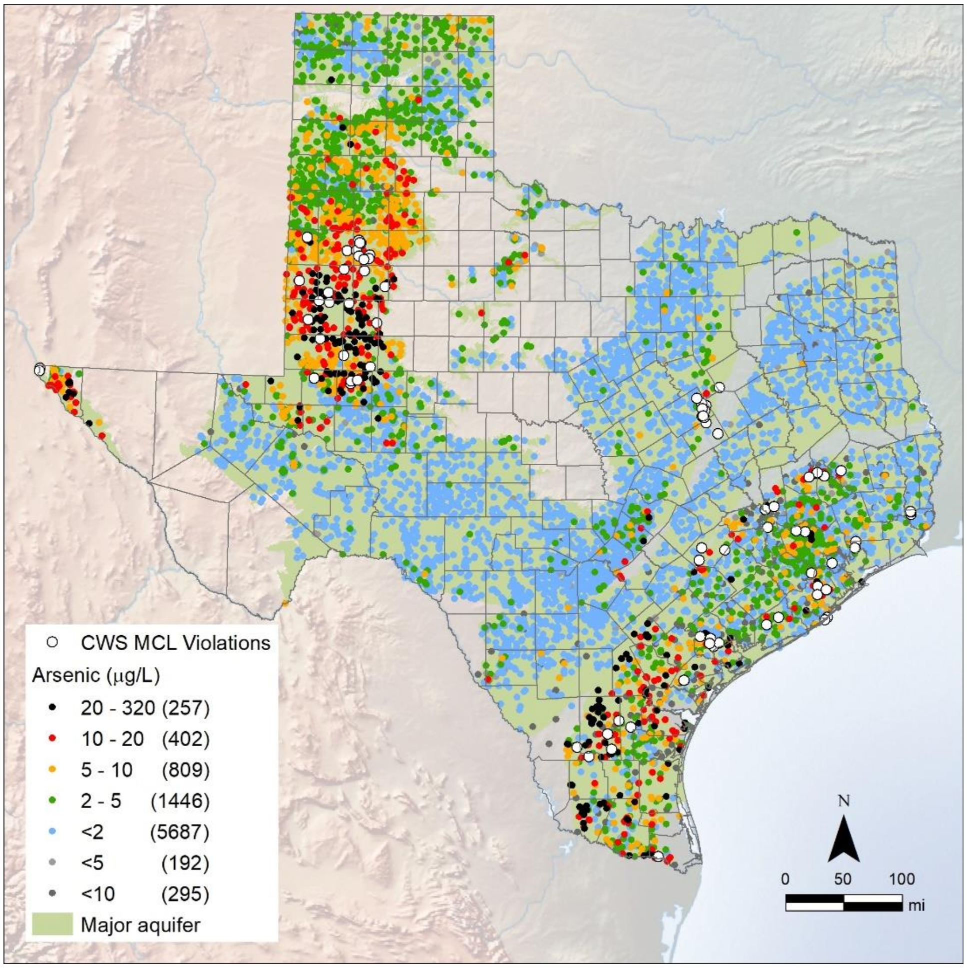
Update: Assessment of Arsenic in Groundwater and Water Supply Systems in Texas



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. Many previous studies indicate that elevated arsenic concentrations in groundwater primarily originate from natural geologic sources. The objective of this study was update results from a 2018 study to quantify the distribution of groundwater arsenic in the major aquifers in Texas and assess linkages to populations using this water. Groundwater arsenic data were compiled from 9,088 wells sampled between 1992 and 2024. The spatial distribution of elevated arsenic concentrations was mapped by aquifer using indicator kriging based on two threshold concentrations: 5 μg/L being considered in the EPA Integrated Risk Information System assessment within EPA and 10 μg/L representing the current EPA Maximum Contaminant Level (MCL). The current number of non-compliant Community Water Systems (CWSs) and associated populations were obtained from EPA listings and the estimated populations with non-compliant domestic system water were obtained from the U.S. Geological Survey water use data adjusted for county-level population changes between 2015 and 2023.

Results show that a total of 659 samples exceeded the arsenic MCL of 10 µg/L, representing 18.8% of all analyses with detectable arsenic and 7.2% of all samples used in this study and 5,578 samples (61.4% of all samples) were below analytical detection limits. The remaining samples with detectable arsenic levels (3,510 samples, 38.6% of all samples) have a median concentration of 4.1 µg/L arsenic, with a relatively narrow 5th to 95th percentile range of 1.1 µg/L to 25.6 µg/L.

The total reported 2023 population served by CWSs is 30,370,000, virtually identical to the population of 30,500,000 estimated by the US Census, indicating that the populations served are somewhat overestimated by the CWSs. Based on adjusting the 2015 USGS county estimates by population changes since that time, the estimated 2023 population served by domestic (i.e., non-CWS) systems is 1,460,000, representing 4.8% of the state population.

The highest arsenic concentrations are found in the southern Gulf Coast, southern High Plains, and the Trinity aquifer. During 2021 – 2023, a total of 88 CWSs were non-compliant in terms of arsenic with an associated population of about 296,000. The most affected populations are located in the southern Gulf Coast area (Gulf Coast aquifer, 46 systems with 99,979 people), the general Waco metropolitan area (Trinity aquifer, 9 systems with 12,429 people), and large areas of the High Plains region (Ogallala aquifer, with 29 systems, 178,068 people). The City of Midland is the largest population system currently in violation with a population served of 142,334. The estimated affected major aquifer domestic system population is 81,422.

The EPA Integrated Risk Information System is considering a reduced arsenic MCL of 5 µg/L. If the MCL is reduced from 10 to 5 µg/L and current conditions do not change, the numbers of violating systems would increase by a factor of 5 to 454 systems and the associated populations would increase by a factor of 15 to 4,406,000 people, representing an increase from the current 1% to 14% of the state population. The estimated affected domestic system population would increase by a factor of 2.4 to 194,000.

While the State has been making considerable progress towards bringing CWSs into compliance, there are still a number of non-compliant CWSs. There are a variety of approaches for managing arsenic contamination in small CWSs, including point of entry and point of use systems.

Introduction

This report provides an update to a previous study originally published in 2018 with the same title. As such, the general formatting and language are similar or identical in places. Arsenic (As) contamination in groundwater is widespread in the U.S. (Nordstrom, 2002; Smedley and Kinniburgh, 2002; Welch and Stollenwerk, 2003). The maximum contaminant level (MCL) for arsenic was reduced from 50 µg/L to 10 µg/L in 2001 with public water systems being required to comply to the new standard in January 2006 (US EPA, 2018). This regulation applies to public water systems but not domestic wells (privately owned) which are not regulated. A recent analysis of the domestic well population vulnerable to arsenic contamination indicates that ~2.1 million (M) people out of a population of 44 M people using domestic wells in the U.S. rely on groundwater with arsenic levels exceeding the MCL of 10 µg/L (Ayotte *et al.*, 2017). Texas ranks 7th in terms of domestic population impacted by arsenic contamination, with ~95,000 people affected. This study used logistic regression with 42 variables used as proxies for arsenic, including climate, groundwater recharge, soil properties, and geologic variables etc.

Groundwater arsenic levels greater than the MCL represent a health hazard. The form of arsenic determines the health impacts. Inorganic forms or arsenic are ~100 times more toxic than organic forms and trivalent arsenite is ~60 times more toxic than hexavalent arsenate. The dominant exposure pathway for humans is in food; however, organic forms of arsenic in food have negligible toxicity (Abernathy et al., 2003). Long-term exposure to arsenic from drinking-water has been linked to cancer, skin lesions, cardiovascular disease, and diabetes. Long-term exposure to arsenic in groundwater is also linked to skin, lung, bladder, kidney, and liver cancers. Arsenic can also cause various noncancerous diseases, including hypertension, diabetes, skin lesions, and hyperkeratosis of hand and feet (Tseng et al., 2000). In utero and early childhood exposure has been related to impairment of cognitive development and higher mortality in young adults (Farzan *et al.*, 2013; Tolins *et al.*, 2014). Arsenic is routinely added to chicken feed to make chickens more robust (Rutherford et al., 2003). Arsenic is associated with coal burning in China. Lesikar et al. (2006) also reviewed health effects of arsenic relative to Texas aquifers.

Previous studies in Texas examined the distribution of naturally occurring contamination in major and minor aquifers in the State quantifying exceedances of U.S. Environmental Protection Agency (EPA) primary and secondary maximum contaminant levels (MCL) for drinking water (Reedy et al., 2011; 2019). An estimated 14% of the aquifer volume in the state was estimated to be in the high-risk category of primary MCL exceedance. Any primary MCL exceedance in the high probability category is 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.

It is important to understand the processes affecting groundwater arsenic levels. Although arsenic is widely distributed in rocks, mobilization of arsenic into groundwater is often the limiting factor to the occurrence of elevated arsenic levels in groundwater (Smedley *et al.*, 2002). Critical factors related to the distribution of elevated groundwater arsenic levels include

(1) Arsenic source

(2) Process for mobilizing arsenic into groundwater

(3) Low recharge rates limited arsenic flushing in aquifers

Previous studies have identified important factors for delineating aquifer vulnerability to arsenic contamination (Smedley *et al.*, 2002). Environments with 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). Mobilization mechanisms 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). An example of processes operating in oxidizing conditions is shown by aquifers in Argentina which have a high influx of arsenic influx from volcanic glass dissolution, followed by arsenic adsorption onto hydrous Fe or Al oxides, and then mobilization related to elevated pH (8–9) related to mineral weathering (Smedley *et al.*, 2005; Bhattacharya *et al.*, 2006). Previous studies have identified elevated concentrations of arsenic in the southern High Plains (SHP) aquifer in Texas (Nativ and Smith, 1987; Nativ, 1988; Hudak, 2000). This region falls into the low temperature, non-mining area in the classification of Smedley and Kinniburgh (2002). Groundwater is under oxidizing conditions based on O_2 (DO), NO_3, and SO_4 levels. High arsenic levels were originally attributed to application of arsenical pesticides to defoliate cotton because of the spatial coincidence 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). Later studies that involved intensive drilling of the unsaturated zone and sampling of soil profiles and chemical analyses, show that water-extractable arsenic from application of pesticides is limited to the zone near the land surface (60 cm) and is also linked with elevated PO_4 levels from application of fertilizers (Reedy *et al.*, 2007). Elevated arsenic levels > 3 ft depth beneath native rangeland and cropland regions are attributed to a geologic source because native rangelands were never subjected to pesticide applications and elevated PO_4 levels were not found at depth beneath native rangeland and cropland settings.

Detailed studies of groundwater arsenic contamination have been conducted in hot spots of arsenic contamination in Texas, including the southern High Plains and southern Gulf Coast regions (Gates *et al.*, 2011; Scanlon *et al.*, 2009). In the southern High Plains, almost 50% of the analyses were found to have arsenic levels exceeding the MCL. Contamination with arsenic was linked to F, V, Se, B, Mo and SiO_2 suggesting 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 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 is not causing arsenic mobilization. The data indicate that arsenic mobilization through the southern High Plains Aquifer is likely attributed to 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 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 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, water in ~30% of the wells had 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 major 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 from three sources: the Texas Water Development Board (TWDB) groundwater database, the Texas Commission of Environmental Quality (TCEQ) public water supply (PWS) database, and the US Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS) database. Data for Texas in the SDWIS database are provided by TCEQ. Water supply systems in the SDWIS database are categorized as either a Community Water System (CWS) or a non-Community Water System. This study focuses on CWSs and for clarity we adopt the SDWIS database term "CWS" to reference equivalent systems in both the SDWIS and PWS databases.

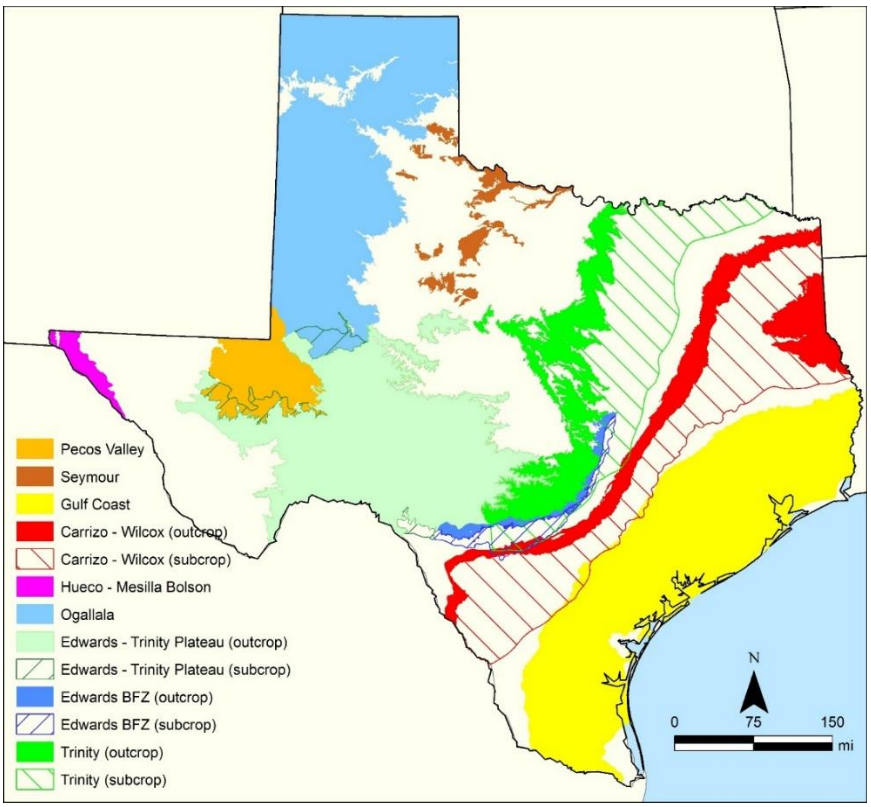

Figure 1. Major Aquifers of Texas.

The TWDB database contain water analyses sampled from groundwater well-heads prior to any treatment processes and the results are accepted as 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 generally reflect post-treatment conditions.

The source aquifer for pumped water is 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 nine major aquifers (Figure 1). Samples from the TWDB database represent major aquifers only. Samples from the PWS database include some wells completed in minor aquifers for systems that source water from multiple aquifers. 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.

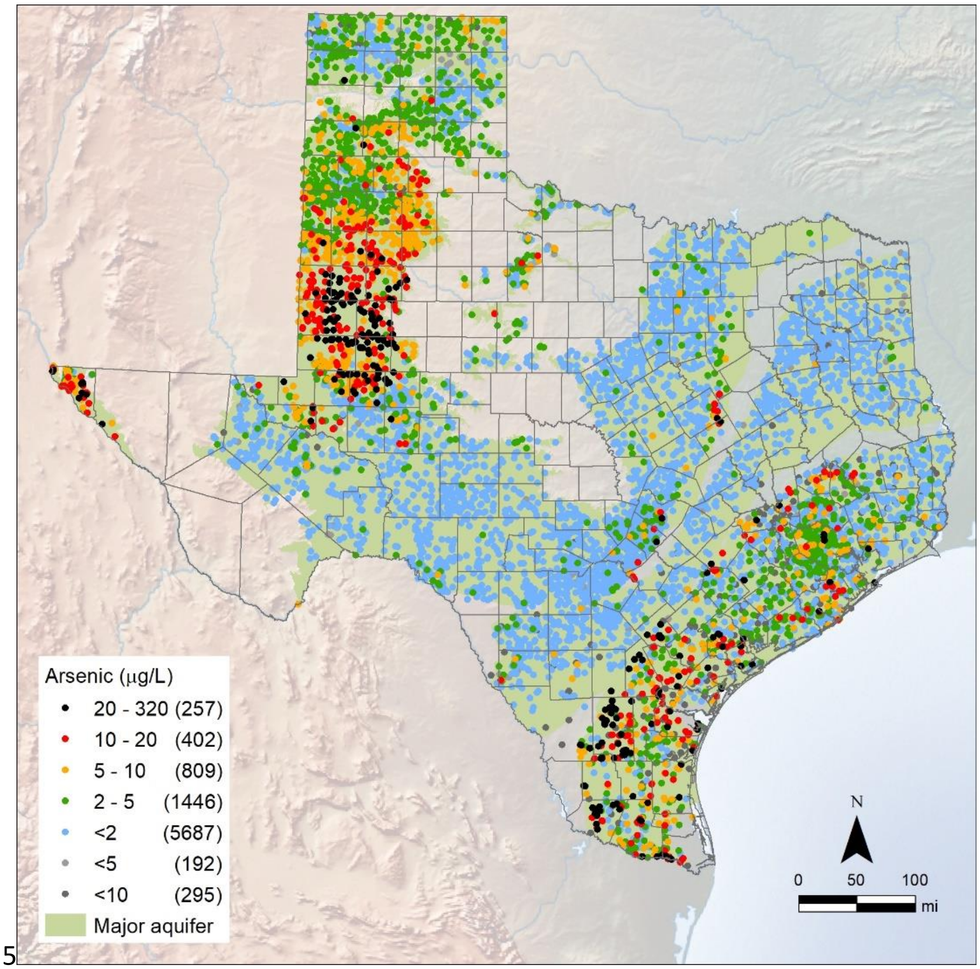

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Figure 2. Spatial distribution of groundwater arsenic concentrations in Texas major aquifer groundwater, including samples collected from 1992 – 2024. The numbers of samples in each concentration range are shown in parenthesis. Samples exceeding the EPA MCL (10 mg/L) totaled 659. The 5,687 samples symbolized as <2 include 596 detected and 5,091 non-detected concentrations.

Samples from 9,088 groundwater wells in Texas are represented in this study (Figure 2). Among these are 5,578 samples with arsenic concentrations below various method detection limits, representing 61% of all samples. The highest non-detect concentration level included in this study is equal to the EPA Maximum Contamination Level (MCL) of 10 µg/L for drinking water, representing 295 samples, or ~3% of all samples. A small number of samples with detection limits above the MCL were rejected. Most of the non-detect samples (5,091, 56% of all samples) have a detection limit of 2 µg/L or lower.

The remaining 3,510 samples had arsenic concentrations above the various method detection limits, representing 39% of all samples. Of these, the median concentration is 4.3 µg/L and 659 samples exceeded the 10 µg/L MCL concentration, representing 19% of detected concentrations and 7% of all the arsenic data in this study.

At Risk Population Estimates

A separate assessment was performed to estimate the various populations at risk of exposure to arsenic concentrations both above 5 µg/L and above the 10 µg/L MCL. The analysis focused on two general classes of water supply systems that were assessed separately, including 1) CWSs that are regulated by the TCEQ and 2) domestic or otherwise self-supplied systems that are not regulated.

We used several sources of data to examine spatial and temporal trends in the total Texas and county populations and the populations associated with CWSs and with self-supplied or domestic wells. The US Census provides populations based on the decennial US Census and on annual estimates for intervening years at both the state and county level. The TCEQ provides reported populations served for each currently reporting CWS as well as the county served by each system. The USGS provided estimates of county level water use every five years through 2015 that include estimated public and self-supplied (domestic) populations. Finally, spatial and temporal trends in new domestic well completions beginning in 2003 to the present are available in the Submitted Drillers Report (SDR) database curated by the TWDB.

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 CWS system and are referred to in this study are non-PWS systems. Estimates of the at-risk non-CWS population were made by aquifer using the kriging probability maps discussed earlier coupled with estimates of the non- CWS county populations from the United States Geological Survey (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- CWS 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 domestic populations are evenly distributed within each county. The county areas were not adjusted for areas served by CWSs. Therefore, the at-risk populations may be conservatively over-estimated in areas dominated by CWSs. 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 BFZ aquifer overlies the Trinity aquifer and where the Ogallala and Pecos aquifers overlie the Edwards-Trinity Plateau aquifer. Secondary areas with this situation that affect relatively smaller populations are where minor aquifers either overlie each other or are overlain by a major aquifer. Reasoning that the shallowest aquifer in a given overlapping area is likely the primary water source for domestic systems, this study assigns the populations for a given area to the shallowest aquifer in a given area.

GIS Spatial 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 ArcMap 10.7.1 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 that arsenic concentrations exceed a selected threshold value. Two threshold values were used. A lower threshold of 5 µg/L representing a conservative estimate to identify areas where the likelihood that groundwater arsenic concentrations exceed "background". 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 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 for all nine of the major aquifers. The kriging procedures were combined for the Ogallala and Pecos Valley aquifer samples due to the relatively sparse coverage along their mutual boundary.

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 less than or equal to the threshold value or 1 (one) if the data point is greater than the threshold value. A semi-variogram is created that represents the average variance between data locations as a function of the separation distance between the data points. The semi-variogram may include directional anisotropy components if the variance displays structure based on azimuthal direction within the data. A mathematical model is then fit to the semi-variogram points and this model is 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 six categories with descriptive terms, including none (0%), very low (<10%), low (10-40%), elevated (40-60%), high (60-90%), 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 reproduced as page-width size graphics in Appendix I for the reader's convenience.

Results

General Results

There were 9,088 samples from wells completed in the major aquifers. A total of 81% of the major aquifer groundwater arsenic concentration data in this study (7,325 samples) are at or below the 5 µg/L threshold while 7.2% (659 samples) had arsenic concentrations above the 10 µg/L MCL threshold.

The Hueco-Mesilla Bolson had the greatest percentage of samples exceeding the MCL (28.8%), followed by the Ogallala (17.7%), Gulf Coast (11.1%), and Pecos Valley (6.1%) aquifers (Figure 3). The remaining major aquifers had from 0.1% to 1.7% of samples above the MCL.

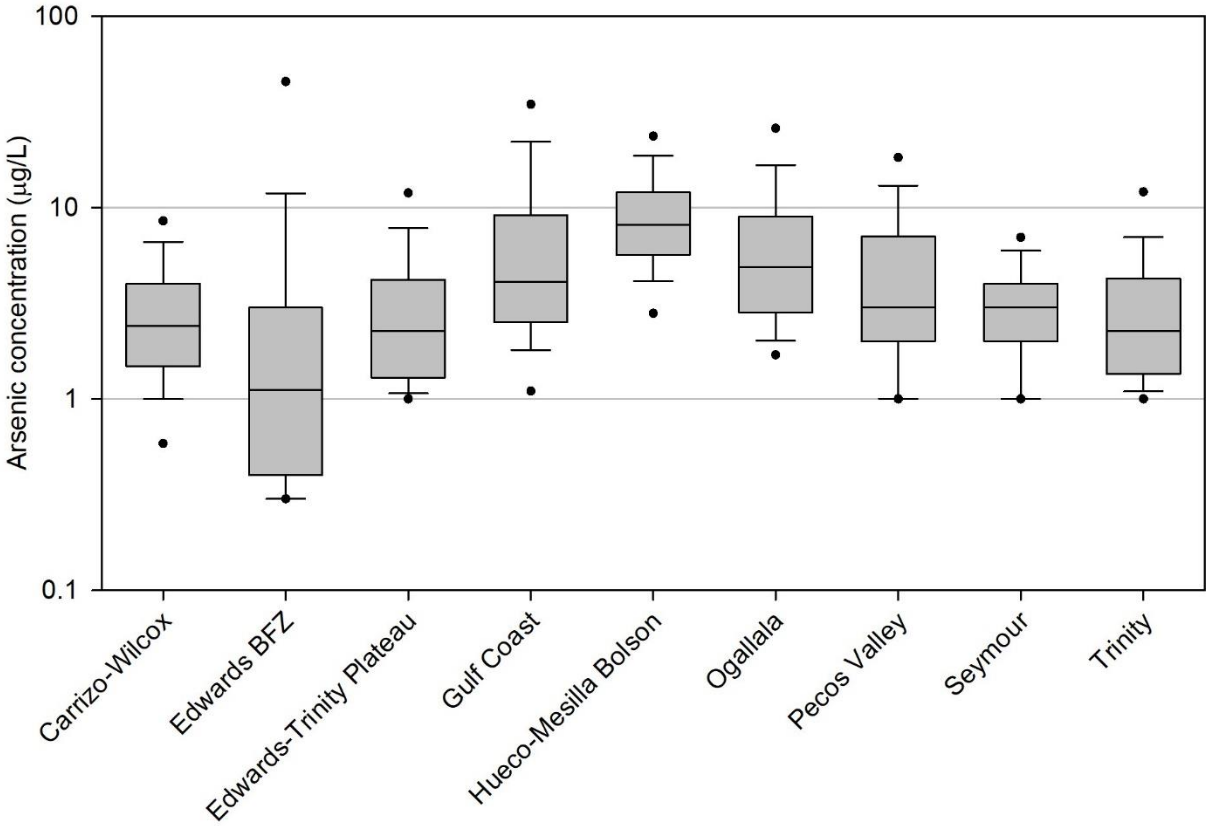

Figure 3. Distribution of detected groundwater arsenic concentrations in the individual major aquifers of Texas (3,510 samples). The lines inside the shaded boxes represent the 50th percentiles (medians), the shaded boxes represent the 25th to 75th percentile ranges, the upward and downward lines extending from the boxes are terminated by horizontal lines at the 10th and 90th percentiles, and the points represent the 5th and 95th percentiles.

