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UNUSUALLY SENSITIVE AREAS FOR DRINKING WATER RESOURCES REPORT FOR TEXAS

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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 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.

Filter criteria 2 could not be applied in Texas because data were not available to determine if surface water sources have an adequate alternative source of water. Therefore, all CWS and NTNCWS that obtain their water from surface water sources are automatically designated as USAs. 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 Texas.

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 (EPA) (USEPA/600/2-91/043) by Pettyjohn et al. is used to determine the parts of an aquifer at risk to contamination from a hazardous liquid pipeline release. The Pettyjohn classification is based on an assessment of the potential contamination of groundwater throughout the United States by the subsurface emplacement of fluids through injection wells. The classification is listed below:

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

<u>Class Ia: Unconsolidated Aquifers</u>. 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: Semiconsolidated Aquifers. Consist of semiconsolidated 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 is distinguishing those wells that obtain their water from Class I or Class IIa USA aquifers (filter criteria 3 and 5), from those that do not (filter criteria 4). Another key is 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 are USAs in most cases. On the other hand, wells that tap an aquifer in its subcrop belt where the aquifer is overlain by a confining unit, such as a layer of impermeable shale, are classified as Class III, and are not USAs. In the latter situation, the overlying impermeable layer would prevent a pipeline release from reaching the aquifer, so there is no threat of contamination from a hazardous liquid pipeline release.

IDENTIFYING USAs FOR DRINKING WATER RESOURCES IN TEXAS

The Geology and Pettyjohn Classification of Aquifers in Texas

As shown in Table 1, there are nine major aquifers in Texas (summarized by U.S. Geological Survey, 1996).

TABLE 1. Texas aquifers and their classification according to the Pettyjohn classification scheme.

Name	Description	Pettyjohn Classification
Alluvial aquifers along major streams	Valley and terrace deposits of major rivers (e.g., Brazos)	Class Ia because the deposits are permeable sands and gravels
Rio Grande	Late Tertiary/Quaternary alluvial sediments	Class Ia because the deposits are permeable sands and gravels
Pecos River Basin	Surficial Cenozoic alluvial deposits	Class Ia because the deposits are permeable sands and gravels
Seymour	A Holocene/Pleistocene erosional remnant in the upper Red and Brazos River Basins	Class Ia because these alluvial deposits are permeable sands and gravels

TABLE 1. Continued.

Name	Description	Pettyjohn Classification
High Plains	Tertiary river deposits (Ogallala Formation)	Class Ic because these sandstones are semi-consolidated, high yield aquifers
Coastal Lowlands	Miscellaneous sand deposits located in the Coastal Plain seaward of the Jackson/ Vicksburg outcrop belt	Class Ia if the source is Pliocene or younger because these sediments are unconsolidated and highly permeable; Class Ic if the source is Oligocene/ Miocene in age because the rocks are semi-consolidated, high yield aquifers
Coastal Uplands	Upper Claiborne aquifer (Eocene), Lower Cliborne-Upper Wilcox aquifer (Eocene), and Middle Wilcox aquifer (Paleocene)	Class Ic USAs because these Tertiary sandstones are semi-consolidated, high yield aquifers
Edwards-Trinity System	Edwards (Balcones fault region), Edwards-Trinity (Trans-Pecos or Edwards Plateau region), and Trinity Cretaceous aquifers	Class Ib where the Edwards and Edwards-Trinity aquifers are highly faulted and fractured limestones; Class IIa where the consolidated sandstones of the Trinity aquifer yield over 50 gpm
Blaine	Permian Pease River Group; Dog Creek Shale, Blaine Gypsum; Blaine Formation	Class Ib because these anhydrite and gypsum deposits are commonly cavernous
Minor Aquifers	Lipan	Class Ia because this aquifer consists of unconsolidated to semi-consolidated gravel, conglomerate, sand, silty-clay, and calishe
	Nacatoch and Blossom	Class Ic because these rocks are semi-consolidated sandstones that have high yields
	Capitan Reef Complex, Marble Falls, Ellenburger-San Saba, Marathon, and Bone Spring-Victorio Peak	Class Ib because these aquifers are porous limestones that contain solution features

TABLE 1. Continued.

Name	Description	Pettyjohn Classification
Minor Aquifers	Woodbine, Dockum, and Hickory	Class IIa because these consolidated sandstones typically yield over 50 gpm
	Igneous; Precambrian rocks and volcanic formations	Class IIb because these are highly consolidated rocks with low yield

Data Sources

The Texas Natural Resources Conservation Commission (NRCC) maintains a database of surface water intakes and groundwater wells for public water systems. These data contain information for the type of well (ground or surface), names of source aquifers, well depths, and PWS_ID (link to the federal database Safe Drinking Water Information System [SDWIS]). To distinguish the Transient Noncommunity (TNC) groundwater wells from the CWS and NTNCWS, the SDWIS database was downloaded from EPA, imported into the INFO Database Management System, and checked for accuracy against the Texas NRCC database. Unfortunately, SDWIS had only 1,483 records (total ground and surface) for Texas, which does not come close to the almost 17,000 public water supply wells in Texas. These data were insufficient to eliminate all of the TNC wells, as required by filtering criteria 1. Therefore, an undetermined number of TNC wells were classified as USAs, and they should be identified and not treated as USAs when the data are verified. Also, in applying filtering criteria 2 and 3, it was assumed that all wells do not have an adequate alternative source of water. Based on the 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 for this project.

The Texas Natural Resource Information Service distributes aquifer data from the Water Development Board, GIS Division. The boundaries of the major and minor aquifers, both outcrop and subcrop, were digitized from 1:250,000 scale geologic maps into individual Arc/INFO coverages. Texas has Sole Source Aquifers (Edwards I and

Edwards II) and these are available from the EPA Region 6, GIS Support Team. The Texas NRCC maintains the Wellhead Protection Area (WHPA) database for some of the Public Water Systems.

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 (Table 2).

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., alluvial valley; geologic formation)
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, distance to nearest aquifer and geographic position to other wells were used to classify the well

The sequential GIS processing began by intersecting the groundwater wells with the polygons delineating the boundaries of the aquifers (Fig. 1). The aquifer data delineate both the outcrop and subcrop areas and these areas can share multiple aquifers. Therefore, each well was attributed to indicate all the outcrop and subcrop areas that the well intersected. For example, if a well obtained water from an alluvial aquifer (using the well source information) and the well was located within the outcrop of the Pecos River aquifer, then this well was Class Ia and is described in the Pecos River aquifer section.

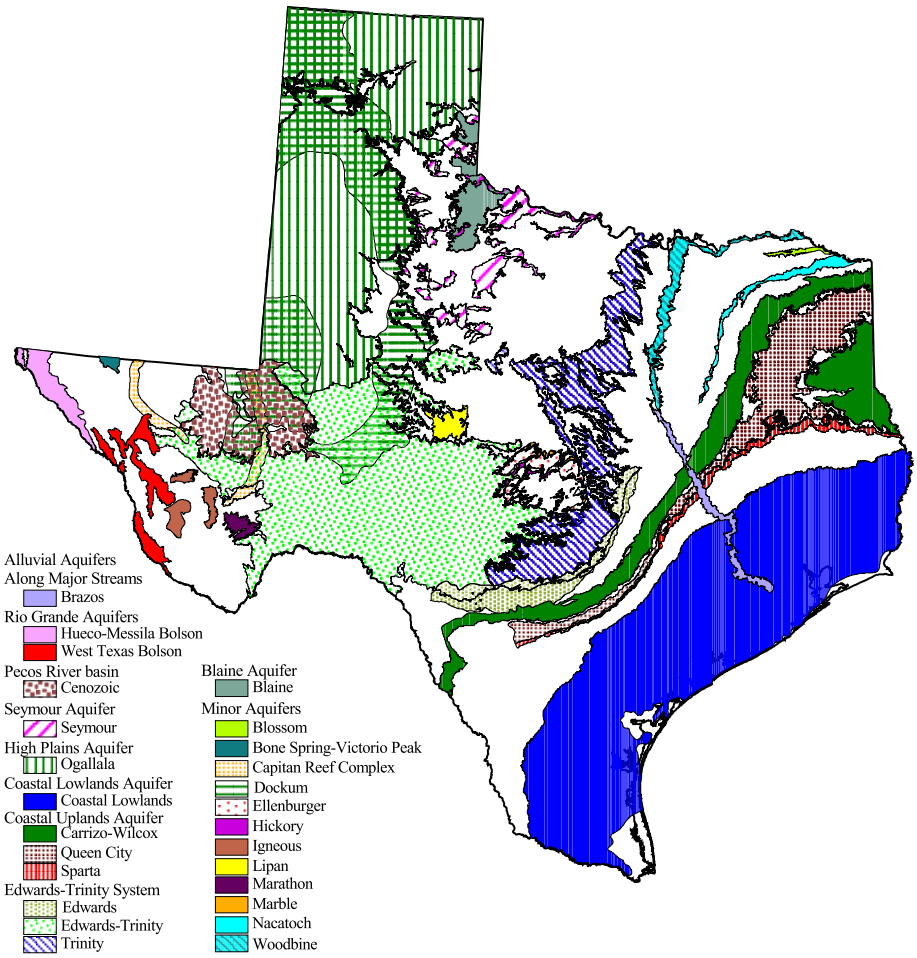

FIGURE 1. Major and minor aquifer outcrop belts in Texas. Except for the Brazos River aquifer, alluvial aquifers along major streams are not shown.

Each well location was checked against the boundary of the aquifer identified as the well's water source. If the well was located outside outcrop or subcrop belts, the well location was checked to see if it falls within the spatial tolerance of the respective data layers. Unfortunately, the minimum mapping unit, or spatial accuracy measurements, were not indicated, so a general estimate of 1,000 meters (m) was used as the allowable spatial tolerance. If a well was located within the boundary of it's source aquifer, then it received a Quality of 1. If the well was located within 1,000 m of the source aquifer's boundary, it received a Quality of 2. If the well was located beyond 1,000 m of the source aquifer's boundary, it received a Quality of 3. If the well did not have source

information, then it received a Quality of 4. The results are presented by aquifer in order, from youngest to oldest, as listed in Table 1 (Fig. 2).

