Kansas Geological Survey

Geochemical Identification of Salinity Source Affecting a House Well in Southwest Pawnee County, Kansas

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for the

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INTRODUCTION

A new house well completed on February 9, 2023, in southwest Pawnee County was found to yield saline water of unknown origin. The well is located in the upland area a little more than six miles south of the Pawnee River and a little more than two miles to the nearest location of Sawmill Creek. The Kansas Corporation Commission (KCC) Oil and Gas Conservation Division initially sent three bottles of water samples each from the house well and from a nearby irrigation well to the Kansas Geological Survey (KGS) for chemical analysis and identification of salinity source(s). After separate analyses of the waters from all six bottles, the results for the three house well samples were found to be substantially different from each other, whereas those for the irrigation well were found to be the same. Based on information from the KCC, it appeared that the different results for the house well samples were caused by time differences during sampling while the well was being pumped. After the KGS communicated the initial results to the KCC, the KCC conducted a pumping test of the well during which they periodically collected samples for which they determined the conductivity and chloride concentration and then collected three bottles of samples (one right after the other) at the end of the pumping to send to the KGS for analysis. This report contains the results of the analyses of the samples and an interpretation of the results for salinity identification.

Drillers' completion records are available from the online WWC5 database at the KGS for both the new house well and the irrigation well. The house well was completed February 9, 2023; the depth and diameter of the borehole are 100 ft and 10 inches, respectively. The 5-inch casing extends from the surface to 60 ft and the screened interval is 60–100 ft. Bentonite grout seals the annular space from the surface to 20 ft and at 48–53 ft, and gravel pack fills the annular space at 20–48 ft and 53–100 ft. The static water level measured on the day of completion was 43 ft below land surface. The lithologic log indicates that the aquifer tapped by the well is Dakota sandstone from 50 to 83 ft; slightly weathered red shale occurs from 83 to 100 ft.

The nearby irrigation well is located about a third of a mile to the northeast of the house well. The well was completed September 12, 2022; the depth and diameter of the borehole are 217 ft and 28 inches, respectively. A 16-inch blank casing extends from 18 inches above the land surface to 157 ft and the screened interval is 157–217 ft. Cement grout seals the annular space from the surface to 20 ft and gravel pack fills the annular space at 20–217 ft. The static water level measured on July 27, 2022, was 92 ft below land surface. The aquifer tapped by the well is Dakota sandstone; the lithologic log reports sandstone intervals of 61–66 ft, 95–99 ft, 133–193 ft, and 200–217 ft, with sandy shale with shale at 80–95 ft and shale with sandstone at 120–133 ft. The lithology of the other intervals is mainly clay or shale. The WWC5 database includes a construction record and two plugging records for irrigation wells located close to the current irrigation well. The construction record is for a well completed August 22, 1998, and a plugging record at that location for December 31, 1999; the well construction was nearly identical to that of the current irrigation well. The static water level measured on August 17, 1998, for the construction record was 39 ft below land surface whereas for the plugging record it was 63 ft below the surface. The other plugging record has a date of July 29, 2022, and a static water level measured as 82 ft, also with a borehole depth of 217 ft. The WIMAS records for water right 17508 for the operating irrigation well indicate an approval date of 1973, a change application for point of diversion approved in 1998, and water use data for 2022–2023. WIMAS records for one of the plugged wells shows water use for 1998–2021 and for the other plugged well for 1981–1997.

An inactive gas well completed in 2020 is located about a fourth of a mile north of the current irrigation well; the KCC well status indicates an expired plugging application. The total depth of the gas well is 2,445 ft below land surface. Two gas well boreholes are located about a fourth of a mile north of the current irrigation well. One borehole is listed as dry and abandoned with a plugging date of 1963 and a total depth of 4,733 ft. The other borehole, close to the first, has a plugging date of 1972 and the same total depth of 4,733 ft. Other inactive and plugged gas wells are located in the same section. Many other active, inactive, and plugged gas wells as well as some active, inactive, and plugged oil wells are in a several miles radius of the house well, including an inactive enhanced oil recovery well with a depth of 4,580 ft and completion date of 2019 about four miles to the northwest of the house well.

METHOD INFORMATION

Nathan Feldkamp of Conservation Division 1, KCC, sent samples in plastic bottles in coolers to the KGS. The KGS kept the samples refrigerated until analysis. The KGS measured specific conductance with a conductivity meter. Aliquots of the samples were injected through syringe filters into a Dionex ion chromatograph to determine the concentrations of the anions chloride, sulfate, bromide, and nitrate. Sample information and chemical data are listed in table 1. The KCC measured conductance with a conductivity meter and determined chloride concentration using a titration method. The linear relationships between specific conductance and chloride concentration for both the KCC and KGS samples in fig. 1 appear to be reasonably consistent for data in tables 1 and 2, although the KGS linear regression shows a little lower chloride concentration for given conductance values or higher conductance for a given chloride concentration than the KCC linear regression.

