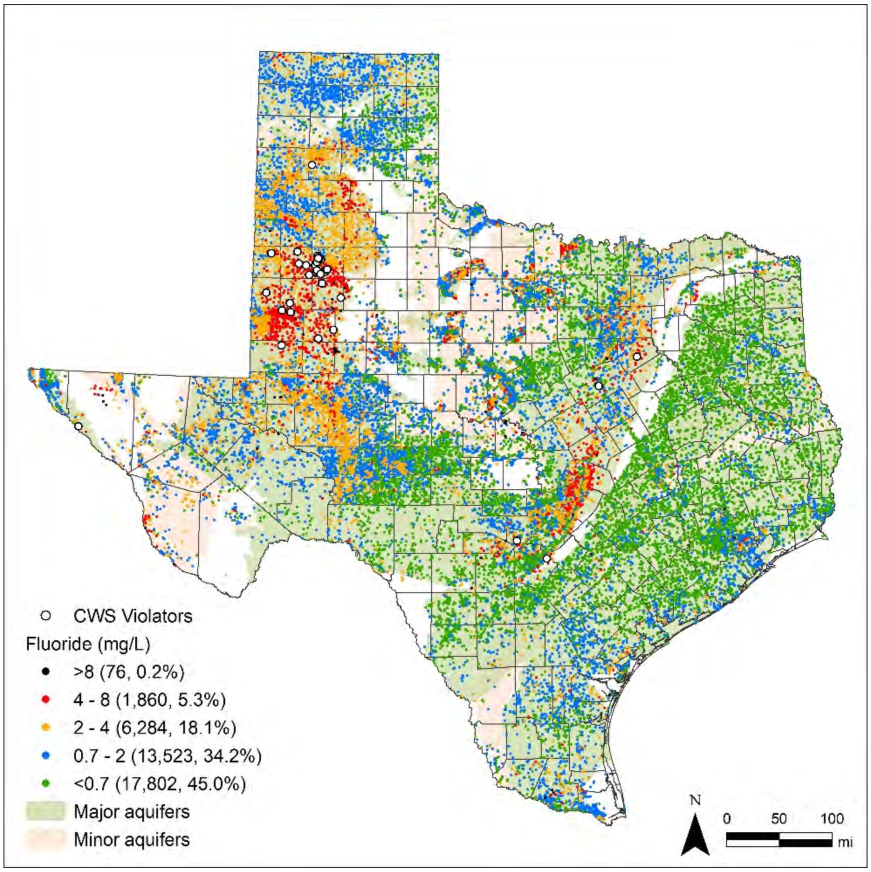
Assessment of Fluoride in Groundwater and Public Water Supply Systems in Texas



by

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Executive Summary

Understanding the spatial distribution of elevated groundwater fluoride levels is an important issue because of adverse health effects of high fluoride (> 2 mg/L, EPA secondary Maximum Contaminant Level, MCL; and >4 mg/L, EPA primary MCL). Many studies indicate that elevated fluoride concentrations in groundwater primarily originate from natural geologic sources.

The objectives of this study were to quantify the distribution of groundwater fluoride in major and minor aquifers in Texas and assess linkages to Community Water Systems (CWSs) and their associated populations that use this water. Groundwater fluoride data were compiled from the Texas Water Development Board database for 39,545 wells based on the most recent samples by well from 1929 through 2021**.** The spatial distribution of elevated fluoride concentrations was mapped for the state and by aquifer using indicator kriging based on three threshold concentrations: 0.7 mg/L representing the U.S. Public Health Standard (USPHS) for dental care, and 2 mg/L and 4 mg/L for health purposes. The current number of non-compliant CWSs and associated populations were obtained from EPA listings and the estimated populations with non-compliant domestic (rural) system water were obtained from the U.S. Geological Survey water use data.

Results show that a total of 1,936 groundwater samples from the TWDB database exceeded the fluoride primary MCL of 4 µg/L, representing ~5% of all fluoride analyses throughout the state. Fluoride violations by CWSs were mostly from major aquifers (85%), primarily the Ogallala aquifer (63%) with much lower percentages from other major aquifers. Median fluoride concentration was also highest in the Ogallala Aquifer (2.1 mg/L) with the 95th percentile of 5.3 mg/L. Concentrations at the 95th percentile generally exceeded 2 mg/L for all major aquifers. A much larger percentage (21%) of samples (8,220 samples) from the TWDB database exceeded the secondary MCL of 2 mg/L fluoride, indicating that if the primary MCL was reduced to 2 mg/L, the percentage of wells exceeding the MCL would increase by about 4 times. Of samples exceeding the 2 mg/L secondary MCL, about 84% are from major aquifers and 16% from minor aquifers, similar to primary MCL exceedances. A total of 21,743 samples exceed 0.7 mg/L (55% of total); therefore, 45% are less than the recommended threshold established by the USPHS to minimize tooth decay.

Texas has the largest number of active CWSs of any state in the U.S. (4,653 systems, 2020). The majority of the population has access to CWSs (28.7 million in 2020; 98.6% of the total census population of 29.1 million) with a much lower number of people relying on domestic or non-Public Water Systems (PWSs) (0.4 million, 1.4% of total population). Texas ranks number 1 in terms of the number of CWSs with any health-based violation (545 CWSs) and number 1 in terms of fluoride violations relative to all of the states in the Continental U.S. (CONUS). A total of 34 CWSs exceeded the fluoride MCL in Texas, mostly (32) in major aquifers and only 2 in minor aquifers based on 2018 – 2020 data. The population impacted by fluoride MCL exceedances from CWSs totaled ~37,700 people (0.1% of the 2020 population) whereas domestic systems (non-CWSs) accounted for ~78,000 people (0.3% of the 2020 population). These percentages are much higher for the secondary MCL of 2 mg/L (CWSs, 3.7% of 2020 population, non-CWSs, 1.1%), indicating that reduction of the primary MCL to 2 mg/L would greatly increase the number of violations and population served.

Major aquifers accounted for the majority of population impacted by primary and secondary MCL violations in terms of population served (99% and 92%, respectively) whereas percentages of population served from major aquifers were lower for non-CWSs (~73% for both primary and secondary MCL). Some of the CWSs with fluoride exceedances also have co-contaminants, primarily arsenic (20), nitrate (3) and radionuclides (6), all in the Ogallala Aquifer. Of these, six systems have reported treatment for inorganics removal, including reverse osmosis (2), filtration (2), activated alumina (1), and innovative techniques (1), yet violations persist. CWSs that exceed fluoride MCL are generally persistent, with 18 CWSs exceeding the MCL for ≥9 out of 12 quarters within a three-year period (2018 – 2020). While the State has been making considerable progress towards bringing CWSs that are out of compliance with respect to fluoride into compliance, there are still a number of non-compliant CWSs. The number of fluoride non-compliant CWSs decreased from 33 in 2018 to 23 in 2020. There are a variety of approaches for managing fluoride contamination in small CWSs.