Based on the EPA database, a total of 296,335 people were served by 88 CWSs that source their water from one of the major aquifers and that were non-compliant with respect to drinking water arsenic concentrations during 2021 – 2023, representing 1.0% of the 2024 Texas total population (Figure 4).

Based on the aquifer GIS analyses coupled with the USGS county water use population data for 2015, an estimated total of 81,422 people, representing about 0.27% of the 2023 Texas total population, were served by domestic water systems with arsenic concentrations above the 10 µg/L MCL threshold (Table 1). Thus, the Texas population served by either CWS or domestic systems with arsenic concentrations above the MCL is estimated at about 378,000 people, representing about 1.2% of the 2024 Texas total population.

Table 1. Major aquifer CWS populations and estimated domestic system populations with arsenic concentrations above background (>5 µgl/L) and above the MCL (>10 µgl/L) during 2021 – 2023.

Arsenic	*CWS Population*	*Domestic Population*	*Total Population*
> 5 µgl/L	4,372,758	193,506	4,566,264
> 10 µg/L	296,335	81,422	377,757

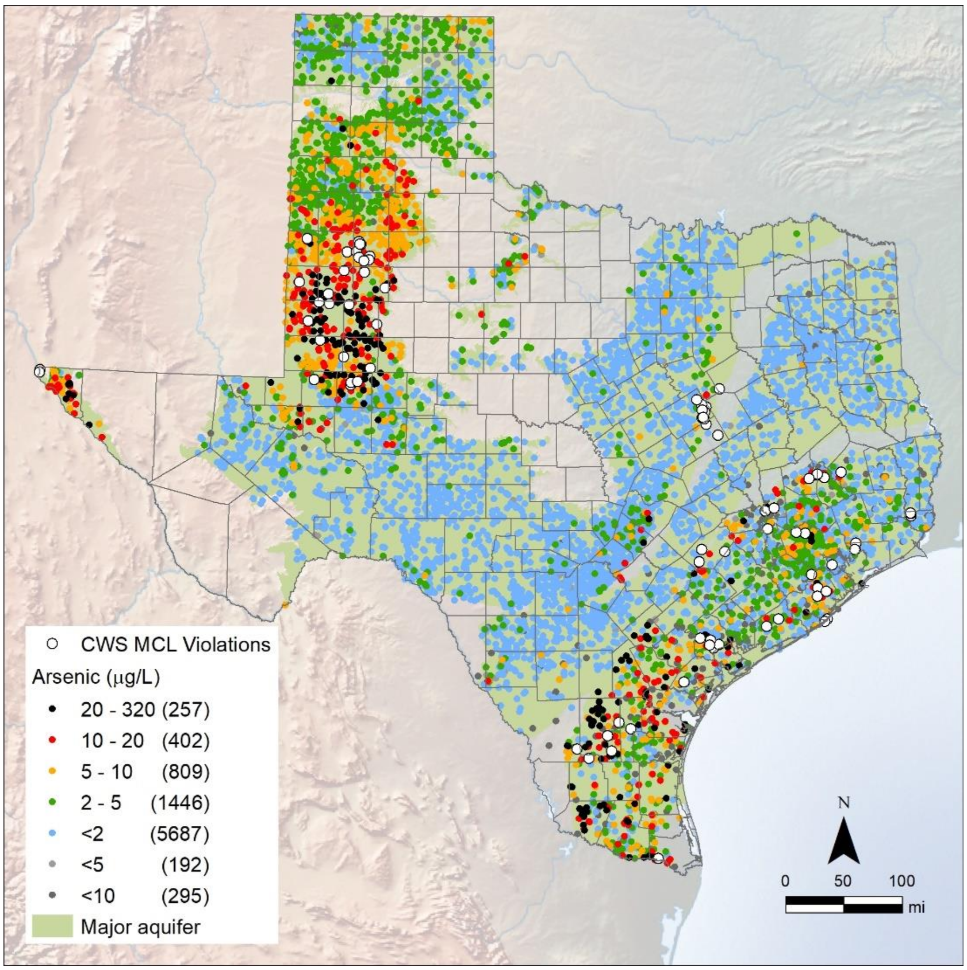

Figure 4. Locations of 88 CWSs that have MCL violations for arsenic concentration in distributed water during 2021 – 2023 based on the EPA database. The violating systems are located primarily in the southern High Plains, the Gulf Coast, and the Waco metropolitan area.

Based on the TCEQ PWS database, a total of 4,406,000 people (about 14% of the 2023 Texas total population) are served by CWSs that have distributed water with arsenic concentrations above 5 µg/L (this includes the current 10 µg/L MCL violations). Most (99.2%, 4,373,000 people) were associated with CWSs that source their water from one of the major aquifers while the remaining were associated with minor aquifer CWSs.

Texas Population Trends

The population of Texas was estimated to be 30.5 million in 2023 (Figure 5), an increase of 5.261 million people (21%) since 2010 and 3.033 million people (11%) since 2015 (Figure 6). Interannual growth rates increased from 1.6% to 1.9% between 2010 and 2015, decreased steadily to 0.8% by 2020, and grew rapidly to 1.6% by 2022.

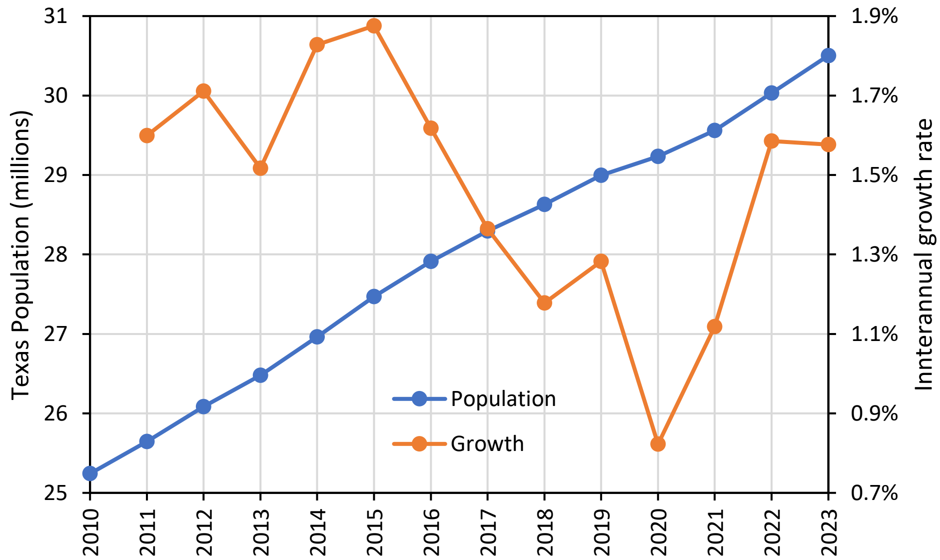

Figure 5. Texas population and interannual changes based on US Census data (2010, 2020) and US Census estimates (other years).

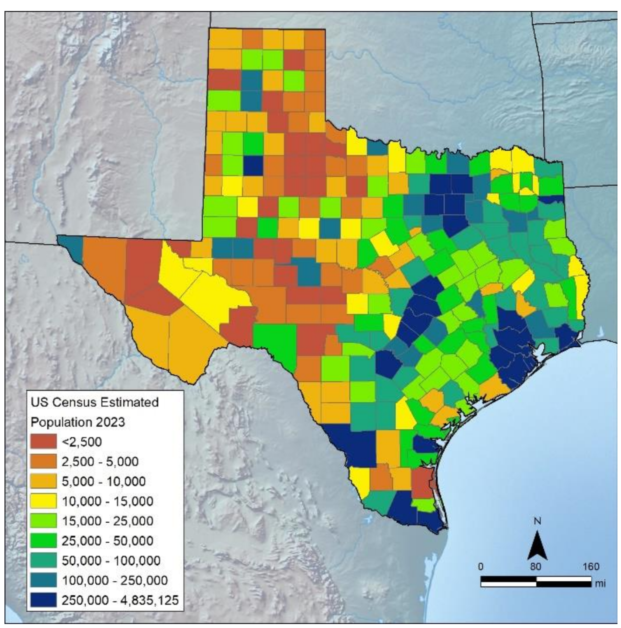

Figure 6. Texas county 2023 populations based on US Census data.

Population changes since 2015 at the county level varied widely with growth concentrated around the major city population centers, including Houston, Dallas-Ft. Worth, San Antonio-Austin, El Paso, and the South Valley while many rural counties across the state experienced populations decreases. Populations of rural counties tended to decrease while populations of more urban counties tended to increase (Figure 7). Overall, the population of the smallest 40% of counties, those with ≤12,000 people, decreased by 48,000 people while the population of the largest 60% of counties increased by 5,310,000 people (Figure 6, Figure 8).

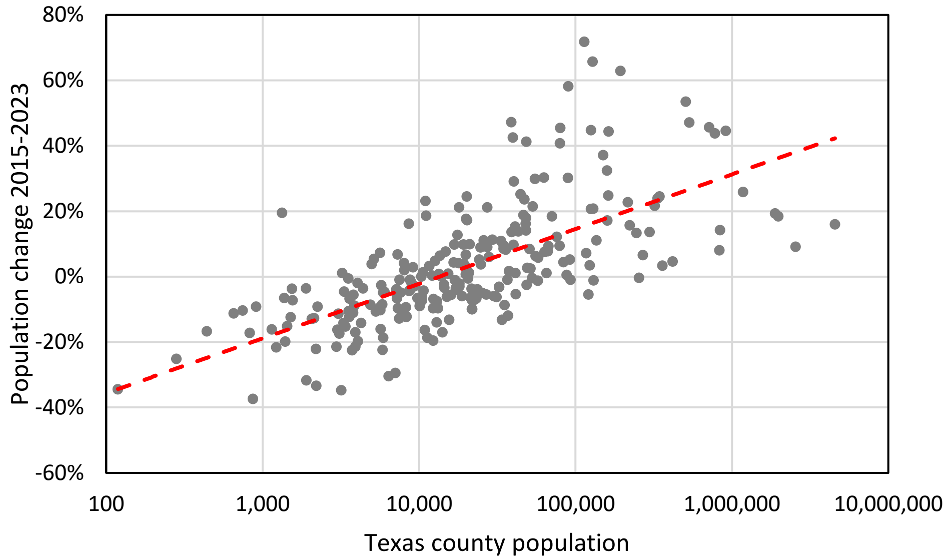

Figure 7. Texas county population change percentages by county size between 2015 and 2023 relative to 2015 populations.

Table 2. Historical evolution of the Texas population relying on CWSs and domestic systems and the relative percentages of the total population. There was no assessment performed for the year 2000 (USGS, https://water.usgs.gov/watuse/data/).

Year	*Total Population*	*CWS Population*	*Domestic Population*	*PWS (%)*	*Non-PWS (%)*
1990	16,986,410	16,129,900	856,510	95.0	5.0
1995	18,723,940	17,550,400	1,173,540	93.7	6.3
2005	22,859,968	20,628,993	2,230,975	90.2	9.8
2010	25,145,561	22,704,975	2,440,586	90.3	9.7
2015	27,469,114	26,154,041	1,315,073	95.2	4.8

A goal for this study was to estimate the county level self-supplied populations, i.e. those depending primarily on domestic groundwater wells for their daily needs. In the initial 2018 study, we used the 2015 USGS self-supplied population estimates (Table 2). However, the USGS did not generate estimates for 2020. Additionally, the USGS estimates have varied widely from 1990 forward, with estimates ranging from 4.8% to 9.8% of the state populations and the estimated populations increased and decreased across that spectrum through time. For instance, the 2010 self-supplied population was estimated as 2.4 million (9.7% of the state population) and the corresponding 2015 population was estimated as 1.3 million (4.8% of the state population). It is difficult to imagine that the self-supplied population percentage decreased by the indicated 1.1 million people, calling into question the methodology used by the USGS to obtain their estimates.

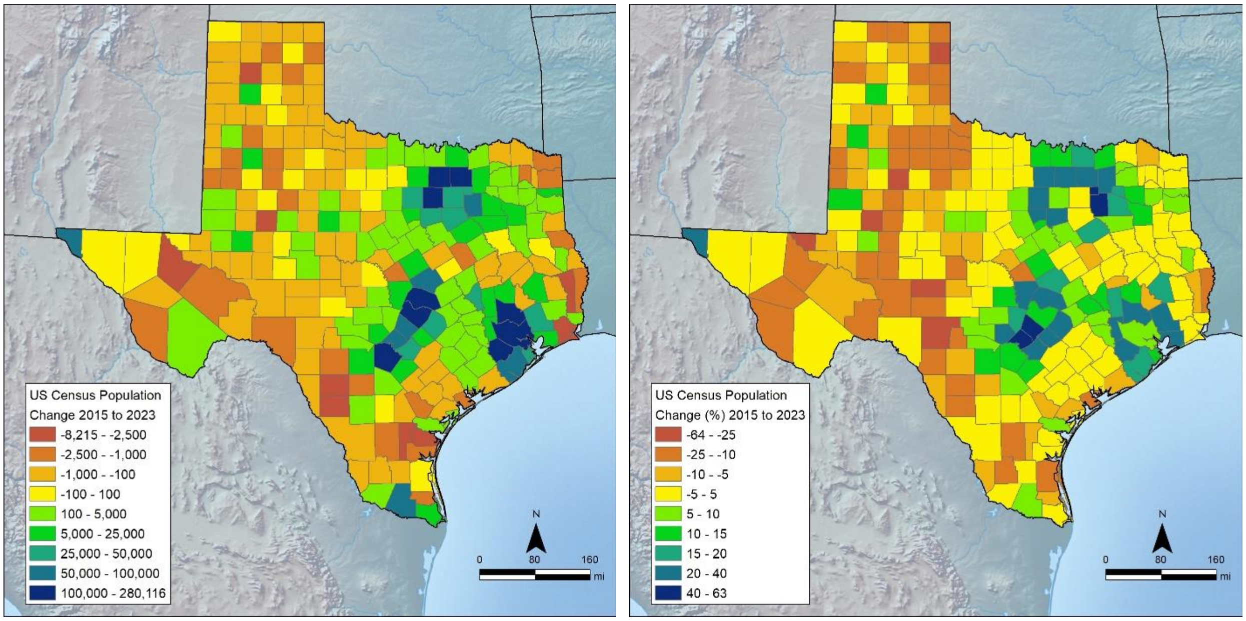

Figure 8. Texas county population changes since 2015, and percentage population changes between 2015 and 2023

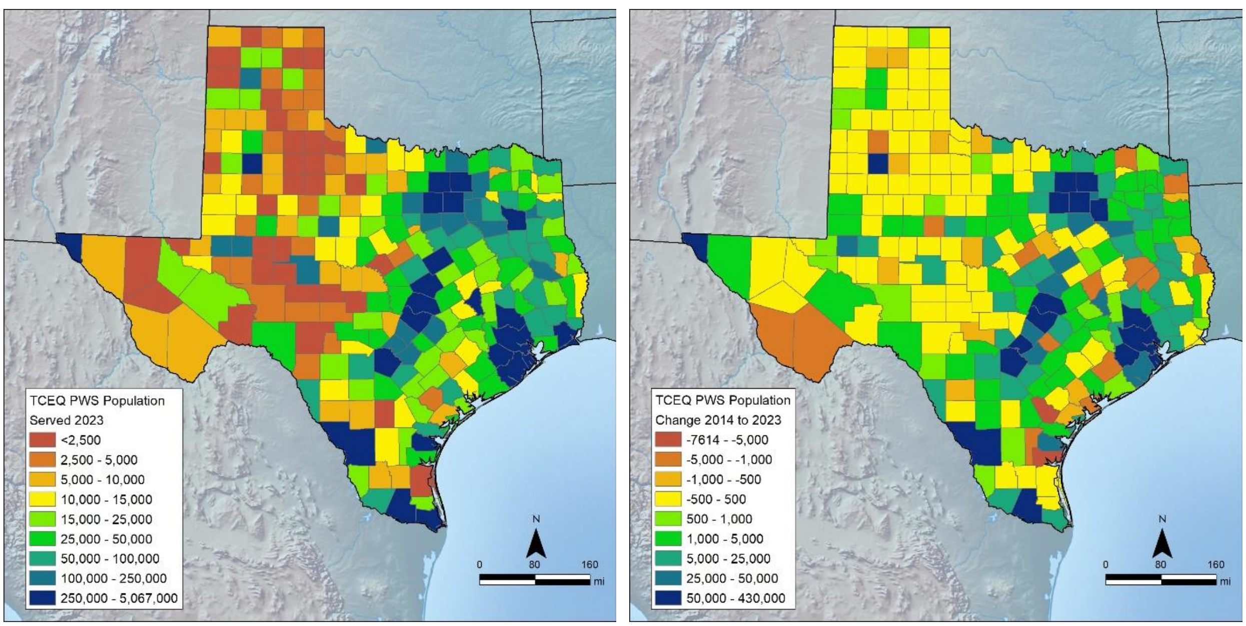

Figure 9. CWS population in 2023 and changes in CWS population between 2014 and 2023.

An alternative approach to estimate the county-level self-supplied populations is by subtraction of the reported CWS populations from the US Census total populations. However, the 2023 reported total Texas CWS population served was 30.37 million people (Figure 9), virtually equal to the total Texas population of 30.50 people estimated by the US Census. By difference, this approach implies that the self-supplied population is only 130,000 people, or 0.4% of the state population. Clearly, this result significantly underestimates the self-supplied population and overestimates the CWS population. Assuming that individual CWS population estimates are within a relatively small percentage of their actual populations, say ±5% to 10%, then errors in the state total population served would be highly skewed toward the larger systems. The total error for smaller, more rural counties would be correspondingly small.

Finally, the Submitted Drillers Report database provides information on the locations of domestic well completions in Texas since 2003. Those data indicate that 93,400 new domestic groundwater wells were completed in Texas since 2015 (i.e., 2016 through 2023, Figure 10). The pattern of well completions is generally similar to that of population growth (Figure 8) with the largest numbers of new wells completed in counties that are adjacent to high population centers likely reflecting primarily suburban growth in these areas. Exceptions are generally located in the region around and south of Lubbock where high demand and locally limited saturated thickness in the Ogallala Aquifer may be driving new well completions that do not necessarily reflect general population changes.

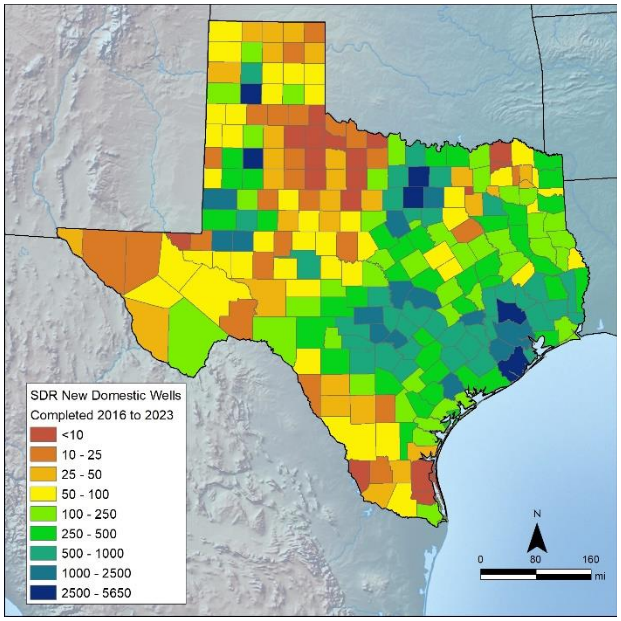

Figure 10. Numbers of new domestic wells completed since 2015 (2016 through 2023).

Despite the apparent limitations, the 2015 USGS self-supplied population estimates are the most recent available. We multiplied the USGS county estimates by the county population change percentages between 2015 and 2023 to obtain estimates of the 2023 self-supplied populations for all Texas counties (Figure 11).

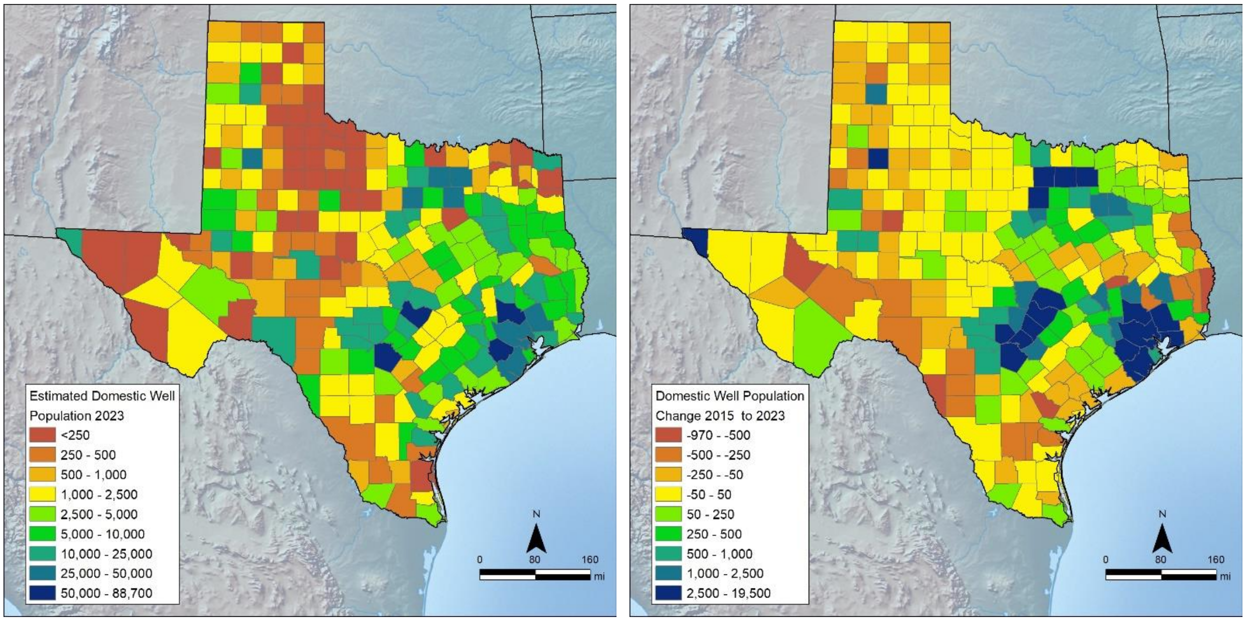

Figure 11. Estimated domestic well populations for 2023 based on 2015 USGS estimates multiplied by US Census population percentage changes.

