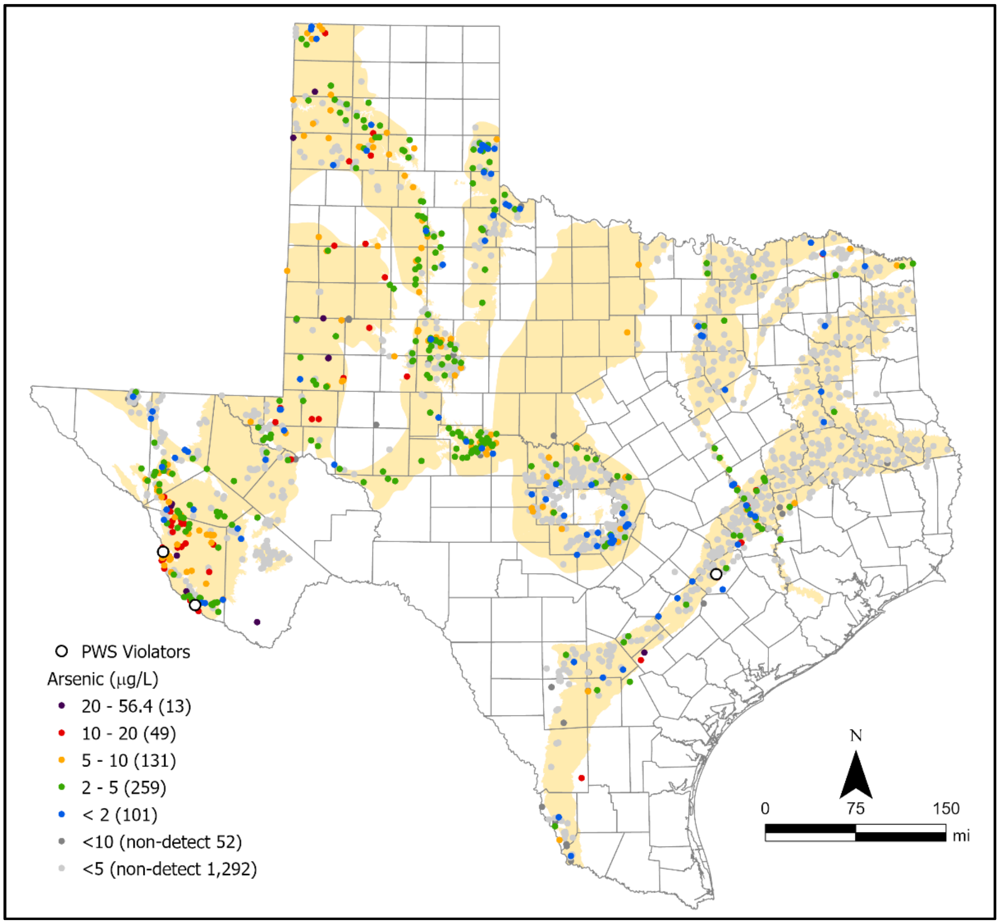
# Updated Assessment of Arsenic in Groundwater and Water Supply Systems in Minor Aquifers in Texas




by

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# Executive Summary

Understanding the spatial distribution of elevated groundwater arsenic levels is a critical issue because of adverse health effects of arsenic in drinking water. Many previous studies indicate that elevated arsenic concentrations in groundwater primarily originate from natural geologic sources. The objective of this study was to update the results from the 2018 report that focused on arsenic distribution in major aquifers by expanding to assess arsenic levels in minor aquifers in Texas.

Groundwater arsenic data were compiled from 1,895 wells from 22 minor aquifers in Texas sampled between 1992 and 2025. The spatial distribution of elevated arsenic concentrations was mapped by minor aquifer using indicator kriging based on two threshold concentrations: 5 μg/L representing nominal background concentration and 10 μg/L representing the EPA Maximum Contaminant Level (MCL). The current number of non-compliant Public Water Supply (PWS) systems and associated populations were obtained from EPA listings and the estimated populations with non-compliant non-PWS system water (domestic/self-supplied systems) were obtained from the U.S. Geological Survey water use data.

Results show that among the minor aquifers a total of 62 samples exceeded the arsenic MCL of 10 μg/L, representing 11% of all analyses with detectable arsenic and 3% of all samples used in this study. A total of 29% of the samples (553 samples) had detectable arsenic levels with a median arsenic concentration of 3.6 μg/L. The remaining 71% (1,342 samples) had non-detectable arsenic concentrations. Overall, 87% of the samples in this study (1,648 samples) were ≤5 μg/L threshold while only 3.3% (62 samples) had arsenic concentrations > 10 μg/L MCL threshold.

A total of ten out of the 22 minor aquifers had samples with arsenic levels exceeding the MCL. The sampling data are generally sparse among the minor aquifers, with the numbers of samples ranging from 10 (Cross Timbers) to 311 (Dockum) and six minor aquifers had fewer than 30 samples. The Edwards-Trinity High Plains had the highest percentage of samples exceeding the MCL (33%), followed by the West Texas Bolsons aquifers (19%) and Igneous (15%) aquifers. Seven aquifers had between 0.8% and 7.1% of samples exceeding the MCL while the remaining 12 aquifers had no samples exceeding the MCL.

Based on the EPA database, a total of only 6,072 people are served by four PWS systems that rely solely on the minor aquifer water sources and that have been non-compliant with respect to drinking water arsenic concentrations in at least one of the last 12 quarters (July 2022 – June 2025) representing 0.02% of the 2025 Texas total population. Most (99.5%, 5,802 people) are associated with a single PWS system, the Fayette Water Supply Company West, located in La Grange, Fayette County, that sources its groundwater from both the Sparta and the Yegua-Jackson aquifers and supplies the water systems for the cities of Flatonia and La Grange. The most likely source of the non-compliant groundwater is the Yegua-Jackson Aquifer.

# Introduction

Widespread groundwater arsenic (As) contamination is a critical issue in the U.S. (DeSimone *et al.*, 2014, Nordstrom, 2002;Welch and Stollenwerk, 2003). The regulations for As were revised in 2001 with a reduction of the maximum contaminant level (MCL) from 50 µg/L to 10 µg/L requiring water systems to comply with the standard in January 2006 (USEPA, 2018). This regulation is only applicable to public water systems whereas domestic wells (privately owned) are not regulated. A recent evaluation of the U.S. domestic well population vulnerable to arsenic contamination indicated that ~2.1 million (M) people out of a population of 44 M people that use domestic wells have groundwater water arsenic levels exceeding 10 µg/L (Ayotte *et al.*, 2017). Based on this study, Texas ranked 7$^{th}$ in terms of domestic population affected by arsenic contamination, with an estimated 95,000 people affected. This study was based on logistic regression with 42 variables used as proxies for groundwater arsenic concentrations, including geologic variables, groundwater recharge, soil properties, and climate etc.

Levels of groundwater arsenic that exceed the MCL are considered a health hazard. Health impacts are affected by the form of arsenic, with inorganic forms of arsenic being ~100 times more toxic than organic forms and trivalent arsenite ~60 times more toxic than hexavalent arsenate (Kain and Ali, 2000(Chung *et al.*, 2014). One of the primary arsenic exposure pathways for humans is in food; however, organic forms of arsenic in food have negligible toxicity (Abernathy et al., 2003; Chung *et al.*, 2014). Arsenic exposure from drinking-water over the long term has been linked to cancer, cardiovascular disease, skin lesions, and diabetes (Shankar *et al.*, 2014). Additional health impacts from groundwater arsenic exposure include skin, lung, bladder, kidney, and liver cancers (Hong *et al.*, 2014). Noncarcinogenic health effects from arsenic exposure include diabetes, hypertension, skin lesions, and hyperkeratosis of hand and feet (Tseng et al., 2000; Martínez-Castillo *et al.*, 2021). Arsenic exposure in utero and during early childhood has been linked to cognitive development impairment and increased mortality in young adults (Farzan *et al.*, 2013; Tolins *et al.*, 2014). Elevated arsenic is also found in chickens as it is added to chicken feed to make chickens more robust (Rutherford et al., 2006; Nigra *et al.*, 2017). High levels of arsenic are found in coal in China resulting in health impacts from coal burning (Finkelman *et al.*, 1999). Health effects of elevated arsenic in Texas aquifers have been noted in previous studies (Lesikar et al., 2006; Hasan *et al.*, 2024).

The distribution of U.S. Environmental Protection Agency (EPA) primary and secondary maximum contaminant levels (MCL) exceedances for drinking water were previously quantified in Texas (Reedy et al., 2011). An estimated 14% of the aquifer volume in the state was mapped in the high-risk category of primary MCL exceedance. Exceedances of any primary MCL in the high probability category were greatest for the Hueco-Mesilla Bolson, Seymour, and Ogallala aquifers and lowest for the Edwards (BFZ) Aquifer by both aquifer area and volume. Arsenic was found to be the most widespread contaminant in the high probability category in major aquifers, followed by fluoride, alpha radiation, nitrate-N, and combined radium.

Arsenic is widely distributed in rocks; however, mobilization of arsenic into groundwater often limits the occurrence of elevated arsenic concentrations in groundwater (Smedley *et al.*, 2002). Important factors affecting the distribution of high groundwater arsenic levels include:

(1) an arsenic source

(2) a process for mobilizing arsenic into groundwater

(3) low recharge rates limiting flushing of arsenic in aquifers

Previous studies have delineated factors affecting groundwater vulnerability to arsenic contamination (Smedley *et al.*, 2002). Vulnerable environments to elevated groundwater arsenic levels include (1) low temperature (1a – non-mining; 1b – mining) and (2) high temperature (geothermal) settings, with low-temperature, non-mining areas having the most widespread distribution of high arsenic (Smedley and Kinniburg, 2002). Mechanisms that mobilize arsenic in these non-mining areas include (1) dissolution of and desorption from Fe oxides in reducing conditions and (2) mineral weathering and evaporation and desorption from Fe oxides and in oxidizing conditions (Smedley *et al.*, 2002). Aquifers in Argentina provide an example of processes operating in oxidizing conditions, such as a high influx of arsenic from volcanic glass dissolution, followed by arsenic adsorption onto hydrous Fe or Al oxides, and then mobilization related to elevated pH (8–9) linked to mineral weathering (Smedley *et al.*, 2005; Bhattacharya *et al.*, 2006). Elevated concentrations of arsenic were found in the Southern High Plains (SHP) aquifer in Texas (Nativ and Smith, 1987; Nativ, 1988; Hudak, 2000)). This region is classified as a low temperature, non-mining area (Smedley and Kinniburgh, 2002). Groundwater is under oxidizing conditions based on $O_2$ (DO), $NO_3$, and $SO_4$ levels. Early studies attributed high arsenic levels to application of arsenical pesticides to defoliate cotton because of collocation of elevated groundwater arsenic and cotton production areas, higher arsenic levels in groundwater in shallow water table areas, and linkages with other contaminants related to agriculture, such as nitrate (Nativ, 1988; Hudak, 2000). However, intensive drilling of the unsaturated zone in these areas and soil-profile sampling and chemical analyses, show that water-extractable arsenic from application of arsenical pesticides is limited to the shallow subsurface soil zone within the upper 2 ft of the land surface (60 cm) and is also linked with elevated $PO_4$ levels from fertilizer application (Reedy *et al.*, 2007). High levels of arsenic at depths > 3 ft depth beneath native rangeland and cropland regions were attributed to a geologic source because native rangelands never received pesticides and high levels of $PO_4$ were not found at depth beneath native rangeland and cropland settings.

Hotspots of groundwater arsenic contamination in Texas were mapped in previous studies, including the southern High Plains and southern Gulf Coast regions (Gates *et al.*, 2011; Scanlon *et al.*, 2009). In the southern High Plains, about half of the analyses had arsenic levels exceeding the MCL of 10 µg/L. Arsenic contamination was correlated with elevated F, V, Se, B, Mo and $SiO_2$ indicating a common origin in volcanic ashes, which are found in the southern High Plains and assumed to originate from the Rocky Mountains to the west. The sequence of processes resulting in groundwater arsenic contamination is thought to be leaching of ashes occurring early on, followed by arsenic adsorption on hydrous metal oxides throughout the southern High Plains, as shown by high correlations between arsenic and other anion such as F and oxyanion forming elements such as V, Se, B and Mo (Scanlon *et al.*, 2009). In oxidizing systems, such as the southern High Plains, the most widespread mechanism for mobilizing arsenic is increased pH associated with increased TDS; however, pH in the southern High Plains is near neutral; therefore, this mechanism did not cause arsenic mobilization. The most likely cause of arsenic mobilization throughout the southern High Plains Aquifer is the counter-ion effect related to a water chemistry change from Ca- to Na-rich water, associated with upward migration of groundwater with high Na and high TDS from the underlying Dockum aquifer. This explanation is supported by the high correlation between arsenic and $Na/(Ca)^{0.5}$ ratios in the aquifer (r= 0.57). This counter-ion effect is likely responsible for mobilizing other ions also as evidenced by high correlations between arsenic and these elements (F, $\rho$ = 0.56; V, $\rho$ = 0.88; Se, $\rho$ = 0.54; B, $\rho$ = 0.51; Mo, $\rho$ = 0.46 and $SiO_2$, $\rho$ = 0.41).

Detailed studies were also conducted in the southern Gulf Coast hotspot of arsenic contamination (Gates *et al.*, 2011). Concentrations of arsenic were found to decrease downdip from the Catahoula Formation, consistent with Miocene volcanic ash in this unit being the primary source of groundwater arsenic in the region. Correlations between arsenic and V, $SiO_2$, and K were found to be high, attributed to weathering of volcanic sediments. The aquifers are characterized by circum-neutral pH and oxidizing conditions, typically associated with immobilization of arsenic by adsorption of arsenate onto Fe oxides and clays. However, groundwater in about 30% of the wells had elevated arsenic levels exceeding the MCL. High levels of Si co-released with arsenic may compete for sorption sites and decrease the arsenate adsorption capacity.

The objectives of this study were to evaluate the distribution of arsenic in the minor aquifers in Texas, considering two threshold levels, 5 µg/L and 10 µg/L (MCL). Indicator kriging was used to evaluate the probability of exceeding these threshold values in the aquifers. The probability of exceeding these thresholds was linked to the population being served by these water sources to determine the vulnerability of the population to elevated arsenic levels. This study builds on previous studies that examined groundwater contamination from a variety of natural sources (Reedy *et al.*, 2007) and detailed process studies examining unsaturated zone and groundwater arsenic levels in the southern High Plains and southern Gulf Coast aquifers (Gates *et al.*, 2009, Reedy *et al.*, 2007; Scanlon *et al.*, 2009).

# Methods

## Data Sources

Data on groundwater arsenic concentrations for this study were obtained primarily from two sources: the Texas Water Development Board (TWDB) groundwater database and the Texas Commission of Environmental Quality (TCEQ) public water supply (PWS) database. The TWDB database contains water analyses sampled from groundwater well-heads prior to any treatment processes, and the results are considered representative of groundwater conditions at that location at the time of sampling. In contrast, the PWS database contains both well-head samples and samples obtained from various locations in the water distribution system. In the initial analysis for this study, only PWS database groundwater well-head samples were used (samples attributed as "raw" water in the database) because samples obtained from locations within the distribution system might reflect post-treatment conditions.

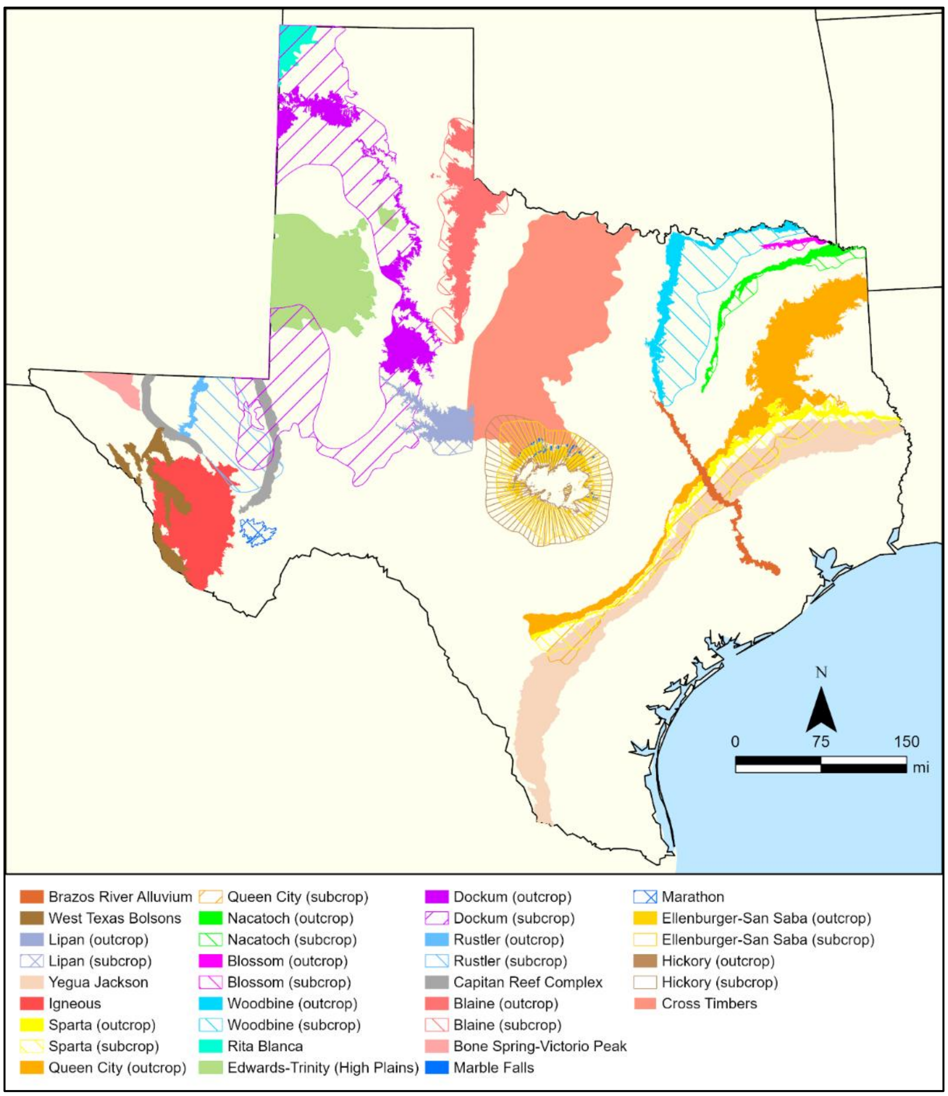



Figure 1. Minor Aquifers of Texas. There are 22 aquifers on the list. The Cypress aquifer was removed, and the Cross Timbers was added to the list in August 2017.

The source aquifer for pumped water was identified for all groundwater wells in both databases. Only samples from wells that were completed in a single aquifer, which represent 98% of all samples, were used in this study. The aquifers represented in this study include the 22 minor aquifers (Figure 1. ) identified and named by the TWDB. Sample data from the PWS and TWDB databases were compared to avoid duplication.

Due to technological improvements in analytical precision and corresponding lower detection limits, only samples obtained during or after 1992 were used in this study, excluding analyses prior to 1992. Only the latest sample from a given well was used in this study. Arsenic concentrations are reported in units of micrograms per liter (µg/L). Analytical detection limits for arsenic varied based on the laboratory and method used. Analytical results for samples with undetectable arsenic concentrations are deemed "non-detects" and results are shown with the "<" symbol followed by the method detection limit.

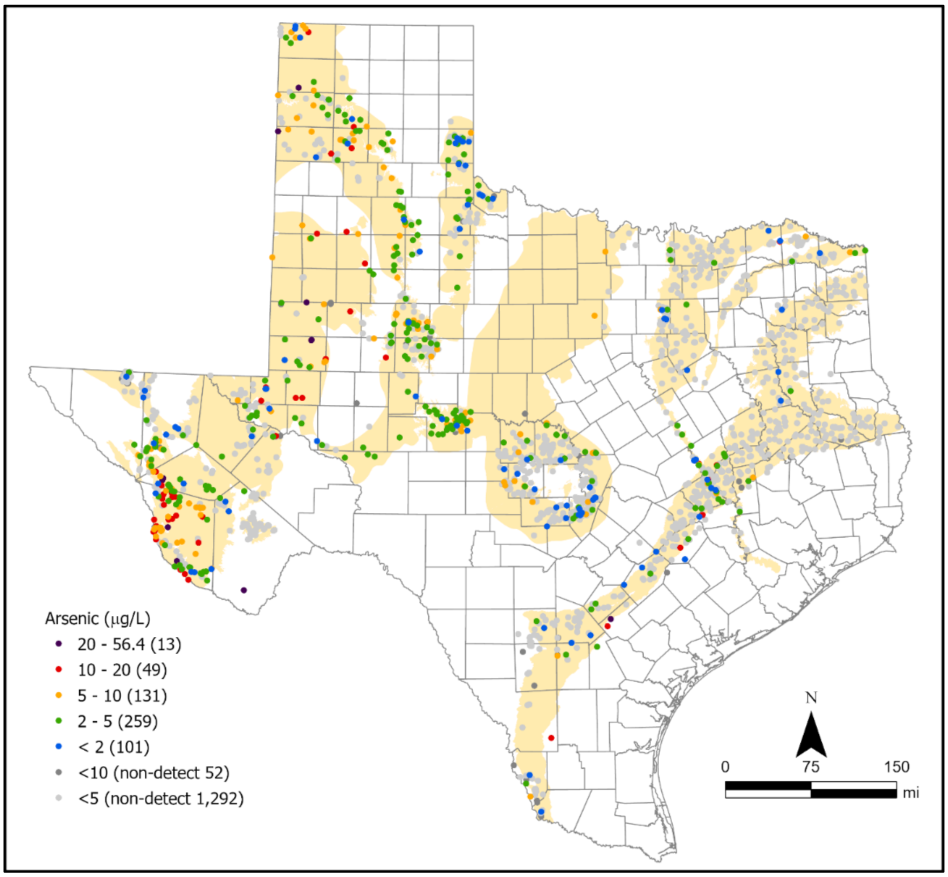



Figure 2. Spatial distribution of arsenic concentrations in Texas groundwater, including samples collected from 1992 – 2025 with detected concentrations (<2 – 56.4 µg/L) and non-detected concentrations (<5 and <10 µg/L). The numbers of samples within the stated concentration ranges are shown in parenthesis and include some samples that are not in a named minor aquifer and not used in this study.

Samples from 1,895 groundwater wells completed in minor aquifers in Texas are represented in this study. Among these are 1,342 samples with arsenic concentrations below the various method detection limits, representing 71% of all samples. The highest non-detect concentration level included in this study is equal to the US Environmental Protection Agency (EPA) drinking water Maximum Contamination Level (MCL) of 10 µg/L (Figure 3). A small number of samples with detection limits above the MCL were rejected. Most of the non-detect samples (1,288, 96%) have a detection limit of ≤5 µg/L.

There were 553 samples with arsenic concentrations above detection limits, representing 29% of all samples. The median detected concentration is 3.6 μg/L (Figure 4). A total of 62 samples exceeded the 10 μg/L MCL concentration, representing 11% of all samples with detected concentrations and 3% of all samples. A total of 360 samples, representing 65% of all samples with detected arsenic concentrations were ≤ 5 μg/L threshold.

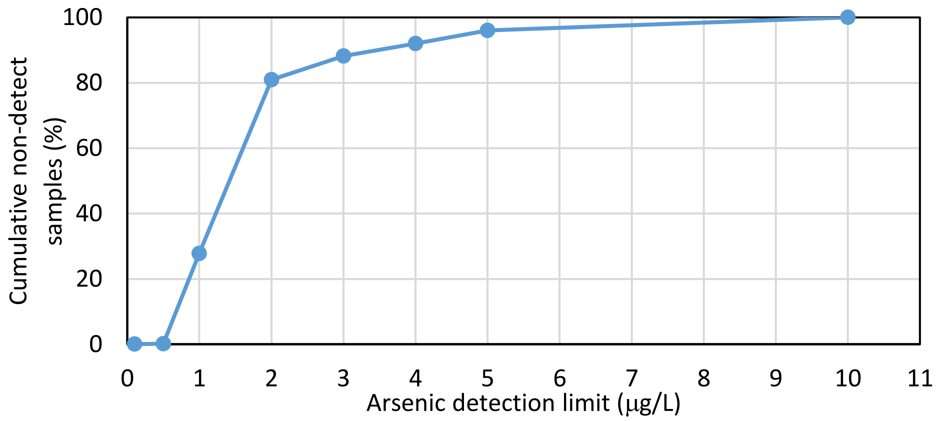



Figure 3. Distribution of non-detect arsenic concentrations.