Introduction

Groundwater fluoride levels in drinking water are of great interest because the optimal range of fluoride, from a health perspective, is narrow, from a minimum of ~0.7 mg/L in order to reduce dental caries (U.S. Public Health Service recommended optimal F concentration in drinking water to minimize dental caries), to a maximum level, the definition of which ranges from 1.5 mg/L (World Health Organization guidance level, WHO, 2011, European Union standard set in 1998) to 4 mg/L (primary MCL in the United States, set by EPA in 1986 for health purposes). The EPA also established a secondary MCL (SMCL) of 2 mg/L for dental purposes that is not Federally enforceable except in California (US EPA, 2020). In 2018, ~73% of the U.S. population were on CWS receiving fluoridated water (0.7 mg/L) (https://www.cdc.gov/fluoridation/statistics/). Texas ranks number 32 in terms of percent of population serve by CWS receiving fluoridated water.

The upper fluoride limits have been established to minimize adverse health impacts related to fluoride toxicity, including dental and skeletal fluorosis, bone fractures, and cognitive and behavioral effects (NRC, 2006). A National Academy of Sciences panel concluded that the EPA MCL of 4 mg/L should be lowered to prevent dental fluorosis and reduce risk of clinical stage II skeletal fluorosis and bone fractures (NRC, 2006). States with highest levels of exposure to fluoride >4 mg/L from community water systems (CWSs) included South Carolina (~105,000 people, F≤6 mg/L), Texas (37,000 people, F≤9 mg/L), Oklahoma (19,000 people, F≤12 mg/L) and Virginia (19,000 people, F≤6 mg/L) (NRC, 2006).

The EPA regulations only apply to public water systems (PWSs) and not to private domestic-supply wells. A recent study shows that ~87% of fluoride concentrations in untreated groundwater in the U.S. were below 0.7 mg/L, the proposed optimal level for oral health (McMahon et al., 2020; U.S. Public Health Service, 2015). This study estimated that ~ 28 million people are potentially served by domestic wells with fluoride levels below the optimal 0.7 mg/L. The narrow range in optimal fluoride concentrations and controversy over recommended upper limits underscore the importance of understanding the sources and mobilization mechanisms impacting fluoride levels in groundwater.

An important source of fluoride is the mineral fluorite (CaF_2) which is found in hydrothermal deposits and rarely in sedimentary deposits (Edmunds and Smedley, 2005). Fluoride is also found adsorbed onto marine clays and is concentrated in phosphates from biogeochemical processes (Edmunds and Smedley, 2005). Anthropogenic inputs include phosphatic fertilizers and contamination from aluminum smelters (Amini et al., 2008). Higher concentrations of fluoride are thought to be controlled primarily by fluorite solubility, as shown by the following reaction: $Ca + 2F = CaF_2$. Based on this reaction, fluoride should be inversely related to Ca, as is found in many regions, such as alkaline volcanic rocks with low-Ca groundwater (Edmunds and Smedley, 2005).

Elevated fluoride is also associated with semiarid climates with low flow rates and limited flushing. Probability maps of global groundwater fluoride levels have been developed based on geology, climate (evapotranspiration/precipitation ratio), water type ($NaHCO_3$), and soil pH conditions (Amini et al., 2008). The global distribution of elevated fluoride was summarized according to geologic settings (geothermal springs [e.g. East Africa, western United States], crystalline basement rocks [West Africa, India, Sri Lanka], volcanic rocks [East Africa], and sedimentary basins [China, Argentina, India, United Kingdom, West Africa, United States]) (Edmunds and Smedley, 2005).

Many studies evaluated different mechanisms for mobilizing fluoride in groundwater. High correlations between fluoride and arsenic in oxidizing systems suggest that both may be mobilized by similar mechanisms (Currell et al., 2011; Smedley et al., 2002). Both arsenic and fluoride may be sorbed onto hydrous metal (Al/Fe/Mn) oxides in oxidizing systems; therefore, ions that compete for the same sorption sites can mobilize both elements, such as PO_4, SO_4, HCO_3, SiO_2, and VO_4. A previous study of arsenic in the southern High Plains aquifer in Texas indicated that the most plausible explanation for arsenic mobilization was changing water chemistry from Ca- to Na-dominant water (owing to the counter-ion effect) by upward movement of saline water from the underlying Dockum aquifer (Scanlon et al., 2009).

A similar mechanism was invoked for mobilizing arsenic and fluoride in the Yuncheng Basin in China (Currell et al., 2011). The counter-ion effect results from the reduced sorption of hydrous metal oxides with replacement of divalent Ca by monovalent Na, resulting in mobilization of arsenic and fluoride. Fluorite is also considered a primary control on elevated fluoride concentrations; therefore, any mechanism reducing Ca should increase fluoride mobility, such as cation exchange of Ca for Na with increasing residence time of groundwater as shown in some sedimentary basins (Edmunds and Walton, 1983; Currell et al., 2011). Increasing pH in these basins should also mobilize both fluoride and arsenic.

Assessing treatment technologies for mitigation of high fluoride can also provide insights into mobilization mechanisms. Basic approaches for mitigating fluoride include techniques based on precipitation, adsorption, ion exchange, membrane filtration, and distillation (Feenstra et al., 2007). Precipitation involves addition of alum (aluminum sulfate), lime, alum and lime together (the Nalgonda process), gypsum, or $CaCl_2$. Commonly used sorbents include activated carbon or alumina, zeolites, clay pots, and bone. More expensive approaches include electrodialysis and reverse osmosis. For waters with elevated fluoride and arsenic, the technology should be selected to treat both.

The objective of this study was to address the following questions:

- What is the spatial variability in groundwater fluoride concentrations in major and minor aquifers in Texas?
- What impact do different regulatory levels (e.g., EPA's 2 and 4 mg/L) have on the percentage of fluoride exceedances?
- What is the potential population served by domestic wells and public water systems with fluoride exceedances (2 and 4 mg/L)

Elevated fluoride levels represent a public health risk because groundwater is the primary source of water in many regions in Texas. The prevalence of high fluoride groundwater also represents an economic challenge for small municipal CWSs that are required to provide chemical treatment. Unique aspects of this study include the long historical water-quality database from the TWDB with good geographical coverage, which provides an opportunity to apply statistical and geospatial approaches to fluoride distributions.