Violating Community Water Systems and Associated Populations

A total of 202 CWSs in Texas had Arsenic Rule MCL violations between 2010 and 2023 (Table 3, Figure 12). The numbers of systems decreased steadily from 122 to 61 systems between 2010 and 2020, followed by a slight increased to 73 systems in 2022. Arsenic Rule MCL violations are generally associated with smaller population systems. A total of 127 (63%) of the violating CWSs served ≤500 people and 195 (97%) served ≤10,000 people.

Table 3. Numbers of Texas CWSs with arsenic MCL violations for different population served categories based on data from 2010 - 2023. Values in last column represent the total numbers of systems across all years.

CWS Population		*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2010 - 2023*	
Range (1000's)	*Cat*															*Total*	*%*
≤0.5	1	74	69	65	61	54	50	49	50	44	39	39	37	42	37	127	62.9
0.5-3.3	2	34	34	34	28	21	23	22	25	20	18	17	20	23	23	49	24.3
3.3-10	3	12	9	9	8	9	8	5	5	2	3	5	3	5	5	19	9.4
10-100	4	2	3	1	1	1	3	2	2	2	1	0	2	3	1	6	3.0
>100	5	0	1	1	1	1	0	0	1	0	0	0	0	0	1	1	0.5
All		122	116	110	99	86	84	78	83	68	61	61	62	73	67	202	100.0

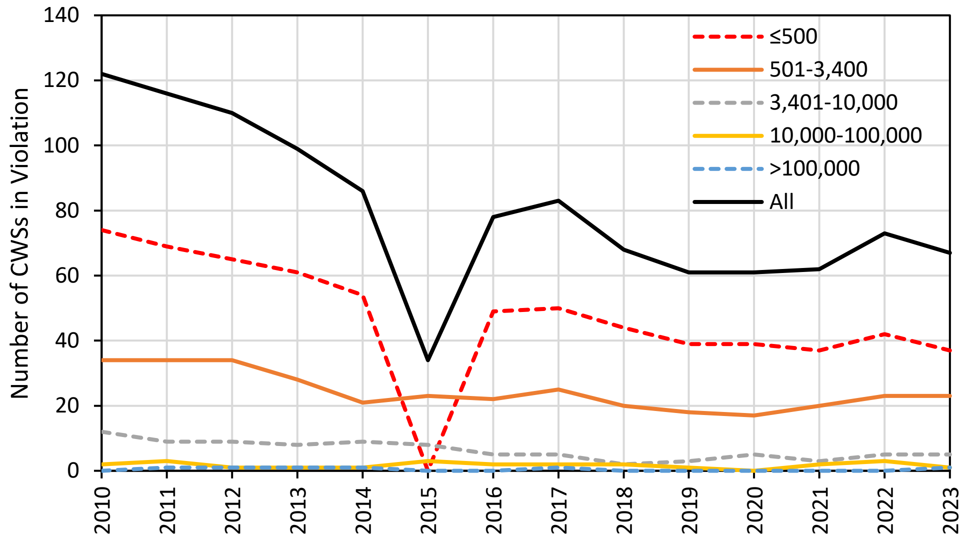

Figure 12. Numbers of Texas CWSs with arsenic MCL violations for different population served categories

Populations associated with the violating CWSs totaled 444,000 people between 2010 and 2023 (Table 4,

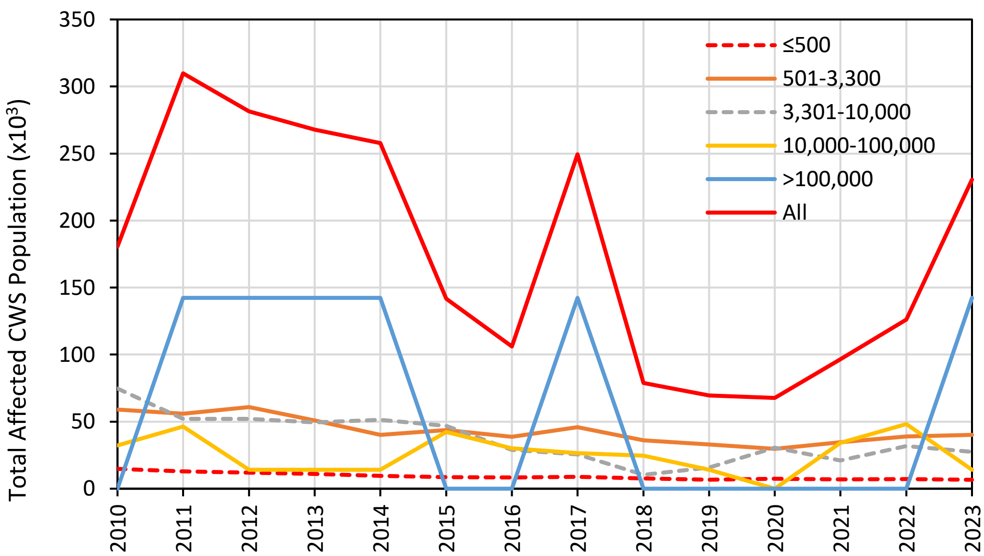

Figure 13), representing approximately 1.5% of the current (2023) Texas Population of 30.5 million. During any given year, the numbers of affected people ranged from 310,000 (2011) to 67,700 (2020). This rather wide range of affected populations reflects a slight overall decreasing trend through time that was strongly overprinted by generally temporary violation periods for a small number of larger systems. The larger systems represent those serving >10,000 people, including the City of Midland serving 142,300 people and the City of Andrews serving 14,100 people in West Texas and five systems located in the Gulf Coast region with populations ranging from 10,600 to 18,100 people.

Table 4. Populations of Texas CWSs with arsenic MCL violations for different population served categories. Values are in 1,000's. Values in last column represent the affected total populations across all years.

CWS Population		*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2010 - 2023*	
Range	*Cat*															*Total*	*%*

(1000's)																	
≤0.5	1	14.8	13.0	12.0	11.1	9.7	8.7	8.4	8.8	7.8	6.8	7.3	6.8	7.2	6.6	20.2	4.5
0.5-3.3	2	59.0	56.0	60.9	50.8	40.2	43.8	38.7	46.0	36.0	33.0	29.7	34.5	39.1	40.1	83.2	18.7
3.3-10	3	74.7	52.2	52.1	49.5	51.3	46.9	28.9	25.7	10.4	15.8	30.7	21.0	31.8	27.5	113.3	25.5
10-100	4	32.2	46.3	14.1	14.1	14.1	42.2	30.1	26.6	24.7	14.1	-	34.1	48.2	14.1	85.0	19.1
>100	5	-	142.3	142.3	142.3	142.3	-	-	142.3	-	-	-	-	-	142.3	142.3	32.1
All		180.7	309.8	281.5	267.9	257.7	141.6	106.1	249.3	78.8	69.6	67.7	96.4	126.2	230.7	444.0	100.0

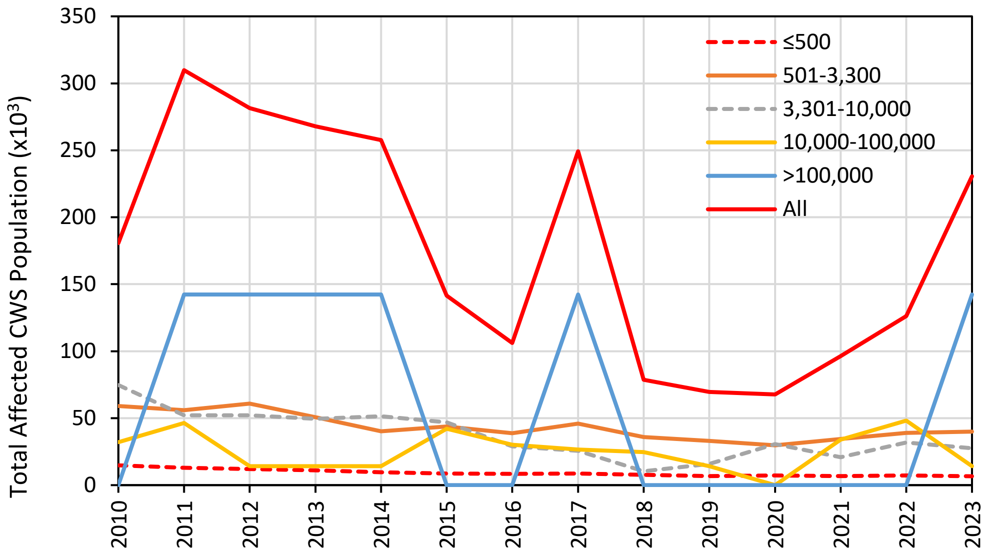

Figure 13. Populations of Texas CWSs with arsenic MCL violations for different population served categories

During the period 2010 – 2023, 36 (18%) of the 202 CWSs with arsenic violations converted to non-public systems (Table 5,

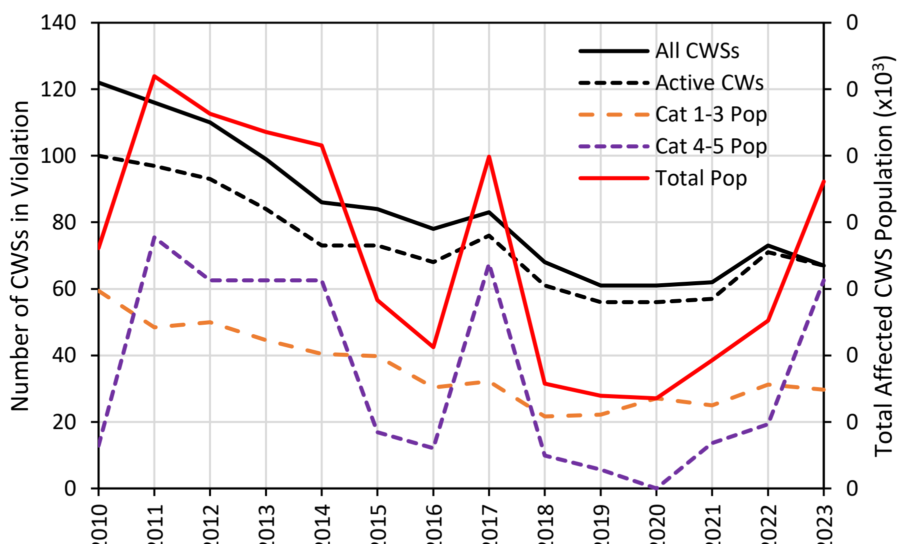

Figure 14). Without exception, all of these systems served ≤500 people, with a median population of 68 people served. The total affected populations were evenly divided between small systems serving ≤10,000 people (216,700 people affected, 49%) and large systems serving >10,000 people (227,300 people affected, 51%). While the affected population for larger systems was erratic across the study period, ranging from 0 to 189,000 people in a given year, the affected population for smaller systems generally decreased steadily from 149,000 in 2010 to about 55,000 by 2018-2019, increasing slightly since then to about 75,000.

Table 5. Numbers of CWSs with arsenic MCL violations (including all systems and currently active systems) and the associated (total) populations within small (Cat 1-3, all systems serving ≤10,000 people) and large (Cat 4-5, all systems serving >10,000 people) size categories. Population values are in 1,000's.

CWSs	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2010 - 2023*
All	122	116	110	99	86	84	78	83	68	61	61	62	73	67	202
Active	100	97	93	84	73	73	68	76	61	56	56	57	71	67	166
Cat 1-3	148.5	121.1	125.0	111.4	101.2	99.4	75.9	80.4	54.1	55.5	67.7	62.3	78.0	74.2	216.7
Cat 4-5	32.2	188.7	156.5	156.5	156.5	42.2	30.1	168.9	24.7	14.1	-	34.1	48.2	156.5	227.3
Total	180.7	309.8	281.5	267.9	257.7	141.6	106.1	249.3	78.8	69.6	67.7	96.4	126.2	230.7	444.0

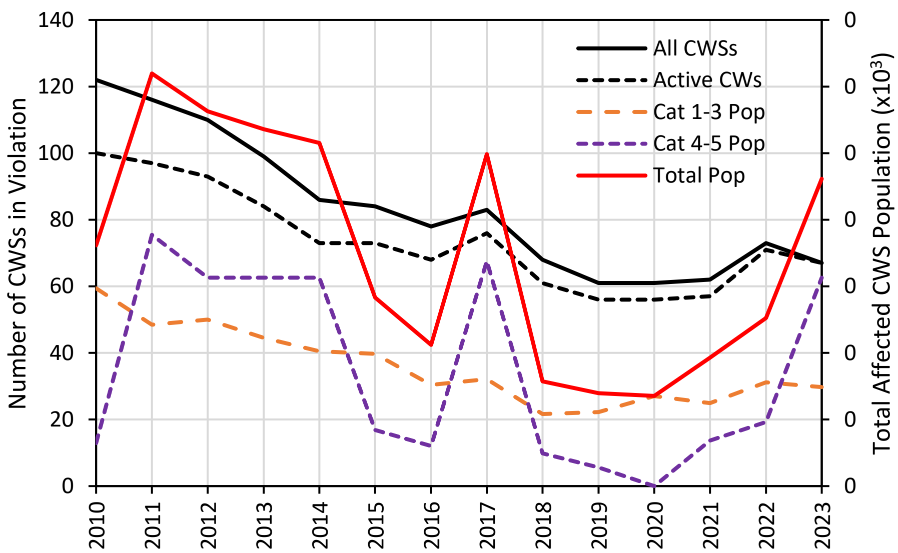

Figure 14. Numbers of CWSs with arsenic MCL violations (including all systems and currently active systems) and the associated (total) populations within small (Cat 1-3) and large (Cat 4-5) size categories.

There were 13 primary source aquifers associated with the violating systems, including seven major and six minor aquifers (Table 6). However, 94% of violating systems and 98% of the associated affected populations had major aquifers as their primary source. It is noted that 58 (29%) of the 202 violating systems and 211,000 (48%) of the total 444,000 affected population were systems having more than one aquifer source. The most prevalent multi-aquifer systems had wells primarily completed in the Ogallala aquifer with some wells completed in the Edwards-Trinity Plateau, Edwards-Trinity High Plains, or Dockum aquifers (10 systems, 159,600 people) or wells primarily competed in the Gulf Coast aquifer with some wells completed in the Carrizo-Wilcox, Sparta, or Other aquifers (9 systems, 36,500 people).

This analysis for this study focuses on recent MCL violations during the period 2021 – 2023 associated with major aquifer source CWSs. There were 88 CWSs with violations that were associated with six of the major aquifers (Table 9). Three of the major aquifers, including the Edwards BFZ, Pecos Valley, and Seymour aquifers did not have any violating CWSs during the recent period. There was a total of 296,335 people associated with all violating systems, primarily with the Ogallala (178,068 people) and the Gulf Coast (99,979 people) aquifers. About half of the population was associated with the City of Midland in the Ogallala aquifer with 142,344 people, which also sources water from the Edward-Trinity Plateau and Dockum aquifers.

Table 6. Numbers of systems and associated populations for CWSs with Arsenic Rule MCL violations during 2010 – 2023 by primary aquifer source. Primary aquifers generally represent the shallowest aquifer in the CWS area. Values for systems and populations having more than one aquifer source are also summarized.

Primary Aquifer	*Systems*		*Population*		*>1 Aquifer*	
	Number	*% of Total*	*Number*	*% of Total*	*Systems*	*Population*
Major Aquifer						
Carrizo-Wilcox	2	1.0	7,783	1.8	2	7,783
Edwards-Trinity Plateau	5	2.5	715	0.2	2	100
Gulf Coast	91	45.0	179,149	40.3	9	36,533
Hueco-Mesilla Bolson	8	4.0	11,866	2.7	3	2,465
Ogallala	69	34.2	203,641	45.9	10	159,567
Pecos Valley Alluvium	1	0.5	3,150	0.7	1	3,150
Trinity	13	6.4	28,168	6.3	1	1,680
Subtotal	189	93.6	434,472	97.8	28	211,278
Minor Aquifer						
Dockum	3	1.5	650	0.1	1	25
Ellenburger-San Saba	1	0.5	40	0.0	0	-
Hickory	1	0.5	5,371	1.2	0	-
Igneous	1	0.5	138	0.0	0	-
West Texas Bolsons	1	0.5	82	0.0	0	-
Other	6	3.0	3,283	0.7	0	-
Subtotal	13	6.4	9,564	2.2	1	25
All Aquifers						
Grand Total	202	100.0	444,036	100.0	58	211,303

Table 7. Numbers of systems and associated populations for CWSs with Arsenic Rule MCL violations during 2021 – 2023 by primary aquifer source. Primary aquifers generally represent the shallowest aquifer in the CWS area. Values for systems and populations having more than one aquifer source are also summarized.

Primary Aquifer	*Systems*		*Population*		*>1 Aquifer*	
	Number	*% of Total*	*Number*	*% of Total*	*Systems*	*Population*
Carrizo-Wilcox	1	1.1	5,353	1.8	1	5,353
Edwards BFZ	0	0.0	-	0.0	0	0
Edwards-Trinity Plateau	2	2.3	452	0.2	0	0
Gulf Coast	46	52.3	99,979	33.7	7	29,983
Hueco-Mesilla Bolson	1	1.1	54	0.0	0	0
Ogallala	29	33.0	178,068	60.1	6	155,867
Pecos Valley Alluvium	0	0.0	-	0.0	0	0
Seymour	0	0.0	-	0.0	0	0
Trinity	9	10.2	12,429	4.2	1	1,680
Total	88	100.0	296,335	100.0	15	192,883

We also analyzed the TCEQ PWS database to identify CWSs and associated populations that distributed water with arsenic concentrations exceeding the proposed MCL of 5 µg/L during the period 2021 – 2023 (Table 8). There were 430 such systems associated with eight of the major aquifers. One of the major aquifers, the Seymour aquifers did not have any exceedances during the recent period. There were 4,373,000 people associated with these systems, primarily in the Gulf Coast (3,229,000 people) and the Hueco-Mesilla Bolson (762,000 people), the Ogallala (253,000 people), and the Trinity (100,000 people) aquifers. Additionally, there were 24 CWSs that rely primarily on minor aquifer sources, with an associated population of 33,600 people, or <1% of the major aquifer population.

Thus, under current conditions, lowering the MCL from 10 µgL to 5 µg/L would result in a 5x increase in the number of systems in violation (454 systems including those supplied by minor aquifers) and a 15x increase in the associated population, representing an increase of 1% to 14% of the total 2023 Texas population.

Table 8. Numbers of systems and associated populations for CWSs with arsenic concentrations greater than the proposed MCL of 5 µg/L during 2021 – 2023 by primary aquifer source. Primary aquifers generally represent the shallowest aquifer in the CWS area. Values for systems and populations having more than one aquifer source are also summarized.

Primary Aquifer	*Systems*		*Population*		*>1 Aquifer*	
	Number	*% of Total*	*Number*	*% of Total*	*Systems*	*Population*
Carrizo-Wilcox	4	0.9	11,237	0.3	1	5,353
Edwards BFZ	1	0.2	2,950	0.1	1	2,950
Edwards-Trinity Plateau	4	0.9	3,815	0.1	0	-
Gulf Coast	286	66.5	3,229,064	73.8	7	53,298
Hueco-Mesilla Bolson	15	3.5	761,835	17.4	1	747,168
Ogallala	89	20.7	252,866	5.8	14	177,079
Pecos Valley Alluvium	4	0.9	10,801	0.2	1	3,150
Seymour	-	0.0	-	0.0	0	-
Trinity	27	6.3	100,190	2.3	1	1,680
Total	430	100.0	4,372,758	100.0	26	990,678

Arsenic Concentrations in the Major Aquifers of Texas

In this study, we updated the maps originally produced in the 2018 report for the nine major aquifers of Texas. The minor aquifers were not revisited here as they represent only 2.2% of the affected population (Table 6). As in the original study, we used groundwater sample results in the TWDB Groundwater Database from wells completed in a single major aquifer, including 8,078 samples analyzed after 1991. For this study, we used an additional 1,010 sample results for “raw” water samples in the TCEQ Public Water Supply database, eliminating duplicate samples between the two databases for a grand total of 9,088 samples (Table 9). As with all of the TWDB samples, The TCEQ raw samples were obtained at or near the well head and prior to any treatment processes.

We used the same indicator kriging methods as for the original report to estimate the spatial probability distribution of groundwater with arsenic at selected threshold concentrations. The 10 μg/L threshold represents the current EPA Maximum Concentration Limit (MCL) for arsenic in water distributed by CWSs. The 5 μg/L threshold is currently under EPA review as a potential future MCL. Finally, new maps based on 2 μg/L threshold were generated to indicate regions where arsenic concentrations exceed nominal background levels. The 5 μg/L and 2 μg/L maps were generated by first removing all non-detect samples that exceeded those respective detection limits.

Arsenic concentrations were detected in 39% of all samples while the remaining 61% had non-detected concentrations at various threshold levels. Most (92.1%) of the non-detect samples had a detection limit of 2 μg/L or less and larger percentages of non-detect samples generally reflect aquifers with lower overall arsenic concentrations. A total of 658 samples (7.2%) had arsenic concentrations in excess of the 10 μg/L MCL. Aquifers with the highest percentage of samples exceeding the MCL include the Hueco-Mesilla Bolson (46 samples, 29%), the Ogallala (324 samples, 17%), and the Gulf Coast (237 samples, 11%). A total of 1,467 samples (16.1%) had arsenic concentrations in excess of the proposed 5 μg/L MCL. A total of 2,913 samples (32.1%) had arsenic concentrations in excess of the 2 μg/L nominal background concentration.

Table 9. Numbers of samples used in the spatial probability analysis.

Major Aquifer	*Number of Samples*	*Detects*					*Non-Detects*			
		All	*>2*	*>5*	*>10*	*% >10*	*All*	*<2*	*<5*	*<10*
Carrizo-Wilcox	1,205	48	30	8	1	0.1	1,157	1,059	59	39
Edwards BFZ	621	50	20	9	6	1.0	571	562	9	-
Edwards-Trinity Plateau	1,124	286	161	57	19	1.7	838	814	21	3
Gulf Coast	2,125	1,028	897	443	237	11.2	1,097	868	32	197
Hueco-Mesilla Bolson	160	142	139	122	46	28.8	18	7	5	6
Ogallala	1,835	1,558	1,406	750	324	17.1	277	217	26	34
Pecos Valley	181	90	63	29	11	6.1	91	79	5	7
Seymour	190	121	89	18	3	1.6	69	59	10	-
Trinity	1,647	187	108	31	11	0.7	1,460	1,427	24	9
All Majors	9,088	3,510	2,913	1,467	658	38.6	5,578	5,092	191	295

The spatial mean risk of exposure to groundwater having concentrations greater than the various threshold levels was determined for county areas that intersect the major aquifers. In areas where multiple aquifers are present, the shallowest aquifer was chosen as the most likely domestic well source.

