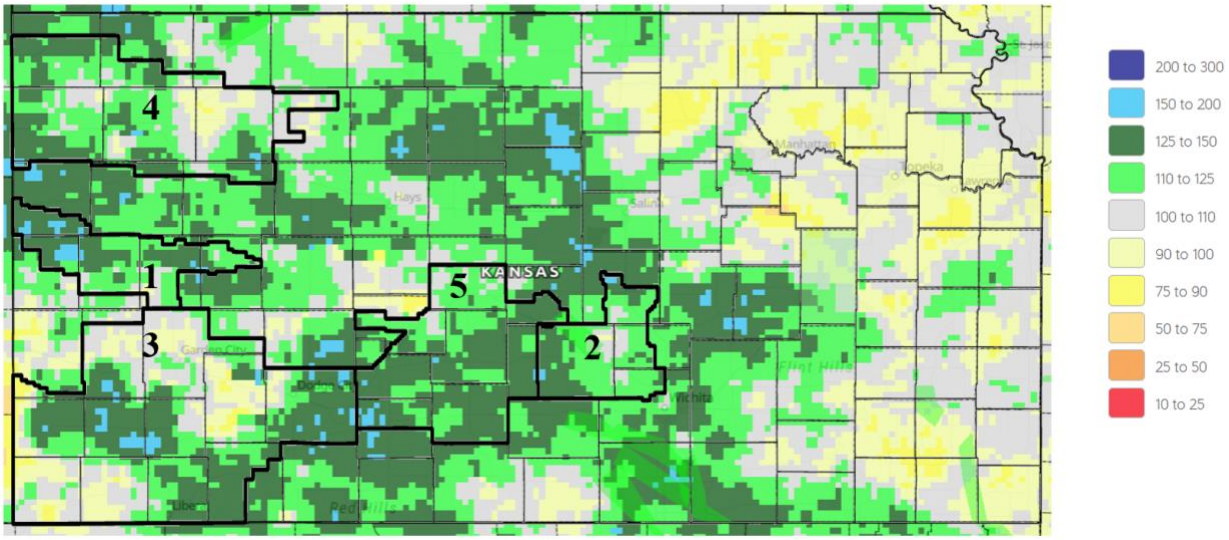


Figure 49. Percent of normal radar precipitation for Kansas in 2025. County lines are displayed and the GMD numbers and boundaries are bolded.

4.4 Water-Level Change in the Groundwater Management Districts

Figure 50 displays the mean annual year-to-year changes in winter water levels during 2005–2025 for all five GMDs; these values are based on every well available for measurement each year (total can vary from year to year) from 2005 to 2026. The changes have been relatively modest in northwestern and west-central Kansas; the annual water-level changes in GMDs 1 and 4 have fluctuated between +0.6 and -1.6 ft. The annual changes in GMD3 during this period were substantially greater (between +0.4 and -3.8 ft), but the largest annual changes were in GMD5 (between +3.0 and -2.7 ft) and GMD2 (between +2.8 and -3.2 ft). Some similarity is evident in the patterns of the water-level changes for the three western GMDs (4, 1, and 3), especially during the last several years.

The mean annual water-level changes in the five GMDs generally mimic the variations in radar precipitation (January–September sum), which also are displayed in fig. 50. The annual water-level changes in 2025 were smaller in the three western GMDs (a rise of 0.1 ft to a decline of -0.6 ft) compared to the 2024 declines (-0.6 to -1.6 ft). These changes reflect the somewhat wetter conditions over western Kansas compared to the previous year. GMDs 2 and 5 experienced substantial rises in water levels in 2025 (1.6 to 2.4 ft) in contrast to the 2024 declines of -0.5 to -0.7 ft. These rises occurred due to the wet climate in 2025 as indicated by both the precipitation values in fig. 50 and the substantially above normal annual rainfall shown in fig. 49 for most of GMDs 2 and 5.

a)

b)

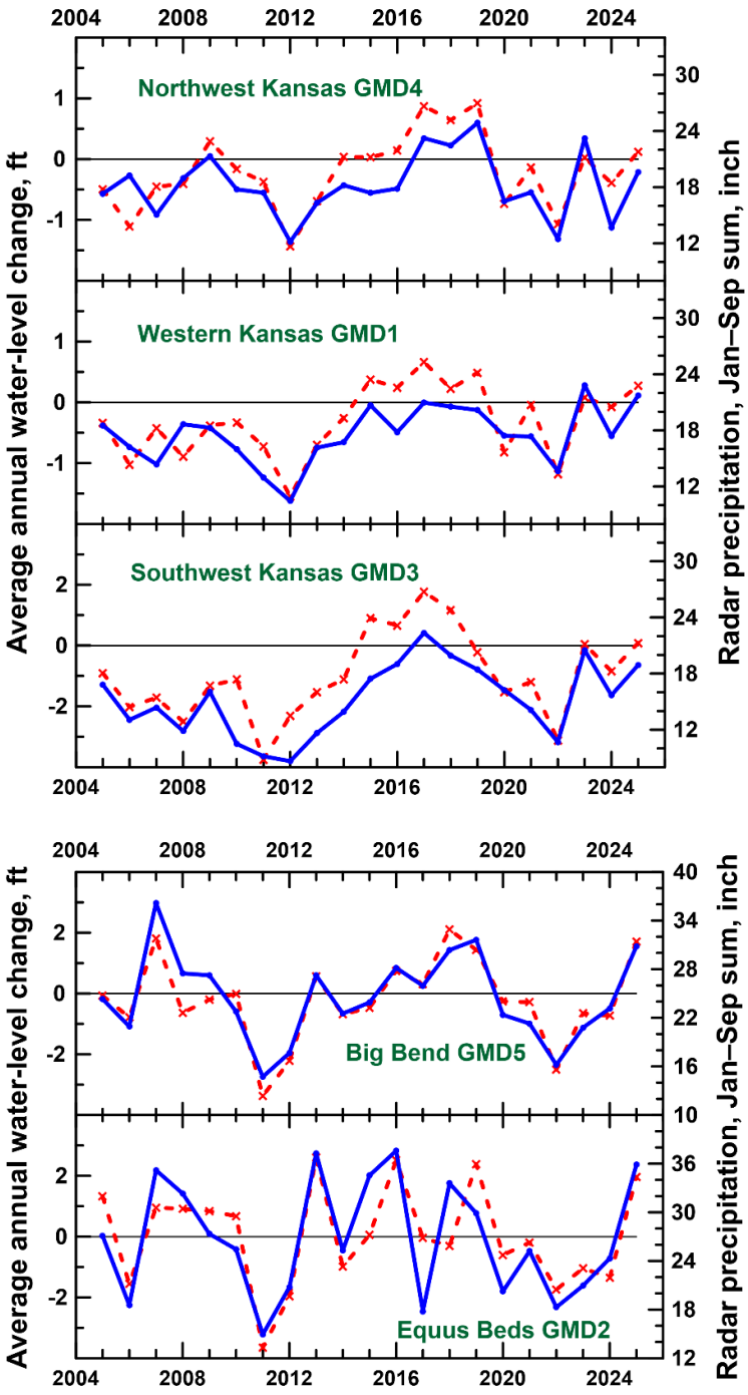


Figure 50. Mean annual water-level change (blue line) and radar precipitation (red dashed line, sum of January–September precipitation) during 2005–2025 for (a) GMDs 4, 1, and 3, and (b) GMDs 5 and 2. The water-level change for a particular year is the water-level difference between the following year and that year. The horizontal black lines represent zero water-level change. The ranges in the y-axes for water-level change in the upper two plots of (a) are half those of the other plots. The ranges in the y-axes for radar precipitation are 4 inches larger for (b) than for (a).

4.4.1 Water-Level Change in the Thomas, Scott, and Haskell County Index Wells

Winter water levels have been measured in the original three index wells since January 2008. Figure 51 shows the annual water-level changes for both the tape and transducer values for January 2008–2026 (transducer values are for the same time as the annual tape measurements) along with the mean water-level changes for the GMDs based on the maximum number of wells measured each year (same as values in fig. 50). The annual changes in the Scott County index well have been within a relatively narrow range (between -0.02 and -1.48 ft for tape measurements; a total absolute range of 1.46 ft), whereas the changes have been appreciably larger at the Thomas County index well (between +2.3 and -2.5 ft for tape measurements; a total absolute range of 4.8 ft), and much greater at the Haskell County index well (between +4.2 and -10.4 ft for tape measurements; a total absolute range of 14.6 ft).

The range in the annual water-level changes for the Scott index well is essentially the same as that for the mean annual water-level change for GMD1 during 2008–2025. In contrast, the ranges in the annual water-level changes for the Thomas and Haskell index wells are substantially greater than the mean water-level changes for GMDs 4 and 3, respectively. Except for the 2015, 2016, 2018, and 2019 changes in the Thomas well and the 2009, 2014, and 2021 changes in the Scott well, the directions of change in the annual water-level changes for the Thomas and Scott index wells are relatively similar to those for the mean annual changes for the GMDs. This indicates that these two wells are usually representative of the patterns in regional water-level variations in the GMDs where they are located. The main discrepancy in the Thomas well is for 2018, when a hailstorm damaged crops in the vicinity of the well, resulting in cessation of irrigation during the growing season and, thus, greater recovery of water levels than usually expected. If this year is removed from the plot, the changes from 2017 to 2019 for the Thomas well and GMD4 are relatively similar.