Methods

Terminology

The term “Public Water System” or PWS has somewhat different meaning depending on the data source used in this study. For data derived from a Texas agency database, a PWS refers to any water system with at least 15 residential service connections or a minimum of 25 people served on a year-round basis, which is equivalent to CWS by EPA classification (see next section). A Non-PWS generally refers to domestic water systems located in rural settings, also with generally stable year-round populations.

The US Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS) database places PWSs into three categories, including Community Water System (CWS), Non-Transient Non-Community Water System (NTNCWS), and Transient Non-Community Water System (TNCWS). For this study, the CWS category was primarily used to prevent double-counting of overlapping populations with Non-CWSs. Examples of NTNCWSs include schools, hospitals, prisons, etc. Examples of TNCWS include campgrounds, highway rest stops, rural gas stations, etc. The SDWIS database contains data regularly uploaded by the various US state agencies responsible for water quality in their state, including the Texas Commission on Environmental Quality (TCEQ). Use of the unqualified term “violation” in this report refers to health-based violations for data derived from the SDWIS database unless otherwise noted

Data from the Texas Water Development Board (TWDB) groundwater database were used to characterize statewide groundwater fluoride concentrations to develop estimates of county rural populations at risk of exposure to fluoride at threshold concentrations of 0.7 mg/L, >2 mg/L, and >4 mg/L. The analysis includes all well use categories in the state. Data from the TCEQ PWS database were used to characterize PWS populations at risk of exposure to fluoride concentrations >2 mg/L based on water quality analyses of distribution system water samples. Data from the SDWIS database were used primarily to characterize CWS populations at risk of exposure to fluoride >4 mg/L, through Non-CWSs are also mentioned.

TWDB Groundwater Data Analysis

Data on groundwater fluoride concentrations for this study were obtained from the TWDB groundwater database. The TWDB database contains analyses of groundwater sampled at the well head prior to any treatment processes and the results are considered representative of groundwater conditions at that location at the time of sampling. The original version of this report used data from groundwater samples collected between 1929 and 2019. Those data were used in the original report to develop rural population risk-of-exposure to fluoride maps for the major and minor aquifers of Texas and also for statewide maps. The current report uses data from groundwater samples collected between 1929 and 2021 for the statewide maps only. About 83% (568) of the samples collected in the interim since those used in the original report represent re-sampling of prior wells and have comparable results. Only about 20% (115) of the new samples represent new wells and these were located in areas with previous high-density sampling. Therefore, the risk analysis aquifer maps were not updated for this report because the interim samples do not alter the results significantly enough to warrant a repeat analysis.

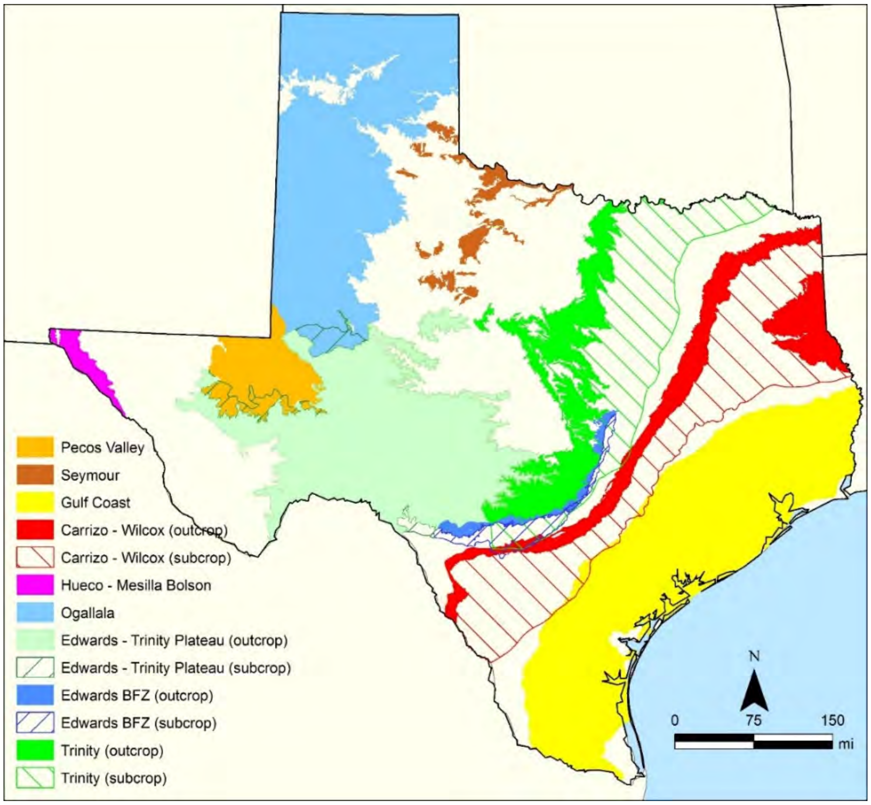

Figure 1. Major Aquifers of Texas.

The source aquifer for pumped water was identified for all groundwater wells in the database. Only samples from wells that were completed in a single aquifer, which represent 88% of all fluoride samples in the database, were used in this study. The aquifers represented in this study include the nine major aquifers (Figure 1) and 21 minor aquifers (Figure 2) identified and named by the TWDB.