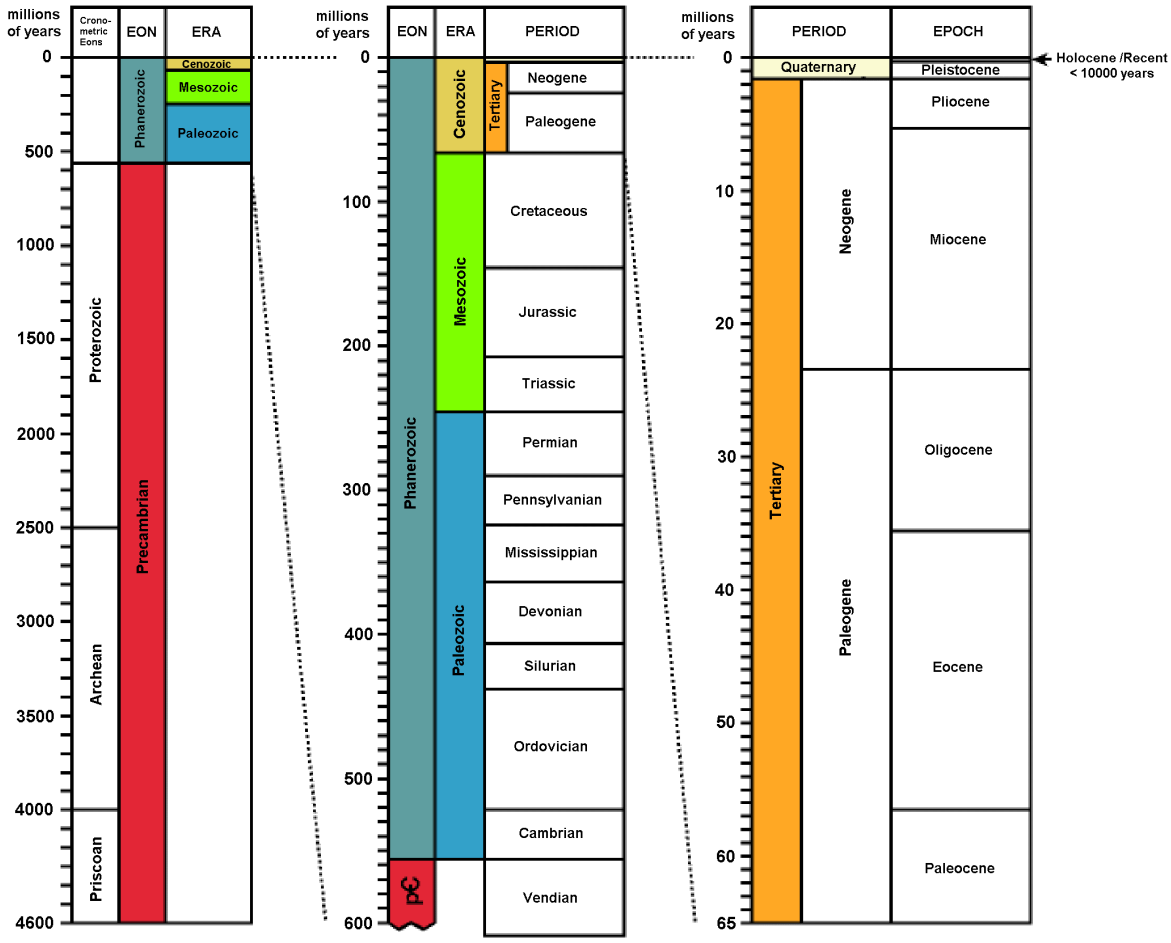

FIGURE 2. Geologic time scale.

Processing Steps

Every public water system well in Texas was classified according to the Pettyjohn scheme. The well data contained attributes for water source(s) and 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. The other spatial data, which were instrumental in classifying the sensitivity of the wells, were boundaries for all aquifers including outcrop and subcrop areas.

RESULTS BY AQUIFER SYSTEM

I. Alluvial Aquifers Along Major Streams

There were 668 wells that obtained water from alluvial sources. Of these, 664 wells were Class Ia because these wells obtained water from aquifers that consist of permeable sands and gravels in hydraulic continuity with the water table (Fig. 3). The USGS (1996) groundwater atlas features the Brazos River alluvial valley as a principal alluvial aquifer in Texas. However, only one of the 668 wells obtained water from the floodplain and terraces of the Brazos River (Quality = 1). Another 25 wells had no source or depth information but were located within the Brazos River aquifer belt and were Class Ia (Quality = 4).

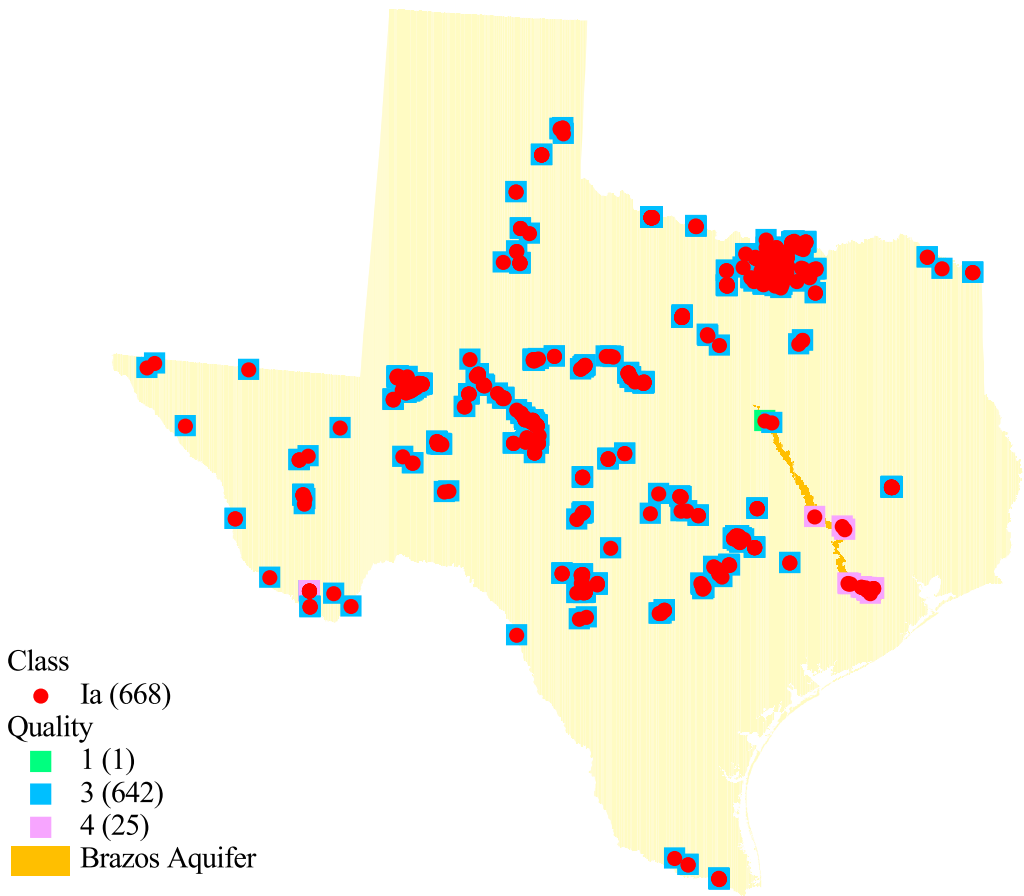

FIGURE 3. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from alluvial aquifers of major rivers (e.g., Brazos River).

The remaining 642 additional wells obtained water from alluvial aquifers and were located throughout the state. These were ranked Class Ia, but Quality of 3, because they did not fall within the Brazos aquifer outcrop belt, the only alluvial valley database available. Lastly, there were four wells that obtained water from the "Pen Formation" and appeared to be alluvial because water depths are shallow (10-12 feet). Therefore, these wells were also Class Ia (Quality = 4).

II. Rio Grande Aquifer

The 355 wells that obtained water from the Rio Grande aquifer system were Class Ia because these late Tertiary/Quaternary sediments are permeable sands and gravels that occur at the surface in hydraulic continuity with the water table (Fig. 4). The Rio Grande system occurs within several relatively small basins in west Texas, including the Hueco-Messila Bolson and the West Texas Bolson, and the wells in this region source alluvial deposits. A total of 332 of the 355 wells were located in the Hueco-Messila Bolson, and the remaining 23 wells were located in the West Texas Bolson. There were 217 wells that had source information (Quality = 1) and the remaining 138 wells had no source information (Quality = 4), but were located within the Rio Grande outcrops.

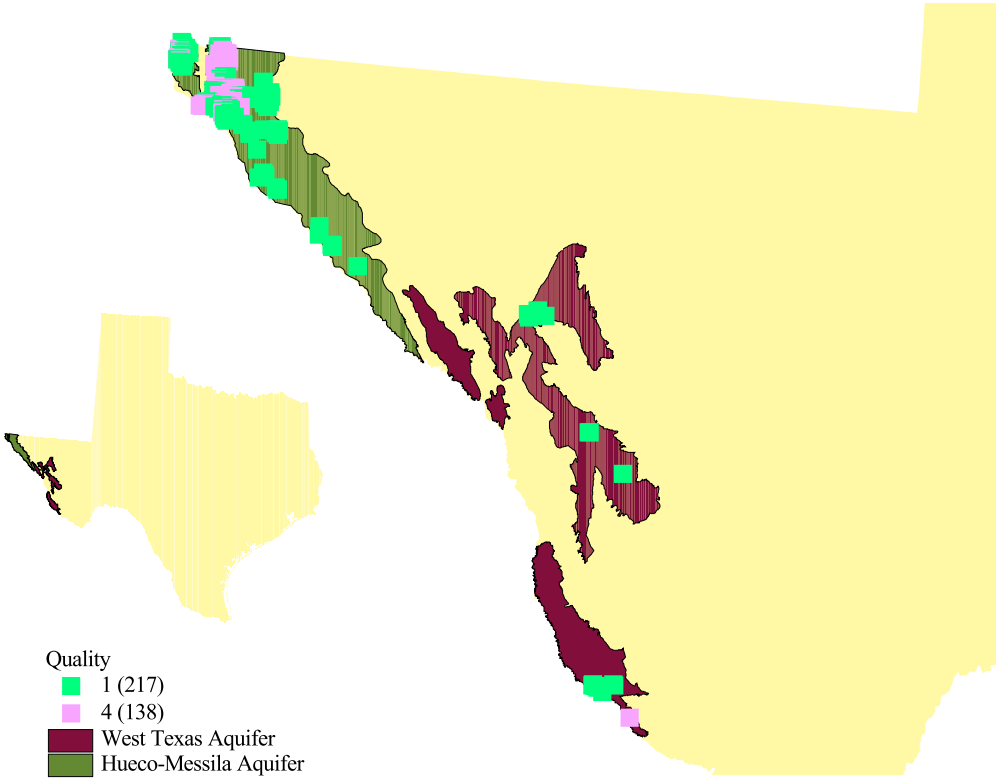

FIGURE 4. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Rio Grande aquifer.

