Prepared for:
Research and Special Programs Administration
Office of Pipeline Safety
Department of Transportation
Washington, DC 20590

UNUSUALLY SENSITIVE AREAS FOR DRINKING WATER RESOURCES REPORT FOR COLORADO

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RPI/R/98-11

December 1998

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UNUSUALLY SENSITIVE AREAS FOR DRINKING WATER RESOURCES REPORT FOR COLORADO

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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, ground water 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 obtain their water from surface water sources are automatically designated as USAs because information on which to evaluate whether they have an adequate alternative water supply is not available. Designation of groundwater sources is 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 Colorado.

A key to implementing the process for identifying USAs for groundwater wells is distinguishing wells that obtain water from Class I or Class IIa aquifers (filter criteria 3 and 5), from those that do not (filter criteria 4). Wells that tap an aquifer below an overlying confining unit, such as a layer of impermeable shale, would be classified as Class III, and thus not be a USA, regardless of the aquifer type.

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. is 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 ground water 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.

IDENTIFYING USAs FOR DRINKING WATER RESOURCES IN COLORADO

The Geology and Pettyjohn Classification of Aquifers in Colorado

As shown in Table 1, there are eleven major aquifer systems in Colorado (summarized from the 1995 U.S. Geological Survey (USGS) publication "Ground Water Atlas of the United States, Segment 2").

TABLE 1. Colorado's aquifers and their classification according to the Pettyjohn et al. classification scheme.

Name	Description	Pettyjohn Classification
Quaternary	Sand and gravel deposits along modern-day stream valleys and deeper, more extensive, river basin aquifers such as the Rio Grande	Class Ia because it is surficial, unconsolidated, and connected directly with the surficial water table; Class III when sourced deeper than 200 feet
High Plains/ Ogallala	Semi-consolidated sandstone interlayered with shale	Class Ic because it consists of highly permeable, semi-consolidated sediments
Dawson	Coarse-grained sandstone interbedded with shale and siltstone	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Tertiary (Uinta-Animas, Browns Park, Green River, and Cuchara Formations)	Consolidated, interbedded sandstones	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm

TABLE 1. Continued.

Name	Description	Pettyjohn Classification
Denver	Moderately consolidated, interbedded shale, sandstone, and siltstone	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Arapahoe	Consolidated, interbedded shale, sandstone, and siltstone	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Laramie-Fox Hills	Fine-grained sandstone or siltstone interbedded with shale	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Cretaceous (Iles, Dakota, Mancos, Mesaverde, and Cliffhouse Formations)	Consolidated, interbedded sandstones	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Jurassic (Entrada and Morrison Formations)	Consolidated, interbedded sandstones	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Triassic and Older (Hermosa and other formations)	Consolidated, interbedded sandstones	Class IIa where it crops out on the surface and where the yield is >50 gpm; Class IIb where it crops out on the surface, but has yields <50 gpm
Pre-Pennsylvanian Igneous	Low yield, undifferentiated, igneous rock	Class IIb because these highly consolidated rocks commonly yield <50 gpm

Data Sources

The Colorado Department of Natural Resources (DNR), Division of Water Resources, maintains a database of groundwater wells for Colorado. This database contains aquifer source, use, depth, and flow rate information for each well. Because the database contains no records for Costilla County, in south-central Colorado, this county is considered outside the study area. As data from this county becomes available, it is expected that Costilla County will be included in the analysis. The USGS maintains an Arc/INFO coverage for surficial geology. Colorado has an approved wellhead protection program, but no digital Wellhead Protection Areas (WHPA) or guidelines for their generation exist at this time. There currently is no readily available data source for identifying TNCWS. Therefore, filtering criteria 1 cannot be implemented at this time. No Sole Source Aquifers (SSA) have been designated in Colorado. Also, in applying filtering criteria 2 and 3, we have assumed that all wells do not have an adequate alternative source of water. Based on our current understanding, determining if there is an adequate alternative source of water will require contacting the owner/operator of each system, which is not feasible at this time. Currently, there are no digital data available for the location of public drinking water surface intakes. It is expected that, as this data becomes available, surface water intakes will be incorporated into the USA analysis for Colorado.

Data Quality

Determining the Pettyjohn classification is the primary objective; however, 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 checking of the resulting USAs. A "quality" variable was added to the data, as defined in Table 2.

Of the more than 300,000 well records in the DNR database, 10,785 were identified as public water supply wells and were included for geospatial processing. Of these, there are 152 (one percent) with missing or ambiguous public water supply status. Wells obtaining water from a particular aquifer and located inside boundaries of the outcrop of that aquifer were given a Quality Rank of 1. Wells obtaining water from a particular aquifer, but located outside the boundary of that aquifer's outcrop, were tested against

TABLE 2. Quality ranks and descriptions.

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

the spatial accuracy of that well point and the associated geology data layer. If the well is located within the spatial accuracy of the associated data layers, it was given a Quality Rank of 2. If it is outside the spatial accuracy of the data layers, it was given a Quality Rank of 3. If the well has no source aquifer, but the well depth was given, it was given a Quality Rank of 4. If the well has no source aquifer or depth information, it was given a Quality Rank of 5.

The spatial accuracy for groundwater wells is +/- 12.2 meters (m) (or 296.7 m); the surficial geology is +/- 250 m.

There are two ways the spatial accuracy of the wells are determined. According to the metadata, locations are determined using either a 40-acre grid or precise measurements (in feet). Thus, there are two possible geocoding methods with differing accuracy. If the well location is measured in feet, it is assumed to have a spatial accuracy equal to that of the basemap, which is the USGS 1:24,000 quadrangle, and therefore the accuracy is 12.2 m. If the well has no feet measurements, the accuracy is 12.2 m plus 284.5 m (the maximum possible error in a square 40-acre grid), resulting in an accuracy of 296.7 m.

Processing Steps

The sequential GIS processing began with the analysis of the well database to extract the public water supply wells. Multiple database attributes were examined to determine if each well is a public water supply well and if it is still in use. In some cases, this information was missing or ambiguous. For wells where that status is unclear, they were included for processing as potential public water supply wells.

Next, the groundwater wells were intersected with the surficial geology polygons (Fig. 1). The surficial geology contains the geologic units that are exposed at the surface. A simple, yet critical, comparison was made between the aquifer from which the well obtains water and the surficial geology where that well is located. For example, a well located in the Denver Basin may obtain water from the Cretaceous Laramie-Fox Hills aquifer, but the well may be located in the outcrop of the Tertiary Arapahoe geologic formation, which overlies the Laramie-Fox Hills aquifer. Because the Laramie Confining Unit lies between the surface and the sourced aquifer, this well is classified as a Pettyjohn Class III well. This scenario is illustrated in Figure 2. Here, Well 1 is located in the outcrop of the Arapahoe Formation, but sourced in the Laramie-Fox Hills aquifer. This well would be classified as a Pettyjohn Class III well. Well 2 is located in the Laramie-Fox Hills Formation and also obtains water from this aquifer, and thus would be classified as a Pettyjohn Class IIa USA, because the interbedded sandstone of this formation is considered a higher yield bedrock aquifer. The classification of Pettyjohn vulnerability for the bedrock aquifers relies on the spatial analysis of where a well is located and which aquifer it obtains water from because this determines the presence or absence of overlying confining units which are barriers to pollution transmission.

