ADDRESSING GROUNDWATER GOALS OF THE MISSOURI REGIONAL PLANNING AREA

Kansas Water Office Contract #16-125

Progress report for Kansas Water Office

by

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Scope of Work

The scope of work of the project is intended to fulfill the data and research portions of two of the main goals of the Missouri Regional Planning Area (MRPA), namely, goal 1) "Since groundwater quality is not well known, compile existing and collect additional data over the next 5 years to establish a baseline"; and goal 3) "Collect additional information to improve safe yield estimate of groundwater and tributary streams within 3 years".

The scope of work for the present project #16-125 is summarized in five items as follows:

Item no. 1. Extract data about the glacial, alluvial and bedrock aquifers in the region from online databases: Water Well Completion Records (WWC5) and Water Well Levels (WIZARD) online databases of the KGS; water use from the Water Information Management and Analysis System (WIMAS) online database of the DWR-KDA served by the KGS; Groundwater Levels and Water Quality online databases of the USGS.

Item no. 2. Obtain non-digital historical data on drilling logs (including available test-hole data), preglacial drainageways, bedrock surface topography, saturated thickness of Pleistocene deposits, and groundwater quality in the area. These data will be assembled from publications and other available sources on groundwater hydrogeology and groundwater quality for counties in the Missouri Regional Planning Area.

Item no. 3. Construct digital databases from collected existing data (available historical reports and online databases).

Item no. 4. Prepare digital maps of updated bedrock surface topography, saturated aquifer thickness, preglacial drainageways, water use, and groundwater quality from digital databases.

Item no. 5. Prepare a report assessing groundwater in storage, general sustainability, and groundwater quality conditions, and determine the greatest needs for the collection of additional data, and recommendations for locations of long-term monitoring sites.

The present progress report, the second of a series of three, covers items no. 3 and 4.

Study Area

The study area is the Missouri Regional Planning Area in northeast Kansas. It includes one county in full (Doniphan –DP) and six counties partially (Marshall –MS, Nemaha –NM, Brown –BR, Atchison –AT, Leavenworth –LV and Wyandotte –WY) (Figure 1).

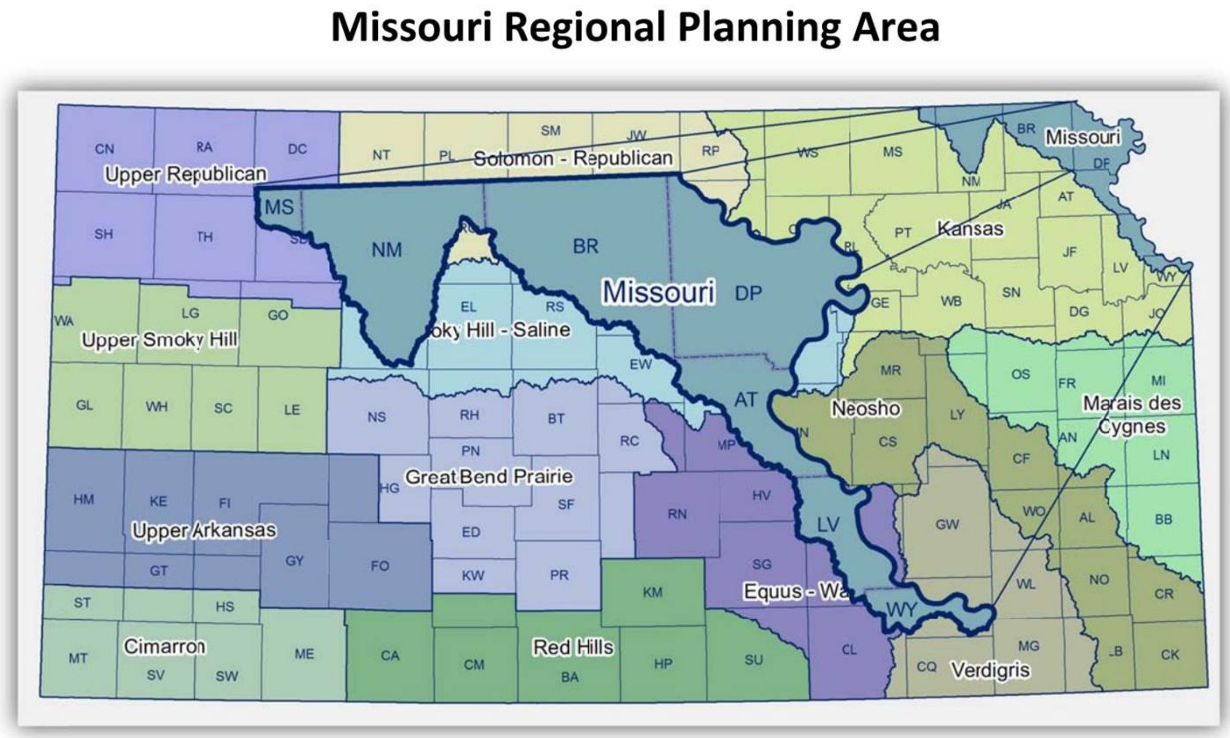

Figure 1. Location of the Missouri Regional Planning Area with its seven counties (from west to east: Marshall –MS, Nemaha –NM, Brown –BR, Doniphan –DP, Atchison –AT, Leavenworth –LV, Wyandotte –WY).

Water use

WIMAS (Water Information Management and Analysis System) is the main and most efficient tool to estimate the surface water and groundwater use in an area in Kansas. WIMAS is a public web-based application allowing users to query, analyze, and map Kansas water rights data. The database is particularly useful to obtain information about the temporal evolution of the number of rights and groundwater and surface water use in an area, subbasin or county. The database is automatically updated every day from the Kansas Department of Agriculture's Division of Water Resources Water Rights Information System. Data for 2016 is under process and will not be available until mid-2017 or later. As a result, the latest year for which we dispose data is 2015.

The total use of groundwater in the MRPA has ranged from 10,523 acre foot (acf) in 1990 to 4,770 acf in 2009 (Figure 2a). These volumes are significantly lower than the maximum authorized groundwater volume of 53,243 acf. The variations in use are generally inversely correlated with climatic conditions; for example, the low use of years 2009 and 2010 were associated with wet conditions (values of the Palmer Drought Severity Index –PDSI- for climatic division 3 of northeast Kansas that are greater than +2 on Figure 3) and the high use in 2013 - 8,053 acf- was during a drought year (a PDSI value less than -2 on Figure 3).

Since 1990 the number of groundwater rights increased in all counties except Wyandotte. That increase is particularly significant in Brown County, from 12 groundwater rights in 2005 to 40 in 2015 (333% increase). No groundwater rights exist in Marshall County within the MRPA (Figure 2b).