IDENTIFICATION OF SALINITY SOURCE

The sources contributing to chloride in the groundwaters were identified using the geochemical methods of Whittemore (1984, 1988, 1995). These methods primarily involve plots of the constituent mass ratios bromide/chloride and sulfate/chloride versus chloride concentration, with points for the water sample data and curves for the mixing of freshwaters with different saltwater source waters. Each mixing curve is generated using an algebraic equation for conservative mixing of two end-member waters. Conservative mixing refers to the simple mixing of waters without chemical reactions (such as mineral precipitation or adsorption, which could alter the concentrations of one or both of the constituents). Bromide and chloride are generally the most conservative constituents in groundwaters and surface waters. The bromide/chloride ratio is multiplied by 10,000 for graphical display to give numbers that range from about one (the lowest mass ratios are near or a little below 0.0001 for halite or rock salt dissolution) upward to higher values. Logarithmic scales are used in the graphs because they produce a more even distribution (separation) of points for large ranges in concentration and ratios than linear scales. The mixing curves bend on the log plots depending on the difference in the ratios relative to the difference in the chloride concentrations for the end points; the lines are straight on the log-log plot if horizontal (bromide/chloride values of end members are the same), vertical (chloride values of end members are the same), or order of magnitude differences in the ratios and chloride concentrations for the two end points are exactly the same.

Table 1. Sample collection information and chemical data. The legal location of the house well is SE/4 of the NE/4 of the NE/4 of Sec. 25, T. 22 S., R. 20 W (22S-20W-25AAD; section quarters are designated by A = NE/4, B = NW/4, C = SW/4, and D = SE/4 in order from left to right of largest to smallest quarter). The legal location of the irrigation well is 22S-19W-19CCD. The NAD83 latitude and longitude locations of the house and irrigation wells are 38.11441, -99.46029 and 38.118227, -99.456569, respectively. Sp.C. is specific conductance.

KGS lab no.	Site name	Sample date	Sp.C. µS/cm	Cl mg/L	SO4 mg/L	NO3-N mg/L	Br mg/L	Br/Cl x 10000	SO4/Cl
2024430-1	House well, bottle 1	10/16/2024	7682	2340	32.8	5.2	5.21	22.27	0.0140
2024430-2	House well, bottle 2	10/16/2024	3450	904	20.4	3.6	1.95	21.58	0.0225
2024430-3	House well, bottle 3	10/16/2024	2413	578	20.0	2.9	1.20	20.81	0.0346
2024431-1	Irrigation well, bottle 1	10/16/2024	531	7.3	19.4	2.67	0.056	76.43	2.643
2024431-2	Irrigation well, bottle 2	10/16/2024	528	7.3	19.3	2.65	0.056	76.65	2.644
2024431-3	Irrigation well, bottle 3	10/16/2024	528	7.4	19.4	2.72	0.058	78.85	2.640
2025003-1	House well, bottle 1	1/17/2025		942	24.8	3.14	2.06	21.86	0.0264
2025003-2	House well, bottle 2	1/17/2025	3542	951	24.9	3.15	2.08	21.86	0.0262
2025003-3	House well, bottle 3	1/17/2025		948	24.8	3.13	2.07	21.79	0.0261

Figure 2 is a bromide/chloride versus chloride concentration plot containing points for samples from the house well, the nearby irrigation well, irrigation wells less than eight miles from the house well that were included in previous investigations for the KCC, and an observation well completed in the Cheyenne Sandstone in central Hodgeman County as part of the KGS Dakota Aquifer Program studies. The Cheyenne Sandstone is considered part of the Dakota aquifer system along with the Dakota Formation and Kiowa Shale. The Cheyenne Sandstone sample is the closest saline groundwater in the Dakota aquifer system to the house well location for which both chloride and bromide concentration data are available. The solid pair of curves in fig. 2 define the zone of mixing of fresh groundwaters with natural saltwaters in the Dakota aquifer system as displayed in fig. 29 in the appendix to KGS Bulletin 260 on the Dakota aquifer (Whittemore et al., 2014). The points for the samples from the three irrigation wells and the Cheyenne Sandstone observation well all fall within the freshwater and saline Dakota water mixing zone.