Every public water system well in Colorado was classified according to the Pettyjohn scheme. The results are presented by aquifer in order, from the youngest to the oldest (Fig. 3), as listed in Table 1. The well data contain attributes for water source(s) and

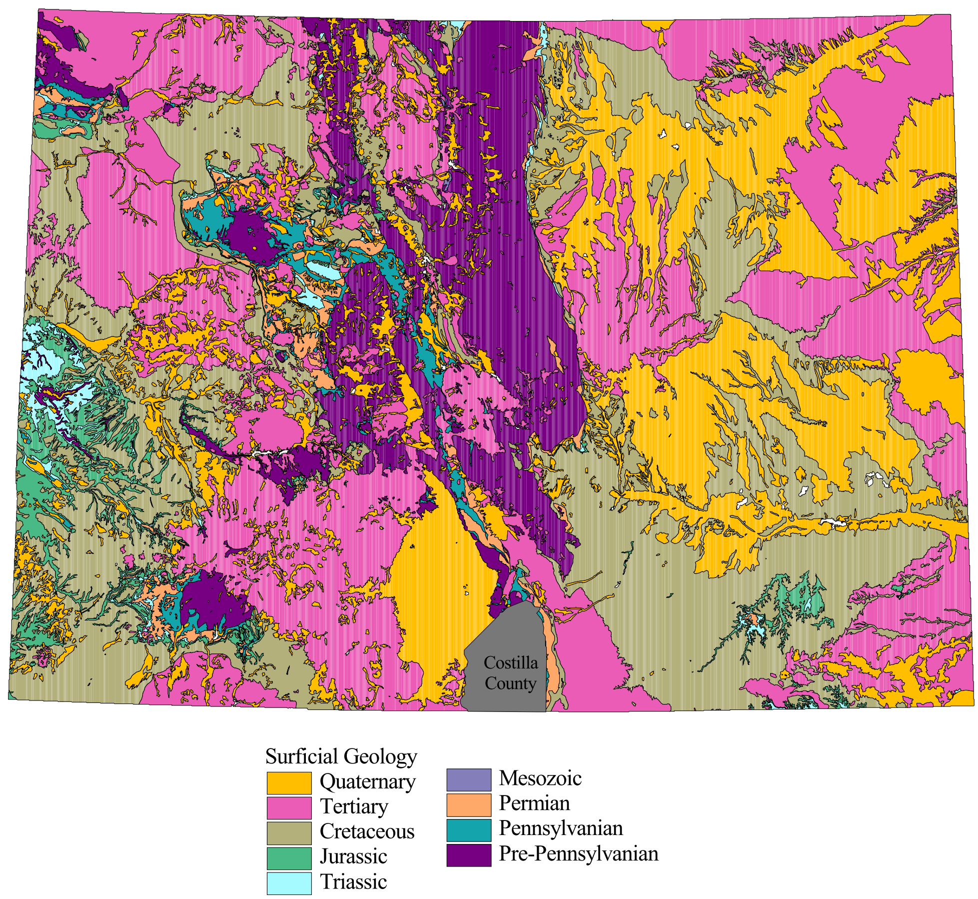

FIGURE 1. Surficial geology of Colorado. Note Costilla County, in black fill pattern, in the south.

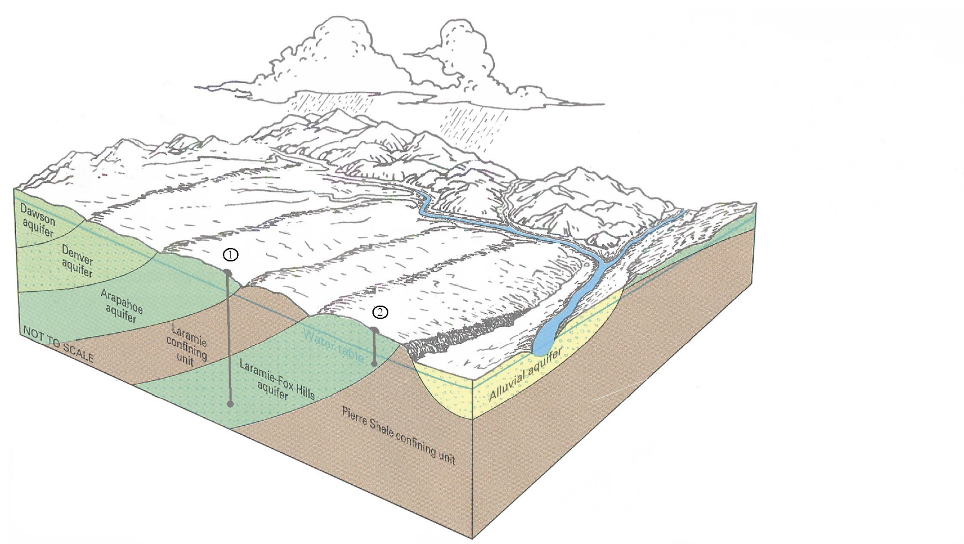

FIGURE 2. Two hypothetical wells in the Denver Basin (modified from USGS publication "Groundwater Atlas of the United States, Segment 2", 1995).

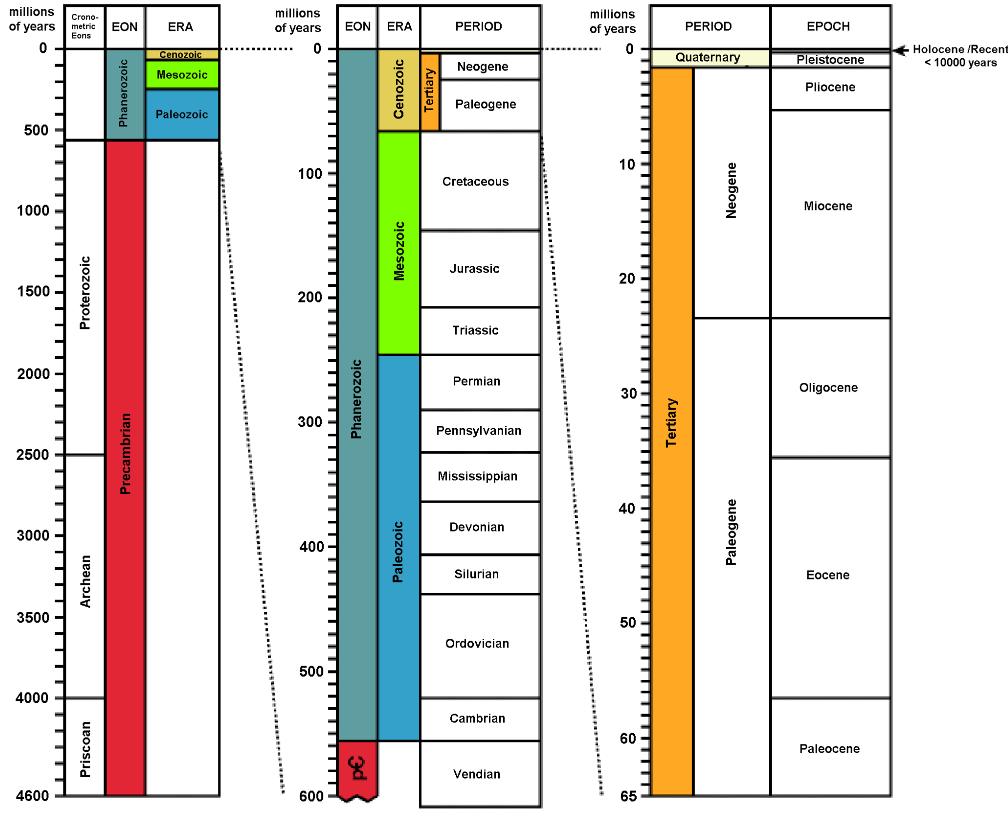

FIGURE 3. Geologic time scale.

well depth. A well can have multiple sources, but the shallowest source was used in the processing steps because it is the one most likely to be impacted by pollutants moving downward from the surface. Surficial geology was also instrumental in classifying Pettyjohn sensitivity.

The following sections outline the processing steps for each aquifer.

RESULTS BY AQUIFER SYSTEM

I. Quaternary Aquifers

There were 3,138 wells (29 percent) that obtained water from alluvial and other Quaternary aquifers in Colorado (Fig. 4). These aquifers included the surficial eolian/alluvial deposits in Eastern Colorado, the Rio Grande aquifer belt in the San Luis Valley in South Central Colorado, the flood plains of the Arkansas and South Platte Rivers in the Great Plains province, and alluvial valleys of smaller rivers around the state. This group of wells represents the largest percentage of public water supply wells in Colorado and are Class Ia, because these Quaternary aquifers were composed of permeable, unconsolidated sand and gravel deposits that connect directly with the surficial water table. If the shallowest sourced interval of a well in the San Luis Valley, which obtains water from the Rio Grande aquifer belt, is greater than 200 feet, then the well was Class III, because the well intake is overlain by confining units (Table 3).