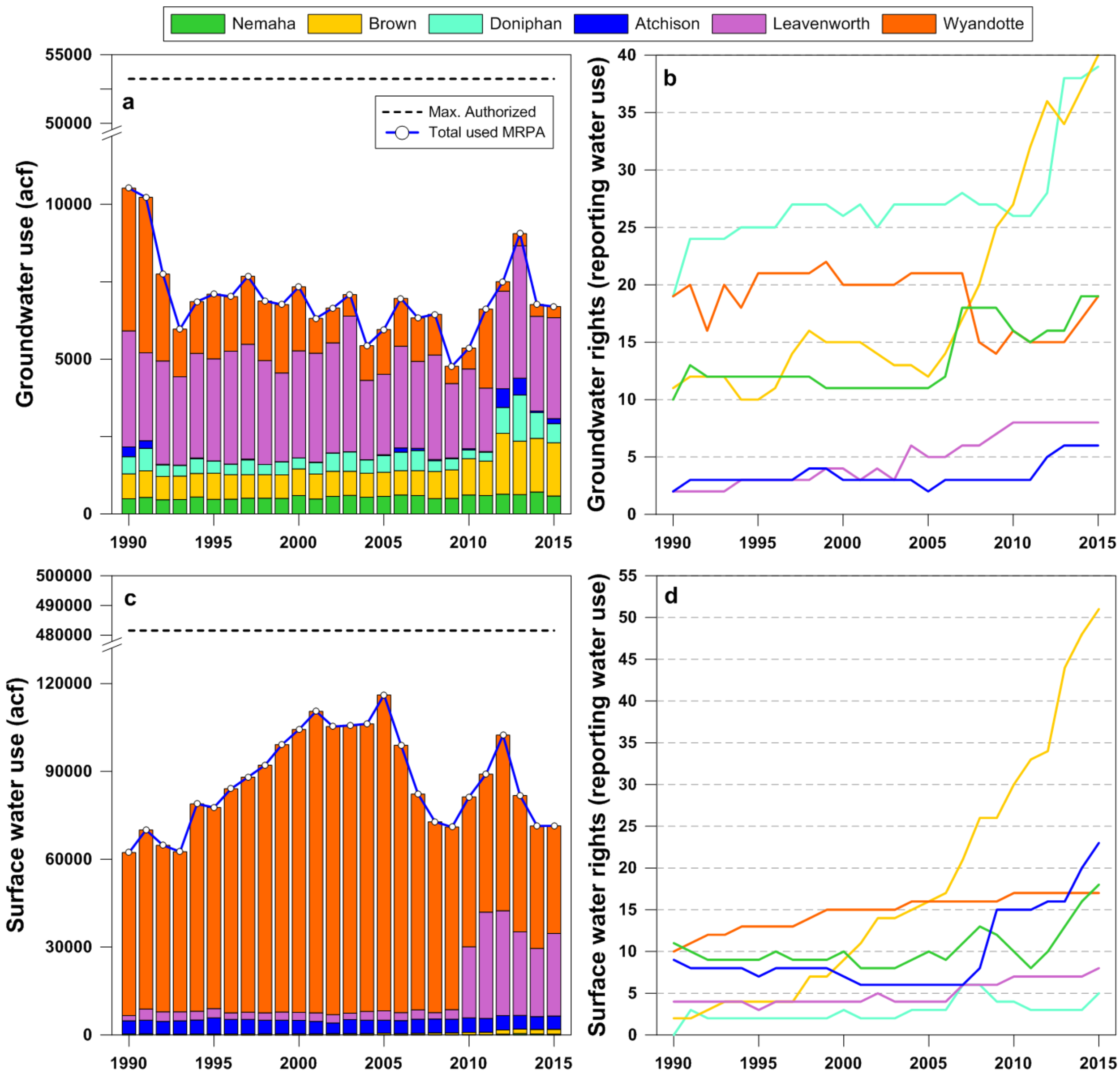

Figure 2. Evolution of groundwater use (a), number of groundwater rights (b), surface water use (c) and surface water rights (d) in the MRPA.

Surface water use in the MRPA in 2015 (71,415 acres feet) was very similar to the use in 1990 (62,270 acres feet), although in between these years the area has seen two peaks in 2005 and 2012, with 116,100 acf and 102,370 acf, respectively (Figure 2c). Wyandotte County is the county that uses the most surface water in the MRPA, although its usage has significantly decreased since 2005, from 107,877 acf to 36,744 acf in 2015. In contrast, Leavenworth County increased surface water use by more than 800% since 2009, from 3,282 acf to 28,197 acf in 2015. Brown County had a steady increase in water use since 1994, going from not using surface water to using more than 1,675 acf in 2015. In fact, the number of surface water rights reporting usage in Brown County has increased exponentially since 1990, from 2 to 51 in 2015 (Figure 2d). In all other counties the number of surface water rights reporting water use has just doubled at the most, as is the case of Atchison County (from 9 in 1990 to 23 in 2015).

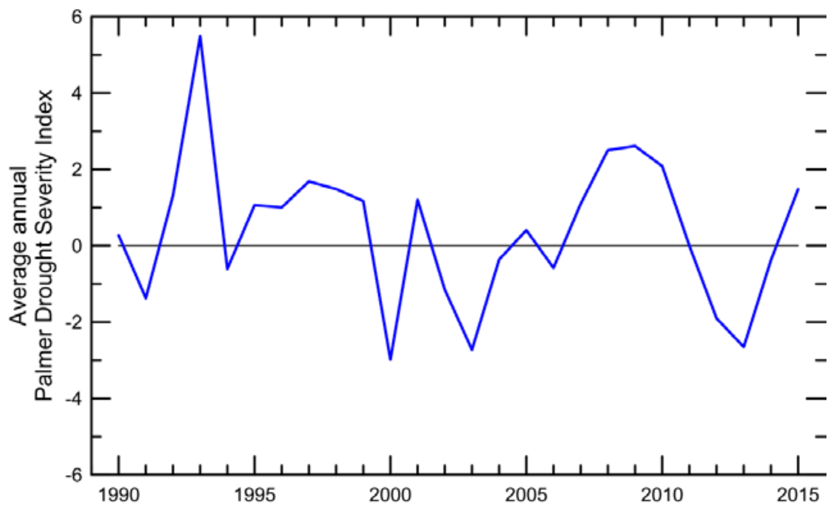

Figure 3. Average annual Palmer Drought Severity Index for climatic division 3 (northeast Kansas) during 1990–2015. A value of zero represents normal climatic conditions; positive and negative values indicate wet and dry periods, respectively.

