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UNUSUALLY SENSITIVE AREAS FOR DRINKING WATER RESOURCES REPORT FOR KANSAS

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UNUSUALLY SENSITIVE AREAS FOR DRINKING WATER RESOURCES REPORT FOR KANSAS

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INTRODUCTION

The Research and Special Programs Administration (RSPA) of the Department of Transportation is required to identify areas unusually sensitive to environmental damage in the event of a hazardous liquid pipeline accident, in accordance with pipeline safety laws (49 U.S.C. Section 60109). Accordingly, workshops were held with regulatory agencies, pipeline operators, and the public during which a process was developed to identify "unusually sensitive areas" (USAs) for drinking water resources. This process, which has been adopted by RSPA, consists of first identifying environmentally sensitive drinking water resources and other primary concerns, and then applying the following five filtering criteria to determine which of the drinking water source locations (i.e., surface water intakes and groundwater wells) should be USAs:

Filter Criteria #1

If the public water system is a Transient Noncommunity Water System (TNCWS), the water intakes shall not be designated as USAs.

Filter Criteria #2

For Community Water Systems (CWS) and Nontransient Noncommunity Water Systems (NTNCWS) that obtain their water supply primarily from surface water sources, and do not have an adequate alternative source of water, the water intakes shall be designated as USAs.

Filter Criteria #3

For CWS and NTNCWS that obtain their water supply primarily from groundwater sources, where the source aquifer is identified as a Class I or Class IIa, as defined in Pettyjohn et al. (1991), and do not have an adequate alternative source of water, the wellhead protection areas for such systems shall be designated as USAs.

Filter Criteria #4

For CWS and NTNCWS that obtain their water primarily from groundwater sources, where the source aquifer is identified as a Class IIb, IIc, III, or U, as defined in Pettyjohn et al. (1991), the public water systems that rely on these aquifers shall not be designated as USAs.

Filter Criteria #5

For CWS and NTNCWS that obtain their water supply primarily from groundwater sources, where the source aquifer is identified as a Class I or Class IIa, as defined in Pettyjohn et al. (1991), and the aquifer is designated as a sole source aquifer, an area twice the wellhead protection area shall be designated as a USA.

All CWS and NTNCWS that obtained their water from surface water sources were automatically designated as USAs because information on which to evaluate whether they have an adequate alternative water supply was not available at the time of this report. Designation of groundwater sources was much more complicated, thus the rest of this discussion describes the process that has been developed and implemented to classify groundwater wells that supply the CWS and NTNCWS in the state of Kansas.

THE PETTYJOHN CLASSIFICATION SCHEME

The aquifer classification scheme developed in a report "Regional Assessment of Aquifer Vulnerability and Sensitivity in the Conterminous United States" for the U.S. Environmental Protection Agency (USEPA/600/2-91/043) by Pettyjohn et al. was used to determine those parts of aquifers at risk to contamination from pipeline releases of a hazardous liquid. The Pettyjohn classification, based on an assessment of the potential contamination of groundwater throughout the United States by the subsurface emplacement of fluids through injection wells, is outlined below:

Class I (Surficial or Shallow Permeable Units; Highly Vulnerable to Contamination)

Class Ia: Unconsolidated Aquifers. Consist of surficial, unconsolidated, and permeable alluvial, terrace, outwash, beach, dune and other similar deposits.

Class Ib: Soluble and Fractured Bedrock Aquifers. Consist of limestone, dolomite, and, locally, evaporitic units that contain documented karst features or solution channels, regardless of size. Also includes sedimentary strata and metamorphic and igneous rocks that are significantly faulted, fractured, or jointed.

Class Ic: Semi-consolidated Aquifers. Consist of semi-consolidated systems that contain poorly to moderately indurated sand and gravel that are interbedded with clay and silt.

Class Id: Covered Aquifers. Consists of any Class I aquifer that is overlain by less than 50 feet of low permeability, unconsolidated material, such as glacial till, lacustrian, and loess deposits.

Class II (Consolidated Bedrock Aquifers; Moderately Vulnerable to Contamination)

Class IIa: Higher Yield Bedrock Aquifers. Consist of fairly coarse sandstone or conglomerate that contain lesser amounts of interbedded fine-grained clastics and occasionally carbonate units. In general, well yields must exceed 50 gallons per minute (gpm) to be included in this class.

Class IIb: Lower Yield Bedrock Aquifers. Consist of the same clastic rock types present in the higher yield systems. Well yields are commonly less than 50 gpm. (Note: We have broadened this definition to include all low-yield, consolidated bedrock aquifers [e.g., crystalline igneous and metamorphic rocks].)

Class IIc: Covered Bedrock Aquifers. Consist of Class IIa and IIb aquifers that are overlain by less than 50 feet of unconsolidated material of low permeability.

Class III (Covered Consolidated or Unconsolidated Aquifers)

This class includes those aquifers that are overlain by more than 50 feet of low permeability material. (Note: We have broadened this definition to include all confined aquifers.)

Class U (Undifferentiated Aquifers)

This classification is used where several lithologic and hydrologic conditions are present within a mappable area. This class is intended to convey a wider range of vulnerability than is usually contained in any other single class.

Subclass V (Variably Covered Aquifers)

The modifier "v" is used to describe areas where an undetermined or highly variable thickness of low permeability sediments overlies the major water-bearing zone. In practice, we have used this modifier where the geologic description of the aquifer indicates that there is a confining unit above the water-producing zone.

The key to identifying groundwater wells that are USAs was distinguishing those wells that obtained their water from Class I or Class IIa USA aquifers (filter criteria 3 and 5), from those that did not (filter criteria 4). Another key was the location of the well with respect to the aquifer outcrop or subcrop. For example, Class I and IIa wells located in the aquifer outcrop belt were USAs in most cases. On the other hand, wells that tapped an aquifer in its subcrop belt where the aquifer was overlain by a confining unit, such as a layer of impermeable shale, were classified as Class III, and were not USAs. In the latter situation, the overlying impermeable layer would prevent a pipeline release from reaching the aquifer, so there is minimal threat of contamination from a hazardous liquid pipeline release.

IDENTIFYING USAs FOR DRINKING WATER RESOURCES IN KANSAS

The Geology and Pettyjohn Classification of Aquifers in Kansas

Kansas is within the Great Plains and Central Lowlands physiographic provinces. The Great Plains physiographic province covers western Kansas. There are two main aquifer systems in the western half of the state: the High Plains or Ogallala aquifer system, and the Great Plains/Dakota aquifer system. The High Plains or Ogallala aquifer system is composed primarily of unconsolidated to semi-consolidated sandstones of Quaternary to Tertiary age. Where the overlying surficial deposits, principally the Quaternary dune sands in the southwest and south-central regions, tend to be in hydraulic continuity with the underlying sandstones, they are considered to be part of this aquifer. In some areas, the High Plains or Ogallala aquifer is covered by deposits of wind-blown loess, which form localized, surficial confining units. The Great Plains/Dakota aquifer system underlies the High Plains or Ogallala system. These two aquifer systems are separated by the Great Plains confining unit. The Great Plains/Dakota aquifer consists of Cretaceous sandstones which are interlayered with shale deposits. Both of these aquifer systems are overlain, in places, by surficial alluvial valley deposits.

The eastern portion of the state, located within the Central Lowland physiographic province, contains the Ozark Plateau aquifer system in the extreme southeast, the Glacial Drift aquifers in the northeast, and various consolidated bedrock aquifers of Pennsylvanian and Permian ages in the central and eastern portions of the state. The Ozark Plateau aquifer system consists of porous, carbonate rock of Mississippian age. The Pleistocene valley aquifers are unconsolidated, coarse sediments buried, in many cases, beneath impermeable glacial material. All of these aquifer systems are overlain, in places, by surficial alluvial valley deposits. As shown in Table 1, there are six major aquifers in Kansas (summarized by U.S. Geological Survey, 1997), organized from youngest to oldest (Fig. 1).