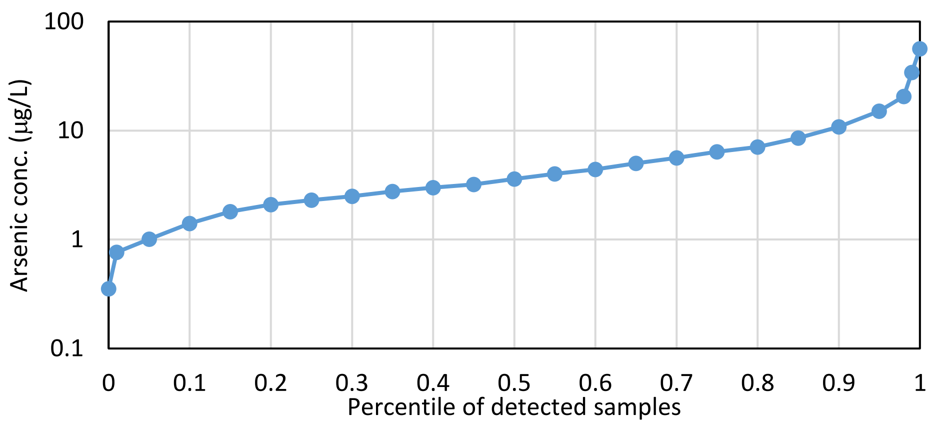



Figure 4. Distribution of detected arsenic concentrations.

## Data Analysis

Arsenic concentrations were evaluated by aquifer for both statistical and spatial distributions. Statistical analyses include simple determinations of the numbers of samples, numbers of non-detects, the mean, minimum and maximum concentrations, and selected percentile concentrations. The Geostatistical Analyst extension in ArcGIS Pro 3.5.2 was used to generate maps representative of the arsenic spatial distribution in the different aquifers. Indicator kriging was used as this method can incorporate the non-detect data as well as the detect data. It also has the advantage that no assumptions are made regarding normality of the underlying (and unknown) distribution of the concentration data.

Indicator kriging does not result in a concentration map. Rather, the output is a map of the estimated probability of arsenic concentrations exceeding a selected threshold value. Two threshold values were used. A lower threshold of 5 µg/L was selected to represent a conservative estimate to identify areas where the likelihood that groundwater arsenic concentrations exceed "background". For these analyses, non-detect samples with detection limits greater than 5 µg/L were omitted.

A higher threshold value of 10 µg/L was used to identify areas where the likelihood that groundwater arsenic concentrations exceed the MCL for drinking water. Maps were generated for both threshold values for each aquifer having sufficient data points to warrant application of the method. As a general rule-of-thumb, it is desirable to have 100 or more data points and 30 to 50 is considered the minimum required to obtain a statistically stable and meaningful result using kriging methods, with consideration further given to the spatial distribution of points within the modeled area. There were sufficient data to produce kriged maps for 16 of the minor aquifers. Of these, 11 aquifers had 63 to 311 points while the remaining five aquifers had between 34 and 44 points.

The indicator kriging procedure begins with a transformation of the concentration data into a binary form of either 0 (zero) if a data point is ≤ the threshold value or 1 (one) if the data point exceeds the threshold value. A semi-variogram or covariance model is created that represents the average variance/covariance between data locations as a function of the separation distance between the data points. The use of either a semi-variogram or covariance is dictated by which approach produces the most consistent model given the individual data sets for each aquifer. The model may include directional anisotropy components if there is structure based on azimuthal direction within the data. A mathematical model was then fit to the semi-variogram or covariance points and this model was used to predict values at locations between the data points. The resulting output is a grid map of predicted probability (or likelihood) values that arsenic concentrations exceed the threshold value. In this study a uniform grid cell size of 1 km x 1 km was selected.

The resulting maps depict the estimated spatial distribution of the probability or likelihood of exceeding the threshold value on an integer scale between 0% and 100%. For this study we characterized the probability ranges using seven categories with descriptive terms, including none (0%), very low (<10%), low (10-25%), moderate (25-50%), elevated (50-75%), high (75-90%), and very high (>90%). The maps should be interpreted in part with consideration given to the spatial distribution of the underlying data as data may be clustered in some areas and relatively sparse elsewhere. Some artifacts may be present in the maps that arise primarily from low data density in given subareas and/or from (directional) anisotropy in the underlying semi-variogram structure.

All of the aquifer probability maps are provided as page-width size graphics in Appendix I for the reader's convenience.

## At Risk Population Estimates

A separate assessment was performed to estimate the various populations at risk of exposure to arsenic concentrations both above nominal background and above the MCL. The analysis focused on two general classes of water supply systems that were assessed separately, including:

1) public water supply systems that are regulated by the TCEQ and

2) domestic or otherwise self-supplied systems that are not regulated.

In the latter case, methods that estimate the populations relying on domestic supplies have not produced consistent results in some areas of Texas. In this updated study of minor aquifer arsenic concentrations, we use the same domestic population estimates from the original 2018 report that were generated by the USGS for 2015.

### Public Water Supply Systems

Public water supply (PWS) systems in Texas are regulated by the TCEQ and ultimately by the US EPA and must provide distribution system water sample analyses to monitor system performance with respect to various potential contaminants of concern, including arsenic. Sample data from the TCEQ database were assessed to estimate the at-risk PWS populations for arsenic concentrations in excess of the nominal background level (> 5µg/L) in the distribution systems. These assessments were based on whether the PWS system had least one distribution water sample with > 5µg/L during the period from January 2012 through about July 2024.

The EPA maintains the Safe Drinking Water Information System (SDWIS) database, a national database of current PWS system water quality compliance with respect to the MCL status for all contaminants of concern (EPA, 2025). The database includes several system attributes of interest to this study, including estimates of the PWS populations served by the PWS systems that are out of compliance and identification of the sources of water for each system (surface water, groundwater, groundwater under the direct influence of surface water, or water purchased from a wholesaler who pumps and treats water). Following are excerpts from the EPA website documentation that define other attributes in the database that are of significance to this study:

<u>*Public Water Supply System Type*</u>

*"The type of public water system (PWS). A public water system is a system for the provision to the public of piped water for human consumption, which has at least 15 service connections or regularly serves an average of at least 25 individuals at least 60 days out of the year.*

- *Community water system - A PWS that serves at least fifteen service connections used by year-round residents or regularly serves at least 25 year-round residents (e.g., homes, apartments and condominiums that are occupied year-round as primary residences).*
- *Transient non-community water system - A non-community water system that does not regularly serve at least 25 of the same persons over six months per year. A typical example is a campground or a highway rest stop that has its own water source, such as a drinking water well.*
- *Non-transient non-community water system - A non-community PWS that regularly serves at least 25 of the same persons over six months per year. A typical example of a non-transient non-community water system is a school or an office building that has its own water source, such as a drinking water well."*

*Compliance Status*

- *“Serious Violator*
    - *'Yes' indicates a public water system with unresolved serious, multiple, and/or continuing violations that is designated as a priority candidate for formal enforcement, as directed by EPA's Drinking Water Enforcement Response Policy.*
    - *EPA designates systems as serious violators so that the drinking water system and primacy agency will act quickly to resolve the most significant noncompliance. Many public water systems with violations, however, are not serious violators. Operators and the primacy agencies are expected to correct the violations at non-serious violators as well, but without the more strict requirements and deadlines applicable to serious violators. If the violations at a non-serious violator are left uncorrected, that system may become a serious violator. When a serious violator has received formal enforcement action or has returned to compliance, it is no longer designated a serious violator. EPA updates its serious violator list on a quarterly basis.*
- *Health-Based Violations*
    - *Violations of maximum contaminant levels (MCLs) or maximum residual disinfectant levels (MRDLs), which specify the highest concentrations of contaminants or disinfectants, respectively, allowed in drinking water; or of treatment technique (TT) rules, which specify required processes intended to reduce the amounts of contaminants in drinking water. MCLs, MRDLs, and treatment technique rules are all health-based drinking water standards.”*

*Compliance Points*

- *“EPA uses a weighted point system that reflects the degree of noncompliance at each public water system; generally more points mean more violations of a serious nature. The point system allows primacy agencies – usually states – to rank public water systems in order of severity of noncompliance, so that those with more serious noncompliance can receive appropriate responses, including formal enforcement action.”*

Table 1. EPA guidelines for assigning violation point values to PWS systems.

| *Points* | *Description* |
|---|---|
| 10 | • Acute contaminant maximum contaminant level (MCL) violation (total coliform or nitrate) |
| 5 | • MCL or treatment technique violation for regulated contaminants other than total coliform or nitrate<br>• Nitrate monitoring and reporting violation<br>• Total coliform repeat monitoring violation |
| 1 | • Monitoring and reporting violation not listed above<br>• Public notice violation<br>• Consumer Confidence Report violation<br>• Additional point for each year a violation is unaddressed |

For this study, we summarized by aquifer the PWS system populations that had health-based violations (as opposed to reporting or public notice violations) related to arsenic. The EPA tracks system compliance on a quarterly basis and summarizes violations for the most recent 12-quarter period (July 2022 – June 2025) plus any new violations reported since the end of the latest official quarter.

## Non-Public Water Supply Systems

Domestic and self-supplied systems are not regulated by the TCEQ. These systems are generally located in rural areas or are otherwise not connected to a regulated PWS system and are referred to in this study are non-PWS systems. Estimates of the at-risk non-PWS population were made by aquifer using the kriging probability maps discussed earlier coupled with estimates of the non-PWS county populations based on projections by the United States Geological Survey for 2015, the latest published year for that information (USGS, 2015, https://water.usgs.gov/watuse/).

The spatial mean probability of exceeding the 10 µg/L MCL threshold value was estimated for each unique aquifer-county area using the GIS probability maps. The spatial means were then multiplied by the non-PWS populations for each county to obtain initial estimates of the at-risk populations. The initial estimates were finally adjusted to remove populations in county areas not underlain by the given aquifers. The final county results were summed across each aquifer.

This approach assumes that the non-PWS populations are evenly distributed within each county. The county areas were not adjusted for areas served by PWS systems. Therefore, the at-risk populations may be conservatively over-estimated in areas dominated by PWS systems. Finally, multiple aquifers are present at the same locations in some areas which could lead to double-accounting of the populations in those overlapping areas. The primary areas where this situation occurs that affect relatively larger populations are where the Edwards Balcones Fault Zone aquifer overlies the Trinity aquifer and where the Ogallala and Pecos aquifers overlie the Edwards-Trinity Plateau aquifer. Secondary areas with this situation occurring and affecting relatively smaller populations are where minor aquifers either overlie each other or are overlain by a major aquifer. This study assigns the populations for a given area to the shallowest aquifer in a given area based on the logic that the shallowest aquifer in a given overlapping area is likely the primary water source for non-PWS systems.

# Results

## PWS and Non-PWS system populations

The total population of Texas increased by a factor of 3.3 between 1960 (9.58 million) and 2025 (31.85 million) with a relatively consistent average annual growth rate of 1.9% since 1990, ranging from 1.2% to 2.2% (Table 2, Figure 5). The 2025 population is estimated to be 31.85 million in 2025 (US Census Bureau). The percentage of the population served by PWS systems varied between about 80-95% between 1960 and 2015 and was 26.2 million in 2015. The USGS did not provide estimates of populations served by PWS and non-PWS water systems after 2015.

The EPA public water supply database, the Safe Drinking Water Information System (SDWIS), indicates that as of July 2025 there were 31.03 million people in Texas served by 4,711 PWSs, which is similar to the current US Census Bureau total state population for 2025 (31.85 million). Therefore, the population served by non-PWS systems cannot be estimated by difference. Historically, the USGS estimated that the population served by non-PWS systems generally fluctuated between about 0.9 to 2.7 million people during 1960 to 2015 and was estimated to be 1.32 million in 2015 (Figure 5). For this study, we assumed that 95% of the population increases after 2015 occurred in areas served by public water supply systems. We estimated that the 2025 non-PWS population increased to ~ 1.59 million, representing 5% of the total state population and an increase of 278,000 people (21%) since 2015 that are served by domestic water supply systems.

Table 2. Historical evolution of the Texas population relying on PWS and Non-PWS systems and the relative percentages of the total population (USGS, https://water.usgs.gov/watuse/data/). Values shown in parenthesis are estimates assuming that the PWS population remained steady at 95% after 2015.

| *Year* | *Total Population* | *Total Growth Rate (%/yr)* | *PWS Population* | *Non-PWS Population* | *PWS (%)* | *Non-PWS (%)* |
|---|---|---|---|---|---|---|
| 1960 | 9,580,000 | - | 8,580,000 | 1,000,000 | 89.6 | 10.4 |
| 1965 | 10,591,000 | 2.1 | 9,450,000 | 1,141,000 | 89.2 | 10.8 |
| 1970 | 11,197,000 | 1.1 | 9,240,000 | 1,957,000 | 82.5 | 17.5 |
| 1975 | 12,236,000 | 1.9 | 9,560,000 | 2,676,000 | 78.1 | 21.9 |
| 1980 | 14,013,000 | 2.9 | 11,390,000 | 2,623,000 | 81.3 | 18.7 |
| 1985 | 16,361,330 | 3.4 | 15,403,760 | 957,570 | 94.1 | 5.9 |
| 1990 | 16,986,410 | 0.8 | 16,129,900 | 856,510 | 95.0 | 5.0 |
| 1995 | 18,723,940 | 2.0 | 17,550,400 | 1,173,540 | 93.7 | 6.3 |
| 2005 | 22,859,968 | 2.2 | 20,628,993 | 2,230,975 | 90.2 | 9.8 |
| 2010 | 25,145,561 | 2.0 | 22,704,975 | 2,440,586 | 90.3 | 9.7 |
| 2015 | 27,469,114 | 1.8 | 26,154,041 | 1,315,073 | 95.2 | 4.8 |
| 2020 | 29,145,505 | 1.2 | *27,688,230* | *1,457,275* | *95.0* | *5.0* |
| 2025 | 31,853,800 | 1.9 | *30,261,110* | *1,592,690* | *95.0* | *5.0* |

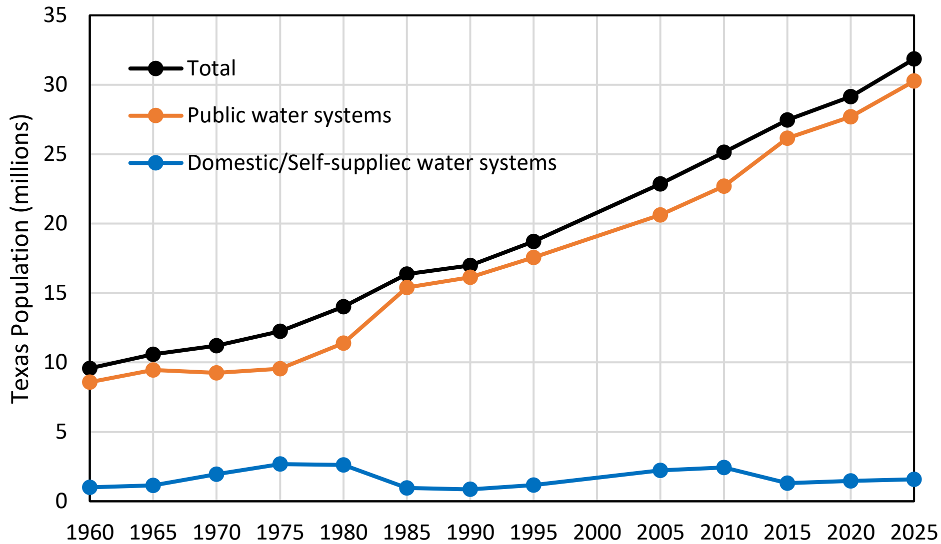



Figure 5. Historical evolution of Texas population relying on Public Water Supply (PWS) vs Domestic/Self-supplied (non-PWS) water systems (USGS, https://water.usgs.gov/watuse/data/).

## General Results

There were 1,895 groundwater wells from the 22 minor aquifers in Texas with water samples that were analyzed for arsenic. A total of 29% of the samples had detectable levels with a median arsenic concentration of 3.6 µg/L. The remaining 71% (1,342 samples) had non-detectable arsenic concentrations. Overall, 87% of the samples in this study (1,648 samples) were ≤5 µg/L threshold while only 3.3% (62 samples) had arsenic concentrations > 10 µg/L MCL threshold.

Among the minor aquifers, there were 62 samples (3.3%) with arsenic >10 µg/L and ten of the minor aquifers had samples with arsenic levels exceeding the MCL. The data are generally sparse among the minor aquifers, with the numbers of samples ranging from 10 (Cross Timbers) to 311 (Dockum) and six aquifers had fewer than 30 samples. The Edwards-Trinity High Plains had the greatest percentage of samples exceeding the MCL (33%), followed by the West Texas Bolsons aquifers (19%) and Igneous (15%) aquifers. Seven aquifers had between 0.8% and 7.1% of samples exceeding the MCL while the remaining 12 aquifers had no samples exceeding the MCL.

Based on the EPA database, a total of only 6,072 people are served by four PWS systems that rely solely on the minor aquifer water sources and that have been non-compliant with respect to drinking water arsenic concentrations in at least one of the last 12 quarters (July 2022 – June 2025) representing 0.02% of the 2025 Texas total population (Figure 7). Most (99.5%, 5,802 people) are associated with a single PWS system, the Fayette Water Supply Company West, located in La Grange, Fayette County, that sources its groundwater from both the Sparta and the Yegua-Jackson aquifers and supplies the water systems for the cities of Flatonia and La Grange. The most likely source of the non-compliant water is the Yegua-Jackson Aquifer.

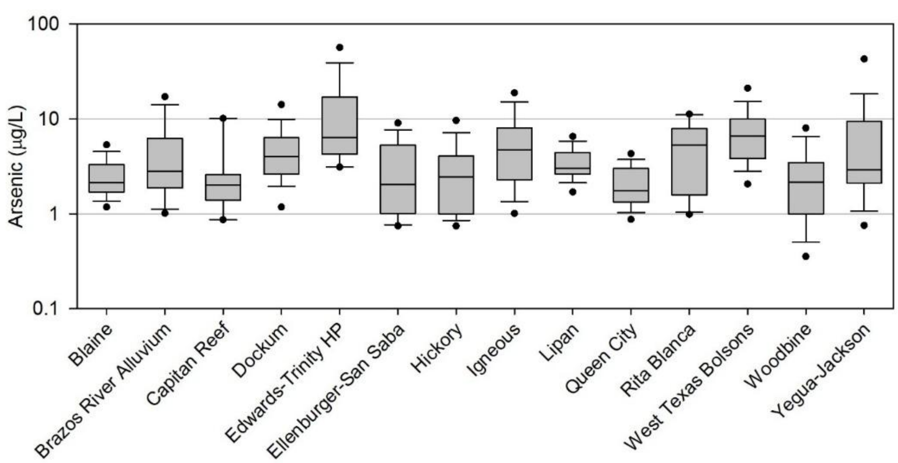



Figure 6. Distribution box plots of detected groundwater arsenic concentrations in the 14 minor aquifers of Texas with at least eight samples. The remaining eight minor aquifers (not shown) had zero to five detected arsenic sample concentrations. The lines inside the shaded boxes represent the 50th percentiles (medians), the shaded boxes represent the 25th to 75th percentile ranges, the upward and downward lines extending from the boxes are terminated by horizontal lines at the 10th and 90th percentiles, and the points represent the 5th and 95th percentiles.

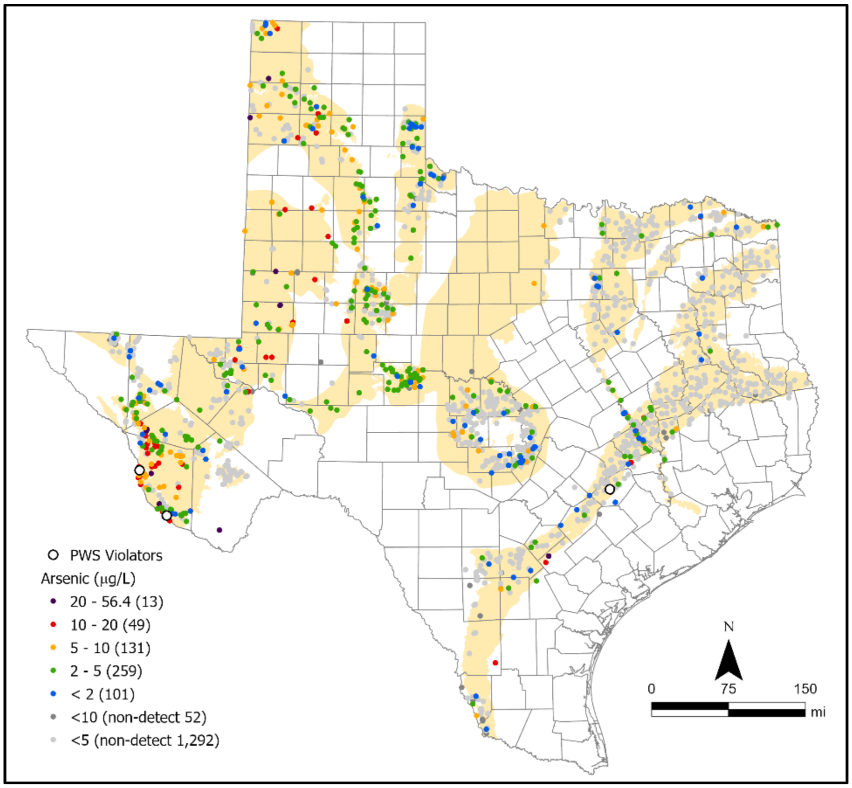



Figure 7. Locations of four PWS systems with solely a minor aquifer groundwater source that have health-related non-compliance violations for arsenic concentration in distributed water based on the EPA database. The violating systems are located in Presidio County and Fayette County.

Based on the TCEQ database, a total of 16,412 people (about 0.05% of the 2025 Texas total population) are served by minor aquifer PWS systems that have distributed water with arsenic concentrations above the background threshold of 5 µg/L (this includes the MCL violations) (Table 3).

Table 3. Texas populations served by minor aquifer PWS and non-PWS systems with arsenic concentrations above background (>5 µgl/L) and above the MCL (>10 µgl/L).

| *Water Source* | *PWS population* | | *Non-PWS population* | *PWS & Non-PWS population* |
|---|---|---|---|---|
| | *Arsenic > 5 µgl/L* | *Arsenic > 10 µg/L* | *Arsenic > 10 µg/L* | *Arsenic > 10 µg/L* |
| All Minor Aquifers | 16,412 | 6,072 | 1,635 | 1,902 |

## Minor Aquifer Results

There were sufficient data (≥30 samples) to perform indicator kriging on arsenic concentrations for 16 of the 22 minor aquifers in Texas. Maps were not generated for the remaining six minor aquifers with <30 data points. Data for the minor aquifers represent 1,894 samples (Table 4). Of all the minor aquifer samples, 29% (553) had detectable concentrations while 71% (1,341) had non-detectable concentrations. A total of 10.2% (193) of the minor aquifer samples exceeded the nominal arsenic background concentration of 5 µg/L and 3.3% (62) samples exceeded the MCL of 10 µg/L. Ten of the minor aquifers had at least one sample with arsenic >10 µg/L. Median detected arsenic concentrations ranged from 1.5 µg/L in the Queen City aquifer to 7.0 µg/L in the Blossom aquifer (Table 5).

