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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Final report

1. 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 for 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 Kansas Geological Survey (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 United States Geological Survey (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, 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.

This final progress report, the third of a series of three, covers items no. 4 and 5.

2. Study Area

The study area is the Missouri Regional Planning Area (MRPA) 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).

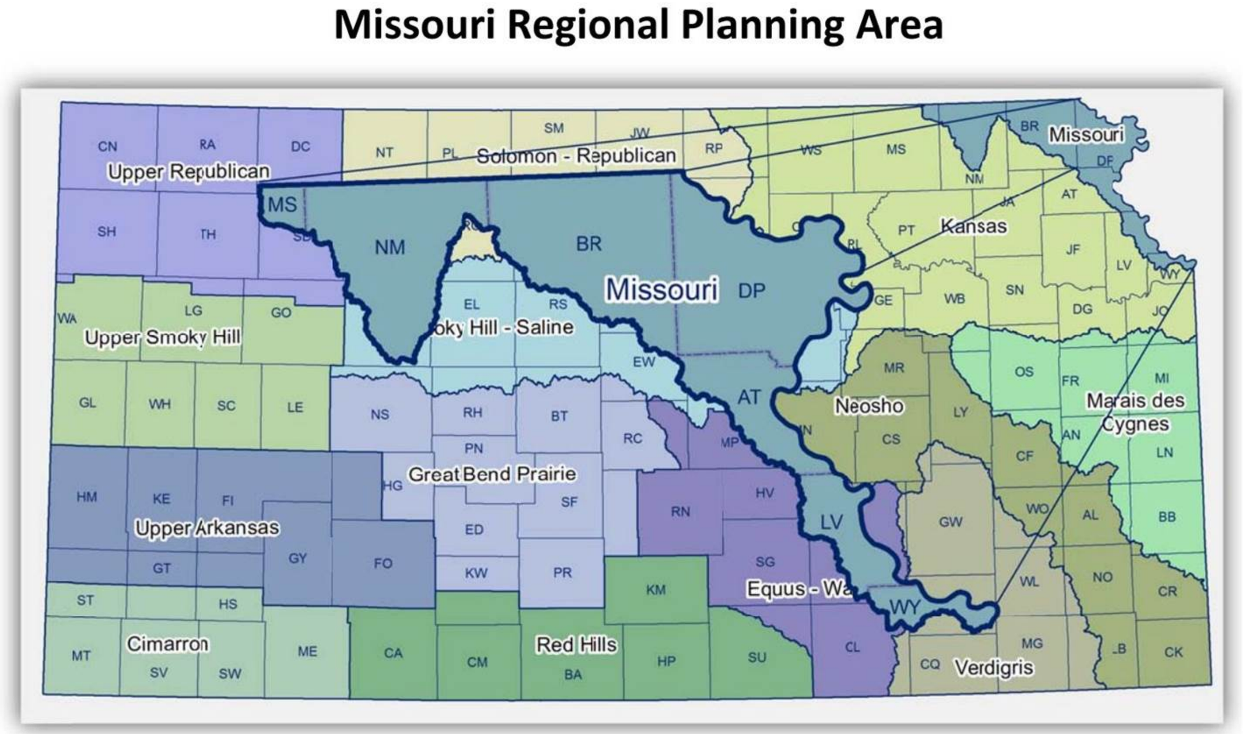

Figure 1. Location of the Missouri Regional Planning Area with its seven counties (from west to east: Marshall –MS, Nemaha –NM, Brown –BR, Doniphan –DP, Atchison –AT, Leavenworth –LV, Wyandotte –WY).

NOTE FOR ALL DIGITAL MAPS. Maps in this report have been built using ArcGIS software. Only general maps are shown here in the form of small images. No details on local areas can be properly reproduced in such size. While the main files are kept at the KGS, they can be distributed upon request and maps at finer scales can be reproduced as well.

3. Water use

Detailed water-use trends per county and total use were presented in the second report of this project (April 2017). In this third and final report, we provide a summary of the water use for the MRPA and each county by comparing the water use from 1990 to the most recent available year, 2015. Water use data are obtained from the WIMAS database (Water Information Management and Analysis System), a public web-based application managed by the Kansas Geological Survey. At the time of the writing of this report, data for 2016 were not available yet.

Since 1990, the surface water use in the MRPA has increased by 11.6%, whereas the groundwater use has decreased by 40%. The overall water use (surface water + groundwater) increased by 5% (Figure 2). When considered per county, Nemaha is the only county that has maintained its groundwater vs. surface water use ratio, that is 60:40. All other counties have seen their groundwater use reduced, with an increase in surface water. Nemaha, Brown, and Doniphan are counties that strongly depend on groundwater, whereas Atchison, Leavenworth, and Wyandotte mainly depend on surface water taken directly from the Missouri River (Figure 3). It is important to note that this information only relates to the portion of the county included in the MRPA. Water use data for the totality of each county may differ.

The industrial water use in the MRPA was limited to Wyandotte County in 1990, and today it has nearly disappeared (Table 1). The municipal use is the highest in the MRPA, particularly in Leavenworth County, whose surface water use increased as much as 1500% since 1990, from 1,765 acre-foot (acf) to 28,197 acf in 2015. Use of both groundwater and surface water for irrigation has increased in nearly all counties since 1990. Brown County, in particular, has seen large increases going from no irrigation use in 1990 to a combined use of surface water and groundwater of 2,315 acf in 2015 (Table 1). Figure 3 shows that the number of irrigation water rights in Brown County is significantly higher than elsewhere in the MRPA, explaining why this county is the biggest user of groundwater for irrigation.

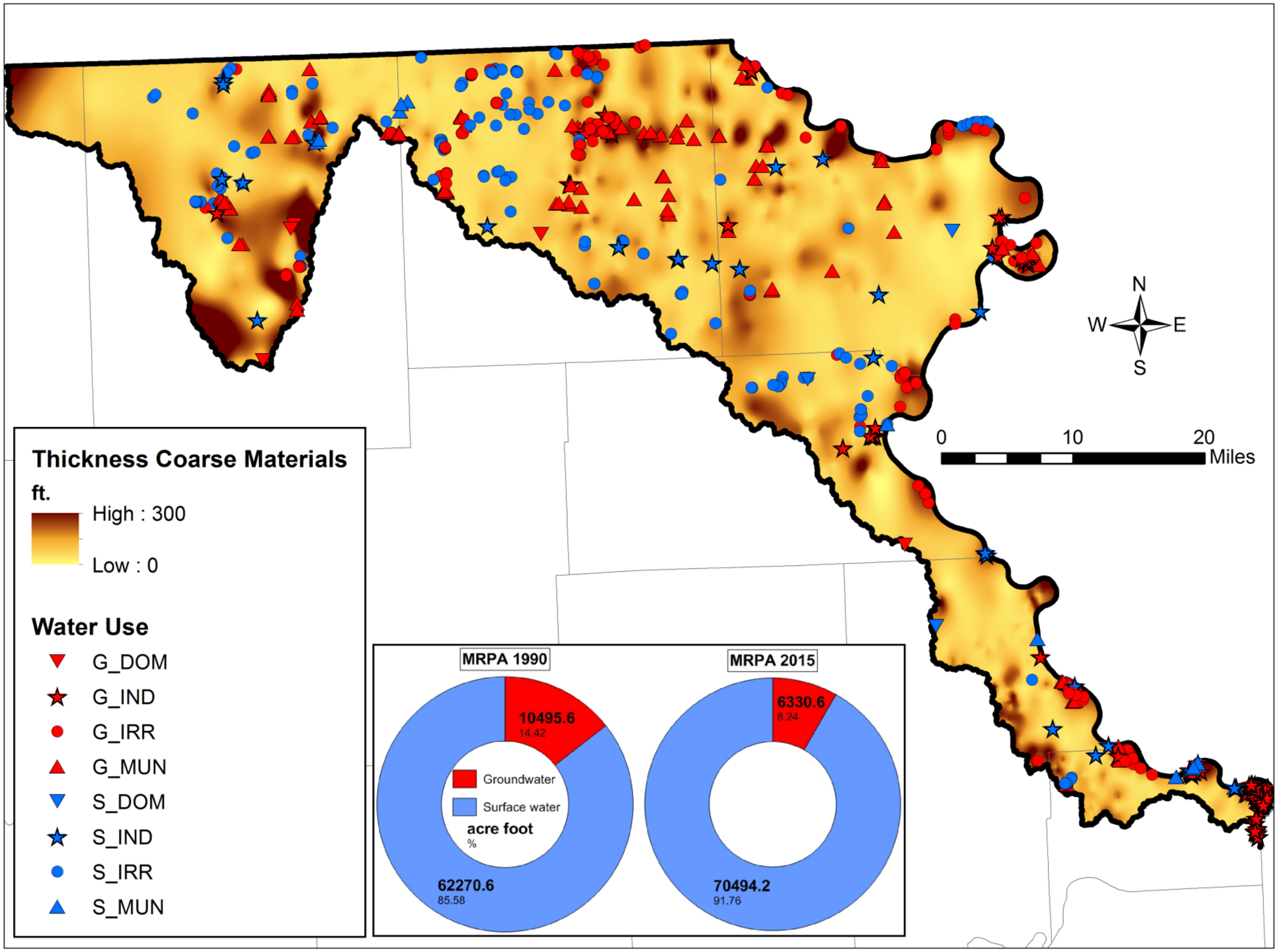

Figure 2. Map of groundwater and surface water use in the MRPA. For comparison, water use from 1990 and 2015 are shown. G: Groundwater; S: Surface water; DOM: Domestic use; IND: Industrial use; IRR: Irrigation use; MUN: Municipal use. Details on the thickness of coarse materials are given in section 9).

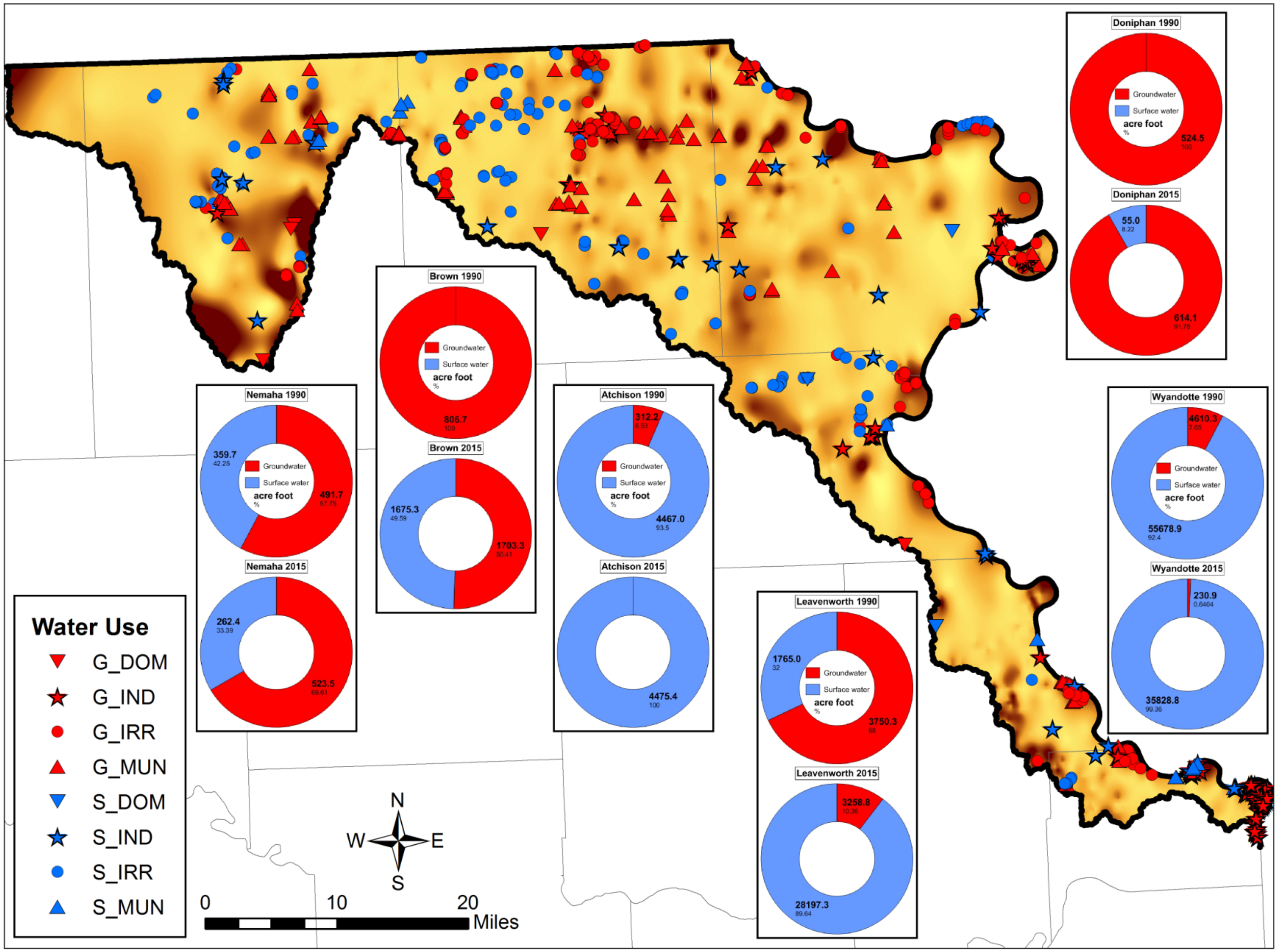

Figure 3. Map of groundwater and surface water use in each county in the MRPA (Marshall County in the MRPA has no water use reported). For comparison, water use from 1990 and 2015 are shown. G: Groundwater; S: Surface water; DOM: Domestic use; IND: Industrial use; IRR: Irrigation use; MUN: Municipal use.

Table 1. Details on water use per county and type of use (in acre-foot –acf). Gw: Groundwater; Sw: Surface water.

County	**Irrigation (acf)**				**Municipal**				**Industrial**			
	1990		**2015**		**1990**		**2015**		**1990**		**2015**	
	Gw	**Sw**	**Gw**	**Sw**	**Gw**	**SW**	**Gw**	**Sw**	**Gw**	**Sw**	**Gw**	**Sw**
Nemaha	0.0	7.72	6.3	262.4	491.7	352.0	517.29	0.0	0.0	0.0	0.0	0.0
Brown	0.0	0.0	1,038.4	1,277.2	806.7	0.0	652.4	398.1	0.0	0.0	12.4	0.0
Doniphan	125.3	0.0	380.0	55	399.3	0.0	233.15	55.0	0.0	0.0	0.9	0.0
Atchison	312.2	0.0	0.0	111.9	0.0	4,467.0	0.0	4,475.4	0.0	0.0	0.0	0.0
Leavenworth	0.0	0.0	41.6	0.0	3,750.3	1,765.0	3,217.24	28,197.2	0.0	0.0	0.0	0.0
Wyandotte	0.0	143.2	144.8	62.9	54.5	55,479.9	0.0	35,828.8	4,555.8	55.7	86.1	19.8
MRPA	437.5	150.9	1,611.1	1,769.5	5,502.3	61,023.9	4,620.07	70,494.2	4,555.8	55.7	99.4	19.8

4. Groundwater quality

Nitrate (NO_3) is the main issue in terms of groundwater quality in the MRPA. A total of 371 historical nitrate analysis were found in the MRPA, with 197 (53%) located in Nemaha County (Figure 4). In regard to the maximum NO_3-N concentration allowed in drinking water, set at 10 mg/L NO_3-N by the US EPA and adopted by the Kansas Department of Health and Environment (KDHE) (https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one), 134 wells had nitrate concentrations above that concentration. Ninety of those wells are located in Nemaha, 40 are located in Brown and Doniphan counties, while the 7 remaining are in Leavenworth and Wyandotte counties. It is important to note that 4 wells at the time of sampling had concentrations beyond 100 mg/L NO_3-N (3 in Nemaha, 1 in Brown), over 10 times greater than the maximum allowable concentration in drinking water.