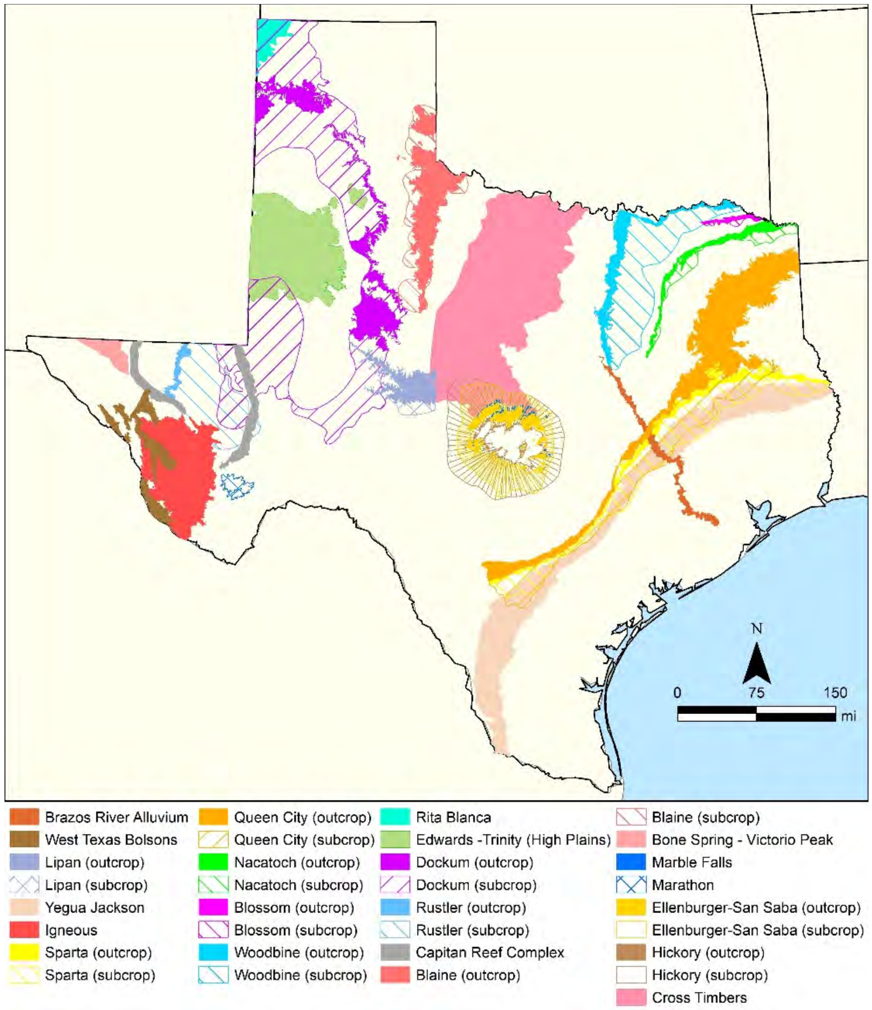

Figure 2. Minor Aquifers of Texas.

Samples from 39,545 groundwater wells in Texas are represented in this study, including 38,683 samples with detected fluoride concentrations (Figure 3). TWDB groundwater database samples analyzed for fluoride were collected between 1929 and 2021 (Figure 4a).

Analytical detection limits for fluoride varied based on the laboratory and method used. Analytical results for samples with undetectable fluoride concentrations are deemed "non-detects" and results are characterized with the "<" symbol followed by the method detection limit. The highest non-detect fluoride concentration level included in this study is 0.5 mg/L, substantially below the EPA drinking water Maximum Contamination Level (MCL) of 4 mg/L and also below the 2 mg/L secondary MCL value and the 0.7 mg/L concentration suggested dental care level. A total of 35 samples with detection limits above 0.5 mg/L were omitted from the data set. Finally, one outlier with a concentration of 350 mg/L (10× greater than the next highest concentration sample) was rejected. The non-detect samples have a median detection limit of 0.1 mg/L and range from 0.01 mg/L to 0.5 mg/L (mean 0.15 mg/L).

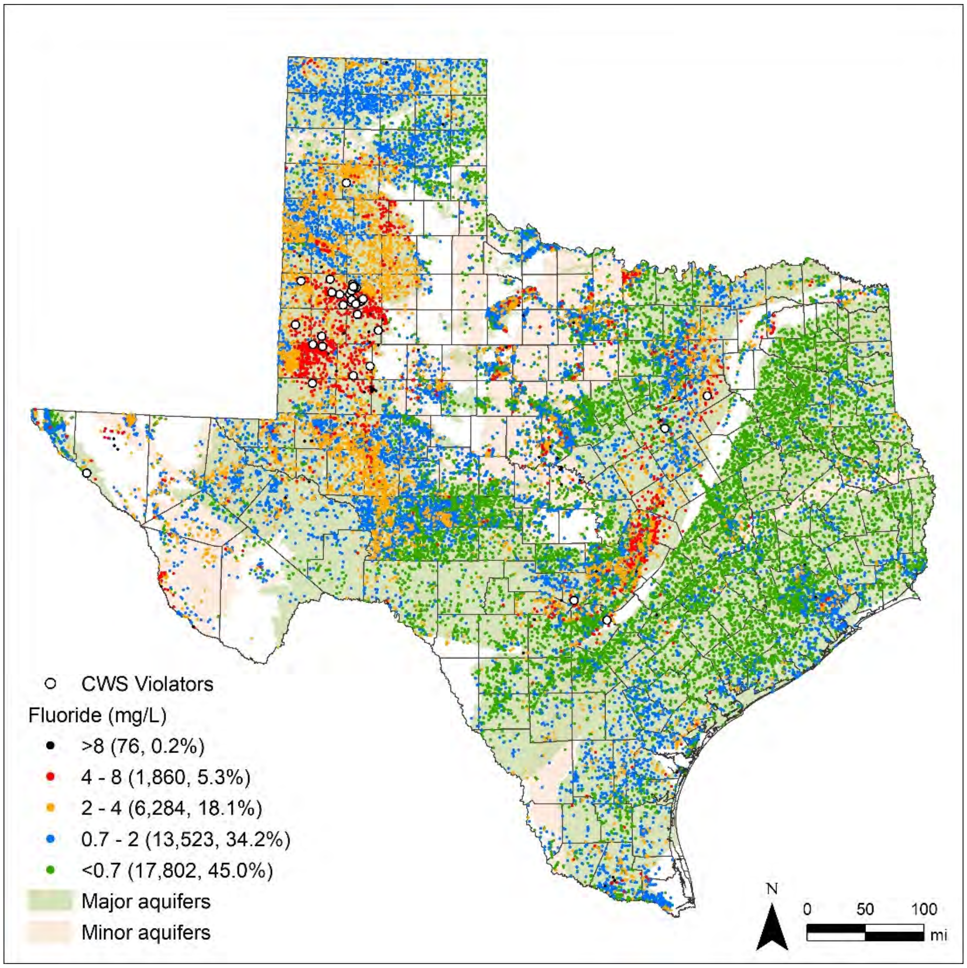

Figure 3. Spatial distribution of groundwater fluoride concentrations in Texas groundwater, including samples collected from 1929 – 2021 with detected concentrations (38,683). The numbers of samples and percentages of all samples within the stated concentration ranges are shown in parenthesis. Samples with non-detect concentrations and samples from wells that were not completed in a single named major or minor aquifer are not included. The locations of 34 community water systems (CWSs) that had any fluoride MCL violation during the period 2018-2020 are also shown.