III. Pecos River Basin Aquifer

There were 146 wells that obtained water from the Pecos River Basin aquifer, which were Class Ia because this Cenozoic alluvial aquifer is composed of permeable sands and gravels (Fig. 5). A total of 102 wells had source information and were located within the Pecos River Basin aquifer outcrop (Quality = 1). Conversely, 44 wells did not have any source information, but were located within the outcrop (Quality = 4).

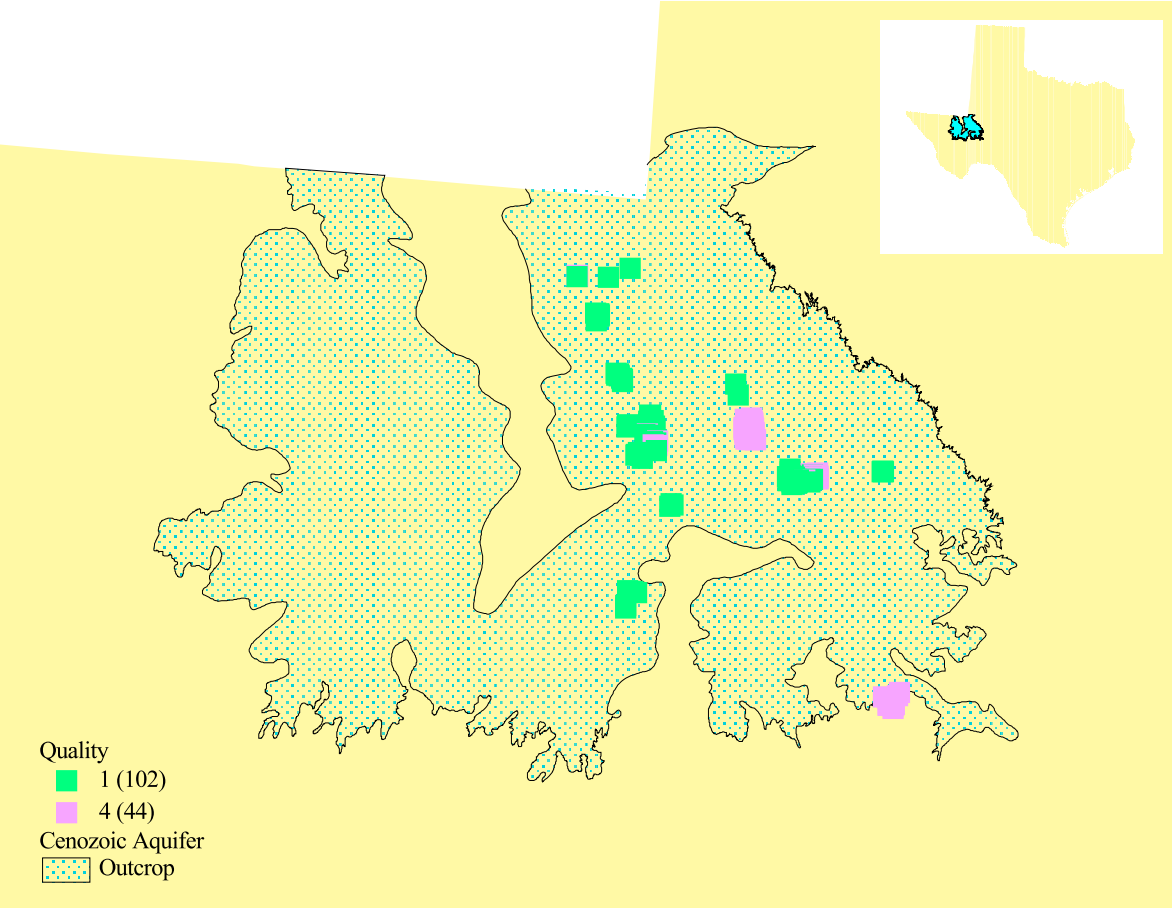

FIGURE 5. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Pecos River Basin aquifer.

IV. Seymour Aquifer

There were 264 wells that obtained water from the Seymour aquifer (Fig. 6). All of these wells were located within the Seymour outcrop belt and were Class Ia because this alluvial Pleistocene aquifer is composed of permeable sand and gravel. The water source for 163 of these wells was identified as alluvial, therefore these were Quality = 1. Conversely, 99 wells were located within the Seymour outcrop but do not have any source information (Quality = 4). Finally, two wells were located within the spatial tolerance of the Seymour outcrop, but because there was no source information, these wells were also Quality = 4.

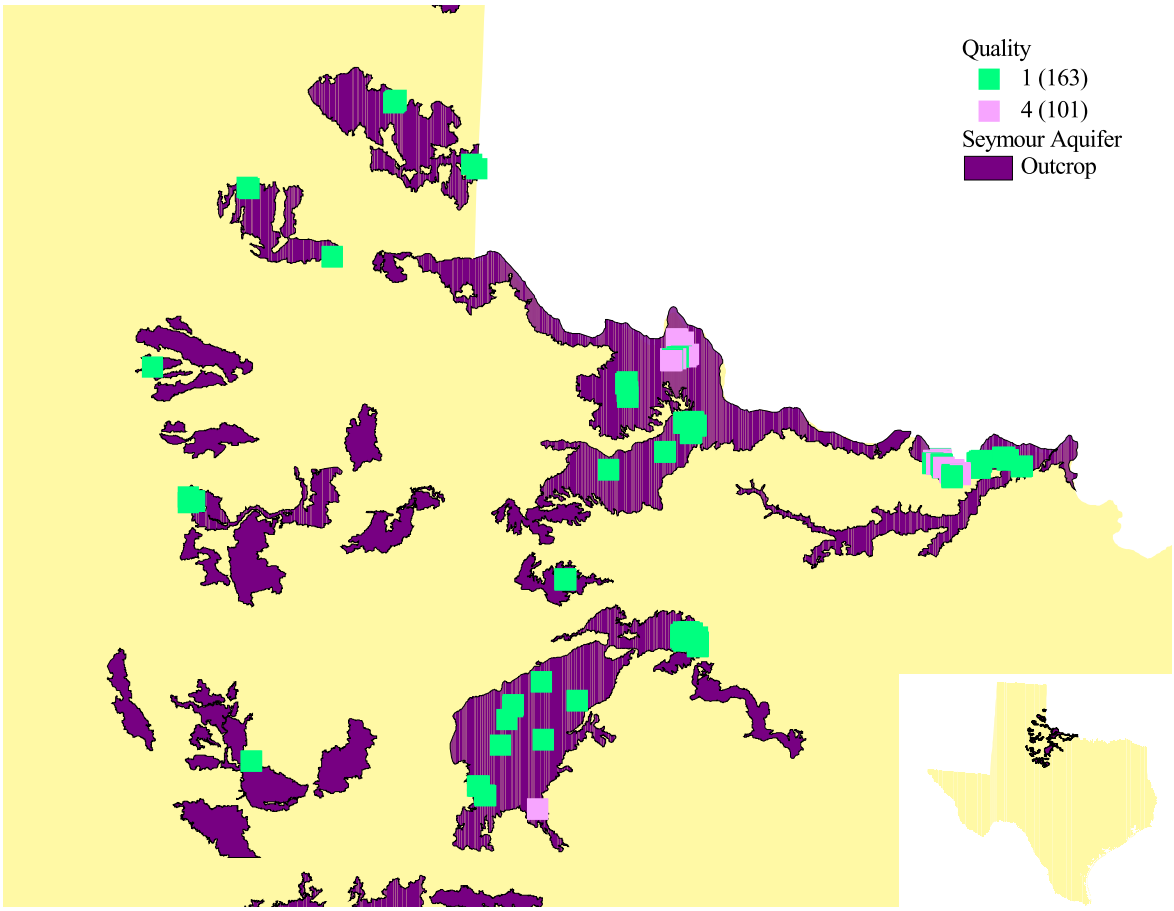

FIGURE 6. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Seymour aquifer. All of these wells were Class Ia.

V. High Plains Aquifer

There were 1,932 wells that apparently obtained water from the High Plains (or Ogallala) aquifer (Fig. 7). Because the Ogallala Formation is a semi-consolidated, high yield sandstone, and these wells were located within the Ogallala outcrop belt, all but one well were Class Ic (Table 3).