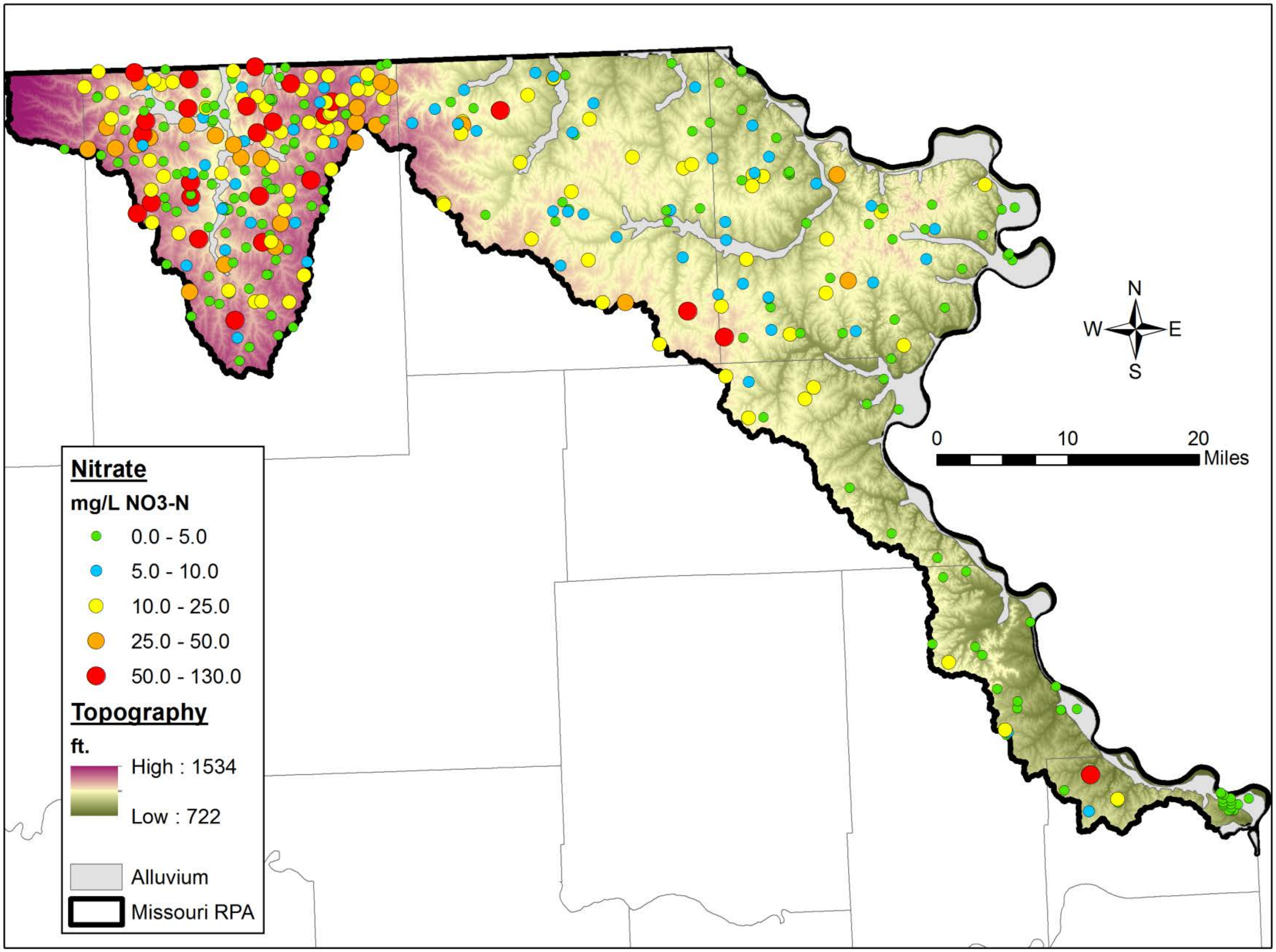

Figure 4. Map showing the 371 groundwater samples in the MRPA with nitrate concentrations available (in mg/L NO_3-N).

The nitrate concentrations provided in Figure 4 need to be considered with extreme care because 63% of the samples (234), were taken between 1967 and 1972, and 97% prior to 2002. The most recent nitrate concentrations correspond to 10 wells sampled in 2011 by the USGS under the National Water-Quality Assessment (NAWQA; https://water.usgs.gov/nawqa/) project. Despite these wells only being sampled once, their nitrate concentrations represent the most recent data available in the area (Table 2). Nonetheless, their location in the MRPA is irregular, only in Nemaha, Brown and Doniphan counties (Figure 5).

Table 2. Nitrate concentrations for the 10 USGS monitoring wells sampled in 2011 in the MRPA. Bold values correspond to concentrations that exceed the maximum drinking water limit (10 mg/L NO_3-N), and italic values denote concentrations that are near the drinking water limit.

Map ID (Figure 5)	USGS ID	Legal ID	County	Aquifer	Depth (ft)	Date	NO_3-N (mg/L)
1	USGS 394754096023301	03S 12E 11CDDD01 SITE 19-1	Nemaha	Glacial	34	8/10/2011	*9.58*
2	USGS 395649095530101	01S 14E 19DADD01 SITE 19-3	Nemaha	Glacial	34	8/9/2011	**13.01**
3	USGS 395915096012701	01S 12E 01CDDA01 SITE 18-3	Nemaha	Glacial	18.5	8/9/2011	1.49
4	USGS 394239095565501	04S 13E 15BAAA01 SITE 0-3	Nemaha	Glacial	69	8/23/2011	4.31
5	USGS 395016095332501	02S 17E 31BADC01 SITE 5-1	Brown	Glacial	43	8/15/2011	2.8
6	USGS 394937095400301	02S 16E 31CDDD01 SITE 31-1	Brown	Glacial	35	8/15/2011	4.85
7	USGS 395727095363101	01S 16E 15DCDC01 SITE 7-1	Brown	Glacial	23.5	8/16/2011	**17.42**
8	USGS 395841095324601	01S 17E 07CBBC01 SITE 11-3	Brown	Glacial	23.5	8/16/2011	2.51
9	USGS 395137095135601	02S 19E 24DDBB01 SITE 28-1	Doniphan	Glacial	43	8/24/2011	4.52
10	USGS 395244095153001	02S 19E 14BDCD01 SITE 8-1	Doniphan	Glacial	38	8/24/2011	*8.52*

The USGS Water-Quality Data for Kansas (https://waterdata.usgs.gov/ks/nwis/qw) was exhaustively examined to find wells in the MRPA with 3 or more samples, regardless of when the samples were taken. A total of 23 wells (5 in Nemaha, 9 in Brown, 8 in Doniphan and 1 in Atchison) with 3 or more samples were found, covering different periods but never going later than 1984 (Figure 5; Table 3). These wells are identified as “USGS Nitrate Trends” in Figure 5.

On another side, additional and more updated information was obtained from the KDHE groundwater quality monitoring program. In particular, 8 wells in Nemaha, Brown, Doniphan, Atchison, and Wyandotte counties were identified with nitrate concentration available between the years 1986 and 2001(Figure 5; Table 4). Unfortunately, this program was suspended in 2002 due to budgetary constraints. These wells are identified as “KDHE Nitrate Trends” in Figure 5.

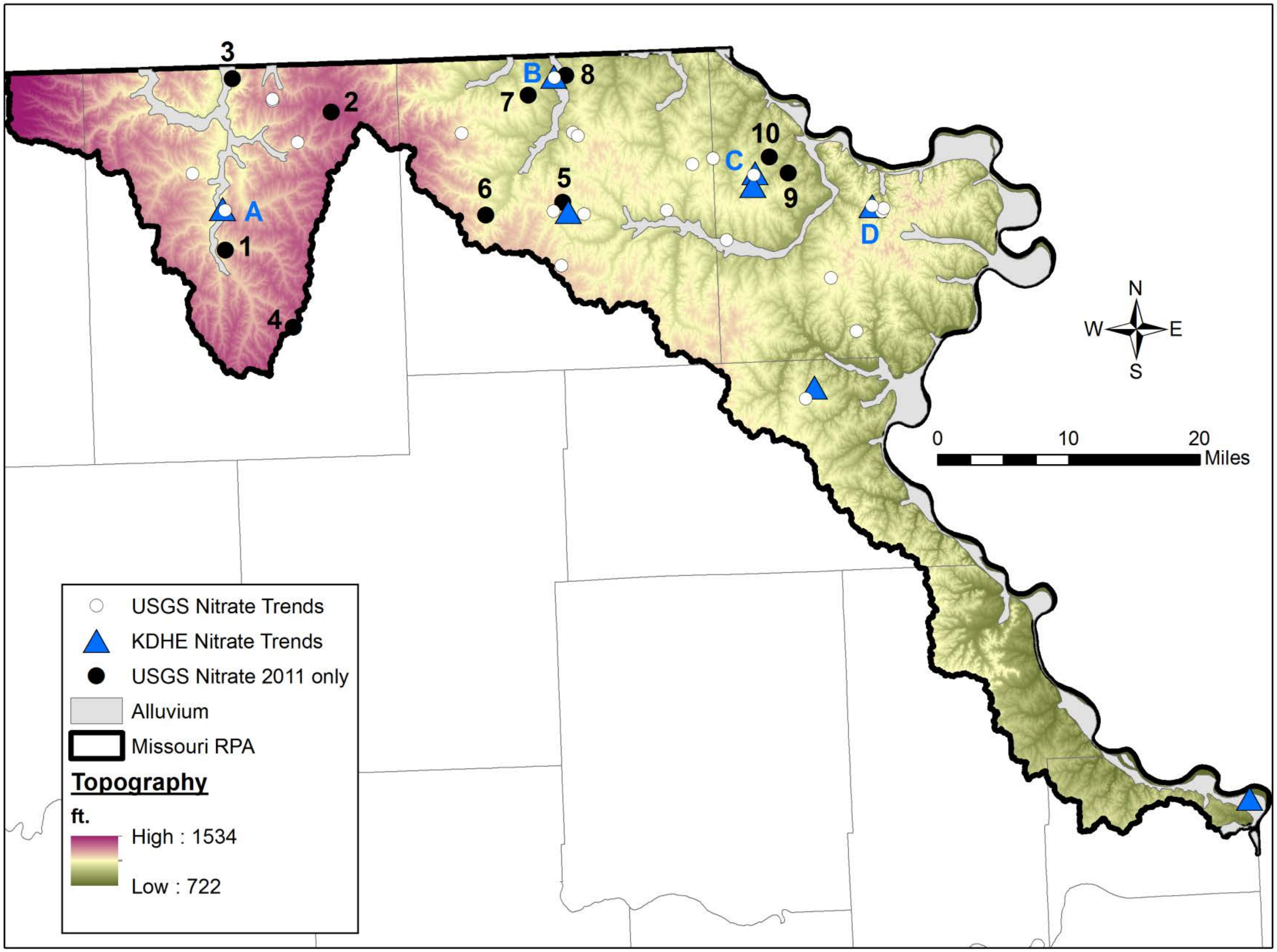

Figure 5. Map showing the location of wells sampled and analyzed by the USGS in 2011 (see corresponding numbers in Table 1 for well details), and wells with historical nitrate trends as measured by both the USGS and KDHE. Letters indicate possible duplicate wells between the USGS and KDHE datasets.

Table 3. Wells with 3 or more nitrate concentrations as found in the USGS Water-Quality Data for Kansas (https://waterdata.usgs.gov/ks/nwis/qw).

USGS ID	Legal ID	Longitude	Latitude	County	Aquifer	Depth (ft.)	Period	Count Samples
USGS 395032096022801	02S 12E 26CDD 01	-96.0414	39.8422	Nemaha	Glacial	35.0	1964 – 1970	3
USGS 395452095560101	01S 13E 35CCC 01	-95.9339	39.9144	Nemaha	Alluvial	40.0	1967 – 1971	4
USGS 395742095580301	01S 13E 16CBD 01	-95.9678	39.96167	Nemaha	Alluvial	115.0	1955 – 1968	6
USGS 395748095580301	01S 13E 16CBA 01	-95.9678	39.9633	Nemaha	Alluvial	120.0	1957 – 1967	7
USGS 395302096051001	02S 12E 16BBB 01	-96.0864	39.8839	Nemaha	Glacial	30.0	1969 – 1981	5
USGS 395833095334401	01S 17E 07CBC 01	-95.5622	39.9758	Brown	Alluvial	40.0	1960 – 1981	20
USGS 395505095415301	01S 15E 35DAD 01	-95.6980	39.9180	Brown	Limestone	92.0	1963 – 1967	3
USGS 395451095321901	01S 17E 32CCD 01	-95.5386	39.9142	Brown	Glacial	45.0	1948 – 1966	4
USGS 395438095315401	02S 17E 05ABC 01	-95.5317	39.9105	Brown	Glacial	97.0	1950 – 1964	5
USGS 394604095334501	03S 17E 30BBB 01	-95.5625	39.7678	Brown	Alluvial	42.0	1963 – 1981	5
USGS 394925095313801	03S 17E 05AAC 01	-95.5272	39.8236	Brown	Glacial	40.8	1954 – 1957	3
USGS 394927095243001	03S 18E 04BA 01	-95.4083	39.8242	Brown	Unknown	60.0	1963 – 1968	4
USGS 394942095341501	02S 16E 36DC 01	-95.5708	39.8283	Brown	Glacial	30.0	1951 – 1965	3
USGS 395227095221001	02S 18E 14CAD 01	-95.3694	39.8742	Brown	Glacial	65.0	1962 – 1981	4
USGS 394057095084001	04S 20E 23CDD 01	-95.14469	39.6825	Doniphan	Glacial	85.0	1967 – 1980	4
USGS 394432095103901	03S 20E 33DCA 01	-95.1777	39.7422	Doniphan	Glacial	90.0	1964 – 1968	4
USGS 394720095192801	03S 19E 18DAA 01	-95.3247	39.7889	Doniphan	Glacial	60.0	1963 – 1981	18
USGS 394846095060101	03S 21E 06DDC 01	-95.1005	39.8128	Doniphan	Glacial	28.0	1945 – 1948	3
USGS 394859095055201	03S 21E 06DAD 01	-95.0980	39.8164	Doniphan	Glacial	37.0	1945 – 1948	4
USGS 394912095065101	03S 21E 06BCC 01	-95.1144	39.8200	Doniphan	Glacial	97.0	1967 – 1981	5
USGS 395135095165501	02S 19E 22CBD 01	-95.2822	39.8597	Doniphan	Glacial	80.0	1961 – 1967	6
USGS 395246095202001	02S 19E 18BCB 01	-95.3391	39.8794	Doniphan	Glacial	160.0	1967 – 1981	5
USGS 393637095131601	05S 20E 18CDC 01	-95.2214	39.6103	Atchison	Glacial	30.0	1967 – 1981	15

Table 4. Wells with nitrate concentration data analyzed over time, from the KDHE statewide groundwater quality monitoring program.