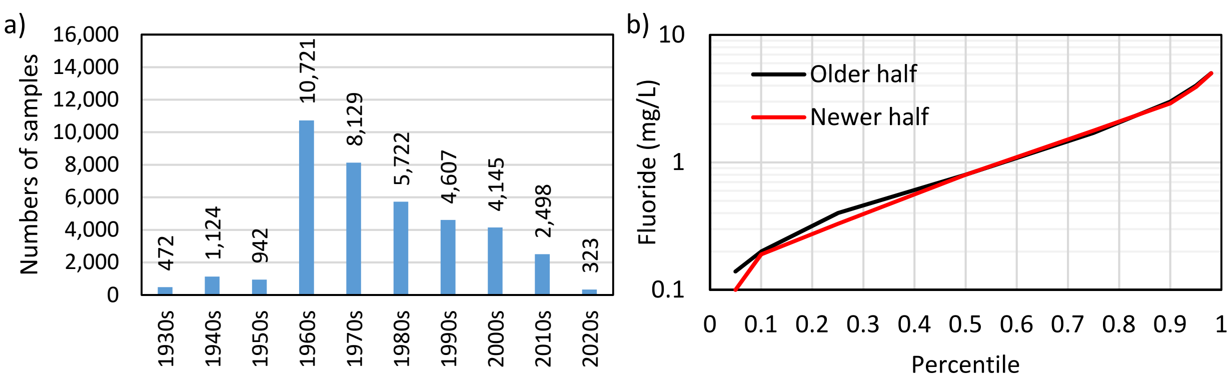

Figure 4. Distributions of a) number of fluoride samples collected by decade and b) percentile distribution of fluoride concentrations for samples collected prior to and on or after the median sample date (4/28/1976). (TWDB groundwater database, 1929-2021).

The concentration distribution of the sample population collected prior to the median sample date (4/28/1976) was compared to that of samples collected on or after the median sample date (Figure 4b). The distributions are virtually identical, with only a slight difference in concentrations below 0.5 mg/L. This indicates that there is no significant bias in the analytical precision of fluoride over the sampled time period and that “older” data can be reliably incorporated to maximize spatial coverage. As this study is primarily focused on fluoride concentration threshold values of 0.7 mg/L, 2 mg/L, and 4 mg/L, the slight difference in distributions below 0.5 mg/L are inconsequential to the results. The data used include only the most recent analysis for each well.

TWDB Data Analysis – Groundwater Conditions and Rural Populations

Fluoride concentrations from the TWDB groundwater database were evaluated by aquifer using various statistical analyses of the most recent analysis for a given well for samples collected from 1929 to 2019. 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 was used to generate maps representative of the fluoride spatial distribution in the different aquifers. Indicator kriging was used as this method can incorporate 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 fluoride concentrations exceed a selected threshold value. Two threshold values were used for the rural population analyses. The threshold of 2 mg/L represents the EPA secondary MCL for drinking water. A higher threshold value of 4 mg/L was used to identify areas where the likelihood that groundwater fluoride concentrations exceed the EPA primary MCL for drinking water. Separate state-wide maps were generated for data over the period 1929 to 2021 at threshold fluoride concentration of 0.7 mg/L, 2 mg/L, and 4 mg/L.

Maps for each aquifer based on the period 1929 to 2019 focused on the primary (>4 mg/L) and secondary (>2 mg/L) EPA MCLs, including aquifers with 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. Further consideration must also be given to the spatial distribution of data point locations within the modeled area, i.e., whether the data are overly clustered in one area and sparse or absent in others. There were more than sufficient data for all nine of the major aquifers while there were sufficient data for only 10 of the minor aquifers. The remaining 11 minor aquifers were not mapped due to insufficient samples or very low percentages of samples above 2 mg/L.

The indicator kriging procedure begins with a binary transformation of the concentration data as either 0 (zero) for all data points less than or equal to the threshold value or 1 (one) for all data points 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 fluoride concentrations exceed the threshold value. In this study a uniform grid cell size of 1 km x 1 km was selected for all but the state-wide scale maps, which used a 2 km x 2 km grid.

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 predicted probability ranges using seven descriptive categories, 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 are present in the maps that arise primarily in regions with little or no data and/or the results of 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.

SDWIS and TCEQ PWS Data Analysis – PWS Conditions and Populations

Public water systems (PWSs) in Texas are regulated under the Safe Drinking Water Act with primacy transferred from EPA to TCEQ and must provide distribution system water sample analyses to monitor system performance with regard to various potential contaminants of concern, including fluoride. There was a total of 7,055 active PWSs in Texas serving 29,537,000 people based on SDWIS data downloaded in April 15, 2021 (Figure 5). CWSs serve stable year-round populations and accounted for 66% of the PWSs serving most of the PWS population (97%, 28,748,000 people). This study focuses on CWSs. Non-CWSs (those with transient or non-transient populations) are not included to avoid double counting of overlapping populations. The SDWIS database was used to characterize CWS systems with fluoride concentrations >4 m/L.

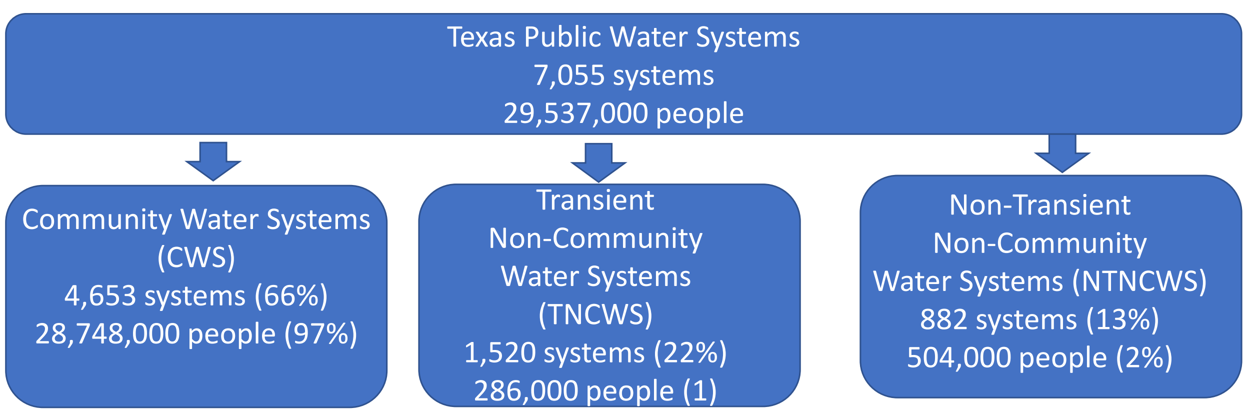

Figure 5. Types, numbers, and total populations served by Texas PWSs in the SDWIS database as of 15 April 2021. Percentages are relative to the combined total number of PWSs and populations served in the database (https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting). The numbers of systems and corresponding populations served are summarized in Table 1.