Table 4. Numbers of arsenic samples from the minor aquifers in Texas since 1992. Values are based on the latest samples from the TWDB groundwater database and raw water samples from the TCEQ PWS database. Samples from wells completed in multiple aquifers are not included.

| *Minor Aquifer* | *Number of Samples* | *Number of Detects* | *Number of Non-detects* | *Detects >5 µg/L* | | *Detects >10 µg/L* | |
|---|---|---|---|---|---|---|---|
| | | | | *Number* | *%* | *Number* | *%* |
| Blaine | 79 | 32 | 47 | 2 | 2.5 | 0 | 0.0 |
| Blossom | 20 | 3 | 17 | 2 | 10.0 | 1 | 5.0 |
| Bone Spring-Victorio Peak | 43 | 2 | 41 | 0 | 0.0 | 0 | 0.0 |
| Brazos River Alluvium | 44 | 21 | 23 | 6 | 13.6 | 2 | 4.5 |
| Capitan Reef Complex | 37 | 8 | 29 | 1 | 2.7 | 1 | 2.7 |
| Cross Timbers | 10 | 2 | 8 | 2 | 20.0 | 0 | 0.0 |
| Dockum | 311 | 181 | 130 | 66 | 21.2 | 16 | 5.1 |
| Edwards-Trinity (High Plains) | 18 | 16 | 2 | 11 | 61.1 | 6 | 33.3 |
| Ellenburger-San Saba | 164 | 19 | 145 | 6 | 3.7 | 0 | 0.0 |
| Hickory | 137 | 22 | 115 | 4 | 2.9 | 0 | 0.0 |
| Igneous | 78 | 51 | 27 | 25 | 32.1 | 12 | 15.4 |
| Lipan | 63 | 52 | 11 | 10 | 15.9 | 0 | 0.0 |
| Marathon | 34 | 0 | 34 | 0 | 0.0 | 0 | 0.0 |
| Marble Falls | 20 | 4 | 16 | 1 | 5.0 | 0 | 0.0 |
| Nacatoch | 34 | 5 | 29 | 1 | 2.9 | 0 | 0.0 |
| Queen City | 226 | 16 | 210 | 0 | 0.0 | 0 | 0.0 |
| Rita Blanca | 14 | 10 | 4 | 5 | 35.7 | 1 | 7.1 |
| Rustler | 29 | 1 | 28 | 0 | 0.0 | 0 | 0.0 |
| Sparta | 119 | 4 | 115 | 2 | 1.7 | 1 | 0.8 |
| West Texas Bolson | 92 | 68 | 24 | 41 | 44.6 | 17 | 18.5 |
| Woodbine | 169 | 14 | 155 | 1 | 0.6 | 0 | 0.0 |
| Yegua-Jackson | 153 | 22 | 131 | 7 | 4.6 | 5 | 3.3 |
| All Minors | 1,894 | 553 | 1,341 | 193 | 10.2 | 62 | 3.3 |

Table 5. Distributions of detected arsenic concentrations from the minor aquifer samples in Texas since 1992. Values are based on the latest samples from the TWDB groundwater database and raw water samples from the TCEQ PWS database. Samples from wells completed in multiple aquifers are not included.

| *Minor Aquifer* | *Detect Samples* | *Mean (µg/L)* | *Percentile (µg/L)* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Min* | *0.05* | *0.1* | *0.25* | *0.50* | *0.75* | *0.90* | *0.95* | *Max* |
| Blaine | 32 | 2.5 | 1.1 | 1.3 | 1.4 | 1.7 | 2.1 | 3.2 | 4.3 | 4.9 | 5.4 |
| Blossom | 3 | 7.9 | 2.0 | 2.5 | 3.0 | 4.5 | 7.0 | 10.9 | 13.2 | 13.9 | 14.7 |
| Bone Spring-Victorio Peak | 2 | 2.5 | 1.9 | 1.9 | 2.0 | 2.2 | 2.5 | 2.9 | 3.1 | 3.1 | 3.2 |
| Brazos River Alluvium | 21 | 4.7 | 1.0 | 1.1 | 1.2 | 2.0 | 2.8 | 6.1 | 9.6 | 15.3 | 17.3 |
| Capitan Reef Complex | 8 | 2.9 | 0.9 | 1.0 | 1.1 | 1.7 | 2.0 | 2.6 | 4.9 | 7.5 | 10.1 |
| Cross Timbers | 2 | 7.1 | 6.9 | 7.0 | 7.0 | 7.0 | 7.1 | 7.2 | 7.3 | 7.3 | 7.3 |
| Dockum | 181 | 5.5 | 0.8 | 1.3 | 2.0 | 2.6 | 4.0 | 6.3 | 9.8 | 11.8 | 45.1 |
| Edwards-Trinity (High Plains) | 16 | 12.5 | 3.1 | 3.1 | 3.2 | 4.3 | 6.4 | 15.3 | 25.1 | 37.6 | 56.4 |
| Ellenburger-San Saba | 19 | 3.0 | 0.7 | 0.8 | 0.8 | 1.0 | 2.0 | 5.3 | 6.2 | 7.8 | 9.0 |
| Hickory | 22 | 3.0 | 0.7 | 0.8 | 1.0 | 1.0 | 2.5 | 4.0 | 6.5 | 7.4 | 10.0 |
| Igneous | 51 | 6.7 | 1.0 | 1.2 | 1.4 | 2.4 | 4.8 | 7.9 | 13.8 | 17.1 | 33.1 |
| Lipan | 52 | 3.5 | 1.2 | 2.0 | 2.2 | 2.7 | 3.0 | 4.3 | 5.7 | 6.4 | 6.9 |
| Marathon | 0 | - | - | - | - | - | - | - | - | - | - |
| Marble Falls | 4 | 3.4 | 2.2 | 2.2 | 2.2 | 2.3 | 2.8 | 3.8 | 5.0 | 5.3 | 5.7 |
| Nacatoch | 5 | 3.7 | 2.0 | 2.0 | 2.1 | 2.2 | 3.4 | 3.7 | 5.7 | 6.3 | 7.0 |
| Queen City | 16 | 2.1 | 0.9 | 1.0 | 1.1 | 1.4 | 1.8 | 2.8 | 3.5 | 3.7 | 4.3 |
| Rita Blanca | 10 | 5.2 | 1.0 | 1.2 | 1.4 | 1.7 | 5.3 | 7.2 | 10.0 | 10.6 | 11.2 |
| Rustler | 1 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| Sparta | 4 | 5.3 | 1.4 | 1.8 | 2.1 | 3.2 | 4.5 | 6.6 | 9.0 | 9.8 | 10.6 |
| West Texas Bolson | 68 | 8.3 | 1.0 | 2.2 | 2.8 | 4.0 | 6.6 | 9.4 | 15.1 | 19.0 | 46.7 |
| Woodbine | 14 | 2.6 | 0.4 | 0.5 | 0.8 | 1.2 | 2.2 | 3.0 | 5.0 | 6.1 | 8.0 |
| Yegua-Jackson | 22 | 7.3 | 0.7 | 1.0 | 1.2 | 2.3 | 2.9 | 8.2 | 17.8 | 18.4 | 47.0 |
| All Minors | 553 | 5.4 | 0.4 | 1.0 | 1.4 | 2.3 | 3.6 | 6.4 | 10.8 | 15.0 | 56.4 |

Table 6. Numbers of minor aquifer PWS systems with arsenic concentrations greater than nominal background (> 5 µg/L) and greater than the MCL (> 10 µg/L) The populations shown are those associated with PWS distribution systems. The numbers of public entity supply systems are also shown. Public entity systems provide non-utility access to the public and do not have an associated fixed population number.

| *Aquifer* | *Arsenic concentrations (>5 µg/L)* | | |
|---|---|---|---|
| | *Public Entity* | *Distribution Systems* | *PWS At-risk Population* |
| Dockum | 3 | 1 | 87 |
| Hickory | 1 | 1 | 60 |
| Igneous | 0 | 3 | 2,029 |
| West Texas Bolsons | 0 | 2 | 5,596 |
| Yegua-Jackson | 0 | 5 | 8,347 |
| Total Minor Aquifers | 4 | 12 | 16,116 |

Table 7. Estimated non-PWS system at risk populations with groundwater arsenic concentrations greater than the MCL (> 10 µg/L) in the minor aquifers. The populations shown represent a 10% increase from the values shown in the original 2018 report (Reedy and Scanlon, 2018).

| *Aquifer* | *Non-PWS at-risk Population* |
|---|---|
| Igneous | 161 |
| Sparta | 279 |
| West Texas Bolsons | 54 |
| Yegua-Jackson | 1,306 |
| Total Minor Aquifers | 1,800 |

## Blaine

The Blaine aquifer covers 5,700 $mi^2$ and extends across parts of 17 counties across an area varying from 20 to 60 miles wide extending southward from the eastern Panhandle region (Figure 8). The aquifer is of Permian age and includes stratigraphic components of the Blaine Formation. The saturated thickness averages 137 ft ranging up to 300 ft. Water quality is generally poor with concentrations generally between 3,000 and 10,000 mg/L TDS with high sulfate concentrations.

A total of 79 samples were analyzed for arsenic during the study period with 32 samples (40%) having detectable arsenic concentrations. Most of the samples were located in the northern half of the aquifer so the kriging results are skewed toward that region. About 90% of the area had no probability of arsenic > 5 µg/L and a further 4.5% had very low to moderate probability of arsenic >5 µg/L. About 5.5% of the total aquifer area had an elevated probability of arsenic >5 µg/L. The median concentration of samples with detectable concentrations was 2.1 µg/L and the $5^{th}$-$95^{th}$ percentile ranged from 1.3–4.9 µg/L. No samples exceeded the arsenic MCL.

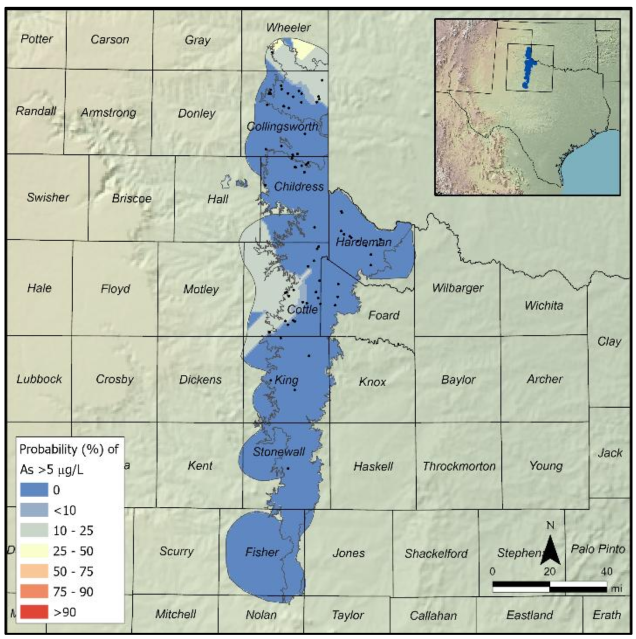



Figure 8. Blaine aquifer probability distribution of arsenic >5 µg/L. No groundwater samples from the Blane aquifer exceeded the 10 µg/L MCL concentration.

No PWS systems impacted were by arsenic concentrations >5 µg/L and therefore no PWS systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Bone Spring–Victorio Peak

The Bone Spring–Victorio Peak aquifer covers 713 $mi^2$ in the northern part of Hudspeth County in West Texas (Figure 10) and extends into southern New Mexico. The aquifer consists is of Permian limestone. The saturated thickness is generally less than 500 ft ranging up to 700 ft. Water quality is generally slightly saline with concentrations generally between 1,000 and 3,000 mg/L TDS ranging up to 10,000 mg/L in the Dell Valley area.

A total of 43 samples were analyzed for arsenic during the study period with only 2 samples (5%) having detectable arsenic concentrations. All of the samples are clustered in the agricultural regions around Dell City and the water is used primarily for irrigation. No samples had arsenic concentrations greater than 5 μg/L so the probability of exceeding 5 μg/L is zero. The two samples with detectable concentrations were 1.9 μg/L and 3.2 μg/L. No samples exceeded the MCL.

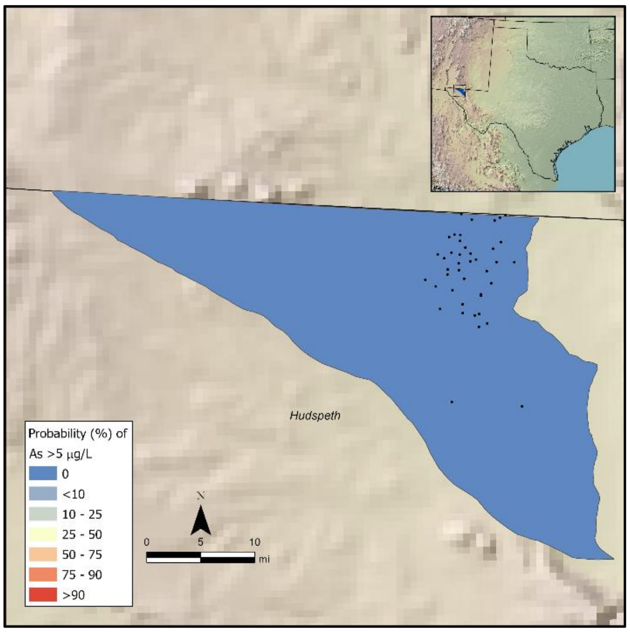



Figure 9. Bone Spring–Victorio Peak aquifer probability distribution of arsenic >5 μg/L. No groundwater samples from the Blane aquifer exceeded the 5 μg/L threshold.

There were no PWS systems impacted by arsenic concentrations >5 μg/L and therefore no PWS systems were impacted by arsenic concentrations >10 μg/L. The non-PWS system at-risk population of >10 μg/L was zero.

## Brazos River Alluvium

The Brazos River Alluvium aquifer covers 1,050 mi$^2$ and extends across parts of 12 counties along the Brazos River corridor for a distance of 350 miles with a width ranging up to 7 miles (Figure 10). The aquifer consists of floodplain and terrace deposits. The saturated thickness averages 50 ft ranging up to 168 ft. The water table slopes towards the river indicating that the Brazos River is primarily gaining and under water table conditions in most areas. Water quality is generally good with TDS concentrations generally below 1,000 mg/L though the water is very hard.

A total of 44 samples were analyzed for arsenic during the study period with 21 samples (48%) having detectable arsenic concentrations. Samples were located along the length of the aquifer but are sparse to absent in many counties. The median concentration of samples with detectable concentrations was 2.8 µg/L and the 5$^{th}$-95$^{th}$ percentile ranged from 1.1–15.3 µg/L. Two samples exceeded the MCL.

About 85% of the area had no probability of arsenic > 5 µg/L and a further 13% had very low to moderate probability of arsenic >5 µg/L. About 2% of the total aquifer area had an elevated probability of arsenic >5 µg/L located in the central part of the aquifer extent in Milam, Burleson, Robertson, and Brazos counties. About 88% of the area had no probability of arsenic > 10 µg/L and the remaining 12% had low probability.

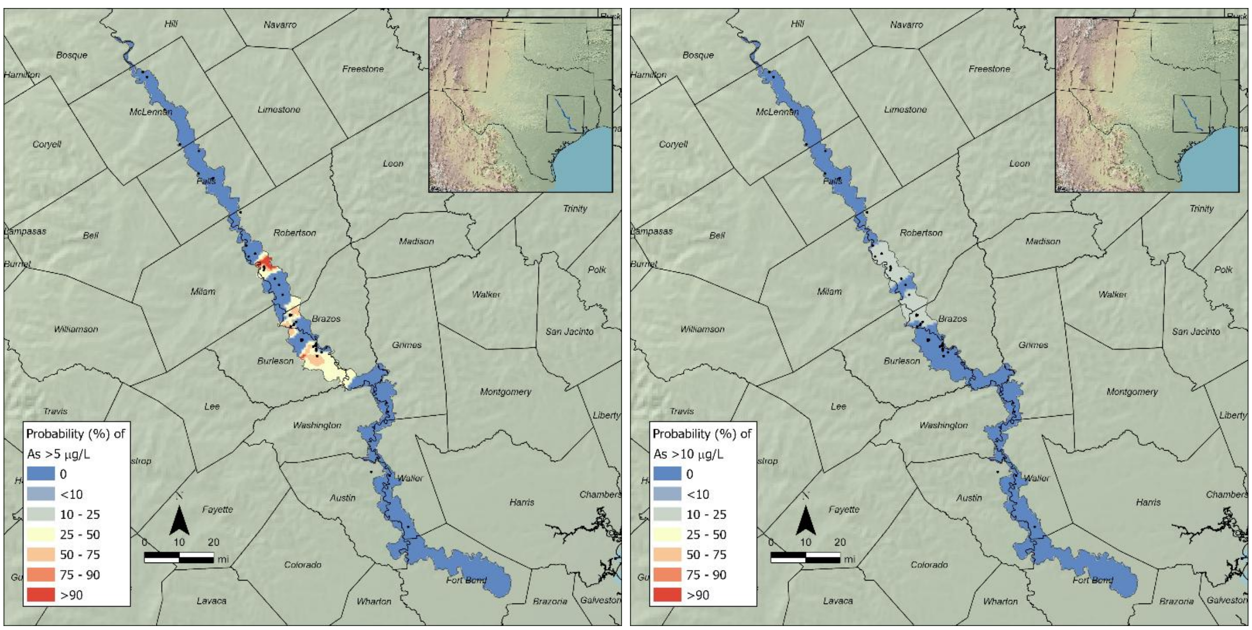



Figure 10. Brazos River Alluvium Aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

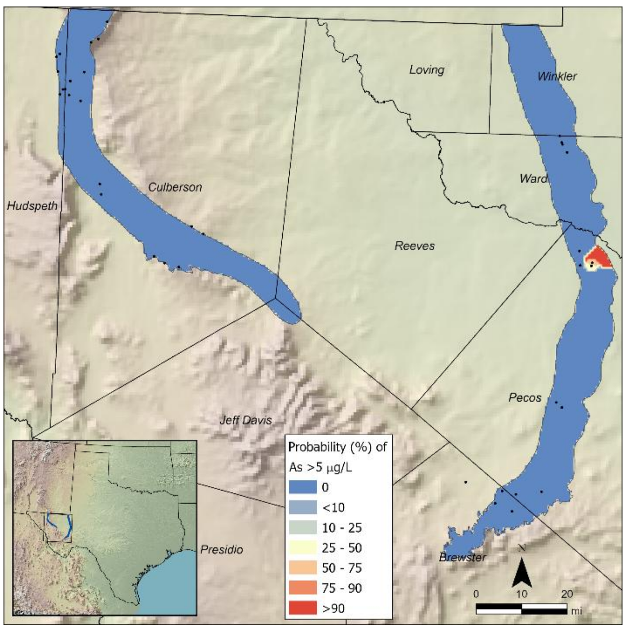
No PWS systems were impacted by arsenic concentrations >5 µg/L and therefore no PWS systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Capitan Reef Complex

The Capitan Reef Complex covers 1,850 $mi^2$ and extends across parts of 8 counties in West Texas, extending into New Mexico to the north (Figure 11). The aquifer consists of massive to cavernous limestone and dolomite ranging up to 2,360 ft thick. The aquifer is confined in most places but outcrops in areas of the western mountains. Water quality is marginal with TDS concentrations above 1,000 mg/L ranging to over 5,000 mg/L TDS. Fresher water from 300 to 1,000 mg/L TDS is present in and near the mountain outcrop areas.

A total of 37 samples were analyzed for arsenic during the study period with 8 samples (22%) having detectable arsenic concentrations. Samples were located in clusters along the length of the aquifer and were sparse to absent in many counties. The median concentration of samples with detectable concentrations was 2.0 µg/L and the $5^{th}$-$95^{th}$ percentile ranged from 1.0–7.5 µg/L. One sample exceeded the arsenic MCL.

About 99% of the area had no probability of arsenic > 5 µg/L while 1% had very high probability located in the central part of the eastern aquifer arm in Pecos County. Similarly, 99% of the area had no probability of arsenic > 10 µg/L and the remaining 1% had very high probability.



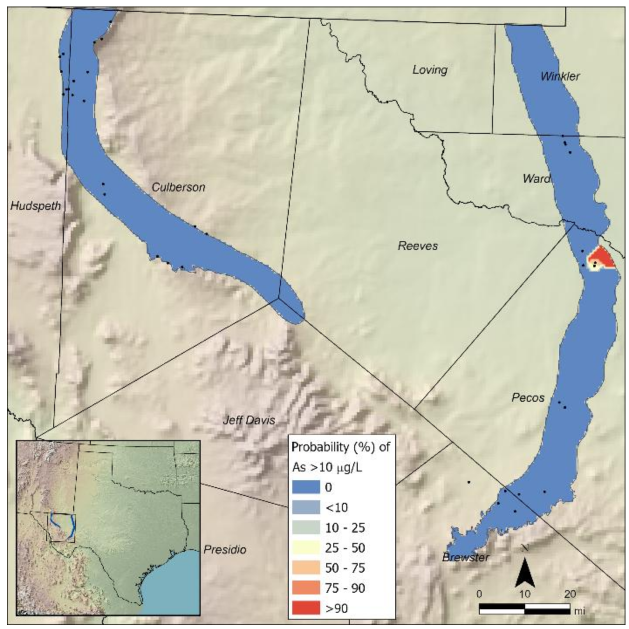




Figure 11. Capitan Reef Complex probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

No PWS system was impacted by arsenic concentrations >5 µg/L and therefore no PWS system was impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Dockum

The Dockum aquifer covers 25,600 mi$^2$ and extends across parts of 46 counties from the Oklahoma border in the northwestern Panhandle to south to the general area of Midland, Texas (Figure 12). The aquifer is Late Triassic age and includes the stratigraphic components of the Dockum Group, including the Santa Rosa, Tecovas, Trujillo, and Copper Canyon formations. Water quality is generally poor with fresh water present primarily in the outcrop areas in the north and southeast. The Dockum underlies the Ogallala, Pecos Valley, Edwards-Trinity Plateau, and Edwards-Trinity High Plains aquifers.

A total of 311 samples were analyzed for arsenic during the study period with 181 samples (58%) having detectable concentrations. About 36% of the area had no probability of arsenic > 5 µg/L and a further 51% had very low to moderate probability of arsenic >5 µg/L. About 13% of the total aquifer area had elevated to very high probabilities of arsenic >5 µg/L. The spatial pattern of probabilities displayed artifacts of limited data density, particularly in the confined areas. About 65% of the area had no probability of arsenic > 10 µg/L and a further 32% had very low to moderate probability of arsenic > 10 µg/L. About 3% of the total aquifer area had elevated to very high probabilities of arsenic >10 µg/L.

The median concentration of samples with detectable concentrations was 4.0 µg/L and the 5$^{th}$-95$^{th}$ percentile ranged from 1.3–11.8 µg/L. A total of 16 samples (5.1%) exceeded the MCL with a range of concentrations from 10.7 µg/L to 45.1 µg/L.

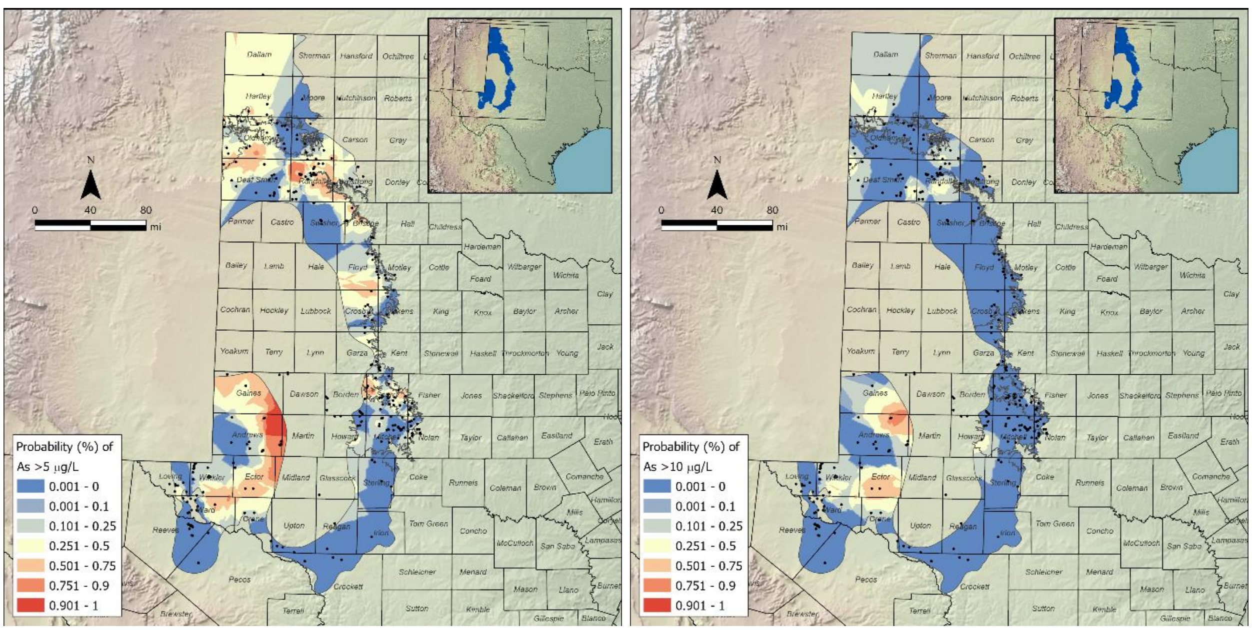



Figure 12. Dockum aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right). While the Dockum is continuous and present in the central "empty" region of the figure, the TWDB limits the extents of the defined aquifer to regions that have water with total dissolved solids (TDS) <3000 mg/L.