Estimates of the self-supplied populations at risk of exposure at the various threshold levels were determined by multiplying the county-wide mean spatial risk by the estimated self-supplied population adjusted for the percentage of the county underlaid by the aquifer. The self-supplied population was estimated by multiplying the 2015 USGS estimated populations by the 2015 to 2032 Census population percent changes. This approach did not removed areas served by CWSs and further assumes that the self-supplied population is evenly distributed across the county area underlaid by the respective aquifers.

Carrizo-Wilcox Aquifer

The Carrizo-Wilcox aquifer covers 36,800 mi^2 in Texas extending from the international border with Mexico in south central Texas to the Arkansas/Louisiana border in northeast Texas (Figure 15). The aquifer underlies all or parts of 65 counties in Texas. It is composed of the Wilcox Group and the overlying Carrizo Formation of the Claiborne Group. The aquifer is up to 3,000 ft in thick locally and the total thickness of sands saturated with fresh water is about 670 ft.

There were 1,204 samples analyzed for arsenic during the study period with only 48 samples (4.6%) having detectable concentrations. The probability of arsenic exceeding 5 µg/L is zero over most (91%) of the aquifer area with only (8%) of the aquifer area in south and south-central Texas having a very low to low probability of arsenic >5 µg/L, located mostly in confined areas. The median concentration of samples with detectable concentrations is 2.4 µg/L and the 5^{th}-95^{th} percentile range is 1.0–7.0 µg/L. Only one sample near the border with Mexico exceeded the MCL with a concentration of 10.8 µg/L.

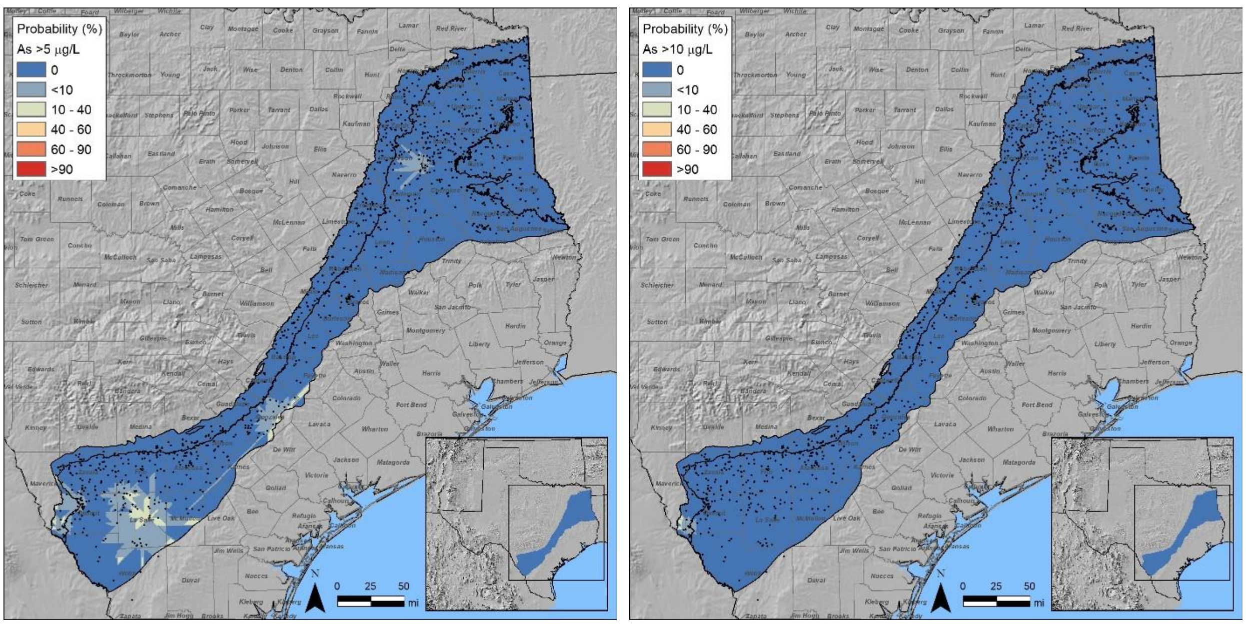

Figure 15. Carrizo-Wilcox aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of four CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 11,237 people. Based on the EPA database, there is one CWS withdrawing water from the Carrizo-Wilcox that is non-compliant for arsenic with a population of 5,353 (Table 10), though this system also withdraws water from the Trinity. The non-PWS system at-risk population of >10 µg/L arsenic is very low at 39, located in southern Maverick County along the international border with Mexico. The non-PWS system at-risk population of >5 µg/L arsenic is low at 449 in localized regions of the confined areas.

Table 10. Carrizo-Wilcox aquifer CWSs with MCL violations for arsenic concentrations based on the US EPA database for the period 2021 through 2023.

PWS ID	*System Name*	*Source Aquifer(s)*	*Population Served*
0730004	Tri County SUD	Carrizo-Wilcox, Trinity	5,353

Edwards (Balcones Fault Zone) Aquifer

The Edwards BFZ aquifer covers 4,300 mi^2 in Texas skirting the eastern and southern boundaries of the Llano Uplift in south central Texas (Figure 16). The aquifer underlies parts of 13 counties in Texas. It composed of the Edwards Limestone and is highly permeable due to dissolution of the unit.

There were 621 samples analyzed for arsenic during the study period with only 50 samples (8.1%) having detectable concentrations. Most (94%) of the aquifer area has no probability of arsenic >5 µg/L with only (6%) of the area in the down-dip edges in confined regions of the aquifer having a very low to low probability of arsenic >5 µg/L. The median concentration of samples with detectable concentrations is 1.1 µg/L and the 5th-95th percentile range is 0.3–16.0µg/L. A total of 5 samples (0.8%) exceeded the MCL with a range of concentrations from 11.6 µg/L to 23.4 µg/L.

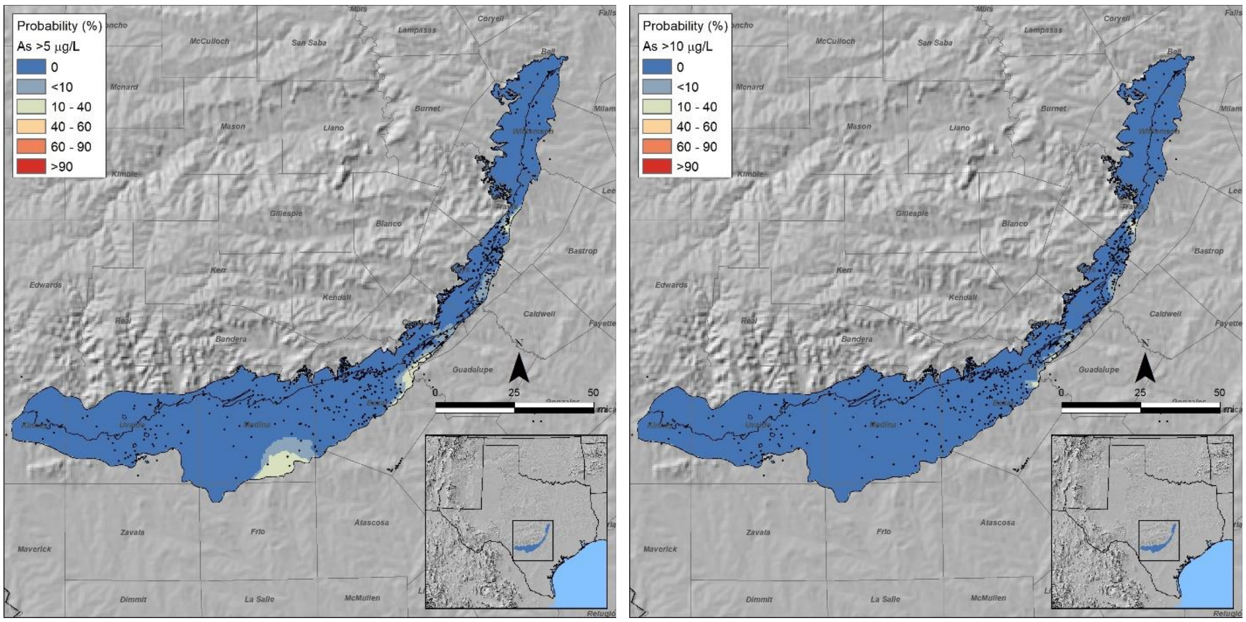

Figure 16. Edwards (BFZ) aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, there is one CWS impacted by arsenic concentrations >5 µg/L, with a population of 2,950 people. Based on the EPA database, there are no PWS systems with arsenic concentrations exceeding the MCL in the Edwards BFZ aquifer. The non-PWS system at-risk population of >10 µg/L is 194 people located primarily in the furthest down-dip areas of the aquifer in Bexar, Travis, Hays, and Comal counties. The non-PWS system at-risk population of >5 µg/L is 476 people located in slightly broader areas of the same counties.

Edwards-Trinity Plateau Aquifer

The Edwards-Trinity Plateau aquifer covers 35,400 mi^2 in Texas including the southern area of the Llano Uplift in south central Texas west to the Pecos River and south to the international border with Mexico (Figure 17). The aquifer underlies all or parts of 40 counties in Texas. Most of the aquifer area (32,400 mi, 92%) is unconfined. Two areas underlie other major aquifers including 1,500 mi^2 (4%) beneath the Pecos Valley Alluvium aquifer and 1,140 mi^2 (3%) beneath the Ogallala aquifer. The aquifer is composed of limestones and dolomites of the Edwards Group and sands in the underlying Trinity Group. Saturated thickness averages 430 ft and is locally greater than 800 ft.

There were 1,124 samples analyzed for arsenic during the study period with 286 samples (25.4%) having detectable concentrations. Most (81%) of the aquifer area has no probability of arsenic >5 µg/L. About 17% of the area has very low to moderate probability of arsenic >5 µg/L, primarily in the areas adjacent to the international border with Mexico. About 2% of the total aquifer area, located primarily in the confined areas beneath the Ogallala aquifer and locally in areas just to the southeast of the Ogallala. The median concentration of samples with detectable concentrations is 2.3 µg/L and the 5th-95th percentile range is 1.0–11.8 µg/L. A total of 19 samples (1.6%) exceeded the MCL with a range of concentrations from 10.3 µg/L to 47 µg/L with the highest concentrations located in or adjacent to the confined areas beneath the Ogallala in Andrews, Ector, and Midland counties.

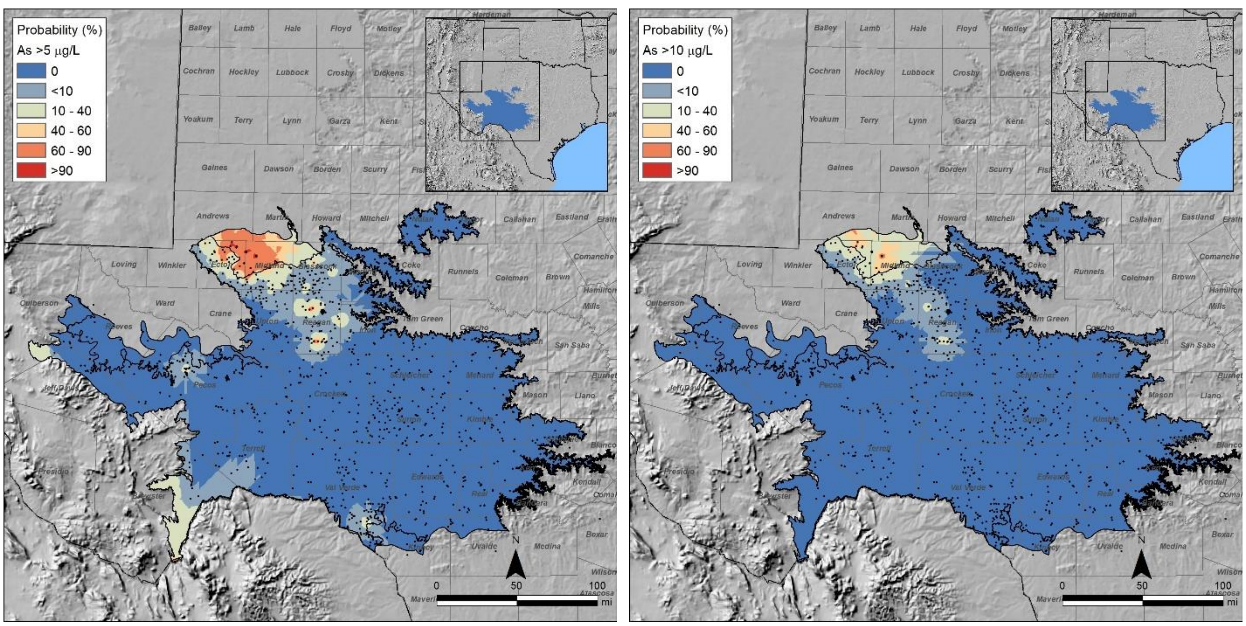

Figure 17. Edwards-Trinity Plateau aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of four CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 3,815 people. Based on the EPA database, there are two CWSs impacted by arsenic concentrations >10 µg/L with a total population served of 358 people (Table 11). The estimated non-PWS system at-risk population of >10 µg/L is 4,923 people and >5 µg/L is 10,371, primarily in Ector and Midland counties. Though the highest risk areas underly the Ogallala aquifer and many domestic wells are likely completed in the Ogallala, the saturated thickness is thin in this region and domestic wells may also be completed in the underlying Edwards-Trinity Plateau. Thus, these results represent upper limits of the non-PWS system at-risk population.

Table 11. Edwards-Trinity Plateau aquifer CWSs with MCL violations for arsenic concentrations based on the US EPA database for the period 2021 through 2023.

PWS ID	*System Name*	*Source Aquifer(s)*	*Population Served*
1650066	Spring Meadow MHP	Edwards-Trinity Plateau	163
1650084	Warren Road Subdivision WS	Edwards-Trinity Plateau	195

Gulf Coast Aquifer System

The Gulf Coast aquifer is a complex system that covers 40,500 mi^2 in Texas extending in a 100-120 mile-wide arc along the entire Texas Gulf Coast from the international border with Mexico to Louisiana (Figure 18). The aquifer underlies all or parts of 56 counties in Texas. The Gulf Coast aquifer is composed of three primary subunits, including from oldest to youngest the Jasper, Evangeline, and Chicot aquifers which outcrop in the most inland areas toward the coast, respectively. Conditions in the aquifer range from unconfined to semi-confined to confined in different areas and depths. Fresh water saturated thickness averages about 1,000 ft.

There were 2,125 samples analyzed for arsenic during the study period with 1,028 samples (48.4%) having detectable concentrations. Arsenic occurrence is widespread in the Gulf Coast aquifer and concentrations tend to increase toward the south, along the inland aquifer boundary, and locally near the coast. Only 5.4% of the aquifer area has no probability of arsenic >5 µg/L. About 80.9% of the area has very low to moderate probability of arsenic >5 µg/L. About 13.7% of the total aquifer area has elevated to very high probabilities of arsenic >5 µg/L, located primarily in the southern third of the region. The median of samples with detectable concentrations is 4.1 µg/L and the 5^{th}-95^{th} percentile range is 1.1–34.6 µg/L. The highest concentrations of groundwater arsenic in Texas are associated with the Gulf Coast aquifer. A total of 237 samples (11.1%) exceeded the MCL with a range of concentrations from 10.1 µg/L to 320 µg/L. This includes 20 samples with concentrations ≥50 µg/L and three samples ≥100 µg/L.

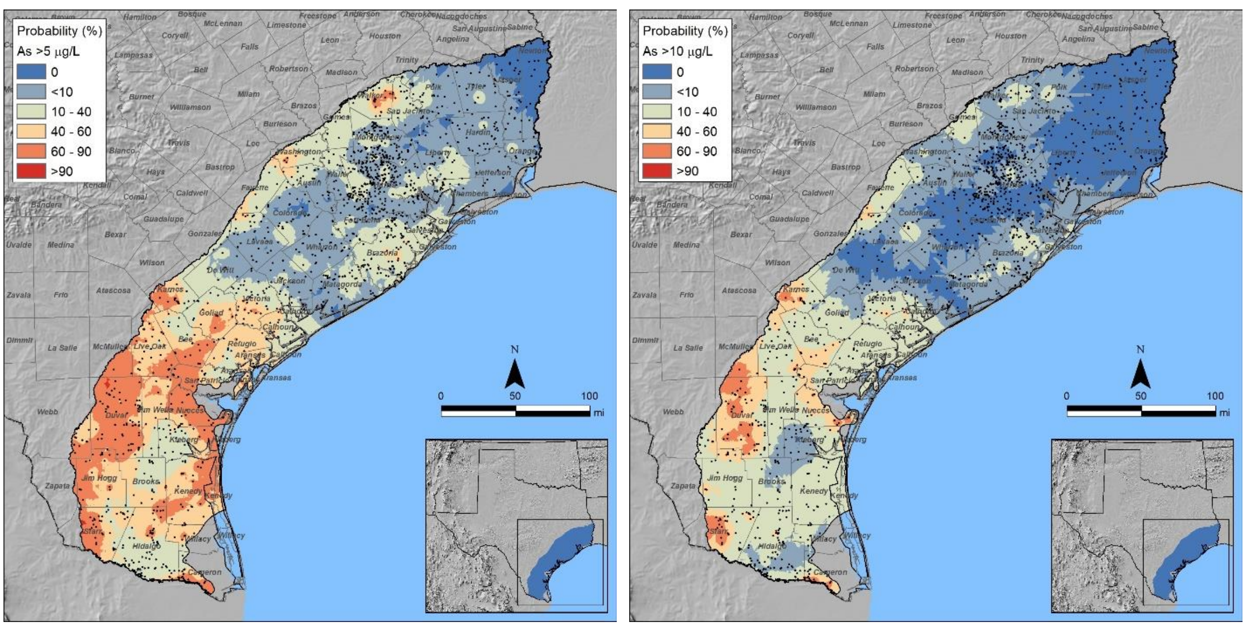

Figure 18. Gulf Coast aquifer system probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of 286 CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 3,229,064 people. Based on the US EPA database, there are a total of 46 CWS that are impacted by arsenic concentrations >10 µg/L with a population of 99,979 people

Table 12). The non-PWS system at-risk population of >10 µg/L is the second highest in the state at 26,475 located primarily in the southern areas of the aquifer, in up-dip areas along the inland boundary of the aquifer, and locally near the coast. The non-PWS system at-risk population of >5 µg/L is much larger at 71,824 people.

Table 12. Gulf Coast aquifer CWSs with MCL violations for arsenic concentrations based on the US EPA database for the period 2021 through 2023.

PWS ID	*System Name*	*Source Aquifer(s)*	*Population Served*
TX0200037	Village of Surfside Beach	Gulf Coast	5,697
TX0200335	Sandy Meadow Estates Subdivision	Gulf Coast	237
TX0200412	Brazoria County Sheriffs Office Detention	Gulf Coast	1,953
TX0200510	Town Of Quintana	Gulf Coast	231
TX0200555	City of Liverpool	Gulf Coast	870
TX0360004	Cotton Bayou Park	Gulf Coast	132
TX0360027	Woodland Acres Subdivision	Gulf Coast	643
TX0360100	Hackberry Creek Subdivision	Gulf Coast	176
TX0660001	Duval County CRD Benavides	Gulf Coast	2,285
TX0660003	San Diego MUD 1	Gulf Coast	6,291
TX0660015	Duval County CRD Concepcion	Gulf Coast	160
TX0710066	Green Acres Mobile Home Park	Gulf Coast, Other	141
TX0750014	Ellinger Sewer and WSC	Gulf Coast	462
TX0750022	Fayette WSC West	Gulf Coast, Sparta, Yegua-Jackson	5,802
TX0750044	Whispering Hills Achievement Center	Gulf Coast	30
TX0790424	Childrens Choice Learning Center	Gulf Coast	100
TX0930034	TDCJ Pack Unit	Gulf Coast	1,597
TX0930048	G & W WSC	Gulf Coast	1,650
TX1010317	Harris County WCID 114	Gulf Coast	5,169
TX1011536	Kitzwood Subdivision	Gulf Coast	99
TX1013562	Bw Grayson Business Park	Gulf Coast	25
TX1080067	Military Hwy WSC Las Rusiasy	Gulf Coast, Other	16,025
TX1240001	Jim Hogg County WCID 2N	Gulf Coast, Other	5,003
TX1250030	Jim Wells County FWSD 1N	Gulf Coast, Other	1,950
TX1610001	City of Bay City	Gulf Coast	18,061
TX1610016	Matagorda County WCID 2	Gulf Coast, Other	564
TX1610140	Tidehaven Consolidated Jr & Sr High TISD	Gulf Coast	500
TX1810034	Sawmill Addition	Gulf Coast	61
TX1810061	Iwanda MHP	Gulf Coast	69
TX1810103	Sugar Pines MHP	Gulf Coast	195
TX1810170	Timer Water System	Gulf Coast	46
TX1870105	Tempe WSC 1	Gulf Coast	2,856
TX1870149	Spring Creek Pure Utilities	Gulf Coast, Other	498
TX1960003	Town of Woodsboro	Gulf Coast	1,233
TX2040024	PB & SC WSC	Gulf Coast	2,301
TX2040051	Dodge Oakhurst WSC 2	Gulf Coast	2,500
TX2040054	Tanglewood Forest Subdivision	Gulf Coast	118
TX2350001	Victoria County WCID 1	Gulf Coast	2,459
TX2350004	Quail Creek MUD	Gulf Coast	1,944
TX2350006	Victoria County WCID 2	Gulf Coast	741
TX2350009	The Estates Of Sandy Hills	Gulf Coast	40
TX2350051	Victoria County Navigation District	Gulf Coast	78
TX2360009	Phelps SUD	Gulf Coast	1,800
TX2370001	City of Hempstead	Gulf Coast	6,687
TX2400003	Bruni Rural WSC	Gulf Coast	350
TX2400009	Webb Consolidated Schools Bruni	Gulf Coast	150

Hueco-Mesilla Bolson Aquifer

The Hueco-Mesilla Bolson aquifer covers 1,400 mi^2 in Texas adjacent to the international border with Mexico in El Paso and Hudspeth counties (Figure 19). The aquifer is composed of basin fill deposits derived from surrounding uplifted areas including the Franklin Mountains in two bolsons, including the Hueco Bolson with a thickness up to 9,000 ft and the Mesilla Bolson with a thickness up to 2,000 ft.

There were 160 samples analyzed for arsenic during the study period with 142 samples (88.8%) having detectable concentrations. Arsenic occurrence is widespread in the Hueco-Mesilla Bolson aquifer and concentrations tend to increase toward the south. Only about 7% of the area has very low to moderate probability of arsenic >5 µg/L. About 93% of the total aquifer area has elevated to very high probabilities of arsenic >5 µg/L. However, most of the samples are clustered in the north and the sample spatial distribution in most of the southern aquifer areas is very sparse, particularly in Hudspeth County. The median concentration of samples with detectable concentrations is 8.2 µg/L and the 5th-95th percentile range is 2.8–22.4 µg/L. A total of 46 samples (28.8%) exceeded the MCL with a range of concentrations from 10.9 µg/L to 47.5 µg/L.