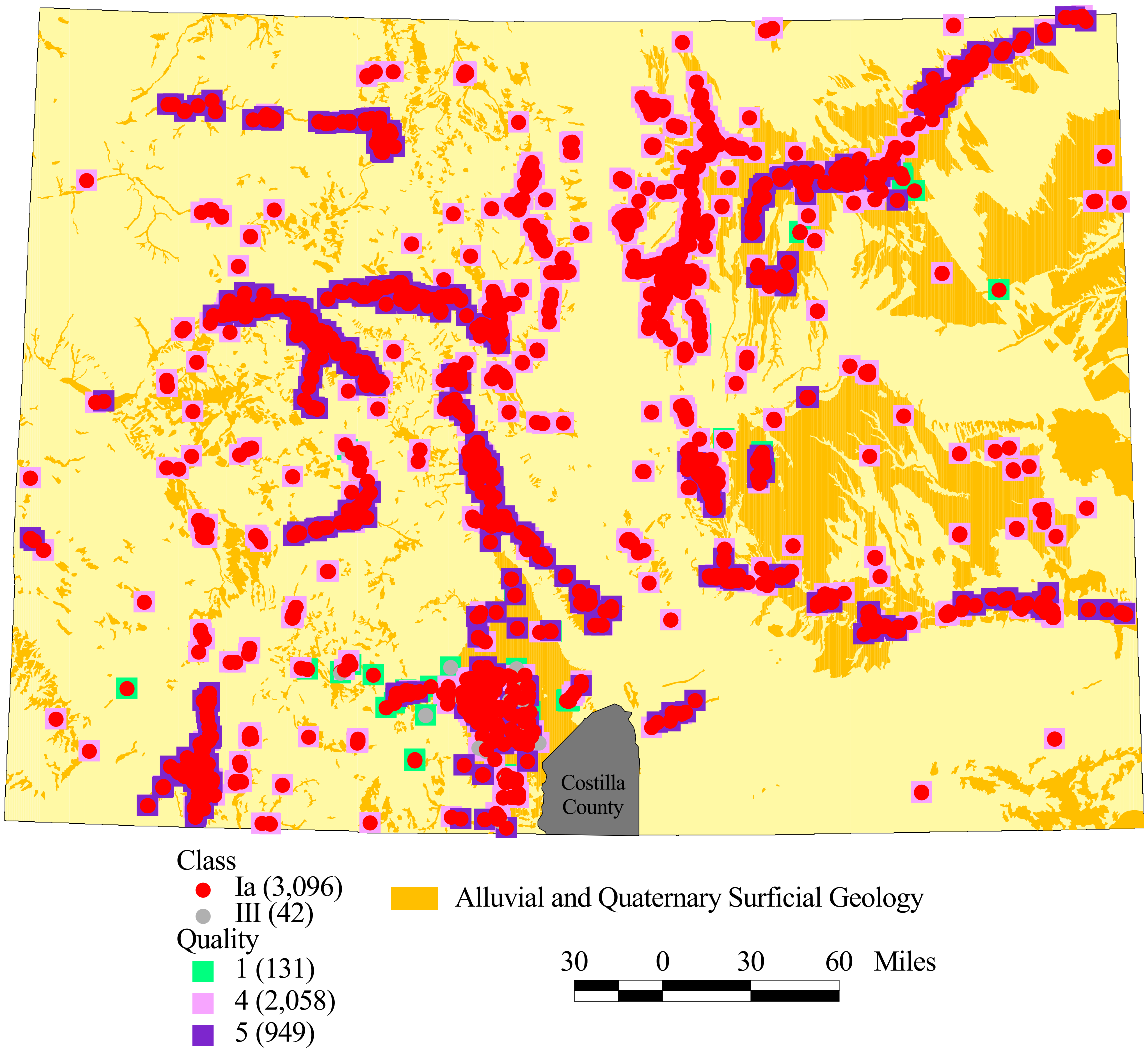

FIGURE 4. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Quaternary aquifers.

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

Number	Class	Quality
99	Ia	1
2,048	Ia	4
949	Ia	5
32	III	1
10	III	4

II. High Plains/Ogallala Aquifer

There were 959 wells (nine percent) that obtained water from the High Plains or Ogallala aquifer in Eastern Colorado (Fig. 5). These wells that source this aquifer were Class Ic, because this aquifer is composed of semi-consolidated sand and gravel interbedded with clay and silt layers (Table 4).

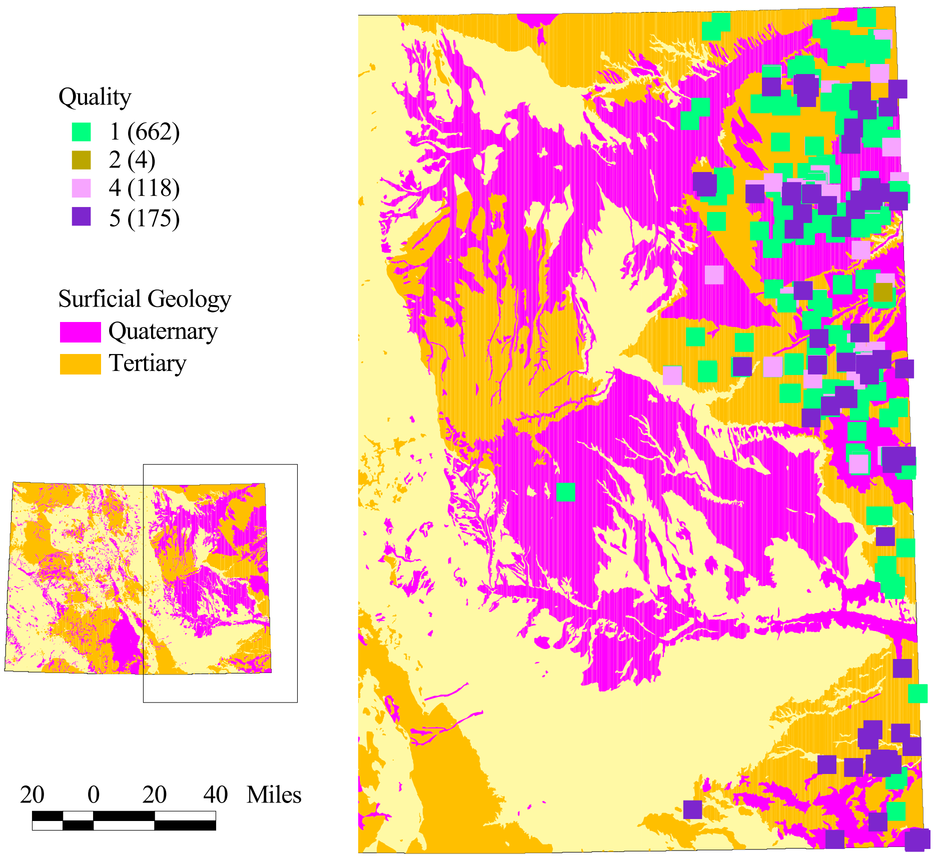

FIGURE 5. Groundwater wells, classified by data quality, that obtained water from High Plains/Ogallala aquifer. All 959 wells are Class Ic.

TABLE 4. Number of wells, Pettyjohn class, and quality rank for the High Plains/ Ogallala aquifer.

Number	Class	Quality
662	Ic	1
4	Ic	2
118	Ic	4
175	Ic	5

III. Dawson Aquifer

There were 683 wells (six percent) that obtained water from the Dawson aquifer located in the Denver Basin in central Colorado (Fig. 6). These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because the Dawson aquifer consists of interbedded, high yield sandstone. 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. If a well was located in the outcrop belt of younger rocks, it was a Class III, due to the existence of overlying impermeable units (Table 5).

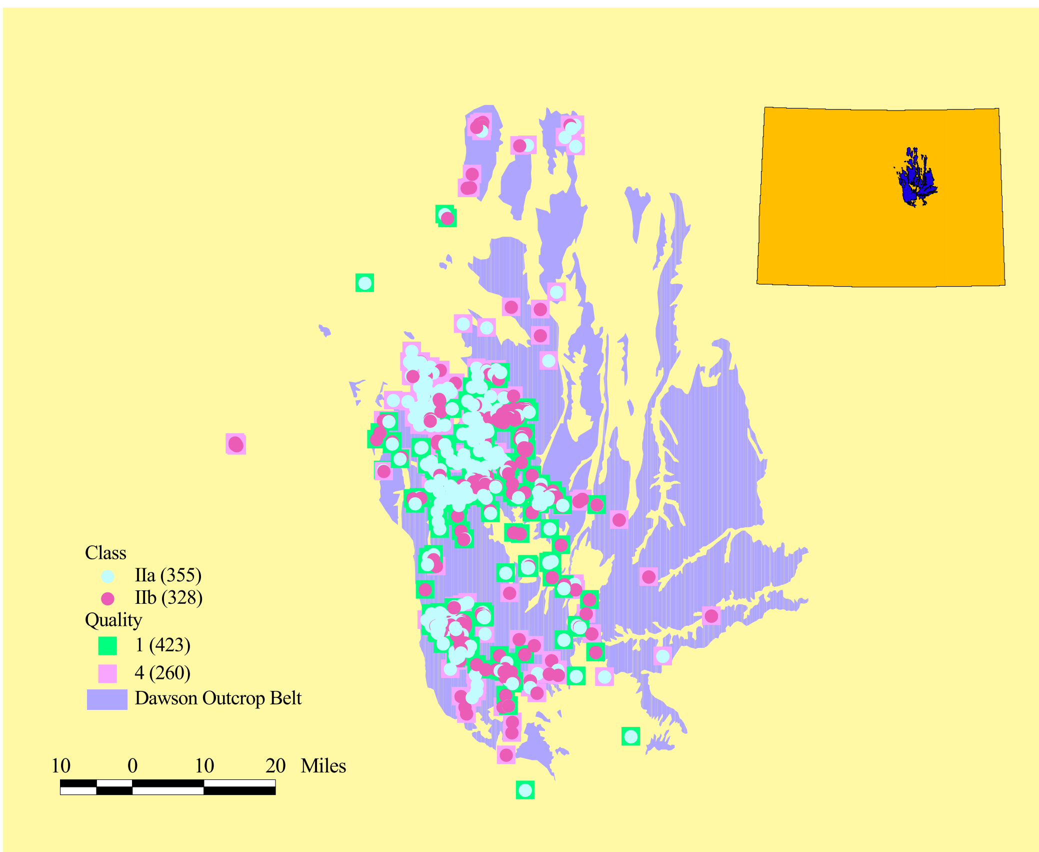

FIGURE 6. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Dawson aquifer.