Based on the TCEQ PWS database, four PWS systems were impacted by arsenic concentrations >5 µg/L, including 3 public entities and 1 distribution system with a population of 87 people. Based on the EPA PWS database, there are no PWS systems that were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was high at 15,463 located primarily in Randall, Potter, and Deaf Smith counties in the north and Ector, Andrews, Gaines and Howard counties in the south. However, these areas also lie within the limits of the (overlying) Ogallala aquifer and the numbers of domestic wells in the Dockum is likely very small. Accordingly, the estimated non-PWS at-risk population was zero.

## Ellenburger–San Saba

The Ellenburger-San Saba aquifer covers 5,300 $mi^2$ and extends across parts of 16 counties surrounding the Llano Uplift in central Texas (Figure 13). The aquifer is composed of a limestones and dolomites of the Tanyard, Gorman, and Honeycut formations of the Ellenburger Group and the San Saba limestone of the Wilberns Formation and total thickness ranges up to 2,700 ft thick. The confined areas of the aquifer dip away from the uplift to depths of 3,000 ft and are compartmentalized by regional block faulting.

A total of 164 samples were analyzed for arsenic during the study period with only 19 samples (12%) having detectable concentrations. About 89% of the area had no probability of arsenic > 5 µg/L and a further 11% had very low to moderate probability of arsenic >5 µg/L. Only about 0.2% of the total aquifer area had elevated to high probabilities of arsenic >5 µg/L. The kriging results display artifacts due to limited data in large areas of the aquifer and the high probability areas are confined to very small areas around wells with elevated concentrations, potentially due to the fault compartmentalization. The median concentration of samples with detectable concentrations was 2.0 µg/L and the $5^{th}$-$95^{th}$ percentile ranged from 0.8–7.8 µg/L. No samples exceeded the 10 µg/L MCL.

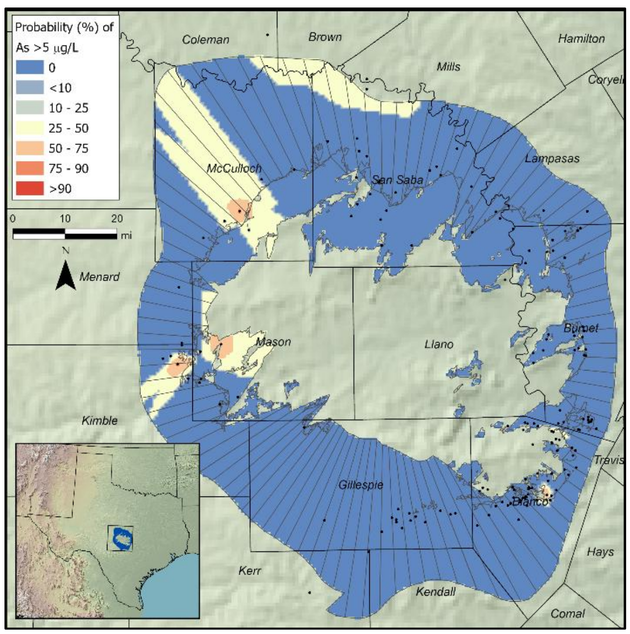



Figure 13. Ellenburger-San Saba aquifer probability distribution of arsenic >5 µg/L. There are no groundwater samples from the Ellenburger-San Saba aquifer that exceed the 10 µg/L MCL concentration.

There were no PWS systems impacted by arsenic concentrations >5 µg/L and therefore no PWS water supply systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Hickory

The Hickory aquifer covers 8,600 mi$^2$ and extends across parts of X counties surrounding the Llano Uplift in central Texas (Figure 14). The aquifer is composed of parts of the Hickory Sandstone Member of the Riley Formation with a total thickness ranging up to 480 ft thick. While water quality is generally good in the Hickory aquifer with TDS < 1,000 mg/L, the primary contaminants of concern are radium and associated radon and gross alpha radiation.

A total of 137 samples were analyzed for arsenic during the study period with only 22 samples (16%) having detectable concentrations. The kriging results display artifacts resulting from limited data in large areas of the aquifer and the high probability areas are generally confined to very small areas around the offending wells, potentially due to fault compartmentalization similar as in the Ellenburger-San Saba aquifer. About 58% of the Hickory area had no probability of arsenic > 5 µg/L and a further 38% had very low to moderate probability of arsenic >5 µg/L. About 4% of the area had elevated to high probabilities, and only about 1% of the total aquifer area had elevated to very high probabilities of arsenic >5 µg/L. The median concentration of samples with detectable concentrations was 2.5 µg/L and the 5$^{th}$-95$^{th}$ percentile range was 0.8–7.4 µg/L. No samples exceeded the 10 µg/L MCL.

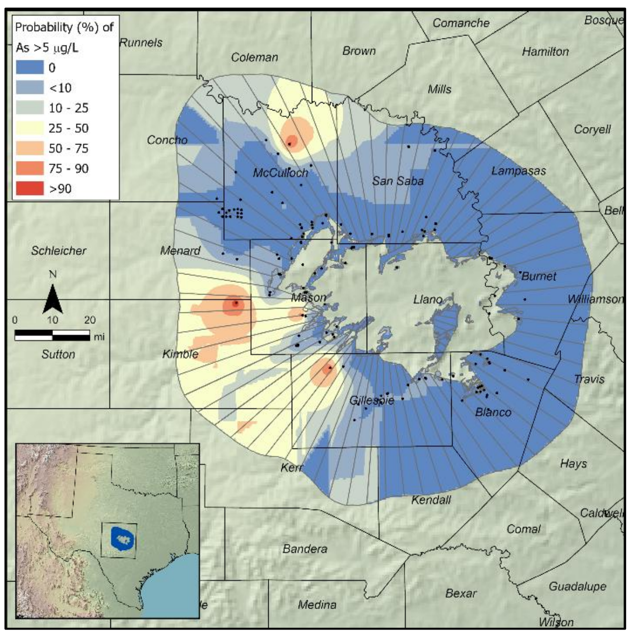



Figure 14. Hickory aquifer probability distribution of arsenic >5 µg/L. There are no groundwater samples from the Hickory aquifer that exceed the 10 µg/L MCL concentration.

Based on the TCEQ PWS database, two PWS systems were impacted by arsenic concentrations >5 µg/L, including 1 public entity and 1 distribution system with a population of 60 people. Based on the EPA PWS database, no PWS systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Igneous

The Igneous aquifer covers 6,100 $mi^2$ and extends across parts of 6 counties in western Texas primarily in Presidio, Jeff Davis, and Brewster counties with minor areas in Culberson, Reeves, and Pecos counties (Figure 15). The aquifer is composed of a complex series of pyroclastic and volcanoclastic sediments up to 6,000 ft thick. The Igneous underlies parts of the West Texas Bolson aquifer.

A total of 78 samples were analyzed for arsenic during the study period with 51 samples (65%) having detectable concentrations. About 30% of the area had no probability of arsenic > 5 µg/L and a further 43% had very low to moderate probability of arsenic >5 µg/L. About 28% of the total aquifer area had elevated to very high probabilities of arsenic >5 µg/L. Only about 5% of the aquifer area had elevated or probabilities of arsenic > 10 µg/L. Data were limited particularly in the central region where probabilities were the highest. The median concentration of samples with detectable concentrations was 4.8 µg/L and the $5^{th}$-$95^{th}$ percentile range was 1.2–17.1 µg/L. A total of 12 samples (19%) exceeded the MCL with a range of concentrations from 10.9 µg/L to 33.1 µg/L.

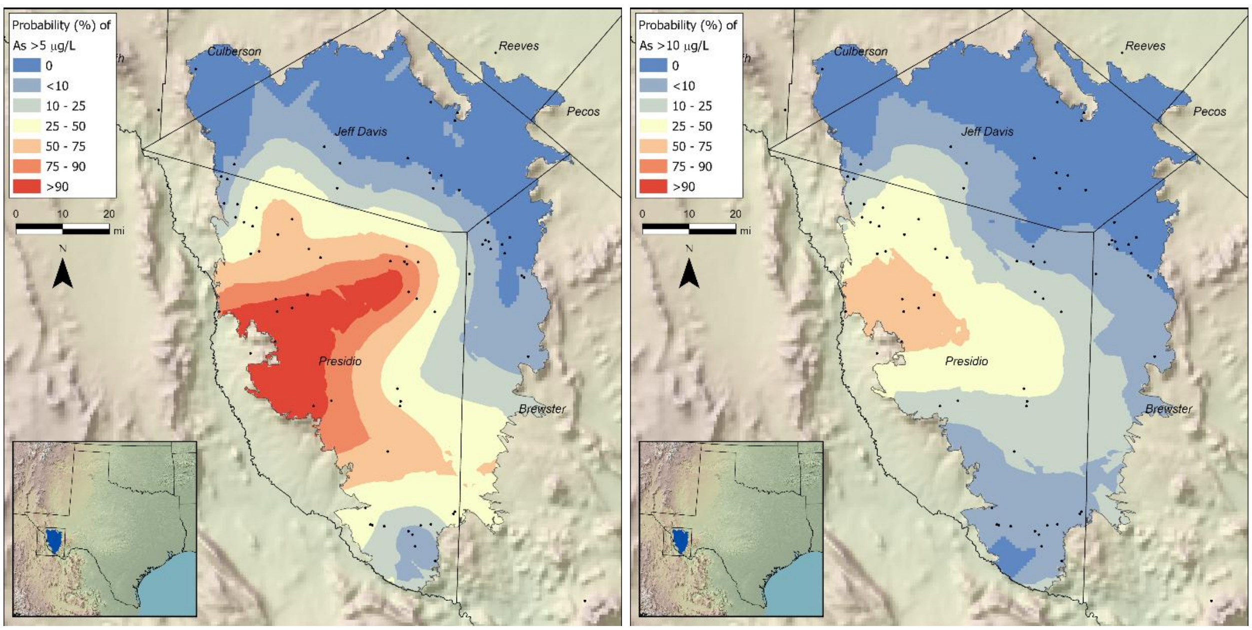



Figure 15. Igneous aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, three PWS systems, all distribution systems, were impacted by arsenic concentrations >5 µg/L with a total population of 2,026 people. Based on the EPA PWS database, there was one PWS distribution system (Candaleira Water Supply Corporation) that was impacted by arsenic concentrations >10 µg/L with a population of 138 people (Table 8). The estimated non-PWS system at-risk population of >10 µg/L was small at 161. However, this is possibly an over-estimate as the population density is generally very low in this region.

Table 8. Igneous aquifer PWS systems with violations for arsenic concentrations based on the US EPA database.

| *PWS ID* | *Name* | *System Type* | *Primary Source* | *Ownership* | *Population Served* |
|---|---|---|---|---|---|
| 1890011 | Candelaria Water Supply Co. | Comm. | GW | Public | 84 |

## Lipan

The Lipan aquifer covers 2,000 mi$^2$ and extends across parts of eight counties in western Texas primarily in Tom Green, Concho, and Runnels counties (Figure 16). The aquifer is composed of valley fill alluvium with up to ~125 ft of saturated thickness. General water quality in the Lipan ranges from about 350 mg/L to 3,000 mg/L TDS. The primary contaminant of concern in the Lipan is nitrate and the aquifer is used primarily for irrigation.

A total of 63 samples were analyzed for arsenic during the study period with 52 samples (83%) having detectable concentrations. About 64% of the area had no probability of arsenic > 5 µg/L and a further 25% had very low to moderate probability of arsenic >5 µg/L. About 11% of the total aquifer area had elevated to high probabilities of arsenic >5 µg/L. The data were limited to the central region of the valley floor and there were no samples from the narrower upland regions to the west and northwest or from the southern confined region. The median concentration of samples with detectable concentrations was 3.0 µg/L and the 5$^{th}$-95$^{th}$ percentiles ranged from 2.0–6.4 µg/L. No samples exceeded the 10 µg/L MCL.

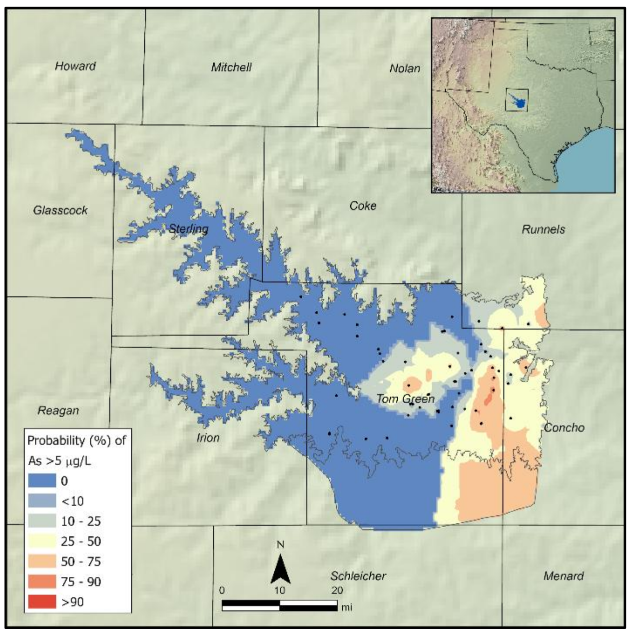



Figure 16. Lipan aquifer probability distribution of arsenic >5 µg/L. No groundwater samples from the Lipan aquifer exceeded the 10 µg/L MCL concentration.

No PWS systems were impacted by arsenic concentrations >5 µg/L and therefore no PWS system exceeded 10 µg/L.

## Marathon

The Marathon aquifer covers 390 mi$^2$ located entirely in Brewster County (Figure 17). The aquifer is composed of tightly folded and faulted limestones and cherts with most well depths shallower than about 250 ft of saturated thickness. General water quality in the Marathon is fresh ranging from about 500 mg/L to 1,000 mg/L TDS and is very hard.

A total of 34 samples were analyzed for arsenic during the study period with zero samples having detectable concentrations. The highest detection limit was 2.0 μg/L.

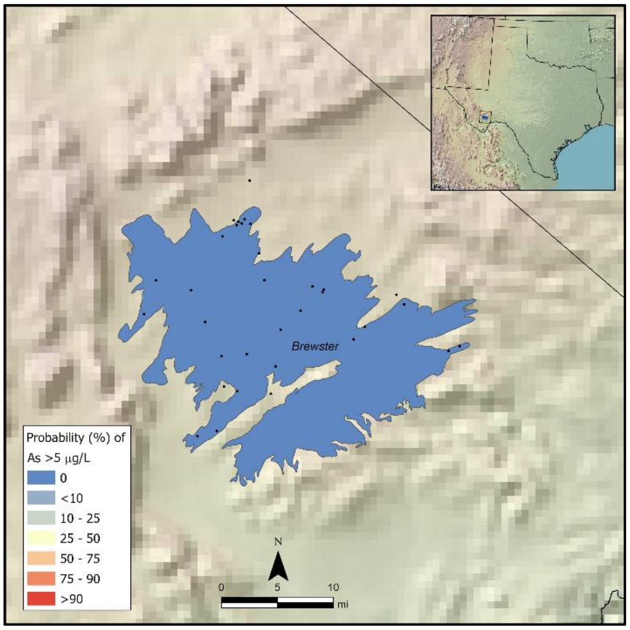



Figure 17. Marathon aquifer probability distribution of arsenic >5 μg/L. No groundwater samples from the Lipan aquifer exceeded the 10 μg/L MCL concentration.

There were no PWS systems impacted by arsenic concentrations >5 μg/L and therefore no PWS systems were impacted by arsenic concentrations >10 μg/L. The non-PWS system at-risk population of >10 μg/L was zero.

## Nacatoch

The Nacatoch aquifer covers 1,800 $mi^2$ located along a narrow corridor that stretches across 17 counties in northeastern Texas (Figure 18). The aquifer is composed of a sequence of sandstones separated by impermeable clay and mudstone layers. Fresh water saturated thickness averages about 50 ft. General water quality in the Marathon is slightly saline ranging from about 1,000 mg/L to 3,000 mg/L TDS and is high in sodium carbonate.

A total of 34 samples were analyzed for arsenic during the study period with 5 samples (15%) having detectable concentrations. About 93% of the area had no probability of arsenic > 5 µg/L and a further 3% had very low to moderate probability of arsenic >5 µg/L. About 4% of the total aquifer area had elevated to high probabilities of arsenic >5 µg/L. The data were limited to the central region of the valley floor and there were no samples from the narrower upland regions to the west and northwest or from the southern confined region. The median concentration of samples with detectable concentrations was 3.4 µg/L and the $5^{th}$-$95^{th}$ percentile ranged from 2.0–6.3 µg/L. No samples exceeded the 10 µg/L MCL.

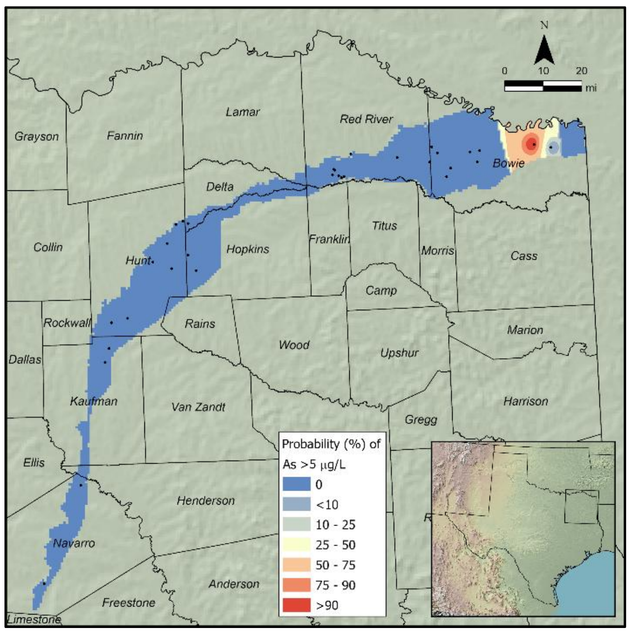



Figure 18. Nacatoch aquifer probability distribution of arsenic >5 µg/L. No groundwater samples from the Nacatoch aquifer exceeded the 10 µg/L MCL concentration.

There were no PWS systems impacted by arsenic concentrations >5 µg/L and therefore no PWS systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Queen City

The Queen City aquifer covers 15,800 mi$^2$ and extends across parts of 42 counties in the upper coastal plain of Texas (Figure 19). The aquifer is composed of sands and loosely cemented sandstones with an average fresh water saturated thickness of 140 ft. General water quality in the Queen City is generally less than 1,000 mg/L.

A total of 226 samples were analyzed for arsenic during the study period with only 16 samples (7%) having detectable concentrations. The entire aquifer area had zero probability of arsenic > 5 µg/L as the highest concentration measured was 4.3 µg/L. The median concentration of samples with detectable concentrations was 1.8 µg/L and the 5$^{th}$-95$^{th}$ percentile ranged from 1.0–3.7 µg/L. No samples exceeded the 10 µg/L MCL.

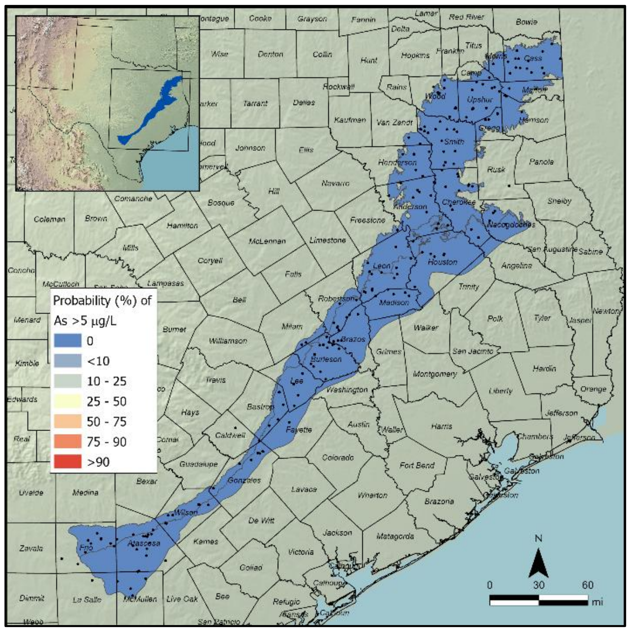



Figure 19. Queen City aquifer probability distribution of arsenic >5 µg/L. No groundwater samples from the Queen City aquifer exceeded the 10 µg/L MCL concentration.

No PWS systems were impacted by arsenic concentrations >5 µg/L and therefore no PWS systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Sparta

The Sparta aquifer covers 7,900 mi$^2$ and extends across parts of 25 counties in the upper coastal plain of Texas (Figure 20). The aquifer is represented by the Sparta Formation of the Claiborne Group with a freshwater saturated thickness of about 120 ft. General water quality in the Sparta is less than 1,000 mg/L TDS.

A total of 119 samples were analyzed for arsenic during the study period with only four samples (3%) having detectable concentrations. About 93% of the area had no probability of arsenic > 5 µg/L and the remaining 7% had a very low probability. The median of samples with detectable concentrations was 4.5 µg/L and the 5$^{th}$-95$^{th}$ percentile ranged from 1.8–9.8 µg/L. One sample exceeded the 10 µg/L MCL (10.6 µg/L).

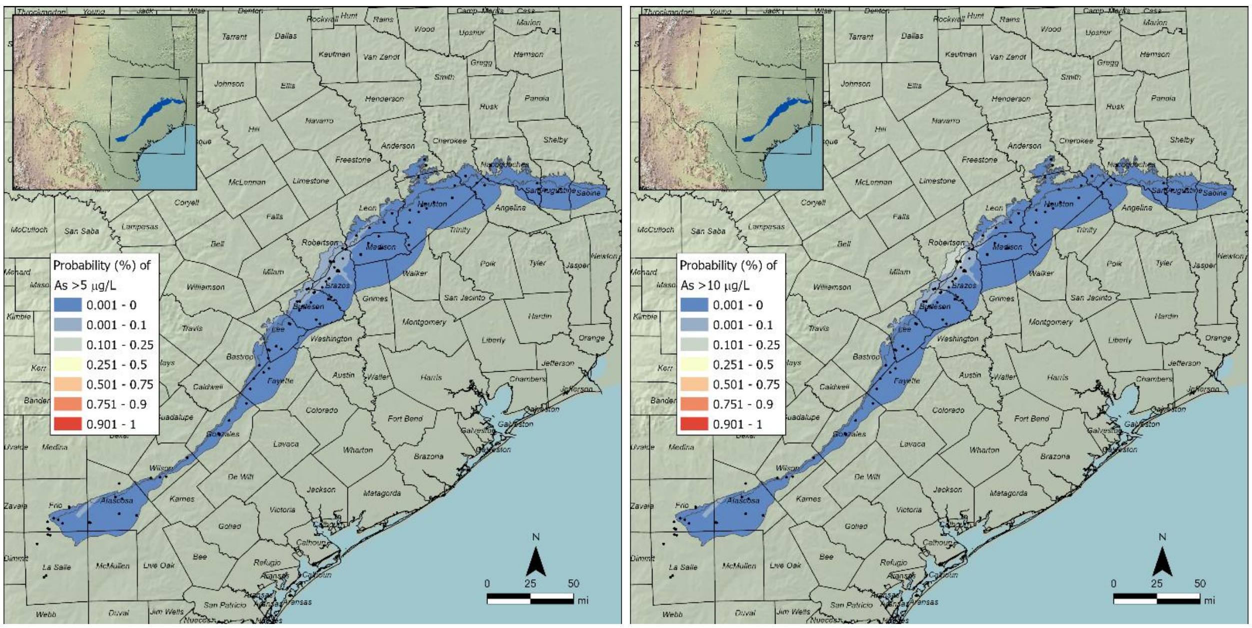



Figure 20. Sparta aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

No PWS systems were impacted by arsenic concentrations >5 µg/L and therefore no PWS water supply systems were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was 253 people.

## West Texas Bolsons

The West Texas Bolsons aquifer covers 1,900 mi$^2$ and extends across parts of 4 counties in west Texas along the international border with Mexico (Figure 21). The aquifer is composed of a series of basin-fill deposits ranging up to 3,000 ft thick with an average freshwater saturated thickness of 580 ft. Water quality is locally <1,000 mg/L TDS but ranges up to 4,000 mg/L TDS.