Although the water-level changes in the Haskell index well (transducer values) showed a decline from 2009 to 2011 followed by a rise from 2011 to 2013 that is similar to the more muted changes for GMD3, the Haskell well water-level changes from 2013 to 2016 often differed substantially from the GMD3 changes for the same period. This difference is mainly related to late fall pumping (late November to mid-December 2014) in the confined aquifer and variations in pumping related to the court-ordered shutdown of nearby irrigation wells (see section 3.3.2.). From 2017 to 2020, water-level declines generally lessened in the Haskell well in comparison to a small increase in declines for GMD3, but that pattern abruptly changed in 2021 and 2022 with the large relative declines in the Haskell well. The change from 2022 to 2023 was the greatest one-year change for the 2008–2025 monitoring period, from -10.4 ft to 4.2 ft. After the water-level rise in 2023, the 2024 and 2025 changes resumed a more similar pattern of declines to those in GMD3.

The 2025 water-level rises for the Thomas and Scott index wells and the decline for the Haskell well compared to declines in 2024 for all three wells primarily resulted from the change from a little below-normal rainfall for the Thomas and Haskell wells and around normal for the Scott well in 2024 to wetter conditions in 2025. Based on figs. 57 and 59, the seasonal radar precipitation for 2025 at the Thomas well was 114% of average, at the Scott well 123% of average, and at the Haskell well 95% of the average for 2008–2025. That compares with 90%, 102%, and 91% in 2024 for the three wells, respectively.

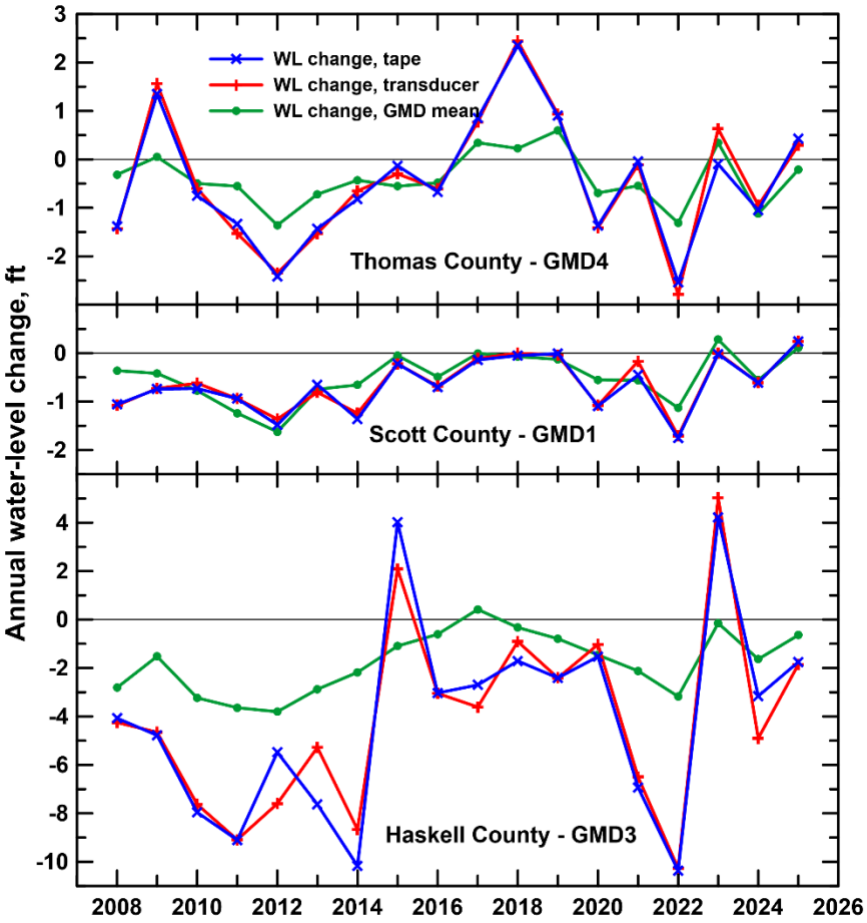


Figure 51. Annual winter (January) water-level changes in the original three index wells and the mean annual changes in the three western Kansas GMDs where they are located. Note the different y-axis range for Haskell County versus that for Thomas and Scott counties. Suspect 2013 tape measurement at the Haskell index well causes the 2012 and 2013 tape water-level change values to be markedly different from those based on the transducer measurements.

4.5 Correlation of Annual Water Use with Annual Water-Level Change

One of the major accomplishments of the index well program has been the discovery of the strong linear relationship between annual water use and annual water-level change in the Kansas HPA and the development of the theoretical support for that relationship. As shown in previous project reports and peer-reviewed publications (e.g., Butler, Whittemore et al., 2015; Butler, Whittemore, Wilson et al., 2016, 2018; Butler, Bohling et al., 2023), this relationship can be used to assess the aquifer response to pumping reductions over a wide range of spatial scales. For example, the pumping reduction that would achieve stable water levels (i.e., a water-level change of zero) for the near future (commonly referred to as Q_{stable}) can be estimated from the relationship.

We have previously examined the correlations between annual water use and annual water-level change for the three original index wells and three additional wells in GMDs 4 (Colby), 1 (SC-8), and 5 (Belpre). In the 2016 report (Butler, Whittemore et al., 2017), we presented the results of a comprehensive examination of the correlations in which we varied the distance over which the water use was summed and used both manual- and transducer-measured water-level change data (see tables 38–39

of Butler, Whittemore et al. [2017] and associated discussion). In this section, we update those correlations with the radius of water use that produced the highest correlation for a particular well, but only for either the 1- or 2-mile radius of water use around a well. Although we found that the correlations were sometimes greater for larger areas around the index wells, the area around which water-level changes are significantly affected by pumping during one year is not expected to exceed 2 miles in a largely unconfined aquifer such as the HPA.

4.5.1 Water Use Versus Water-Level Change at the Thomas County Index Well

Figure 52 displays the correlation between annual water-level change and annual water use in the vicinity of the Thomas County index well for 2008–2025. As indicated earlier, the substantial water-level rise and small water use for 2018 resulted from the cessation of irrigation near the well due to a hailstorm. The drought of 2022 produced the second greatest water use and largest water-level decline since monitoring began. The apparent pumping reduction for stable water levels is 10.7%, which is lower than the 14.2% for the 2008–2017, 2019–2025 period that omits the hail year of 2018 and the 15.6% for all of GMD4 for 2008–2025. The average annual water use during 2008–2025 was 3.9 in./yr for the 2 mi radius area centered on the well, which is substantially greater than the 1.5 in./yr for the entire GMD4 area. The water use for stable water levels (net inflow) was 3.5 in./yr for the 2 mi radius area, which again is substantially greater than the 1.2 in./yr for GMD4. The greater density of water use would be expected to result in more irrigation return flow and more drainage from the newly formed unsaturated zone. However, little lateral inflow would be expected because the permeable zone appears to be discontinuous in the vicinity of the Thomas index well (Butler, Stotler, et al., 2013).

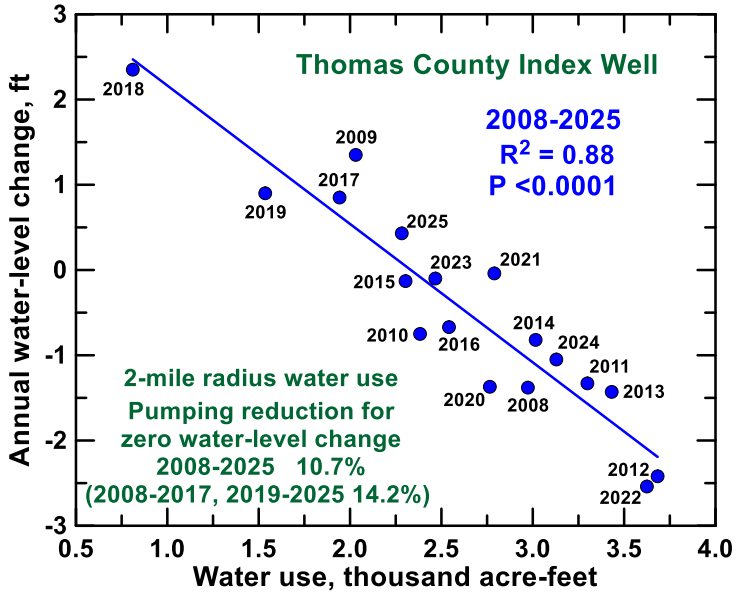


Figure 52. Correlation of annual water-level change based on manual measurements in the Thomas County index well with annual water use within a 2 mi radius centered on the well during 2008–2025.

4.5.2 Water Use Versus Water-Level Change at the Scott County Index Well

Figure 53 displays the correlation between annual water-level change and annual water use in the vicinity of the Scott County index well for 2008–2025. The pumping reduction for stable water levels is

34%, which is higher than the 28% for all of GMD1 for 2011–2025 (GMD1 pumping data before 2011 are questionable). The late-season pumping in the vicinity of the Scott index well has made it difficult to have confidence in the pumping reductions for stable water levels in the vicinity of this well. The average annual water use was 4.2 in./yr for the 2 mi radius area centered on the well, which is substantially greater than the 1.6 in./yr for all of GMD1. The water use for stable water levels (net inflow) was 2.8 in./yr for the 2 mi radius area, which again is substantially greater than the 1.1 in./yr for the entire GMD1 area. The greater density of water use may have produced a locally depressed water table that induces more lateral groundwater inflow and results in more irrigation return flow and more drainage from the newly formed unsaturated zone.