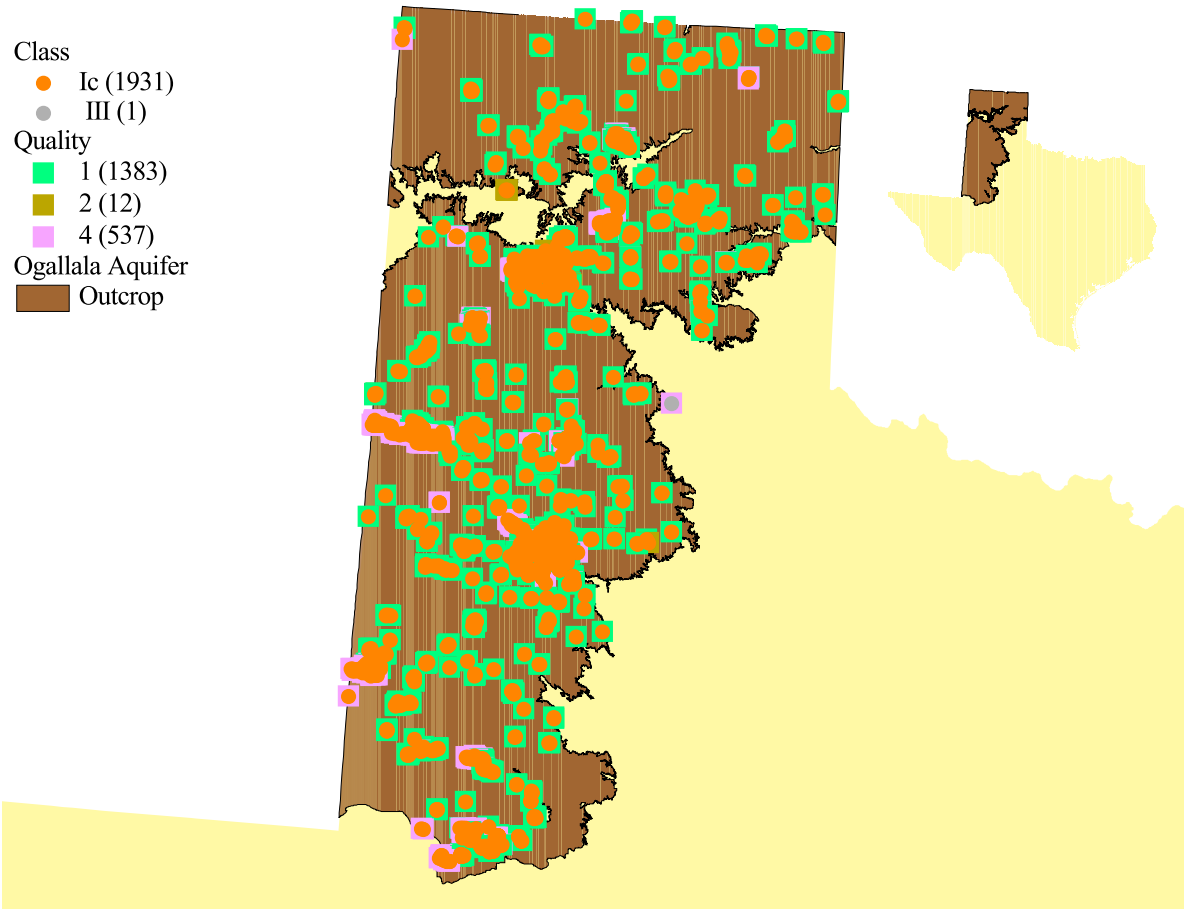

FIGURE 7. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the High Plains (Ogallala) aquifer.

TABLE 3. Number of wells, Pettyjohn class, data quality, and location characteristics for the High Plains aquifer.

Number	Class	Quality	Location Characteristics
1,383	Ic	1	Within the Ogallala outcrop belt
12	Ic	2	Within the spatial tolerance of the Ogallala outcrop belt
536	Ic	4	Within the Ogallala outcrop belt, but no source information
1	III	4	Beyond the Ogallala outcrop belt, but this is the closest aquifer, there was no source information, and assumed aquifer is overlain by a confining unit

VI. Coastal Lowlands Aquifers

There were 5,668 wells (30 percent of the public groundwater wells in Texas) that obtained water from the outcrop of the Coastal Lowlands aquifers (Fig. 8). Of these, there were 5,008 wells that were located in the outcrop belt of, and derived water from, the following: Coastal Lowlands aquifer; Chicot aquifer; Evangeline aquifer; Beaumont Formation; Goliad Sand; and Lagarto Clay. These wells were Class Ia because these Pliocene and younger aquifers consist of unconsolidated, highly permeable sediments. There were 533 wells that were Class Ic because they were located in the outcrop belt of and obtain water from unconfined, older semi-consolidated, high yield aquifers (Catahoula Formation, Jasper aquifer, Fleming Formation, and Oakville Sandstone). Lastly, there were 127 wells that were Class III, because they obtained water from deeper aquifers which are overlain by aquicludes, or were beyond the spatial tolerance of the respective data layers, or they obtained water from the Burkeville aquiclude or Jackson Confining Unit (Table 4).

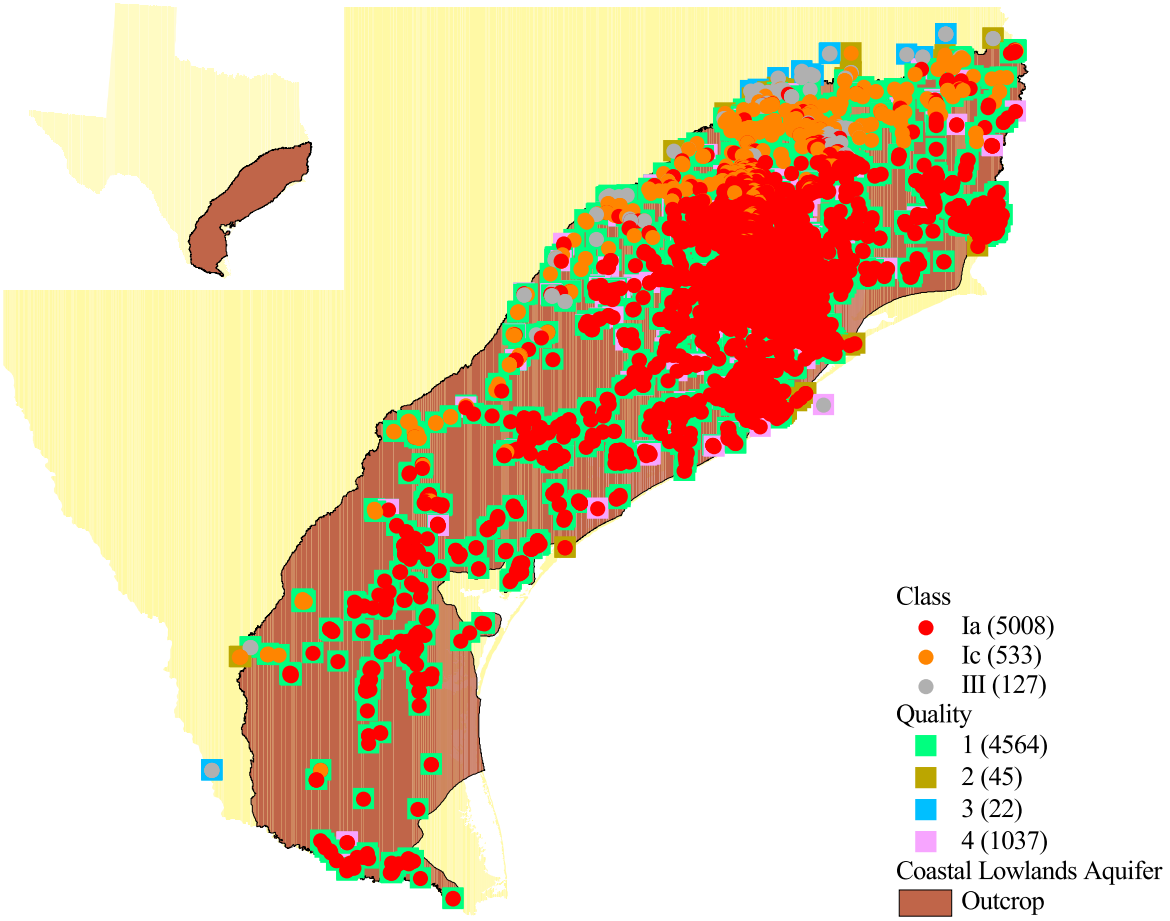

FIGURE 8. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Coastal Lowlands aquifers.

TABLE 4. Number of wells, Pettyjohn class, data quality, and location characteristics for the Coastal Lowlands aquifers.

Number	Class	Quality	Location Characteristics
3,953	Ia	1	Within the Coastal Lowlands aquifer
18	Ia	2	Located within the spatial tolerance of the Coastal Lowlands aquifer
1	Ia	3	Located within the Igneous outcrop and beyond the spatial tolerance
1,036	Ia	4	Located within the Coastal Lowlands aquifer and have no source information
522	Ic	1	Located within the Catahoula Formation

TABLE 4. Continued.

Number	Class	Quality	Location Characteristics
11	Ic	2	Located within the spatial tolerance of the Catahoula Formation
41	III	1	Located within the Burkeville aquiclude
3	III	3	Located beyond the spatial tolerance of the Catahoula Formation
48	III	1	Located within the Jackson Confining Unit
16	III	2	Located within the spatial tolerance of the Jackson Confining Unit
18	III	3	Located beyond the spatial tolerance of the Jackson Confining Unit
1	III	4	Located in the Jackson Confining Unit and has no source information

VII. Coastal Uplands Aquifers

There were 2,150 wells that obtained water from the Coastal Uplands aquifer system (Fig. 9). A total of 798 wells were Class Ic because the aquifers (Carrizo-Wilcox, Queen City, and Sparta) are Tertiary sandstones that are semi-consolidated and produce high yields (Table 5). Twenty-four wells were Class Id because they were located in the Carrizo-Wilcox subcrop (confined) and were less than 50 feet deep. The remaining 1,328 wells were Class III, because they were either located in the subcrops, were deep enough to have aquicludes overlying the water source, or they were beyond the spatial tolerances of the aquifer outcrop belts and, hence, probably have confined water sources.