TABLE 5. Number of wells, Pettyjohn class, and quality rank for the Dawson aquifer.

Number	Class	Quality
214	IIa	1
141	IIa	4
209	IIb	1
119	IIb	4

IV. Tertiary Aquifers

There were 237 wells (two percent) that obtained water from Tertiary aquifers not located in the Denver Basin but throughout Colorado (Fig. 7). Aquifers included the Uinta-Animas, Browns Park, Green River, and Cuchara Formations. These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because these aquifers consisted of interbedded, high yield sandstone. 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. If a well was located in the outcrop belt of younger rocks, it was a Class III, due to the existence of overlying impermeable units (Table 6).

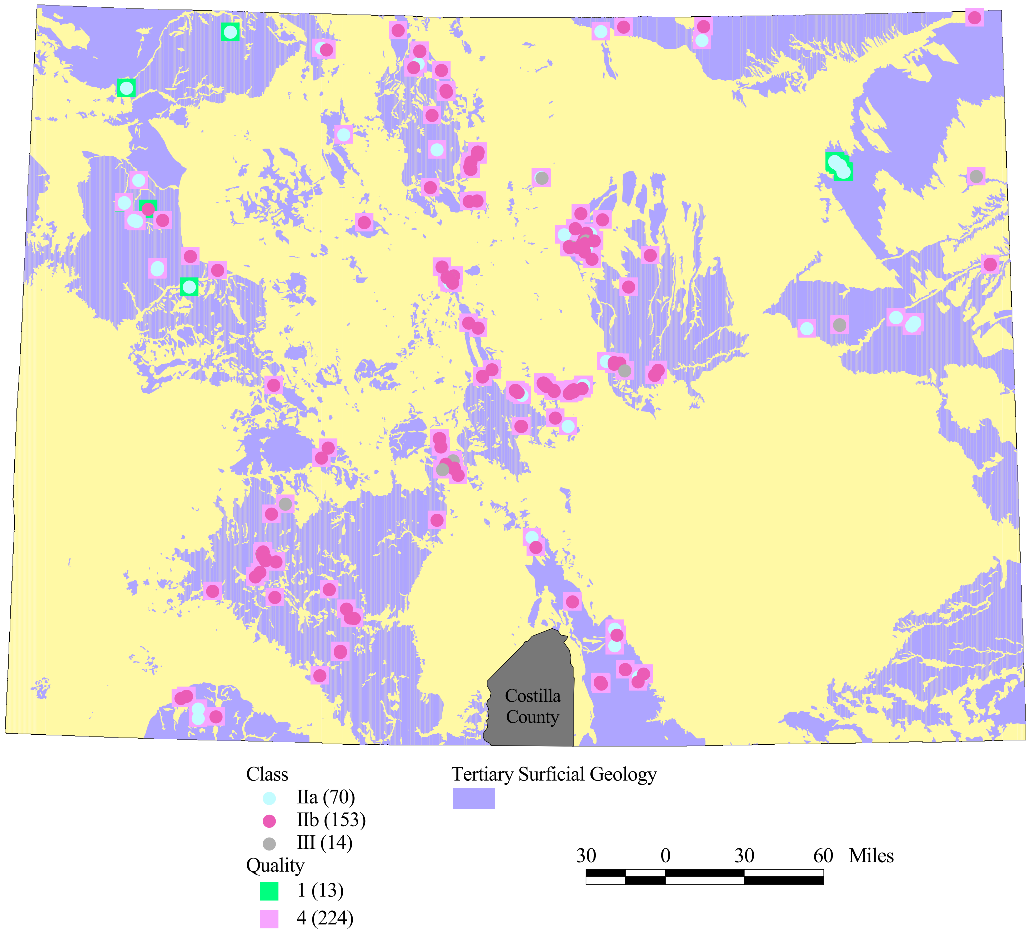

FIGURE 7. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Tertiary aquifers.

TABLE 6. Number of wells, Pettyjohn class, and quality rank for Tertiary aquifers.

Number	Class	Quality
12	IIa	1
58	IIa	4
1	IIb	1
152	IIb	4
14	III	4

V. Denver Aquifer

There were 612 wells (six percent) that obtained water from the Tertiary/Cretaceous Denver aquifer, which is located in the Denver Basin in central Colorado (Fig. 8). These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because the Denver aquifer consists of interbedded, high yield sandstone. 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. If a well was located in the outcrop belts of younger rocks, it was a Class III, due to the existence of overlying impermeable units (Table 7).

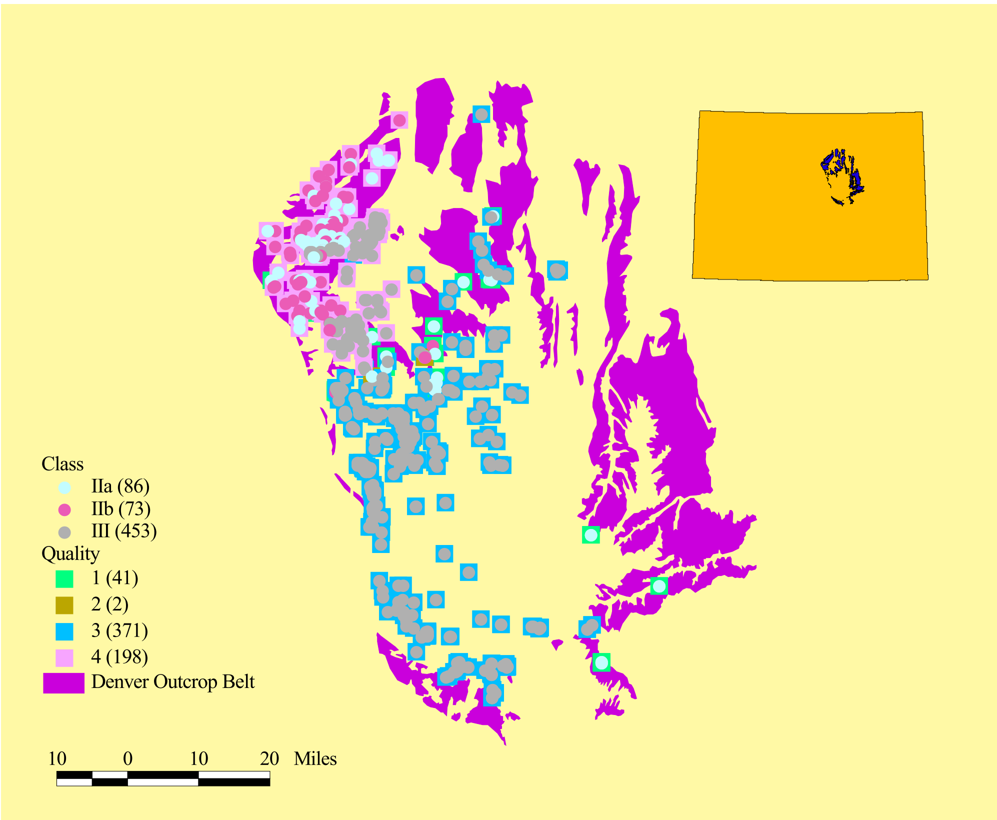

FIGURE 8. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Denver aquifer.

TABLE 7. Number of wells, Pettyjohn class, and quality rank for the Denver aquifer.