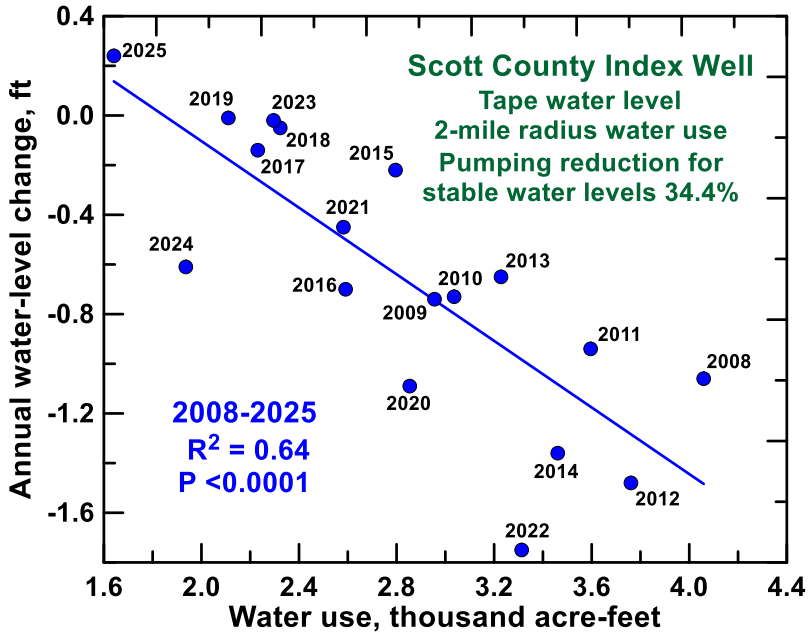


Figure 53. Correlation of annual water-level change based on manual measurements in the Scott County index well with annual water use within a 2 mi radius centered on the well during 2008–2025. The 2022 and 2024 water-level changes appear to have been affected by late-season pumping (recovery began on 11/9/22, and 10/24/24, respectively, while it typically begins in early to mid-September).

4.5.3 Water Use Versus Water-Level Change at the Haskell County Index Well

Figure 54 displays the correlation between the annual change in the water level at maximum recovery in February and annual water use in the vicinity of the Haskell County index well for 2008–2025. We found that we could not get a good correlation with the annual January water-level change, likely because of the effect of late fall pumping, but we could get a good correlation with the maximum recovered water level. The correlation was better for the maximum recovery in February than for the final maximum recovery level because the time of the maximum recovery can vary from year to year. The water-level recovery continues at this index well through the winter and into the spring until pumping starts for the season; the selection of February for the maximum value provided better consistency in the data.

The water use around the Haskell County index well for 2013–2025 (especially during 2015–2020) was substantially lower than for 2008–2012. The lower use is related to both the court-ordered shutdown of nearby pumping wells described in section 3.3.2 and the greater-than-average precipitation in 2013–2020 (especially during 2015–2019) in comparison to that during 2008–2012 in GMD3 (see fig. 50). The pumping reduction for stable water levels for the average annual water use before the court-ordered pumping shutdowns (2008–2012) is 59% (using the linear regression for 2008–2025 and the average annual water use for 2008–2012), which is much larger than the 23% for all of GMD3 for 2008–2025. The pumping reduction for stable water levels for the average annual water use after the full shutdown (2015–2025; 2013 and 2014 were years of partial shutdown as described in section 3.3.2) is 30% (again using the linear regression for 2008–2025), which is appreciably less than for the period before the shutdowns. The average annual water-use rates were 14.3 in./yr and 8.3 in./yr for the 2 mi radius area centered on the well during 2008–2012 and 2015–2025, respectively, which are considerably greater than the 4.0 in./yr for the entire GMD3 area. The water use for stable water levels (net inflow) was 5.8 in./yr for the 2 mi radius area based on the 2008–2025 data, which again is substantially greater than the 3.0 in./yr for all of GMD3. As with the Thomas and Scott index wells, these values indicate that the area of the Haskell well is more heavily pumped than average for GMD3, thereby resulting in a greater net inflow. In this case, the greater density of water use may have induced upward vertical flow from the underlying Dakota aquifer as well as leakage from the thick clay interval overlying the sand unit at the bottom of the HPA in the vicinity of the Haskell well.

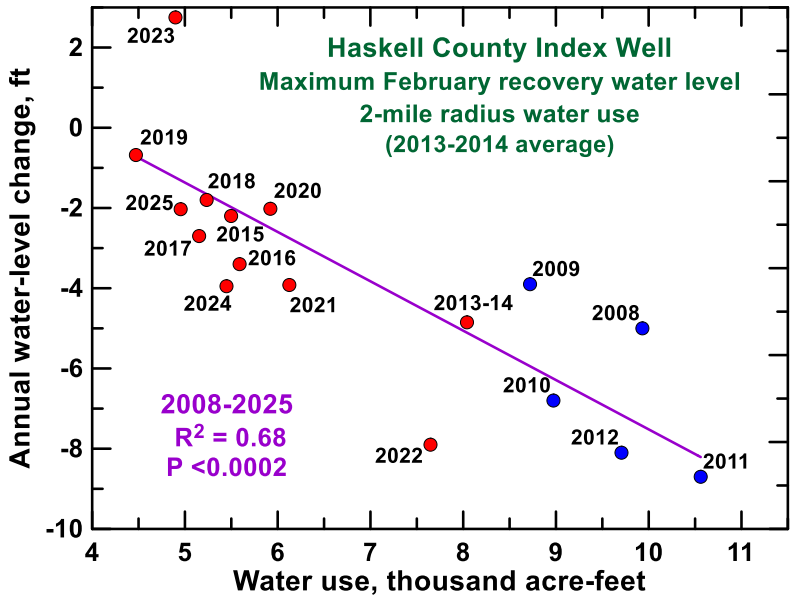


Figure 54. Correlation of change in maximum recovery water level during February based on transducer measurements in the Haskell County index well with annual water use within a 2 mi radius centered on the well during 2008–2025. Red points designate values after the court-ordered shutdowns (see section 3.3.2); 2013 and 2014 values are averaged because of equipment failure at the time of the 2013 maximum recovery. The 2022 value appears to have been affected by late-year (December) pumping; the result is that the 2022 value is more negative than would have been expected for the 2022 annual pumping and the 2023 value is more positive than would have been expected for the 2023 annual pumping.

4.5.4 Water Use Versus Water-Level Change at the Colby, SC-8, and Belpre Wells

The water-level change versus water use relationship is only statistically significant for the 1 mi radius of water use around the Colby index well (fig. 55). In contrast to conditions in the vicinity of most of the index wells, substantial water is pumped for municipal use in the vicinity of the Colby well (58% for 2025 for the 1 mi radius area centered on the well). The percent pumping reduction required to attain stable water levels (53%) is the largest of any of the index wells for which relationships have been developed in the GMD4 and GMD1 areas. The average annual water use was 3.1 in./yr for the 1 mi radius area, which is less than that in the vicinity of the Thomas County index well (3.9 in./yr for 2 mi radius) but substantially greater than the 1.5 in./yr for all of GMD4. The water use for stable water levels (net inflow) was 1.5 in./yr for the 1 mi radius area, which is somewhat greater than the 1.2 in./yr for all of GMD4 but substantially below that in the vicinity of the Thomas index well (3.5 in./yr for a 2 mi radius).

The correlation for the water-level change versus water use relationship at the SC-8 well is higher for the 1 mi than the 2 mi radius area centered on the well (fig. 55). The percent pumping reduction required to attain stable water levels (24%) is less than that required in the vicinity of the Scott County index well (34% for 2 mi radius) and that for all of GMD1 (28%). The average annual water use was 3.9 in./yr for the 1 mi radius area, which is somewhat less than that in the vicinity of the Scott index well (4.2 in./yr for 2 mi radius) but substantially greater than the 1.6 in./yr for all of GMD1. The water use for stable water levels (net inflow), however, was 3.0 in./yr for the 1 mi radius area, which is somewhat greater than that in the vicinity of the Scott index well (2.8 in./yr for 2 mi radius) but much greater than the 1.1 in./yr for all of GMD1.

The correlation for the water-level change versus water use relationship at the Belpre well is higher for the 2 mi than the 1 mi radius area centered on the well (fig. 55). The percent pumping reduction to attain stable water levels was 4.3% and larger than the 1.4% for all of GMD5 for the same period. The much smaller pumping reduction for stable water levels than for the Ogallala region is mainly related to the greater precipitation recharge. The average annual water use was 3.6 in./yr for the 2 mi radius area, which is greater than the 2.4 in./yr for the entire GMD5 area. The water use for stable water levels (net inflow) was 3.4 in./yr for the 2 mi radius area, which again is larger than the 2.4 in./yr for all of GMD5.