The mixing curve with the short dashes in fig. 2 was generated to pass through the points for the house well samples. The pair of curves with the long dashes in fig. 2 is for mixing with a range of possible oil-brine ratios that produce a mixing zone that brackets the extrapolation of the house well mixing curve. Extrapolation of the mixing curve with the short dashes to a chloride concentration of typical oil brines in Kansas suggests that the bromide/chloride ratio of the contamination source would be from around 20 to the mid-20s (after multiplication by 10,000) on fig. 2. Most oil brines from Kansas analyzed by the KGS have bromide/chloride ratios in the range of 20–50 (after multiplication by 10,000), although some have been found with ratios a little below and somewhat above this range. The only oil brines for which both chloride and bromide concentrations are available from Pawnee County are for those in the area of the Macksville sink; the bromide/chloride ratio range (x 10,000) for five brine samples is 35.7–53.5. Oil brines with a ratio range of 20 to the mid-20s exist in central Kansas from Arbuckle, some Simpson (directly above the Arbuckle Group), and Viola (directly above the Simpson Group) strata. Oil production from the Arbuckle is located about four miles to the northwest of the house well.

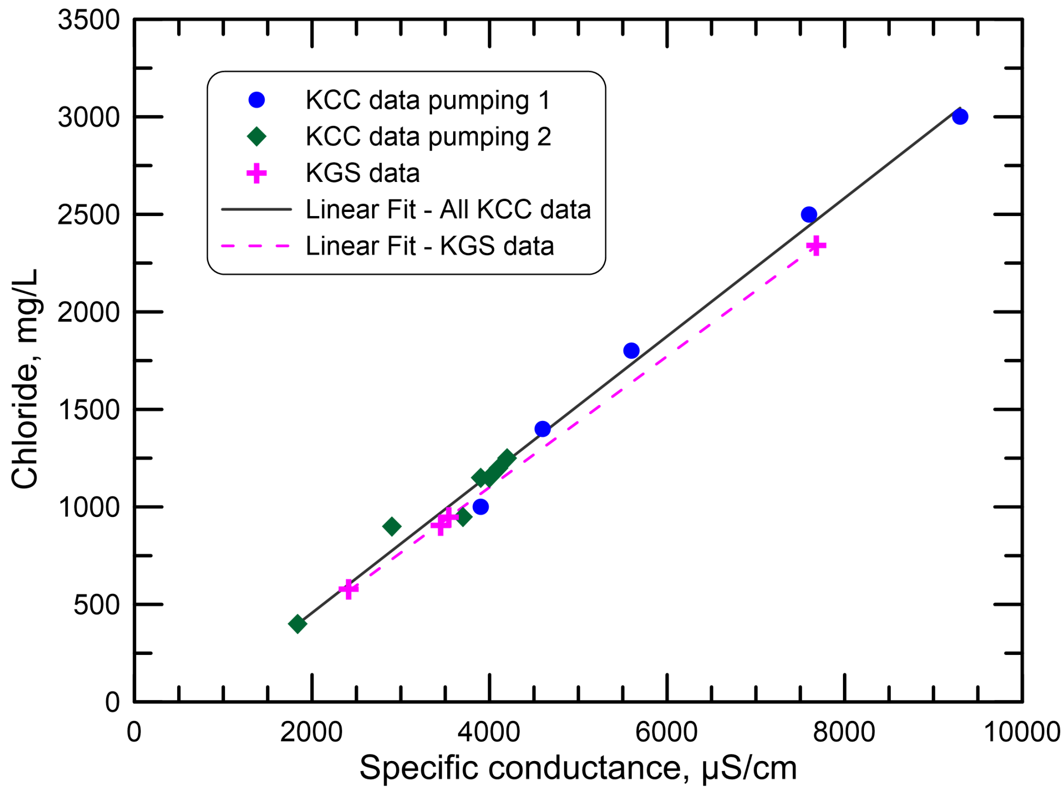

Figure 1. Relationship between specific conductance and chloride concentration for samples collected from the house well on October 16, 2025, and January 17, 2025, and analyzed by the KCC and the KGS.