KDHE ID	Legal ID	Site Name	Longitude	Latitude	County	Aquifer	Depth (ft.)	Period	Count Samples
4941	SWNWNWNW	Handke, E.	-95.2082	39.6223	Atchison	Glacial	24.0	1989 - 2001	7
4958	SWSWSESE	Hiawatha #04	-95.5495	39.8271	Brown	Glacial	55.0	1986 - 2000	11
4965	NWSENWSW	Reserve #01	-95.5626	39.9769	Brown	Glacial	40.0	1986 - 1994	9
3849	SESENWSW	Highland #03	-95.2803	39.8617	Doniphan	Unknown	87.0	1995 - 2000	4
4972	SWNWNWSW	Highland #02	-95.2836	39.8478	Doniphan	Unknown	71.0	1986 - 1993	7
4989	NWSWSWNW	Smith, R.	-95.1147	39.8200	Doniphan	Unknown	97.0	1986 - 1997	9
26255	SENWSESW	Seneca #04	-96.0447	39.8442	Nemaha	Glacial	60.0	1986 - 1997	11
7919	SESWNESW	Owens-Corning #07	-94.6157	39.1468	Wyandotte	Alluvial	121.5	1986 - 2001	10

USGS nitrate trends show that, already in the 1970s, several wells had groundwater nitrate concentration exceeding the drinking limit (see Figure 6b-d). With limited exceptions, most wells below the drinking limit presented upward nitrate trends, such as the well USGS 395302096051001 in Nemaha (Figure 6a), whose nitrate concentration was increased by a factor of 7 (from 1 to 7 mg/L NO_3-N) in just 4 years (from 1977 to 1981). Similar upward trends, but with more gentle slope can be observed in Brown and Doniphan counties.

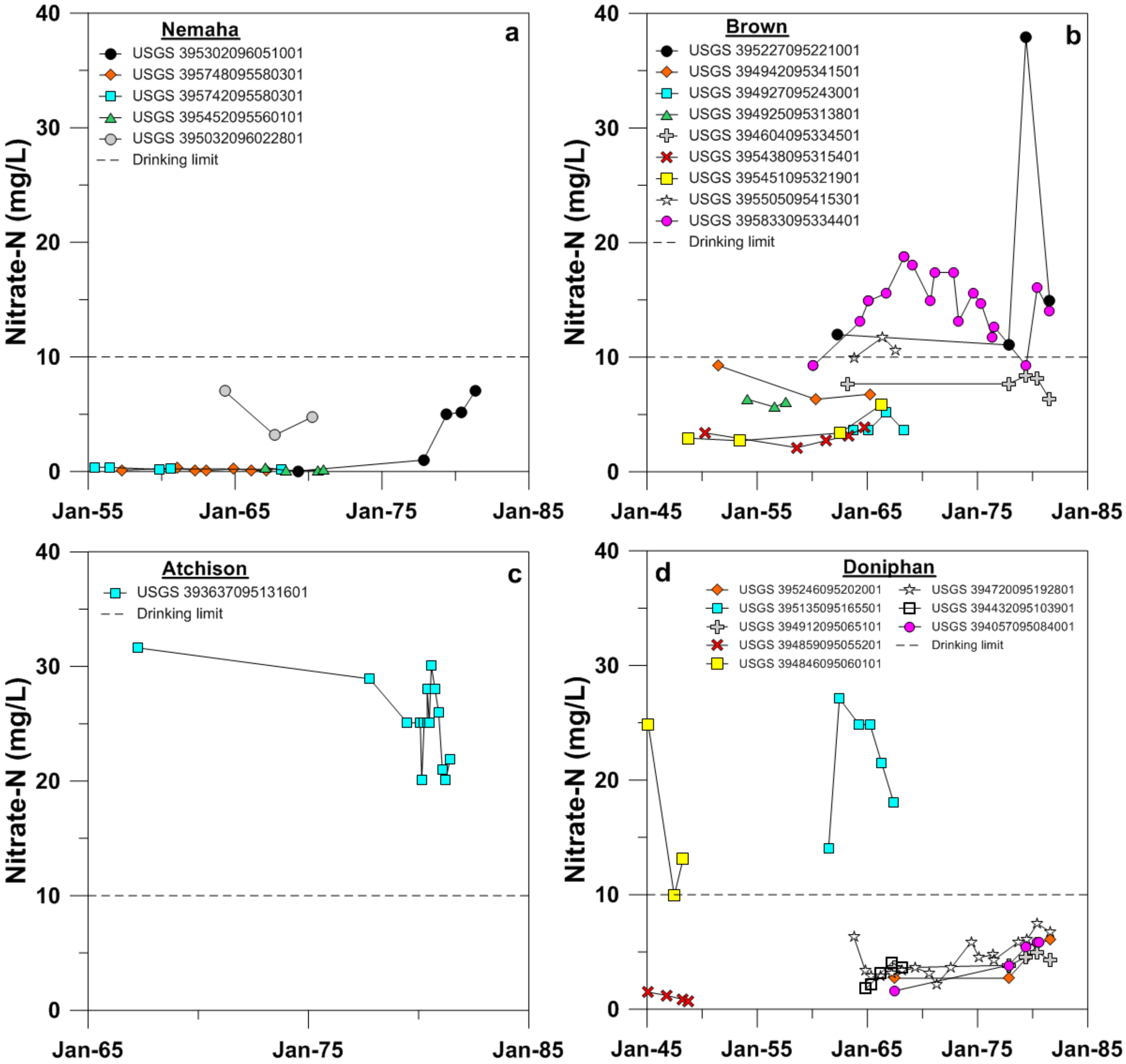

Figure 6. Historical nitrate trends for several wells in (a) Nemaha, (b) Brown, (c) Atchison and (d) Doniphan counties. (Source: https://waterdata.usgs.gov/ks/nwis/qw). The maximum nitrate drinking water limit is shown by a dashed line.

More recent nitrate trends from KDHE do not indicate clear upward or downward trends. Nitrate concentration in some wells remains quite stable and close to the drinking water limit (e.g. Handke well), whereas others show relatively high variability over time (Figure 7). For example, nitrate concentration in well Highland #2 increased from 12 mg/L NO_3-N in 1986 to 31 mg/L a year later and decreased down to 5.4 mg/L in 1991 to then increase to over the drinking water limit in 1993. Reserve#1 rapidly increased from 1.7 to 7.9 mg/L NO_3-N in just two years (from 1986 to 1988), and remained relatively constant until 1992, when sampling was ceased in that well.

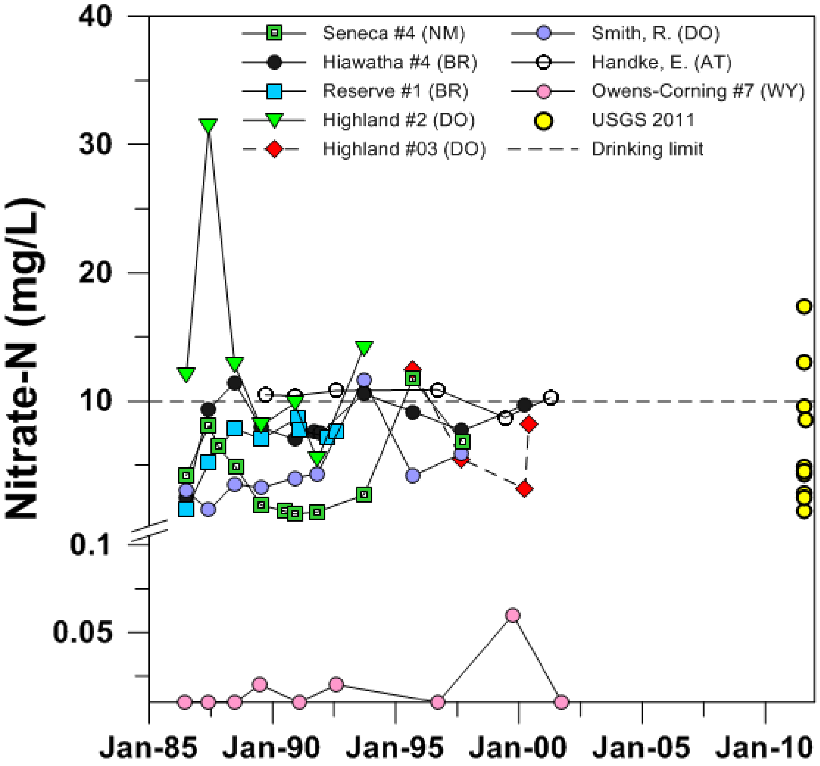

Figure 7. Historical nitrate trends for several wells in different counties (source: KDHE). The most recent nitrate concentrations in the MRPA (USGS in 2011) are shown for comparison. The maximum nitrate drinking water limit is shown with a horizontal dashed line.

Wells with nitrate trends from the USGS and KDHE databases were plotted together and appeared to be 4 potential duplicates (see letters A, B, C and D in Figure 5). Close analysis of these potential duplicates highlighted that KDHE and USGS wells in point A (KDHE: Seneca #04; USGS: 395032096022801) are different wells with different depths (60 ft. and 35 ft. respectively). On the other hand, wells in points B (KDHE: Reserve #01; USGS: 395833095334401) and D (KDHE: Smith, R.; USGS: 394912095065101) appear to be duplicate wells thus the same well. There is a certain degree of uncertainty if wells in point C (KDHE: Highland #03; USGS: 395135095165501) are the same well or not, as depths reported by KDHE and USGS are 87 and 80 ft., respectively. Because KDHE and USGS data sets cover different periods of time, the length of these datasets can be extended by merging both data sets.

Merging both KDHE and USGS data sets for duplicate wells results in nitrate trends covering periods of time as long as 40 years (Figure 8). Nitrate trends in the Smith well seem to steadily increase over time, whereas nitrate trends for wells Reserve #01 and Highland #03 appear to decrease overall. Nonetheless, the last few years for these two wells indicate a new increase in nitrate concentrations. Unfortunately, there is no data for the last 20 years for these wells.

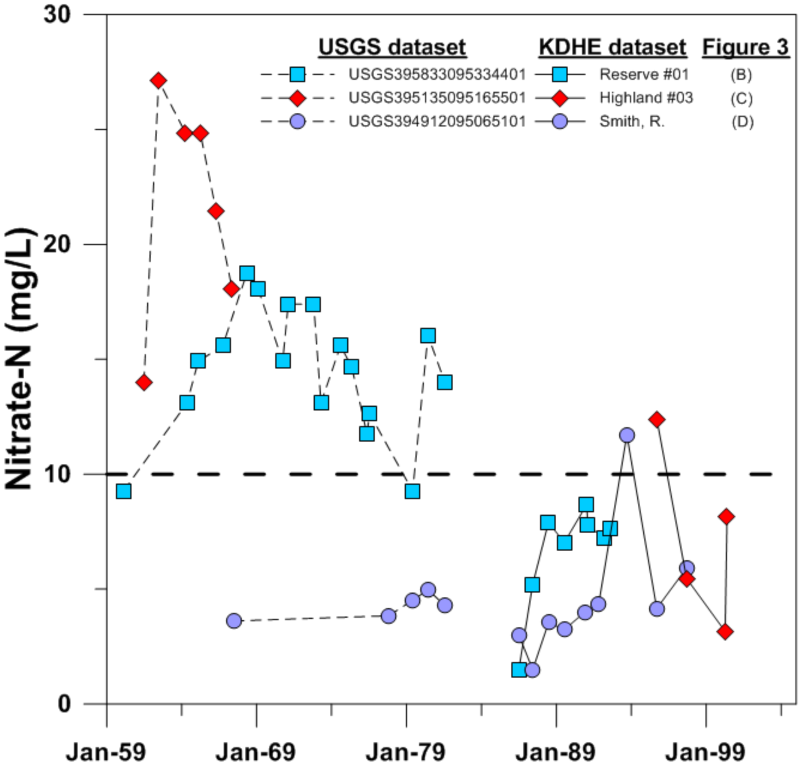

Figure 8. Nitrate historical trends for wells measured by USGS and KDHE at different periods. There is some uncertainty if wells Highland#3 and USGS395135095165501 are the same well.

Overall, historical nitrate concentrations in the MRPA show general upward trends and multiple historical single measurements exceeding the maximum drinking limit. The very last nitrate concentration dating from 2011 indicate that several wells exceeded or were close to the drinking limit. To monitor and take action as required, it is critical to strategically sample several wells in the area to obtain an updated status of the current nitrate conditions.

5. The Public Land Survey System in Kansas and its issues with digital mapping

The legal identification for land and wells in Kansas is made according to the Public Land Survey System (PLSS), a system based in townships and sections that have been applied in the state since 1854. Townships, square pieces of land of approximately 36 mi^2, are designated by both, township and range numbers, read North-south and east-west, respectively, from the baselines shown in Figure 9a. Each township is divided into 36 sections of 1 mi^2 (640 acres) each. Sections, in turn, are divided into smaller units by quarters. One-quarter of a section is 0.25 mi^2 or 160 acres, and a quarter of a quarter is 0.0625 mi^2 or 40 acres. Sections are commonly subdivided down to 0.015625 mi^2 or 10 acre areas (Figure 9b).

Although the PLSS has been a useful system, it cannot be directly used to build hydrogeological digital maps. To locate wells for digital mapping, each well requires its own longitude and latitude coordinates, which can be approximately obtained from the PLSS (each well is given the center coordinates of the 10-acre subdivision in which it is located). However, if multiple wells are on the 10 acres, they all will share the same longitude and latitude coordinates (the center of the 10-acre area). The problem lies in the fact that each one of these wells is likely to have, for example, different bedrock elevations. That means that all the bedrock elevation for the same 10-acre area will need to be consolidated into a single value. In some cases, the bedrock elevations for wells in the same 10-acre area will be similar, thus a simple average between the two depths will suffice. However, in other cases, the bedrock elevations can be significantly different between wells, and in these cases, the median is used to avoid the consolidated bedrock elevation be influenced by potential outliers.