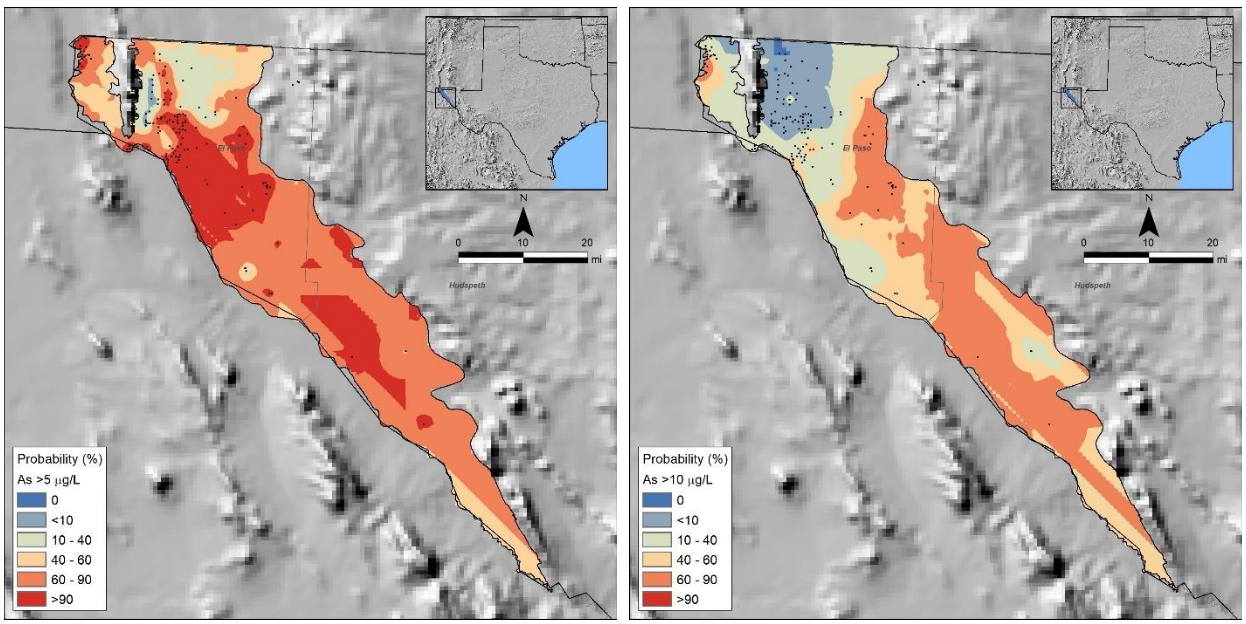

Figure 19. Hueco-Mesilla Bolson aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of 15 CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 761,835 people. Based on the EPA PWS database, there was one PWS water supply systems impacted by arsenic concentrations >10 µg/L (Table 13). The non-PWS system at-risk population of >10 µg/L is moderate at 5,078 and of >5 µg /L is 9,636 located almost entirely in El Paso County due to the very low population density of Husdpeth County.

Table 13. Hueco-Mesilla Bolsons aquifer CWSs with MCL violations for arsenic concentrations based on the US EPA database for the period 2021 through 2023.

PWS ID	*System Name*	*Source Aquifer(s)*	*Population Served*
0710139	Valley Acres MHP	Hueco-Mesilla Bolson	54

Ogallala Aquifer

The Ogallala aquifer covers 36,300 mi^2 in Texas extending across most of the panhandle and southward to Midland. The aquifer underlies all or parts of 49 counties in Texas (Figure 20). The Ogallala in Texas is part of the High Plains Aquifer System, the largest in the United States. It consists primarily of unconsolidated sediments ranging from clay to gravel and has a thickness up to about 800 ft. Thickness varies by region and the thickness is much less (150-300 ft) in the southern areas. The Ogallala is in hydraulic contact with the Pecos Valley aquifer to the southwest and also with the underlying Edwards-Trinity (High Plains), Dockum, and Rita Blanca aquifers.

There were 1,835 samples analyzed for arsenic during the study period with 1,558 samples (84.9%) having detectable concentrations. Arsenic occurrence is widespread in the Ogallala aquifer and concentrations are notably higher in the southern areas. About 17% of the area has no probability of arsenic > 5µg/L and a further 36% has very low to moderate probability of arsenic >5 µg/L. About 23% of the total aquifer area has elevated to high probabilities of arsenic >5 µg/L and fully 24% of the aquifer area has a very high probability. The median concentration of samples with detectable concentrations is 4.9 µg/L and the 5th-95th percentile range is 1.7–25.9 µg/L. A total of 325 samples (17.7%) exceeded the MCL with a range of concentrations from 10.1 µg/L to 164 µg/L with 9 samples >50 µg/L.

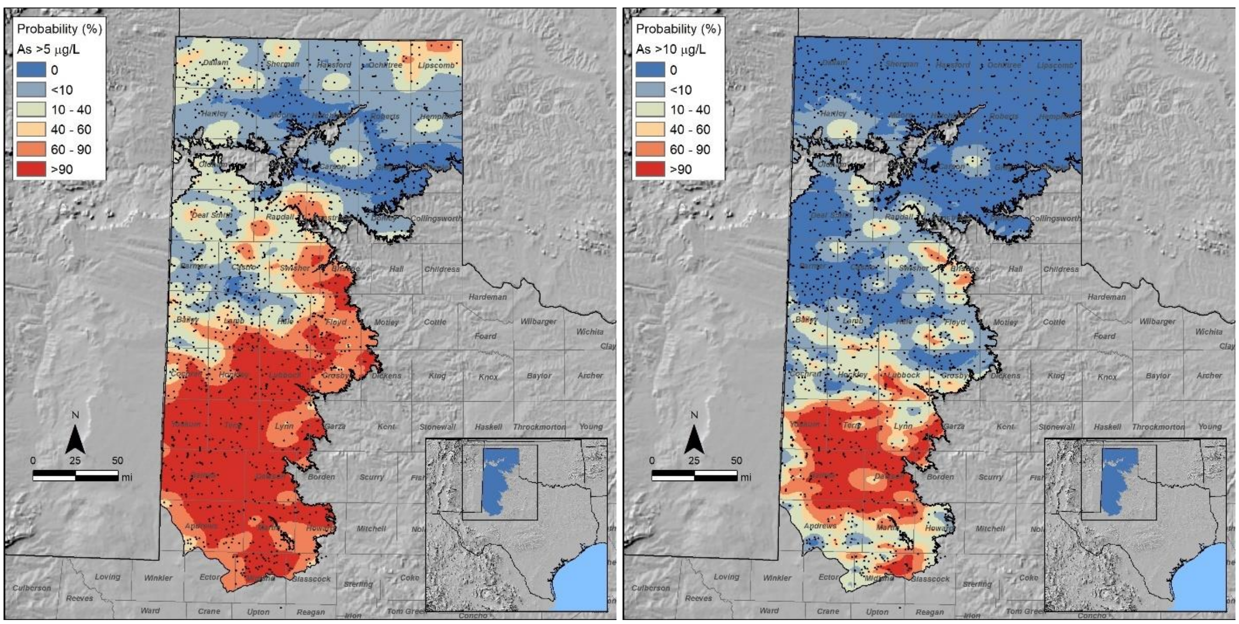

Figure 20. Ogallala aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of 89 CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 252,866 people. Based on the EPA PWS database, there are a total of 29 PWS water supply systems that are impacted by arsenic concentrations >10 µg/L with a total population of 178,068 people (Table 14). The non-PWS system at-risk population of >10 µg/L is the highest in the state at 39,838 located primarily in the areas of the aquifer south of Lubbock. The non-PWS system at-risk population of >5 µg/L is also the highest in the state at 87,908.

Table 14. Ogallala aquifer CWSs with MCL violations for arsenic concentrations based on the US EPA database for the period 2021 through 2023.

PWS ID	*System Name*	*Source Aquifer(s)*	*Population Served*
TX0020001	City of Andrews	Ogallala	14,109
TX0170010	Borden County Water System	Ogallala	275
TX0400001	City of Morton	Ogallala	1,690
TX0580013	Welch WSC	Ogallala	315
TX0830001	City of Seagraves	Ogallala, ETHP	2,417
TX0830011	Loop WSC	Ogallala	300
TX0830012	City of Seminole	Ogallala, ETHP	8,917
TX1100010	City of Smyer	Ogallala, ETHP	474
TX1520039	Peaceful Lane Village	Ogallala	90
TX1520094	Town North Village Water System	Ogallala	360
TX1520147	Short Road Water Supply	Ogallala	147
TX1520149	Stormlight MHP	Ogallala	76
TX1520152	Town North Estates	Ogallala	216
TX1520192	Terrells MHP	Ogallala	60
TX1520198	Valley Estates	Ogallala	68
TX1520199	Wolfforth Place	Ogallala	411
TX1520247	Country View MHP	Ogallala	54
TX1520263	Jaguars Gold Club Lubbock	Ogallala	25
TX1520265	Cash Register Services	Ogallala	115
TX1530004	City of New Home	Ogallala	326
TX1530005	Grassland WSC	Ogallala	55
TX1590001	City of Stanton	Ogallala	2,492
TX1650001	City of Midland Water Purification	Ogallala, ETHP, Dockum, Other	142,344
TX1650057	Twin Oaks MHP Midland	Ogallala, ETHP	234
TX1650077	South Midland County Water Systems	Ogallala	165
TX1650197	Margies MHP	Ogallala	60
TX2230002	City of Meadow	Ogallala	592
TX2230003	City of Wellman	Ogallala	200
TX2510002	City of Plains	Ogallala, ETHP	1,481

ETHP: Edwards-Trinity High Plains

Pecos Valley Aquifer

The Pecos Valley aquifer covers 6,800 mi^2 extending across parts of 12 counties in west Texas (Figure 21). The Pecos Valley consists of alluvial and aeolian deposits that locally reach up to 1,500 thick with an average saturated thickness of about 250 ft.

There were 181 samples analyzed for arsenic during the study period with 90 samples (49.7%) having detectable concentrations. Higher arsenic concentrations are restricted to the northeastern half of the aquifer. About 34% of the area has no probability of arsenic > 5µg/L and a further 35% has very low to moderate probability of arsenic >5 µg/L. About 31% of the total aquifer area has elevated to high probabilities of arsenic >5 µg/L. The spatial pattern of probabilities displays artifacts of limited data density, particularly in the areas with the higher concentrations. The median concentration of samples with detectable concentrations is 3.0 µg/L and the 5th-95th percentile range is 1.0–16.1 µg/L. A total of 11 samples (6.1%) exceeded the MCL with a range of concentrations from 11 µg/L to 51 µg/L.

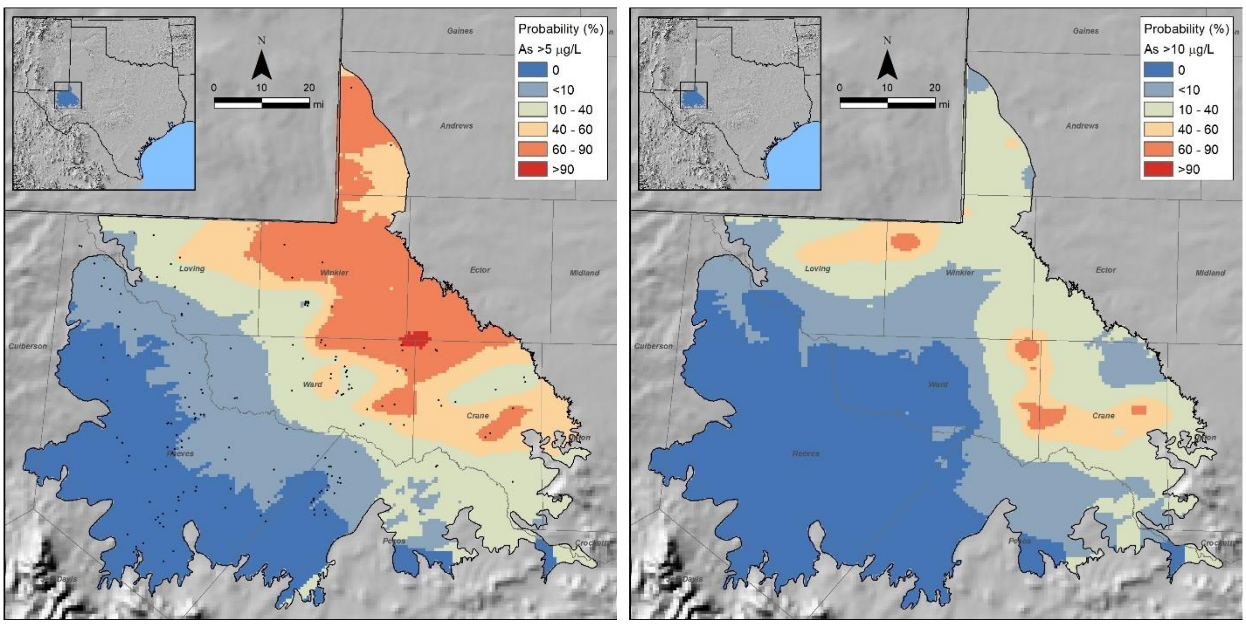

Figure 21. Pecos Valley aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of four CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 10,801 people. Based on the EPA database, there are no CWSs impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L is low at 1,422 located primarily in Ector, Andrews, and Crane counties. The non-PWS system at-risk population of >5 µg/L is 4,676.

Seymour Aquifer

The Seymour aquifer covers 3,400 mi^2 and is present as a series of isolated pods that extending across parts of 23 counties in north central Texas (Figure 22). The aquifer consists of conglomerate, gravel, sands, and silty sands ranging up to 360 ft thick. Most of the aquifer is affected by high nitrate-N concentrations.

There were 190 samples analyzed for arsenic during the study period with 121 samples (63.7%) having detectable concentrations. About 30% of the area has no probability of arsenic > 5µg/L and a further 69% has very low to moderate probability of arsenic >5 µg/L. Less than 1% of the total aquifer area has elevated probabilities of arsenic >5 µg/L. The spatial pattern of probabilities displays artifacts of limited data density. The median concentration of samples with detectable concentrations is 3.0 µg/L and the 5th-95th percentile range is 1.0–6.9 µg/L. A total of 3 samples (1.6%) exceeded the MCL with a range of concentrations from 10.2 µg/L to 11.0 µg/L.

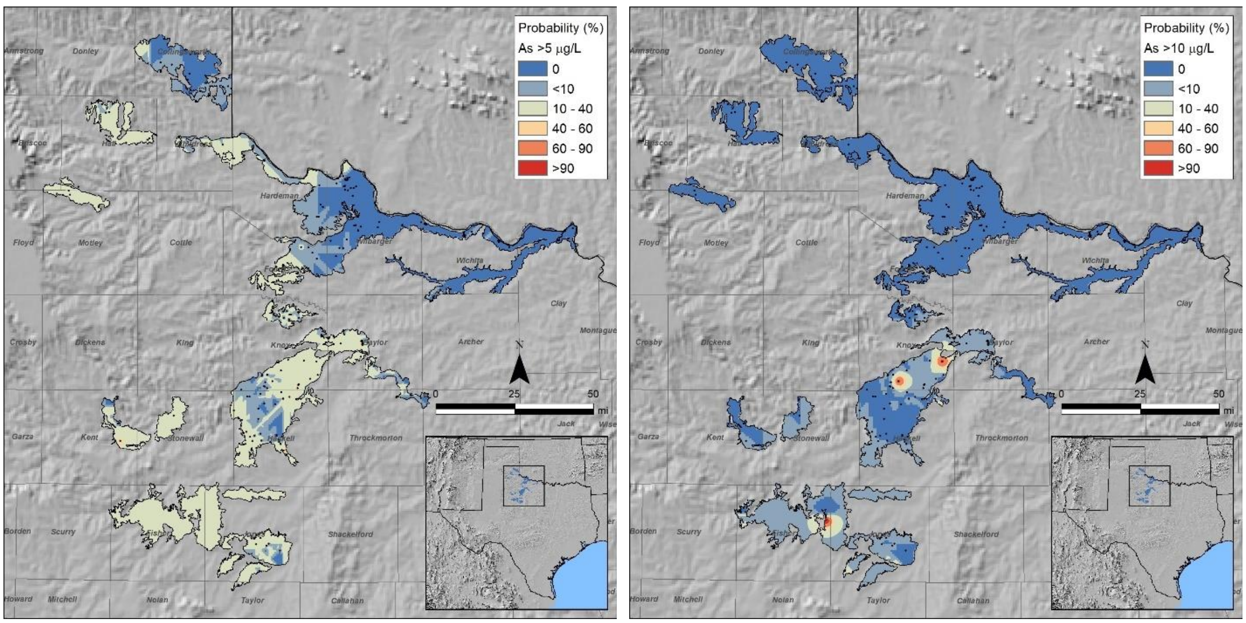

Figure 22. Seymour aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, there are no CWSs impacted by arsenic concentrations >5 µg/L. Based on the EPA database, there are no CWSs that are impacted by arsenic concentrations >10 µg/L. The non-PWS system at-risk population of >10 µg/L is very low at 180 located primarily in Knox, Fisher, and Jones counties. The non-PWS system at-risk population of >5 µg/L is 573.

Trinity Aquifer

The Trinity aquifer covers 32,100 mi^2 and extends across parts of 60 counties from north central to south central Texas (

Figure 23). The aquifer includes several units of the Early Cretaceous Trinity Group, including permeable units in the Antlers, Glen Rose, Paluxy, Twin Mountain/Travis Peak, Hensell, and Hosston formations. Total fresh water thickness ranges from 600 ft in North Texas to about 1,900 ft in Central Texas.

There were 1,647 samples analyzed for arsenic during the study period with 187 samples (11.4%) having detectable concentrations. About 75% of the area has no probability of arsenic > 5 µg/L and a further 23% has very low to moderate probability of arsenic >5 µg/L. Only about 2% of the total aquifer area has elevated to high probabilities of arsenic >5 µg/L. The median concentration of samples with detectable concentrations is 2.3 µg/L and the 5th-95th percentile range is 1.0–11.6 µg/L. A total of 12 samples (0.7%) exceeded the MCL with a range of concentrations from 11 µg/L to 23.4 µg/L.

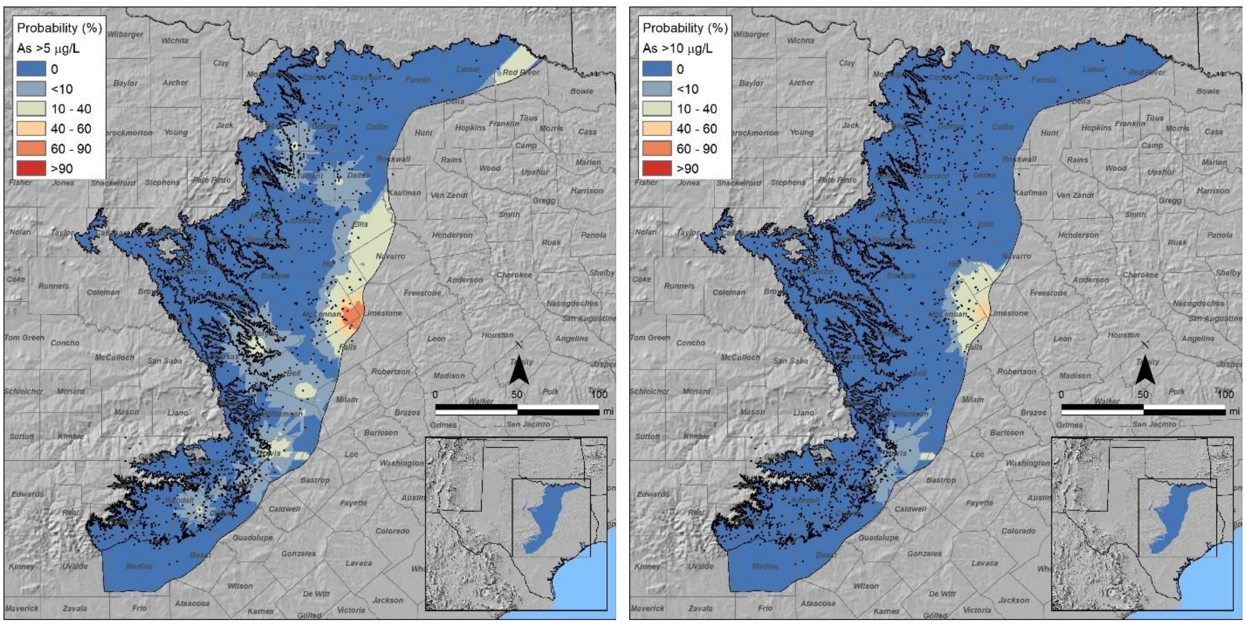

Figure 23. Trinity aquifer probability distribution of arsenic >5 µg/L (left) and >10 µg/L (right).

Based on the TCEQ PWS database, a total of 27 CWSs are impacted by arsenic concentrations >5 µg/L, with a population of 100,190 people. Based on the EPA database, there are a total of 9 CWSs that are impacted by arsenic concentrations >10 µg/L with a population of 12,429 people (Table 15). The non-PWS system at-risk population of >10 µg/L is moderate at 3,273 located primarily in Travis, McLennan, Falls, Hays, and Hill counties. The non-PWS system at-risk population of >5 µg/L is moderate at 7,592. It is noted that the Woodbine aquifer, a minor aquifer, overlies much of the confined regions of the Trinity aquifer in areas north of McLennan County and the non-PWS populations may be overestimated in this area.

Table 15. Trinity aquifer CWSs with MCL violations for arsenic concentrations based on the US EPA database for the period 2021 through 2023.

PWS ID	*System Name*	*Source Aquifer(s)*	*Population Served*
TX0730016	Perry WSC	Trinity	429
TX1470011	Prairie Hill WSC	Trinity	2,145
TX1550005	City of Mart	Trinity	1,846
TX1550016	Axtell WSC	Trinity	1,914
TX1550025	EOL WSC	Trinity	2,195
TX1550027	Leroy Tours Gerald WSC	Trinity, Other	1,680
TX1550037	M S WSC	Trinity	744
TX1550040	City of Riesel	Trinity	1,476
TX1550136	R M S WSC	Trinity	0

Summary

Quantifying the spatial distribution of groundwater arsenic concentrations in aquifers in Texas is critical for managing groundwater resources in the state. Previous studies show that arsenic hotspots in the southern High Plains and southern Gulf Coast aquifers originate from geologic sources. This study evaluated the probability of groundwater arsenic levels exceeding threshold levels of 5 µg/L and 10 µg/L (the EPA MCL) using 9,088 analyses from 1992 – 2024. Results of the study highlight hotspots of arsenic contamination with high probabilities (> 50%) in the southern Ogallala aquifer, southern Gulf Coast aquifer, the Hueco-Mesilla Bolson and West Texas Bolsons aquifers, and the Trinity aquifer. The number of water samples that exceeded the MCL totaled 659 (7.2% of all analyses).

Most of the Texas population is served with water from CWSs, estimated as 30,370,000 people in 2023 by the systems whereas the number of people relying on domestic water supplies totaled 1.46 million in 2023 (4.8% of population). The CWSs population estimates are generally overestimated as the US Census population for Texas was 30,500,000 for 2023. There are 88 non-compliant PWS systems that source water from one of the major or minor aquifers that provide water to ~296,000 people. These system locations are generally consistent with the hotspots of arsenic contamination, with 46 CWSs in the Gulf Coast, 29 in the southern High Plains, and 9 in the Trinity Aquifer east of Waco. The associated populations include 178,068 in the Ogallala, 99,979 in the Gulf Coast, and 12,429 people in the Trinity. Based on a county level analysis, it is estimated that there are a further 81,422 people with domestic system water exceeding the EPA MCL in Texas.