TABLE 1. Kansas aquifers and their classification according to the Pettyjohn et al. (1991) classification scheme.

Aquifer Name	Aquifer Description	Pettyjohn Classification
Alluvial	Valley and terrace deposits of major rivers (e.g., Missouri, Kansas)	Class Ia because these deposits are permeable sands and gravels
Glacial Drift	Mostly coarse-grained deposits of Pleistocene age that fill buried preglacial bedrock valleys	Class Id where overlain by <50 feet of impermeable glacial till, because these deposits are permeable sands and gravels; if these aquifers are overlain by >50 feet of till, they are Class III
High Plains or Ogallala	Tertiary semi-consolidated sandstones and overlaying Quaternary dune sands	Class Ic because these sandstones are semi-consolidated, high-yield aquifers; Class Ia where composed of Quaternary dune sands; Class Id where overlain by less than 50 feet of loess; Class III where overlain by greater than 50 feet of loess

TABLE 1. Continued.

Aquifer Name	Aquifer Description	Pettyjohn Classification
Great Plains/ Dakota	Cretaceous consolidated sandstones	Class IIa because these sandstones typically yield greater than 50 gpm; Class III where overlain by confining units
Pennsylvanian and Permian	Consolidated bedrock (primarily sandstones)	Class IIa in outcrop belt if yield is greater than 50 gpm; Class IIb if yield is less than 50 gpm
Ozark Plateau	Porous, carbonate rock of Mississippian age	Class Ib because these carbonate rocks contain solution features; Class III where overlain by confining units

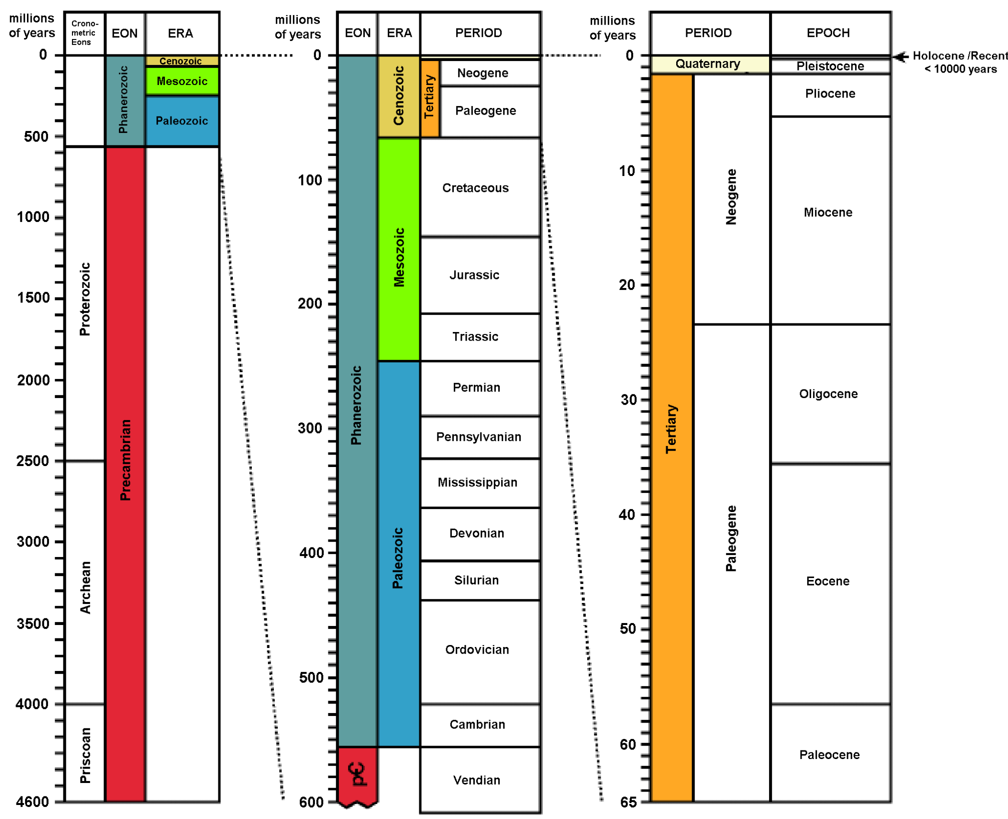

FIGURE 1. Geologic time scale.

Data Sources

The Kansas Department of Agriculture, Division of Water Resources, maintains a database of well permits for the state. Through multiple communications, the Division of Water Resources identified the "municipal" database as the appropriate list of records for the drinking water USA analysis. Therefore, although there was no specific information identifying TNCWS, it is believed that the municipal database contains only the CWS and NTNCWS well information, and this can be confirmed during future reviews of Kansas USAs. Each well record, which represents a particular water right for a point of diversion (well or surface water intake), has information about location, depth, flow rate, well type, and well status.

The Data Access and Support Center (DASC) at the University of Kansas provided a surficial geology data layer (1:500,000) from the Kansas Geological Survey. The DASC also provided data layers for the boundaries and elevations of the top and bottom of the major aquifers at scales from 1:500,000 to 1:1,000,000.

Data Quality

Every municipal well in Kansas was classified according to the Pettyjohn (1991) scheme. The classification for wells located in bedrock aquifers relied on the spatial analysis of where the wells were located and the aquifers they obtained water from. This spatial analysis determined the existence of overlying confining units which are barriers to pollution transmission. A system was implemented for tracking the spatial and attribute accuracy of the data in order to maintain a record of the decisions made and to allow future checking of the resulting USAs. A "quality" variable was added to the data, as defined in Table 2.

In Kansas, no drinking water well database existed that identified the aquifer water source for each well. Thus, no wells in Kansas have a Quality Rank of 1-3. Instead,

TABLE 2. Quality ranks and descriptions.

Quality Rank	Description of the Data Quality
1	Source information was available and the well was located within the boundary of the associated data layer.
2	Source information was available and the well was located within the spatial tolerance of the associated data layer.
3	Source information was available and the well was located beyond the spatial tolerance of the associated data layer.
4	Source information was not available, but depth, distance to nearest aquifer, and geographic position were used to classify the well, which was located within the boundary of the associated data layer.
5	Source information was not available, but depth, distance to nearest aquifer, and geographic position were used to classify the well, which was located within the spatial tolerance of the associated data layer
6	Source information was not available, but depth, distance to nearest aquifer, and geographic position were used to classify the well, which was located beyond the spatial tolerance of the associated data layer
7	Source and depth information were not available, but other attributes (e.g., distance to nearest surficial outcrop or to nearest attributed wells) were used to classify the well.

well depth, aquifer maps, and aquifer elevation limits were used to identify an aquifer source for each well. However, to maintain consistency with the ranking system used during the processing of other states, the quality ranks were expanded and range from a low of 4 to a high of 7 in Kansas. These additional ranks were added to describe the range of attribute and spatial accuracies when no source information was known. The following distances (from the metadata reports) were used to determine the spatial accuracy for each data layer:

groundwater wells: +/- 12.2 meters

surficial geology: +/- 250 meters

aquifer extent (all aquifers except Dakota): +/- 250 meters

aquifer extent (Dakota aquifer): +/- 500 meters

Processing Steps

The steps below outline the Geographic Information System (GIS) processing that was performed in deriving the final classification of the wells and generation of the USAs.