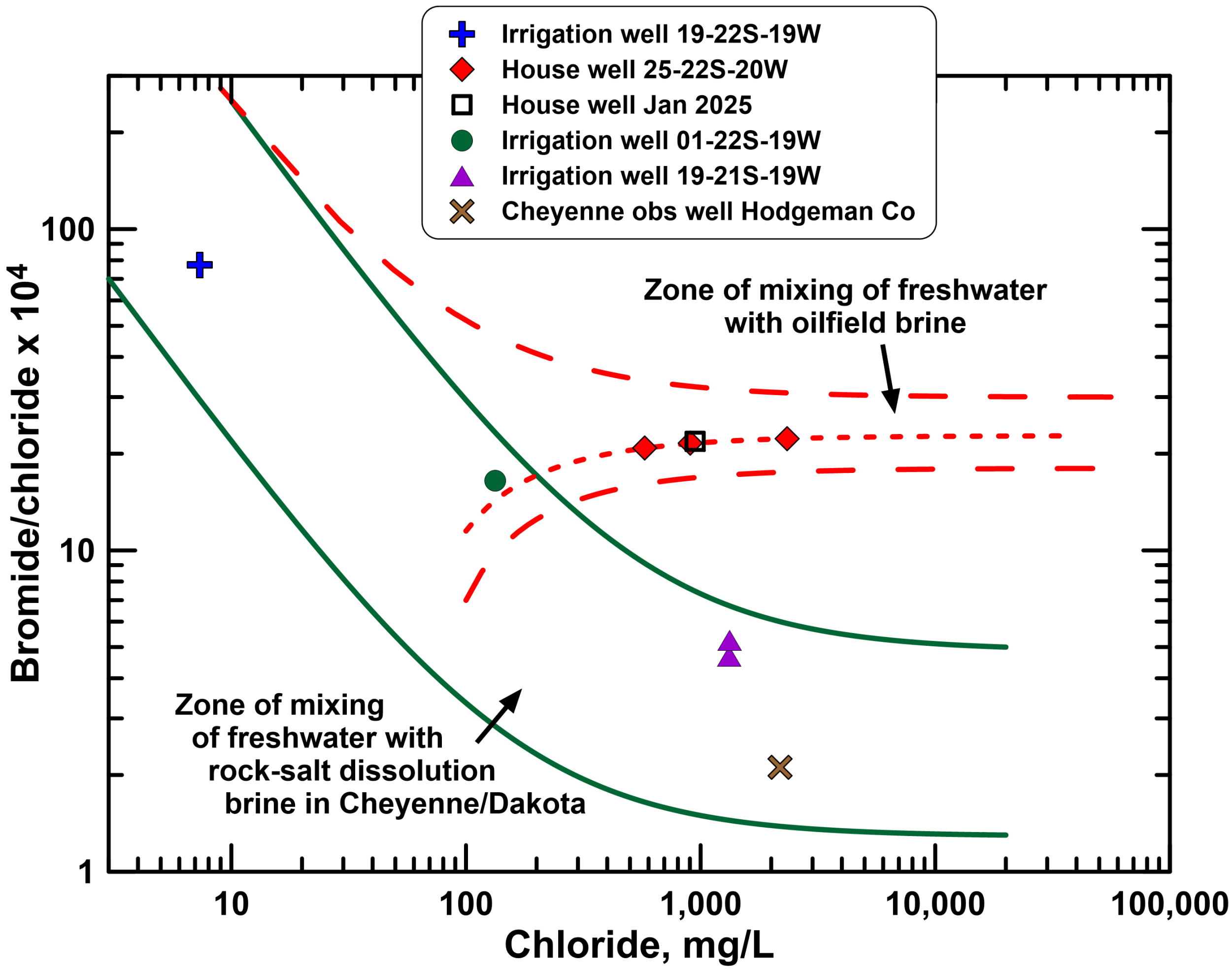

Figure 2. Bromide/chloride ratio versus chloride concentration for groundwaters from the house well and nearby irrigation well, two other irrigation wells in Pawnee County, and an observation well in the Cheyenne Sandstone in Hodgeman County. Each curve represents the mixing of an end point for freshwater with an end point for either natural saltwater from the Dakota aquifer system (from fig. 29 in Whittemore et al., 2014) or from expected oil brine fitting as a source for the house well salinity. Each pair of solid and long dashed curves encloses a zone of mixing between freshwater and saltwater or brine. The curve with short dashes is calculated to pass through the points for the house well samples.

A sulfate/chloride ratio versus chloride concentration plot with mixing curves (fig. 3) is often a useful complementary approach to the bromide/chloride ratio plot for salinity source determination. Sulfate is a relatively conservative constituent for use in most cases of salinity identification although conditions in which the solubility product for gypsum or anhydrite is exceeded and these minerals can be precipitated or where sulfate could be chemically reduced to sulfide should be considered. Figure 3 displays points for the water samples collected from the house well, nearby irrigation well, the other irrigation wells included in fig. 2, wells in the Dakota aquifer within a 10-mile radius of the house well, wells in the Cheyenne Sandstone in Hodgeman and Pawnee counties, and oil and gas brines in Pawnee County. The solid pair of curves in fig. 3 defines the zone of mixing of fresh groundwaters with natural saltwater in the

Dakota aquifer system based on the data for the points displayed. The mixing curve with the short dashes in fig. 3 was generated to pass through the points for the house well samples. The pair of curves with the long dashes in fig. 3 is for the mixing of fresh groundwater with oil or gas well brines based on the brine data for Pawnee County.