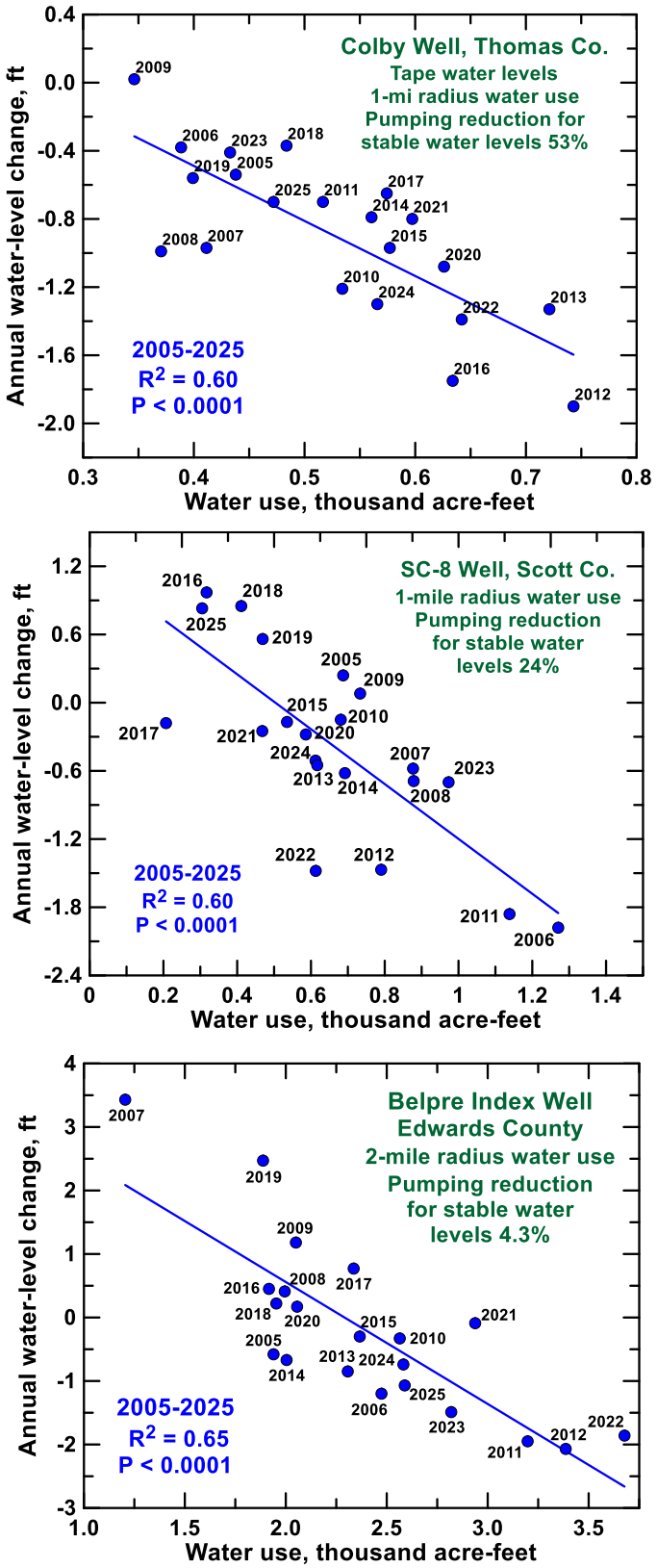


Figure 55. Correlation of annual water-level change in the Colby, SC-8, and Belpre wells with annual water use within a 1 or 2 mi radius centered on the wells during 2005–2025.

4.6 Relationship of Water Use and Climatic Conditions

As indicated earlier, climatic conditions generally had the greatest influence on water-use variations over the last few decades because the irrigated acreage, crop type, and application rate have not changed substantially over the HPA in Kansas. Where changes in these quantities have occurred, climate and water use relationships can be used with changes in irrigated area and application rates to determine their impact. We have found that the sum of the radar precipitation for the extended irrigation season generally captures the climatic conditions that drive pumping in support of irrigated agriculture in the Kansas HPA; the monthly ranges for the irrigation season that give optimum correlations with water use vary among index wells. Figure 50 includes the variation in January–September radar precipitation versus time since 2005 for all five GMDs. This plot shows that 2017 was the wettest year experienced in GMDs 1 and 3 since 2005 and close to that in GMD4 (2019 was slightly wetter) for this monthly range. The wettest year since 2005 in GMD5 was 2007, whereas the wettest year in GMD2 was 2013. The driest years were during the drought of 2011–2012; the lowest precipitation in GMDs 1 and 4 occurred during 2012, and the lowest in GMDs 2, 3, and 5 during 2011.

4.6.1 Correlation of Annual Water Use with Radar Precipitation

Based on earlier work in the index well program, we have found that water use and precipitation relationships can be used to identify where water use has been reduced and whether the reduction was achieved through a decrease in irrigated area or changes in pumping. In previous years' reports, we have examined the correlations between annual groundwater use and radar precipitation (within selected areas around the wells) for the three original index wells and three additional wells in GMDs 4 (Colby), 1 (SC-8), and 5 (Belpre). In the 2016 report (Butler, Whittemore et al., 2017), we presented the results of a comprehensive examination of the correlations in which we varied the area over which the water use was summed and the range and number of months for which the radar was summed; results were presented for both the nearest point or pixel of radar data (representing a 6.6 mi^2 area) and the spatial mean of the nine-point (pixel) block (representing a 60 mi^2 area) of radar precipitation values centered on the well (see table 40 of Butler, Whittemore et al. [2017] and associated discussion). In this section, we update the correlations using the 2 mi radius of water use (based on the explanation in section 4.5 above) and the 60 mi^2 area for radar precipitation for the three original index wells and the three additional wells.

All of the water use within the 2 mi radius of the Thomas County well is for irrigation, whereas typically about 99% of the use around the Scott County well is for irrigation. The monthly precipitation sums that give optimum correlations for the Thomas County and Scott County index wells are March–August and February–September, respectively (fig. 56), which essentially span the irrigation season. The 2019 and 2017 precipitation amounts were the greatest during 2008–2025 for the Thomas and Scott County wells, respectively. However, the water use surrounding the Thomas County well in 2018 was substantially lower than the water use for any other year; this was caused by the shutdown of irrigation wells in the vicinity due to destruction of crops by a hailstorm. Thus, 2018 is plotted as a separate anomalous point, and data for 2008–2017 and 2019–2025 are used for the regression line in fig. 56. The hailstorm occurred in mid-May 2018 and the precipitation for that month within the 60 mi^2 area surrounding the Thomas County well was anomalously high (7.48 in.). No significant water conservation is evident in the 2 mi circle around the well during 2008–2025. The irrigated area actually increased

several percent during the last few years, and no substantial decrease has occurred in water use per irrigated area (water application rate).

The linear regression for 2018–2025 for the Scott County well is significantly offset to lower water use than for the regression for 2008–2017 (fig. 56), indicating less water use for the same climatic conditions. Similar offsets in the water use and precipitation relationship are observed for the Sheridan-6 LEMA, Wichita County, and GMD1 (Whittemore, Butler, Bohling et al., 2023). Possible explanations for the lower water use include more efficient irrigation, decreased irrigated area, and increased difficulty in pumping due to the declining aquifer thickness in the area of the Scott index well. A plot of irrigation water use per irrigated area versus radar precipitation (fig. 57), which would show a significant difference in regression lines for 2008–2017 and 2018–2025 as in fig. 56 if irrigation efficiency were the main explanation, shows that the confidence intervals overlap for the two periods and indicate no significant difference. Thus, improvements in irrigation efficiency do not appear to be responsible for the offset in the total water use plot (fig. 56). Instead, a decrease in irrigated area during 2008–2025 (fig. 58) is the probable explanation for the decreased water use during 2018–2025 compared to 2008–2017. The general decrease in irrigated area occurred during 2008–2017; the irrigated area did not change substantially during 2017–2024 but dropped in 2025.

Over 99% of the water use within the 2 mi radius circle for the Haskell County well is for irrigation. The plot for the water use and radar precipitation relationship for the Haskell index well (fig. 59) displays the data before and after the court-ordered shutdown of nearby irrigation wells (see section 3.3.2.). The plot shows the much lower water use for a given precipitation after the well shutdowns compared to before. A similar break in the relationship is seen for the correlation between annual water use and radar precipitation in the Sheridan-6 LEMA (Butler, Whittemore, Wilson et al., 2018; Whittemore, Butler, and Wilson, 2023; Whittemore, Butler, Bohling et al., 2023), although the two regression lines are closer to being parallel for the LEMA than for the Haskell County index well. The 2013–2014 period was for a limited shutdown and thus is not appropriate for plotting with the data after the complete shutdown. A main difference in the plot for the Haskell well from those for the Thomas and Scott wells is the appreciably lower slope; pumping near the Haskell well for the pre- and post-shutdown periods does not respond as much to changes in precipitation as at the other wells. In fact, except for 2022, the points for 2015–2025 exhibit little change with precipitation. The decrease in annual irrigation application rate within the 2 mi circle around the Haskell well from 18.6 in. during 2008–2012 to 13.1 in. during 2015–2025 also indicates the transition from high to substantially lower water use.