1. Digital data layers for surficial geology, aquifer extents and elevations, and public water supplies (groundwater wells and surface water intakes) were obtained from data providers. The well data were processed to delete multiple water right records for the same public water supply (PWS), while retaining the most complete and recent data for that PWS. Thus, 3,591 water right records were processed to yield 2,561 wells and 211 surface water intakes (813 duplicate records were deleted).

2. The groundwater well data layer was intersected with the surficial geology (Fig. 2) and the aquifers (Fig. 3) to associate each well with both features.

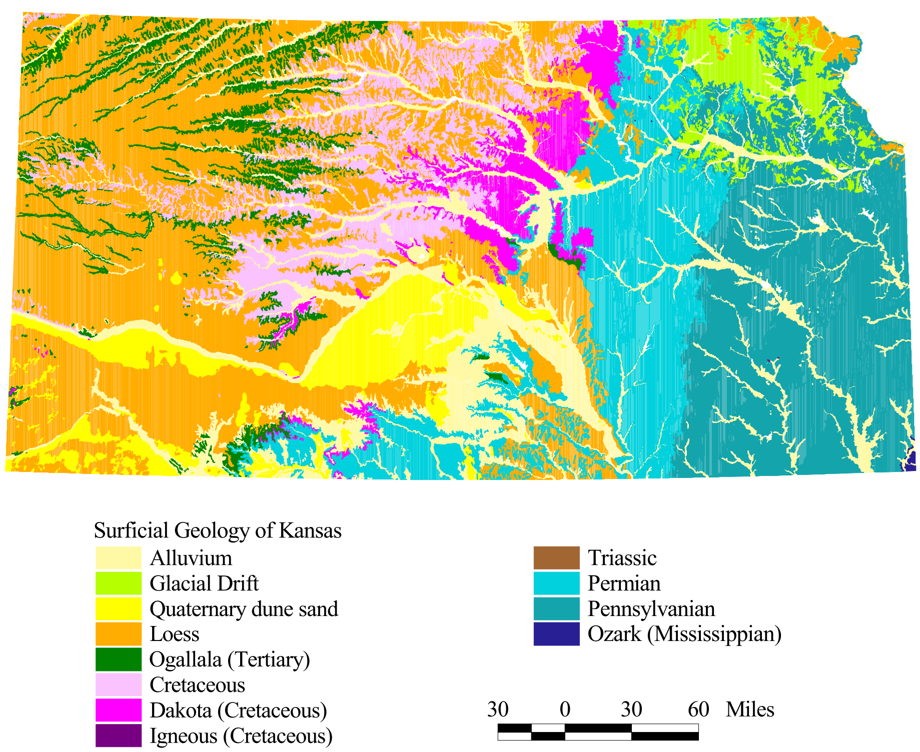

FIGURE 2. Surficial geology of Kansas.

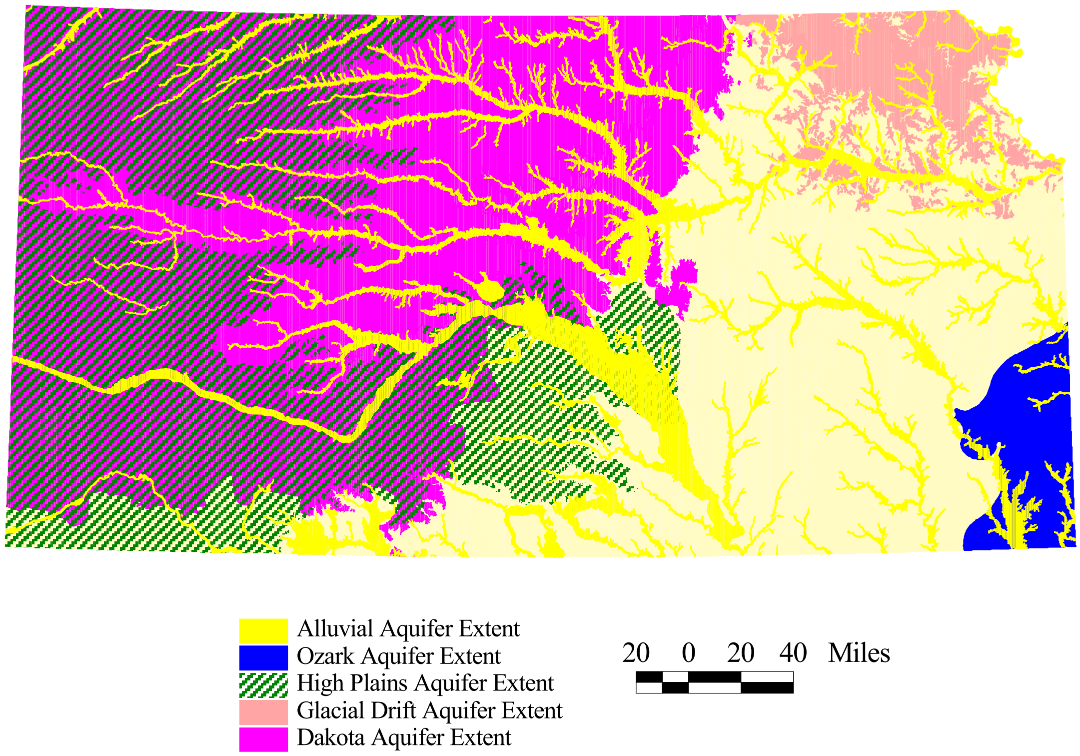

FIGURE 3. Location of the major aquifers of Kansas.

3. For wells that were located within the boundaries of more than one aquifer (Great Plains/Dakota and overlying High Plains or Ogallala) (Fig. 4), a comparison was made between the depth of the well and the elevation limits of the top and bottom of the aquifers in question. An aquifer elevation data layer for the top of the Dakota aquifer was used to determine whether each well was deep enough to penetrate and obtain water from this aquifer (Fig. 5).

4. Pettyjohn class and data quality were calculated using the surficial geology and aquifer where the well was located. For example, if a well was located in the Dakota/Great Plains aquifer, and within the outcrop of that aquifer, then this well was Class IIa with a Quality of 4, and is described in the Dakota/Great Plains aquifer section. All wells were processed, from youngest to oldest aquifer, to determine if they were within the spatial accuracy of the associated aquifer boundary data layer. Wells located outside the outcrop belt of the aquifer from which they obtain water were processed to determine if they were within the spatial accuracy of the respective outcrop data layer.

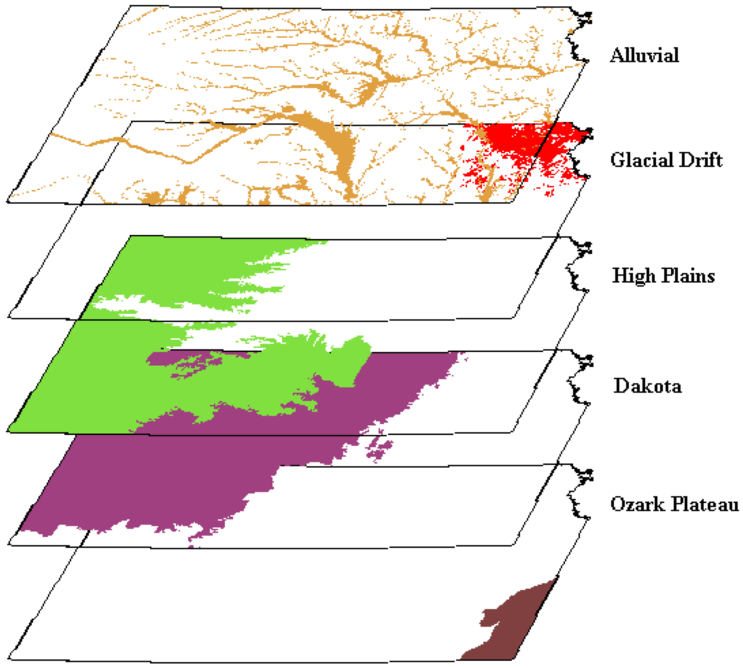

FIGURE 4. The major aquifers of Kansas. Younger aquifers overlay older aquifers.