Municipal use is the most important use of groundwater in the MRPA, with a yearly average usage around 5,000 acf since 1990. Two small peaks of usage occurred in 2003 and 2013, with 6,032 and 5,526 acf per year, respectively (Figure 4a). In average, municipal use represents 68% of the total groundwater use in the MRPA. In contrast, industrial use dramatically decreased since 1991 (4,555 acf), and nowadays its use is as low as 100 acf per year. Groundwater irrigation use saw a notorious increase between 2005 and 2013 (from 324 acf to 2,746 acf), although the usage slightly decreased in the last two years, being 1,611 in 2015. Recreational activities represented no use of groundwater until 2011, but since then small peaks of usage occurred, notably in 2012 and 2013, with approximately 400 acf per year. Groundwater used for stock remained nearly steady since 1990, although its usage nearly doubled from 2011, being 77 acf in 2015. “Other” activities (no differentiation reported) that use groundwater have high variability in their use, with more than 1,000 acf per year between 1994 and 1997, and a peak of 2,153 acf in 2011. Except these usage peaks, the groundwater use by “other” activities is small when compared to municipal and irrigation use.

Municipal use represents in average 95% of the total surface water use in the MRPA (Figure 4b). There are two peaks of surface water use in 2005 and 2012 (108,660 and 99,091 acf, respectively), but these peaks do not match with two peaks observed in the groundwater municipal use, in 2003 and 2013. Similarly with groundwater, the use of surface water for irrigation purposes increased since 2005, from 243 acf to 1,769 acf in 2015. Surface water use for industrial, recreational and stock purposes is either zero (i.e. stock) or negligible. It is worth noting that there was no use of surface water for "other" activities in 1990 and 1991, but its usage significantly increased from 1992 to reach 8,120 acf in 2001. Since then, surface water use for "other" activities has decreased to less than 1,000 acf in 2015.

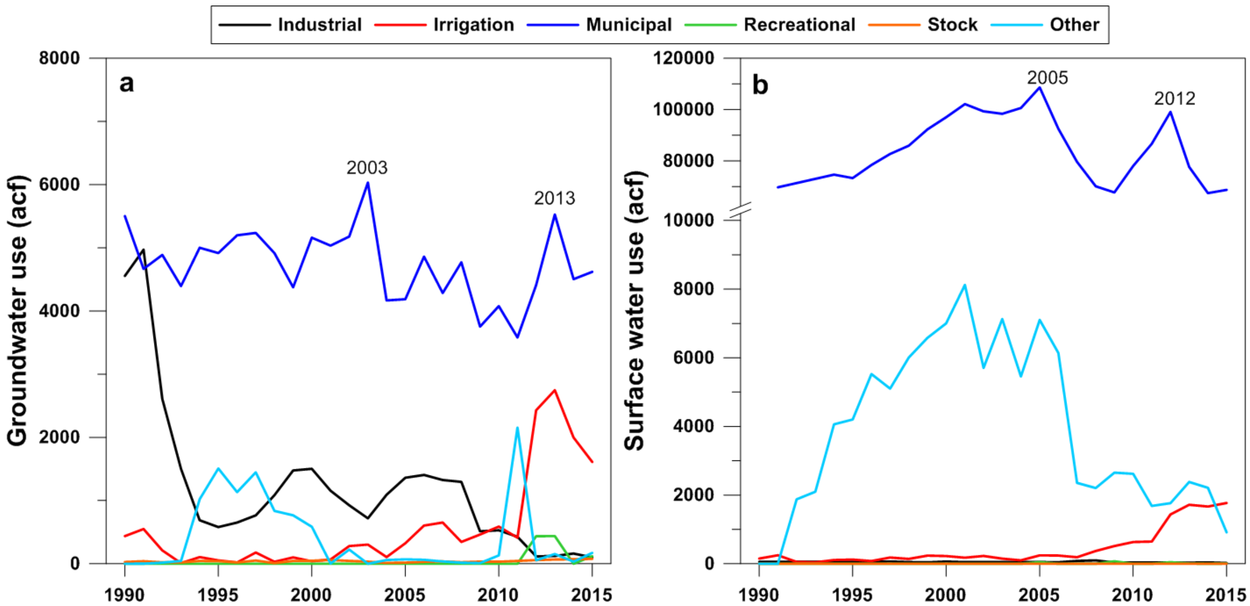

Figure 4. Groundwater (a) and surface water (b) use by activities. Note that domestic water is not accounted for in WIMAS because its use is considered insignificant compared to all other uses.

Test-hole data update

As we noted in our report in January 2017, KGS established contact with Ground Water Associates, Inc. (GWA), in November 2016, to obtain test-hole data from projects including drilling performed by GWA for cities and rural water districts in the area. Despite GWA agreeing to provide KGS with the contact information for the cities and rural water districts for which they worked in the study area, the situation changed during early 2017. They were reluctant to ask their clients to release information after a review of legal issues.

Despite not getting access to test-hole data is an important drawback, we were able to collect test-hole data from geological surveys performed during the last century by KGS and USGS in the counties included in the MRPA. Overall 2,846 test-hole were found, of which 1,092 are within the MRPA study area (Figure 5).

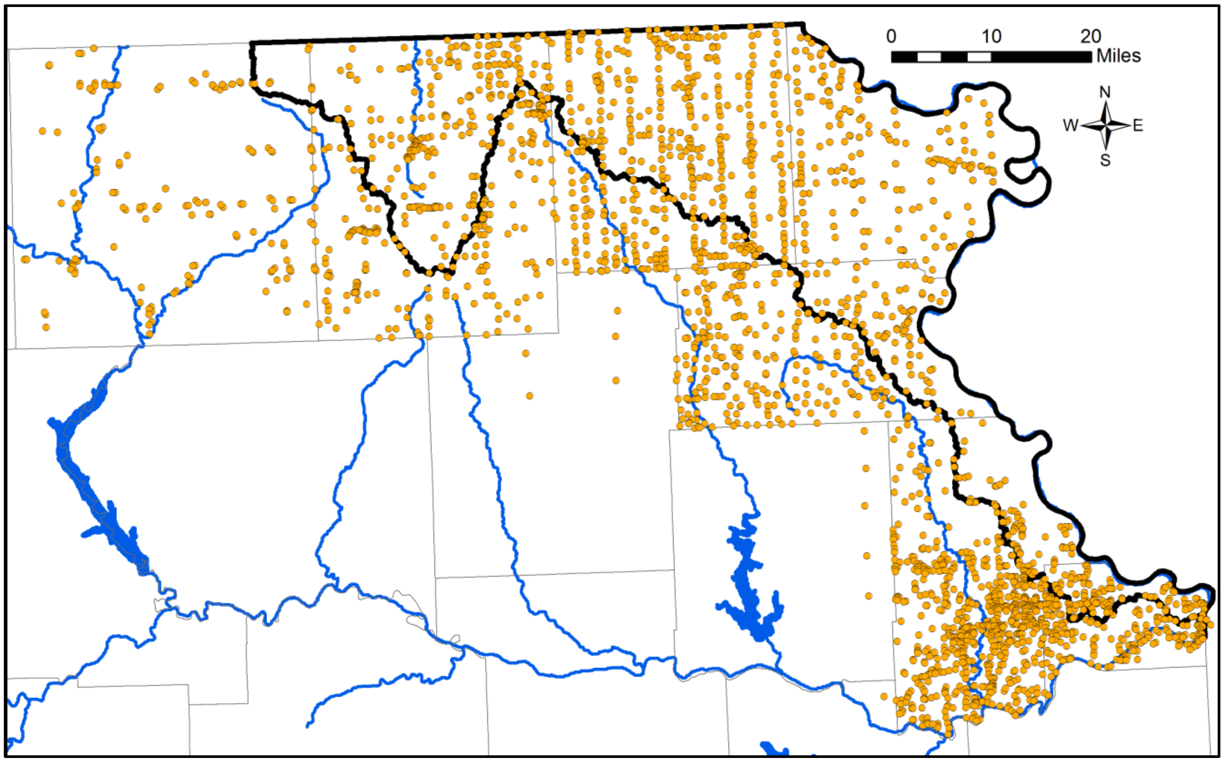

Figure 5. Map with the 2,846 test-hole in Marshall, Nemaha, Brown, Doniphan, Atchison, Leavenworth and Wyandotte counties, including those in the MRPA study area.