In areas with large and continuous aquifers (such as the High Plains Aquifer), the issue of having several wells on a 10-acre area is less important. However, in areas where aquifers are associated with glacial deposits, such as the MRPA, this is a worrisome issue. In these areas, aquifers are discontinued and often limited to glacial valleys where bedrock elevation and aquifer thickness can substantially change within short distances. We believe this is particularly an issue at the local scale in some areas. At the regional scale, maps should be representative of conditions thanks to the large number of test holes and wells used to construct them.

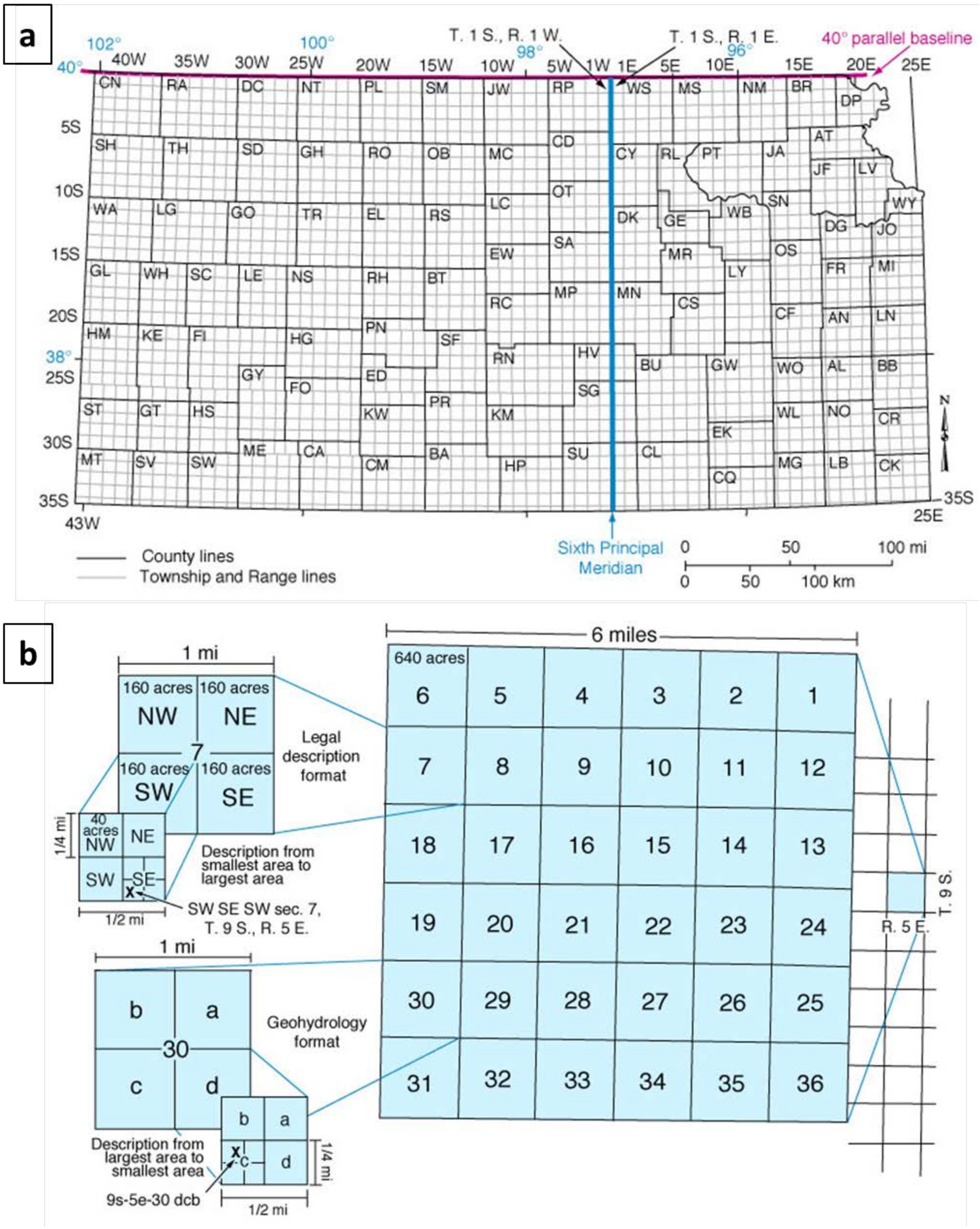

Figure 9. (a) Map of township and range lines in Kansas. (b) Diagram illustrating section numbering and method of assigning legal well descriptions in Kansas (Suchy, 2002).

6. Unifying surface elevations

Most test holes and wells have a land surface elevation that was reported during drilling. We are uncertain about how this elevation was taken and its accuracy. To avoid introducing an unknown elevation error, the surface elevation for each site has been calculated from the digital topographic map shown in the background of Figure 5.

7. Map of bedrock elevation

The map of bedrock elevation is the basis for building all maps shown in the following sections of this report. To prepare this map only test holes and wells that reached the bedrock were used. After consolidating wells and test holes duplicates (wells with the same longitude and latitude but different bedrock elevation), a total of 1,027 wells from the WWC5 database and 994 test holes were used (Figure 10). Except for few areas with limited test holes and wells, the whole MRPA is, in general, well covered, providing high confidence to the bedrock elevation map.

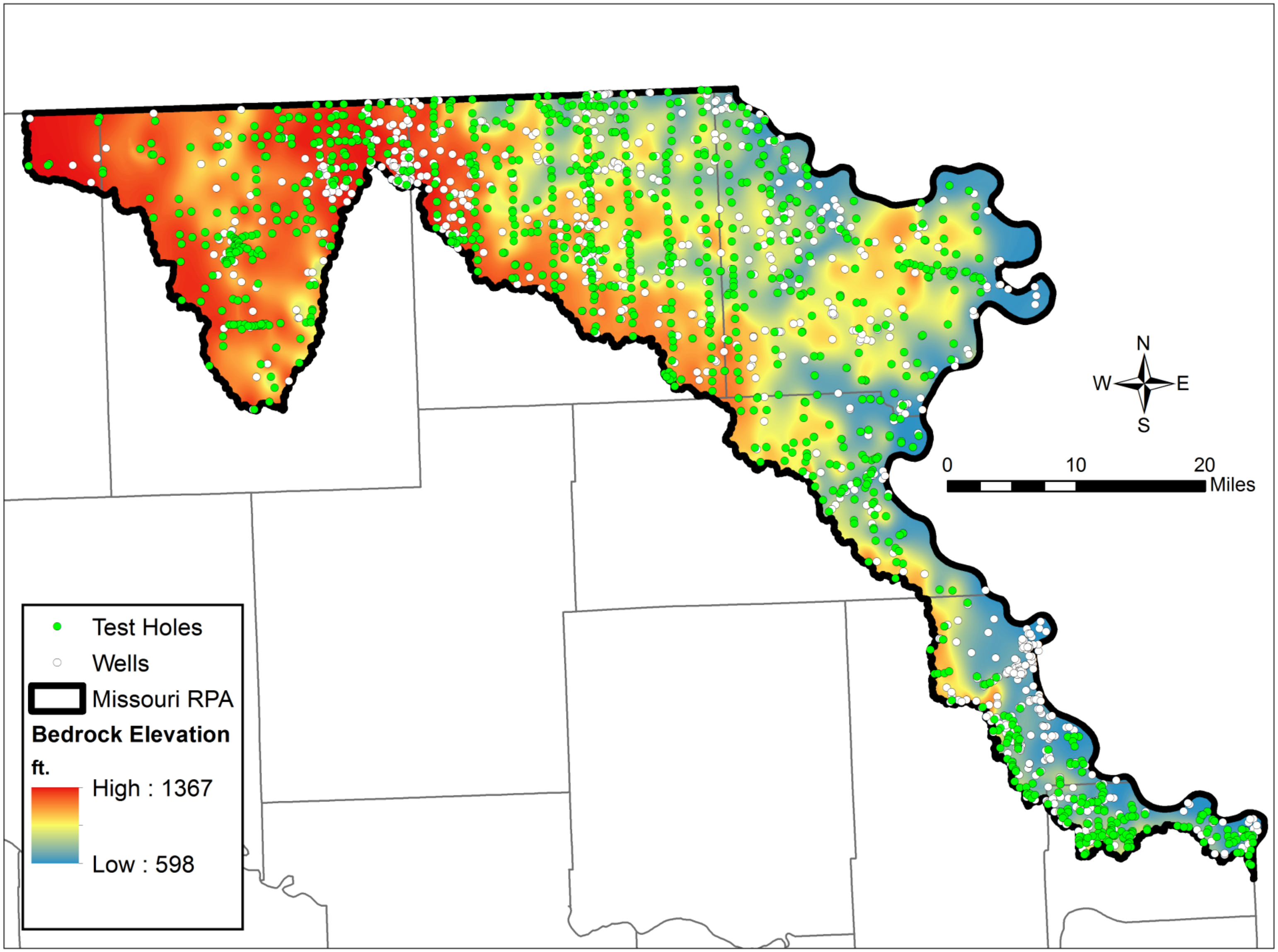

Figure 10. Map of bedrock elevation showing the 1,027 wells and 994 test holes on which it is based.

In Figure 11 the bedrock elevation is shown without the test holes and wells used for a clearer representation of the bedrock surface. The bedrock elevation has a west – east gradient, with highest elevations (1,367 ft) in Marshall and Nemaha counties, and lowest elevations (598 ft) in the eastern sides of Doniphan, Atchison, Leavenworth and Wyandotte counties, next to the Missouri River. In between, particularly in Brown, Doniphan and Atchison counties, a number of valleys oriented N-S and NE-SW are clearly shown, corresponding to glacial valleys carved by glaciers during the Pleistocene (~2,000,000 – 10,000 y BC). After the glaciers retreated and melted, these valleys were filled with the sediment transported in the ice, which now compose the most important aquifer in the MRPA. For more details about the extent of glaciated areas and the aquifers in the United States, including northeast Kansas, see Bayless et al. (2017).

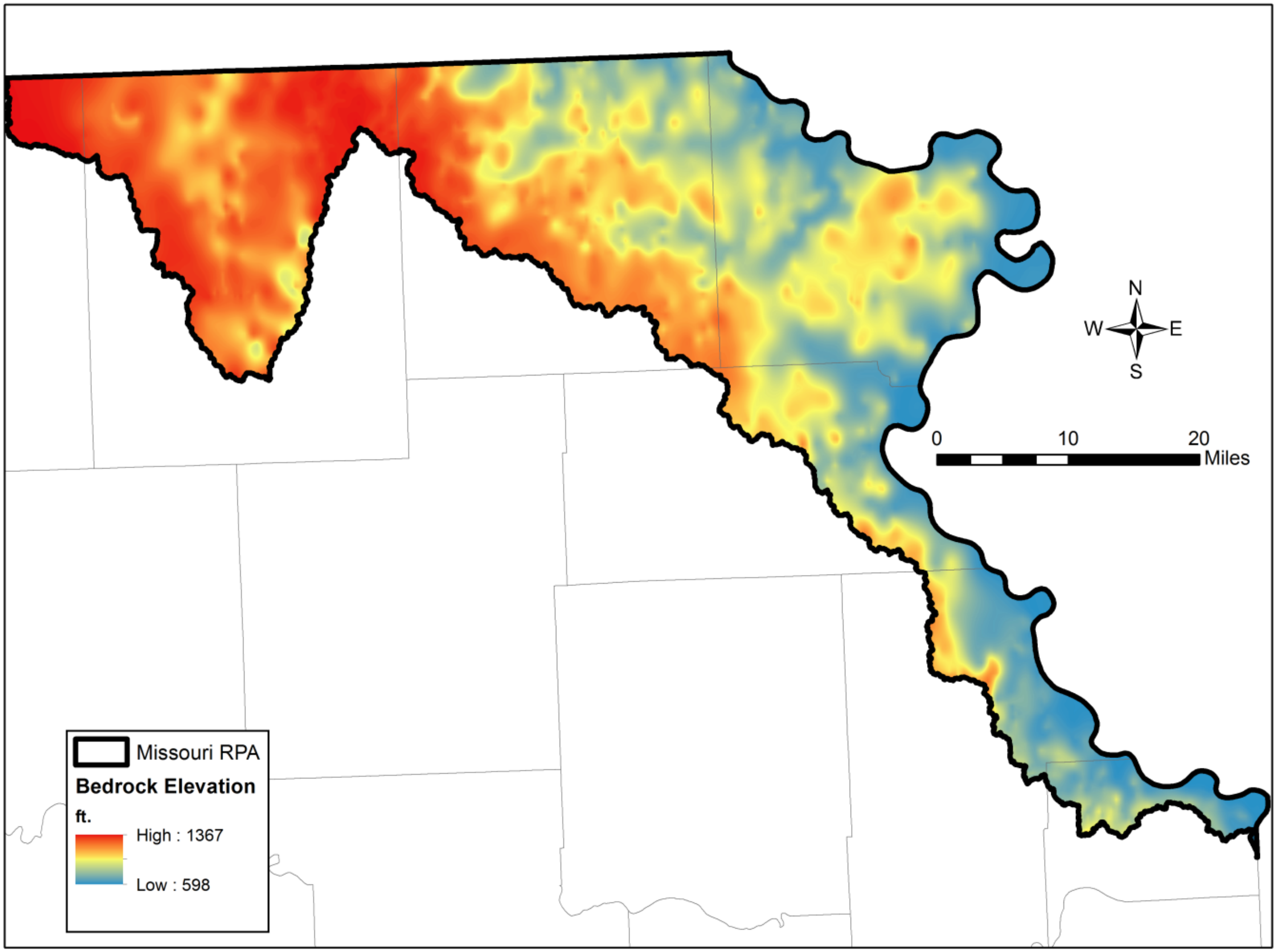

Figure 11. Map of bedrock elevation. A total of 1,027 wells and 994 test holes were used to build the map (shown in Figure 10).

Driller's logs from the WWC5 database do not specify if the materials found are of glacial origin. However, for some of the test holes that information was recorded during drilling. Those test holes are mainly located in those counties where the bedrock elevation map indicates the presence of glacial valleys (northern Atchison, Doniphan and Brown counties; Figure 12). Not coincidentally, there are no test holes in Leavenworth and Wyandotte indicating the presence of glacial till, as the shallow subsurface the parts of these counties in the MRPA mainly consist of alluvial material from the Missouri River.