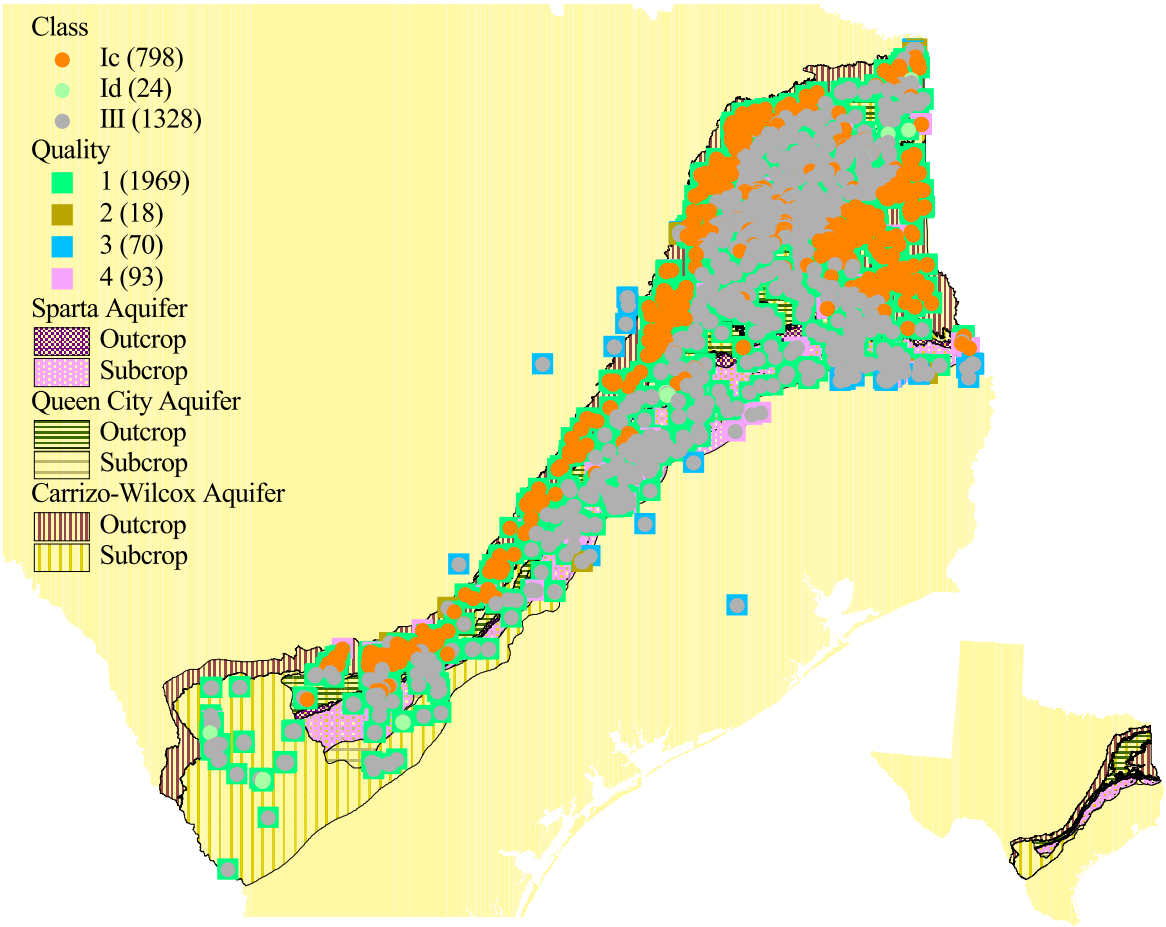

FIGURE 9. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Coastal Uplands aquifers.

TABLE 5. Number of wells, Pettyjohn class, data quality, and location characteristics for the Coastal Uplands aquifers.

Number	Class	Quality	Location Characteristics
4	Ic	1	Located in the Carrizo-Wilcox outcrop belt
54	Ic	1	Located in the Queen City-Sparta aquifer outcrop belt
685	Ic	1	Located in the Carrizo-Wilcox aquifer outcrop belt
6	Ic	2	Located within the spatial tolerance of the Carrizo-Wilcox aquifer outcrop belt
55	Ic	4	Have no source information and are located in the Carrizo-Wilcox, Queen City, or Sparta outcrop belts

TABLE 5. Continued.

Number	Class	Quality	Location Characteristics
24	Id	1	Located in the Carrizo-Wilcox aquifer subcrop and are less than 50 feet deep
6	III	1	Located in the Carrizo-Wilcox outcrop belt and obtain water from the Midway Group confining unit
27	III	1	Located in the Coastal Uplands aquifer subcrops and obtain water from the Jackson Confining Unit
28	III	1	Obtain water from the Queen City-Sparta aquifer and are located in the Carrizo-Wilcox subcrop
146	III	1	Located in the Queen City-Sparta aquifer subcrop
1,003	III	1	Located in the Carrizo-Wilcox aquifer subcrop and are deeper than 50 feet
4	III	2	Located within the spatial tolerance of the Queen City-Sparta aquifer subcrop
8	III	2	Located within the spatial tolerance of the Coastal Uplands outcrop belts and obtain water from the Midway Group confining unit
10	III	3	Located beyond the spatial tolerance of the Coastal Uplands outcrop belts and obtain water from the Midway Group confining unit
12	III	3	Located beyond the spatial tolerance of the Carrizo-Wilcox aquifer
48	III	3	Located beyond the spatial tolerance of the Queen City-Sparta aquifer
24	III	4	Have no source information and are located in the subcrops of the Coastal Uplands aquifers
6	III	4	Have no source information, are located closest to the Coastal Uplands Aquifers, and are not located in any outcrop or subcrop

VIII. Edwards-Trinity Aquifer System

There were 3,954 wells (24 percent of public groundwater wells in Texas) that obtained water from aquifers in the Edwards-Trinity aquifer system (Fig. 10). The Edwards-Trinity aquifer system is composed of three primary aquifers: the Edwards aquifer; the Edwards-Trinity aquifer; and the Trinity aquifer. There were 477 wells that obtained water from these three aquifers and were located in either the Edwards or Edwards-Trinity aquifers and were Class Ib because these aquifers are primarily highly fractured and faulted porous limestones (Table 6). There were 1,293 wells that obtained water from the Trinity or Edwards aquifer, were located in the Trinity outcrop, and were Class IIa because the Trinity aquifer consists mostly of consolidated sandstone that typically yields more than 50 gpm. Lastly, there were 2,184 wells that were Class III, because: (1) they were located in aquifer subcrops which have overlying aquicludes; (2) there was evidence of a confining unit above the aquifer they were obtaining water from; or (3) they were not located within the spatial tolerance of an outcrop and, hence, the water source is probably overlain by a confining unit.

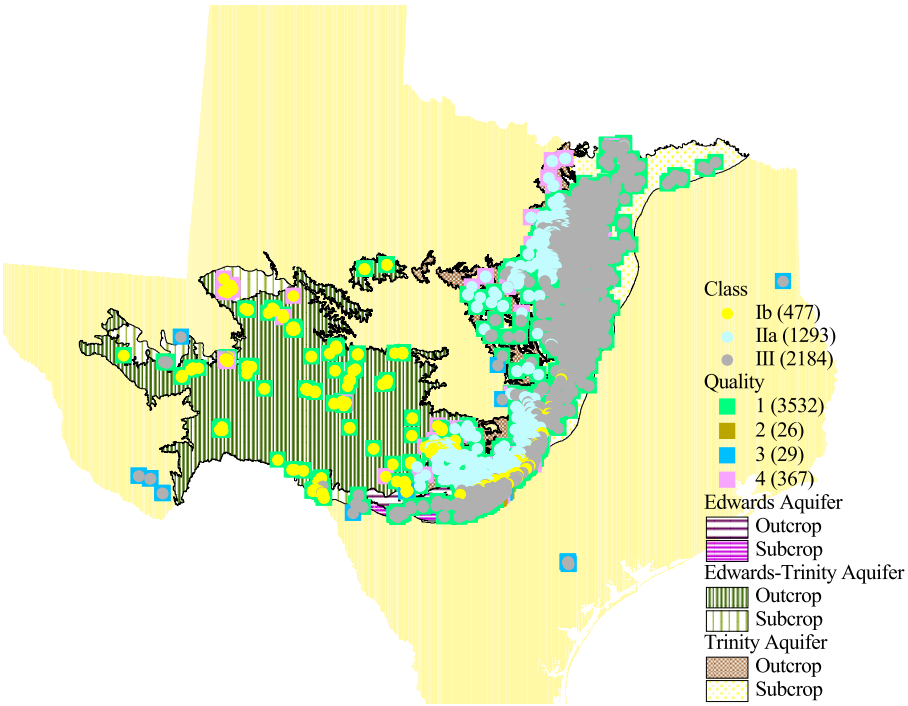

FIGURE 10. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Edwards-Trinity aquifer system.

TABLE 6. Number of wells, Pettyjohn class, data quality, and location characteristics for the Edwards-Trinity aquifer system.

Number	Class	Quality	Location Characteristics
1	Ib	1	Obtains water from the Trinity aquifer and is located in the Edwards aquifer outcrop belt
151	Ib	1	Obtain water from the Trinity aquifer and are located in the Edwards-Trinity aquifer outcrop belt
242	Ib	1	Obtain water from the Edwards aquifer and are located in Edwards or Edwards-Trinity aquifer outcrop belt
1	Ib	4	Obtains water from the San Andres limestone formation and is located within the Edwards-Trinity aquifer outcrop belt
82	Ib	4	No source information and are located in either the Edwards or Edwards-Trinity aquifer outcrop belt
117	IIa	1	Obtain water from the Paluxy Formation and are located in the Trinity aquifer outcrop belt
1,035	IIa	1	Obtain water from the Trinity aquifer and are located within the Trinity aquifer outcrop belt
24	IIa	3	Obtain water from the Edwards aquifer and are located in the Trinity aquifer outcrop belt
2	IIa	4	No source information and are located within the spatial tolerance of the Trinity aquifer outcrop belt
115	IIa	4	No source information and are located within the Trinity aquifer outcrop belt
1	III	1	Obtains water from the Trinity aquifer and is located in the Edwards aquifer subcrop
9	III	1	Obtain water from the Trinity aquifer and are located in the Edwards-Trinity aquifer subcrop
532	III	1	Obtain water from the Edwards aquifer and are located in Edwards, Edwards-Trinity, or Trinity aquifer subcrops

TABLE 6. Continued.

Number	Class	Quality	Location Characteristics
590	III	1	Obtain water from the Paluxy Formation and are located in the Trinity aquifer subcrop
862	III	1	Obtain water from the Trinity aquifer and are located in the Trinity aquifer subcrop
15	III	2	Obtain water from the Edwards aquifer and are located within the spatial tolerance of the Edwards aquifer subcrop
1	III	3	Obtains water from the Paluxy Formation and is located beyond the spatial tolerance of the Trinity aquifer
3	III	3	Obtain water from the Edwards aquifer and are located beyond the aquifer spatial tolerance
13	III	3	Obtains water from the Trinity aquifer and is not located in an aquifer outcrop belt
1	III	4	No source information and is closest to the Edwards-Trinity aquifer but beyond the spatial tolerance
1	III	4	No source information and is located within the spatial tolerance of the Edwards aquifer subcrop
157	III	4	No source information and are located in the subcrops of the Edwards, Edwards-Trinity, or Trinity aquifers

IX. Blaine Aquifer

There were 59 wells that obtained water from the Blaine (Paleozoic) aquifer (Fig. 11). Only two wells were Class Ib because they were located in the Blaine outcrop belt where the anhydrite and gypsum are commonly cavernous, which allows for pollution penetration. The remaining 57 wells were Class III, because they were either located in the Blaine subcrop, or they were located beyond the spatial tolerance of the aquifer, or the well had no source information (Table 7).