Water-well driller's information

All the information from completed wells in the MRPA study area was retrieved from the WWC5 (Water Well Completion Records Database). A total of 4,437 wells were found in the MRPA area, but only 2,011 had drillers' logs in an electronic form that is readily accessible. The remaining 2,426 were manually processed to make the drillers' log digitally available and ready to use in the current and future projects.

Thickness of unconsolidated materials

The thickness of unconsolidated materials is calculated by substracting the topographic elevation from the bedrock surface elevation at each location where both values are known. Work is in progress to build digital maps of that parameter. Topographic elevation is an accurately-known parameter, thus the accuracy of the thickness of unconsolidated materials primarily relies on the accuracy of the bedrock surface elevation reported either in test-hole or water-well driller's information.

Bedrock surface

The bedrock surface is critical information for calculating the thickness of unconsolidated and/or glacial deposits. The bedrock surface was obtained from test-hole and WWC5 records. Test-hole are drilled with the purpose to study the geology and hydrogeology of an area, thus 97% of them were drilled at least to the bedrock. The purpose of wells in the WWC5 is to exploit water from the aquifer, thus reaching the bedrock is not the target. This explains why only 55% (2,447 in number) reached the bedrock during drilling. That means for the purpose of the current project, 45% of completed wells in the MRPA study area cannot be used to determine the total thickness of unconsolidated deposits (and therefore, saturated thickness). Figure 6 shows a preliminary map of the bedrock surface built using test-hole information only. Work is ongoing to include water-well information from the WWC5 to update the bedrock surface elevation map and obtain a more accurate version.

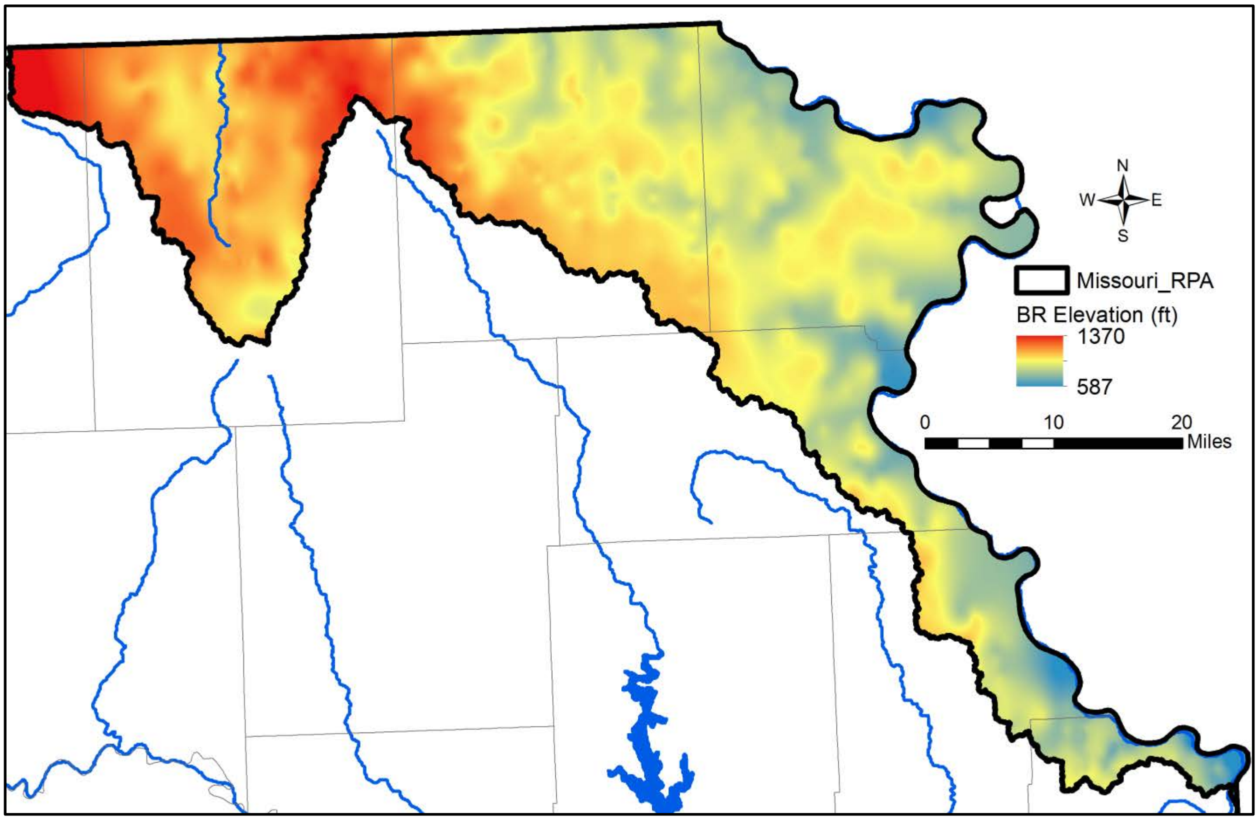

Figure 6. Preliminary map of bedrock surface elevation using test-hole information only.

Saturated thickness (groundwater level)

The saturated thickness of an aquifer is essential information for assessing the groundwater resources of an area and their future management. The monitoring work that the KGS has been performing in the High Plains Aquifer exemplifies the importance of obtaining reliable continuous monitoring of groundwater levels both spatially and temporally. We found a substantial number of static water-level measurements that were performed at the time of drilling test-hole (Figure 7) and water wells (Figure 8).

Nevertheless, it is important to stress that the majority of these water-level measurements are of limited use for calculating today's saturated thickness of unconsolidated materials. More than 80% of the static water levels were from test-hole data obtained between 1955 and 1985. The remaining 20% are even older. Thus, the water levels from test-hole average at least 50 years old, and may no longer be representative of actual conditions. However, many of these test-holes were reported as dry, and this is very valuable information for our purposes, as we can assume with relatively high confidence that those locations measured during years that were not exceptional droughts remain dry today.