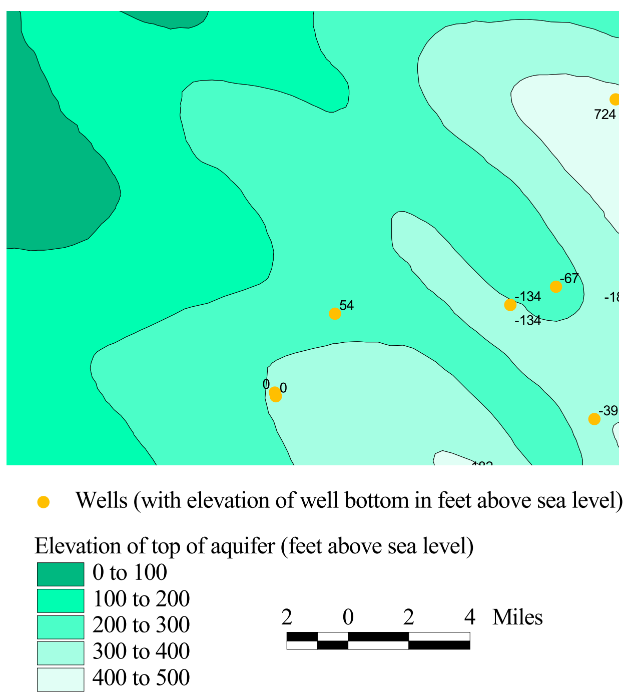

FIGURE 5. Elevation zones of the top of the Dakota aquifer and groundwater wells shown with well depths. Of these wells, only the well at a depth of 724 feet (upper right) was deep enough to penetrate the Dakota aquifer.

5. Where the surficial deposits consisted of loess or glacial till, the Pettyjohn class was dependent on the thickness of the overlying glacial till or loess. Because there were no digital data for till or loess thickness, the assumption was made that wells deeper than 60 feet had at least 50 feet of overlying loess or till and those less than 60 feet deep had less than 50 feet of overlying loess or till. If a well was less than 60 feet deep, it was Class Id. If a well was 60 feet deep or greater, it was Class III. If there was no depth information, the overlying loess or till thickness was assumed to be less than 50 feet, and these wells were Class Id (Quality = 7).

6. The USA polygons were generated by selecting all of the Class Ia, Ib, Ic, Id, and IIa wells. A buffer of with a radius of 2 miles (3,128.694 m) was then created around this subset of wells and to produce the USAs. This distance was determined by the Wellhead Protection Area Program of Kansas as the default preliminary wellhead protection area. These USAs were created using "region" topology to allow for overlapping, but unique polygons. There were no sole source aquifers in Kansas.

RESULTS BY AQUIFER SYSTEM

I. Alluvial Aquifers

The alluvial aquifers occur as bands of Holocene and Pleistocene alluvial sediment that fill the valleys created by rivers and streams, including the Kansas and Arkansas Rivers. There were 764 wells located within the boundaries (including spatial tolerance) of these aquifers and all were less than 200 feet deep. These wells were determined to obtain water from these aquifers. There were also 608 wells located within the boundaries (including spatial tolerance) of these aquifers that had no depth information (Quality = 7). It was assumed that these wells obtained water from the shallower, more vulnerable, alluvial aquifers, rather than any deeper, underlying aquifer. These wells may obtain water from deeper underlying aquifers, but need to be checked to identify the aquifer source and well depth. These 1,372 wells (Fig. 6) represent the largest percentage (53 percent) of public water supply wells in Kansas, and were Class Ia (Table 3), because these Quaternary aquifers are composed of permeable, unconsolidated sand and gravel deposits that connect directly with the surficial water table.

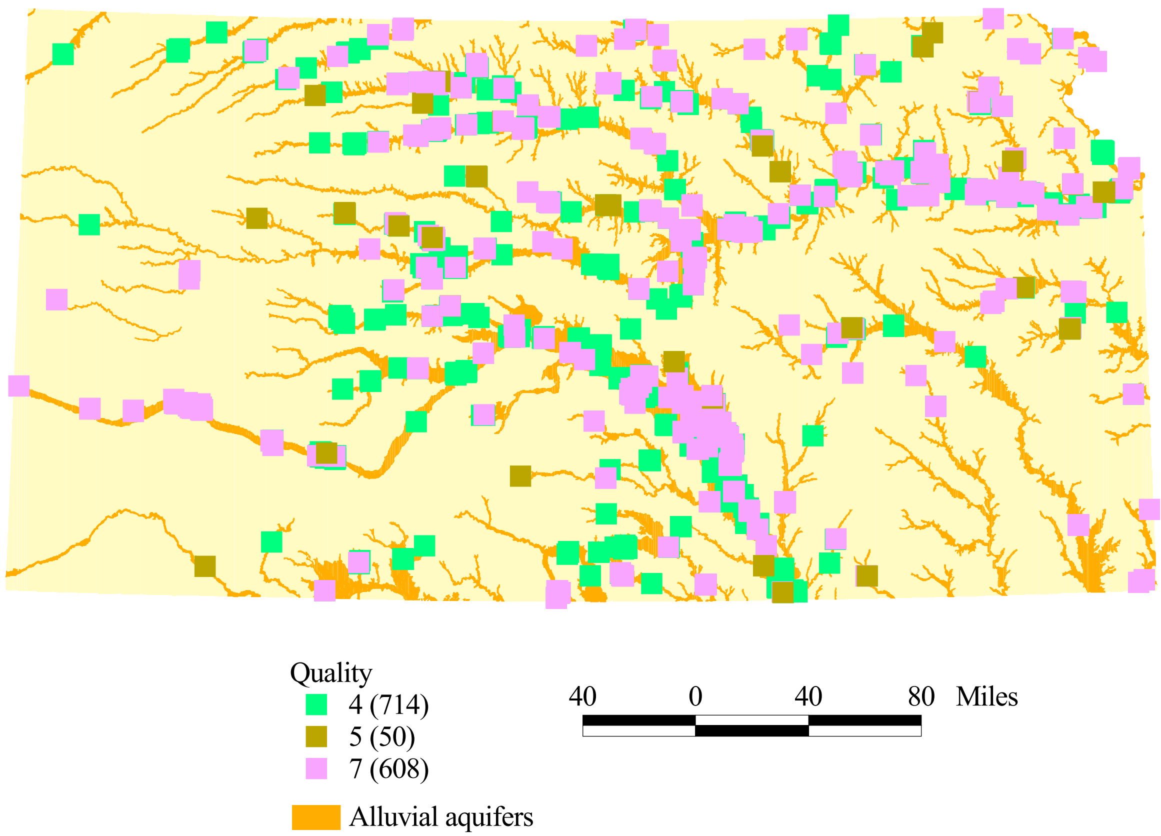

FIGURE 6. Groundwater wells, by data quality, that obtained water from alluvial aquifers. All 1,372 wells were Class Ia.

TABLE 3. Number of wells, Pettyjohn class, and quality rank for alluvial aquifers.