Number	Class	Quality
25	IIa	1
1	IIa	2
60	IIa	4
16	IIb	1
1	IIb	2
56	IIb	4
371	III	3
82	III	4

VI. Arapahoe Aquifer

There were 572 wells (five percent) that obtained water from the Cretaceous Arapahoe aquifer, which is located in the Denver Basin in central Colorado (Fig. 9). These wells were Class IIa if they were located in an outcrop belt of the Arapahoe Formation, due to the permeability and high yield of this consolidated bedrock 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).

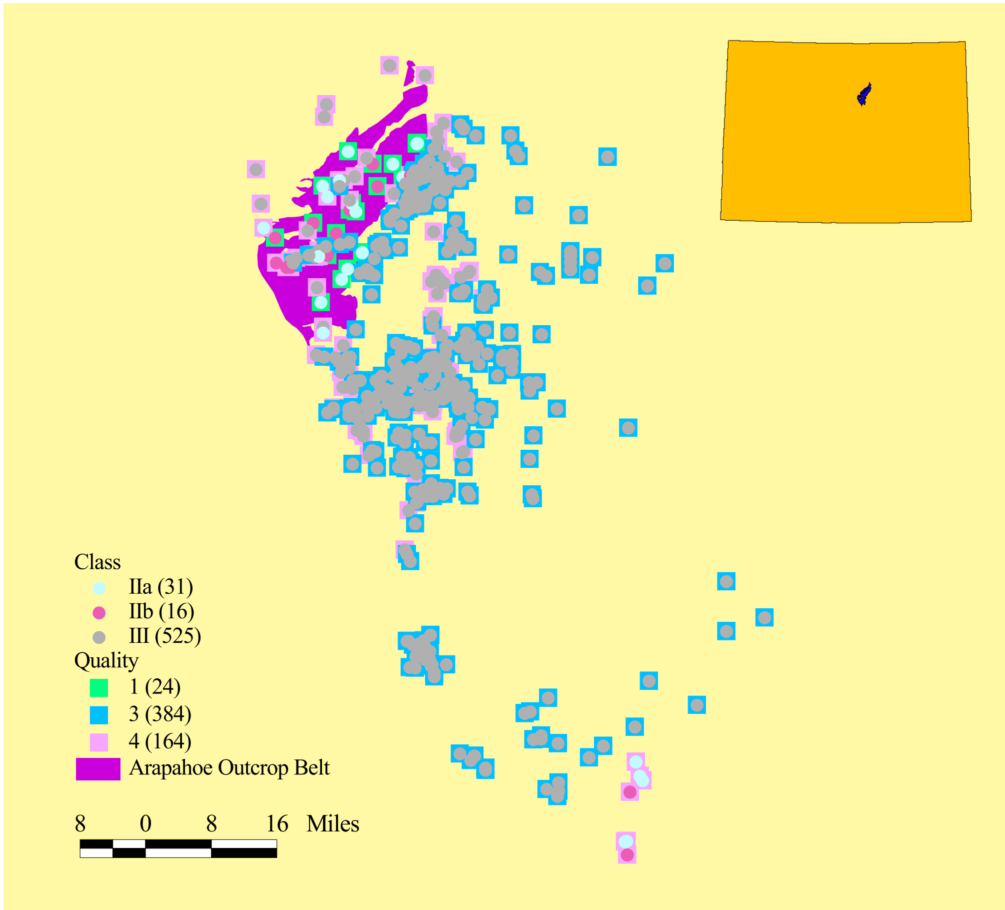

FIGURE 9. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Arapahoe aquifer.

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

Number	Class	Quality
16	IIa	1
15	IIa	4
8	IIb	1
8	IIb	4
384	III	3
141	III	4

VII. Laramie-Fox Hills Aquifer

The 696 wells (six percent) that obtained water from this Cretaceous aquifer were located in the Denver Basin of central Colorado (Fig. 10). These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because these aquifers consist of interbedded, high yield sandstone. 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. If a well was located in the outcrop belt of younger rocks, it was a Class III, due to the existence of overlying impermeable units (Table 9).

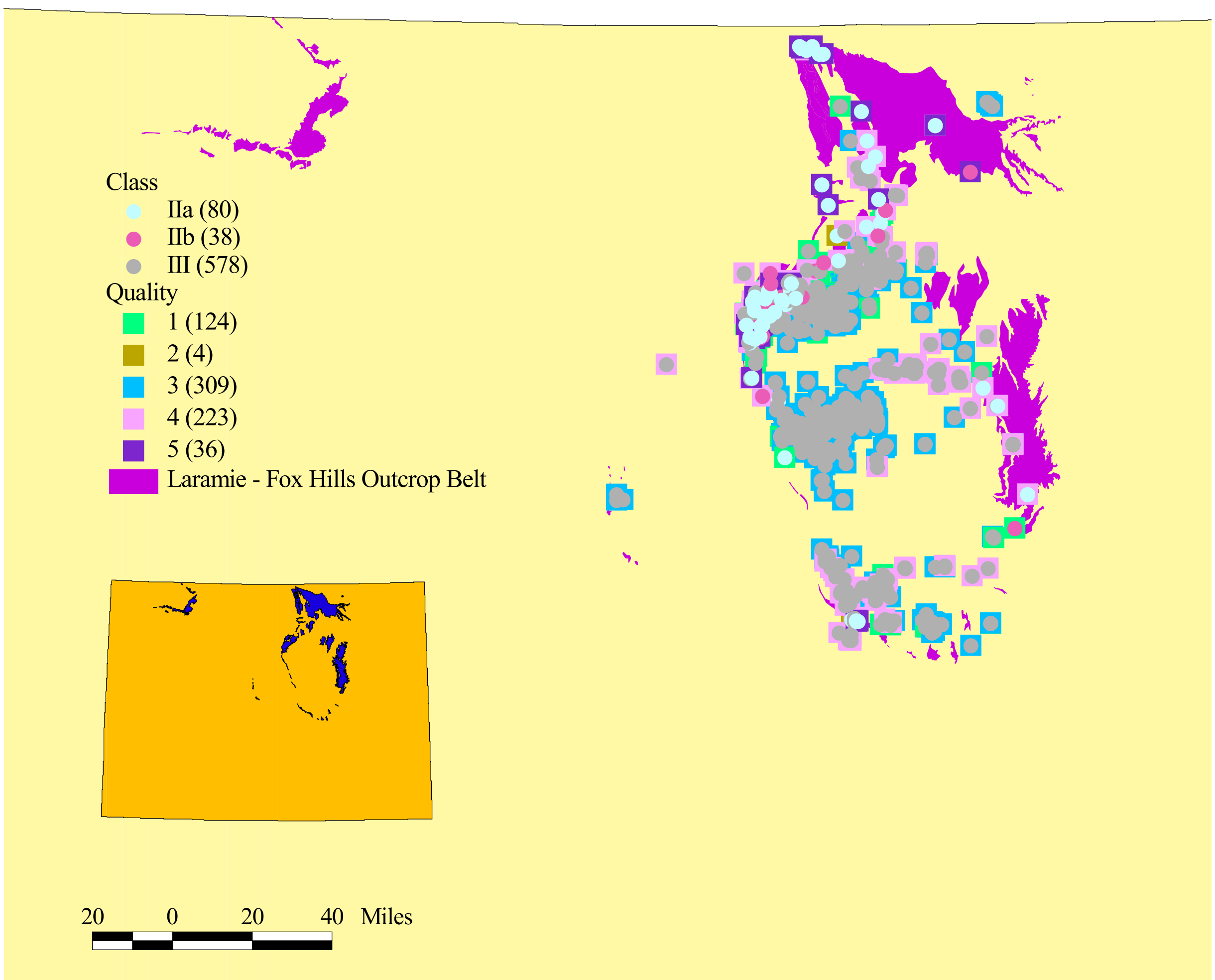

FIGURE 10. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Laramie-Fox Hills aquifer.

TABLE 9. Number of wells, Pettyjohn class, and quality rank for the Laramie-Fox Hills aquifer.

Number	Class	Quality
20	IIa	1
2	IIa	2
24	IIa	4
34	IIa	5
28	IIb	1
2	IIb	2
6	IIb	4
2	IIb	5
76	III	1
309	III	3
193	III	4

VIII. Cretaceous Aquifers

There were 799 wells (seven percent) that obtained water from Cretaceous aquifers not located in the Denver Basin, which include the Dakota, Iles, Mancos Shale, Mesaverde, and Cliffhouse Formations (Fig. 11). These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because these aquifers consist of interbedded, high yield sandstone. If the well produced less than 50 gpm, it was Class IIb. If the flow rate was unknown, it was assumed to be greater than 50 gpm. If a well was located in the outcrop belt of younger rocks, it was a Class III, due to the existence of overlying impermeable units.