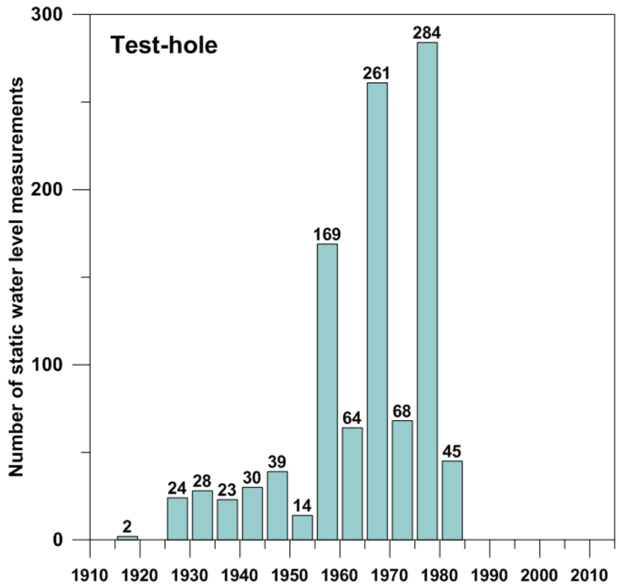

Figure 7. Number of static water-level measurements from test-hole data.

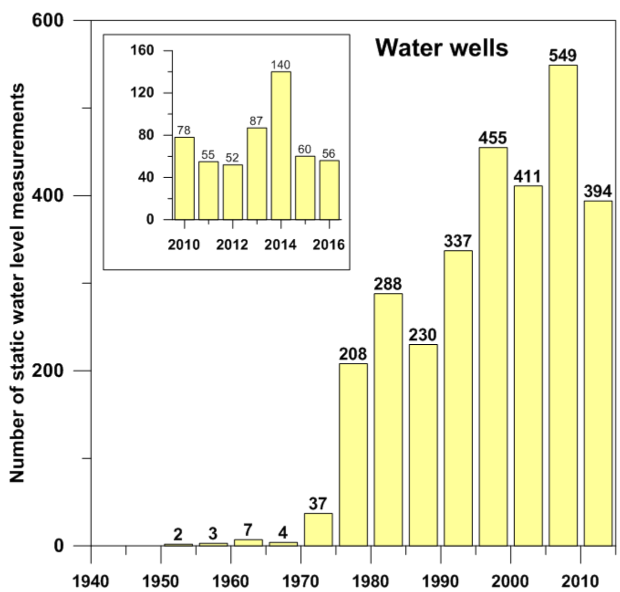

Figure 8. Number of static water-level measurements from the WWC5 database.

Static water-level data for completed water wells are more recent compared to test-hole data, but their usefulness remains limited because only one static water level per well is available and the values were measured at different locations during the year. Groundwater level can have a strong seasonal and spatial variability. The best approach to producing reliable maps of saturated thickness and its evolution over time is to monitor the groundwater level every year during the same season and in the same wells. Work is ongoing to maximize the useful of the available data.

Groundwater chemistry

Groundwater chemistry in the MRPA was obtained from three sources: the USGS Water-Quality Data for Kansas (https://waterdata.usgs.gov/ks/nwis/qw), KGS bulletins (Ward, 1974; Bayne and Schoewe, 1967, Denne et al., 1998) and the Kansas Department of Health and Environment (KDHE). Several sampling campaigns were carried out in the past as collaborative work between the KGS and USGS, resulting in many duplicate analyses between the USGS Water Quality Data for Kansas and KGS bulletins. After removing all duplicates, the total number of groundwater analyses since 1939 (year of the oldest groundwater analysis on record) is 450. Their distribution per years and counties is shown in Figure 9.

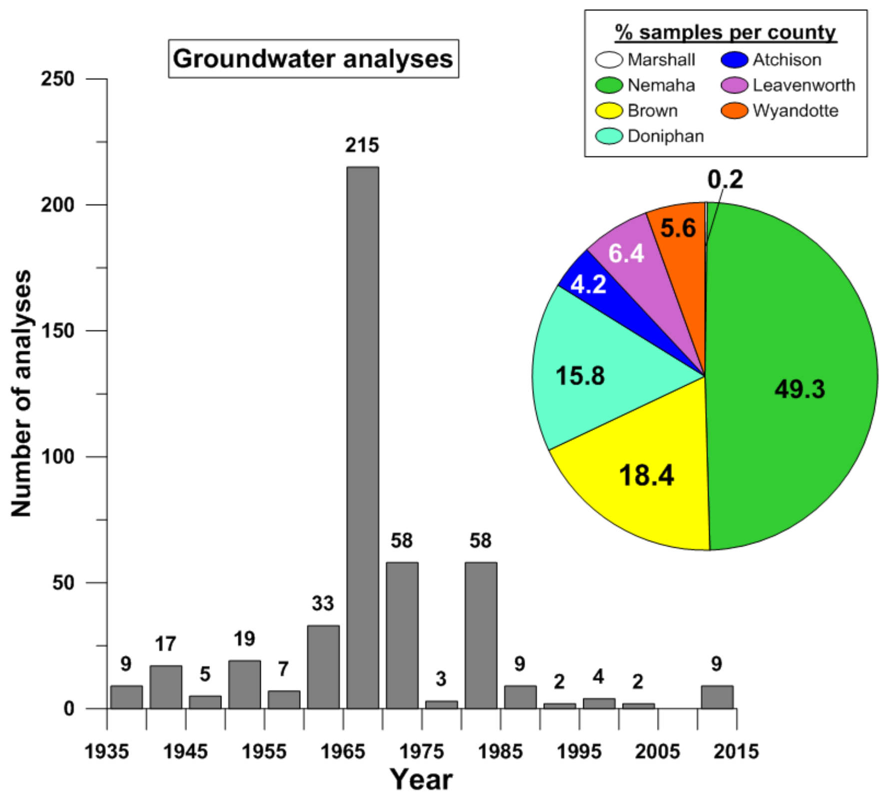

Figure 9. Groundwater chemical analyses performed in the MRPA, distributed per year and by county.

Groundwater chemical analyses were mainly performed during two periods: 1) 1965–1975, when the USGS performed 60% of the total analyses in the area, and 2) in 1981, when 59 groundwater samples were analyzed in a collaborative campaign of USGS and KGS as part of a study covering northeastern Kansas (Denne et al., 1998). Overall, Nemaha County has the highest number of analyses compared to all other counties. The reason for that is unknown. The most recent analyses correspond to nine monitoring wells managed and sampled by the USGS in 2011 in Nemaha (3), Brown (4) and Doniphan (2) Counties (see Figure 10).