Table 1a. Numbers of active PWSs in Texas and the US by population served category and PWS type in the SDWIS database as of 15 April 2021.

Region	*System Type*	*Populations Served*					
		<500	*501 – 3,300*	*3,301 – 10,000*	*10,001 – 100,000*	*>100,000*	*All*
Texas	CWS	2,050	1,539	700	323	41	4,653
	NTNCWS	753	118	10	-	1	882
	TNCWS	1,416	102	2	-	-	1,520
	All	4,219	1,759	712	323	42	7,055
US	CWS	26,113	13,093	4,931	3,880	436	48,453
	NTNCWS	14,409	2,359	157	38	1	16,964
	TNCWS	73,022	2,874	74	12	-	75,982
	All	113,544	18,326	5,162	3,930	437	141,399

Table 1b. Total populations served by all active PWSs in Texas and the US by population served category and PWS type in the SDWIS database as of 15 April 2021. Note that total populations for system types other than CWS likely include populations from the CWS category at least in part.

Region	*System Type*	*Populations Served*					
		<500	*501 – 3,300*	*3,301 – 10,000*	*10,001 – 100,000*	*>100,000*	*All*
Texas	CWS	388,853	2,340,246	4,001,194	8,156,665	13,860,559	28,747,517
	NTNCWS	94,743	151,816	53,897	-	203,375	503,831
	TNCWS	191,449	89,633	7,896	-	-	285,567
	All	675,045	2,581,695	4,062,987	8,156,665	14,063,934	29,536,915
US	CWS	4,399,897	18,897,541	28,981,033	111,817,641	143,739,345	304,639,373
	NTNCWS	1,990,852	2,532,951	876,466	812,466	203,375	6,400,738
	TNCWS	6,791,382	2,689,438	382,952	247,616	-	10,039,342
	All	13,182,131	24,119,930	30,240,451	112,877,723	143,942,720	321,079,453

For this study, we summarized by aquifer the CWSs and associated populations that had health-based violations (as opposed to monitoring, reporting, or public notice violations) related to fluoride, including systems that were active on the date that the SWDIS database was accessed for this study (April 15, 2021). The SDWIS database tracks system compliance on a quarterly basis. This study primarily summarizes violations for the 12-quarter period from January 2018 through December 2020. This period was used to capture recent information for systems that may alternate between compliant and non-compliant conditions during successive quarters. Time series of historical violations for fluoride and various other water quality compliance rules and rule groups were consolidated at the annual level so that CWS violations were counted only once during a given calendar year regardless of the number of violations that a system may have incurred.

Because sample results below 4 mg/L are not routinely included in the SDWIS database, data from the TCEQ PWS database were used to estimate the at-risk CWS populations for fluoride concentrations in excess of the EPA secondary MCL (>2 mg/L) in the distribution systems. These assessments are based on whether the CWS had at least one distribution water sample with fluoride >2 mg/L during the period from January 2017 through about July 2020.

SDWIS Database Definitions

The EPA maintains a national database (Safe Drinking Water Information System, SDWIS) of current active CWS water quality compliance with respect to the MCL status for all contaminants of concern. The database includes several system attributes of interest to this study, including estimates of the populations served by the CWSs 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 verbatim excerpts from the EPA website documentation that define attributes in the database that are of significance to this study (https://echo.epa.gov/tools/data-downloads/sdwa-download-summary):

Public Water System Type

"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).*
- *Non-community water system*
  - *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 supply 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 supply 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."*

<u>*Compliance Points*</u>

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

Table 2. EPA guidelines for assigning violation point values to PWSs.

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 • Nitrate monitoring and reporting violation • Total coliform repeat monitoring violation
1	• Monitoring and reporting violation not listed above • Public notice violation • Consumer Confidence Report violation • Additional point for each year a violation is unaddressed

Non-Public Water 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 and are referred to in this study as non-PWSs. Estimates of the at-risk non-PWS populations were made by aquifer using the kriging probability maps discussed earlier coupled with estimates of the non-PWS county populations from the United States Geological Survey (USGS, 2015, https://water.usgs.gov/watuse/). The USGS report provides total populations and populations relying on PWSs. This study uses the difference between those two populations to estimate the rural (non-PWS) population in each county of Texas.

The spatial mean probabilities of exceeding both the 2 mg/L and 4 mg/L fluoride MCL threshold values were estimated for each unique aquifer-county intersecting area based on the GIS probability maps. The spatial probability of exceedance mean values were multiplied by the non-PWS population estimates for each county to obtain initial estimates of the at-risk populations. The initial estimates were finally adjusted to remove populations in those 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 PWSs. 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 BFZ aquifer overlies the Trinity aquifer and where the Ogallala and Pecos Valley Alluvium aquifers overlie the Edwards-Trinity Plateau aquifer. Similar secondary areas affecting smaller populations occur 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 non-PWS systems, this study assigns those populations to the shallowest aquifer in a given area.

Social Vulnerability Index

The US Centers for Disease Control (CDC) periodically publishes a national dataset characterizing what they term the Social Vulnerability Index (SoVI). The dataset is based on data at the US Census Tract level and is made available at that resolution and also at the US County level. The dataset contains several components. For this study we used the current Overall Vulnerability (i.e., SoVI) statistic which is based on the US Census Bureau American Community Survey (ACS) for the period 2014-2018 (Figure 6).

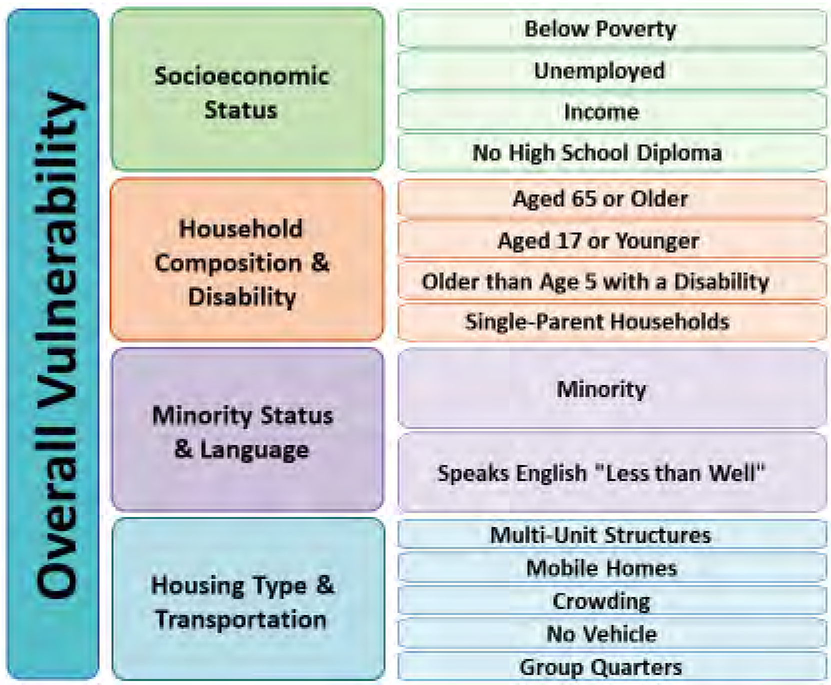

Figure 6. Components of the Centers for Disease Control (CDC) Social Vulnerability Index (SoVI) based on The US Census Bureau American Community Survey (ACS) for the period 2014-2018 (https://www.atsdr.cdc.gov/placeandhealth/svi/index.html).