Number	**Class**	**Quality**
714	Ia	4
50	Ia	5
608	Ia	7

II. Glacial Drift Aquifers

The Glacial Drift aquifers in northeastern Kansas consist of Pleistocene alluvial valleys buried beneath glacial till. There were 126 wells (five percent) located within the boundaries (including spatial tolerance) of this aquifer (Fig. 7). The Pettyjohn classification of these wells was dependent on the thickness of the overlying glacial till. Because there was no digital data for till thickness, the assumption was made that wells deeper than 60 feet had at least 50 feet of overlying till and those less than 60 feet deep had less than 50 feet of overlying till. If a well was less than 60 feet deep, it was a Class Id (Table 4). If a well was 60 feet deep or greater, it was Class III. If there was no depth information, the overlying till thickness was assumed to be less than 50 feet, and these wells were Class Id (Quality = 7). Wells inside the boundaries of both the Glacial Drift aquifer and a modern alluvial aquifer, but deeper than 200 feet, were assumed to penetrate the modern alluvial valley and obtain water from the deeper, Pleistocene sediment. These wells were also Class Id, because it was assumed that there was less than 50 feet of impermeable material between the Pleistocene aquifer and the overlying alluvial sediments.

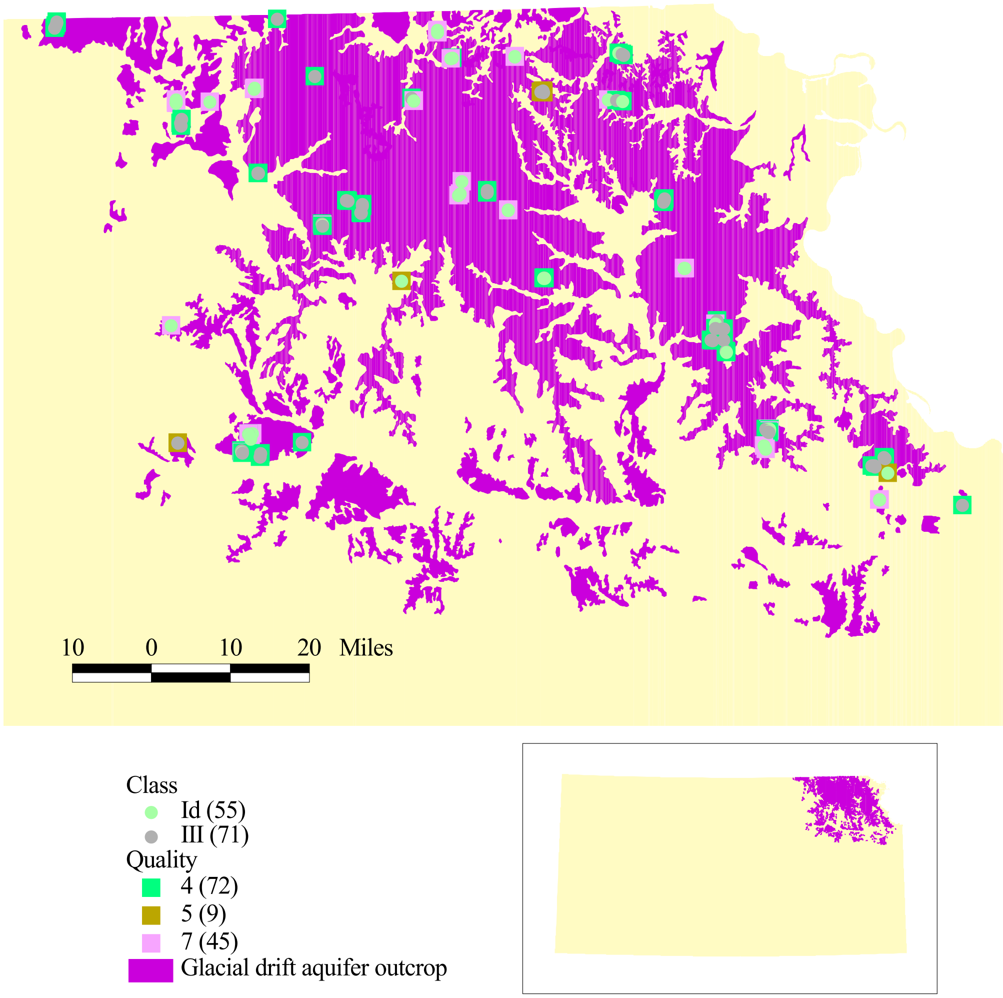

FIGURE 7. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from glacial drift aquifers.

TABLE 4. Number of wells, Pettyjohn class, and quality rank for glacial drift aquifers.

Number	Class	Quality
9	Id	4
2	Id	5
45	Id	7
63	III	4
7	III	5

III. High Plains or Ogallala Aquifer

The High Plains or Ogallala aquifer is composed of Tertiary semi-consolidated sandstone and gravel overlain with unconsolidated surficial deposits of Quaternary dune sands and locally confined by deposits of wind-blown loess. A total of 477 wells (19 percent) were determined to obtain water from this aquifer (Fig. 8). This determination was accomplished by comparing the depths of wells located within the boundaries (including spatial tolerance) of the aquifer, and the elevation ranges of both the High Plains/Ogallala aquifer and the underlying Great Plains/Dakota aquifer (see Fig. 4). For those wells that did not have depth information (126 wells and Quality = 7), it was assumed that these wells obtained water from the shallower, more vulnerable, High Plains or Ogallala aquifer, rather than the deeper Great Plains/Dakota aquifer. These wells may obtain water from the Dakota aquifer, but need to be checked to identify the aquifer source and well depth.

Once the aquifer was determined, the following processing steps were used to identify the Pettyjohn classification. First, wells that were located within the Quaternary dune sand sediment outcrops were Class Ia because these surficial sediments are highly permeable and in hydraulic continuity with the underlying aquifer. Second, wells that were located in the outcrop belts of the semi-consolidated High Plains or Ogallala aquifer were Class Ic because these sandstones are highly porous. The remainder of the aquifer is covered by wind blown loess deposits of variable thickness. Because there was no digital data for loess thickness, the assumption was made that wells deeper than 60 feet had at least 50 feet of overlying loess and those less than 60 feet deep had less than 50 feet of overlying loess. If a well was less than 60 feet deep, it was a Class Id. If a well was 60 feet deep or greater, it was Class III. If there was no depth information, the overlying loess thickness was assumed to be less than 50 feet, and these wells were Class Id (Quality = 7) (Table 5).