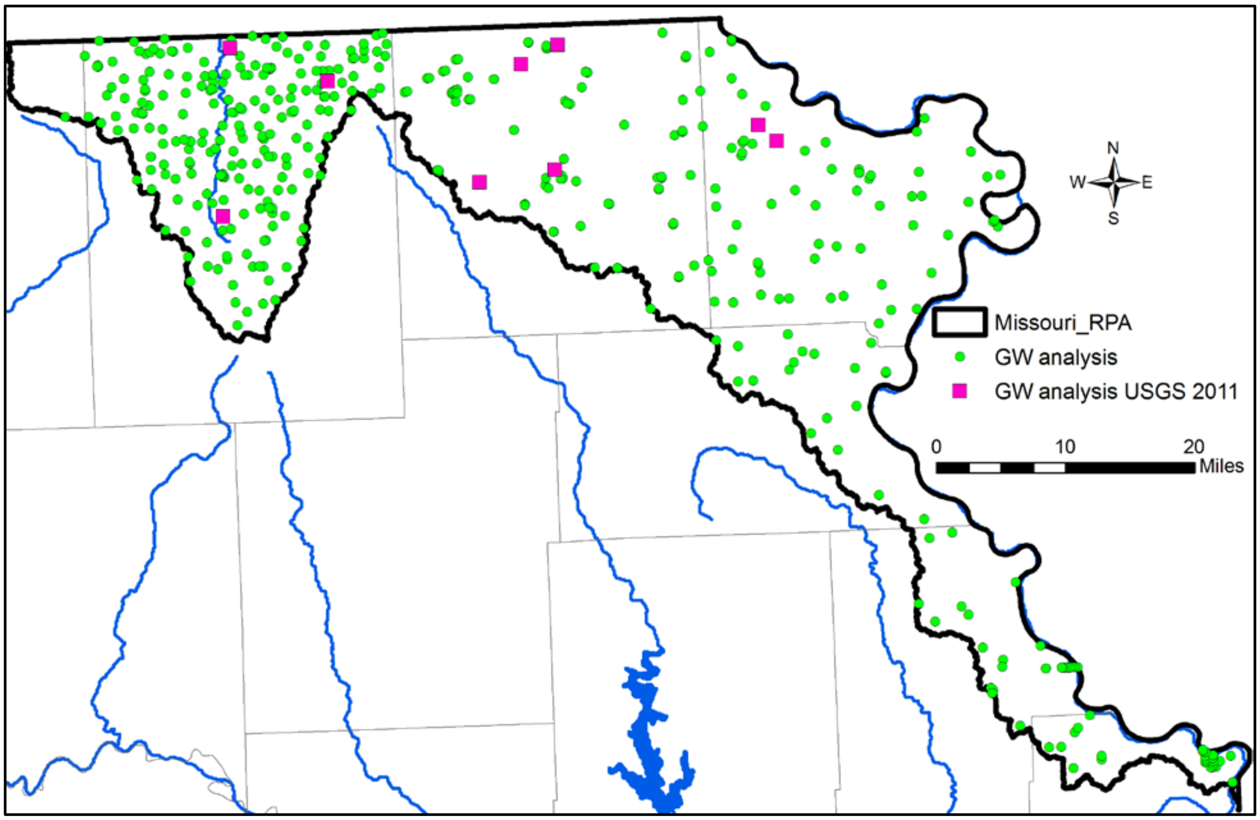

Figure 10. Map showing the location of the 450 groundwater samples with chemical analyses performed in the MRPA since 1939. The most recent analyses were performed in 2011 (shown with solid squares).

It is important to note that not all the analyses can be considered as complete analyses of major constituents and species of special interest to water supplies since in many cases, only 2 or 3 parameters were measured. In order to determine the water type, for example, at least all of the major anions (bicarbonate - HCO_3, chloride - Cl, sulfate - SO_4), and major cations (calcium - Ca, magnesium - Mg, sodium - Na, potassium - K) need to be reported. Among the 450 analyses, only 194 (43%) include concentrations for both major anions and cations. A Piper diagram was prepared to determine the main water type of the area based on the 194 analyses and if major differences exist for groundwater from glacial, alluvial, and bedrock aquifers (Figure 11). Mostly all groundwater samples in the MRPA fall towards the left of the Piper diagram, which represents groundwater rich in Ca and HCO_3. This is consistent with an area with limestone and calcareous shale bedrock. Two alluvial aquifer samples, in Brown and Leavenworth counties, fall on the right-hand side of the Piper diagram, inferring high concentrations of Cl, SO_4 and Na, thus relatively saline groundwater. Denne et al. (1998) observed that occasionally upward movement of saline groundwater from Permian bedrock could be the origin of some saline groundwater in overlying deposits. A possible alternative explanation for saline water could be groundwater affected by septic systems of homes that use conventional water softeners (which require salt solution to regenerate the softener media).