If the EPA arsenic MCL was reduced from 10 to 5µg/L given current conditions, the number of CWSs in violation would increase by a factor of 5 to 454 systems (430 sourcing from major aquifers and 24 from minor aquiers) and the associated populations would increase by a factor of 15 to 4,406,000 people (4,373,000 sourcing from major aquifers and 33,000 from minor aquifers), representing 14% of the state population. The estimated affected major aquifer domestic system population would increase by a factor of 2.4 to 194,000.

Acknowledgements

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Appendix I – Enlarged Maps

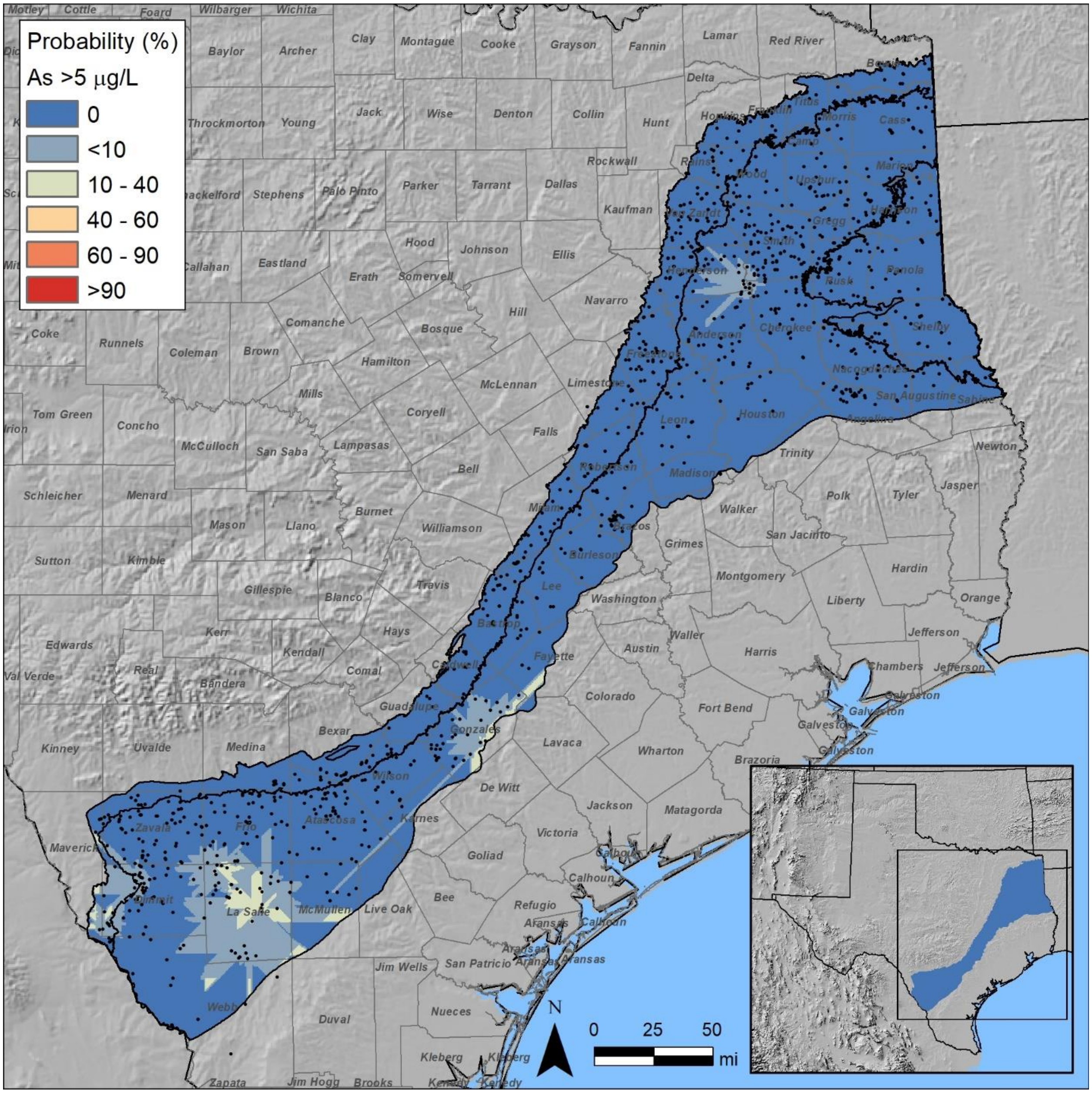

Figure 15. Carrizo-Wilcox aquifer probability distribution of arsenic >5 µg/L.

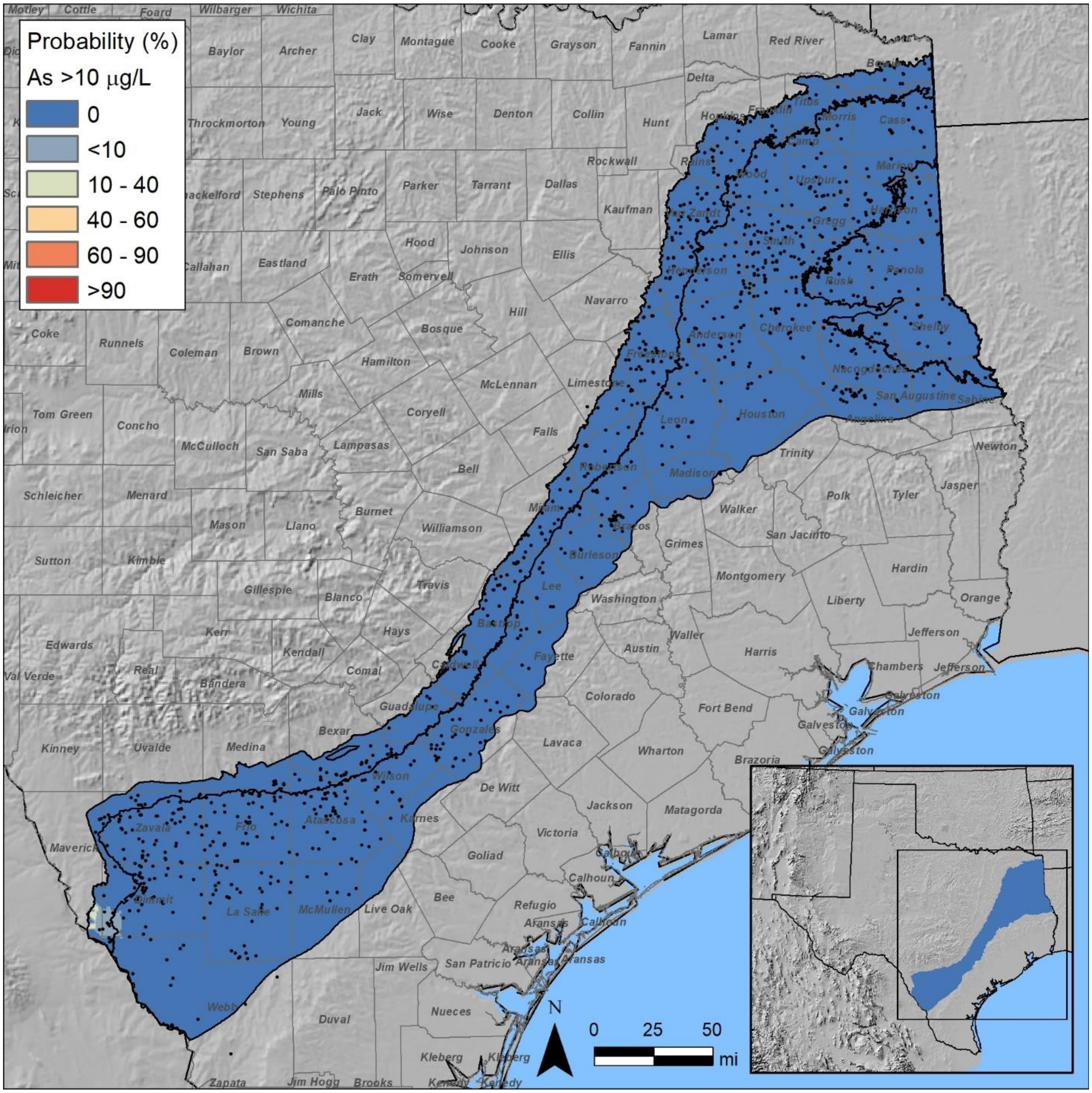

Figure 15. Carrizo-Wilcox aquifer probability distribution of arsenic >10 μg/L.

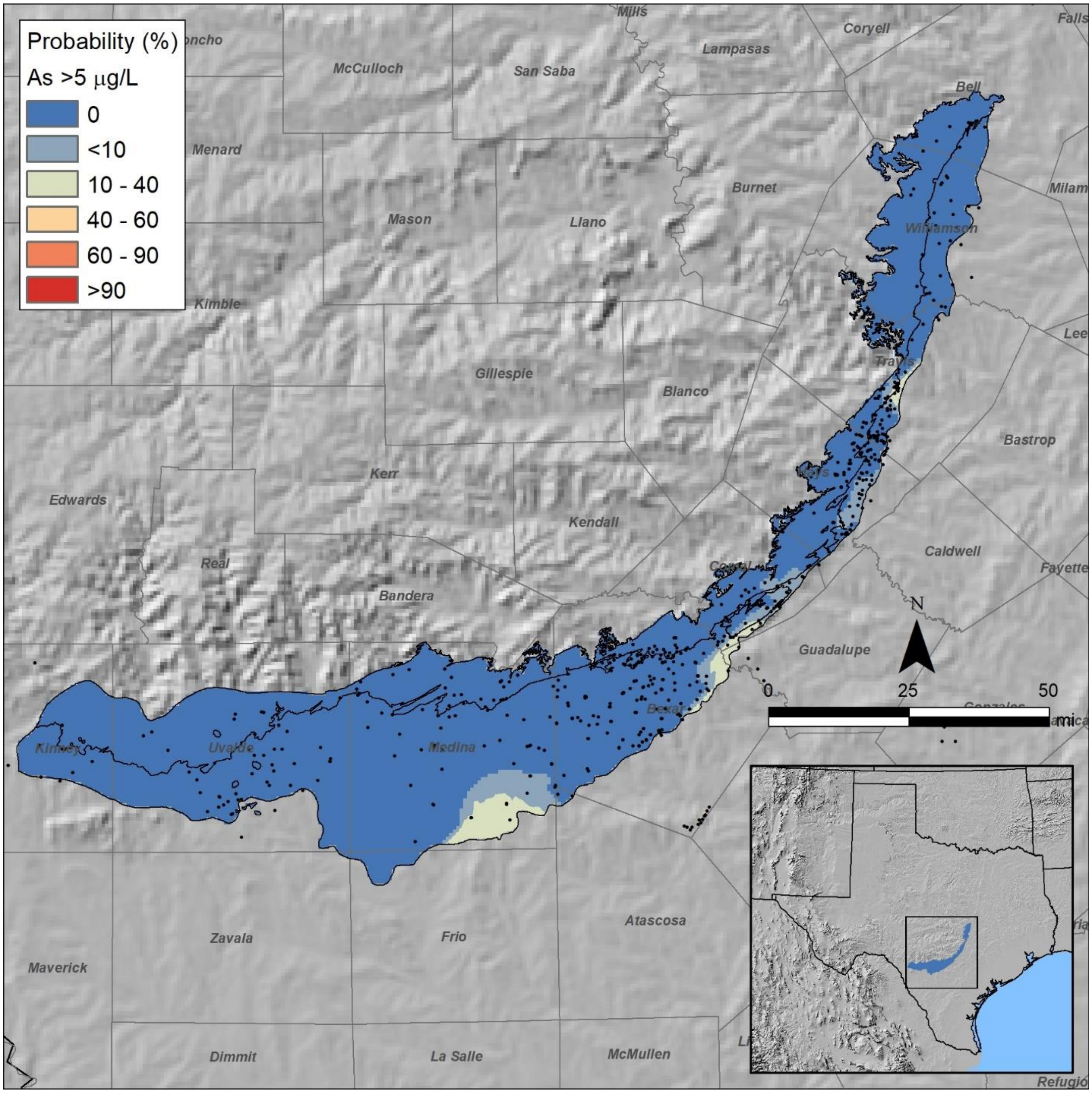

Figure 16. Edwards (BFZ) aquifer probability distribution of arsenic >5 µg/L.

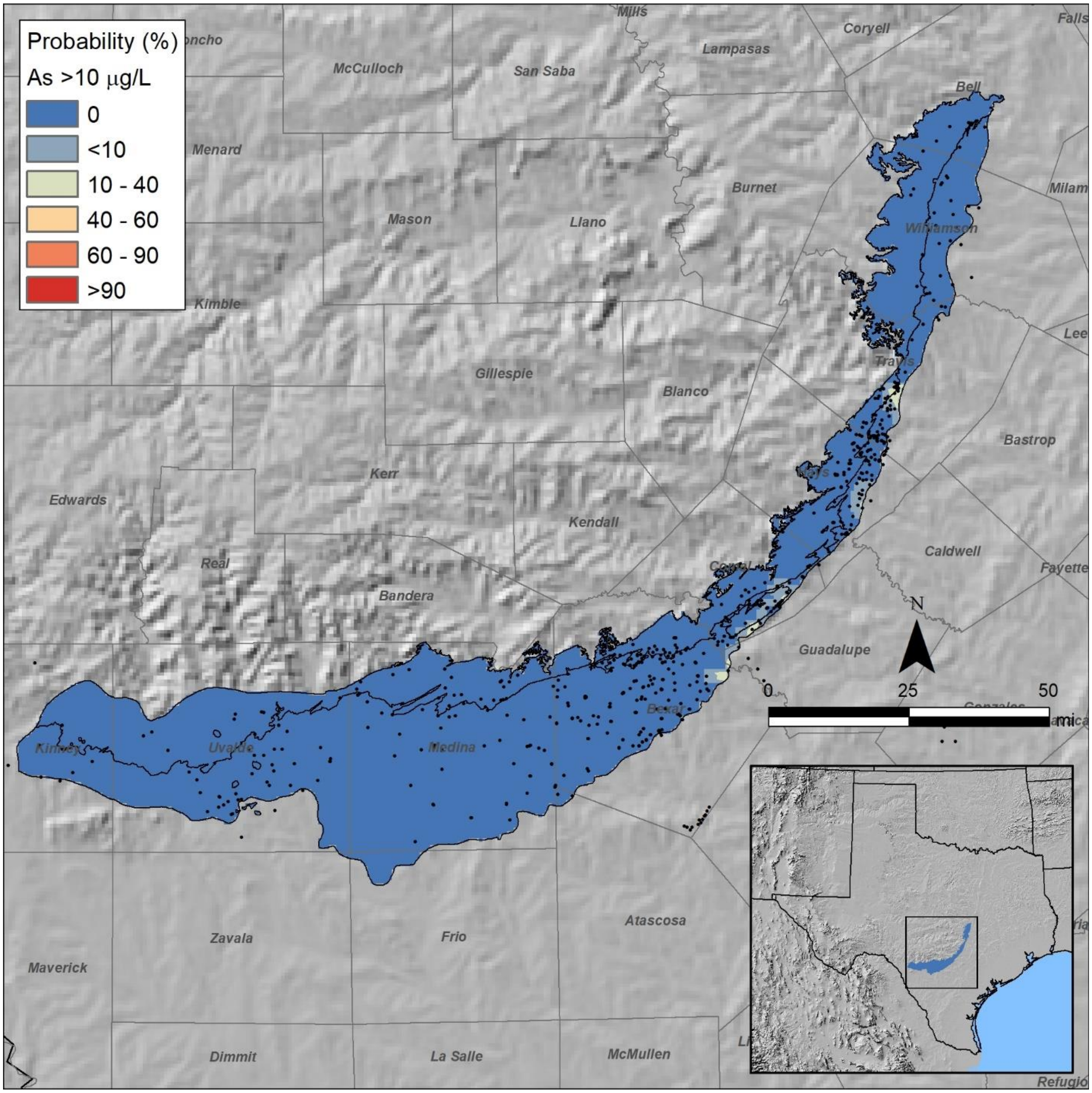

Figure 16. Edwards (BFZ) aquifer probability distribution of arsenic >10 μg/L.

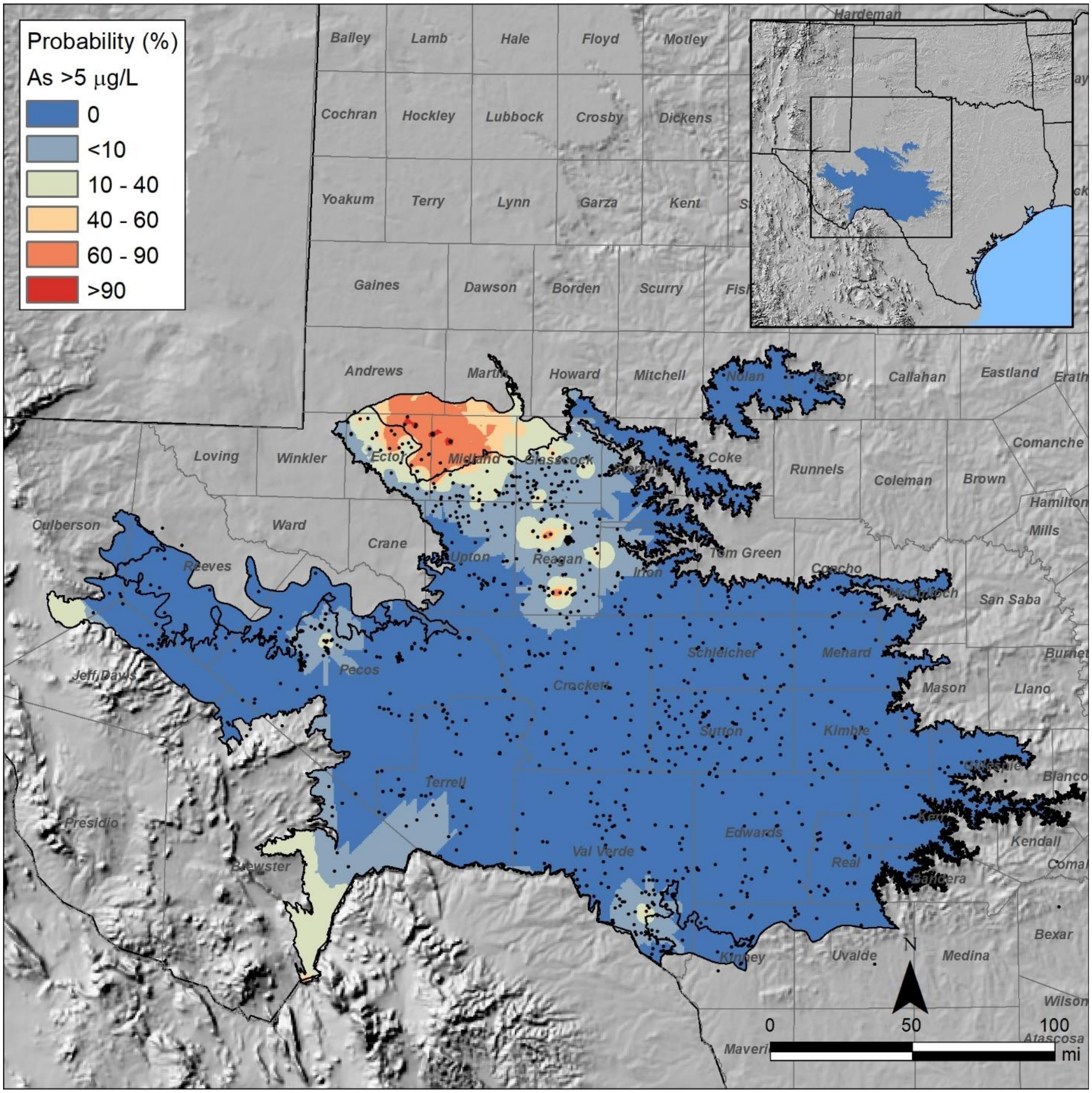

Figure 17. Edwards-Trinity Plateau aquifer probability distribution of arsenic >5 μg/L.

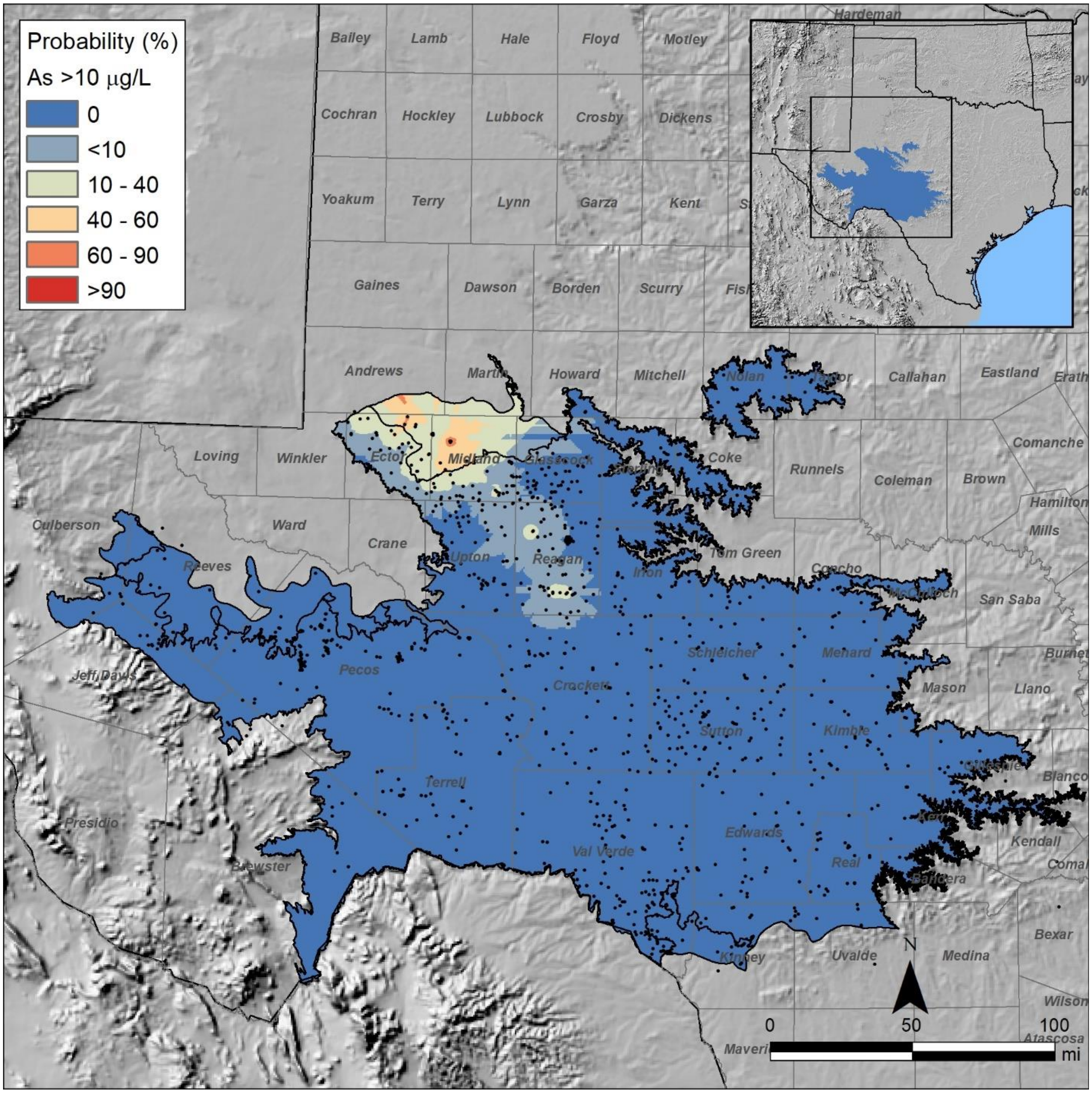

Figure 17. Edwards-Trinity Plateau aquifer probability distribution of arsenic >10 μg/L.