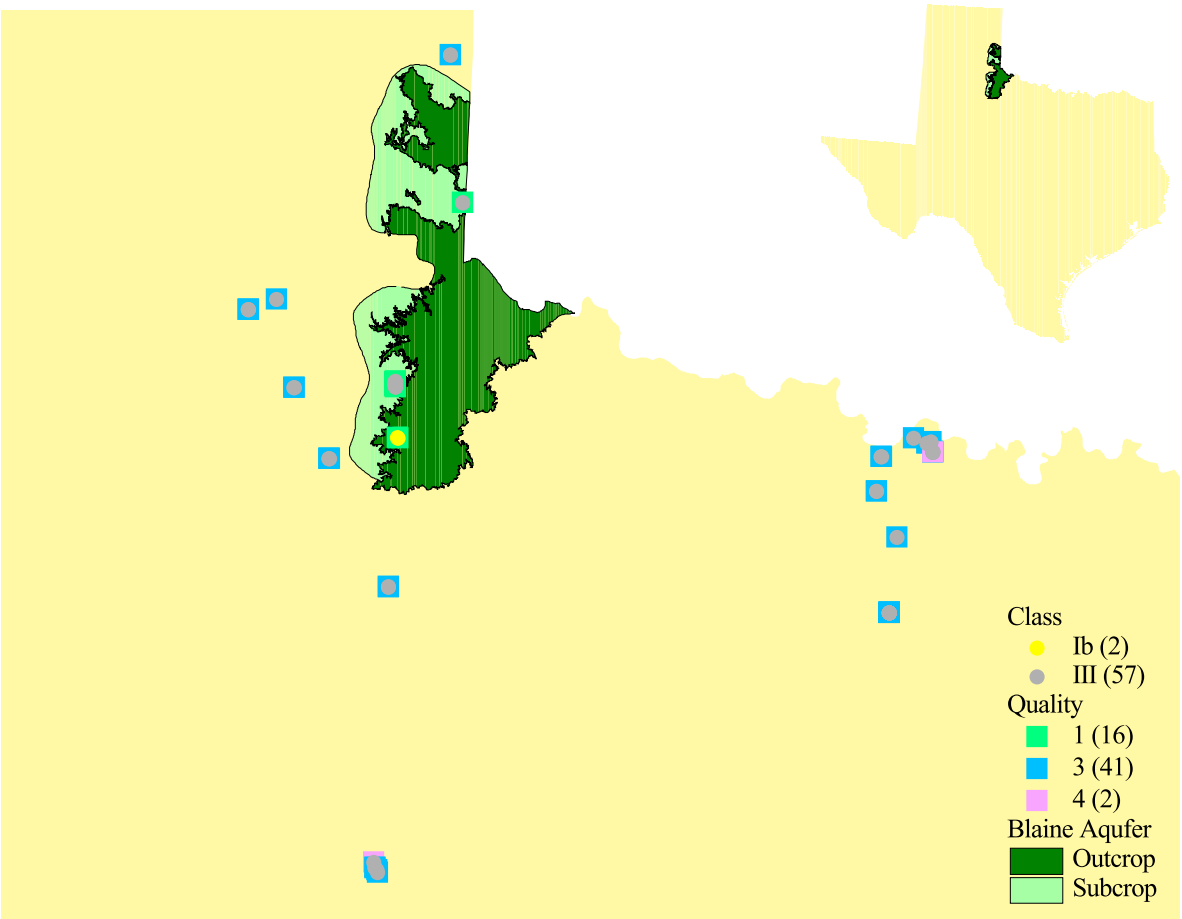

FIGURE 11. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Blaine aquifer.

TABLE 7. Number of wells, Pettyjohn class, data quality, and location characteristics for the Blaine aquifer system.

Number	Class	Quality	Location Characteristics
2	Ib	1	Obtain water from the Blaine aquifer and are located in the outcrop belt
14	III	1	Obtain water from the Blaine aquifer and are located in the Blaine aquifer subcrop
6	III	3	Obtain water from the Blaine aquifer and are located beyond the spatial tolerance of the Blaine aquifer

TABLE 7. Continued.

Number	Class	Quality	Location Characteristics
14	III	3	Obtain water from the Paleozoic Erathum without a specific aquifer reference and are not located in a subcrop or outcrop belt
11	III	3	Obtain water from the Quartermaster Formation or Whitehorse Group, and are located beyond the spatial tolerance of the aquifer
10	III	3	Obtain water from the Wichita Formation and are located beyond the spatial tolerance of the Blaine aquifer
2	III	4	No source information and is closest to the Blaine aquifer but beyond the spatial tolerance

X. Minor Aquifers

There were 938 wells that obtained water from a variety of minor aquifers across Texas (Fig. 12). There were 22 wells that obtained water from the Lipan aquifer and were located in the outcrop. These were Class Ia because this aquifer consists of porous, unconsolidated gravel, conglomerate, sand, silty clay, and caliche. There were 44 wells that obtained water from the Nacatoch and Blossom aquifers and were located within their outcrop belts. These wells were Class Ic because these rocks are semi-consolidated and have high yields. There were 36 wells that obtained water from the Capitan Reef Complex (3), Marble Falls aquifer (8), Ellenburger-San Saba aquifer (20), Marathon aquifer (2), and the Bone Spring-Victorio Peak aquifer (3), and were located in the respective outcrop belts. These wells were Class Ib because these aquifers are composed of porous limestones that contain solution features. There were 102 wells that obtained water from the Woodbine (71), Dockum (13), and Hickory (18) aquifers, and were located in their respective outcrop belts. These wells were Class IIa because these highly consolidated sedimentary rocks typically yield well over 50 gpm. There

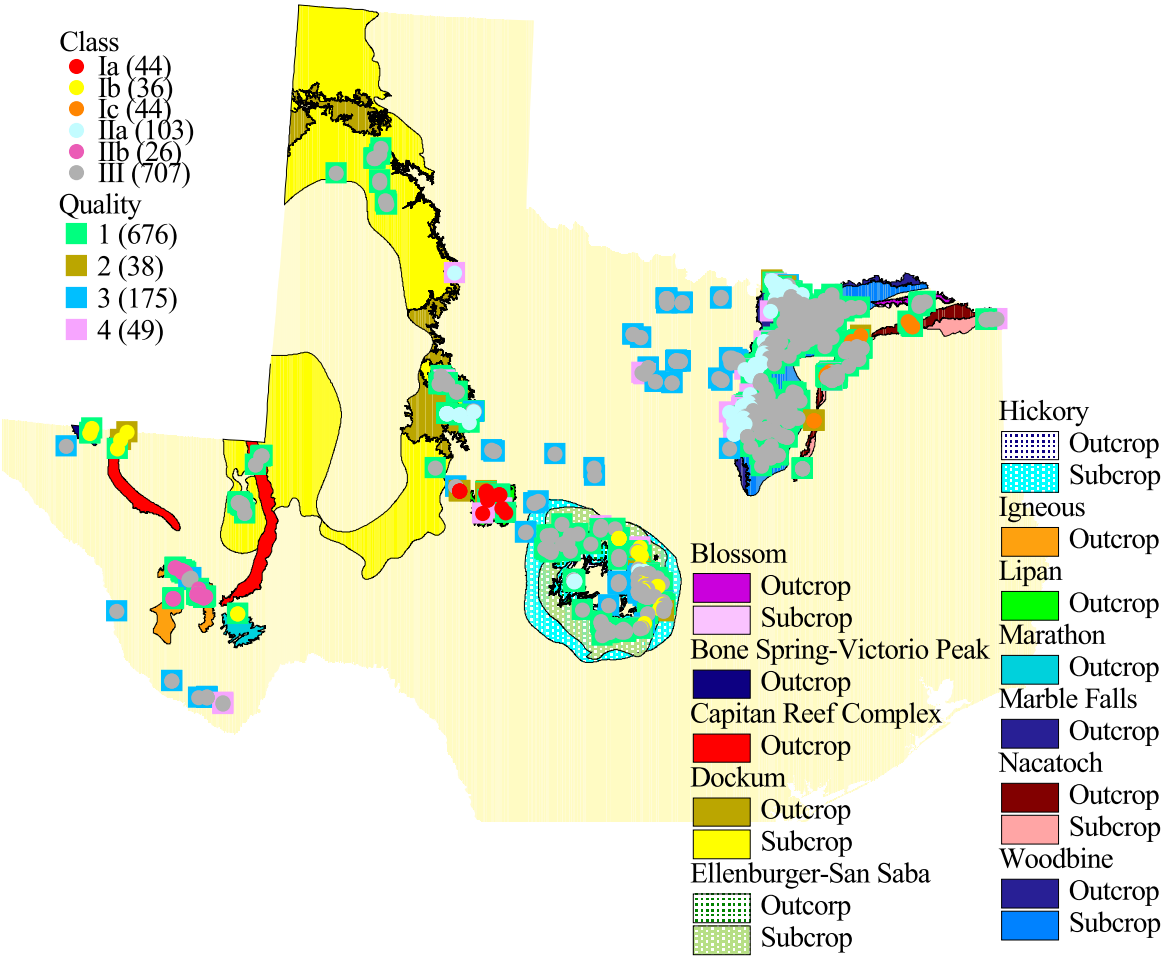

FIGURE 12. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Minor aquifers.

were 26 wells that obtained water from the Igneous aquifer, and were located in the outcrop belt. These wells were Class IIb because these rocks consist of Precambrian and volcanic crystalline rocks with low permeability. Lastly, there were 707 wells that were located in the aquifer subcrops, Class III, and were covered by confining units (Table 8).

TABLE 8. Number of wells, Pettyjohn class, data quality, and location characteristics for the Minor aquifer system.

Number	Class	Quality	Location Characteristics
11	Ia	1	Obtain water from the Lipan aquifer and are located within the outcrop belt
9	Ia	2	Obtain water from the Lipan aquifer and are located within the spatial tolerance of the outcrop belt
2	Ia	4	No source information and are located within the Lipan aquifer outcrop belt
1	Ib	1	Obtains water from the Capitan Reef Complex and is located in the aquifer outcrop belt
2	Ib	1	Obtain water from the Marathon aquifer and are located within the aquifer outcrop belt
3	Ib	1	Obtain water from the Bone Spring-Victorio Peak aquifer and are located in the aquifer outcrop belt
7	Ib	1	Obtain water from the Marble Falls aquifer and are located in the aquifer outcrop belt
8	Ib	1	Obtain water from the Ellenburger-San Saba aquifer and are located in the aquifer outcrop belt
2	Ib	2	Obtain water from the Capitan Reef Complex and are within the spatial tolerance of the aquifer outcrop belt
11	Ib	2	Obtain water from the Ellenburger-San Saba aquifer and are within the spatial tolerance of the aquifer outcrop belt
1	Ib	4	No source information but the well is located within the outcrop belt of the Ellenburger-San Saba aquifer
1	Ib	4	No source information and is located within the Marble Falls outcrop belt
39	Ic	1	Obtain water from the Nacatoch aquifer and are located in the aquifer outcrop belt

TABLE 8. Continued.