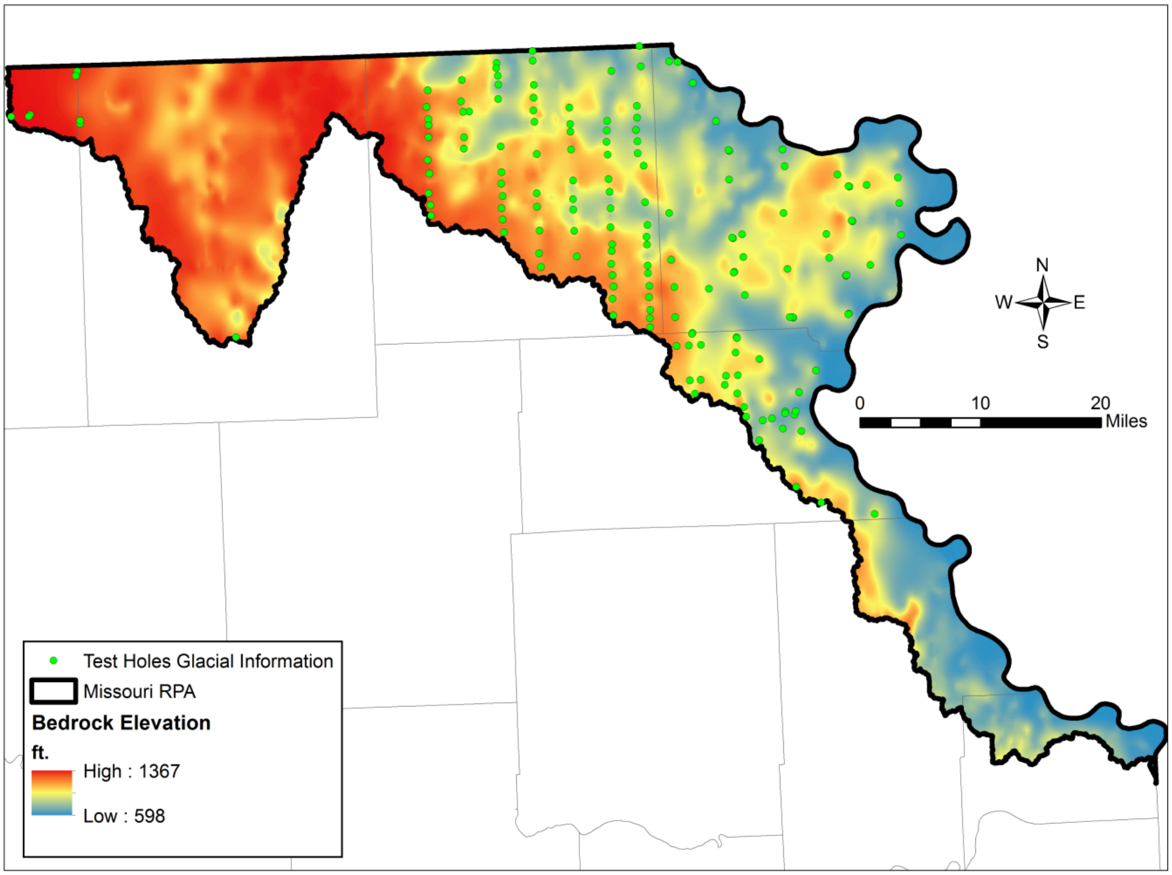

Figure 12. Map of bedrock elevation with the location of test holes where the presence of glacial materials was recorded. Not all test holes contain information about the presence or absence of glacial materials, thus other areas of the map, such as Nemaha for example, may contain glacial till.

Although only wells that reached the bedrock were used to build the map of bedrock elevation, some wells that did not reach the bedrock still provided valuable information. If a well did not reach the bedrock but the elevation of its completed depth is higher than the interpolated bedrock elevation (as shown in Figure 11), it is likely the interpolated bedrock elevation is correct or close to its actual elevation. However, for those wells that did not reach the bedrock but for which the elevation of the completion depth is lower than the interpolated bedrock elevation, the bedrock elevation should be lower at these points than what is shown in Figure 11. Nonetheless, we have no indication how much deeper the bedrock elevation is. All we can say with certainty is that the bedrock elevation at these points is lower than what the map shows (Figure 13).

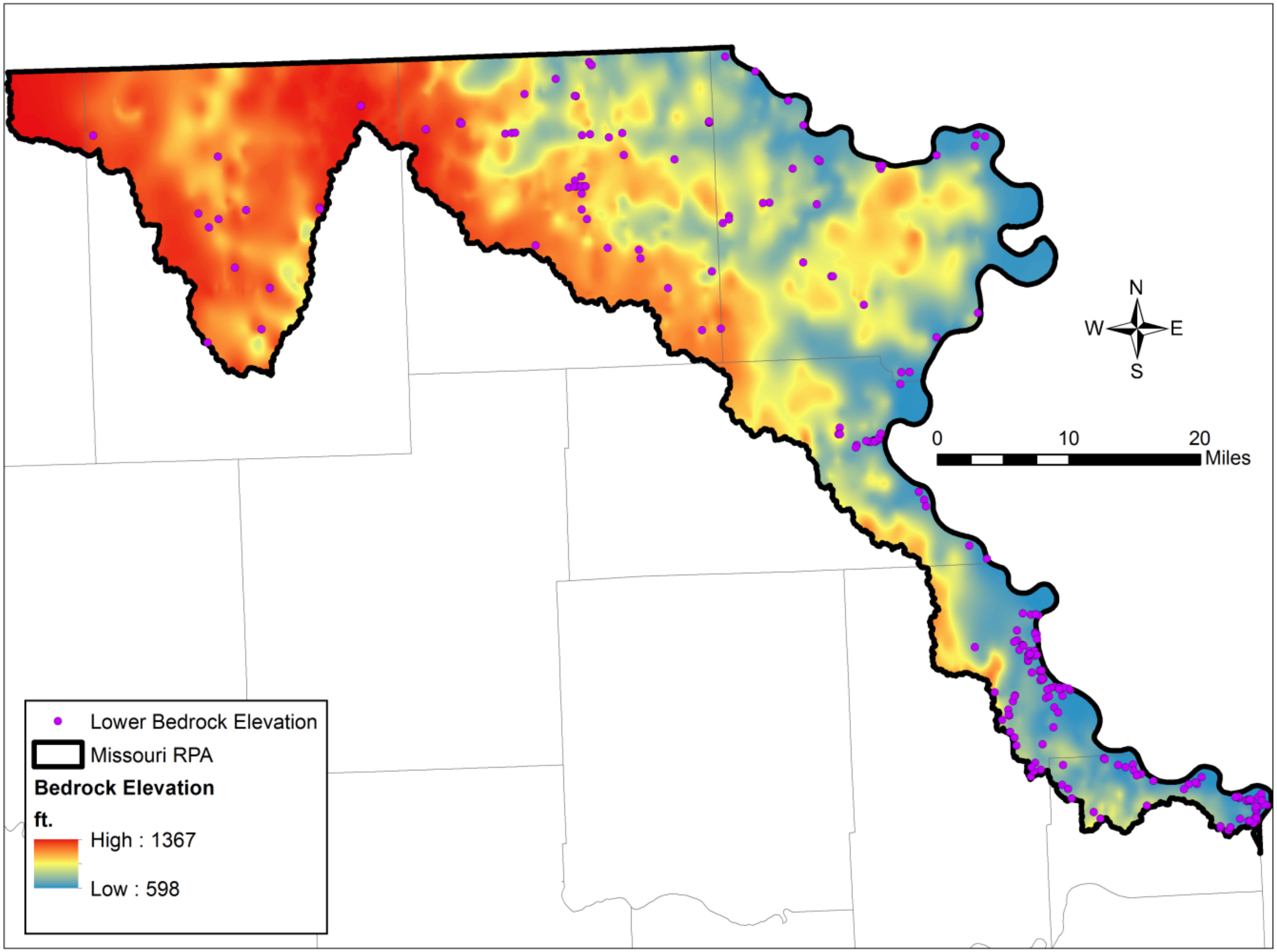

Figure 13. Map of bedrock elevation showing locations where bedrock elevation is lower than the one shown on the map. Dots are wells that did not reach the bedrock but whose completion depth is lower than the interpolated bedrock.

8. Map of unconsolidated materials

The thickness of unconsolidated materials has been calculated subtracting the bedrock elevation (Figure 13) from the topographic surface (Figure 5). The resulting map (Figure 14) does not provide the aquifer thickness, as it is the thickness of all materials (clay, silt, sand, gravel, sandstone, etc.) between the bedrock and the land surface. Although in some cases the thickness of unconsolidated materials can be close to the aquifer thickness, the thickness of unconsolidated materials is greater than the actual aquifer thickness in most cases.

Those wells that did not reach the bedrock but whose completion depth is deeper than the interpolated bedrock elevation, indicate areas of a minimum thickness of unconsolidated materials. The greatest thickness of unconsolidated materials are observed in southern Nemaha County and the eastern borders of Doniphan, Atchison, Leavenworth and Wyandotte counties, where thick formations of alluvial sediments from the Missouri River are present. In other areas, the thickness is highly variable as expected for a glaciated area.

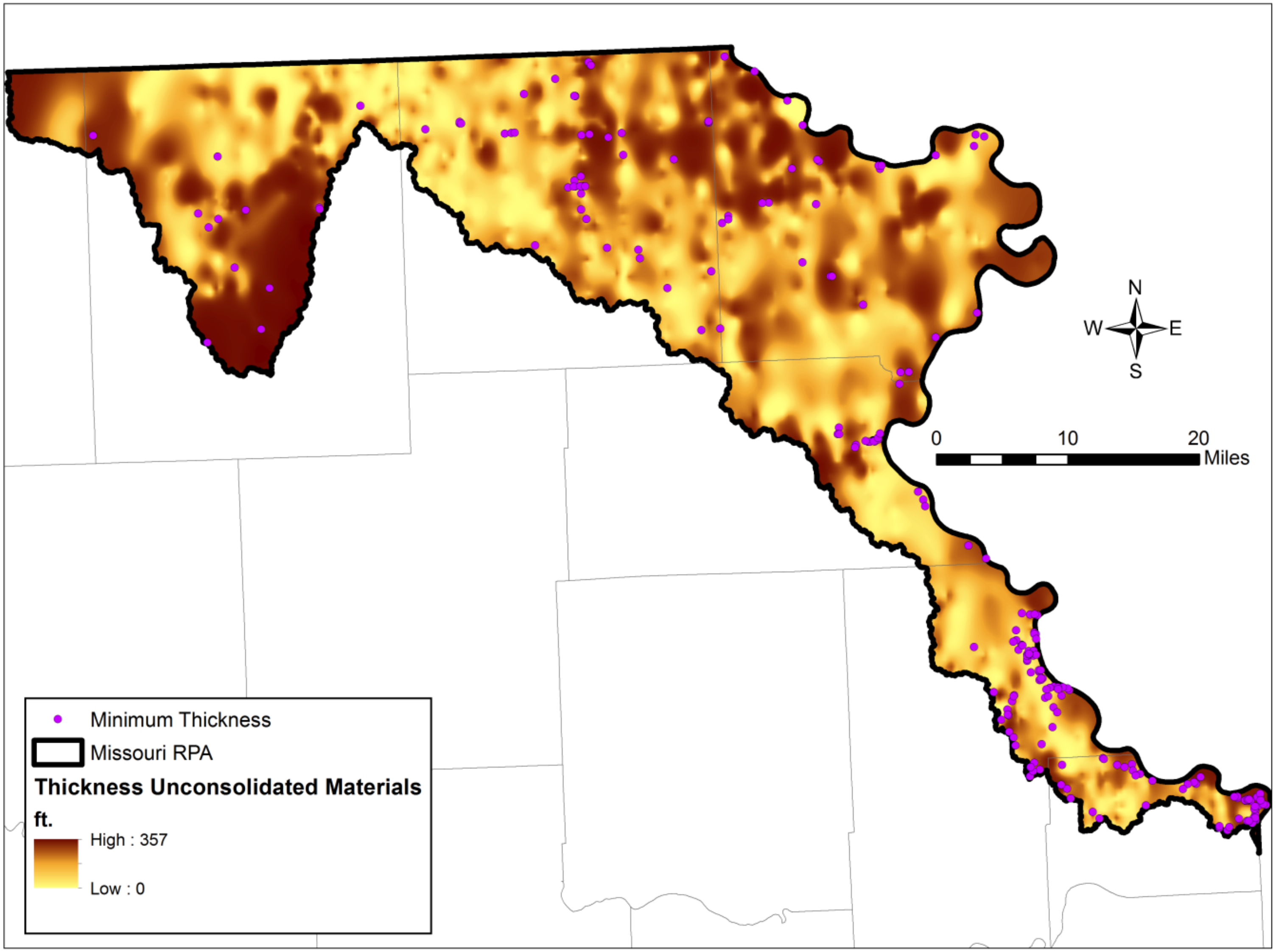

Figure 14. Thickness of unconsolidated materials. Dots represent wells that did not reach the bedrock but whose completion depth is lower than the interpolated bedrock; they thus represent areas of a minimum thickness of unconsolidated materials.

9. Map of coarse materials

Figure 15 shows the 1,759 driller's log with information about the thickness of coarse materials, including sand, gravel, and sandstone. Figure 16 is a map of the thickness of coarse materials without the data points plotted. The map shows the thickness of permeable materials that often are found in aquifers, but it provides no information about where groundwater can be found, the depth to the water table, or the saturated thickness. Nonetheless, a total of 363 test holes were reported as dry at drilling time (between 1917 and 1983). As seen in Figure 17, the location of these test holes mainly corresponds to areas where the thickness of coarse materials is lower.

Maximum thicknesses of coarse material of up to 300 ft. are found in the eastern border next to the Missouri River, southern Nemaha County and disconnected spots on the northern side of Brown and Doniphan counties. As expected for a glaciated area, aquifers do not have much continuity and their thickness is limited in space (unlike, for example, the High Plains Aquifer in western Kansas).