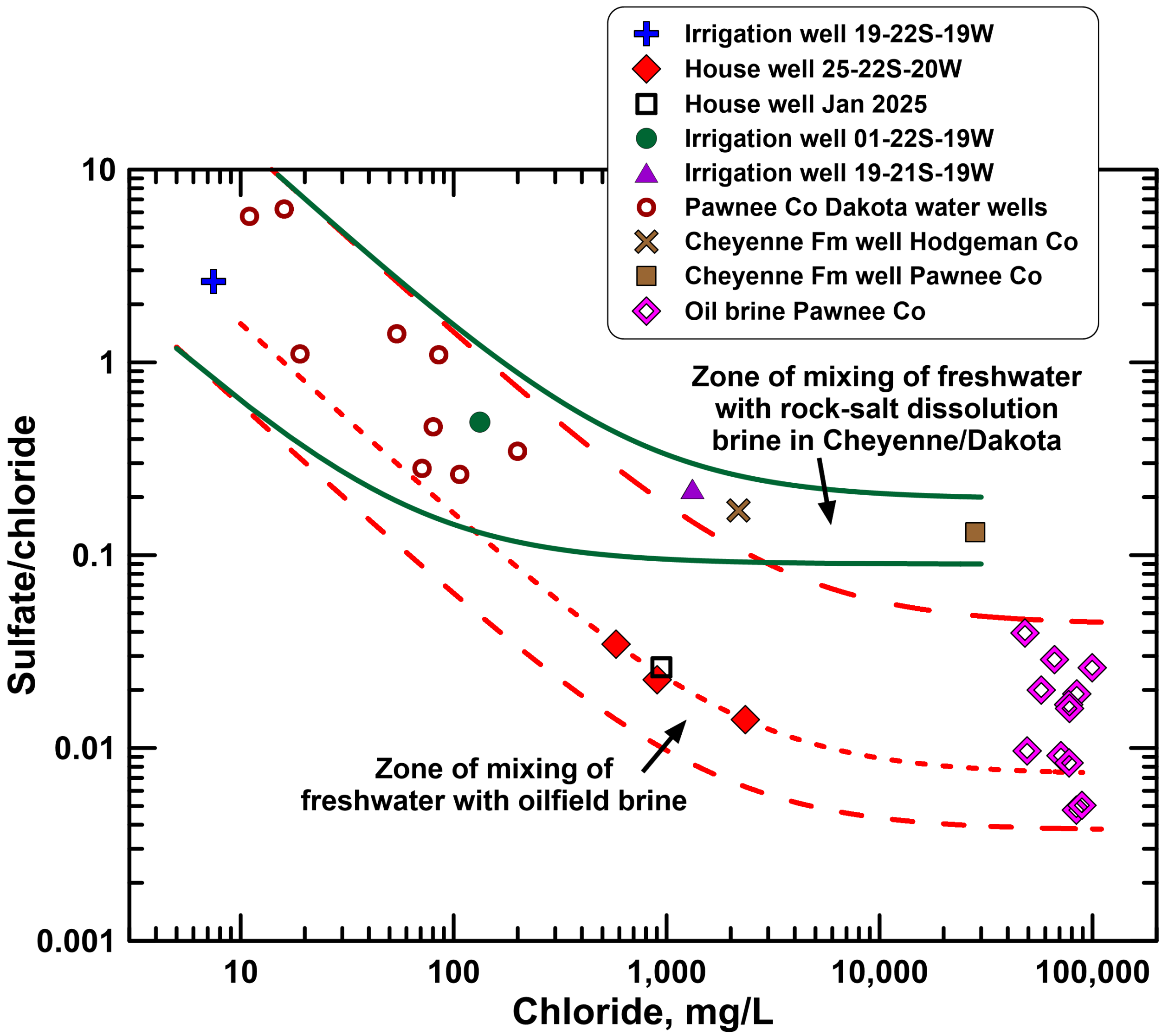

Figure 3. Sulfate/chloride ratio versus chloride concentration for groundwaters from the house well, nearby irrigation well, two other irrigation wells in Pawnee County, water wells in the Dakota aquifer within a 10-mile radius of the house well, observation wells in the Cheyenne Sandstone in central Hodgeman and central Pawnee counties, and oil brines in Pawnee County. Each curve represents the mixing of an end point for freshwater with an end point for either natural saltwater from the Dakota aquifer system or from oil brines in Pawnee County. Each pair of curves encloses a zone of mixing between freshwater and saltwater or brine.