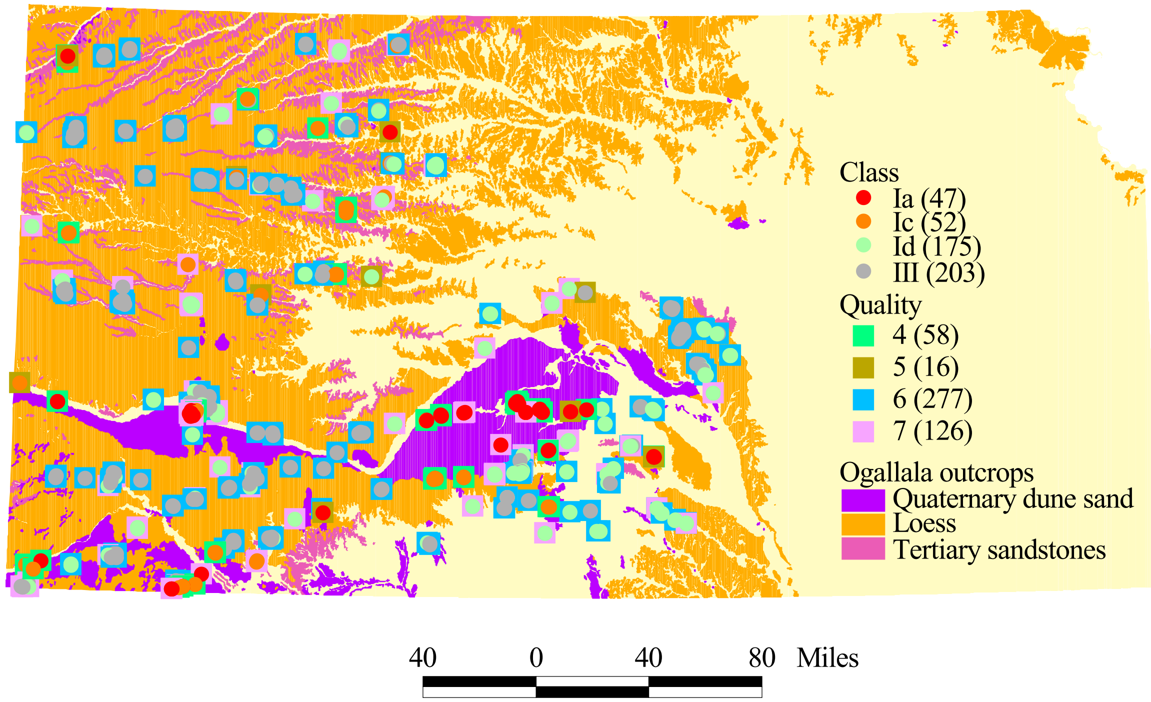

FIGURE 8. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the High Plains or Ogallala aquifer.

TABLE 5. Number of wells, Pettyjohn class, and quality rank for the High Plains or Ogallala aquifer.

Number	Class	Quality
21	Ia	4
6	Ia	5
20	Ia	7
37	Ic	4
8	Ic	5
7	Ic	7
1	Id	5
80	Id	6
99	Id	7
1	III	5
197	III	6

IV. Great Plains/Dakota Aquifer

The Great Plains/Dakota aquifer is composed of Cretaceous interbedded, high yield sandstone. A total of 281 wells (11 percent) were determined to obtain water from this aquifer. This determination was accomplished by comparing the depths of wells located within the boundaries (including spatial tolerance) of the aquifer, and the elevation ranges of both the Great Plains/Dakota aquifer and the overlying High Plains or Ogallala aquifer. For those wells that did not have depth information, it was assumed that these wells obtained water from the shallower, more vulnerable, High Plains or Ogallala aquifer, rather than the deeper Great Plains/Dakota aquifer. These wells may obtain water from the Dakota aquifer, but need to be checked to identify the aquifer source and well depth.

Wells located within the boundaries (including spatial tolerance) of the Great Plains/Dakota aquifer outcrop belt (Fig. 9) were Class IIa because these sandstones commonly yield more than 50 gpm. If a well was located outside the outcrop belt of this aquifer, it was a Class III, due to the existence of overlying impermeable units (Table 6).

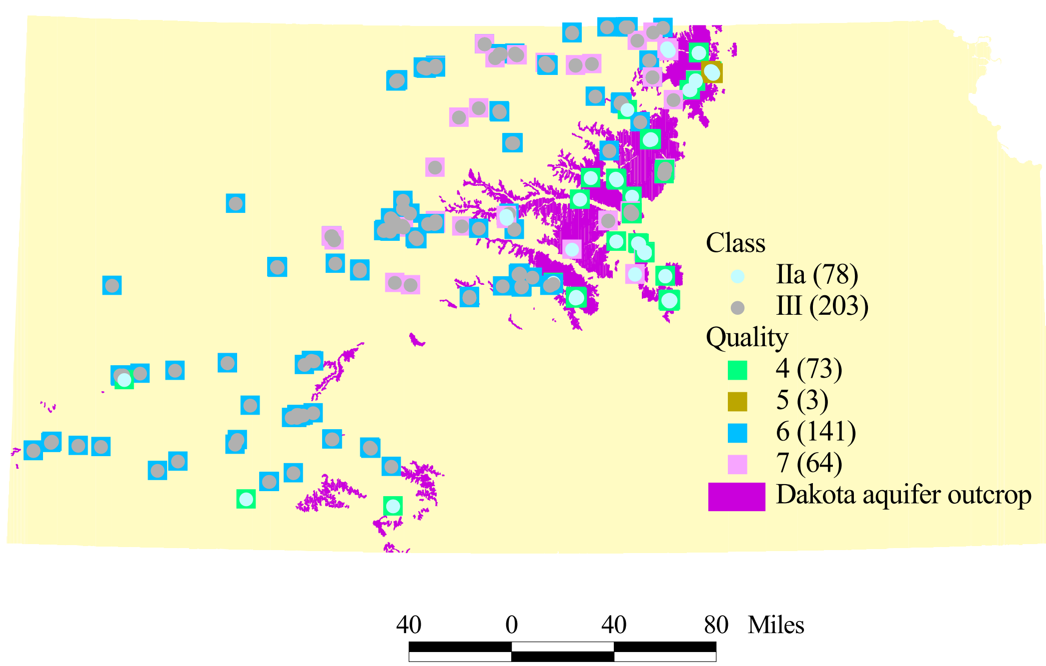

FIGURE 9. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Great Plains/Dakota aquifer.

TABLE 6. Number of wells, Pettyjohn class, and quality rank for the Great Plains/ Dakota aquifer.

Number	Class	Quality
60	IIa	4
3	IIa	5
15	IIa	7
13	III	4
141	III	6
49	III	7

V. Pennsylvanian and Permian Aquifers

These aquifers consist of consolidated bedrock, primarily sandstone. There were 249 wells (10 percent) located in Pennsylvanian and Permian formations and assumed to obtain water from these aquifers (Fig. 10). These wells were Class IIa if they produced more than 50 gpm. If the well produced less than 50 gpm, it was a Class IIb. If the flow rate was unknown, it was assumed to be greater than 50 gpm and thus Class IIa (Table 7).

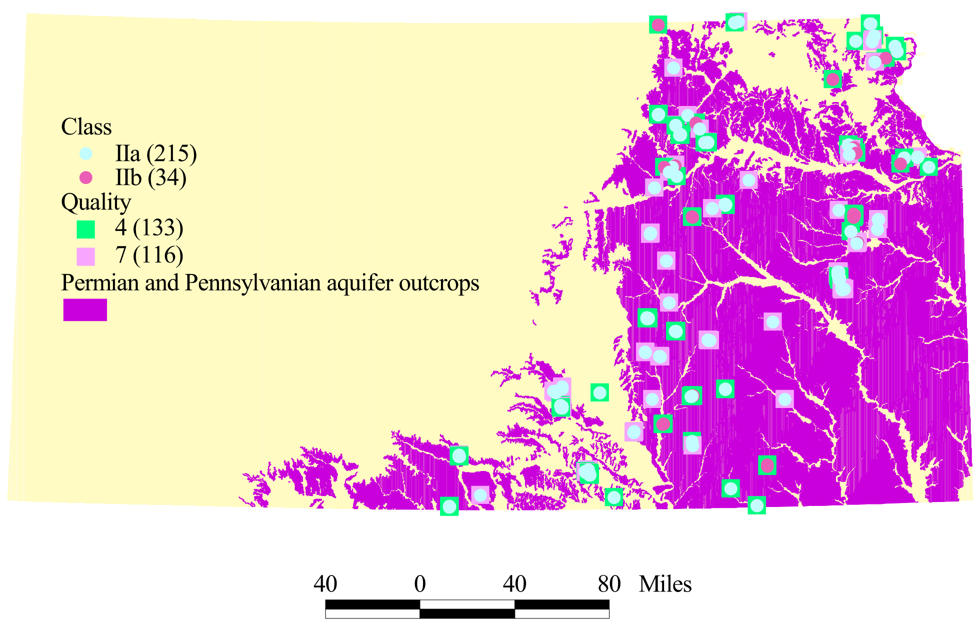

FIGURE 10. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Pennsylvanian and Permian aquifers.