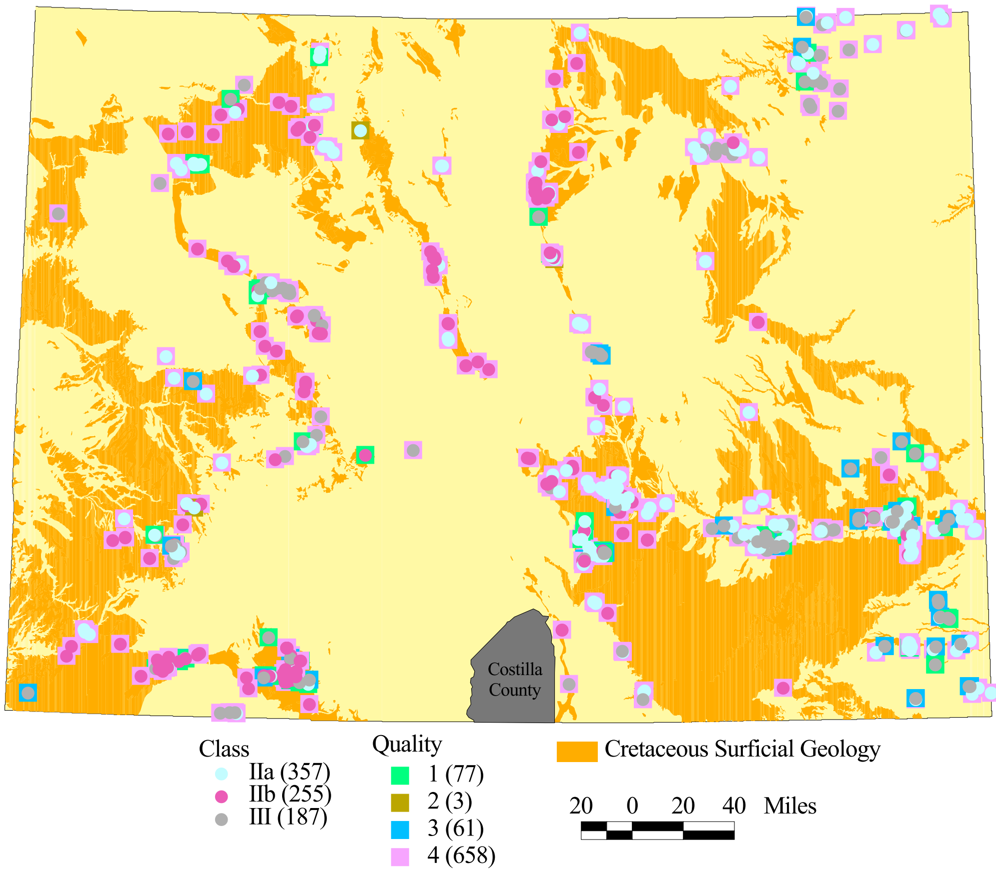

FIGURE 11. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Cretaceous aquifers.

TABLE 10. Number of wells, Pettyjohn class, and quality rank for Cretaceous aquifers.

Number	Class	Quality
33	IIa	1
3	IIa	2
321	IIa	4
20	IIb	1
235	IIb	4
24	III	1
61	III	3
102	III	4

IX. Jurassic Aquifers

There were 56 wells (0.5 percent) that obtained water from Jurassic aquifers, which include the Entrada and Morrison Formations. These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because these aquifers consist of interbedded, high yield sandstone. If the well produced less than 50 gpm, it was Class IIb. If the flow rate was unknown, it was assumed to be greater than 50 gpm. If a well was located in the outcrop belt of younger rocks, it was a Class III, due to the existence of overlying impermeable units (Table 11).

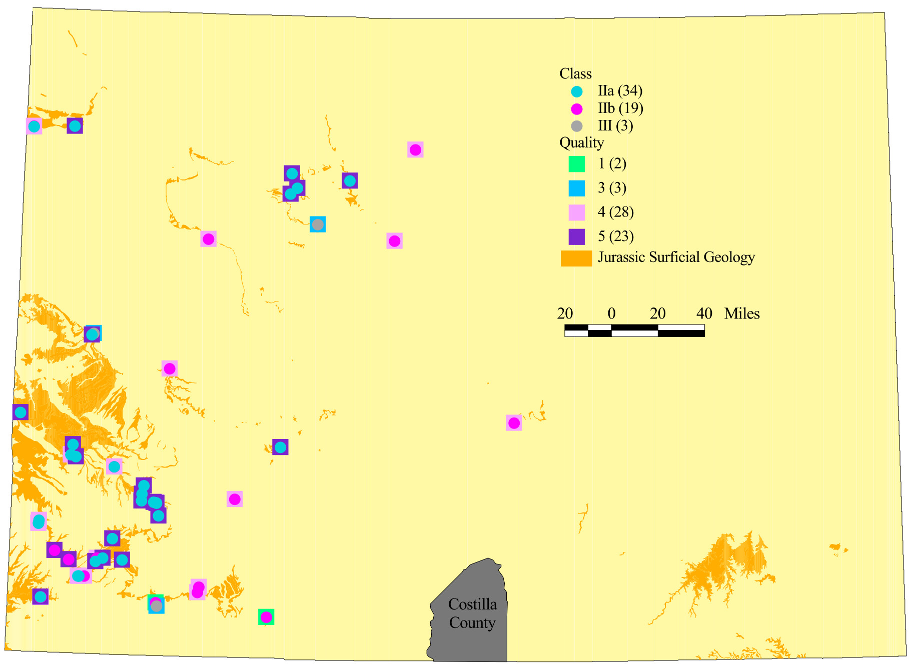

FIGURE 12. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Jurassic aquifers.

TABLE 11. Number of wells, Pettyjohn class, and quality rank for Jurassic aquifers.

Number	Class	Quality
13	IIa	4
21	IIa	5
2	IIb	1
15	IIb	4
2	IIb	5
3	III	3

X. Triassic and Older Aquifers

There were 117 wells (one percent) that obtained water from Triassic and older aquifers, which include the Hermosa and other formations (Fig. 13). These wells were Class IIa if they produced more than 50 gpm and were located in the aquifer outcrop belt, because these aquifers consist of interbedded, high yield sandstone. If the well produced less than 50 gpm, it was Class IIb. If the flow rate was unknown, it was assumed to be greater than 50 gpm. If a well was located in the outcrop belt of younger rocks, it was a Class III, due to the existence of overlying impermeable units (Table 12).

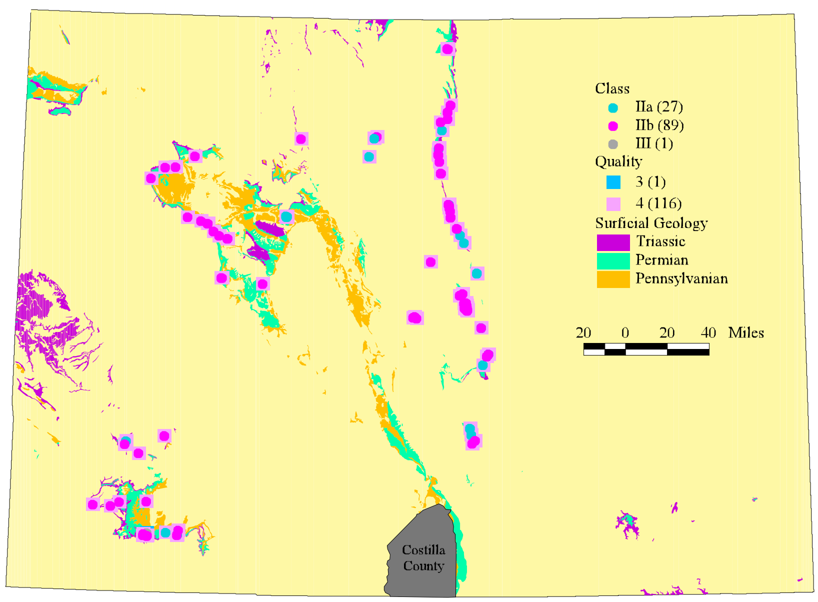

FIGURE 13. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Triassic and older aquifers.

TABLE 12. Number of wells, Pettyjohn class, and quality rank for Triassic and older aquifers.

Number	Class	Quality
27	IIa	4
89	IIb	4
1	III	3

XI. Pre-Pennsylvanian Igneous Aquifers

There were 934 wells (nine percent) that obtained water from the Pre-Pennsylvanian aquifers of the Front Range in central Colorado (Fig. 14). These wells were Class IIb, because these aquifers consisted of low-yield, undifferentiated igneous rocks (Table 13).