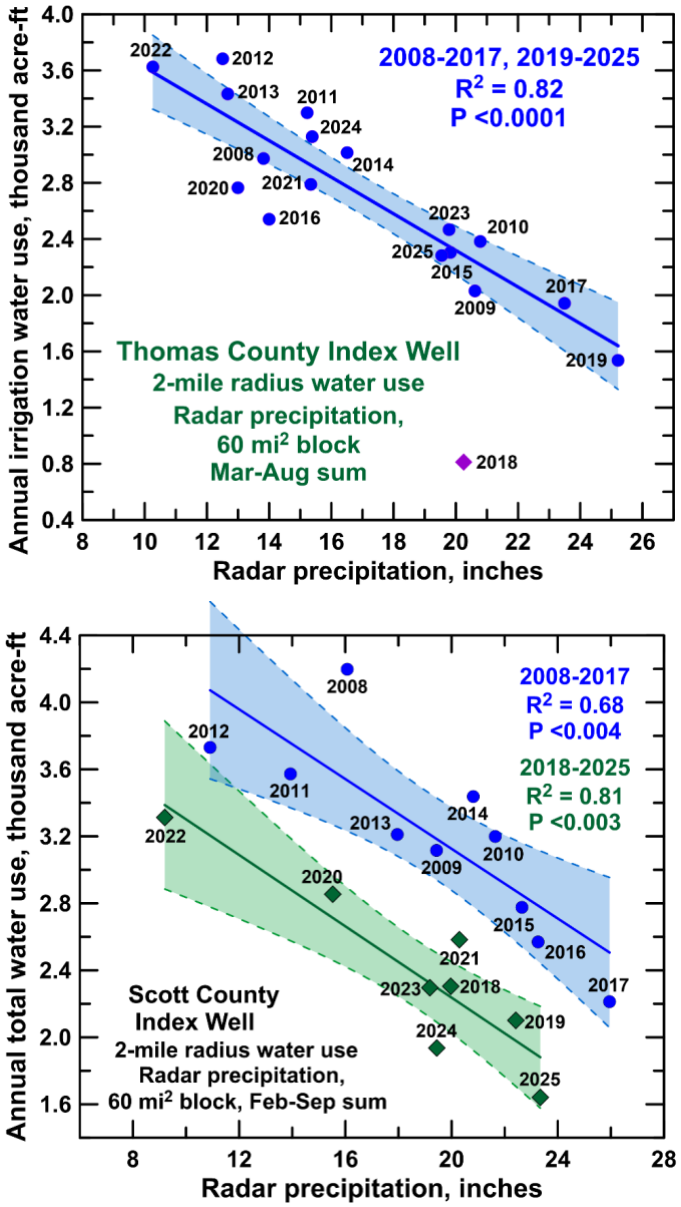


Figure 56. Correlation of annual total groundwater use with radar precipitation at the Thomas County and Scott County index wells for 2008–2017 (both) and 2019–2025 (Thomas) and 2018–2025 (Scott). The shaded intervals represent 95% confidence intervals for the regressions.

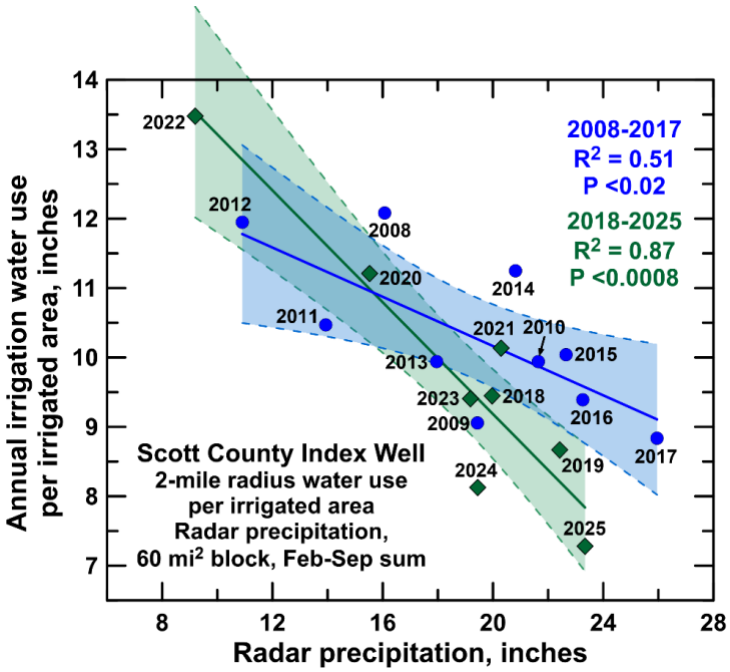


Figure 57. Correlation of annual irrigation groundwater use per irrigated area with radar precipitation at the Scott County index well for 2008–2025. The shaded intervals represent the 95% confidence interval for the linear regressions.

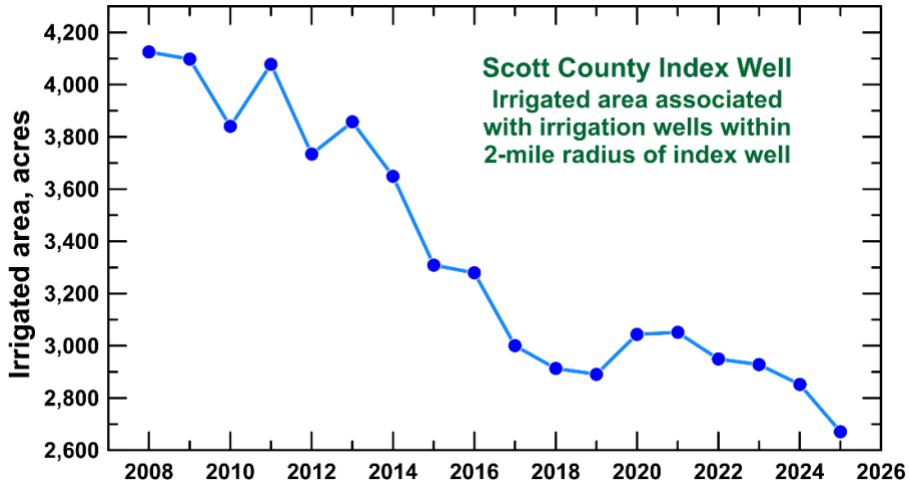


Figure 58. Change in irrigated area associated with the irrigation wells within the 2 mi radius of the Scott County index well for 2008–2025.

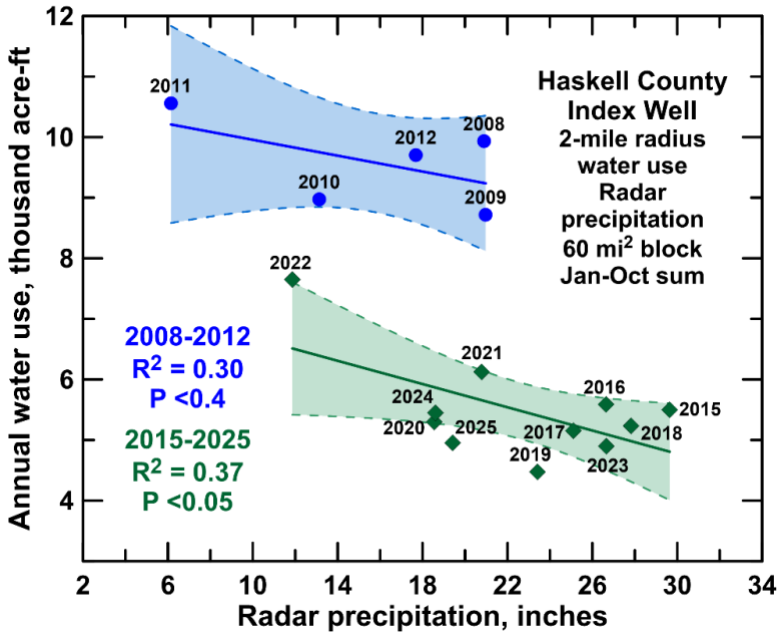


Figure 59. Correlation of annual total groundwater use with radar precipitation at the Haskell County index well for 2008–2025. The 2008–2012 and 2015–2025 periods represent years before and after the onset of a court-ordered shutdown of nearby irrigation well pumping; points for the 2013–2014 period, which was for a limited shutdown (see section 3.3.2), are not included.

Figure 60 shows the correlations between water use and radar precipitation for the three additional wells (Colby, SC-8, and Belpre). Groundwater is used for multiple purposes within the 2 mi radius around the Colby well (fig. 61), but the focus here is on water use for irrigation. The monthly range that gives the optimum correlation (March–October) is longer than that for the Thomas County well (March–August). The irrigation water use for 2018–2025 is significantly lower than 2008–2017 (-22.2%) at the average precipitation for 2005–2025. The irrigated area changed little between these periods (-1.2%), but the irrigation application rate changed substantially (-17.6%). It thus appears that irrigation conservation measures based on improved irrigation efficiency have been implemented since the establishment of the district-wide LEMA in GMD4 in April 2018. The tracking of water use with precipitation is also greater (higher R^2 value) for 2018–2025 than 2005–2017, similar to that observed for the pre-LEMA and LEMA periods for the SD-6 LEMA. The greatest groundwater use within the 2 mi radius of the Colby well is for municipal supply, but municipal use changed little after establishment of the district-wide LEMA (+2.3%).