TABLE 7. Number of wells, Pettyjohn class, and quality rank for Pennsylvanian and Permian aquifers.

Number	Class	Quality
102	IIa	4
113	IIa	7
31	IIb	4
3	IIb	7

VI. Ozark Plateau Aquifer

This aquifer consists primarily of Mississippian carbonate bedrock. There were 56 wells (two percent) located within the boundaries (including spatial tolerance) of this aquifer that were determined to obtain water from this aquifer (Fig. 11). These wells were Class Ib if they were located within the boundaries (including spatial tolerance) of the outcrop belt of the aquifer, due to the high porosity of this formation. Wells that were located in the outcrop belts of younger rocks were Class III, due to the existence of overlying impermeable layers (Table 8).

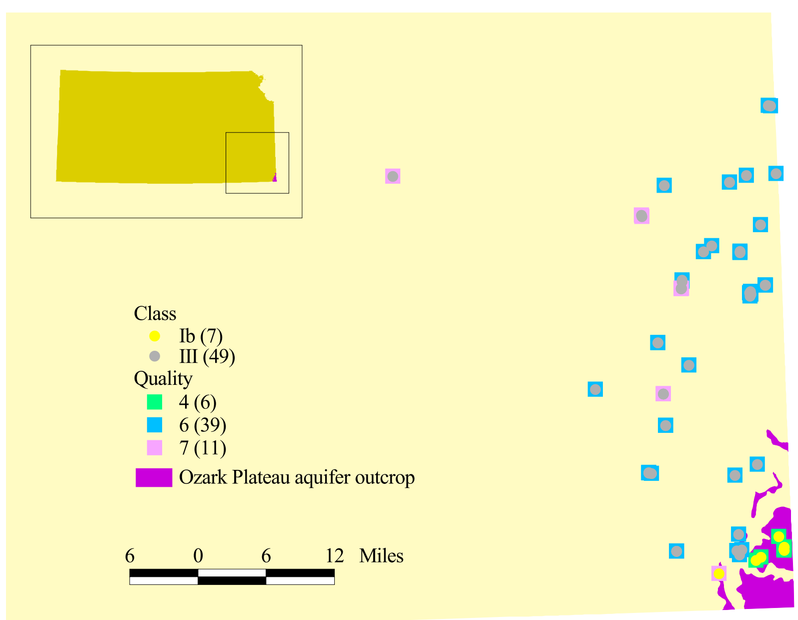

FIGURE 11. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Ozark Plateau aquifer.

TABLE 8. Number of wells, Pettyjohn class, and quality rank for the Ozark Plateau aquifer.

Number	Class	Quality
6	Ib	4
1	Ib	7
39	III	6
10	III	7

SUMMARY

The final USAs were derived by selecting all of the 2,001 Pettyjohn Class Ia, Ib, Ic, Id and IIa wells (Fig. 12) and buffering them by 3,128.694 m (two miles) to create WHPAs (Fig. 13). Though no digital WHPAs have been developed in Kansas, the Wellhead Protection Program for the state has identified two miles as the default radius for preliminary WHPAs. In the GIS database, the USAs have “region” topology, which means that wells that are closer than two miles to each other have overlapping polygons and are still identified by each well and all of the associated attributes of each well (Fig. 14). Of the 2,561 public water system groundwater wells in Kansas, 1,419 were classified as Ia, seven were classified as Ib, 52 were classified as Ic, 230 were classified as Id, and 293 were classified as IIa (Table 9). Therefore, 78 percent of the public groundwater wells in Kansas were identified as USAs. This high proportion is a result of the abundance of permeable aquifers at shallow depths, particularly alluvial aquifers, the absence of impermeable overburden, and the lack of specific information on which aquifers the wells were obtaining water from.

Data quality is always a concern when performing spatial analysis among various data layers. When identifying the location of wells within aquifers, the application of spatial tolerances identified 1,056 wells within the polygons (Quality = 4), 78 were identified within the spatial tolerance (Quality = 5), and 457 were identified as beyond the spatial

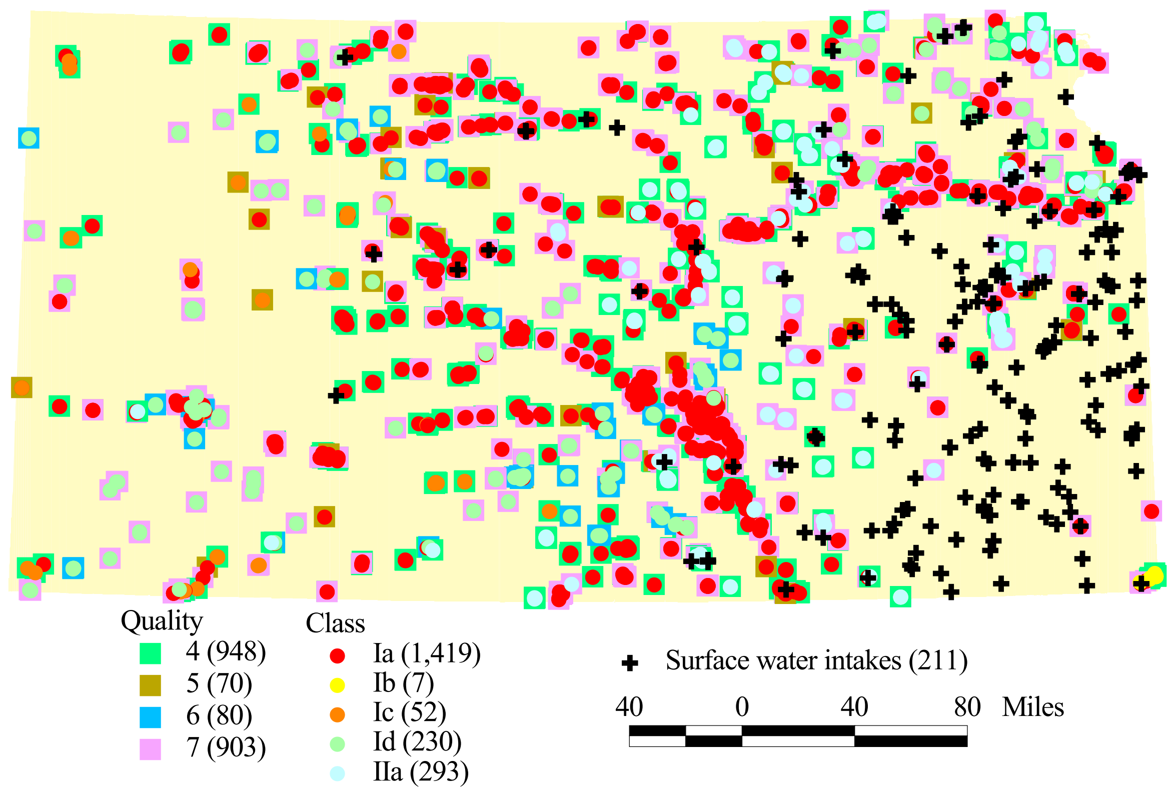

FIGURE 12. Kansas groundwater wells identified as USAs, by Pettyjohn classification and data quality.

tolerance (Quality = 6). The most important variable in assessing the Pettyjohn vulnerability classification, without information on the source of the water, was depth. There were 970 wells (38 percent) that did not have depth information identified (Quality = 7). Although these wells need to be checked, they were still classified using the aquifer data layers and nearby wells (Table 10).