A total of 92 samples were analyzed for arsenic during the study period with 68 samples (74%) having detectable concentrations. About 65% of the area had a very low to moderate probability of arsenic >5 µg/L. About 35% of the total aquifer area had elevated to very high probabilities of arsenic >5 µg/L. Data were limited and one bolson had no data. The median concentration of samples with detectable concentrations wasd 6.6 µg/L and the 5$^{th}$-95$^{th}$ percentile ranged from 2.2–19.0 µg/L. A total of 17 samples (19%) exceeded the MCL with a range of concentrations from 10.3 µg/L to 46.7 µg/L.

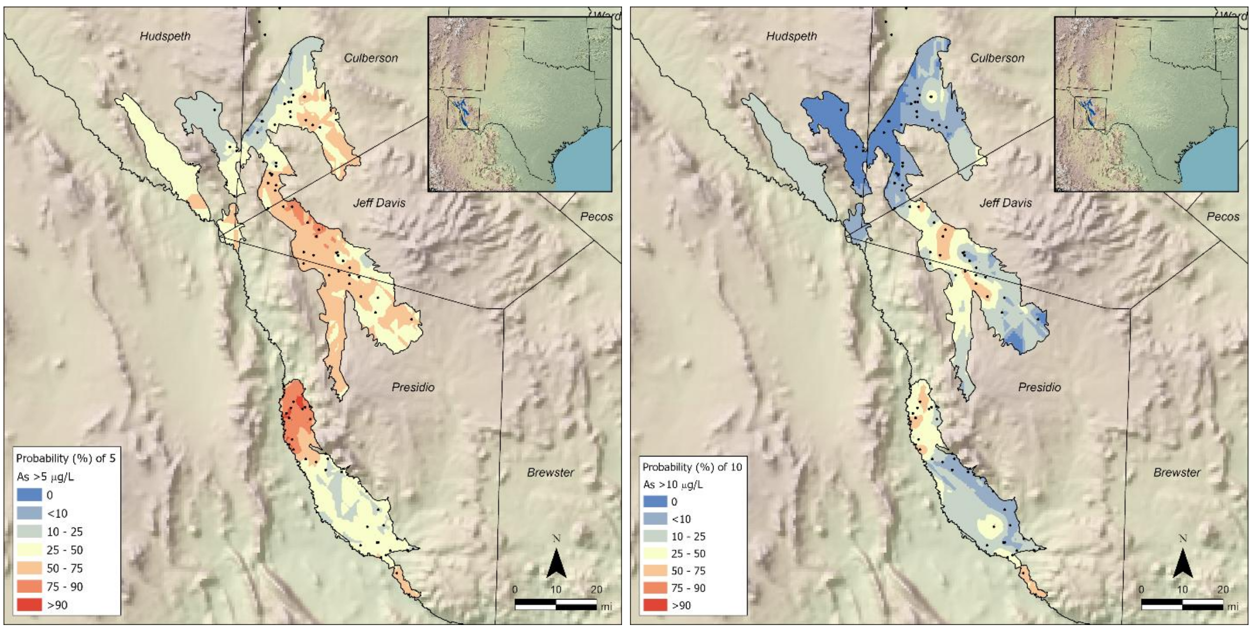



Figure 21. West Texas Bolsons aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database two PWS systems were impacted by arsenic concentrations >5 µg/L with a total population of 5,596 people. Based on the EPA PWS database, one PWS distribution system was impacted by arsenic concentrations >10 µg/L (Table 9). The estimated non-PWS system at-risk population of >10 µg/L is small at 54.

Table 9. West Texas Bolsons aquifer PWS systems with violations for arsenic concentrations based on the US EPA database.

| *PWS ID* | *Name* | *System Type* | *Primary Source* | *Ownership* | *Population Served* |
|---|---|---|---|---|---|
| 1890012 | Redford Water Supply | Comm. | GW | Public | 82 |

## Woodbine

The Woodbine aquifer covers 7,300 $mi^2$ and extends across parts of 17 counties in north central Texas (Figure 22). The aquifer is composed of interbedded sandstones, shales, and clays up to 600 ft thick with an average freshwater saturated thickness of 160 ft. Water quality tends to decrease with increasing depth with <1,000 mg/L TDS shallower than about 1,500 ft ranging up to 4,000 mg/L TDS at greater depths.

A total of 169 samples were analyzed for arsenic during the study period with 14 samples (8%) having detectable arsenic concentrations. About 99.7% of the area had no probability of arsenic >5 µg/L. About 0.5% of the total aquifer area had elevated to very high probabilities of arsenic >5 µg/L. The median concentration of samples with detectable concentrations was 2.2 µg/L and the $5^{th}$-$95^{th}$ percentile ranged from 0.5–6.1 µg/L. No samples exceeded 10 µg/L MCL.

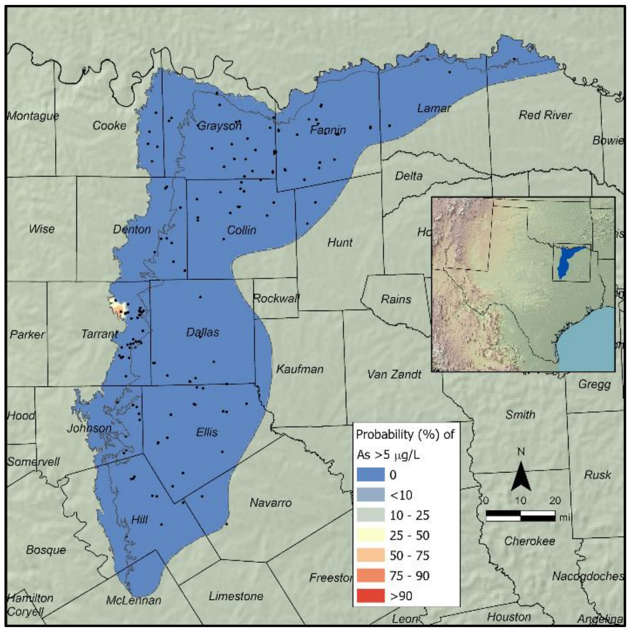



Figure 22. Woodbine aquifer probability distribution of arsenic >5 µg/L. No groundwater samples from the Woodbine aquifer exceeded the 10 µg/L MCL concentration.

Based on the TCEQ PWS database there were no PWS systems impacted by arsenic concentrations >5 µg/L. Based on the EPA PWS database, there were no PWS systems that were impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L was zero.

## Yegua-Jackson

The Yegua-Jackson aquifer covers 10,900 $mi^2$ and extends across parts of 34 counties in west Texas in Presidio, Jeff Davis, Culberson, and Hudspeth counties (Figure 23). The aquifer is composed of a series of basin-fill deposits ranging up to 3,000 ft thick with an average freshwater saturated thickness of 580 ft. Water quality is locally <1,000 mg/L TDS but ranges up to 4,000 mg/L TDS.

A total of 153 samples were analyzed for arsenic during the study period with 22 samples (14%) having detectable concentrations. About 61% of the area had no probability of arsenic >5 µg/L while 22% of the area had a very low to moderate probability of arsenic >5 µg/L. Data were limited in the southern areas of the aquifer where arsenic concentrations were highest. The median concentration of samples with detectable concentrations ws 2.9 µg/L and the $5^{th}$-$95^{th}$ percentile ranged from 1.0–18.4 µg/L. A total of 5 samples (4%) exceeded the MCL with a range of concentrations from 10.7 µg/L to 47 µg/L.

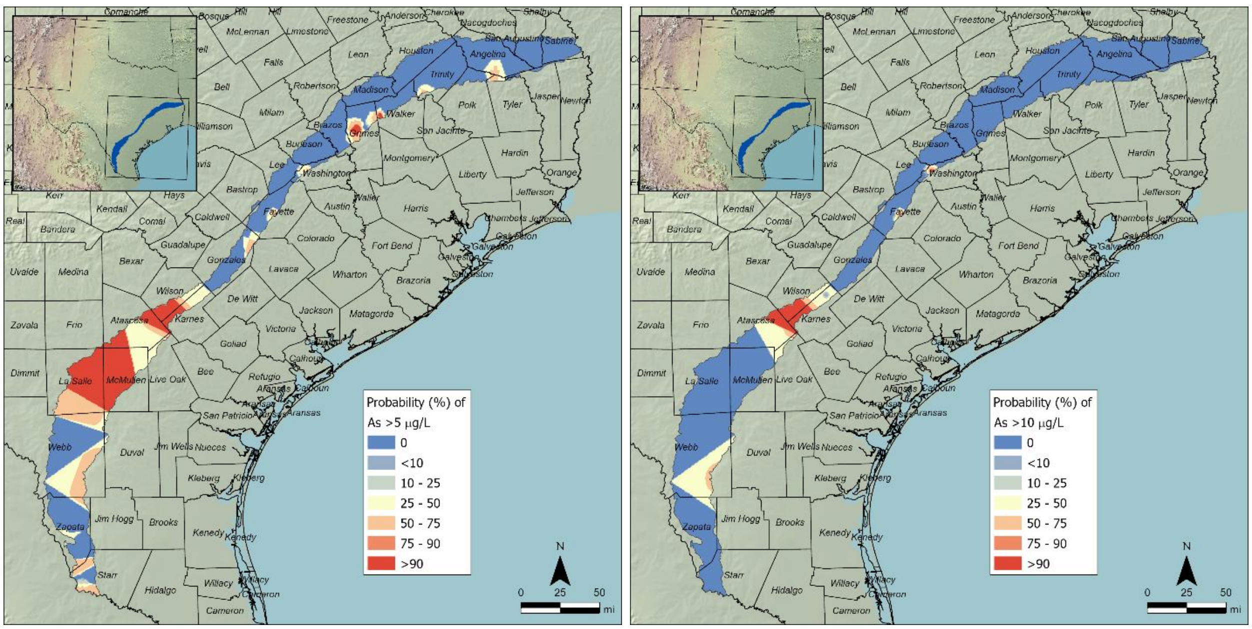



Figure 23. Yegua-Jackson aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database five PWS systems were impacted by arsenic concentrations >5 µg/L with a total population of 8,347 people. Based on the EPA PWS database, two PWS distribution systems were impacted by arsenic concentrations >10 µg/L with an associated population of 6,942 people (Table 10). The estimated non-PWS system at-risk population of >10 µg/L was 1,309 people.

Table 10. Yegua-Jackson aquifer PWS systems with violations for arsenic concentrations based on the US EPA database. Both systems obtain their water from the Fayette Water Supply Co. West (PWS ID 0750022)

| *PWS ID* | *Name* | *System Type* | *Primary Source* | *Ownership* | *Population Served* |
|---|---|---|---|---|---|
| 0750002 | City of Flatonia | Comm. | GW | Local Government | 1,969 |
| 0750003 | City of La Grange | Comm. | GW | Local Government | 4,973 |

## Summary

Quantifying the spatial distribution of groundwater arsenic concentrations in aquifers in Texas is critical for managing groundwater resources in the state. This study evaluated the probability of groundwater arsenic levels in the minor aquifers of Texas exceeding threshold levels of 5 µg/L, considered above background, and exceeding 10 µg/L (the EPA MCL) using 1,895 analyses from 1992 – 2025. The number of water samples that exceeded the MCL totaled 62 (3% of all analyses).

A total of 62 samples exceeded the arsenic MCL of 10 µg/L, which represents 11% of all analyses with detectable arsenic and 3% of all samples used in this study. The median arsenic concentration in the samples with detectable arsenic (29% of samples, 553 samples) was 3.6 µg/L. Most samples (71% of samples, 1,342 samples) had non-detectable arsenic concentrations. Overall, 87% of the samples in this study (1,648 samples) were ≤5 µg/L threshold while only 3.3% (62 samples) had arsenic concentrations > 10 µg/L MCL threshold.

Arsenic MCL exceedances were restricted to 10 out of the 22 minor aquifers. The percentages of MCL exceedances were highest in the Edwards-Trinity High Plains Aquifer (33% of samples), followed by the West Texas Bolsons aquifers (19%) and Igneous (15%) aquifers. Seven aquifers had between 0.8% and 7.1% of samples exceeding the MCL while the remaining 12 aquifers had no samples exceeding the MCL.

A total of four PWS systems that rely solely on minor aquifer water sources had reported arsenic noncompliance in a total of at least one of the last 12 quarters (July 2022 – June 2025). These PWS systems serve ~6,072 people and accounts for 0.02% of the 2025 Texas total population. Most (99.5%, 5,802 people) are associated with a single PWS system, the Fayette Water Supply Company West, located in La Grange, Fayette County, that sources its groundwater from both the Sparta and the Yegua-Jackson aquifers and supplies the water systems for the cities of Flatonia and La Grange. The most likely source of the non-compliant groundwater is the Yegua-Jackson Aquifer.

## Acknowledgements

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## Appendix I – Enlarged Maps

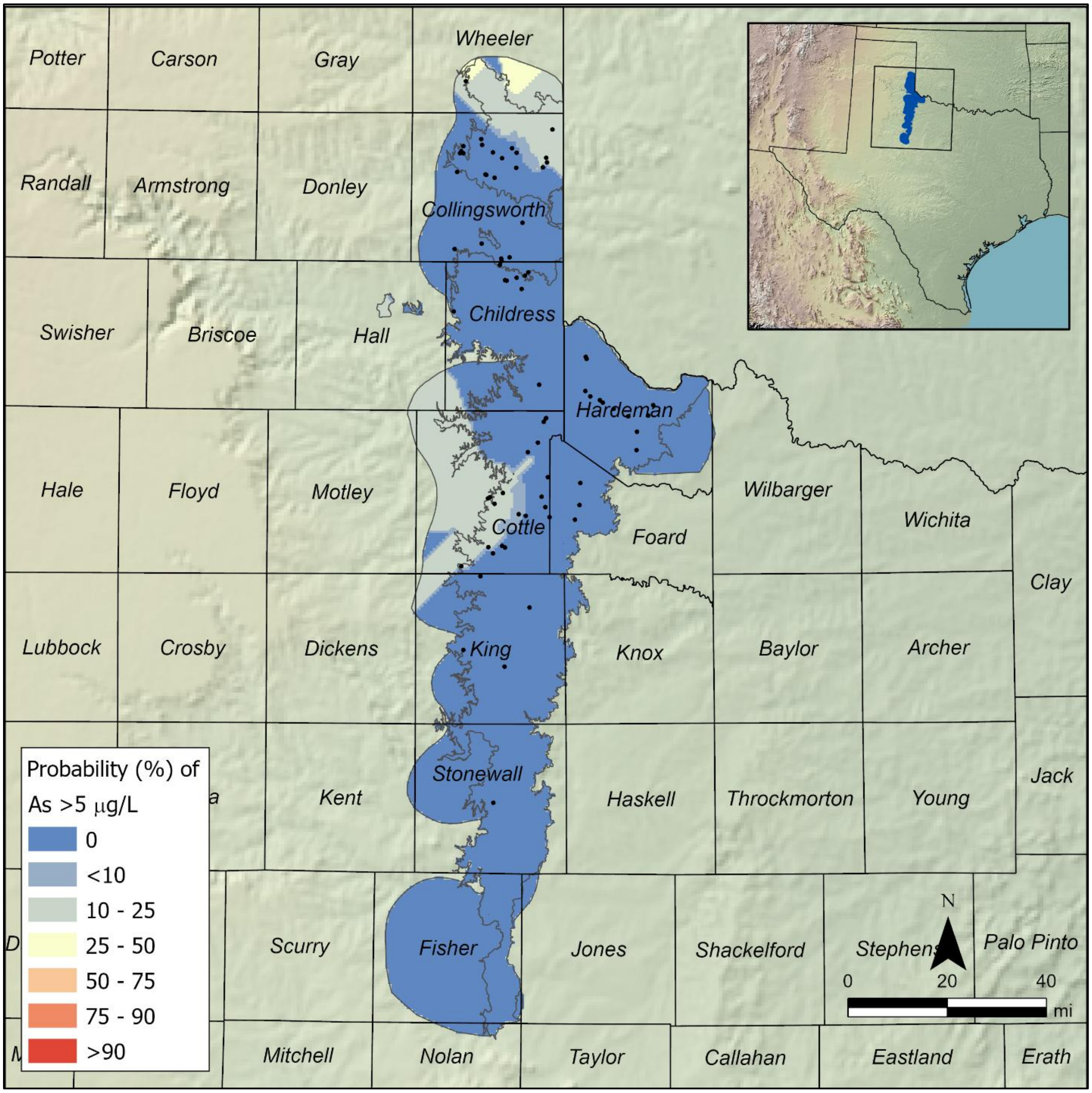


Figure 24. Blaine aquifer probability distribution of arsenic >5 µg/L.

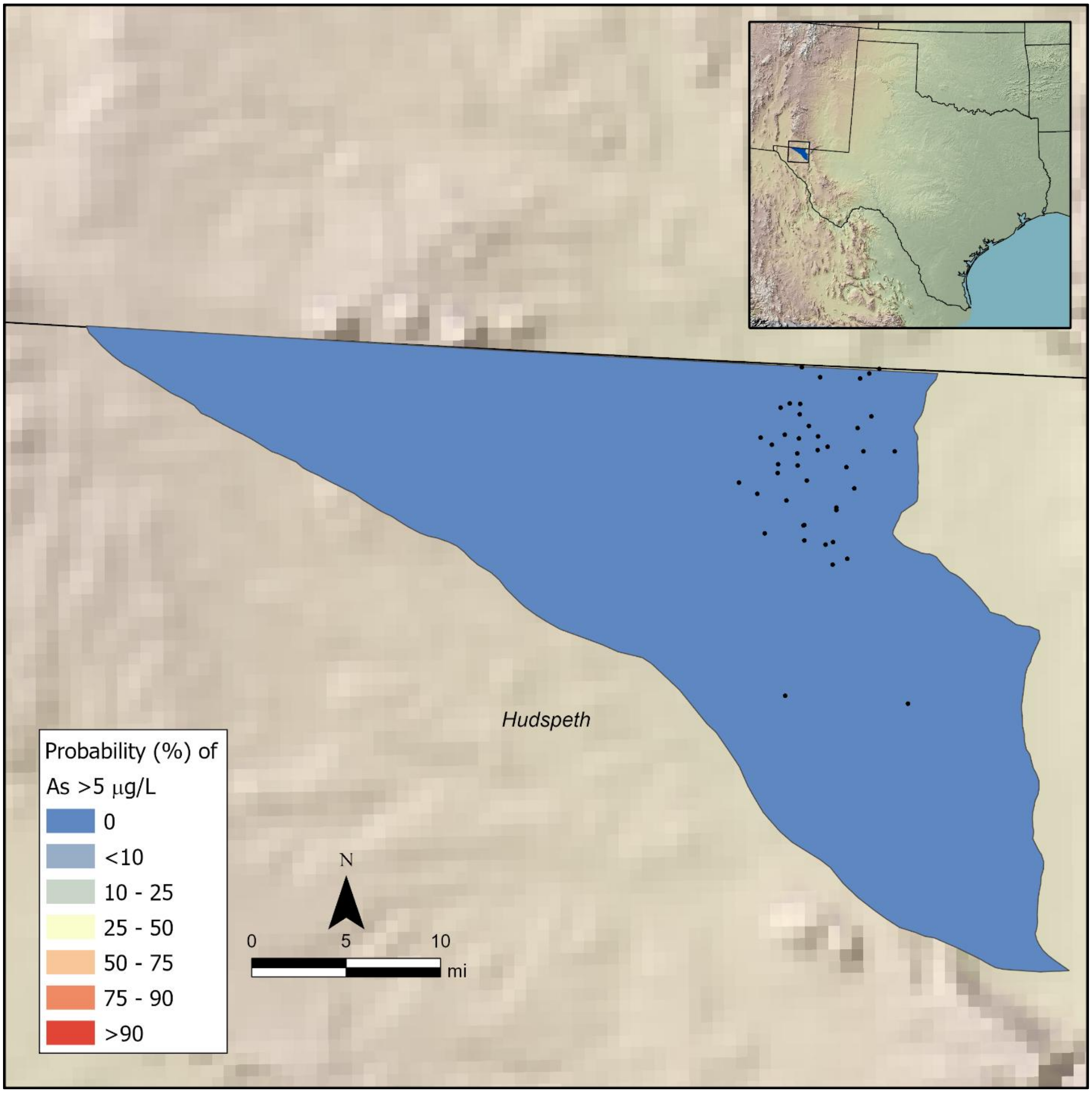


Figure 25. Bone Spring–Victorio Peak aquifer probability distribution of arsenic >5 μg/L.

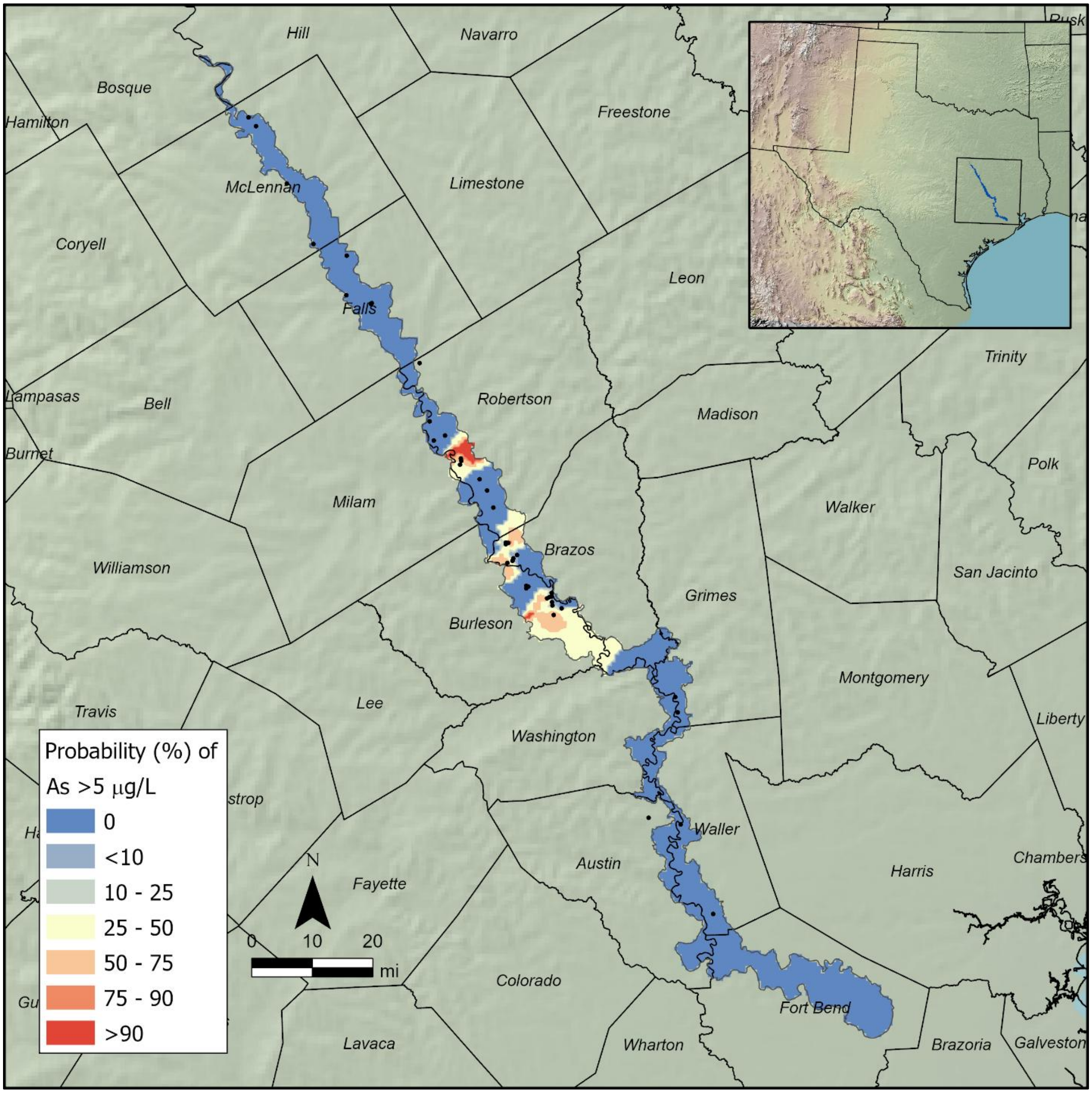


Figure 26. Brazos River Alluvium aquifer probability distribution of arsenic >5 µg/L.