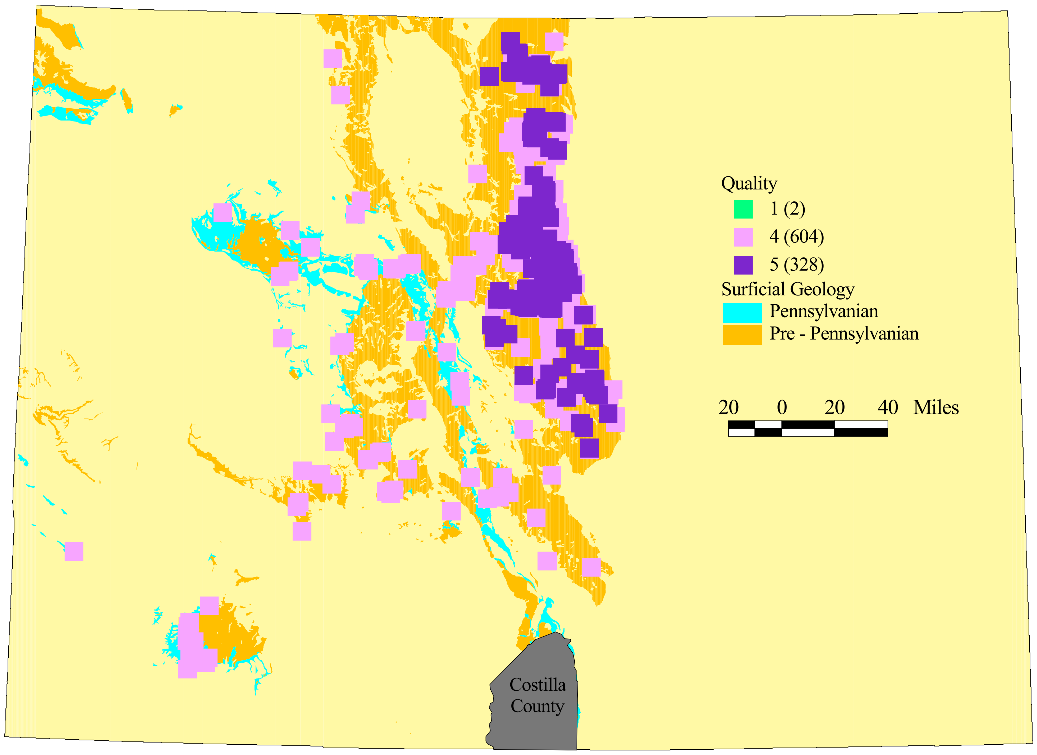

FIGURE 14. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Pre-Pennsylvanian igneous aquifers. All 934 wells were Class IIb.

TABLE 13. Number of wells, Pettyjohn class, and quality rank for Pre-Pennsylvanian igneous aquifers.

Number	Class	Quality
2	IIb	1
604	IIb	4
328	IIb	5

SUMMARY

The final USAs were derived by selecting all of the 5,095 Pettyjohn Class Ia, Ic, and IIa wells (Fig. 15) and buffering them by 609.6 m (which equals 2,000 feet) to create the default WHPAs (Colorado does not have an implemented Wellhead Protection Program) (Fig. 16). In the GIS database, the USAs have "region" topology, which means that wells that are closer than 2,000 feet to each other have overlapping polygons and are still identified by each well and all of the associated attributes of each well (Fig. 17). Of the 10,785 public water system groundwater wells in Colorado, 3,096 were classified as Ia USAs, 959 were classified as Ic USAs, and 1,040 were classified as IIa USAs. Therefore, 47.2 percent of the public groundwater wells in Colorado were identified as USAs (Table 14). This high proportion is a result of the abundance of permeable aquifers at shallow depths and the absence of confining overburden.

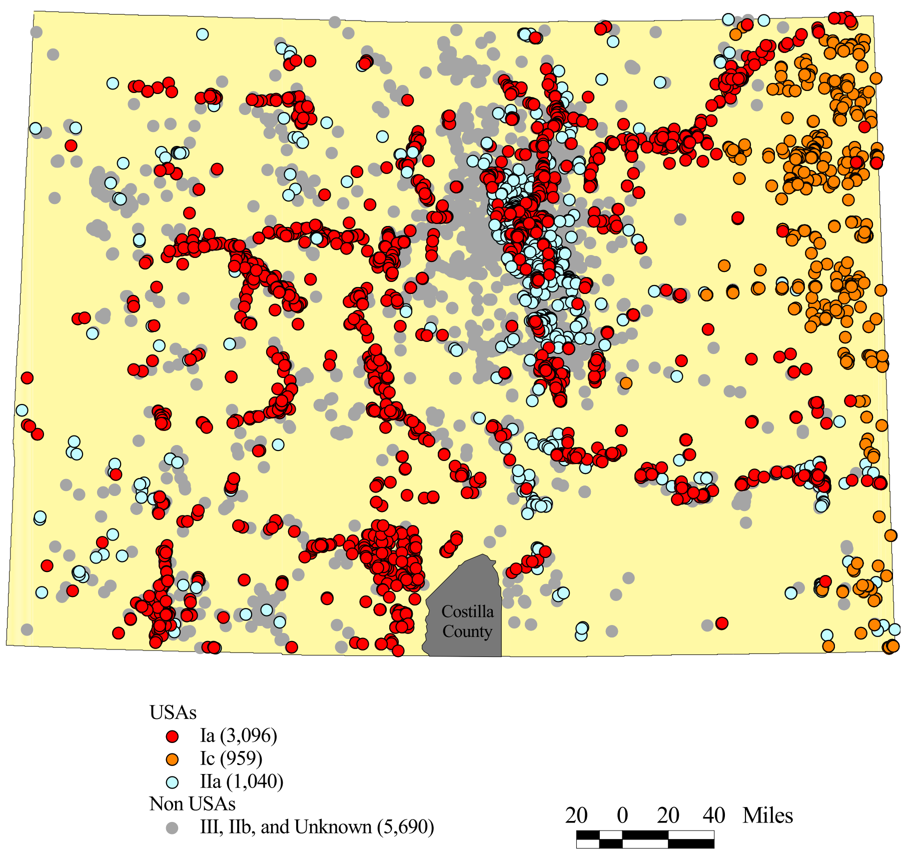

FIGURE 15. Colorado groundwater wells, by Pettyjohn classification.

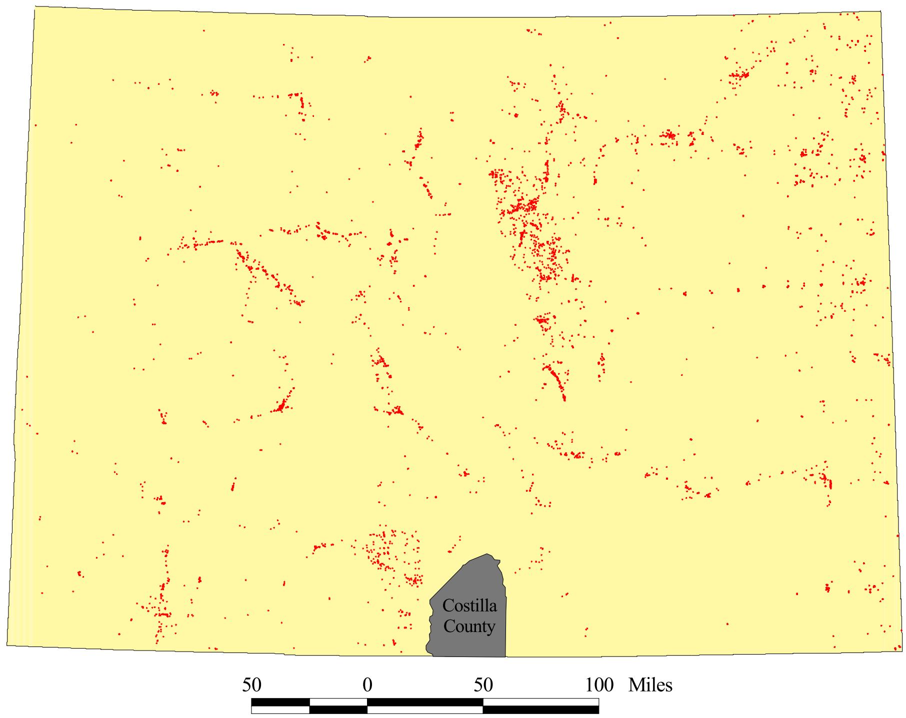

FIGURE 16. Final Colorado groundwater well drinking water USAs (5,095).