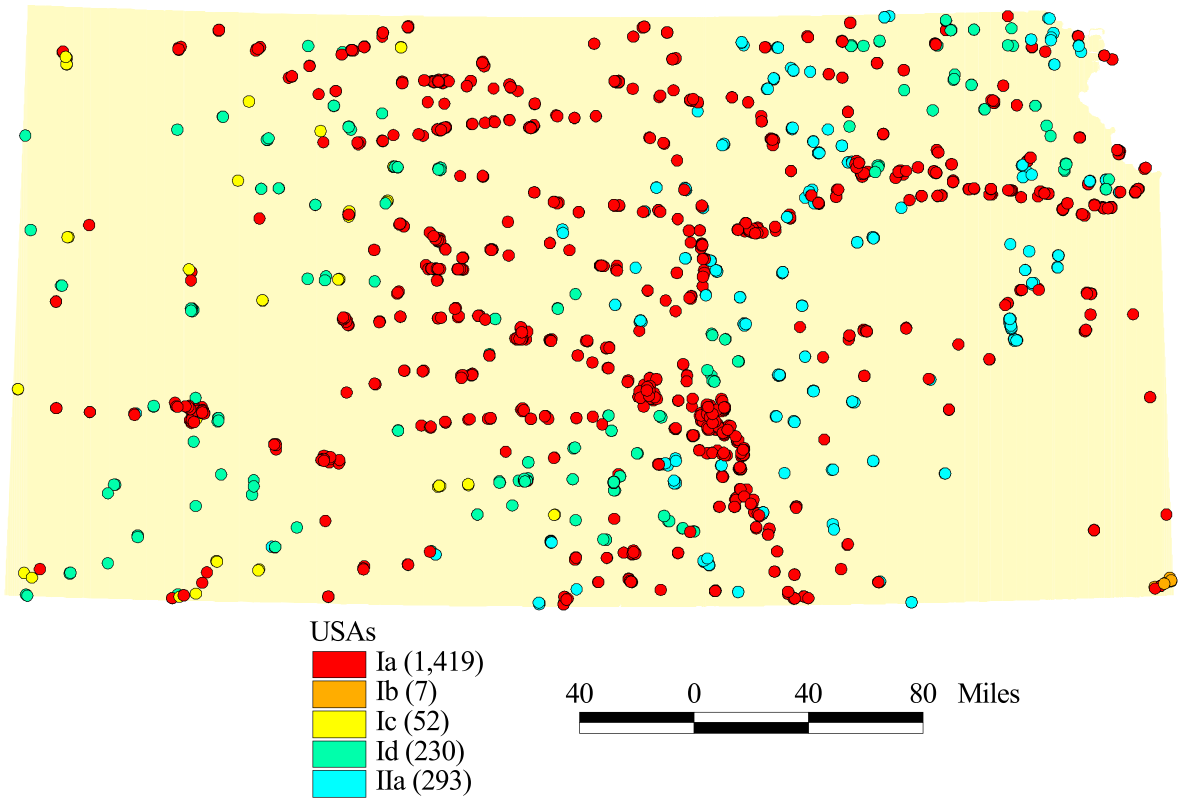

FIGURE 13. Final Kansas groundwater well drinking water USAs. Note that the USA polygons in Kansas, with a 2-mile radius, are much larger than the default USAs, with a 2,000-foot radius, used for other states.

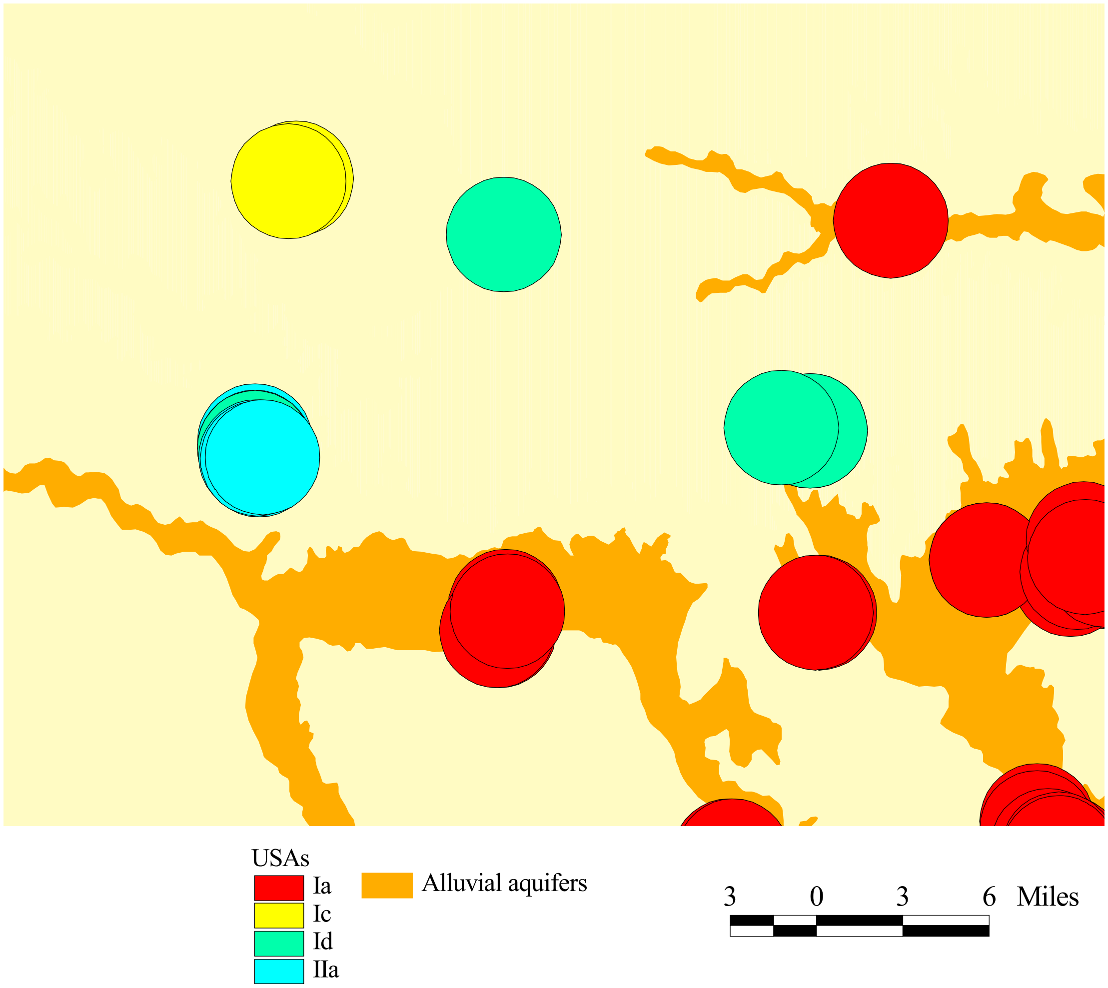

FIGURE 14. A closer view of the "region" GIS topology illustrating the overlapping groundwater USAs.

TABLE 9. Classification of the groundwater USAs in Kansas.

Class	Number of Groundwater Wells	Percentage
Ia	1,419	55.4
Ib	7	0.3
Ic	52	2.0
Id	230	9.0
IIa	293	11.5
IIb	34	1.3
III	526	20.5

TABLE 10. Data quality of the groundwater USAs in Kansas.

Quality Rank	Number of Groundwater USAs	Percentage
4	1,056	41.1
5	78	3.1
6	457	17.9
7	970	37.9

REFERENCES

Pettyjohn, W.A., M. Savoca, and D. Self, 1991. Regional assessment of aquifer vulnerability and sensitivity in the conterminous United States. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., Report No. EPA/600/2-91/043, 319 pp.

U.S. Geological Survey, 1997. Ground water atlas of the United States: Segment 3, Kansas, Missouri, Nebraska. Hydrologic Investigations Atlas 730-C, U.S. Geological Survey, Reston, Va., 24 pp.