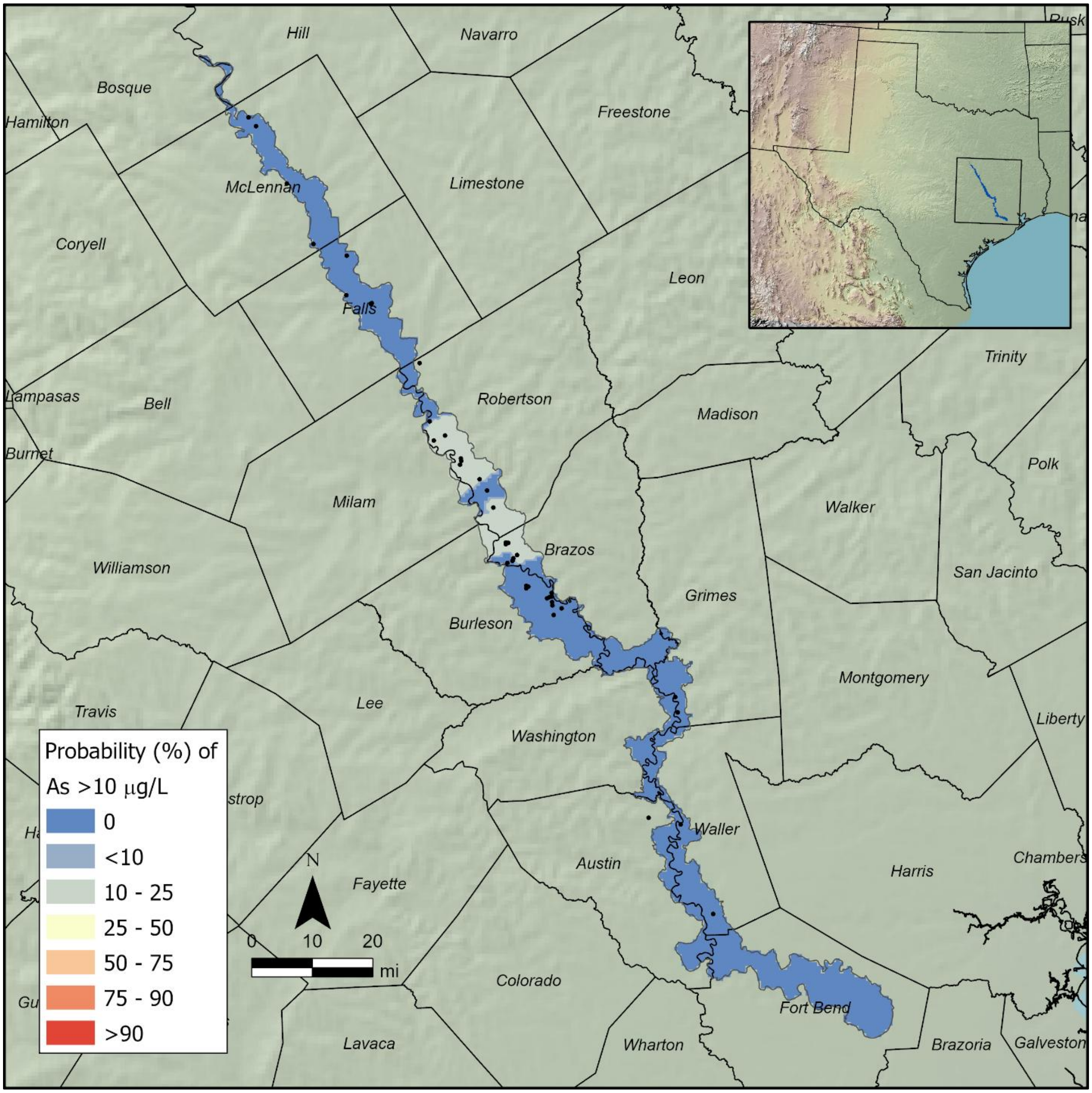


Figure 27. Brazos River Alluvium aquifer probability distribution of arsenic >10 µg/L.

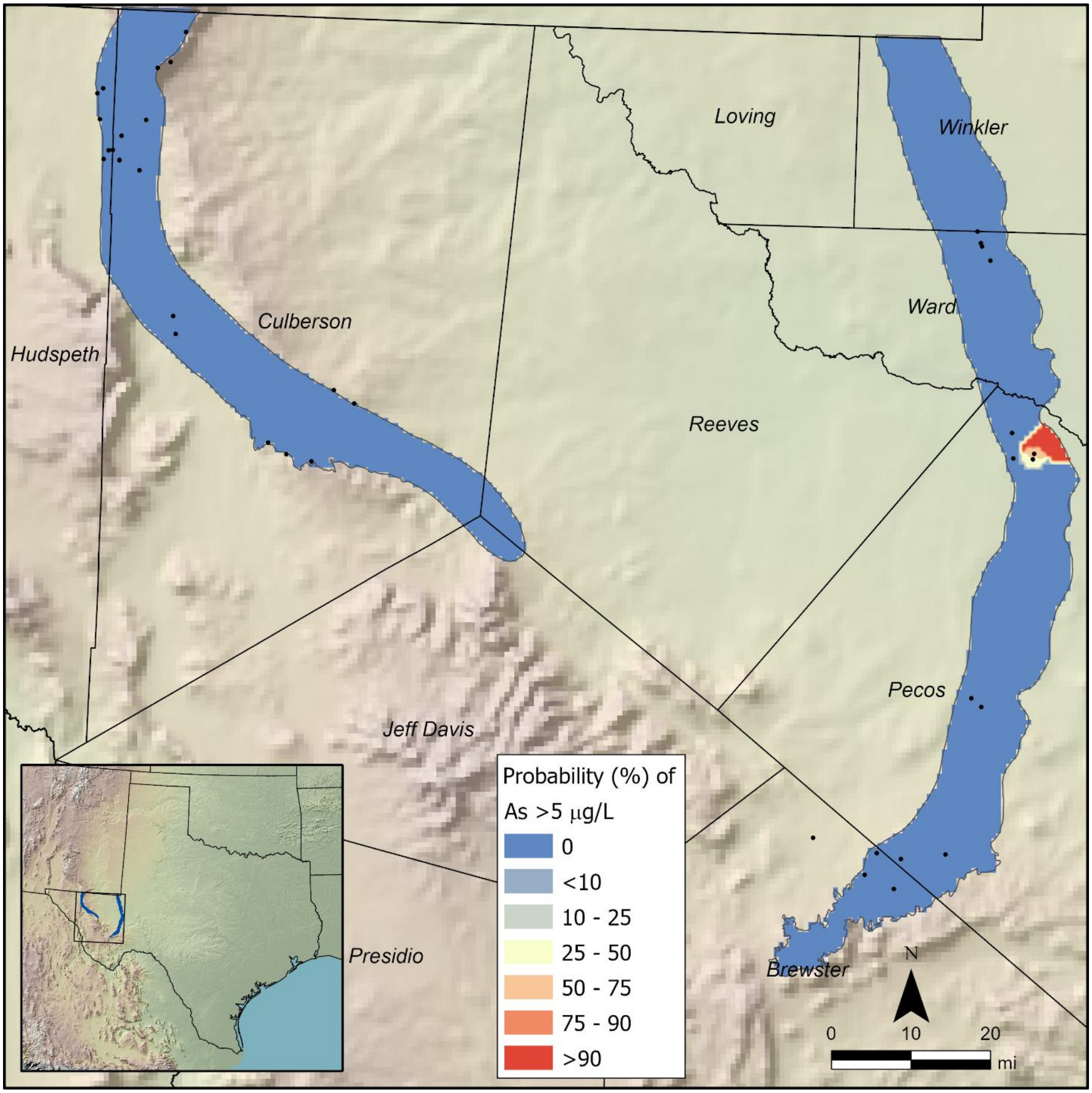


Figure 28. Capitan Reef Complex aquifer probability distribution of arsenic >5 µg/L.

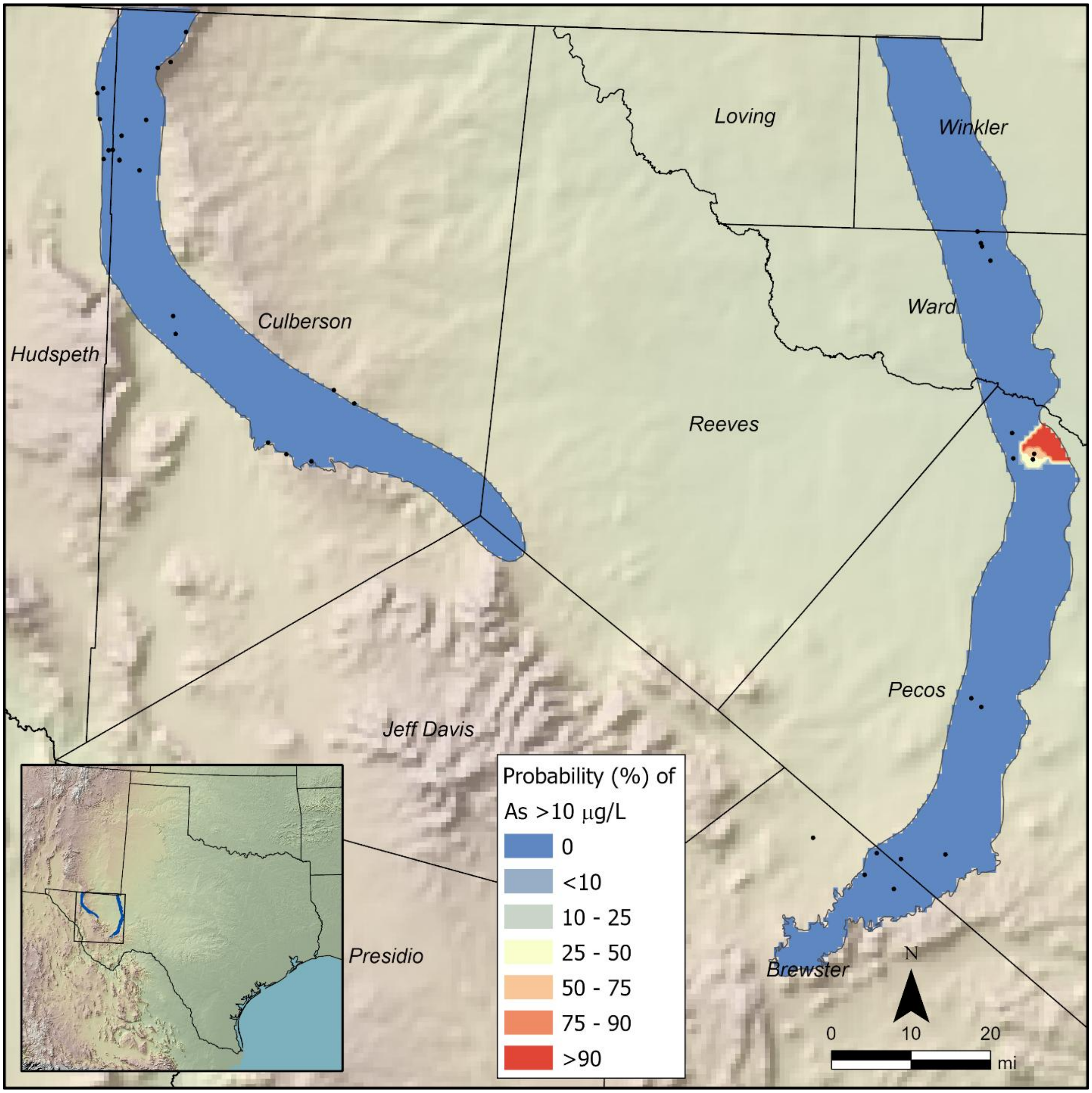


Figure 29. Capitan Reef Complex aquifer probability distribution of arsenic >10 µg/L.

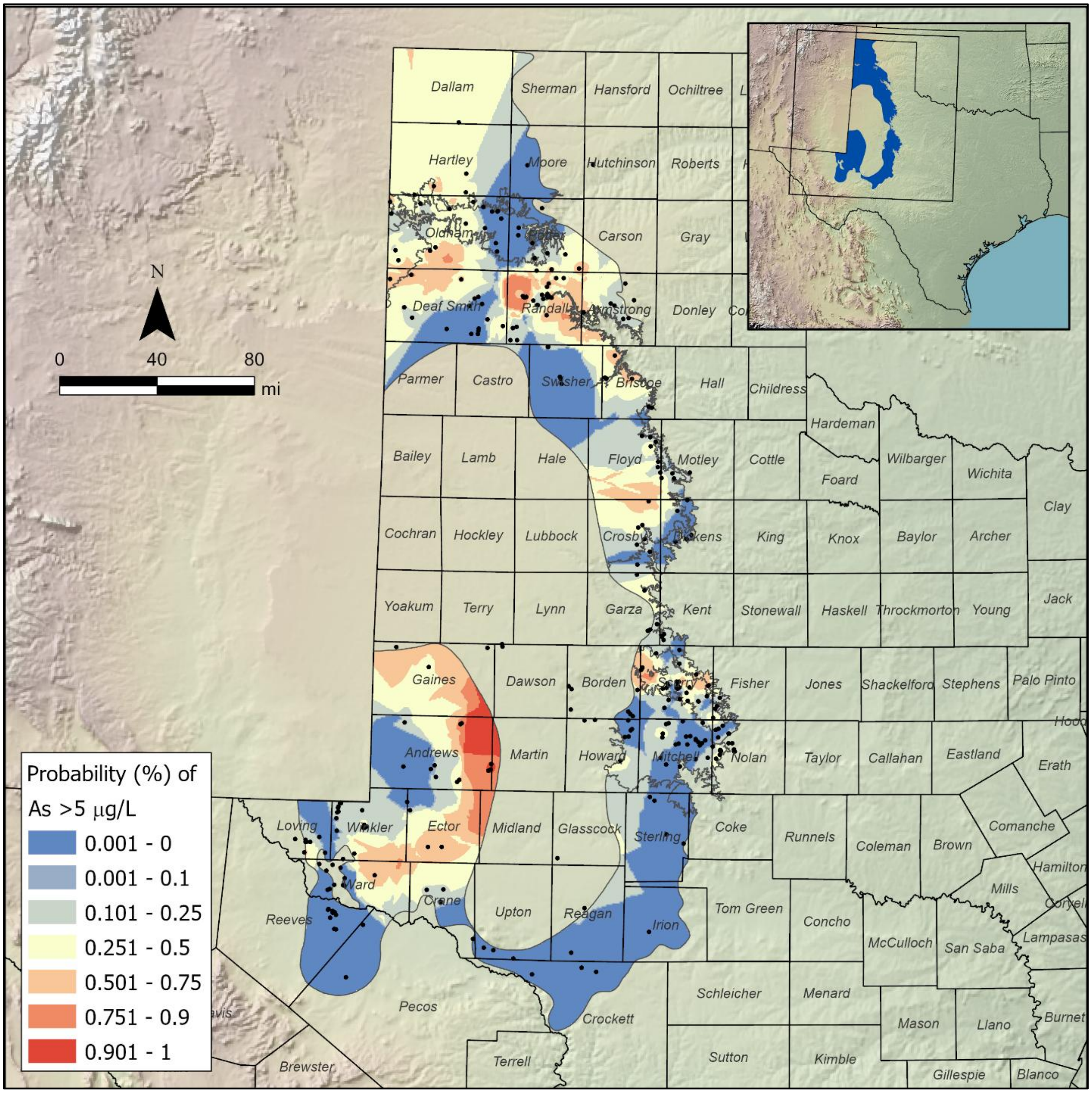


Figure 30. Dockum aquifer probability distribution of arsenic >5 µg/L.

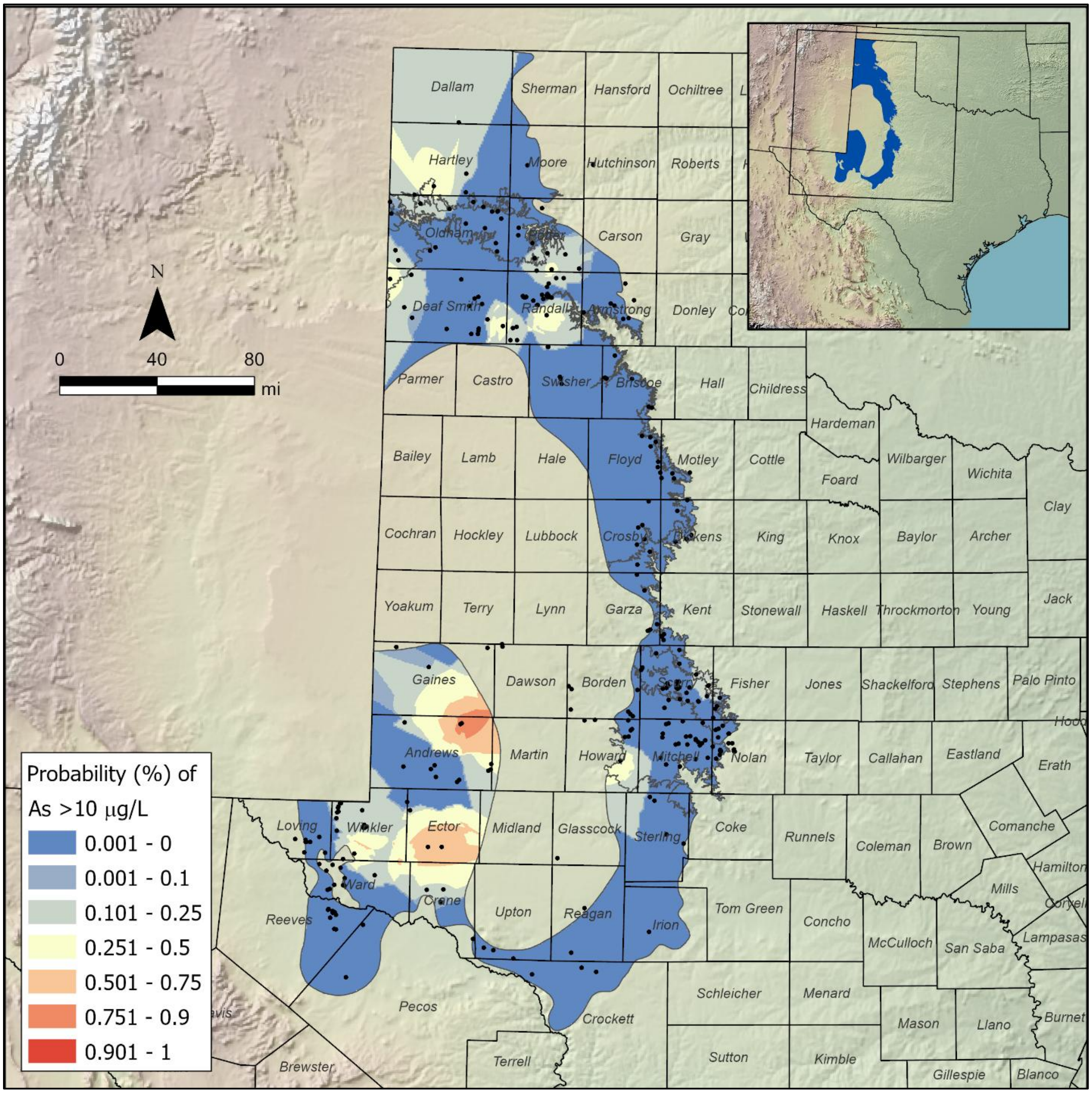


Figure 31. Dockum aquifer probability distribution of arsenic >10 µg/L.

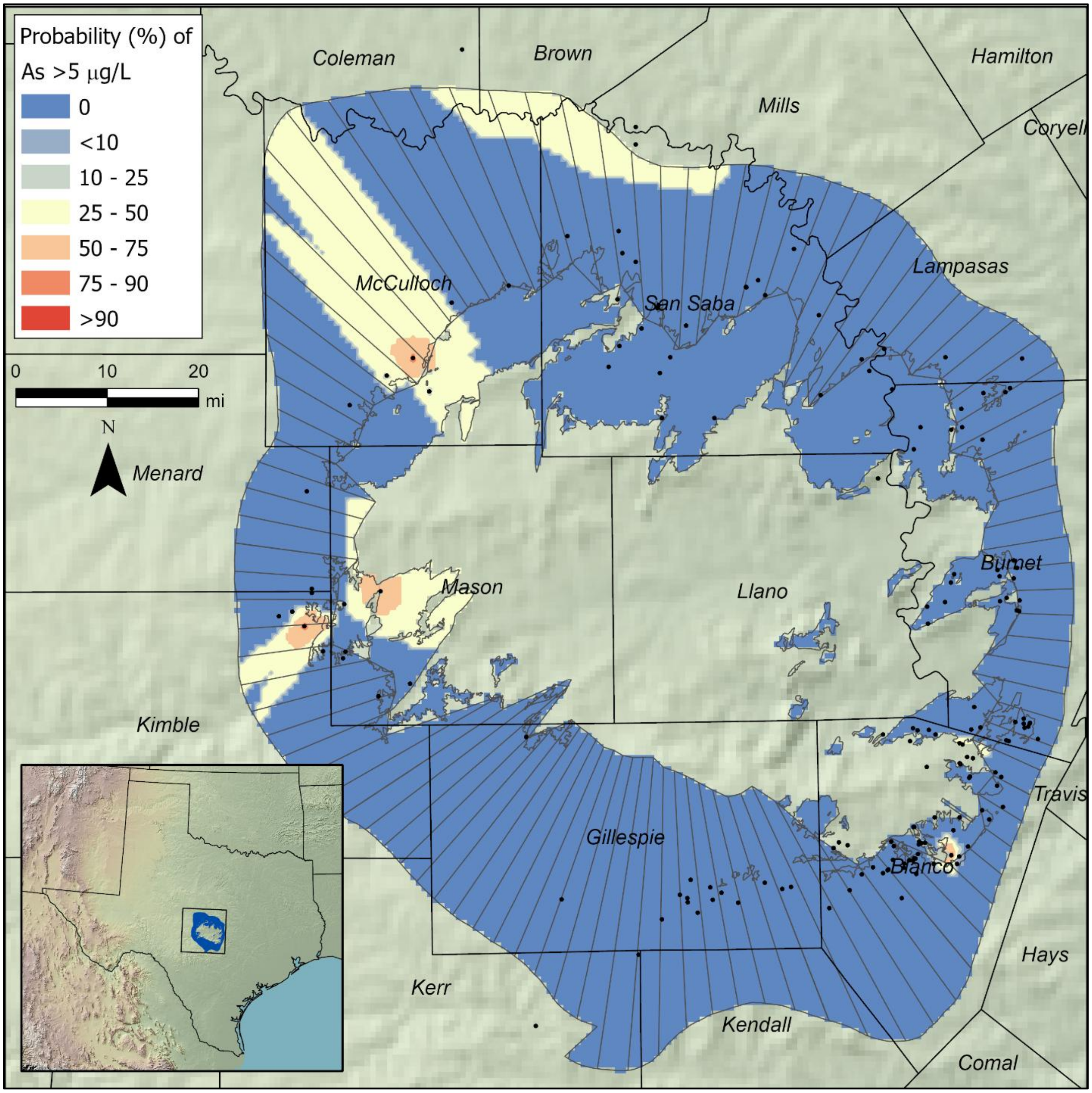


Figure 32. Ellenburger-San Saba aquifer probability distribution of arsenic >5 µg/L.