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 1,499 wells within the polygons (Quality = 1), 13 were identified within the spatial tolerance (Quality = 2), and 1,130 were identified as beyond the spatial tolerance (Quality = 3). The most important variable in assessing the Pettyjohn vulnerability classification is the source of the water. Unfortunately, as was stated above, there were 4,650 wells (43 percent) that did not have sources identified (Quality = 4). Although these wells need to be checked, they were still classified using the aquifer data layers. Additionally there were 3,493 wells (32 percent), generally located along alluvial valleys, that did not have source or depth information (Quality = 5). Of these 1,982 (18 percent) of these wells remain unranked and need to be checked by the state. The highest quality wells are predominantly located in the Ogallala (High Plains) aquifer in eastern Colorado, the Denver Basin, and the San Luis Valley in south-central Colorado (Fig. 18 and Table 15).

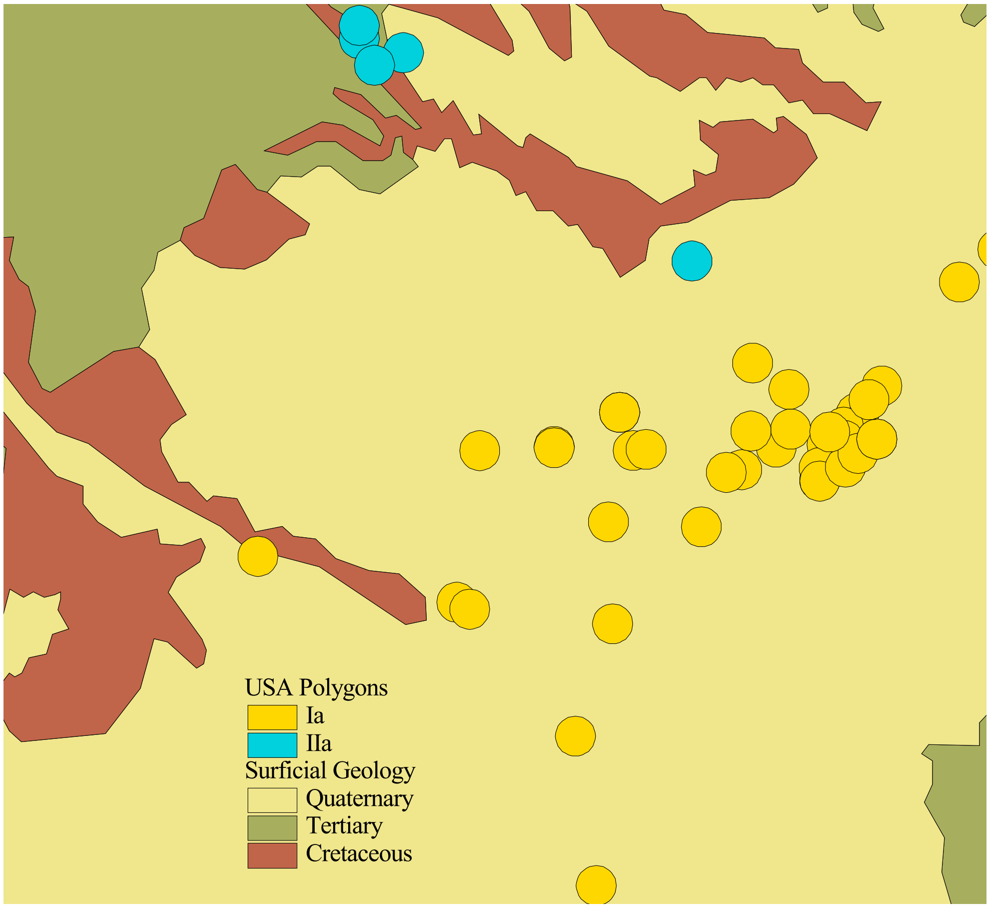

FIGURE 17. A closer view of the "region" GIS topology illustrating the overlapping groundwater USAs.

TABLE 14. Number and percentage of wells by Pettyjohn classification.

Classification	Number of Groundwater PWSs	Percentage
Ia	3,096	28.7
Ic	959	8.9
IIa	1,040	9.6
IIb	1,905	17.7
III	1,803	16.7
Unclassified	1,982	18.4

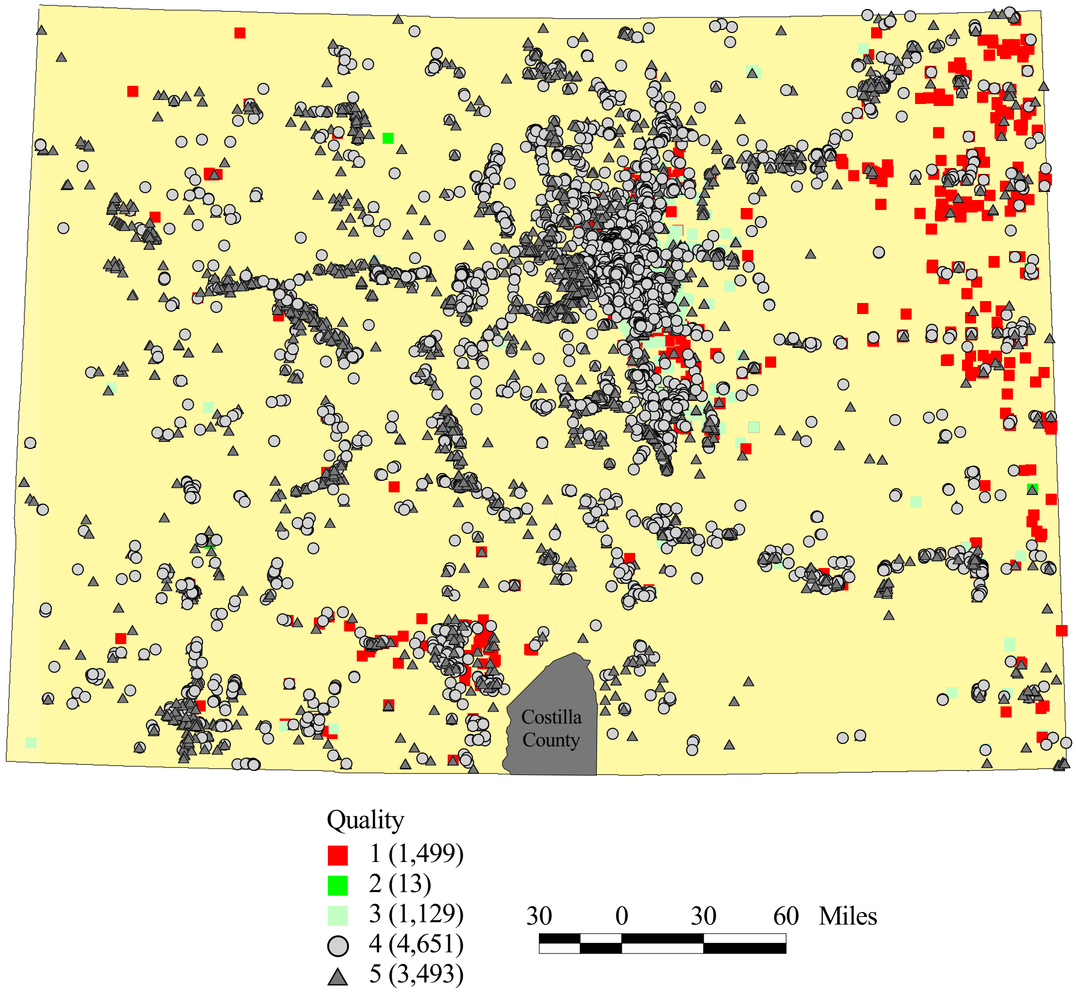

FIGURE 18. Groundwater wells by data quality. Notice the abundance of wells (1,511) that have no source or depth information (Quality = 5) and generally follow the path of the alluvial valleys. Conversely, notice the remaining 1,982 wells that are Quality = 5, are located outside alluvial valleys, and have "Unknown" Pettyjohn classification.

TABLE 15. Data quality of the Colorado PWSs.

Quality Rank	Number of Groundwater PWSs	Percentage
1	1,499	13.9
2	13	0.1
3	1,130	10.5
4	4,650	43.1
5	3,493	32.4

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, 1995. Ground water atlas of the United States: Segment 2, Arizona, Colorado, New Mexico, Utah. Hydrologic Investigations Atlas 730-C, U.S. Geological Survey, Reston, Va., 32 pp.