Number	Class	Quality	Location Characteristics
4	Ic	2	Obtain water from the Nacatoch aquifer and are located within the spatial tolerance of the aquifer outcrop belt
1	Ic	4	No source information and located in the Nacatoch aquifer outcrop belt
11	IIa	1	Obtain water from the Hickory aquifer and are located within the aquifer outcrop belt
12	IIa	1	Obtain water from the Dockum aquifer and are located within the aquifer outcrop belt
49	IIa	1	Obtain water from the Woodbine aquifer and are located in the Woodbine outcrop belt
4	IIa	2	Obtain water from the Woodbine aquifer and are located within the spatial tolerance of the aquifer outcrop belt
7	IIa	2	Obtain water from the Hickory aquifer and are located within the spatial tolerance of the outcrop
1	IIa	4	No source information and is located in the Dockum aquifer outcrop belt
18	IIa	4	No source information and are located in the Woodbine aquifer outcrop belt
26	IIb	1	Obtain water from the Igneous aquifer and are located within the outcrop belt
6	III	1	Obtain water from the Blossom aquifer and are located in the aquifer subcrop belt
27	III	1	Obtain water from the Ellenburger-San Saba aquifer and are located in the aquifer subcrop belt
59	III	1	Obtain water from the Dockum aquifer and are located in the aquifer subcrop belt
64	III	1	Obtain water from the Nacatoch aquifer and are located in the aquifer subcrop belt
93	III	1	Obtain water from the Hickory aquifer and are located in the aquifer subcrop belt

TABLE 8. Continued.

Number	Class	Quality	Location Characteristics
263	III	1	Obtain water from the Woodbine aquifer and are located in the aquifer subcrop belt
1	III	2	Obtains water from the Ellenburger-San Saba aquifer and is within the spatial tolerance of the aquifer subcrop belt
1	III	3	Obtains water from the Bone Spring-Victorio Peak aquifer and is located beyond the spatial tolerance of the aquifer outcrop belt
6	III	3	Obtain water from the Ellenburger-San Saba aquifer and are located beyond the spatial tolerance of the aquifer subcrop belt
9	III	3	Obtain water from the Lipan aquifer and are located beyond the spatial tolerance of the aquifer
14	III	3	Obtain water from the Woodbine aquifer and are located beyond the spatial tolerance of the aquifer outcrop belt
35	III	3	Obtain water from the Marble Falls aquifer and are located beyond the spatial tolerance of the aquifer outcrop belt
42	III	3	Obtain water from the Igneous aquifer and are located beyond the spatial tolerance of the aquifer
67	III	3	Obtain water from the Hickory aquifer and are not located within the spatial tolerance
2	III	4	No source information and are not located in any outcrop or subcrop but are nearest to the Igneous aquifer
3	III	4	No source information and is located beyond the spatial tolerance but nearest to the Marble Falls aquifer subcrop belt
5	III	4	No source information and located within the Dockum subcrop belt

TABLE 8. Continued.

Number	Class	Quality	Location Characteristics
6	III	4	No source information and are located in the subcrop of the Hickory aquifer
8	III	4	No source information and are located in the Nacatoch subcrop belt

SUMMARY

Of the 16,134 public water system groundwater wells in Texas, 6,468 wells were identified as Class Ia; 515 were identified as Class Ib; 3,306 were identified as Class Ic; 24 were identified as Class Id; and 1,396 were identified as Class IIa. Therefore, 72 percent (11,709) of the public groundwater wells in Texas were identified as USAs (Fig. 13). This high proportion is a result of the abundance of permeable aquifers at shallow depths and the absence of confining overburden, such as glacial till. Additionally, all 622 surface water intakes were classified as USAs.

The final USAs were derived by selecting all of the Pettyjohn Class Ia, Ib, Ic, Id, and IIa wells (11,709), and buffering them by the appropriate distance to create the USA area for each well. Although Texas has an approved Wellhead Protection Program, only 324 wells had a defined distance. Therefore, the remaining wells used the default WHPA radius of 2,000 feet. Additionally, there are two Sole Source Aquifers (SSA) in Texas as defined by the EPA Region 6. These aquifers are the Edwards 1 and the Edwards 2 aquifers. In contrast to the aquifer outcrops and subcrops, the SSAs cover a unique area and were analyzed with the groundwater wells. The wells that obtained water from either the Edwards or the Edwards-Trinity aquifers were intersected with the SSAs and those wells that were located within the SSAs had twice the specified radius (Fig. 14). The final USAs, as defined using the radius and SSAs, cover very little of the State of Texas (Fig. 15). From a closer perspective, the resulting USA areas may overlap (Fig. 16). To maintain the data for each well (i.e., aquifer source, class, and quality), the "region" topology was used where these overlapping areas remain distinct.

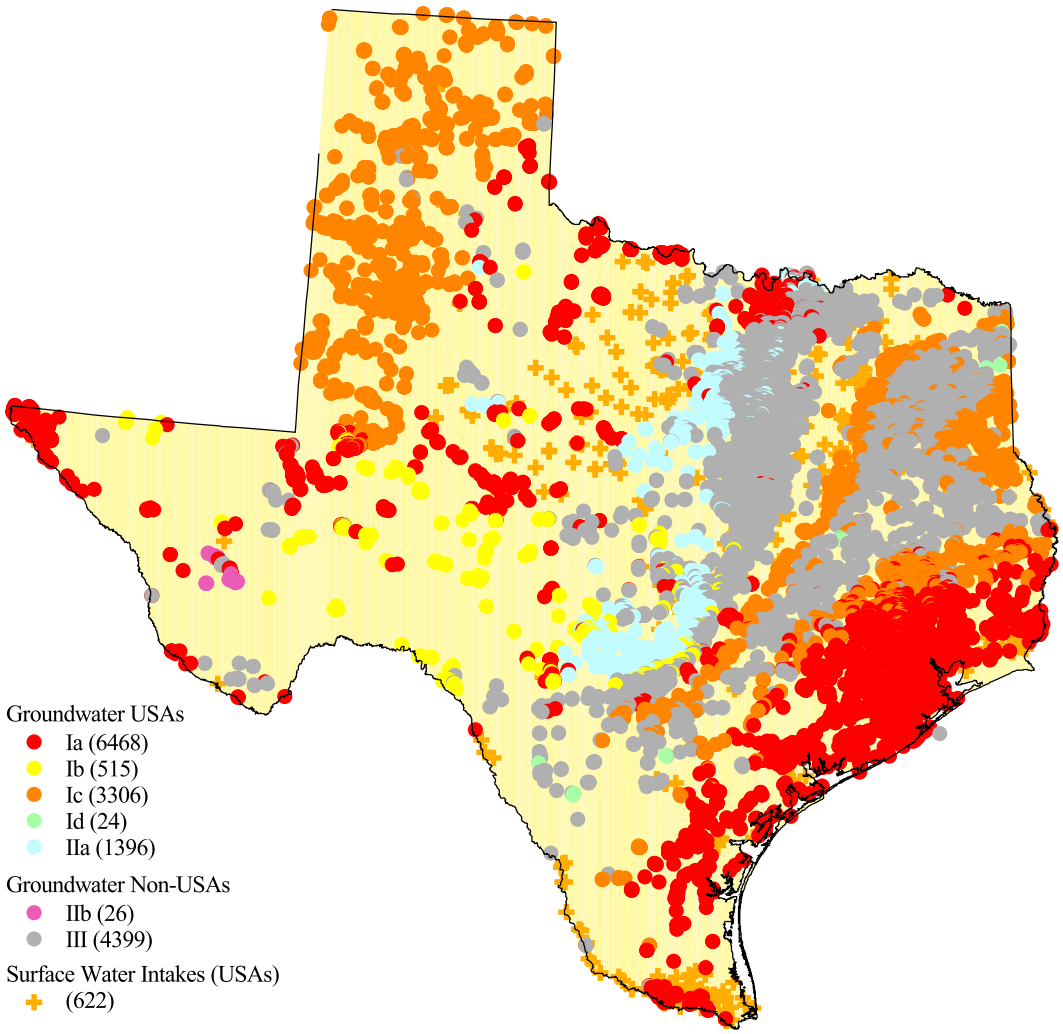

FIGURE 13. Texas drinking water USAs.

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 12,623 wells within the polygons (Quality = 1), 139 were identified within the spatial tolerance (Quality = 2), and 979 could not be accurately identified, because they were beyond the spatial tolerance (Quality = 3). The most important variable in assessing the Pettyjohn vulnerability classification is the source of the water. Unfortunately, there were 2,393 wells (14 percent) that did not have identified sources (Quality = 4), and, although these wells need to be checked, they were still classified using the aquifer data layers and other criteria, such as proximity to known aquifers.