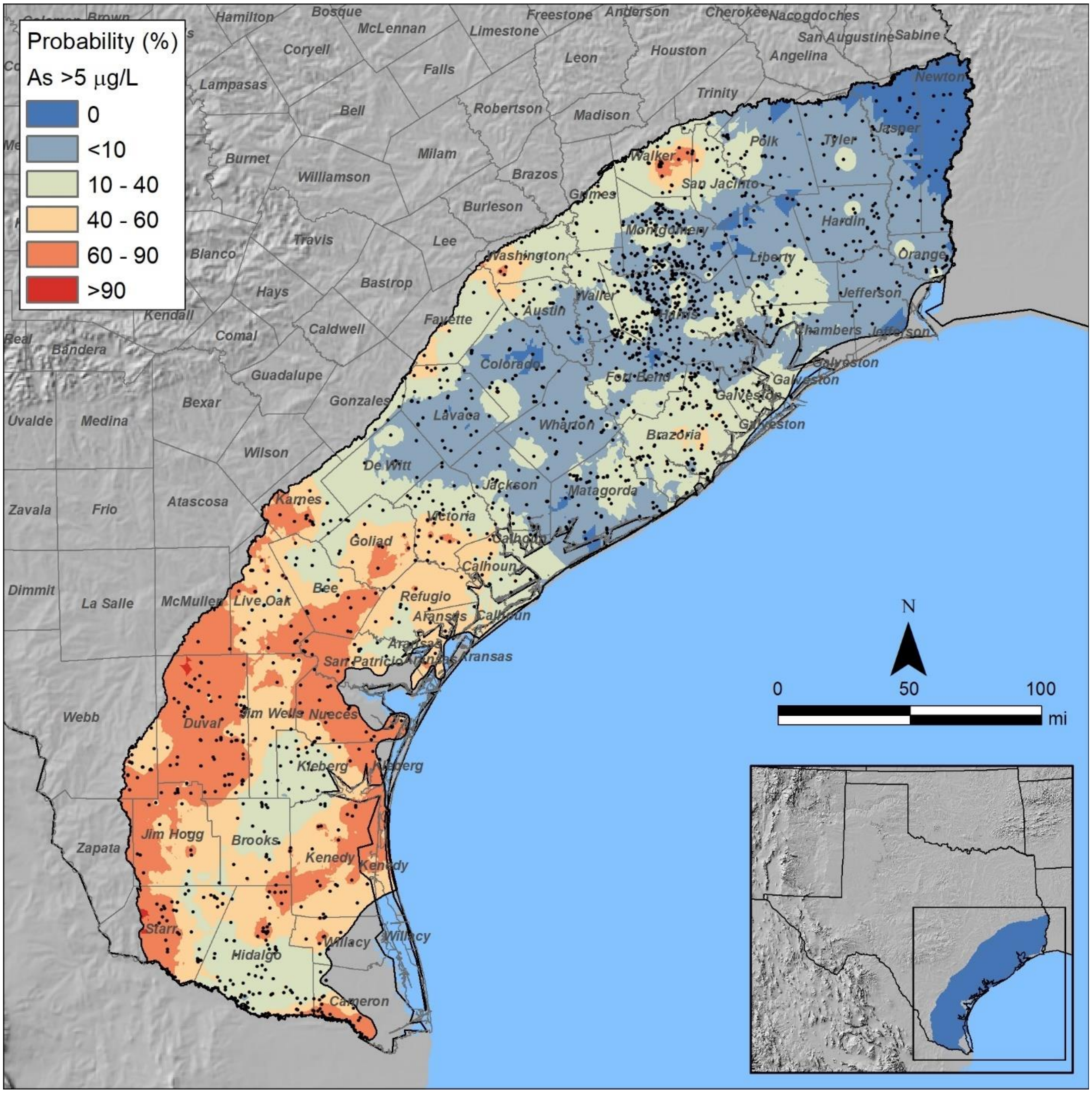

Figure 18. Gulf Coast aquifer system probability distribution of arsenic >5 µg/L.

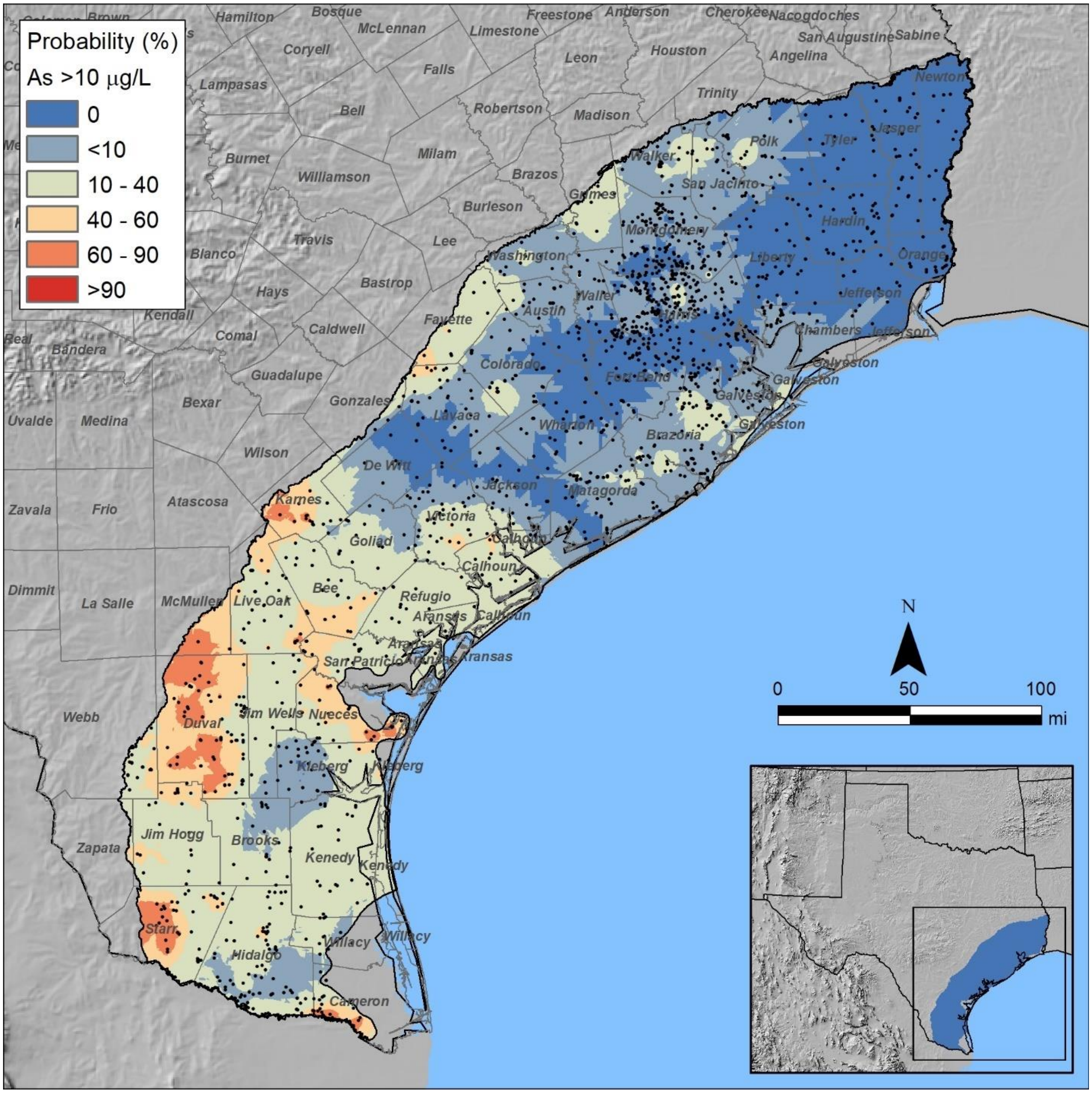

Figure 18. Gulf Coast aquifer system probability distribution of arsenic >10 µg/L.

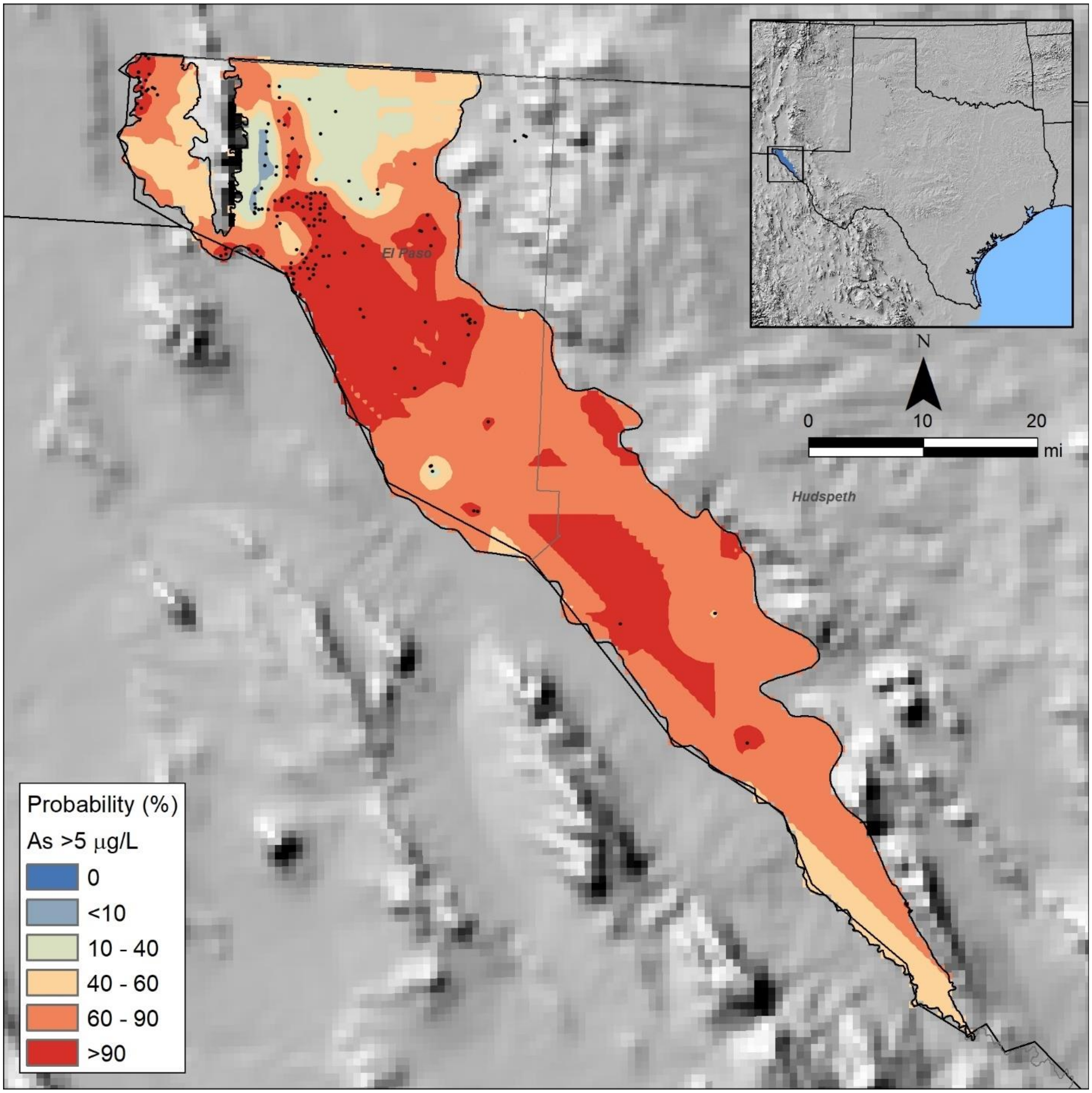

Figure 19. Hueco-Mesilla Bolson aquifer probability distribution of arsenic >5 µg/L.

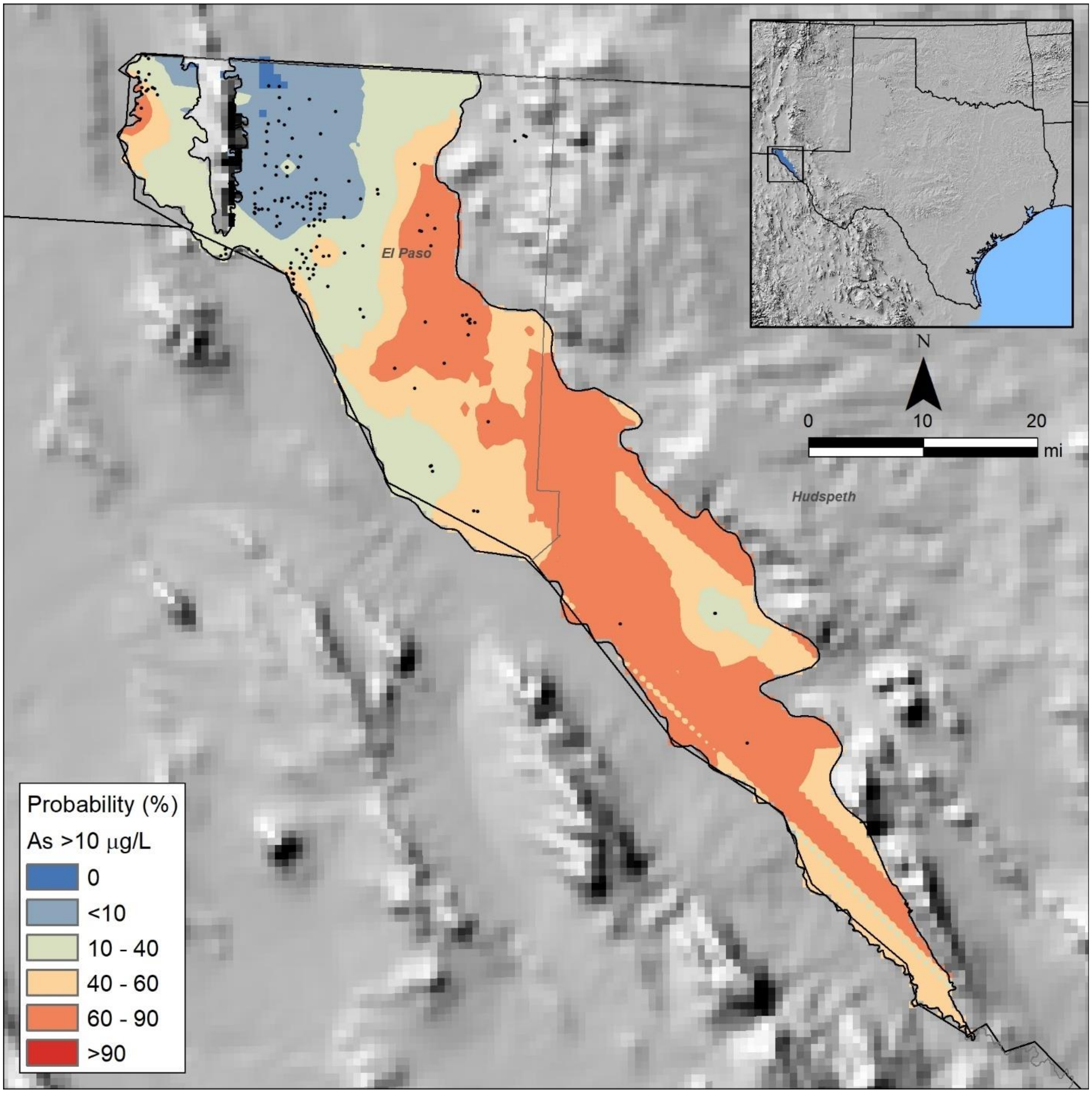

Figure19. Hueco-Mesilla Bolson aquifer probability distribution of arsenic >10 μg/L.

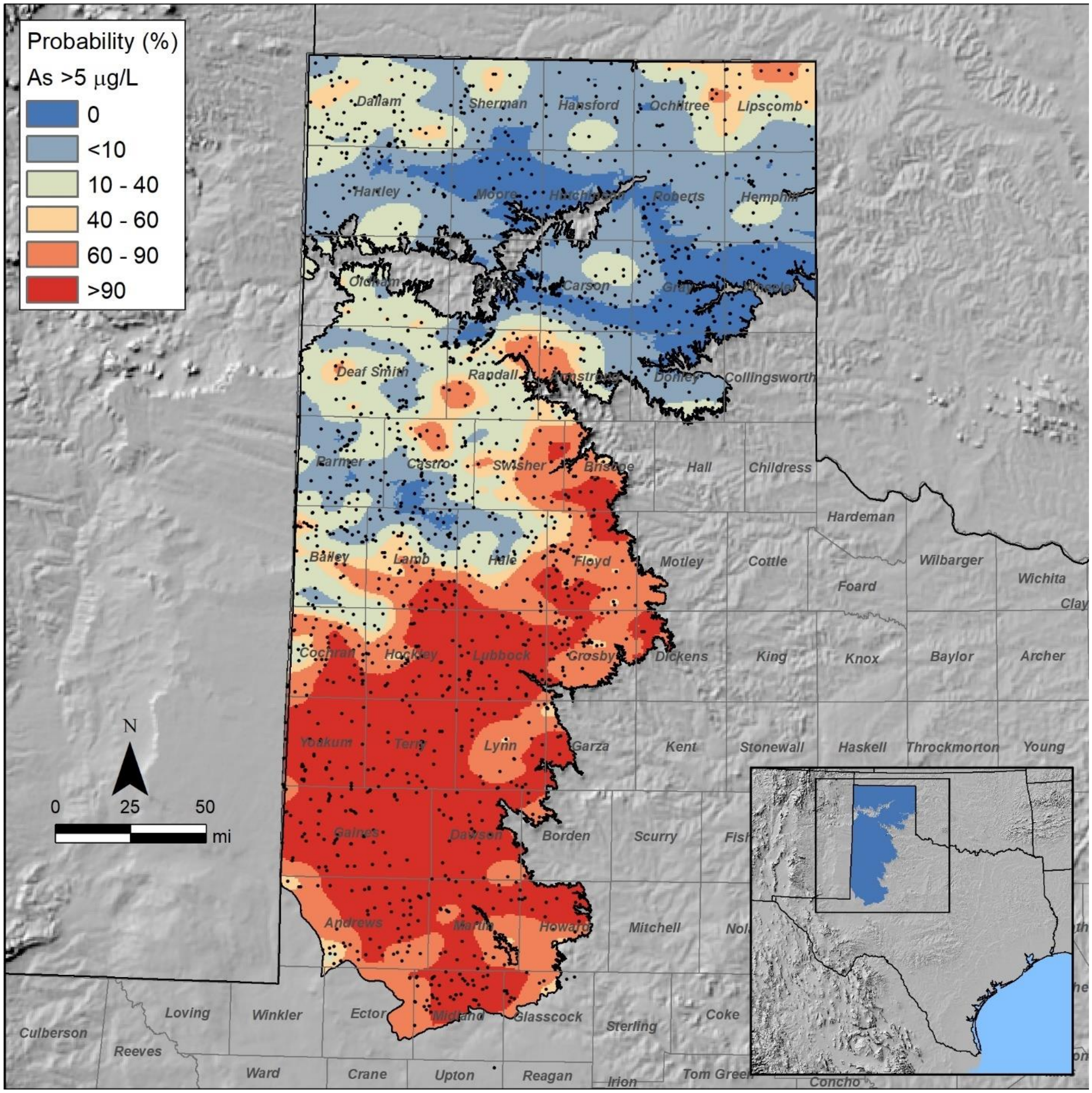

Figure 20. Ogallala aquifer probability distribution of arsenic >5 µg/L.

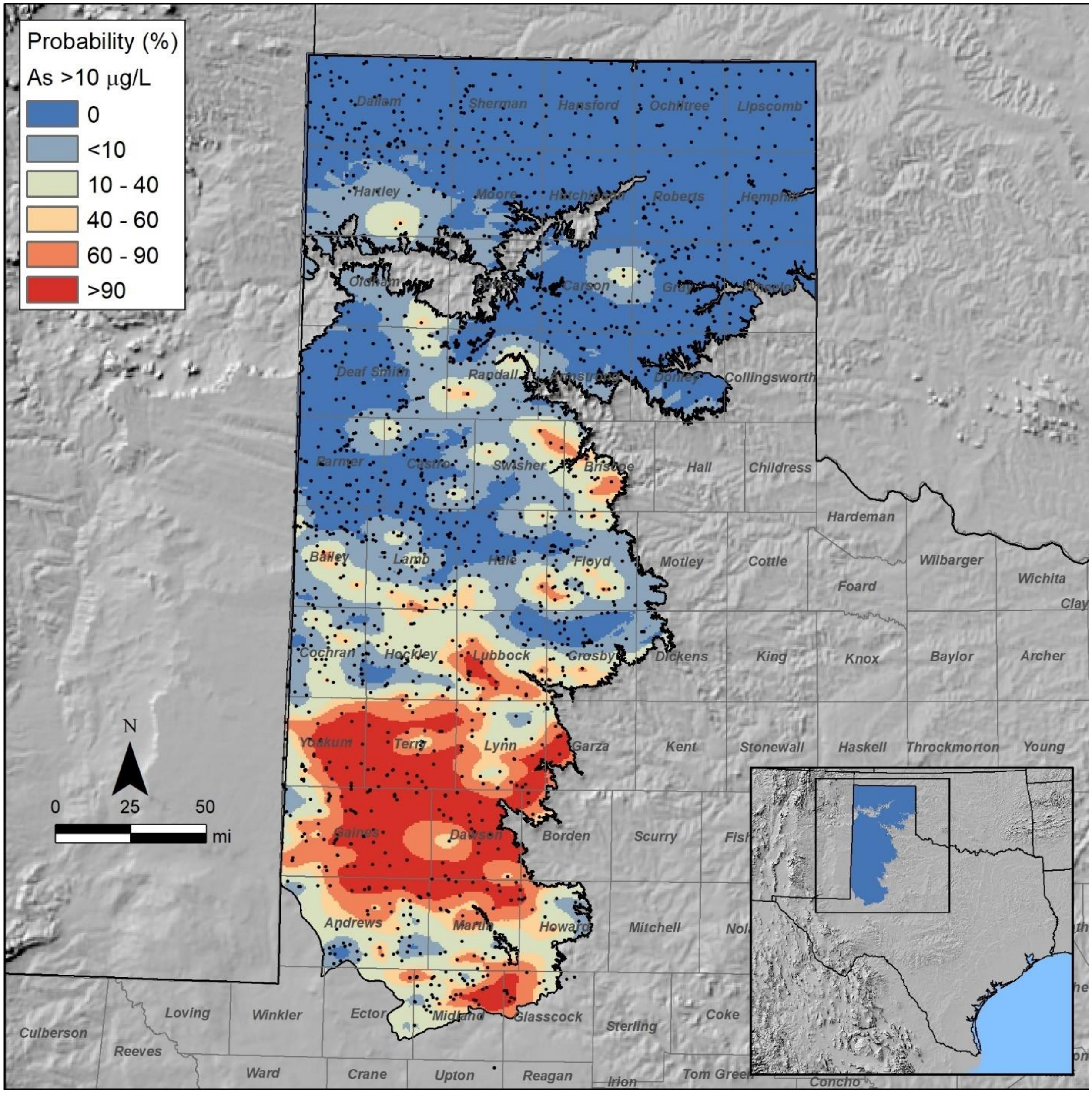

Figure 20. Ogallala aquifer probability distribution of arsenic >10 μg/L.