Based on the mixing curve plots (figs. 2 and 3), the most probable salinity source contaminating the groundwater of the house well is oil or gas field brine. The fact that the nearby irrigation well yields freshwater and has a deeper screened interval (157–217 ft) than the house well (60–100 ft) also indicates that saline water in the Dakota aquifer system would not be the expected salinity source; in general, the salinity of groundwater in the Dakota aquifer increases with depth. Salt used for road deicing and conventional water softeners would give a similar bromide/chloride geochemical signature as the natural saline water in the Dakota aquifer system that was derived from intrusion of halite dissolution saltwater in underlying Permian strata that dispersed into overlying Dakota strata.

PUMPING TEST

The KCC performed a pumping test on January 17, 2025, that involved pumping the house well for 20 minutes, turning the pump off for 30 minutes, and then pumping the well for 30 minutes. The KCC collected samples every five minutes during both pumping periods and measured the specific conductance and chloride concentration in the samples; results are in table 2. A water sample was collected a couple minutes after the KCC collected its sample at the end of the second pumping and sent to the KGS for analysis (table 1). Figure 4 displays the specific conductance and chloride concentration with time for samples collected during the pumping test.

Table 2. Specific conductance and chloride concentration determined by the KCC for samples collected during the pumping test of the house well on January 17, 2025.

Time, am	Minutes after pumping start	Sp.C., µS/cm	Cl, mg/L
10:00	0	9,300	3,000
10:05	5	7,600	2,500
10:10	10	5,600	1,800
10:15	15	4,600	1,400
10:20	20	3,900	1,000
	30 min recovery		
10:50	0	2,900	900
10:55	5	1,840	400
11:00	10	3,700	950
11:05	15	4,200	1,250
11:10	20	4,100	1,200
11:15	25	4,000	1,150
11:20	30	3,900	1,150

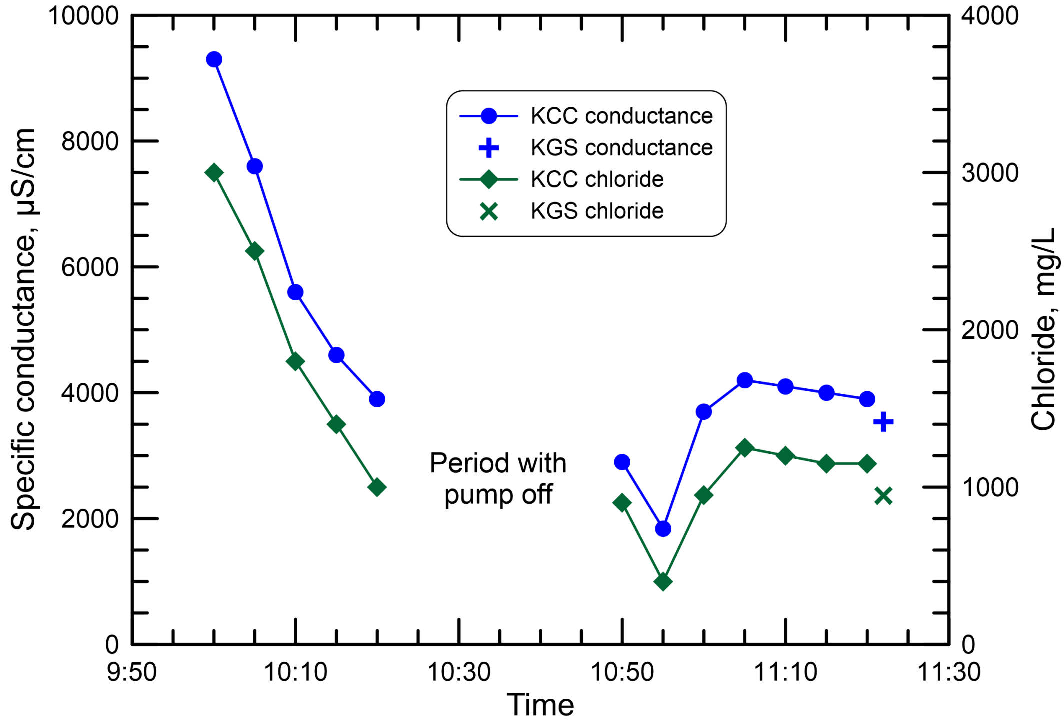

Figure 4. Specific conductance and chloride concentration of samples collected and analyzed by the KCC during the pumping of the house well on January 17, 2025, and for a sample collected by the KCC a couple minutes after the end of the pumping and sent to the KGS for analysis.