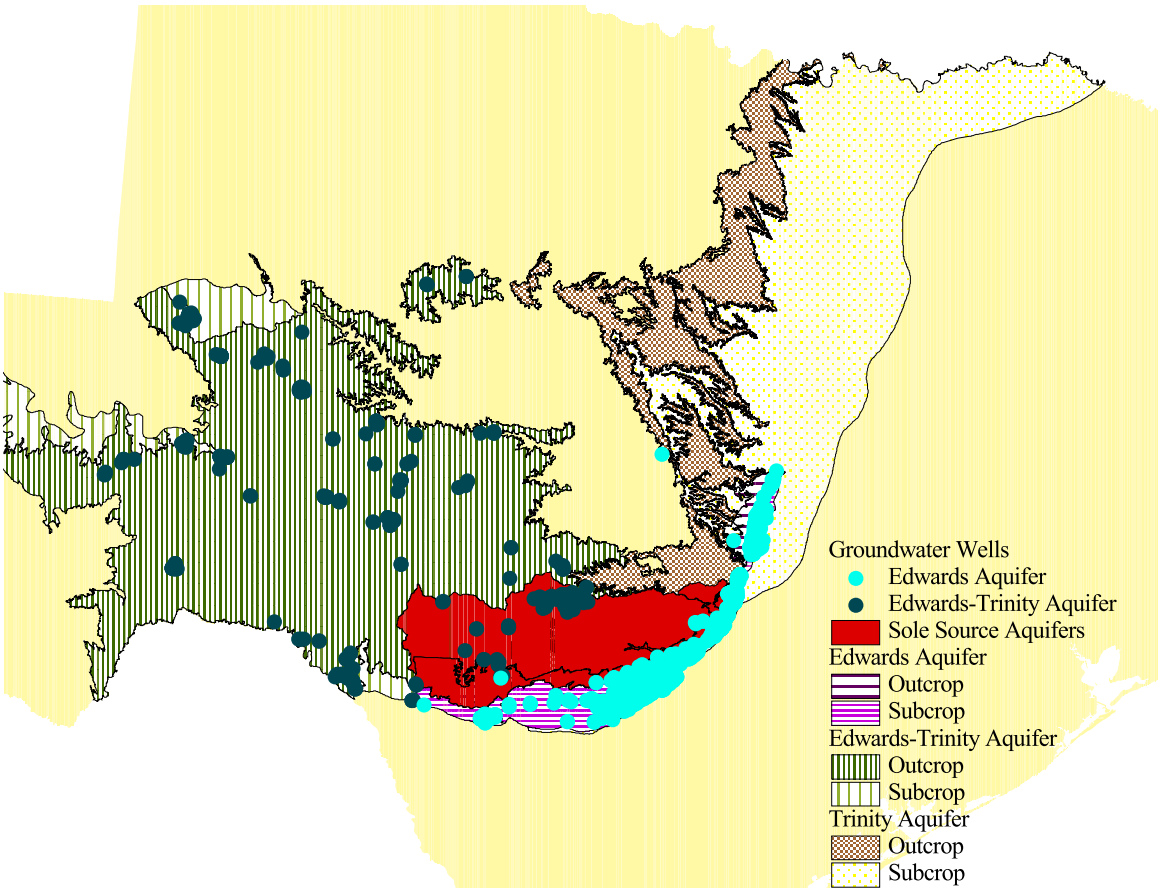

FIGURE 14. Edwards I and Edwards II Sole Source Aquifers, Edwards-Trinity aquifer System, and wells that obtained water from either Edwards or Edwards-Trinity aquifers.

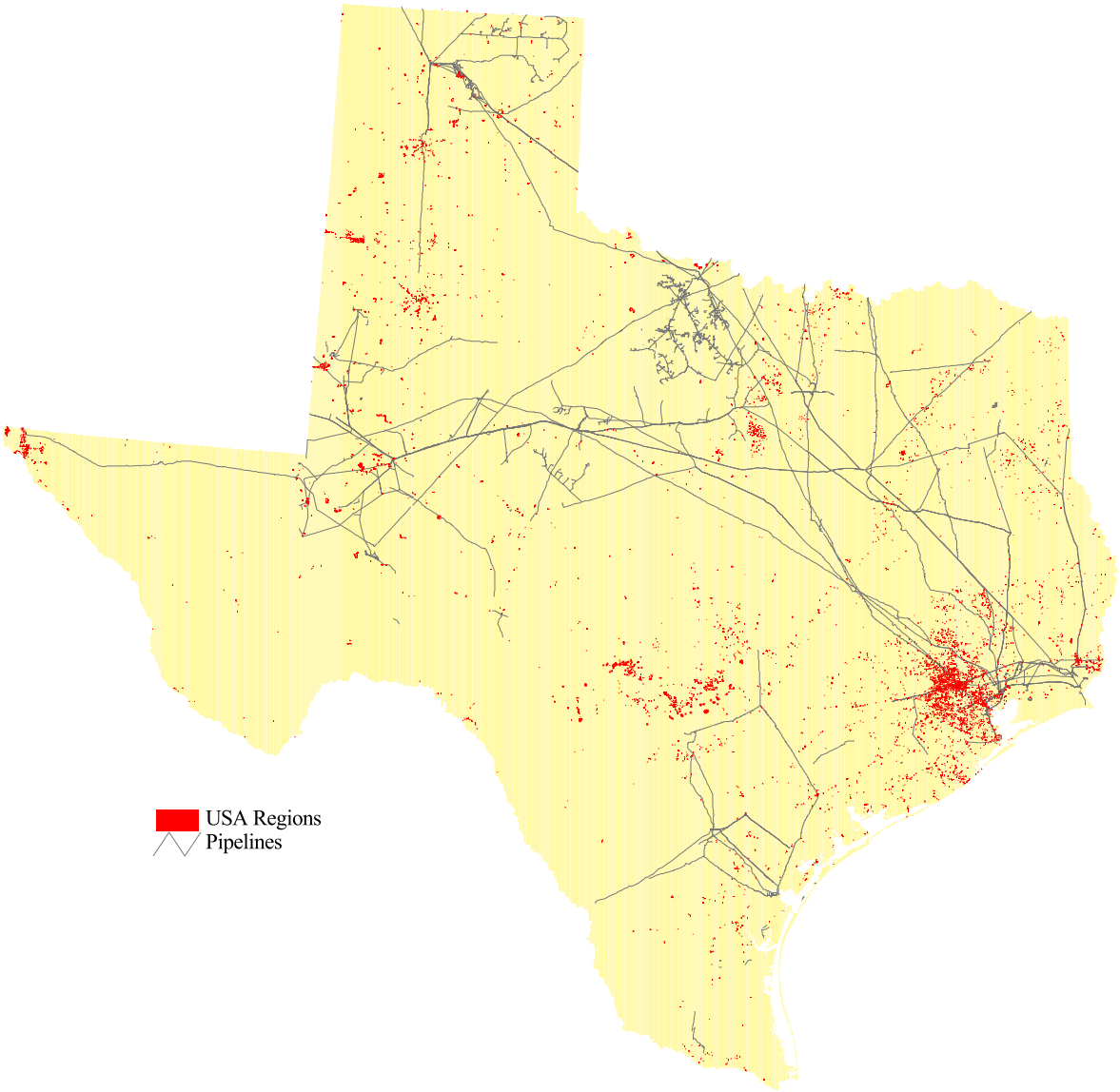

FIGURE 15. Final Texas groundwater well drinking water USAs.

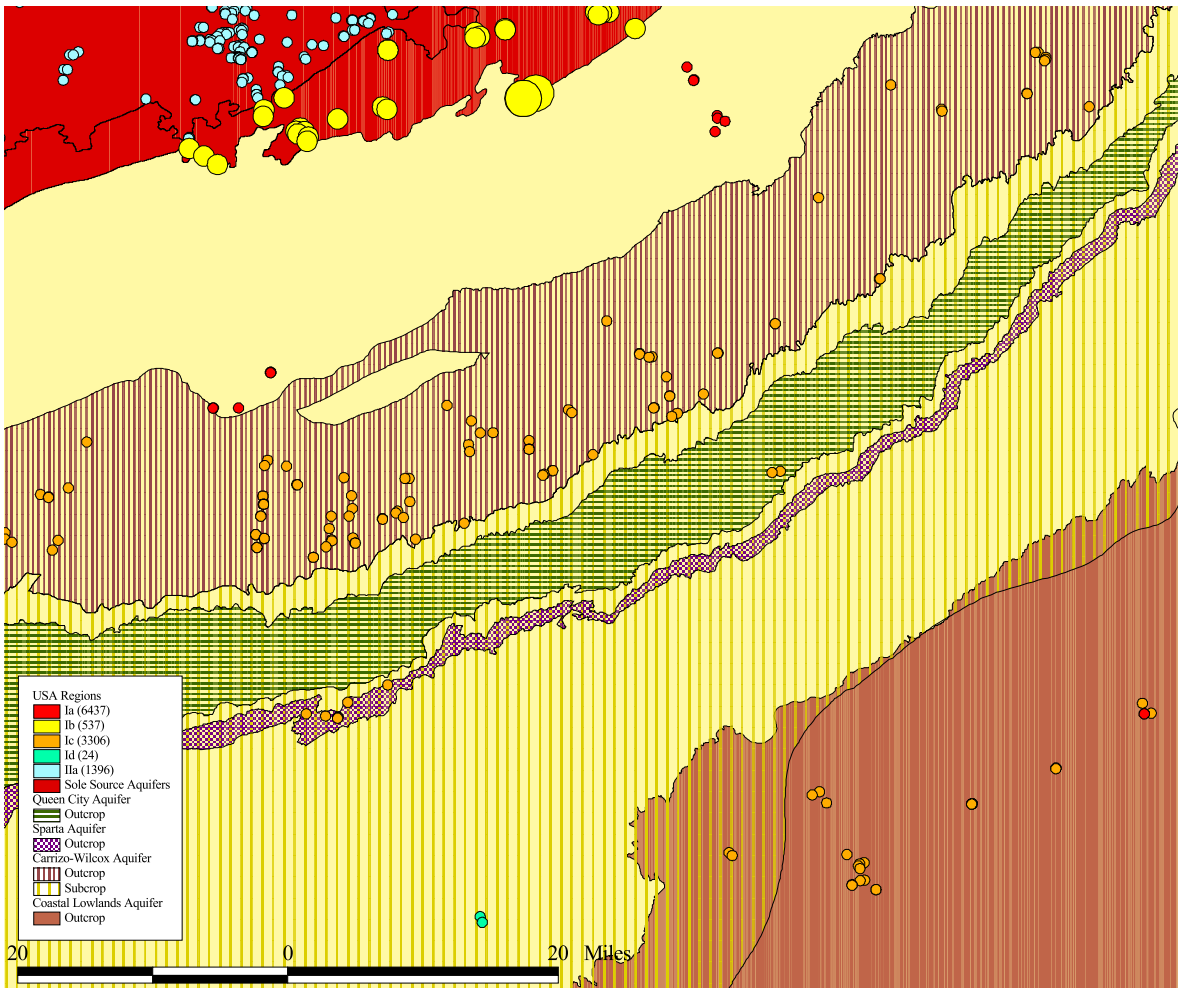

FIGURE 16. Portion of Texas illustrating the multiple sizes of drinking water USAs and how they overlap across the landscape.

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