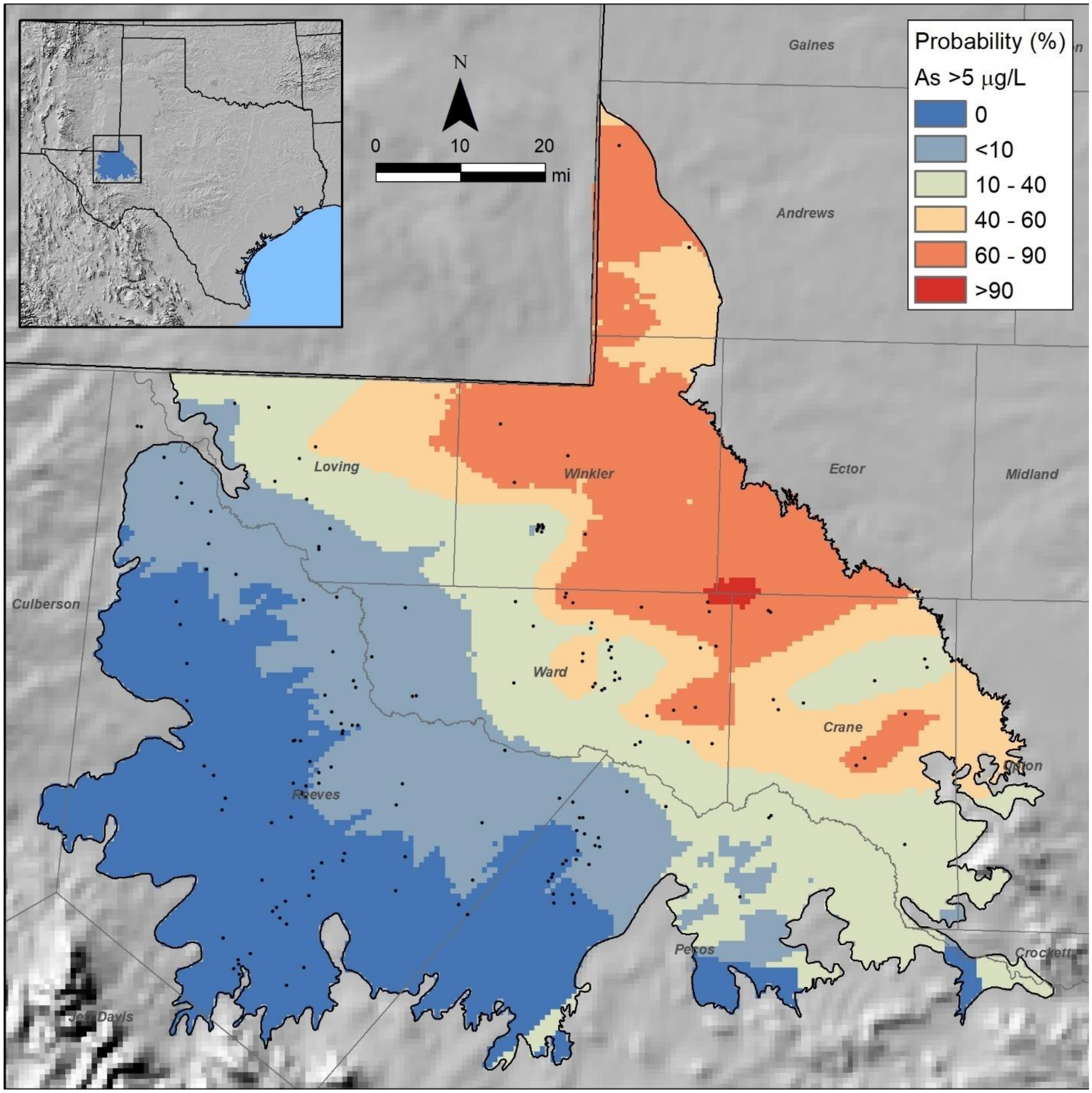

Figure 21. Pecos Valley aquifer probability distribution of arsenic >5 µg/L.

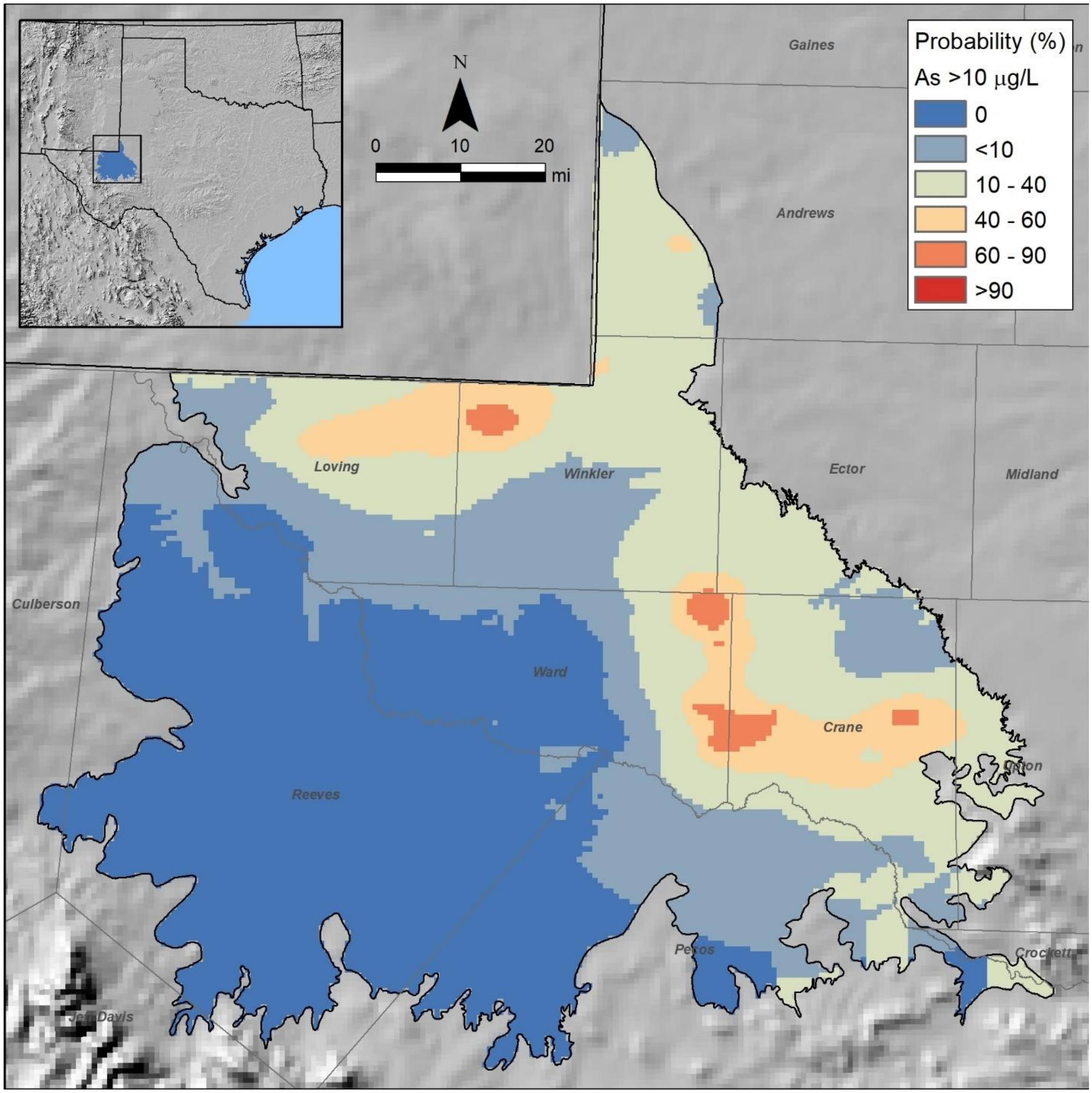

Figure 21. Pecos Valley aquifer probability distribution of arsenic >10 μg/L.

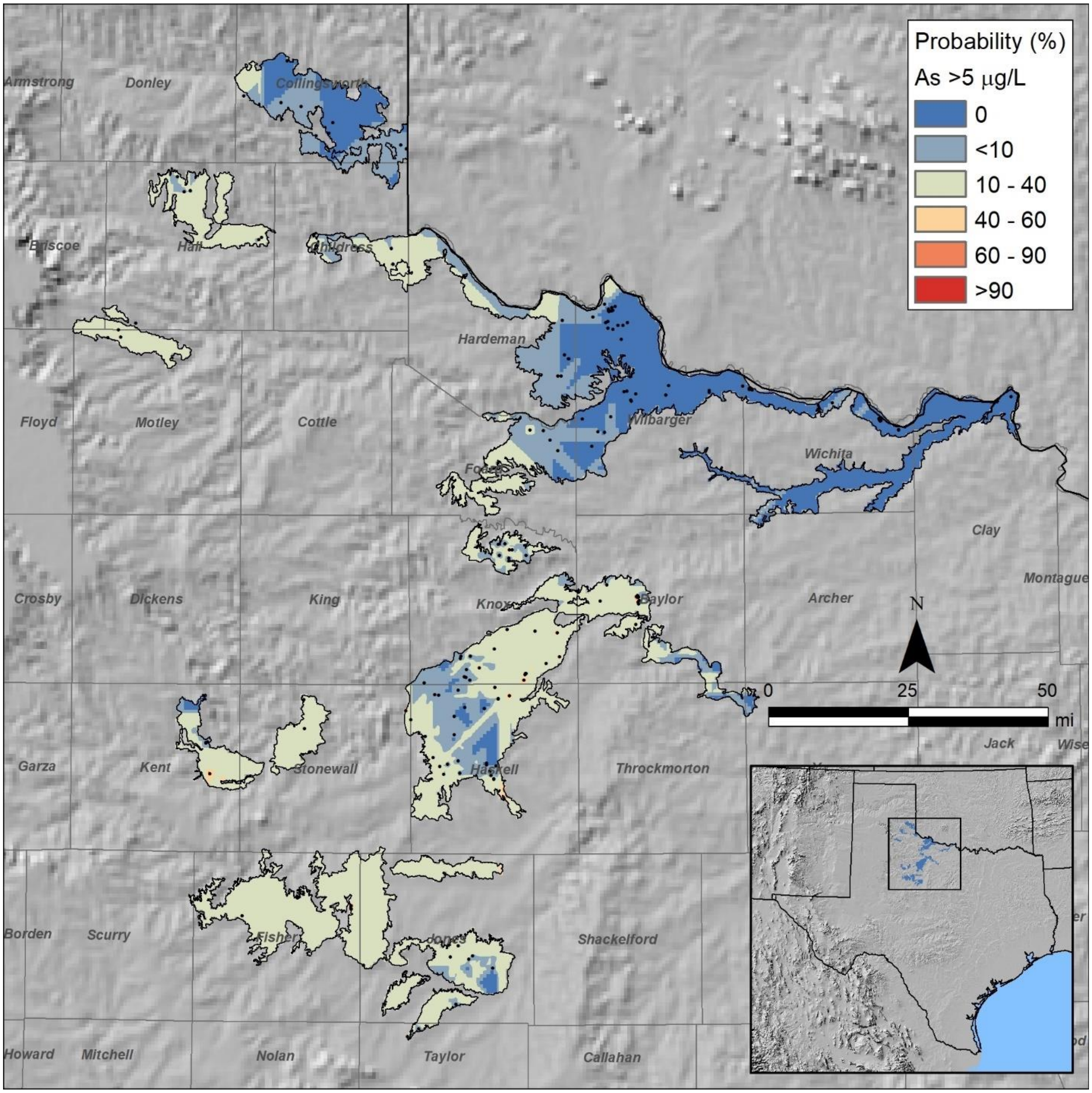

Figure 22. Seymour aquifer probability distribution of arsenic >5 µg/L.

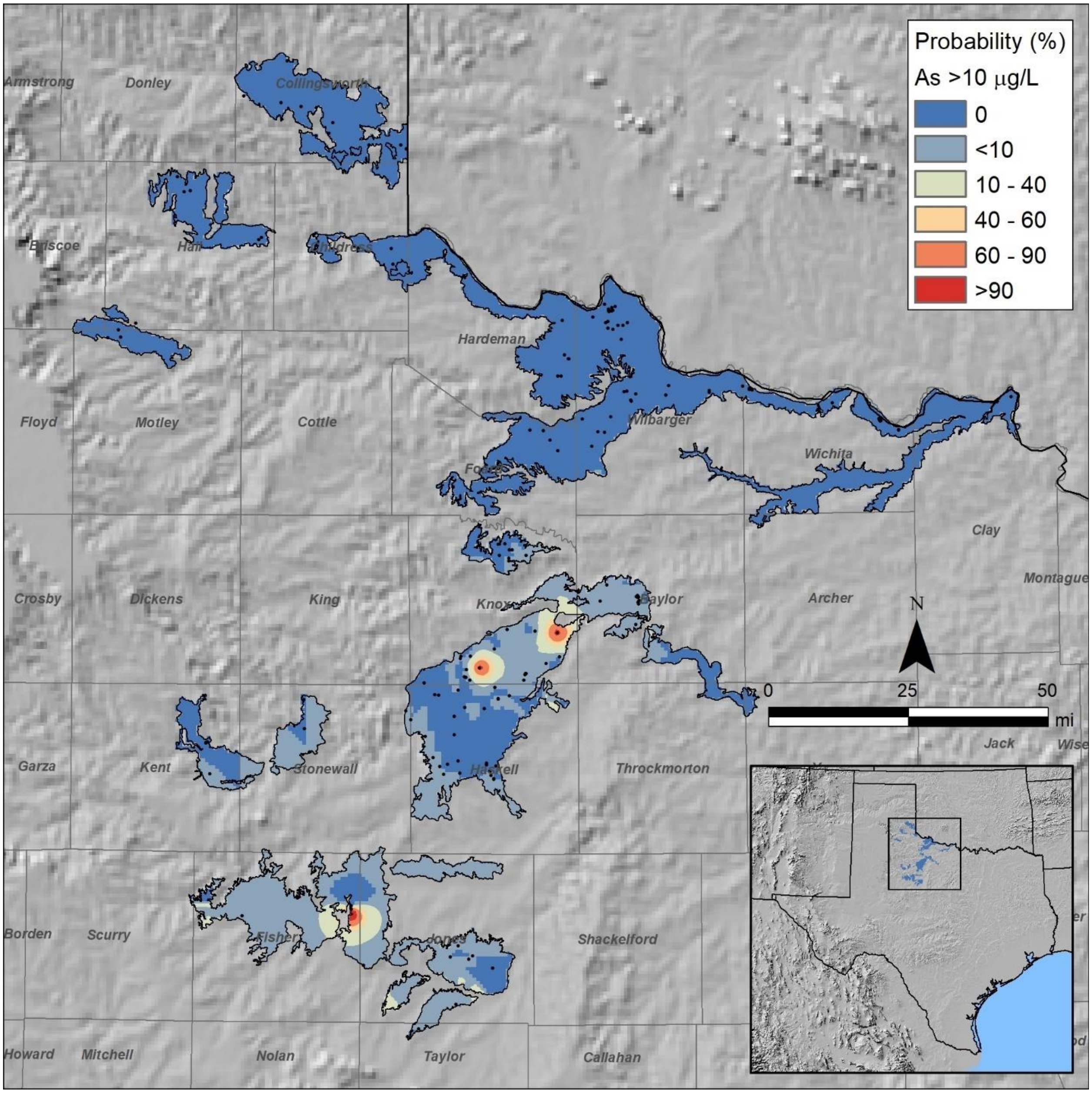

Figure 22. Seymour aquifer probability distribution of arsenic >10 μg/L.

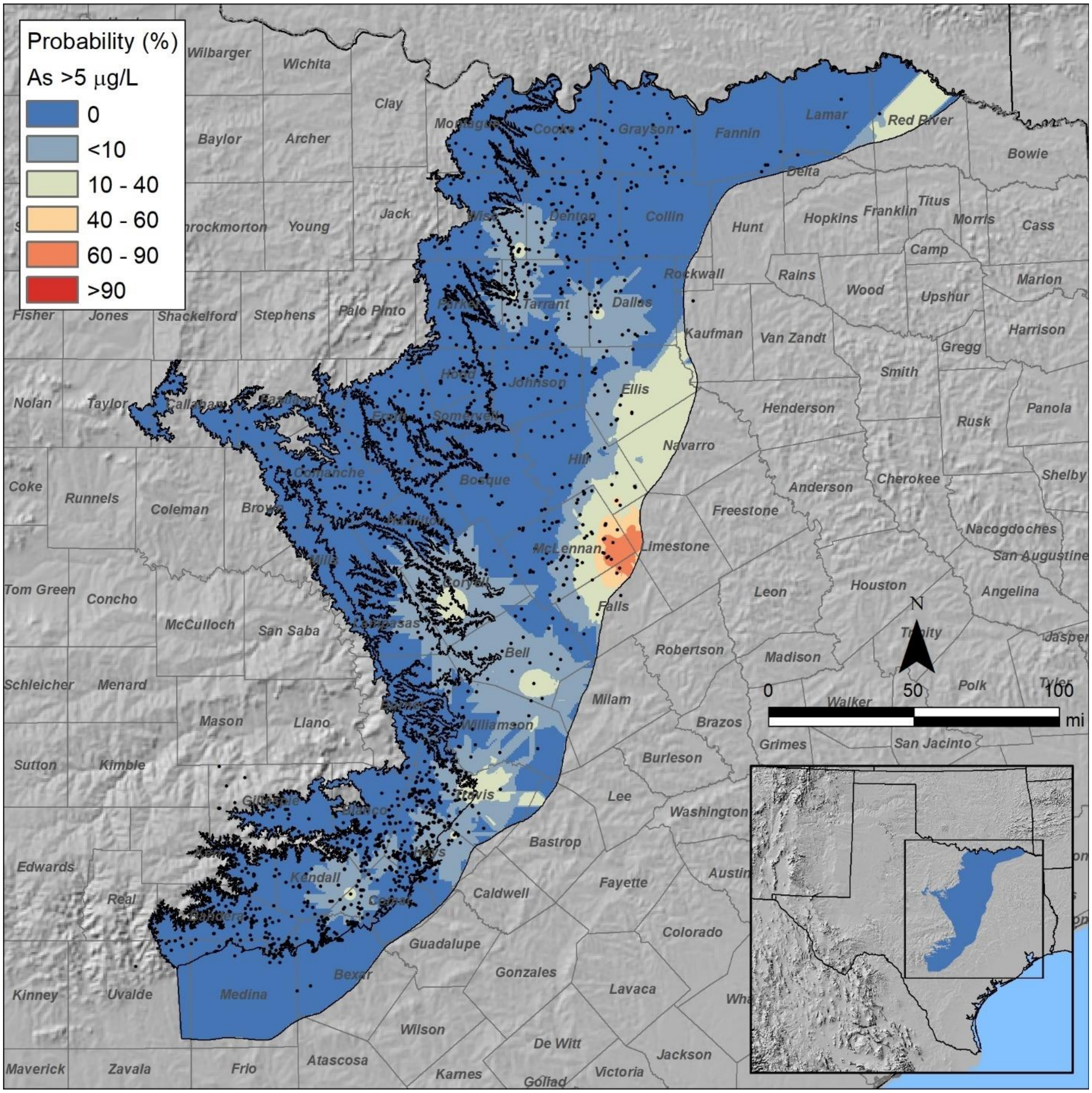

Figure 23. Trinity aquifer probability distribution of arsenic >5 µg/L.

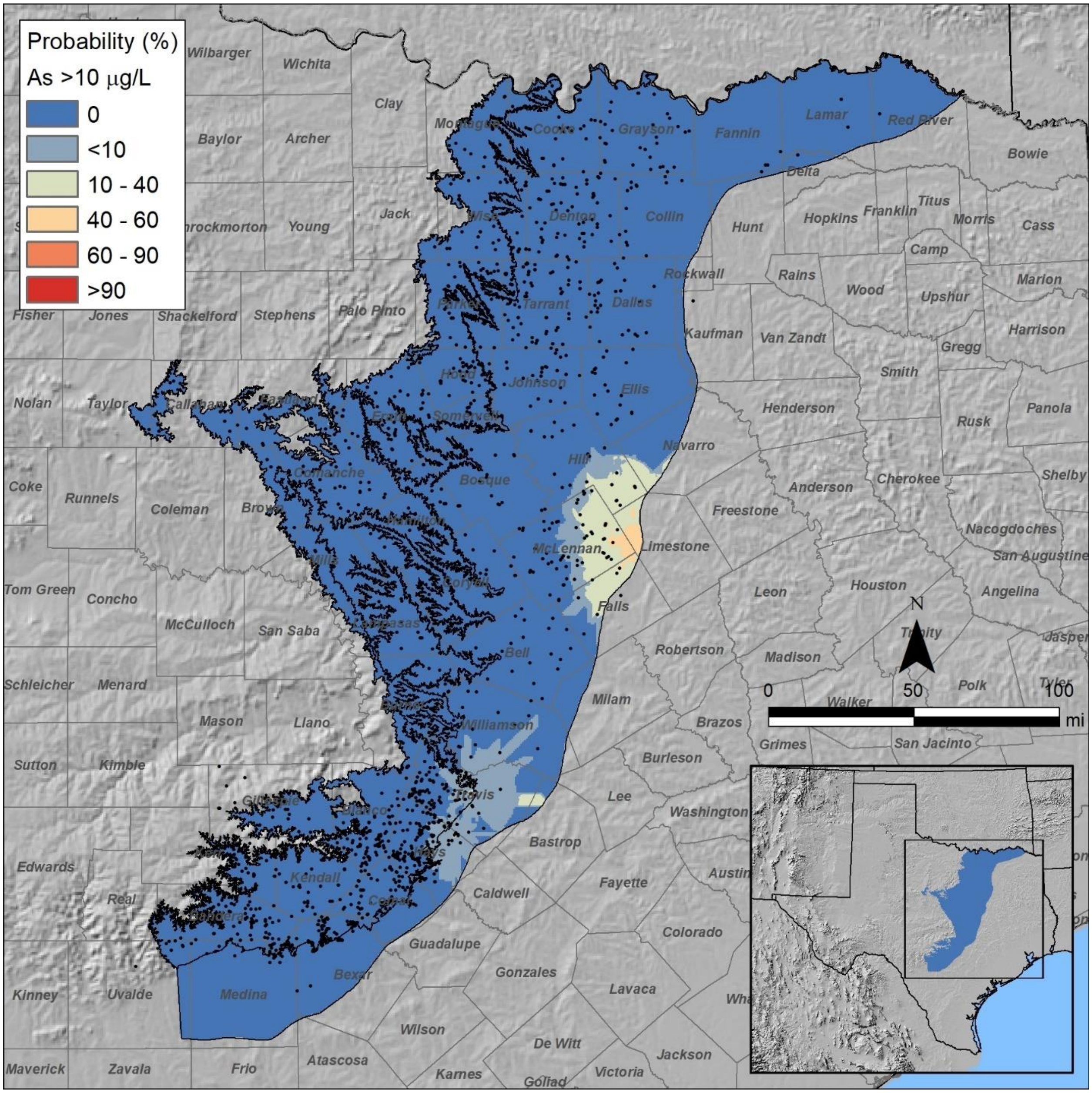

Figure 23. Trinity aquifer probability distribution of arsenic >10 μg/L.