The water-use data for 2005–2007 for the SC-8 well appear to be too high, as a much better correlation (R^2 increasing from 0.55 to 0.81) is obtained using the 2008–2017 data (fig. 60). In this case, all the water use within the 2 mi radius of the index well is for irrigation. The monthly precipitation range for the SC-8 well optimum correlation is the same as for the Scott County index well. As with the Scott County and Colby wells, the water use during 2018–2025 was below that for 2008–2017 for a given precipitation. Although the SC-8 and Scott County index wells are relatively near one another, the irrigated area within the 2 mi radius of the SC-8 well did not decrease during 2008 to 2025 but it did

vary appreciably from year to year. However, the irrigation application rate did decrease from 2008–2017 (10.3 in.) to 2018–2025 (8.2 in.). Thus, the decrease in water use between the two periods for the SC-8 well was achieved by increasing irrigation efficiency rather than by decreasing irrigated acreage as with the Scott County well.

The precipitation versus water-use plot for the Belpre well is displayed for 2005–2025 in fig. 60 (irrigation is the only water use in the area). As with the SC-8 well, the optimum monthly range for precipitation started in February. This early monthly start may indicate that pre-irrigation, which is typically done to enhance soil moisture, is important enough to affect the correlation. In contrast to the Scott, Colby, and SC-8 wells, no significant separation occurs between earlier and later periods so only one regression line and confidence interval are shown. There is no evidence that conservation measures have decreased water use around the Belpre well during the 2005–2025 period. However, generally increasing linear trends in groundwater use and irrigation application rate per irrigated area are observed for 2005–2025. No trend appears in the irrigated area within the 2 mi radius around the Belpre well.

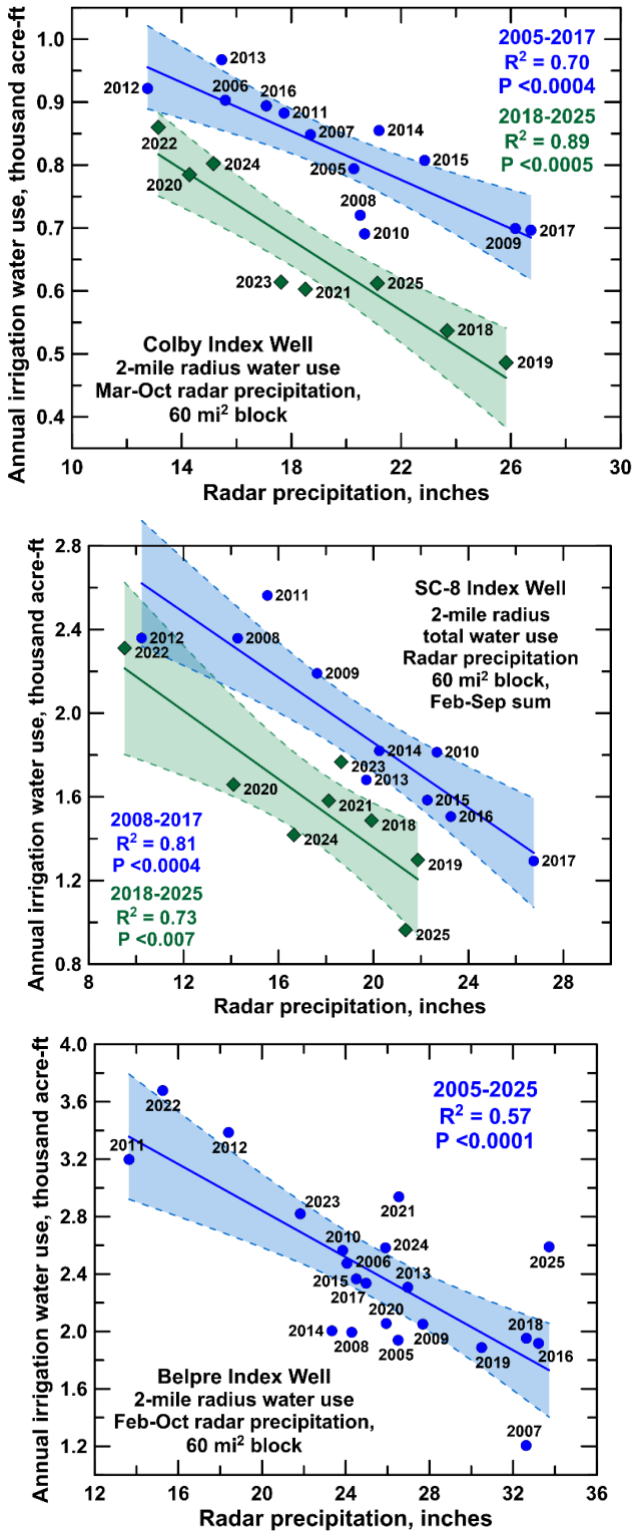


Figure 60. Correlation of annual irrigation groundwater use with radar precipitation at the Colby, SC-8, and Belpre wells for 2005–2025 (Colby and Belpre) and 2008–2025 (SC-8).

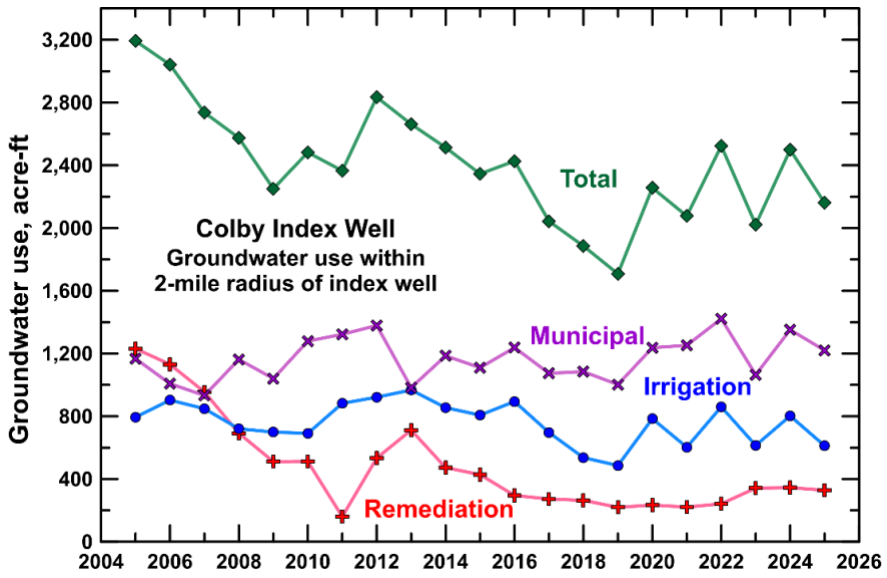


Figure 61. Annual groundwater use during 2005–2025 within a 2 mi radius of the Colby index well.

5 Summary of 2025–2026 Accomplishments and Plans for 2026–2027

5.1 Accomplishments, 7/2025–6/2026

- Collected and processed data from all wells currently involved in the index well program. Telemetered data from 34 wells are served online in real time. Each well was visited approximately quarterly and downloads from all wells have been used for analysis and presentations.
- Drilled one new well in GMD3, added an integrated transducer-datalogger unit to begin monitoring, and will shortly add telemetry equipment to begin remote real-time viewing of data.
- Applied the in-field calibration approach developed through the index well program to transducer data from index wells in GMDs 1, 2, and 4 to correct for sensor drift.
- Continued analysis of hydrographs from all wells.
- Continued comparison of transducer data with the results of the annual water-level program.
- Continued an analysis of the utility of radar precipitation data for use in relationships with annual water-level change and water use in the vicinity of the index wells.
- Continued assessment of relationships among precipitation, annual water-level change, and annual water use at the index wells and the GMDs.
- Continued integration of program data into the digital Kansas High Plains Aquifer Atlas (Fross et al., 2012).
- Gave presentations about the index well program to KWO, DWR, and GMD personnel, among others.

5.2 Planned Activities, 7/2026–6/2027

- Continue monitoring and processing water-level data from all wells currently involved in the index program. Visit each well quarterly to take manual measurements of water levels and download data from sensors.
- Continue analysis of hydrographs from all wells involved in the program.
- Drill one new well in GMD3 and equip an existing well in GMD5 with transducer and telemetry equipment.
- Apply the in-field calibration approach developed through the index well program to correct for sensor drift in index wells in GMDs 3 and 5.
- Sample water at as many index wells as possible.
- Continue assessment of the information that can be acquired from hydrograph inspection.
- Assess major factors contributing to net inflow.
- Continue assessment of the relationships among radar precipitation data, annual water-level change, and annual water use for all five GMDs.
- Give presentations about the index well program to KWO, DWR, and GMD personnel, among others.