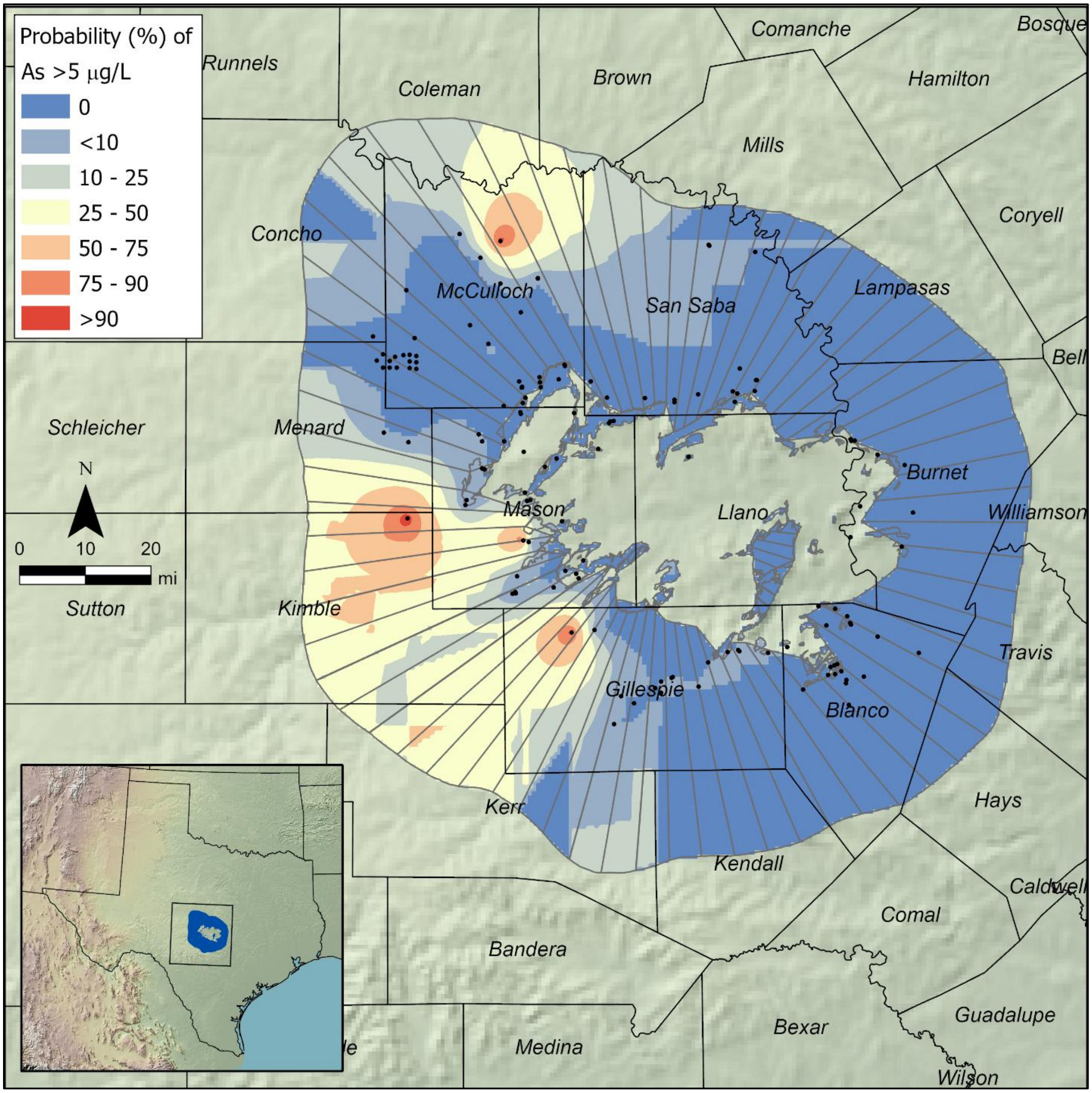


Figure 33. Hickory aquifer probability distribution of arsenic >5 µg/L.

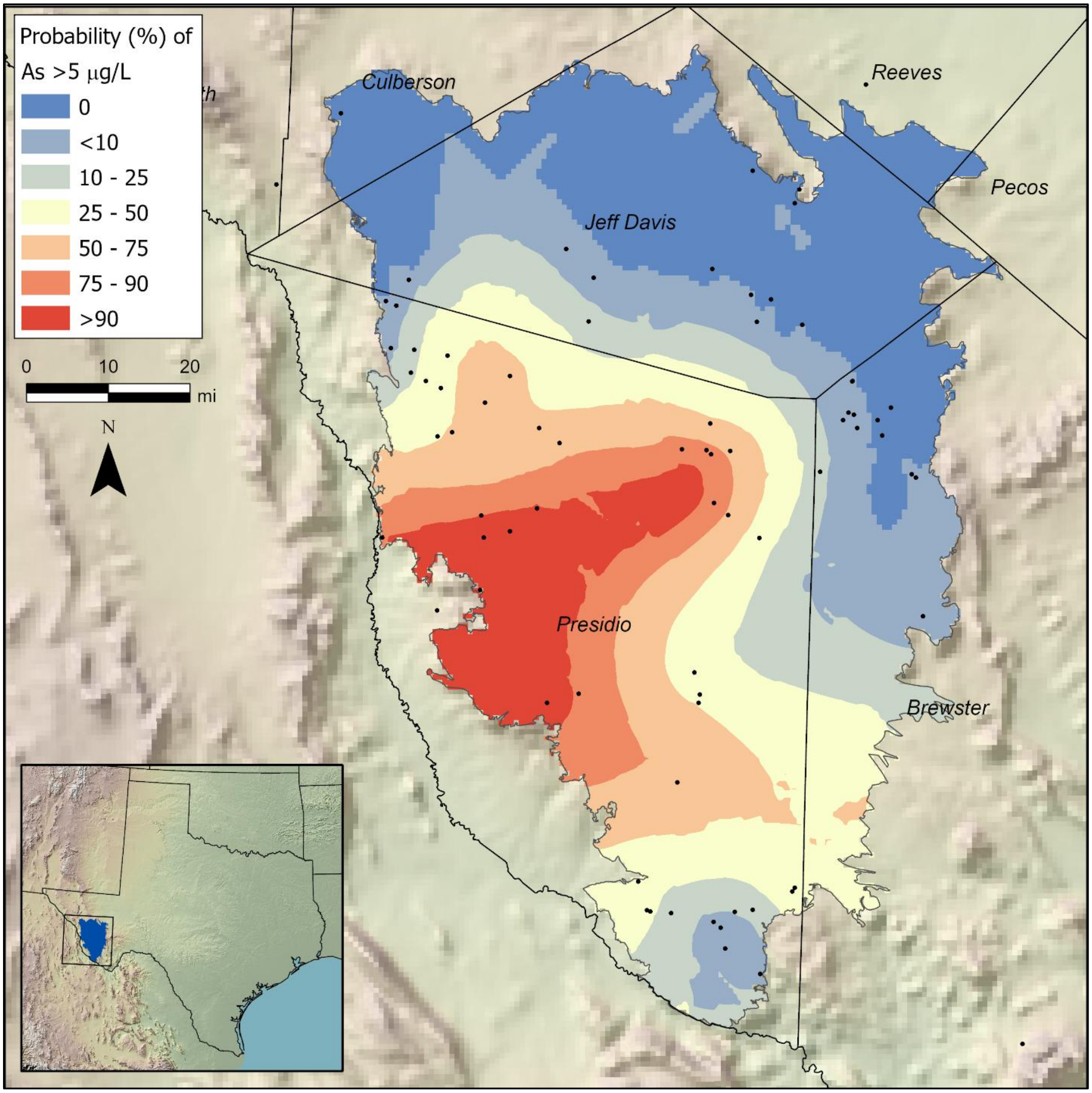


Figure 34. Igneous aquifer probability distribution of arsenic >5 μg/L.

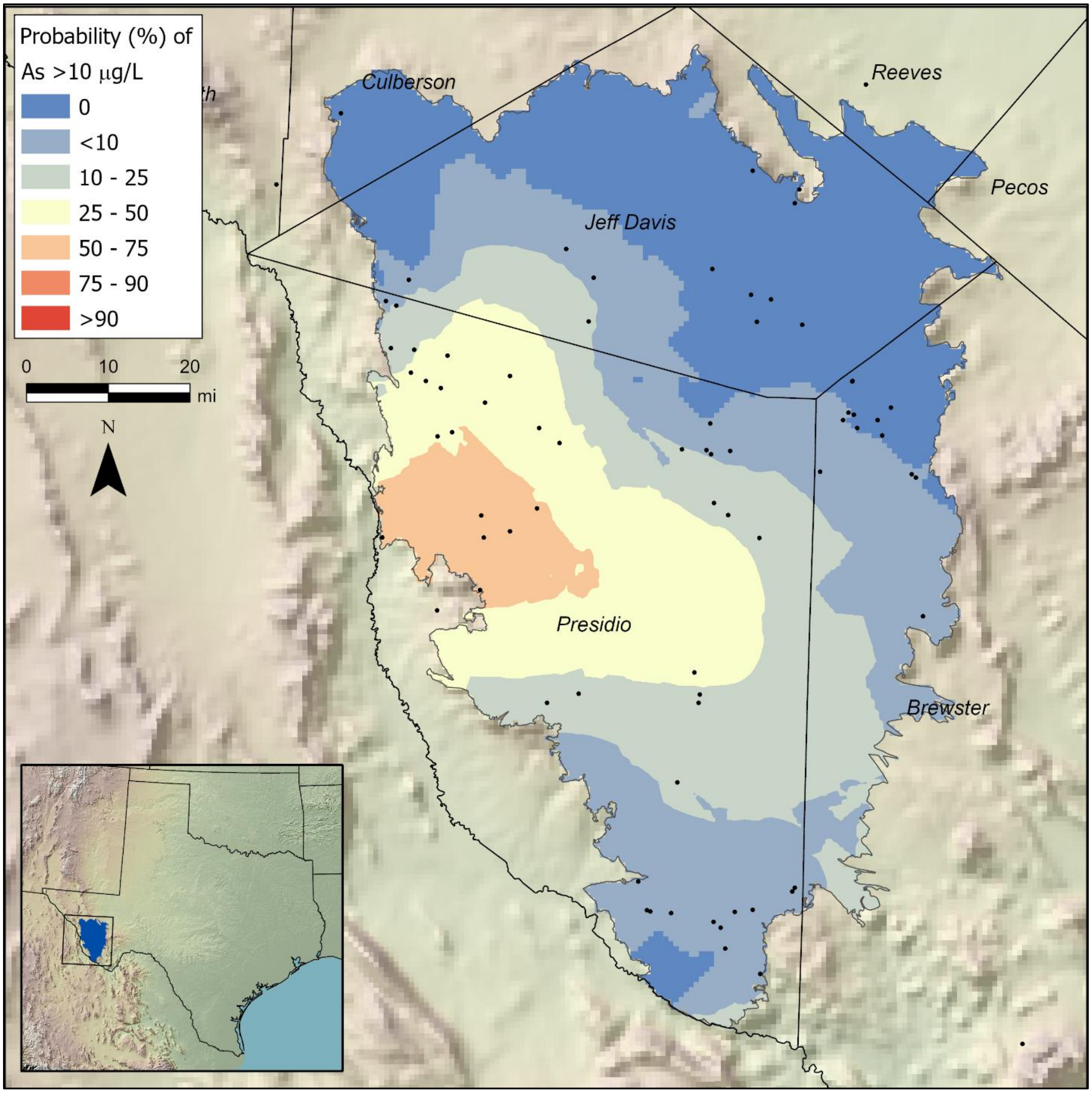


Figure 35. Igneous aquifer probability distribution of arsenic >10 μg/L.

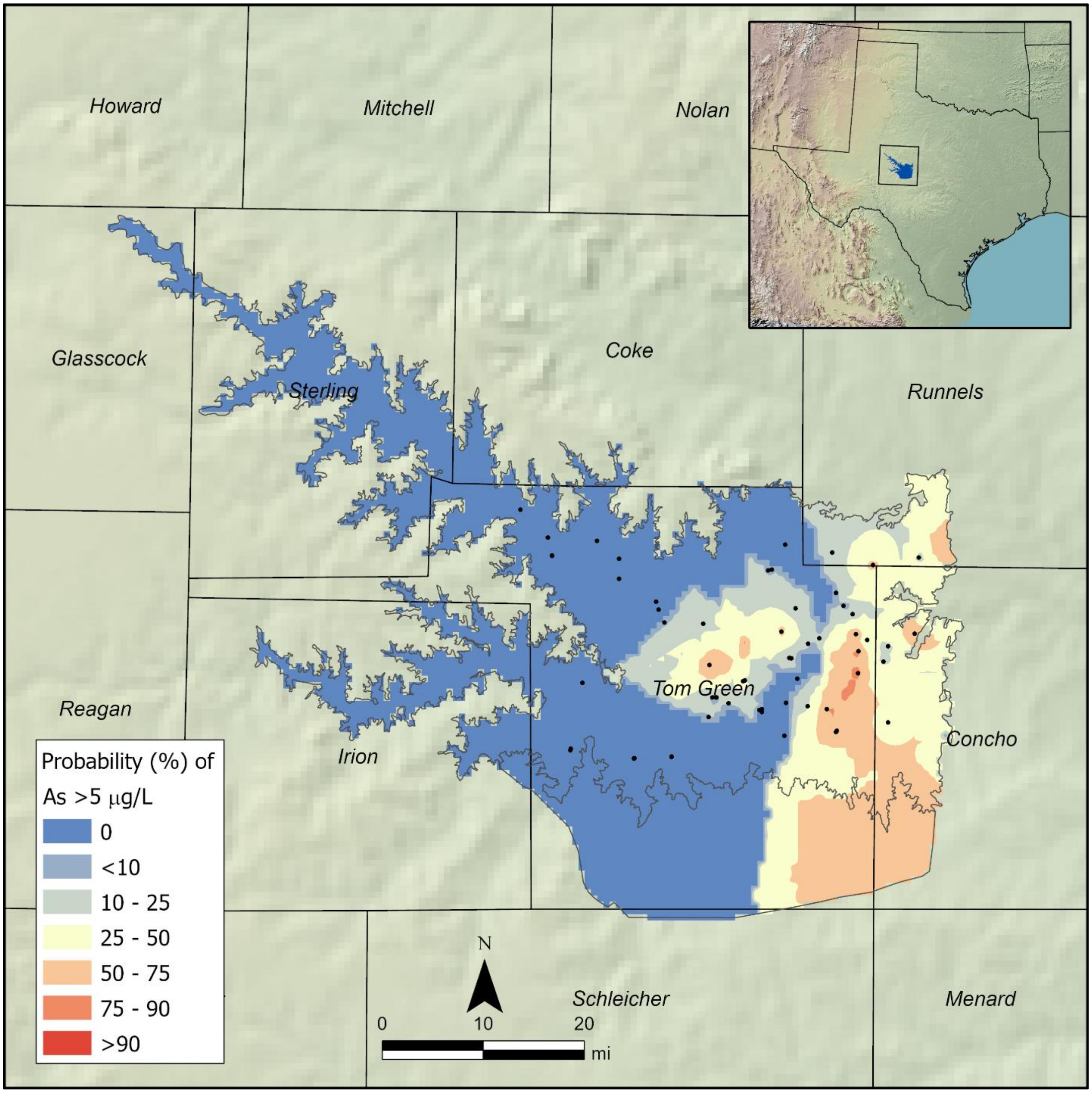


Figure 36. Lipan aquifer probability distribution of arsenic >5 µg/L.

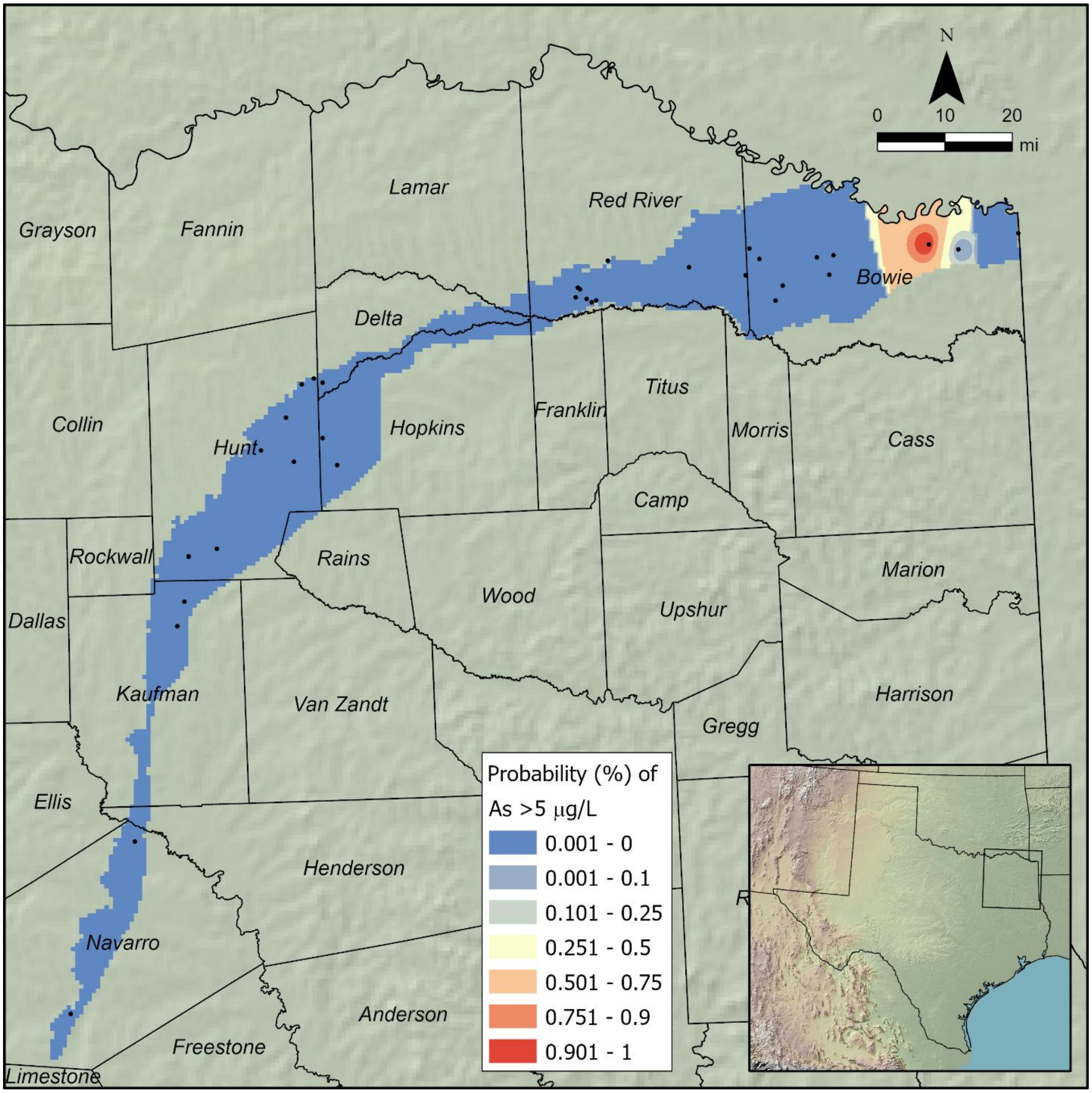


Figure 37. Nacatoch aquifer probability distribution of arsenic >5 μg/L.

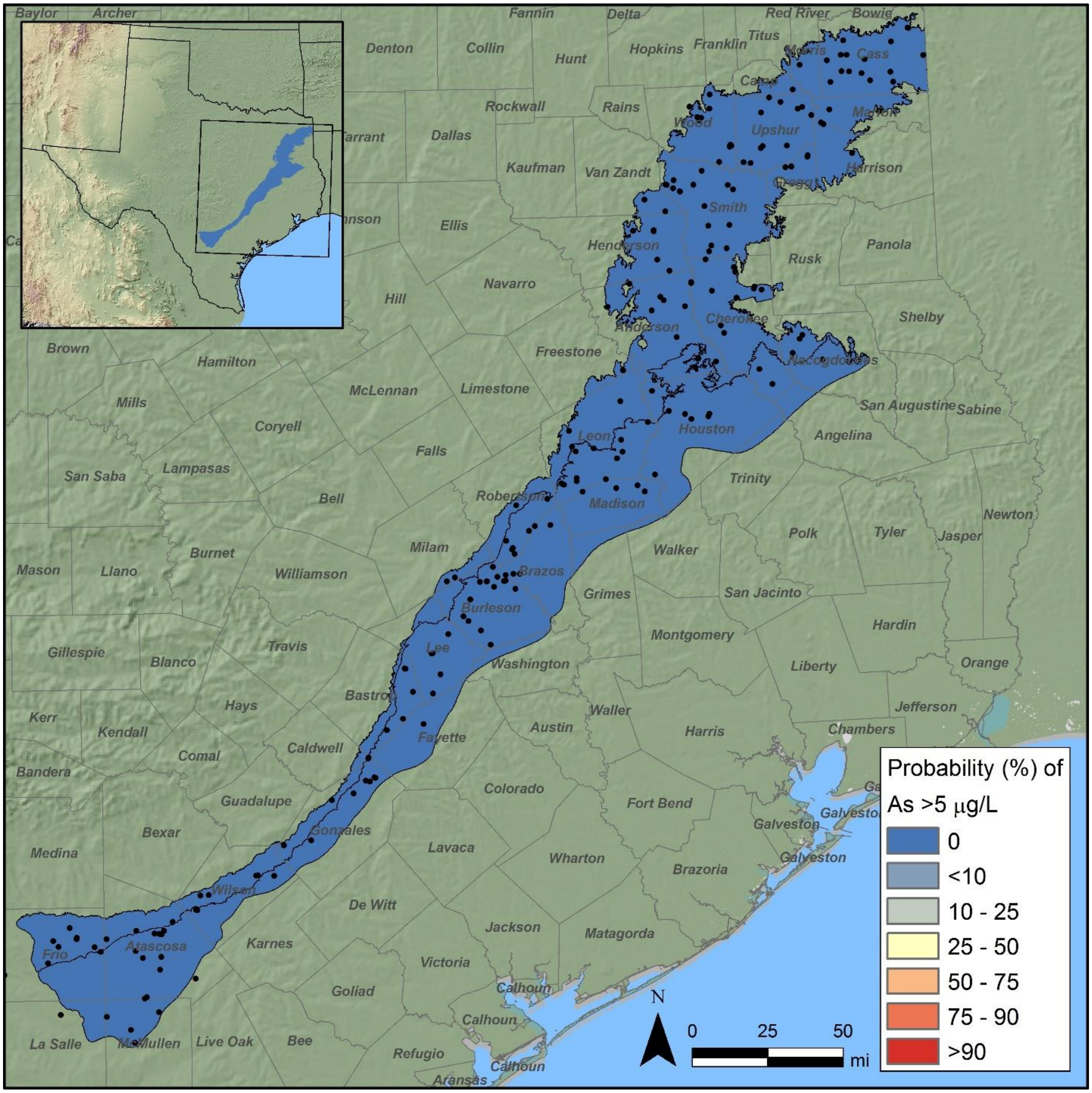


Figure 38. Queen City aquifer probability distribution of arsenic >5 μg/L.

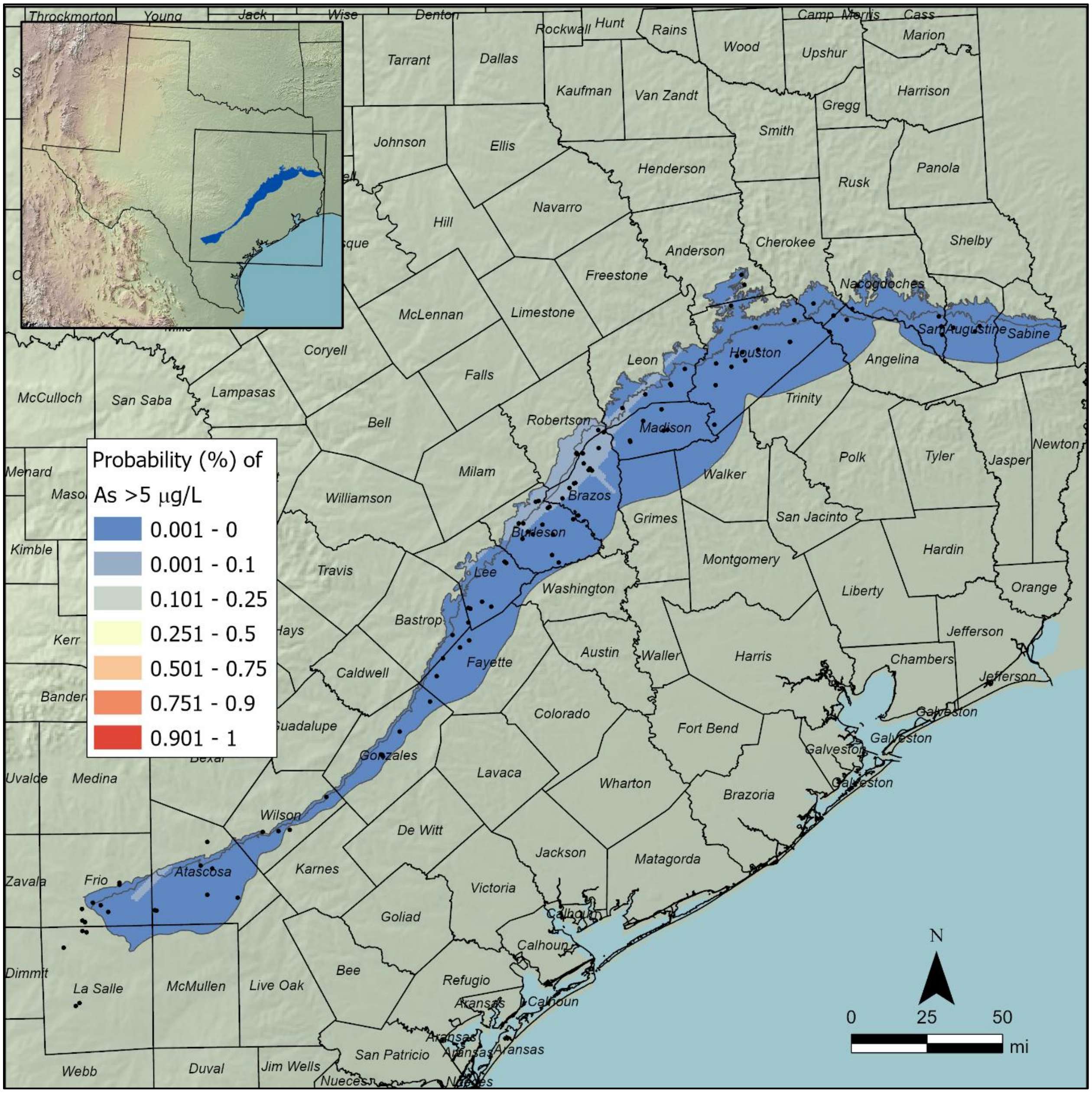


Figure 39. Sparta aquifer probability distribution of arsenic >5 µg/L.