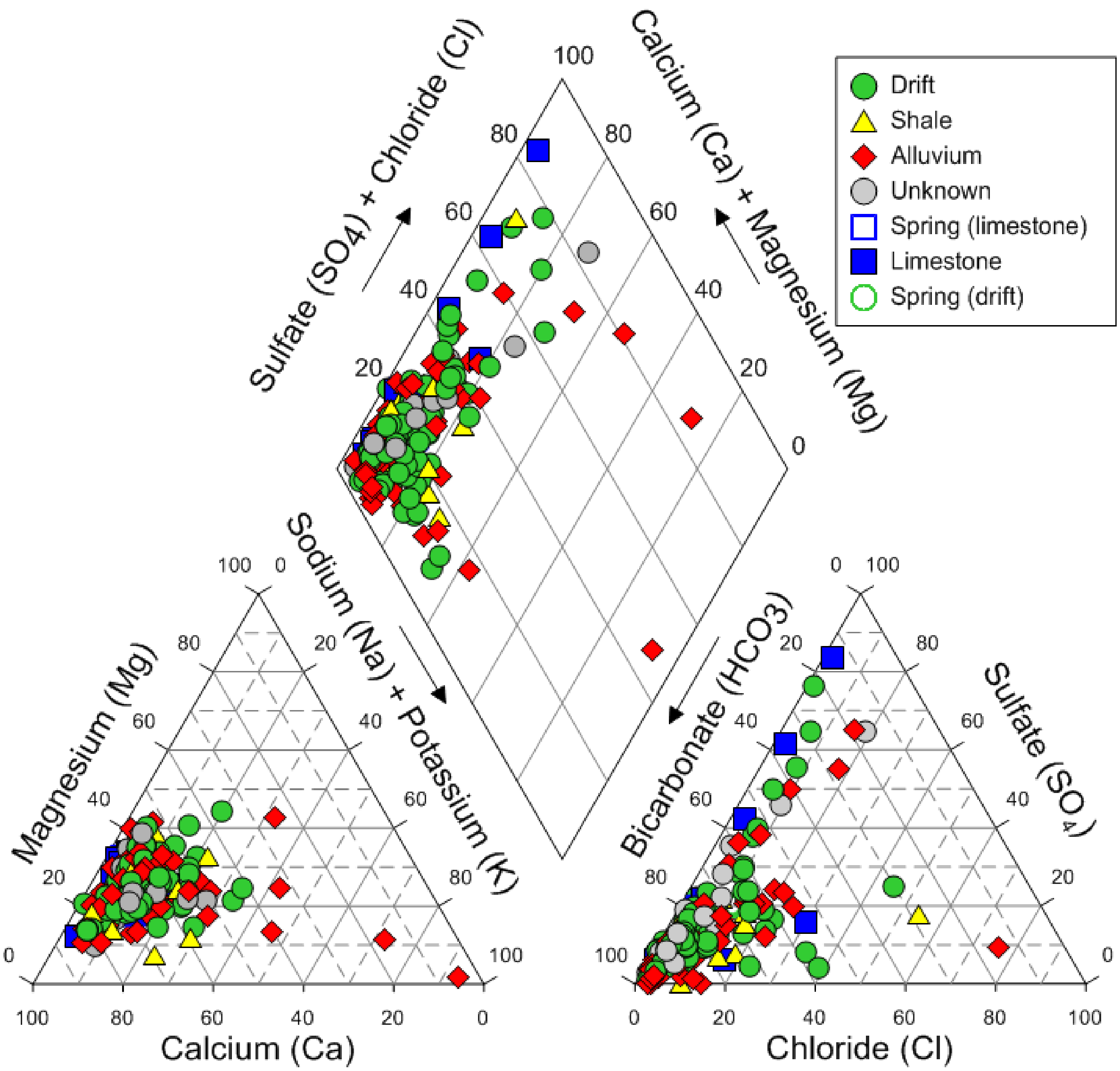

Figure 11. Piper diagram for the 194 groundwater samples with complete chemistry in the MRPA.

The MRPA is predominantly a rural area, thus particular attention was given to nitrate (NO_3) concentrations. A total of 370 nitrate concentrations were found in the MRPA. We have spatially analyzed the variation of nitrate in regard to the maximum NO_3-N concentration allowed in public supplies of drinking water, set at 10 mg/L NO_3-N by the US EPA and adopted by KDHE (https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one) (Figure 12). A subset of 236 wells (64%) have concentrations lower than 10 mg/L of NO_3-N, and among them 179 present concentrations lower than 5 mg/L NO_3-N. However, 90 wells (25%) have twice the maximum drinking limit, and nitrate concentrations exceed 100 mg/L NO_3-N in 4 wells, reaching up to 128 mg/L NO_3-N in a well sampled in 1962 in Brown County.

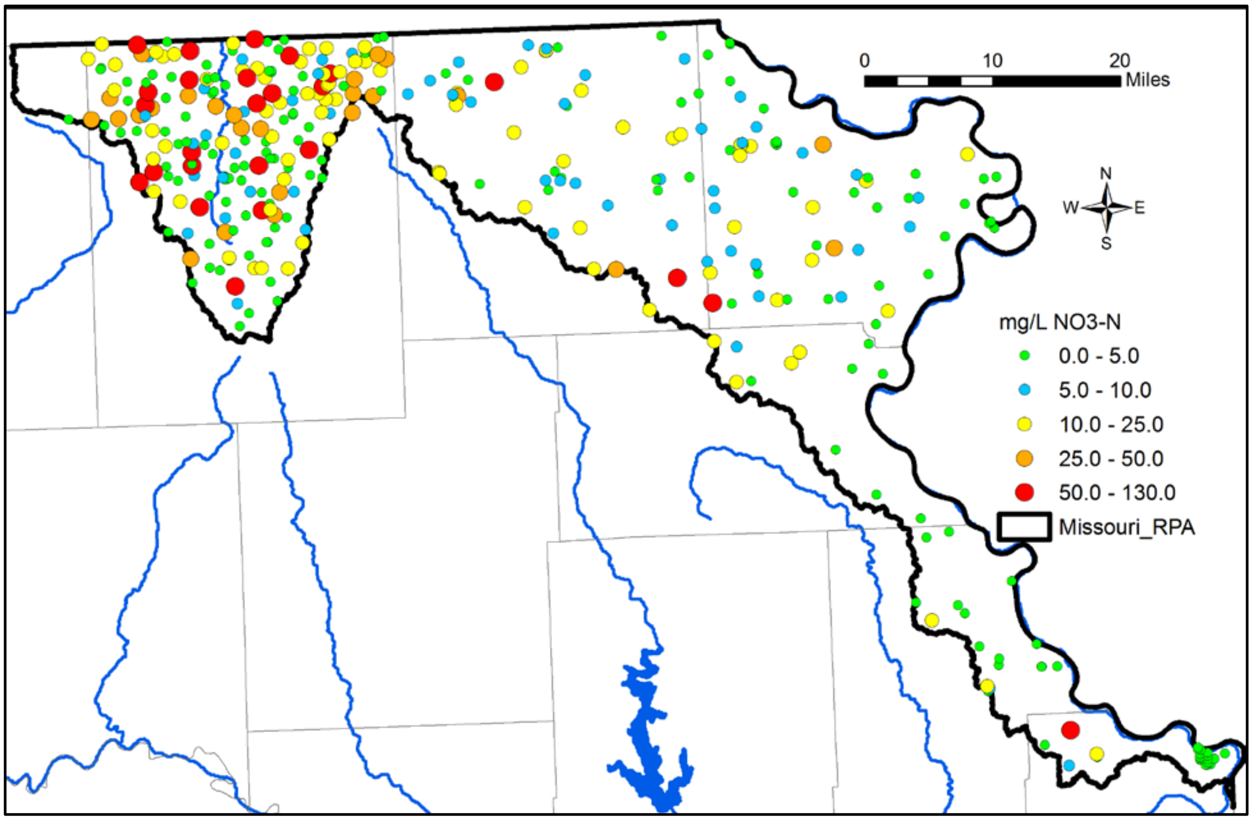

Figure 12. Map showing the 371 groundwater samples in the MRPA with nitrate concentrations (in mg/L NO_3-N).

Nitrate concentrations in 9 USGS wells sampled in 2011 span from 1.49 mg/L to 17.42 mg/L NO_3-N (Table 1). The number of samples in 2011 is very small and any formal comparison with samples from the mid-1970s would be inaccurate. Nonetheless, it is relevant to point out that 7 wells out of the 9 (78%) have nitrate concentrations below 10 mg/L NO_3-N, and 5 are below 5 mg/L NO_3-N. Two wells out of the 9 (22%) have concentrations between 10 and 20 mg/L NO_3-N. These percentages are quite similar to those from the historical analyses. It is deemed reasonable that a thorough campaign across the MRPA would be required to update the status of nitrate contamination.

Table 1. Nitrate concentrations for the 9 USGS monitoring wells sampled in 2011 in the MRPA study area.