The SoVI statistic is based on 15 variables relating to population characteristics in four broad categories, including socioeconomic status, household composition and disability, minority status and language, and housing type and access to transportation (Figure 6). Values for SoVI range from zero (0, least vulnerable) to one (1, most vulnerable) and represent the normalized sums of the individual variables for a given tract or county. The SoVI values were summarized at the US County level for the CONUS and for Texas in this study.

Results

Populations served by PWSs and Non-PWSs

The total population of Texas increased by a factor of about 3 between 1960 (9.6 million) and 2015 (27.5 million) and further to the present population of ~29.1 million in 2020 (Figure 7). The percentage of the population served by PWSs has varied between about 80-95% during that time and was estimated at 26.2 million in 2015 (Table 3). The population served by non-PWSs generally fluctuated between about 0.4 to 2.7 million people during that time and was estimated to be 0.4 million in 2020. As a percentage of the total population, the non-PWS population ranged from 10% to 22% between 1960 and 1980 and decreased to 2% in 2020.

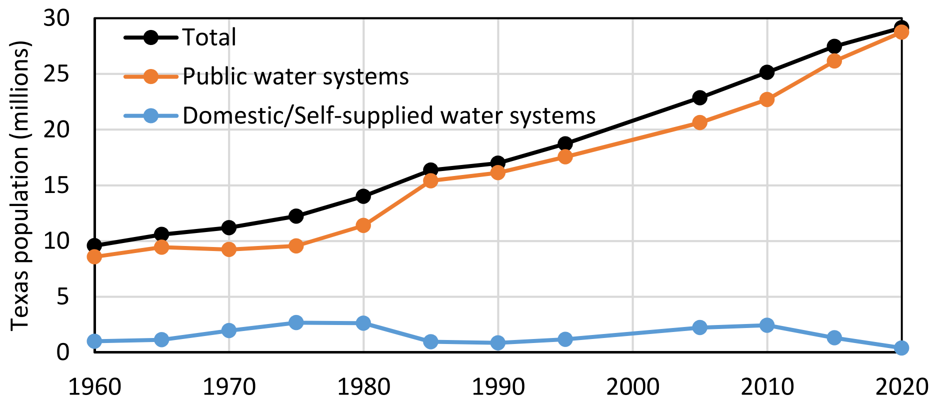

Figure 7. Historical evolution of Texas population relying on Public (CWS) vs Domestic/Self-supplied (non-PWSs) (USGS, https://water.usgs.gov/watuse/data/) for 1990-2015. Values for 2020 are based on the SDWIS database. Values are summarized in Table 3. (https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting)

Table 3. Historical evolution of the Texas population relying on PWS (CWSs) and Non-PWSs and the relative percentages of the total population (USGS, https://water.usgs.gov/watuse/data/).

Year	*Total Population*	*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	9,450,000	1,141,000	89.2	10.8
1970	11,197,000	9,240,000	1,957,000	82.5	17.5
1975	12,236,000	9,560,000	2,676,000	78.1	21.9
1980	14,013,000	11,390,000	2,623,000	81.3	18.7
1985	16,361,330	15,403,760	957,570	94.1	5.9
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
2020*	29,145,505	28,747,517	397,988	98.4	1.6

*PWS values based on 2020 SDWIS database.

Texas CWS National Rankings for Rule Violations

The state of Texas shows large variability in the distribution of counties with CWSs having any health-based violation relative to Social Vulnerability Index (SoVI), with many counties without any health-based violations (2018 – 2020 SDWIS data), particularly in the High Plains (Figure 8). However, counties in the Rio Grande Valley and East Texas fall into the highest category of SoVI and health-based violations. Populations in Texas with higher SoVI generally increase with higher terciles of any health-based violation (Table 6). For example, ~ 2,500 people are classified within the lowest SoVI and lowest tercile of health-based violation whereas almost 1 million people fall into the category with the highest SoVI and highest tercile of health-based violations. Within the top tercile of health-based violations, SoVI populations peaked within the middle SoVI tercile. These results indicate that higher SoVI populations are more at risk of health-based violations.

Texas ranks variously among the top five states with regard to numbers of CWSs that had recent (2018-2020) health-based violations (Table 4). Texas ranks number 1 of all states in terms of number of CWSs with any health-based violation and ranks within the top 2 for many of the other health-based violations. Only SWTR, GWR, and organics rank lower relative to other states. Texas ranking in terms of CWS populations served is ranges from 2 – 8 for different health-based violations. The rankings reflect in part that Texas has both the largest number of CWSs of any state (4,653) and the second largest state population served by CWSs (~28.7 million) after California. Accordingly, for total affected populations expressed as percentages of the state-wide total populations served by all CWSs, Texas ranks variously between 6 and 24 among other continental US (CONUS) states. Fluoride violations are regulated under the Inorganics Rule. For fluoride violations, Texas ranks number 1 in terms of number of CWSs, number 3 in terms of population served, and number 5 on a per-capita basis. Fluoride MCL violations constitute 88% (81) of all reported quarterly Inorganics Rule violations (92) in Texas that occurred during 2018-2020.

Table 4. Numbers of community water systems, affected populations, and per-capita affected populations with health-based violations for the various water quality rules for CWSs in Texas. Fluoride (fluoride) is included in the Inorganics Rule violations. Also shown are (any inorganic) which includes Inorganics, Arsenic, and Nitrates violations and (any HB violation) which includes all health-based violations for all of the rules. This table is based on data from the SIDWIS database for the period from Jan 2018 through Dec 2020 and accessed on April 15, 2021. Highest ranked states/areas are based on affected CWS population percentages.