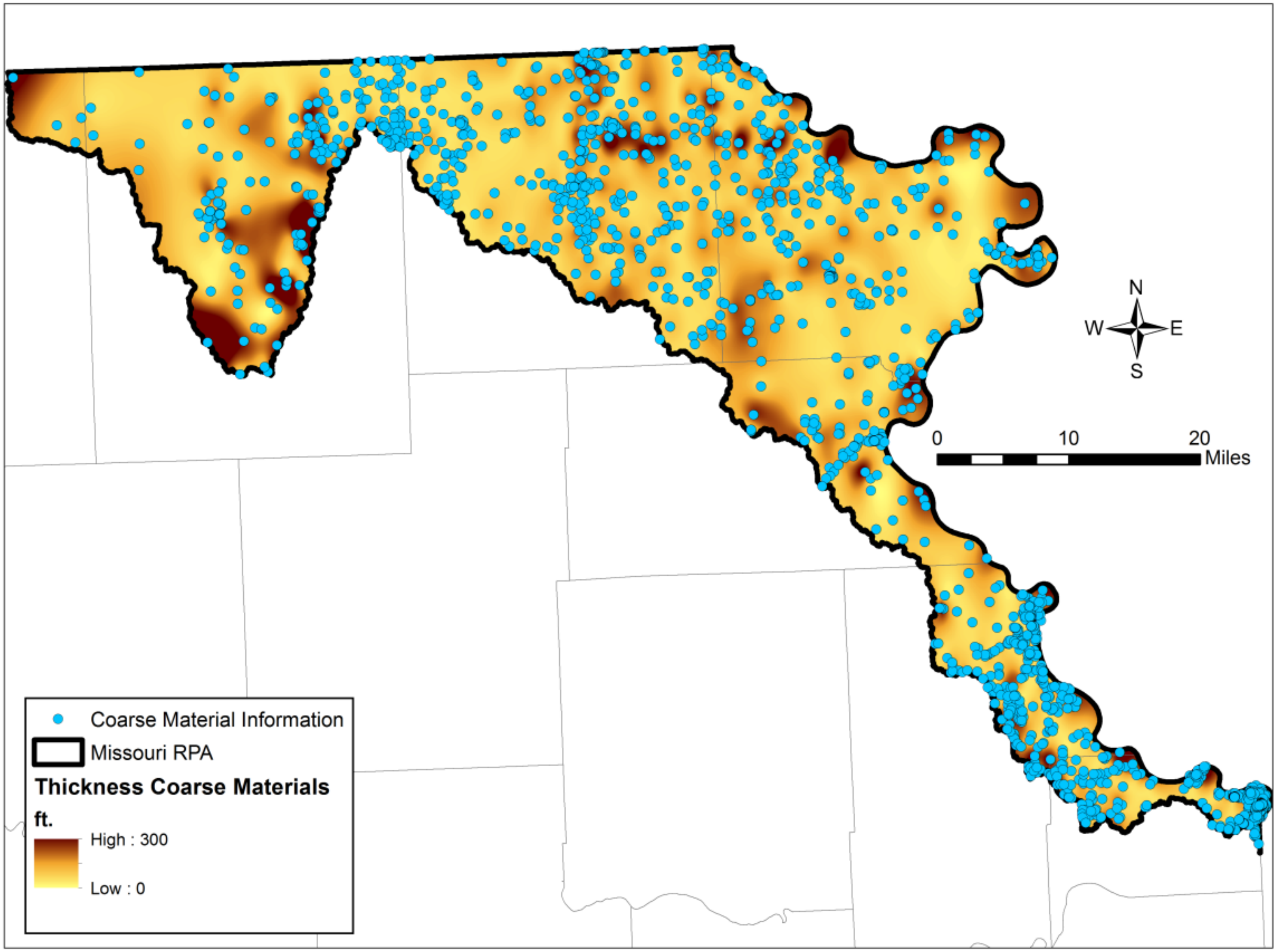

Figure 15. Map showing the 1,759 driller's logs used to calculate the thickness of coarse materials. The thickness of coarse materials is shown as the background. See Figure 16 for a clearer view of the thickness.

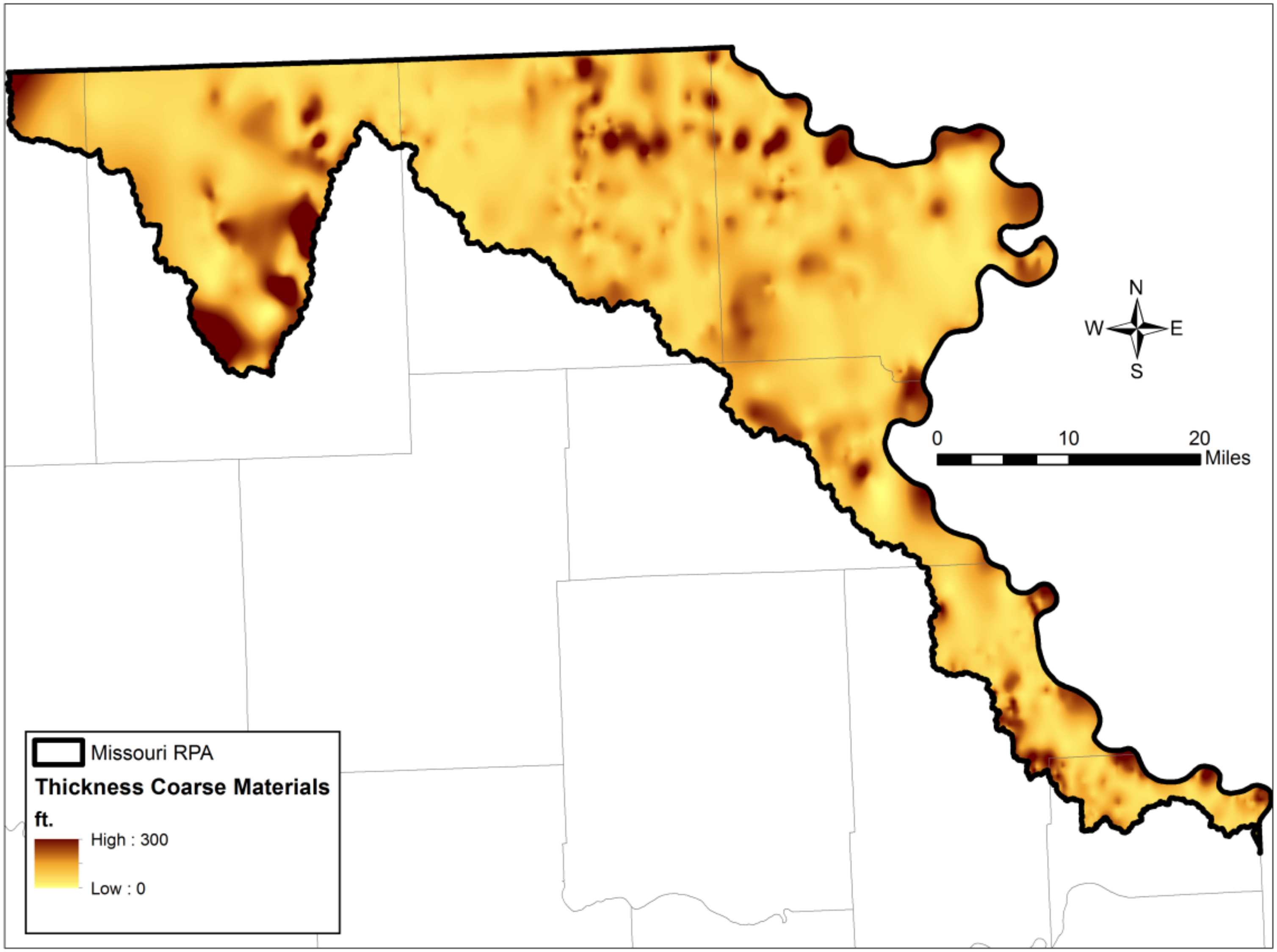

Figure 16. Map of the thickness of coarse materials. Coarse materials include sand, gravel, and sandstone (permeable materials often found in aquifers).

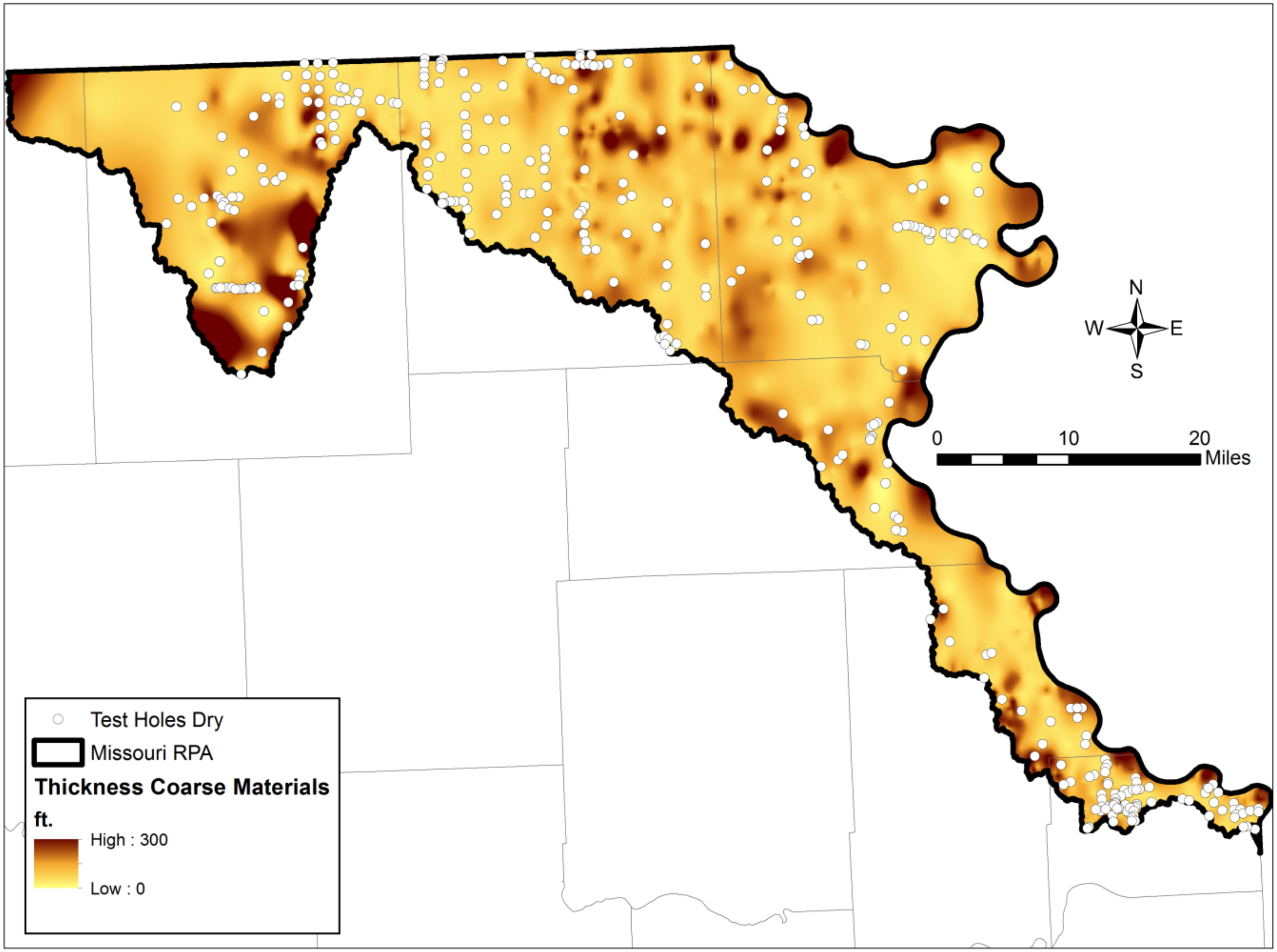

Figure 17. Map of the thickness of coarse materials showing the 363 test holes that were found to be dry (drilled between 1917 and 1983).

10. Groundwater level trends

Only one well in the MRPA currently has equipment for continuous monitoring of groundwater level; this well is located in the northeast of Nemaha County (number 2 in Figure 5). This well (USGS 395649095530101 01S 14E 19DADD01 site 19-3) was drilled in 2011 as part of the National Water-Quality Assessment (NAWQA; https://water.usgs.gov/nawqa/) project. Its water level was manually measured in 2011 (static water level at time the well was drilled) and the groundwater was sampled (13.01 mg/L NO_3-N; see Section 4 for details). In December 2015, the USGS installed a pressure transducer that takes readings every 15 mins (Figure 18).

The groundwater level hydrograph in Figure 18 shows characteristic fluctuations related to seasonal climatic conditions: groundwater level rises in spring and fall, and declines in summer and winter. There seems to be no influence from nearby pumping because there are no irrigation wells in the area (irrigation wells in Nemaha County are very limited compared to other counties in the MRPA, such as Brown County). The static groundwater level measured at time the well was drilled in 2011 was compared to the monitored groundwater level on the same day of the year in 2016, revealing a decrease of approximately 1 foot. That 1-foot decrease cannot by judged representative of what happens in the MRPA for two reasons: 1) this well does not seem to be affected by pumping, and 2) general conclusions cannot be drawn from measurements from just a single well. A proper network of wells equipped with pressure transducers and additional wells that are manually measured once a year at the same time are essential for reaching any conclusions on groundwater level dynamics and prospects for sustainability.

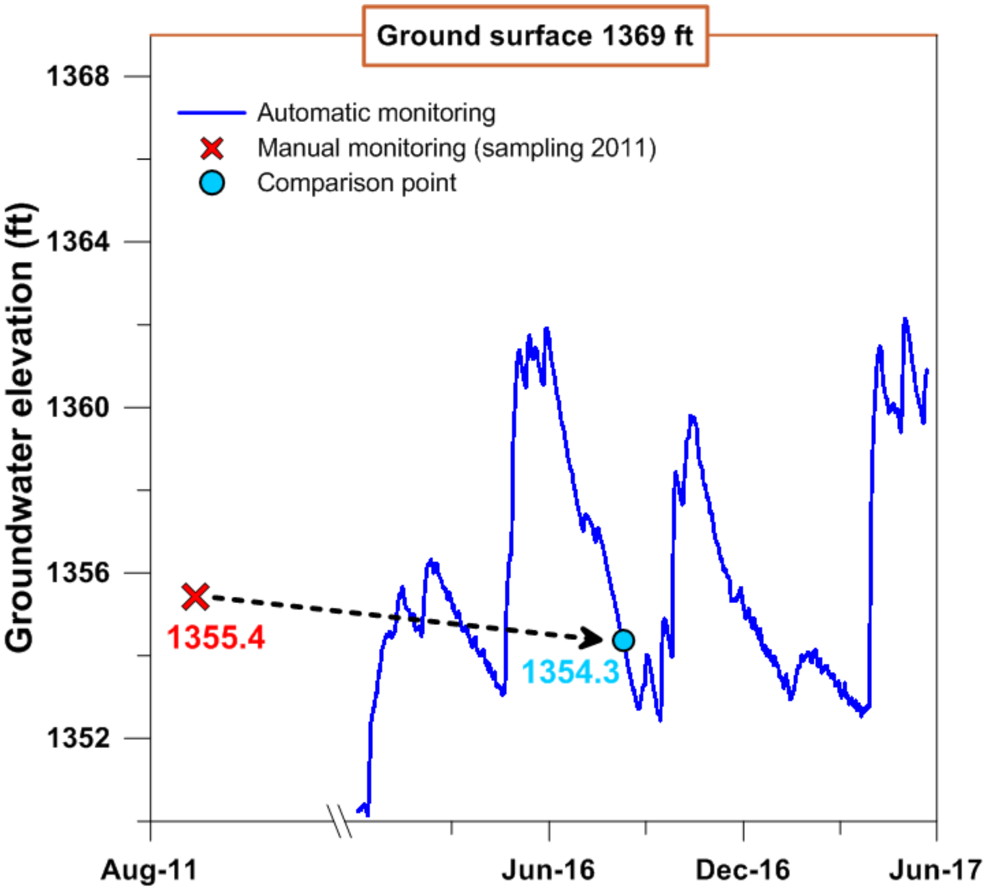

Figure 18. Groundwater level data for well USGS 395649095530101 01S 14E 19DADD01 site 19-3 (https://waterdata.usgs.gov/ks/nwis/uv/?site_no=395649095530101&PARAmeter_cd=62610,62611). The monitoring well was first manually monitored on August 8, 2011. Since December 2015, the USGS has continuously monitored the water level in this well. The water level for August 8, 2016, is shown for comparison with the initial groundwater level on August 8, 2011.