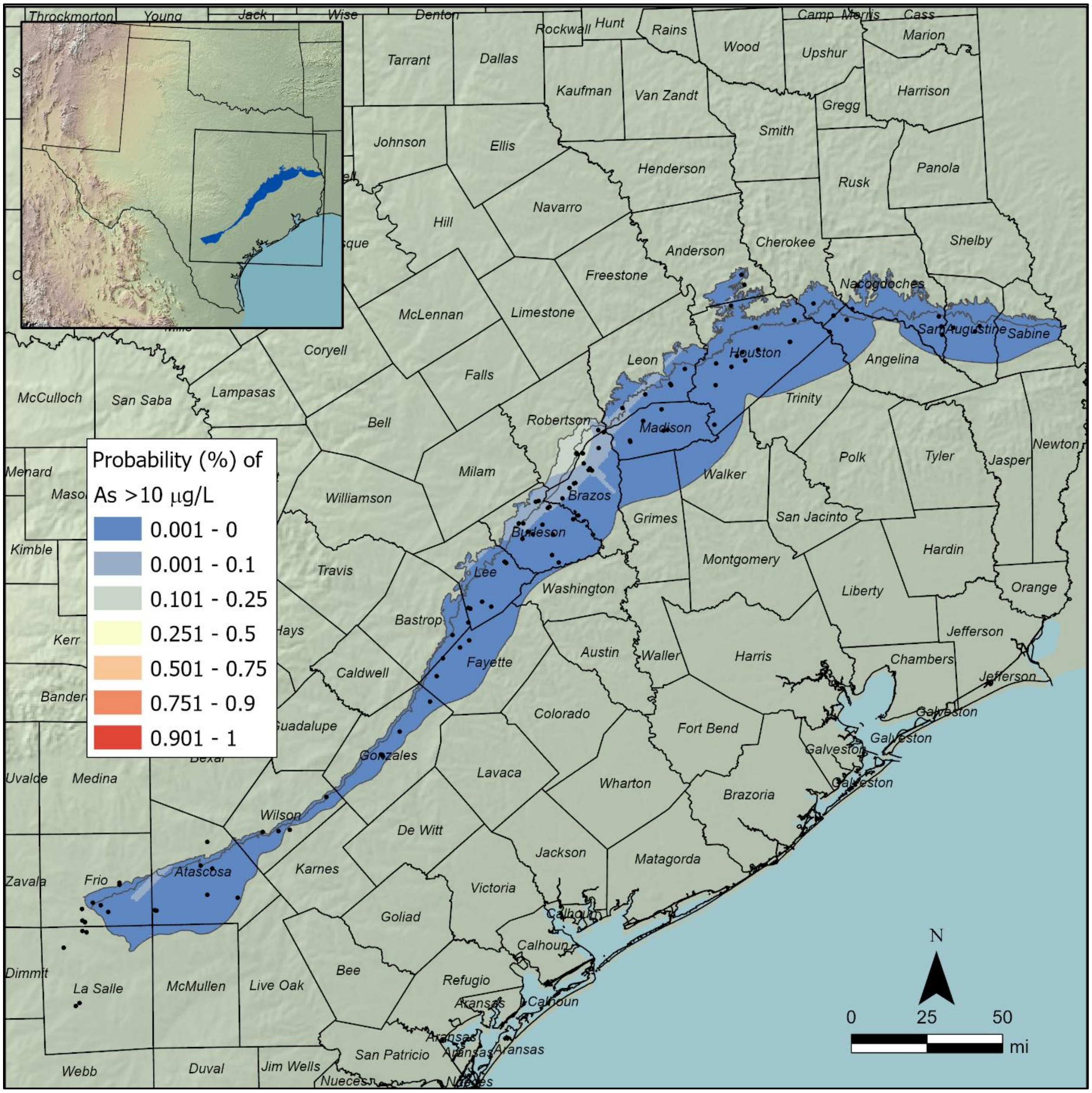


Figure 40. Sparta aquifer probability distribution of arsenic >10 µg/L.

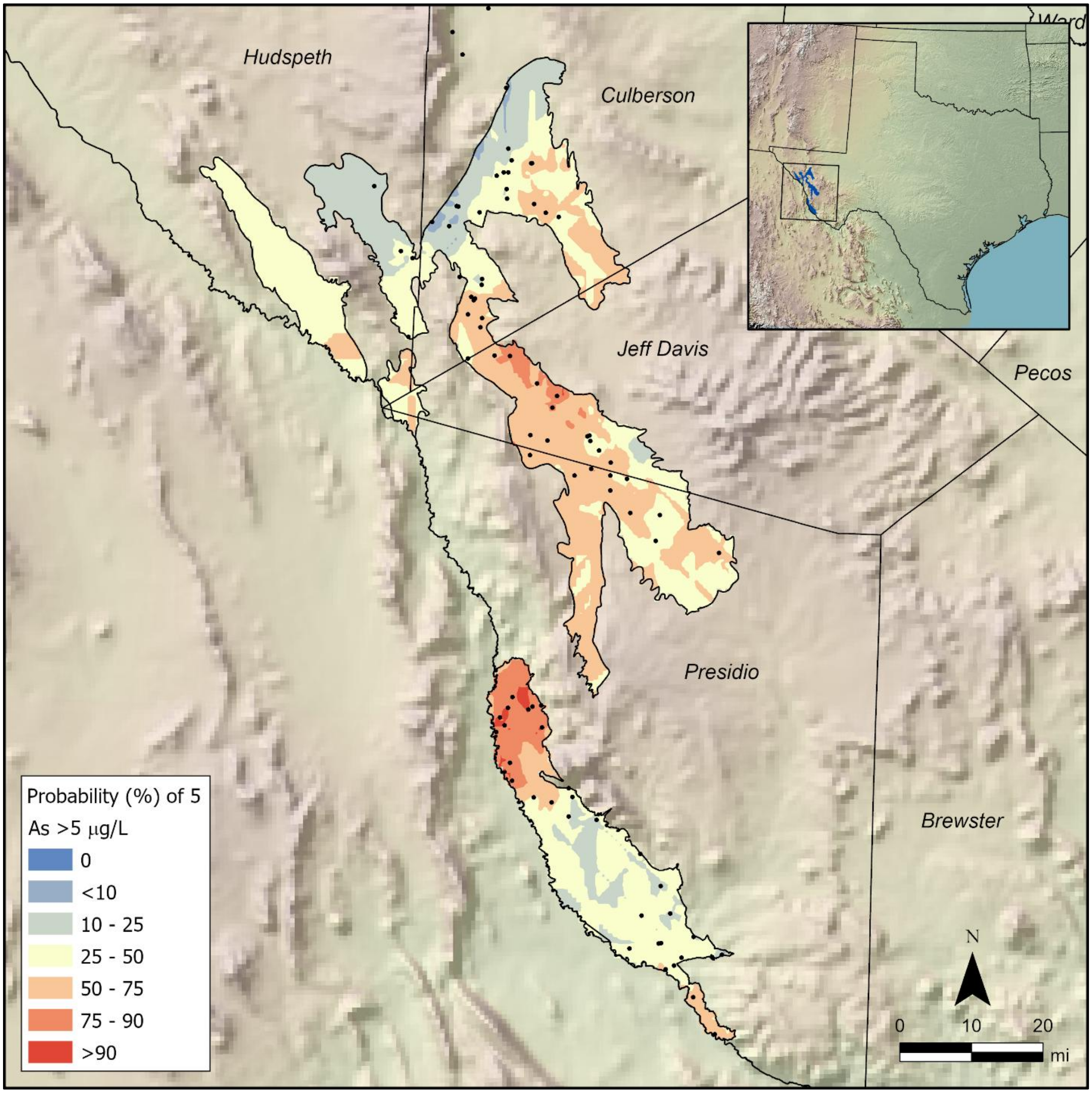


Figure 41. West Texas Bolsons aquifer probability distribution of arsenic >5 µg/L.

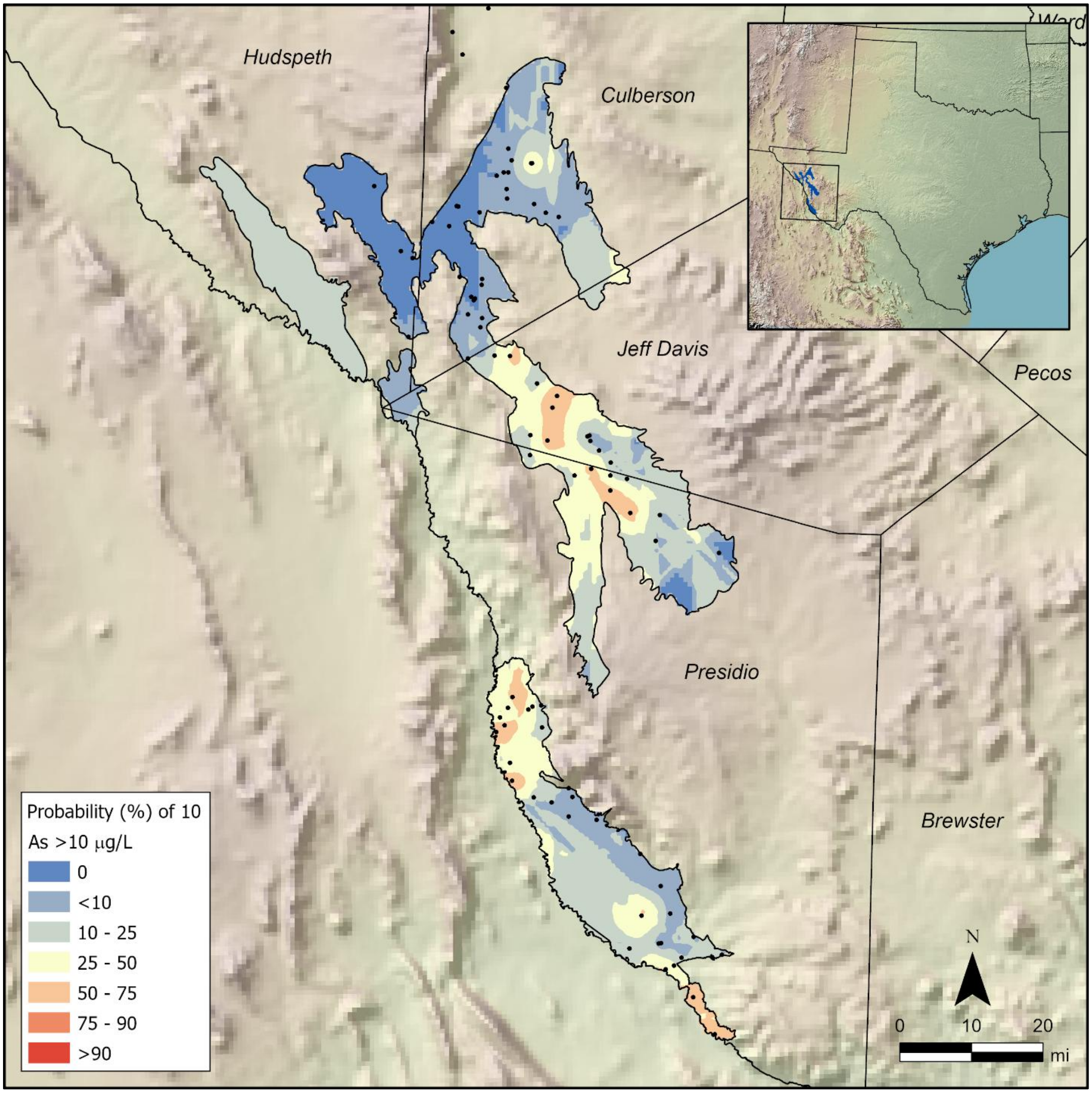


Figure 42. West Texas Bolsons aquifer probability distribution of arsenic >10 µg/L.

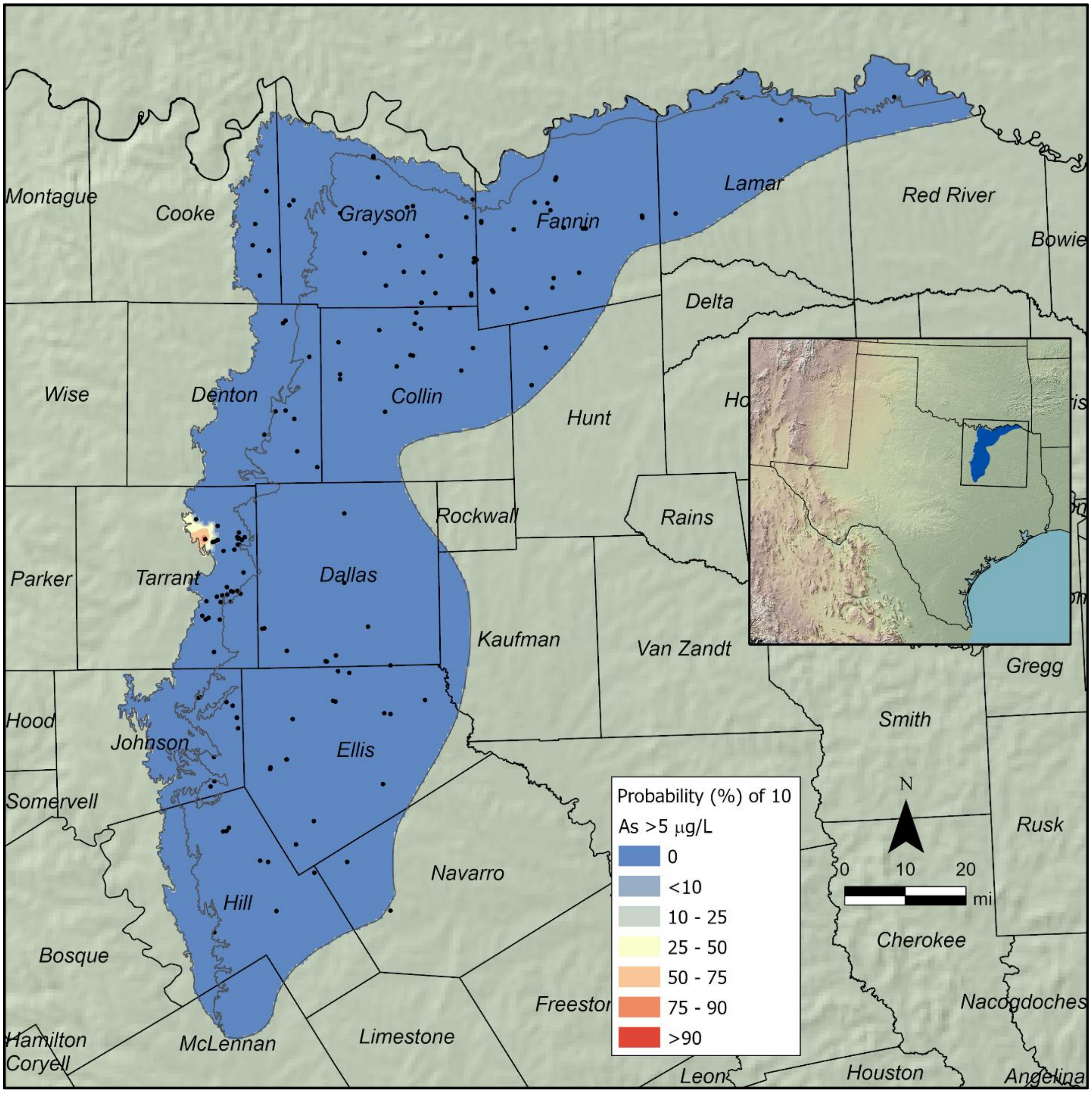


Figure 43. Woodbine aquifer probability distribution of arsenic >5 µg/L.

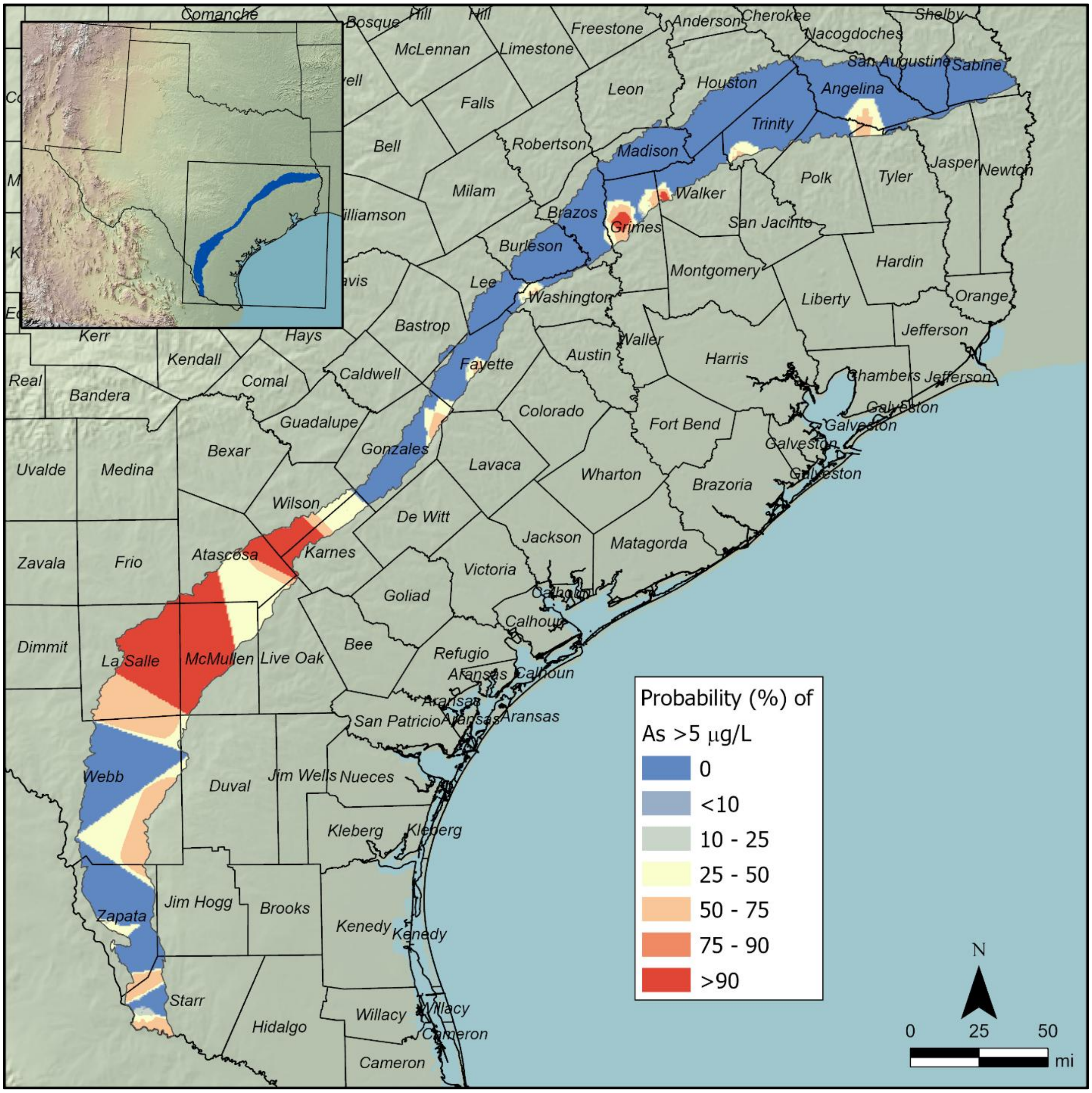


Figure 44. Yegua-Jackson aquifer probability distribution of arsenic >5 µg/L.

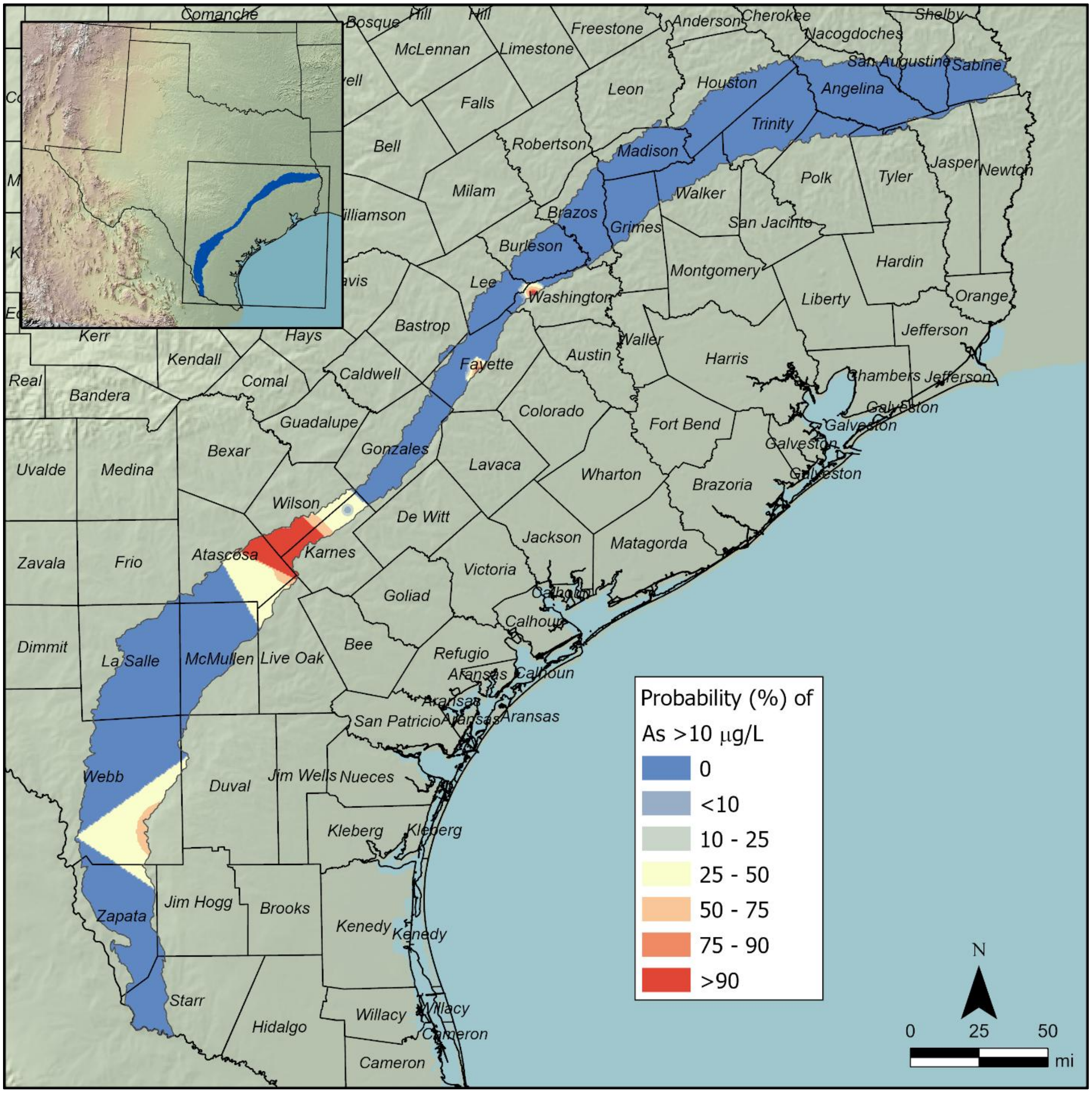


Figure 45. Yegua-Jackson aquifer probability distribution of arsenic >10 µg/L.