6 References

Bohling, G. C., Butler, J. J., Jr., Whittemore, D. O., and Wilson, B. B., 2021, Evaluation of data needs for assessments of aquifers supporting irrigated agriculture: Water Resources Research, v. 57, no. 4. https://doi.org/10.1029/2020WR028320

Buchanan, R. C., Wilson, B. B., and Butler, J. J., Jr., 2023, The High Plains aquifer: Kansas Geological Survey Public Information Circular 18, 6 p. http://www.kgs.ku.edu/Publications/pic18/index.html

Buddemeier, R. W., Stotler, R., Butler, J. J., Jr., Jin, W., Beeler, K., Reboulet, E., Macfarlane, P. A., Kreitzer, S., Whittemore, D. O., Bohling, G., and Wilson, B. B., 2010, High Plains aquifer calibration monitoring well program: Third year progress report: Kansas Geological Survey, Open-File Report 2010-3, 117 p. http://www.kgs.ku.edu/Hydro/Publications/2010/OFR10_3/index.html

Butler, J. J., Jr., Bohling, G. C., Perkins, S. P., Whittemore, D. O., Liu, G., and Wilson, B. B., 2023, Net inflow: An important target on the path to aquifer sustainability: Groundwater, v. 61, no. 1. https://doi.org/10.1111/gwat.13233

Butler, J. J., Jr., Bohling, G. C., Whittemore, D. O., and Wilson, B. B., 2020a, A roadblock on the path to aquifer sustainability: Underestimating the impact of pumping reductions: Environmental Research Letters, v. 15, 014003. https://doi.org/10.1088/1748-9326/ab6002

Butler, J. J., Jr., Bohling, G. C., Whittemore, D. O., and Wilson, B. B., 2020b, Charting pathways toward sustainability for aquifers supporting irrigated agriculture: Water Resources Research, v. 56, no. 10. https://doi.org/10.1029/2020WR027961

Butler, J. J., Jr., and Johnson, C. K., 2024, Groundwater depletion: A global challenge for intergenerational equity, Interpretation, v. 78, no. 1. https://doi.org/10.1177/00209643231201998

Butler, J. J., Jr., Knobbe, S., Reboulet, E. C., Whittemore, D. O., Wilson, B. B., and Bohling, G. C., 2021, Water well hydrographs: An underutilized resource for characterizing subsurface conditions: Groundwater, v. 59, no. 6. https://doi.org/10.1111/gwat.13119

Butler, J. J., Jr., Stotler, R. L., Whittemore, D. O., and Reboulet, E. C., 2013, Interpretation of water-level changes in the High Plains aquifer in western Kansas: Groundwater, v. 51, no. 2, p. 180–190. https://doi.org/10.1111/j.1745-6584.2012.00988.x

Butler, J. J., Jr., and Whittemore, D. O., 2024, Groundwater depletion reduces drought resiliency: Nature Water, v. 2, p. 10–11. https://doi.org/10.1038/s44221-023-00185-3

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., and Bohling, G. C., 2017, High Plains aquifer index well program: 2016 annual report: Kansas Geological Survey, Open-File Report 2017-10, 144 p. http://www.kgs.ku.edu/Hydro/Publications/2017/OFR17_10/index.html

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., and Bohling, G. C., 2019, High Plains aquifer index well program: 2018 annual report: Kansas Geological Survey, Open-File Report 2019-19, 62 p. https://www.kgs.ku.edu/Hydro/Publications/2019/OFR19_19/OFR2019-19.pdf

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., and Bohling, G. C., 2020, High Plains aquifer index well program: 2019 annual report: Kansas Geological Survey, Open-File Report 2020-2, 71 p. http://www.kgs.ku.edu/Publications/OFR/2020/OFR2020-2.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

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., and Bohling, G. C., 2022, High Plains aquifer index well program: 2021 annual report: Kansas Geological Survey, Open-File Report 2022-27, 128 p. http://www.kgs.ku.edu/Publications/OFR/2022/OFR2022-27.pdf

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., and Bohling, G. C., 2023, High Plains Aquifer index well program: 2022 annual report: Kansas Geological Survey, Open-File Report 2023-55, 122 p. https://www.kgs.ku.edu/Publications/OFR/2023/OFR2023-55.pdf

Butler, J. J., Jr., Whittemore, D. O., Knobbe, S., Reboulet, E., Wilson, B. B., and Bohling, G. C., 2024, High Plains aquifer index well program: 2023 annual report: Kansas Geological Survey, Open-File Report 2024-32, 84 p. http://www.kgs.ku.edu/Publications/OFR/2024/OFR2024-32.pdf

Butler, J. J., Jr., Whittemore, D. O., Knobbe, S., Reboulet, E., Wilson, B. B., and Bohling, G. C., 2025, High Plains aquifer index well program: 2024 annual report: Kansas Geological Survey, Open-File Report 2025-58, 91 p. http://www.kgs.ku.edu/Publications/OFR/2025/OFR2025-58.pdf

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., Stotler, R. L., and Bohling, G. C., 2015, High Plains aquifer index well program: 2014 annual report: Kansas Geological Survey, Open-File Report 2015-3, 135 p. http://www.kgs.ku.edu/Hydro/Publications/2015/OFR15_3/index.html

Butler, J. J., Jr., Whittemore, D. O., Reboulet, E., Knobbe, S., Wilson, B. B., Stotler, R. L., and Bohling, G. C., 2016, High Plains aquifer index well program: 2015 annual report: Kansas Geological Survey, Open-File Report 2016-4, 179 p. http://www.kgs.ku.edu/Hydro/Publications/2016/OFR16_4/index.html

Butler, J. J., Jr., Whittemore, D. O., Wilson, B. B., and Bohling, G. C., 2016, A new approach for assessing the future of aquifers supporting irrigated agriculture: Geophysical Research Letters, v. 43, no. 5, p. 2,004–2,010. https://doi.org/10.1002/2016GL067879

Butler, J. J., Jr., Whittemore, D. O., Wilson, B. B., and Bohling, G. C., 2018, Sustainability of aquifers supporting irrigated agriculture: A case study of the High Plains aquifer in Kansas: Water International, v. 43, no. 6, p. 815–828. https://doi.org/10.1080/02508060.2018.1515566

Cain, S., III, Davis, G. A., Loheide, S. P., II, and Butler, J. J., Jr., 2004, Noise in pressure transducer readings produced by variations in solar radiation: Ground Water, v. 42, no. 6, p. 939–944. https://doi.org/10.1111/j.1745-6584.2004.t01-12-.x

Fross, D., Sophocleous, M. A., Wilson, B. B., and Butler, J. J., Jr., 2012, Kansas High Plains Aquifer Atlas: Kansas Geological Survey. http://www.kgs.ku.edu/HighPlains/HPA_Atlas/index.html

McMahon, P. B., 2001, Vertical gradients in water chemistry in the Central High Plains aquifer, Southwestern Kansas and Oklahoma Panhandle, 1999: U.S. Geological Survey, Water-Resources Investigations Report 01-4028, 47 p.

Stotler, R., Butler, J. J., Jr., Buddemeier, R. W., Bohling, G. C., Comba, S., Jin, W., Reboulet, E., Whittemore, D. O., and Wilson, B. B., 2011, High Plains aquifer calibration monitoring well program: Fourth year progress report: Kansas Geological Survey, Open-File Report 2011-4, 185 p. https://www.kgs.ku.edu/Hydro/Publications/2011/OFR11_4/index.html

Whittemore, D. O., Butler, J. J., Jr., Bohling, G. C., and Wilson, B. B., 2023, Are we saving water? Simple methods for assessing the effectiveness of groundwater conservation measures: Agricultural Water Management, v. 287, 108408. https://doi.org/10.1016/j.agwat.2023.108408

Whittemore, D. O., Butler, J. J., Jr., and Wilson, B. B., 2015, Prediction of water-level changes and water use in the High Plains aquifer from radar precipitation: Abstract H14B-04, American Geophysical Union Meeting, San Francisco, California.

Whittemore, D. O., Butler, J. J., Jr., and Wilson, B. B., 2016, Assessing the major drivers of water-level declines: New insights into the future of heavily stressed aquifers: Hydrological Sciences Journal, v. 61, no. 1, p. 134–145. https://doi.org/10.1080/02626667.2014.959958

Whittemore, D. O., Butler, J. J., Jr., and Wilson, B. B., 2023, 2023 status of the High Plains aquifer in Kansas: Kansas Geological Survey, Technical Series 25, 25 p. https://kgs.ku.edu/sites/kgs/files/files/TechSeriespdfs/TS25.pdf