11. Map of saturated thickness

Maps of saturated thickness are built with static water levels measured in different wells at the same time or within a small window of time (days). Such water-level measurements, when performed year after year at the same time, allow determination of changes in saturated thickness of the studied aquifer. That kind of information, together with groundwater pumping rates, can be used as a groundwater management tool. Two major issues in the MRPA limit our ability to perform such analysis: 1) there does not exist a network of wells that are systematically measured every year at nearly the same time, and 2) aquifers are not spatially continuous as in other areas (e.g. the High Plains Aquifer), making interpolation of water levels a very uncertain process.

As it can be seen in Figure 19, the number of groundwater level measurements for 2016 is very limited. Including all the groundwater level measurements since 2011, the spatial distribution of groundwater level measurements improves but their location is, as expected, strongly related to those areas where the thickness of the coarse material is greater, leaving vast areas with no groundwater level information. In addition to the limited spatial representation, only one measurement per site is typically available, which is at the time the well was drilled, which can be at virtually any time of the year. Groundwater levels naturally fluctuate over a year following characteristic seasonal climate conditions. Levels typically rise during spring and fall and decline during summer and winter. Pumping for drinking water supply, irrigation, and other purposes can intensify these natural fluctuations.

Despite the previously reported issues, we have attempted to build a map of saturated thickness using groundwater level data for the period 2011 – 2016, including measurements from all seasons (Figure 20). This map is obviously not representative of actual conditions and is shown here only to highlight the limitations of groundwater level data in the MRPA for management purposes.

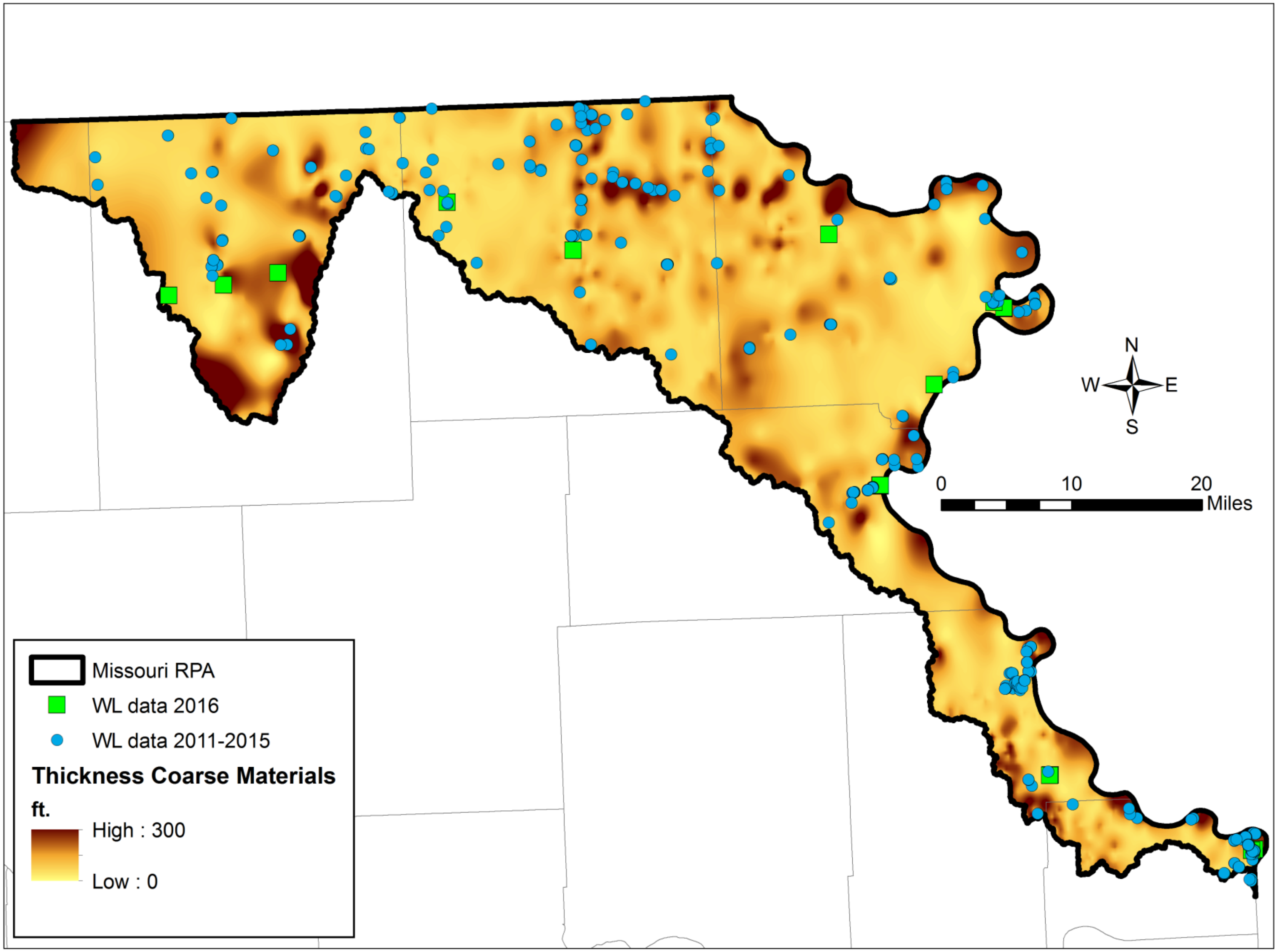

Figure 19. Map showing wells with one measured value of static water level depth (at the time the well was drilled). The thickness of coarse material is shown in the background to highlight the direct relationship between the location of wells with water level information and the thickness of coarse material.

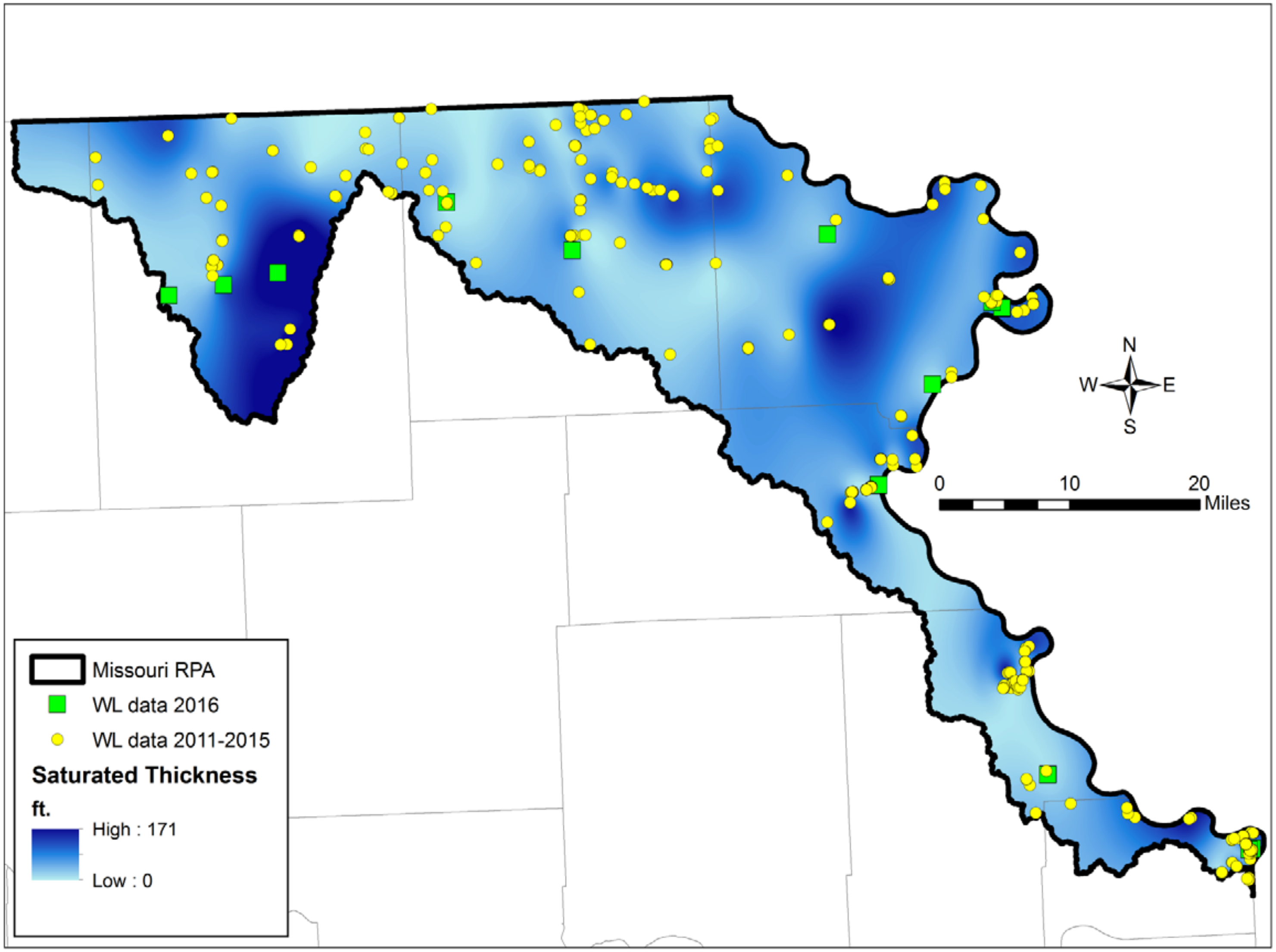

Figure 20. Map of saturated thickness in the MRPA. Water level data from 2011 to 2016, measured at different times of the year, are used. **This map is not representative of reality** because groundwater levels measured from different years and seasons are used. Ideally, all groundwater levels should be measured at the same time each year.

Although there is no temporal evolution of groundwater levels in the MRPA, we have attempted to build maps of saturated thickness during irrigation (April – September; Figure 21) and non-irrigation (October – March; Figure 22) periods using the whole dataset of static water levels since 1936. The goal of these maps is to highlight if the saturated thickness significantly changes from one period to another, and where. Dividing the hydrologic year into just two periods is a simplistic manner to proceed. However, these maps are not meant to represent the actual saturated thickness but to simply highlight relative changes in saturated thickness between two seasons of significant difference in water use. Additionally, these maps are built with individual measurements over 80 years, bringing together wet and dry years. **Consequently, these maps are not representative of actual conditions.**

The most noticeable difference between Figure 21 (irrigation period; April - September) and Figure 22 (no irrigation period; October – March) is the extension of the saturated thickness in Nemaha County. During the irrigation period, the area of greatest saturated thickness is considerably reduced in comparison to the non-irrigation period. The absolute value of saturated thickness for the irrigation period (332 ft.) is unexpectedly greater than the saturated thickness for the no-irrigation period (270 ft.). However, a closer look at the data shows that the static water level measured in 2008 in four wells in south Nemaha County, before being plugged, is the cause of such potential “anomaly”.

Similarly to what was observed for the thickness of coarse materials (Figure 16), the distribution of saturated thickness during irrigation and non-irrigation is discontinued, with areas of great saturated thickness next to areas of much lower saturated thickness. This is particularly noticeable in Brown and Doniphan counties. It is not possible to conclude, with the available data, that saturated thickness decreases during irrigation periods in these areas, but it is appreciable in certain areas that saturated thickness increases during non-irrigation periods, such as southeast Doniphan. However, in western Brown and northern Doniphan counties, the maps seem to evidence that the saturated thickness increases during irrigation periods. However, a close analysis of the data indicates that these areas of increased thickness could be the result of poor spatial well distribution.

Another interesting outcome is the comparison between maximum saturated thickness obtained using static water levels between 2011 and 2016 (Figure 20) and maximum saturated thickness using the whole dataset since 1936 (Figure 21 and Figure 22). A maximum saturated thickness of 171 ft. was obtained in south Nemaha County, whereas saturated thickness of up to 300 ft. was calculated when using the whole dataset since 1936. A close analysis of the wells responsible for such great saturated thickness reveals that this is mainly caused by groundwater levels measured between 1985 and 1995. Despite the data available does not allow us to perform a more rigorous analysis, the available data seems to evidence important seasonal variation of saturated thickness and potentially lost of saturated thickness over time in those areas with originally greatest saturated thickness, such as Nemaha County.

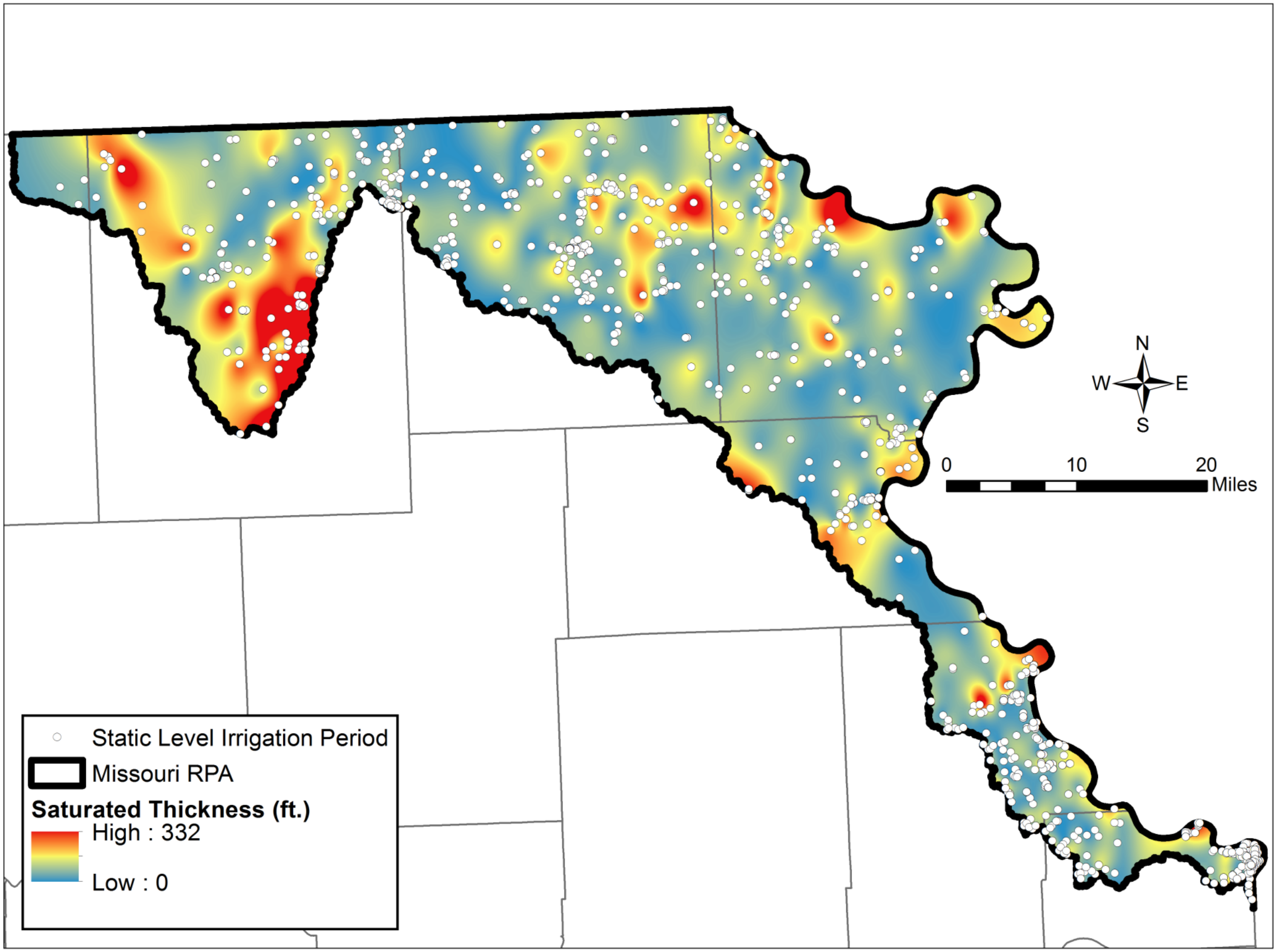

Figure 21. Map of saturated thickness for the irrigation period (April - September). The map has been built using static water levels from 1955 to 2016 measured at single locations (solid dots).