DISCUSSION

The well log indicates that the well is grouted from 0 to 20 ft below the land surface within topsoil and clay. Assuming that the grout was inserted appropriately, this would rule out contamination from the land surface that could pass through the annular space of the well. However, the interval of the grout (48–53 ft) is only 2 ft within a shale (48–50 ft) and 3 ft within the top of the sandstone that starts at 50 ft. If that 2 ft grout layer within the shale was not inserted appropriately or the bottom of the shale is somewhat permeable, then maybe saltwater infiltration from the surface could have entered the uppermost part of the sandstone and the well.

Movement of surface or very near surface saltwater from the nearby gas field within a mile to the northeast of the house well does not appear to be a probable source because the house well is upgradient in elevation from the gas field. For example, the ephemeral stream that passes near the house well drains toward the gas field.

The pumping test and the depth of the pump in the well could give some idea for the depth of the sandstone from which the saltwater is derived. If there is a substantial time before the well was pumped, then the saltwater causing the contamination would have time to enter the well through the gravel pack and screen and mix with the water in the screened interval. The landowner indicated that the company that installed the well said that the top of the pump is 10 ft above the bottom of the well and the pump is 3–4 ft long.

If the saltwater contamination were from the surface or entered the near surface or upper part of the sandstone unit through a nearby unplugged borehole, either the water in the upper part of the sandstone would be more saline than deeper in the unit or the salinity would be about the same from the saltwater contaminating the whole unit in that locality due to the greater density of the saltwater than the freshwater. Clayey sandstone units in the sandstone too thin to be recorded by the well driller could possibly segregate zones of different salinity in the sandstone unit and keep more saline water stratified in the upper part of the unit. The gravel pack of the well could facilitate the migration of denser, more saline water deeper in the sandstone unit. If the water were more saline in the upper part of the sandstone unit and if the gravel pack had allowed saline water to move down into the area of the well opposite the pump, water pumped could potentially decrease in salinity with time as more water was drawn from the deeper, less saline part of the sandstone opposite the pump. After the pump was turned off and water entered the well to remove the cone of depression, the water entering the screened interval could preferentially come from the less saline/fresher, deeper portion of the sandstone. When the pump was turned on again, it would initially draw water from the casing in the lower part of the screened interval that would be less saline water. Thus, the salinity could drop as was observed at the beginning of the second phase of the pumping. As the pumping continued to remove the casing volume and the water level dropped, the water could come from the entire sandstone and be a mix of the saltwater entering in the upper sandstone and the less saline water in the lower sandstone so the salinity would rise but to a level at which the mixture would not change much and that would not be as high as when the well was first pumped; this is what was observed. If the gravel pack did not allow a substantial amount of shallower saline water to migrate to the lower part of the well during the time between drilling and pumping, then the substantial decrease in salinity observed during initial pumping would not fit well the scenario of greater salinity in the upper than the lower part of the sandstone unit. Also, if the salinity of the water in the sandstone unit were fairly uniform, the conductivity changes in the pump test would not be as pronounced as observed, so that scenario would not fit.

If the saltwater entered the lower part of the sandstone unit, then a gradient in the water salinity in the sandstone unit might be expected, with less saline or fresh water in the upper part of the unit. The water in the upper part of the screened interval would remain less saline because the greater density of the saltwater would keep it at the bottom of the casing in the screened interval. Although saline water can diffuse upward, this is a very slow process. With the pump in the lower part of the screened interval where the saltwater is entering, the salinity of the water would be high when the well first started pumping. Then the salinity would decrease as water from higher in the casing mixed with the water being pumped and continue to decrease when the water pumped was a mixture of the deeper, more saline and shallower, less saline or fresh water from the sandstone unit. When the pump stopped and the water level rose, water would continue to enter the screened interval. If the permeability of the sandstone unit were approximately uniform with depth, more saline water in the deeper part of the unit could be expected to enter the screened interval where the pump is located. Then when the pump was started after the half-hour delay, the conductivity of the water pumped might be expected to rise at first then decrease as water was drawn in from both the upper less saline and deeper more saline part of the unit. This was not observed. However, if the permeability of the upper part of the sandstone unit were greater than the lower part, a greater amount of fresher, shallower water could enter the gravel pack and inside the screened pipe during the recovery period. The initial conductivity decrease might mainly represent the water drawn from within the screened pipe. Then, as the water level declined in the well, if the decline reduced the amount of water flowing from the upper part of the sandstone, the salinity could rise as the relative proportion of the deeper, more saline water increased due to water drawn in from the gravel pack. As the pumping continued, the mix of the water being pumped from the formation appears to have become more constant, although slowly decreasing with time. The slow decrease could represent a slightly greater amount of water flowing through the formation outside the borehole from the upper sandstone.