USGS ID	Local ID	County	Aquifer	Depth (ft)	Date	NO_3-N (mg/L)
USGS 395016095332501	02S 17E 31BADC01 SITE 5-1	Brown	Glacial	43	8/15/2011	2.8
USGS 394937095400301	02S 16E 31CDDD01 SITE 31-1	Brown	Glacial	35	8/15/2011	4.85
USGS 395727095363101	01S 16E 15DCDC01 SITE 7-1	Brown	Glacial	23.5	8/16/2011	**17.42**
USGS 395841095324601	01S 17E 07CBBC01 SITE 11-3	Brown	Glacial	23.5	8/16/2011	2.51
USGS 395137095135601	02S 19E 24DDBB01 SITE 28-1	Doniphan	Glacial	43	8/24/2011	4.52
USGS 395244095153001	02S 19E 14BDCD01 SITE 8-1	Doniphan	Glacial	38	8/24/2011	8.52
USGS 394754096023301	03S 12E 11CDDD01 SITE 19-1	Nemaha	Glacial	34	8/10/2011	9.58
USGS 395649095530101	01S 14E 19DADD01 SITE 19-3	Nemaha	Glacial	34	8/9/2011	**13.01**
USGS 395915096012701	01S 12E 01CDDA01 SITE 18-3	Nemaha	Glacial	18.5	8/9/2011	1.49

Ongoing work

The following steps will be taken during the next and final stage of the project:

- Build a digital map of the bedrock surface elevation combining test-hole and water-well drilling data;
- Build a digital map of the thickness of unconsolidated materials;
- Data permitting, build a map of the saturated thickness of Pleistocene deposits;
- Identify those areas where uncertainty is large and propose what type(s) of information would be required and where it should be collected to substantially decrease the uncertainty.

Sources of information

Information on water-well driller's and test-hole logs, water usage, water chemistry, and water levels was collected from a variety of sources at the KGS, KDHE and USGS. Some of these sources are in a digital format (including pdf scanned copies of original hard copies), while other sources are in hard copy format only from the KGS archives (see, for example, Figure 13).

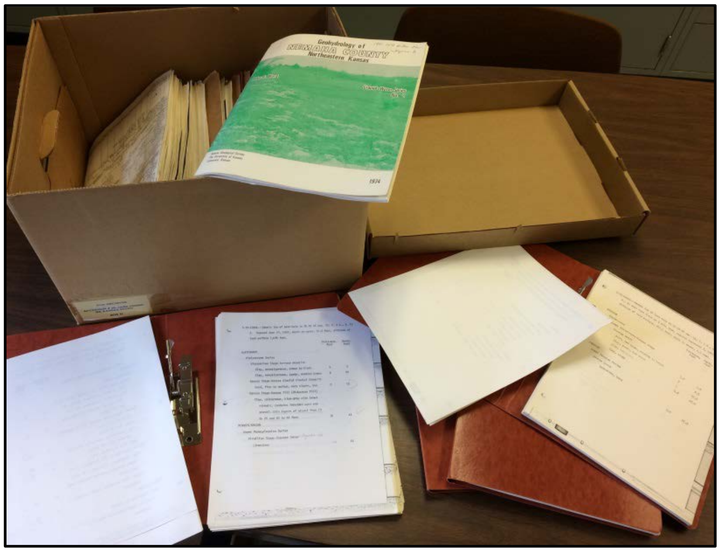

Figure 13. An example of hard copies with test-hole information for Atchison (Ward, 1970) and Brown (Bayne and Schoewe, 1967) counties, as found in the KGS archives, accession #30, box D.

The following lists the sources of information:

Online databases:

- WIMAS (Water Information Management and Analysis System). Online database of the DWR-KDA served by the KGS. http://hercules.kgs.ku.edu/geohydro/wimas/index.cfm
- WWWC5 (Water Well Completion Records Database). http://www.kgs.ku.edu/Magellan/WaterWell/index.html
- USGS Water-Quality Data for Kansas. https://waterdata.usgs.gov/ks/nwis/qw

Kansas Department of Health and Environment (KDHE):

- Groundwater Inorganic Data for the Northeast District, period 1985 – 2011.

KGS Bulletins (includes online files and hard copies in the KGS archives):

- Frye, J.C. 1941. Reconnaissance of ground-water resources in Atchison County, Kansas. Kansas Geological Survey, Bulletin 38, pt. 9. (http://www.kgs.ku.edu/Publications/Bulletins/38_9/).

- Frye, J.C. and Waters, K.L. 1950. Subsurface reconnaissance of glacial deposits in northeastern Kansas. KGS Bulletin 86, Part 6. (http://www.kgs.ku.edu/Publications/Bulletins/86_6/index.html).
- Walters, K.L. 1954. Geology and ground-water resources of Marshall County, Kansas. Kansas Geological Survey, Bulletin 106. (http://www.kgs.ku.edu/General/Geology/Marshall/index.html).
- Bayne, C.K and Schoewe, W.H. 1967. Geology and ground-water resources of Brown County, Kansas. Kansas Geological Survey, Bulletin 186. (http://www.kgs.ku.edu/General/Geology/Brown/index.html).
- Bayne, C.K. 1970. Sample Logs of Test Holes. Doniphan County, Kansas. Form 9-014. (*Note: only hard copy available at the KGS archives*).
- Ward, J.R. 1970. Sample logs of test holes. Atchison County, Kansas. (*Note: only hard copy available at the KGS archives*).
- Ward, J.R. 1974. Geohydrology of Nemaha County, Northeastern Kansas. Kansas Geological Survey, Ground-water Series 2. (http://www.kgs.ku.edu/Publications/Bulletins/GW2/).
- Denne, J.E., Miller, R.E., Hathaway, L.R., O'Connor, H.G. 1990a. Hydrogeology and geochemistry of glacial deposits in northeastern Kansas: Test-hole and well data. Kansas Geological Survey, Open-File Report 90-23A. (http://www.kgs.ku.edu/Hydro/Publications/1990/OFR90_23A/index.html).
- Denne, J.E., Miller, R.E., Hathaway, L.R., and O'Connor, H.G. 1990b. Hydrogeology and geochemistry of glacial deposits in northeastern Kansas – water quality data: Kansas Geological Survey, Open-file Report 90-23B. (http://www.kgs.ku.edu/Hydro/Publications/1990/OFR90_23B/index.html)
- Denne, J.E., Miller, R.E., Hathaway, L.R., O'Connor, H.G., Johnson, W.C. 1998. Hydrogeology and geochemistry of glacial deposits in Northeastern Kansas. Kansas Geological Survey, bulletin 229. (http://www.kgs.ku.edu/Publications/Bulletins/229/index.html).

USGS reports:

- Ward, J.R. 1973. Geohydrology of Atchison County, Northeastern Kansas. US Geological Survey, Hydrologic investigations, Atlas HA-467. (https://pubs.er.usgs.gov/publication/ha467).
- Bayne, C.K. 1973. Geohydrology of Doniphan County, Northeastern Kansas. USGS Hydrologic Investigations, Atlas HA-462. (https://pubs.er.usgs.gov/publication/ha462).