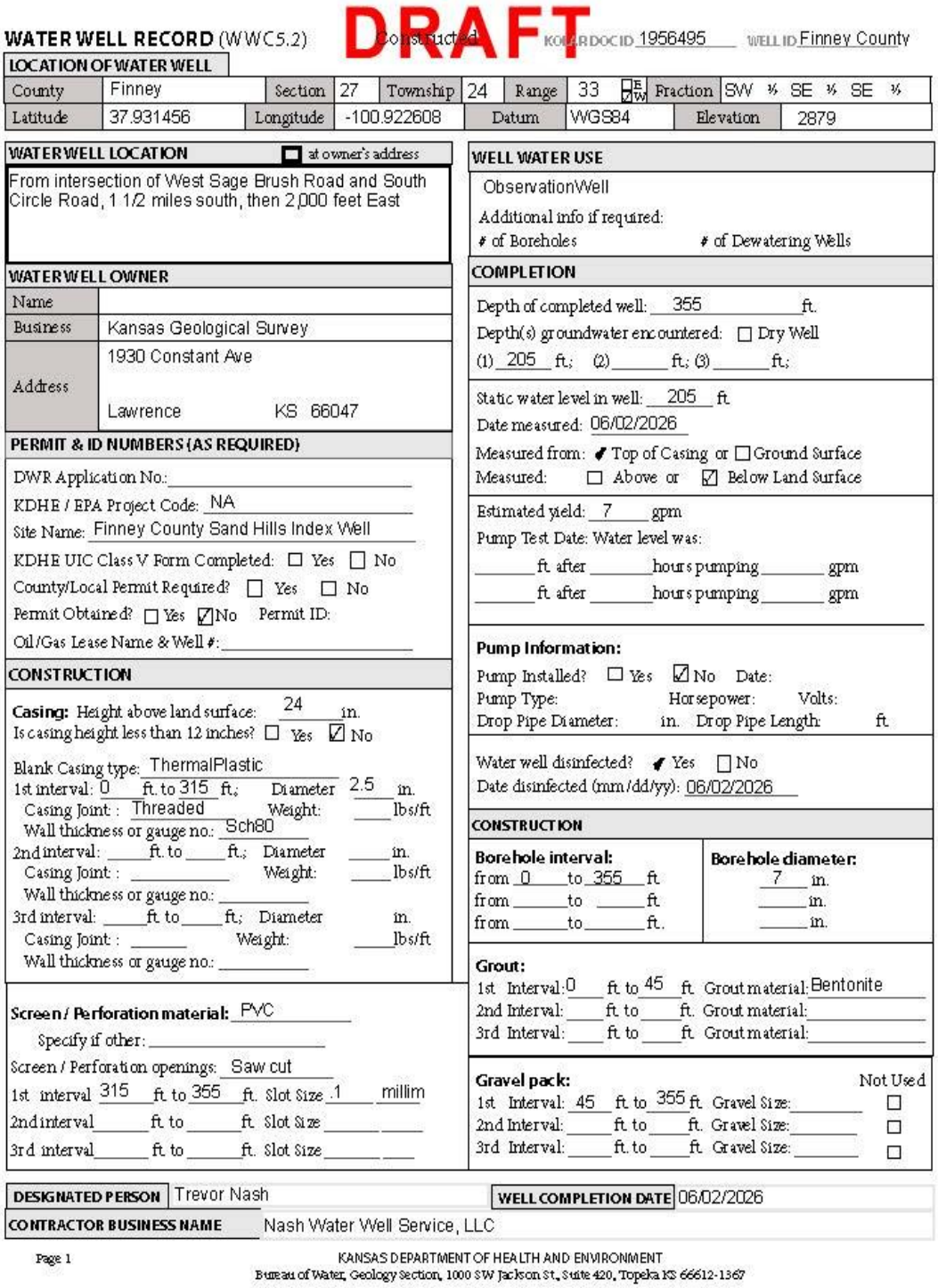
Whittemore, D. O., Butler, J. J., Jr., Wilson, B. B., and Woods, J., 2015, Using radar precipitation to estimate water-level changes and water use in the High Plains aquifer: Governor's Conference on the Future of Water in Kansas, Manhattan, Kansas, abstract.

Young, D. P., Buddemeier, R. W., Butler, J. J., Jr., Jin, W., Whittemore, D. O., Reboulet, E., and Wilson, B. B., 2008, High Plains aquifer calibration monitoring well program: Year 2 progress report: Kansas Geological Survey, Open-File Report 2008-29, 54 p. http://www.kgs.ku.edu/Hydro/Publications/2008/OFR08_29/index.html

Young, D. P., Buddemeier, R. W., Whittemore, D. O., and Reboulet, E., 2007, High Plains aquifer calibration monitoring well program: Year 1 progress report on well installation and aquifer response: Kansas Geological Survey, Open-File Report 2007-30, 44 p. http://www.kgs.ku.edu/Hydro/Publications/2007/OFR07_30/index.html.

7 Appendix: Draft WWC5 Form for New Index Well in Finney County

Sand Hills Index Well WWC5 Form (page 1)



WATER WELL RECORD (WWC5.2) DRAFT Constructed KGS DOCID 1956495 WELL ID Finney County

LOCATION OF WATER WELL

County	Finney	Section	27	Township	24	Range	33 E ☑ W	Fraction	SW ¼ SE ¼ SE ¼
Latitude	37.931456	Longitude	-100.922608	Datum	WGS84	Elevation	2879		

WATER WELL LOCATION ☐ at owner's address

From intersection of West Sage Brush Road and South Circle Road, 1 1/2 miles south, then 2,000 feet East

WATER WELL OWNER

Name	
Business	Kansas Geological Survey
Address	1930 Constant Ave Lawrence KS 66047

PERMIT & ID NUMBERS (AS REQUIRED)

DWR Application No.:
KDHE / EPA Project Code: NA
Site Name: Finney County Sand Hills Index Well
KDHE UIC Class V Form Completed: ☐ Yes ☐ No
County/Local Permit Required? ☐ Yes ☐ No
Permit Obtained? ☐ Yes ☑ No Permit ID:
Oil/Gas Lease Name & Well #:

CONSTRUCTION

Casing: Height above land surface: 24 in.
Is casing height less than 12 inches? ☐ Yes ☑ No

Blank Casing type: ThermalPlastic
1st interval: 0 ft. to 315 ft.; Diameter 2.5 in.
Casing Joint: Threaded Weight: lbs/ft
Wall thickness or gauge no.: Sch80
2nd interval: ft. to ft.; Diameter in.
Casing Joint: Weight: lbs/ft
Wall thickness or gauge no.:
3rd interval: ft. to ft.; Diameter in.
Casing Joint: Weight: lbs/ft
Wall thickness or gauge no.:

Screen / Perforation material: PVC
Specify if other:
Screen / Perforation openings: Saw cut
1st interval 315 ft. to 355 ft. Slot Size .1 millim
2nd interval ft. to ft. Slot Size
3rd interval ft. to ft. Slot Size

WELL WATER USE

ObservationWell
Additional info if required:
# of Boreholes # of Dewatering Wells

COMPLETION

Depth of completed well: 355 ft.
Depth(s) groundwater encountered: ☐ Dry Well
(1) 205 ft.; (2) ft.; (3) ft.;

Static water level in well: 205 ft
Date measured: 06/02/2026
Measured from: ✔ Top of Casing or ☐ Ground Surface
Measured: ☐ Above or ☑ Below Land Surface

Estimated yield: 7 gpm
Pump Test Date: Water level was:
ft. after hours pumping gpm
ft. after hours pumping gpm

Pump Information:
Pump Installed? ☐ Yes ☑ No Date:
Pump Type: Horsepower: Volts:
Drop Pipe Diameter: in. Drop Pipe Length: ft.

Water well disinfected? ✔ Yes ☐ No
Date disinfected (mm/dd/yy): 06/02/2026

CONSTRUCTION

Borehole interval:
from 0 to 355 ft
from to ft
from to ft.

Borehole diameter:
7 in.
in.
in.

Grout:
1st Interval: 0 ft. to 45 ft. Grout material: Bentonite
2nd Interval: ft. to ft. Grout material:
3rd Interval: ft. to ft. Grout material:

Gravel pack: Not Used
1st Interval: 45 ft. to 355 ft. Gravel Size: ☐
2nd Interval: ft. to ft. Gravel Size: ☐
3rd Interval: ft. to ft. Gravel Size: ☐

DESIGNATED PERSON Trevor Nash **WELL COMPLETION DATE** 06/02/2026
CONTRACTOR BUSINESS NAME Nash Water Well Service, LLC

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KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT
Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka KS 66612-1367

Sand Hills Index Well WWC5 Form (page 2)

WATER WELL RECORD (WWC-5) Constructed DRAFT KOLAR DOC ID 1956495 WELL ID Finney County

LOCATION OF WATER WELL

County	Finney	Section	27	Township	24	Range	33	E W	Fraction	SW ¼ SE ¼ SE ¼	
Latitude	37.931456	Longitude	-100.922608	Datum	WGS84	Elevation	2879				
Well Owner		Well Owner Business		Kansas Geological Survey							

NEAREST SOURCE OF POTENTIAL CONTAMINATION or ✔ No potential source of contamination within 100 ft.

Source:	Source:
Distance from well (ft): Direction from well:	Distance from well (ft): Direction from well:
Source description:	Source description:
Required information for local entity? ☐ Yes ☐ No	Required information for local entity? ☐ Yes ☐ No

LITHOLOGIC LOG **AQUIFER, if known**

FROM	TO	LITHOLOGY
0	10	sand,fine to medium
10	37	sand,fine to coarse,gravelly,small to large
37	62	clay,tan,brown
62	130	sand,fine to coarse,gravelly,small to large
130	140	clay,caliche stringers,tan,white and fine to medium sand
140	160	sand,fine to coarse,gravelly,small to large
160	185	sand,fine to coarse,gravelly,w/cemented sand and rock layers and streaks
185	220	sand,fine to coarse,gravelly,w/brown clay streaks
220	260	sand,fine to medium,clayey,tannish,brownish streaks
260	285	sand,fine to coarse,gravelly,thin streaks of small
285	300	sand,fine to coarse
300	320	sand,fine to coarse,gravelly,small streaks
320	353	sand,fine to coarse
353	356	clay,tan,tan and yellow
356	368	shale,unknown,blue

COMMENTS

This water well was constructed reconstructed pursuant to the stated water well contractor's license and was completed on 06/02/2026. I certify that this record is true to the best of my knowledge and belief. This water well rcord was completed on under the business name of Nash Water Well Service, LLC, KS Water Well Contractor's License No. 846 under the authority of the designated person as defined in K.A.R. 28-30-2(j) and signed and certified by the electronic signature of the designated person at its submittal: Trevor Nash. Send one copy to the water well owner and the contractor should retain one copy.

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KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT
Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka KS 66612-1367

K.S.A. 82a-1212
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