As indicated earlier, the freshwater yielded from deeper in the Dakota aquifer at the nearby irrigation well suggests that oil/gas brine does not appear to have contaminated the sandstone unit tapped at the irrigation well. Thus, the contamination appears to be a local occurrence. No nearby houses and domestic wells are in the area around the new house well. No record of an oil/gas borehole close to the house well is in the database of the KGS. However, the earliest record of a borehole in the general area of the house well has a date of 1942 (and was a little over a mile to the east-northeast of the house well) and many wells were drilled during the 1950s.

If an unrecorded exploration oil/gas well in the early days of petroleum exploration was located near the house well, an old saltwater pit might have locally contaminated the shallow subsurface. The abandoned 1942 borehole mentioned above was drilled to a depth of 5,364 ft, which would have been through the Viola, Simpson, and Arbuckle strata. If an unrecorded borehole near the house well was poorly or not plugged, then saltwater might be able to come up that borehole and enter the Dakota aquifer if the pressure in the deep subsurface formations was great enough. This possibility might occur if the pressure from an enhanced oil recovery operation in the Arbuckle (as recorded in the KGS online oil and gas records) four miles to the northwest of the house well could have been transmitted with time to a borehole close to the house well location. If the surface casing of the oil/gas well had only been removed from a depth above the top of the sandstone unit at the house well, then saltwater could have entered that unit near the house well from the near surface. If a more substantial part of the surface casing had been removed, it might have been possible for saltwater from a borehole to directly enter into the Dakota sandstone unit tapped by the well. The status of the enhanced recovery well is currently inactive as indicated by the KCC. Therefore, if the pressure in the Arbuckle from that recovery well could have reached the house well location, it might be dissipating.

The salinity of the water was decreasing during the last 15 minutes of the pumping test of the house well. The extent of the local contamination is unknown. However, if it is limited, the possibility exists that substantial pumping of the house well could remove enough of the contaminated groundwater to provide usable water; with time, the salinity might be expected to continue to slowly decrease.

CONCLUSIONS

The geochemical signature of the saline water pumped from the house well indicates that the most probable salinity source contaminating the groundwater of the house well is oil or gas field brine. The signature does not fit natural saltwater from the Dakota aquifer or conventional water softener or road salt. These sources also do not fit because a nearby irrigation well draws water from deeper in the Dakota aquifer and no nearby houses are located near the new house well (and new house next to the well).

The salinity of water from a two-phase pumping test of the house well showed substantial changes with time. Based on the location of the pump in the well in the lower part of the screened interval and the salinity changes in the pumped water, two scenarios are possible, depending on the relative permeabilities of the upper and lower zones of the sandstone unit in which the house well is screened: surface/near-surface saltwater entering the top of the sandstone unit in which the house well is screened or saltwater entering the lower part of the sandstone unit.

The house well contamination appears to be a very local occurrence. The house well is upgradient of the nearby gas field located to the northeast. If operations of the gas field had contaminated the Dakota aquifer, the irrigation well next to the gas field and screened in the Dakota aquifer might also be expected to be contaminated. Even if shallow contamination from the gas field exists and clay strata keep it from penetrating deeper into the Dakota aquifer where the irrigation well is screened, the gravel pack that extends to within 20 ft of the land surface in the irrigation well might be expected to have allowed the infiltration of shallow contamination to the screened interval of the irrigation well. The water yielded by the irrigation well is fresh with no signs of brine contamination.

What appears to be very local contamination of the aquifer tapped by the house well may point to an old, unrecorded exploration well for oil or gas. A saltwater pit associated with its drilling might be a source. The borehole of an unrecorded well, if poorly or not plugged, might possibly have allowed deep formation brine to enter the Dakota aquifer if the pressure was great enough, such as if the pressure from an enhanced oil recovery operation about four miles to the northwest of the house well could have been transmitted to the location. The oil well converted to the enhanced recovery well was completed in the Arbuckle, a formation that can contain brine with a geochemical signature similar to that which is the expected saltwater contamination source for the house well.

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