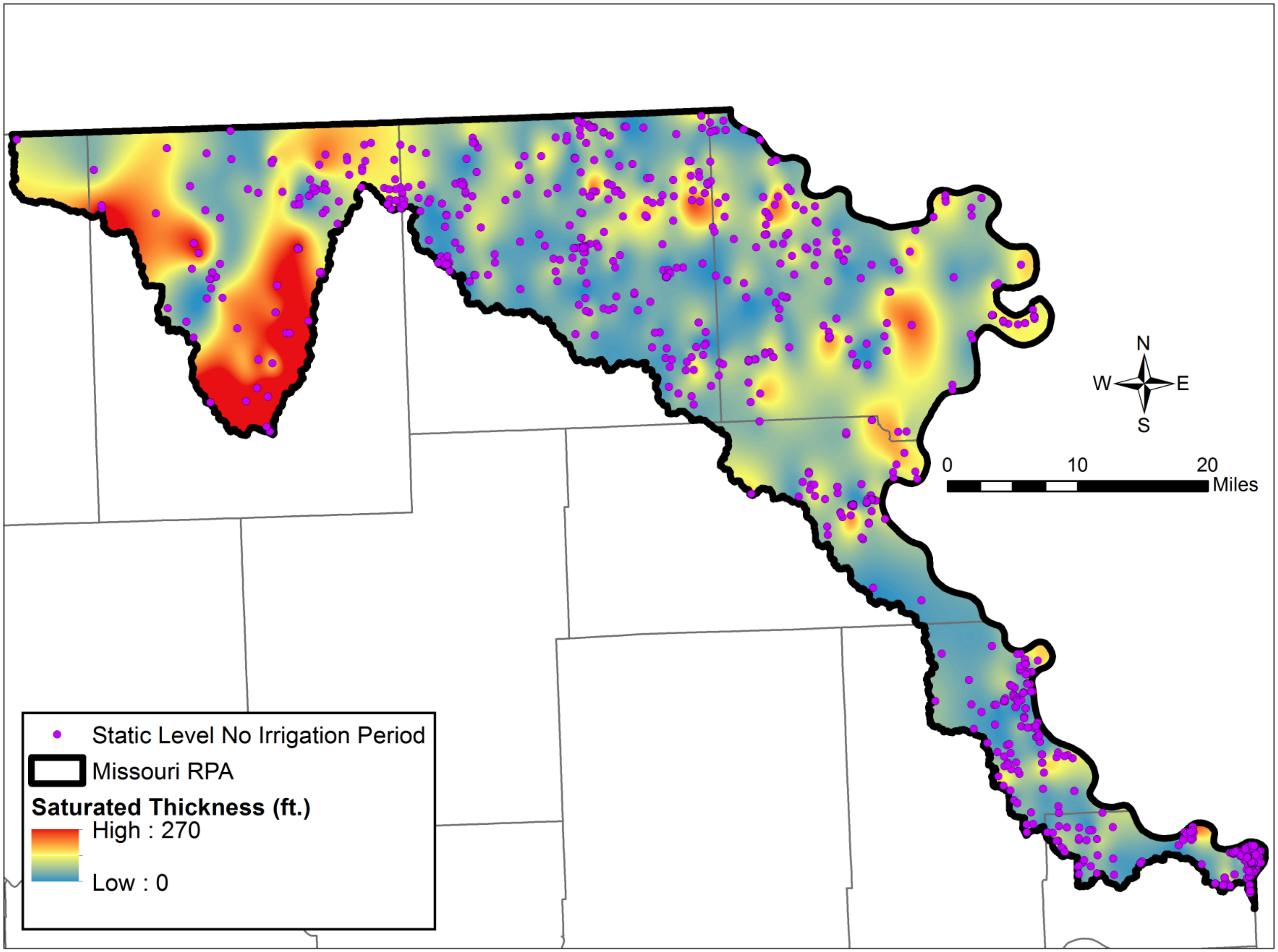

Figure 22. Map of saturated thickness in the MRPA for the no irrigation period (October - March). The map has been built using static water levels from 1936 to 2016 measured at single locations (solid dots).

12. Follow up on the Missouri Regional Advisory Committee meeting (June 22, 2017, Atchison)

The Kansas Geological Survey presented a summary of the project Phase I results at the Missouri Regional Advisory Committee meeting on June 22, 2017, held in Atchison, Kansas. The groundwater nitrate data presented were obtained from old USGS and KDHE sampling campaigns. However, and based on the feedback we obtained during the presentation, it appears that we may be missing some data in our actual nitrate dataset, particularly water quality data from raw water in municipal locations and rural water districts. We believe this data is not available at KDHE because they did not supply us with it upon our request for groundwater nitrate data. We believe that raw water quality data from municipal water supply locations and rural water districts would contribute to obtaining a more up to date nitrate situation in the MRPA. Contacts have been launched with Water One (Water District No. 1 of Johnson County) to obtain details on where that information can be found and how KGS can obtain it.

13. Conclusions and recommendations for Phase II

The Kansas Geological Survey collected information on water-well driller's and test hole logs, water usage, water chemistry, and water levels from a variety of digital and hard copy sources at the KGS, KDHE, and USGS. The data have been analyzed and compiled, from which detailed maps of water usage, groundwater quality, bedrock elevation, unconsolidated materials, and coarse materials have been made. Accurate maps of saturated thickness, depth to groundwater, and the changes in both cannot yet be made because of the limited amount of groundwater level data through time.

We conclude that the MRPA has two main issues constraining us to draw recommendations for general groundwater sustainability: 1) historical chemistry analyses show that nitrate has been an important issue in terms of groundwater quality. Today, there is insufficient data on nitrate contamination for us to determine the full extent of that problem; 2) the MRPA only has static water level measurements that were obtained at the time a well was drilled. These measurements are insufficient and are not adequate to determine groundwater level changes with time. However, the number of existing wells that could be potentially used to establish a monitoring network for both groundwater level and quality is large.

To address the main issues found in the MRPA, we propose an action plan based on three approaches:

1. **Establishment of a monitoring network with automatic and manual groundwater level monitoring**. Scientists from the KGS have been continuously monitoring the dynamics of groundwater levels in the High Plains Aquifer for close to 10 years and performing annual winter water-level measurements for much longer, allowing them to develop approaches for assessing the impact of management actions and prospects for aquifer sustainability (Butler et al., 2016; Whittemore et al., 2015). The method relies on a dense and long-term monitoring network and pumping data. For example, this approach allowed KGS scientists to determine that pumping reductions of around 25% in the High Plains Aquifer would stabilize presently decreasing groundwater levels over much of northwestern Kansas. Such recommendations are only possible if both groundwater levels and reported pumping data are known. With the WIMAS database, the KGS has the needed pumping information. However, as shown in this report, there are no data on the temporal fluctuations of groundwater levels. *Ideally, a dense monitoring network of strategically located wells near irrigation and municipal areas (the two principal groundwater uses in the MRPA), modeled after the network in the High Plains aquifer, should be at least manually monitored once a year at the same time of the year, and a number of other wells should be equipped with automatic pressure transducers*. The KGS has ample experience developing, managing and maintaining dense monitoring networks, as demonstrated with their work in the High Plains Aquifer.

2. **Drilling new monitoring wells in areas of limited spatial distribution of existing wells**. The groundwater level monitoring network should target irrigation and municipal wells, as well as monitoring wells surrounding areas of major groundwater exploitation. Figure 23 provides an overview of the location of constructed wells with irrigation, municipal and monitoring uses in the MRPA. Traditionally the distribution of wells in an area obeys to the underground geology, and the MRPA is not an exception to that. Clusters of wells can be observed in the alluvial plain of the Missouri River (see Doniphan, Atchison, Leavenworth and Wyandotte counties in Figure 23), and areas of central Brown and Nemaha counties. However, other areas such as Marshall, west of Nemaha, southeast of Doniphan, northwest of Atchison and north of Leavenworth, have apparently no constructed wells, or very limited spatial distribution. We anticipate these areas would benefit of drilling new monitoring wells in order to complement the already existing wells. Groundwater in the MRPA being much shallower than in the High Plains Aquifer, drilling could be potentially performed using the KGS Geoprobe® 7822DT, although that would depend on the local geology of the area. For example, in areas of compact glacial till material, more robust drilling tools may be required.

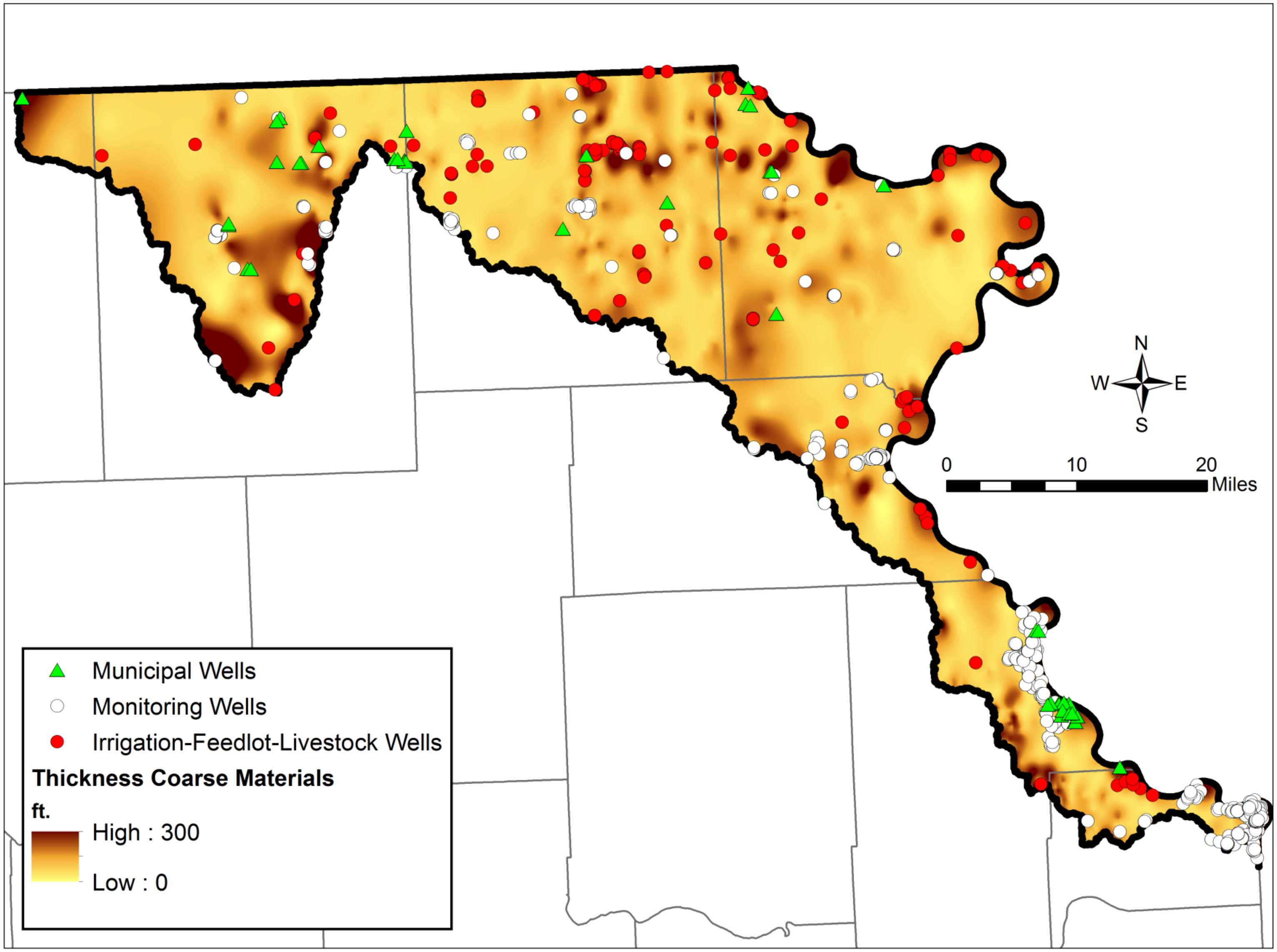

Figure 23. Map showing wells used for irrigation/feedlot/livestock, public water supply (municipal) and monitoring wells, according to the WWC5 database, that could potentially be used to develop the groundwater level monitoring network in the MRPA.

3. **Development of a groundwater quality monitoring network**. Nitrate contamination in groundwater can have four main sources: fertilizers from cropland, manure from farmland, septic tanks, and sewage systems. It is impossible to determine a single source for an area as big as the MRPA, and the issue needs to be treated at the site scale. There are rigorous techniques allowing proper determination of the source, but those require knowledge of the local hydrogeology and, most importantly, groundwater sampling for nitrate analysis (and other constituents such as B, Cl, and Na, among others), and isotopic composition ($\delta^{15}N$, $\delta^{11}B$, $\delta^{18}O$-NO_3, $^{87}Sr/^{86}Sr$) over time (Degnan et al., 2016; Esser et al., 2009; Ma et al., 2016; Widory et al., 2004; Widory et al., 2005). It is only with this kind of information that actual nitrate contamination can be reported and possible sources identified. The municipal use being the activity that consumes the most groundwater, and potentially affecting the highest number of people, we propose to develop a monitoring quality network based on wells for municipal use. However, it is imperative that the water sample is the raw water drawn from the aquifer and not the water after treatment. Despite such an action plan might seem costly in a short term, if nitrate contamination sources are not well identified, the cost of water treatment and of potentially having to abandon contaminated wells and drill new wells is more expensive over the long term.

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