Rule / Rule Group	*Texas Systems*			*Texas Populations*				*Highest Rank State/Area*
	Number	*National Rank*	*% of TX Systems*	*Affected*	*National Rank*	*Affected (%)*	*National Rank*	
Inorganics	37	1	0.80	46,659	3	0.16	8	NY
(fluoride)	34	1	0.73	37,683	3	0.13	5	UT
Arsenic	71	2	1.53	110,363	2	0.38	10	NN
Nitrates	33	1	0.71	11,139	2	0.04	10	ID
(any inorganic)	115	2	2.47	143,375	2	0.50	15	NY
Radionuclides	170	1	3.65	195,657	3	0.68	18	NY
DBPRs	242	1	5.20	940,425	3	3.27	20	RI
SWTR	34	5	0.73	236,454	8	0.82	8	WV
GWR	35	5	0.75	39,621	7	0.14	24	LA
RTCR	53	2	1.14	137,166	7	0.48	23	NN
Organics	3	3	0.06	5,089	6	0.02	6	PA
LCR	68	1	1.46	100,283	8	0.35	11	NJ
(any HB violation)	545	1	11.71	2,690,600	2	9.36	21	RI

DBPR: Disinfectant and Disinfection Byproduct Rule, SWTR: Surface Water Treatment Rule, GWR: Groundwater Rule, RTCR: Revised Total Coliform Rule, NN: Navajo Nation (Arizona). Parentheses are used to refer to contaminants that do not have a specific rule (fluoride, any inorganic).

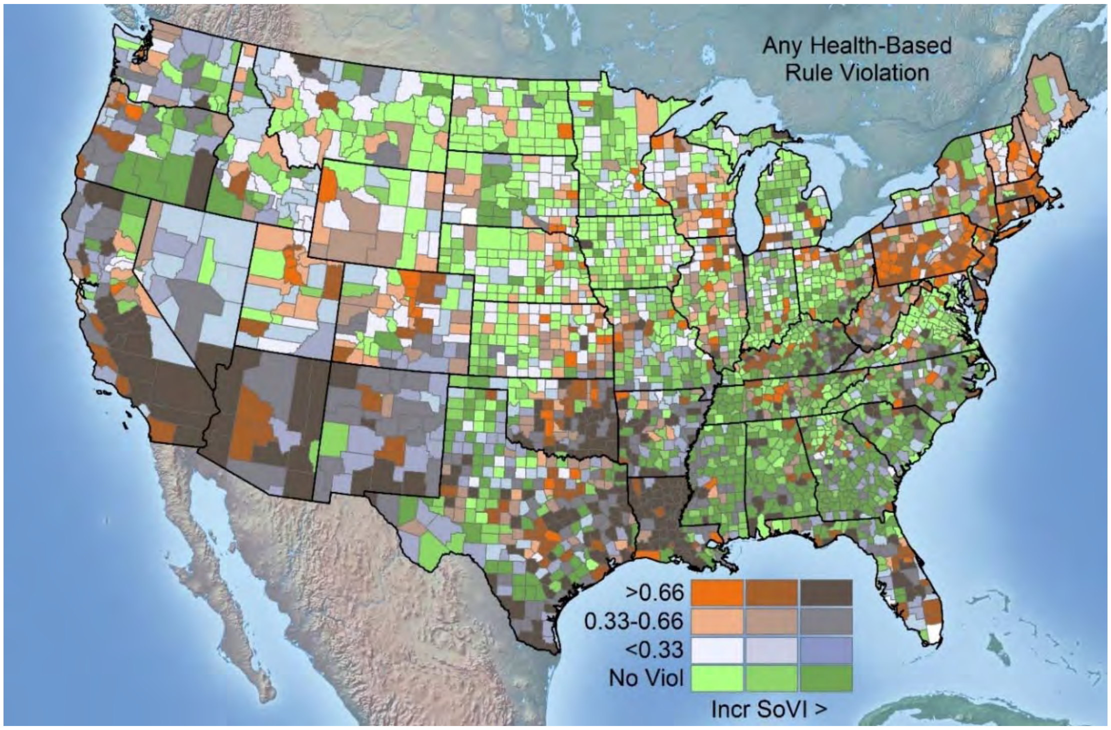

Figure 8. National county-level map comparing terciles of CWS populations having any health-based violation for the period 2018 – 2020 vs terciles of SoVI (Social Vulnerability Index, 2018). The choropleth map is similar to that used by Fedinick et al., 2019. Green tinted areas represent SoVI terciles for counties having no health-based violation for any CWS in that county. The SoVI is a normalized score with values ranging from 0 (least vulnerable) to 1 (most vulnerable) as described in the Methods Section of this report. Values are summarized in Table 5.

Table 5. Populations and percentages of total CWS populations associated with terciles of US and Texas county level SoVI (normalized) values and terciles of CWS populations with any health-based violation in the SDWIS database during the period 2018-2020. Percentages of total values are relative to the US CWS population of 304,639,000 and to the Texas CWS population of 28,748,000. Cell colors correspond to the legend in Figure 8. Values reflect violating CWS populations in each category except (none, green) which represents the total population in each category.

Region	*Violation Population Percentile Range*	*County SoVI Percentile Range*					
		<0.33		*0.33-0.66*		*>0.66*	
		People	*% CWS Total*	*People*	*% CWS Total*	*People*	*% CWS Total*
CONUS	>0.66	6,593,480	2.16	8,873,069	2.91	11,847,418	3.89
	0.33-0.66	428,817	0.14	525,369	0.17	565,289	0.19
	<0.33	69,206	0.02	60,571	0.02	45,406	0.01
	(none)	24,583,097	8.07	42,483,088	13.95	24,182,759	7.94
Texa	>0.66	75,931	0.26	1,475,123	5.13	964,138	3.35
	0.33-0.66	16,552	0.06	61,749	0.21	89,884	0.31
	<0.33	2,461	0.01	6,133	0.02	11,547	0.04
	(none)	792,723	2.76	186,762	0.65	1,042,498	3.63

Historical Texas Community Water System Violations

Time series of CWSs with health-based violations in Texas shows that system violations of the DBP Rule (DBPR) has since early 2000s, peaking in 2005 and 2015 (Figure 9a). Total affected populations are also dominated by DBPR since early 2000s (Figure 9b). The Lead and Copper Rule (LCR) violations peaked in the early 1990s, in terms of number of systems and populations served. System violations of the Ground Water Rule (GWR) increased from ~ 2010 peaking in 2019 and ranked 2nd after DBPR violations (Fig. 9a). Fluoride violations are classified within the Inorganics Rule, which includes many other contaminants but is dominated by fluoride, which accounted for 88% of all health-based violations under that rule in Texas.

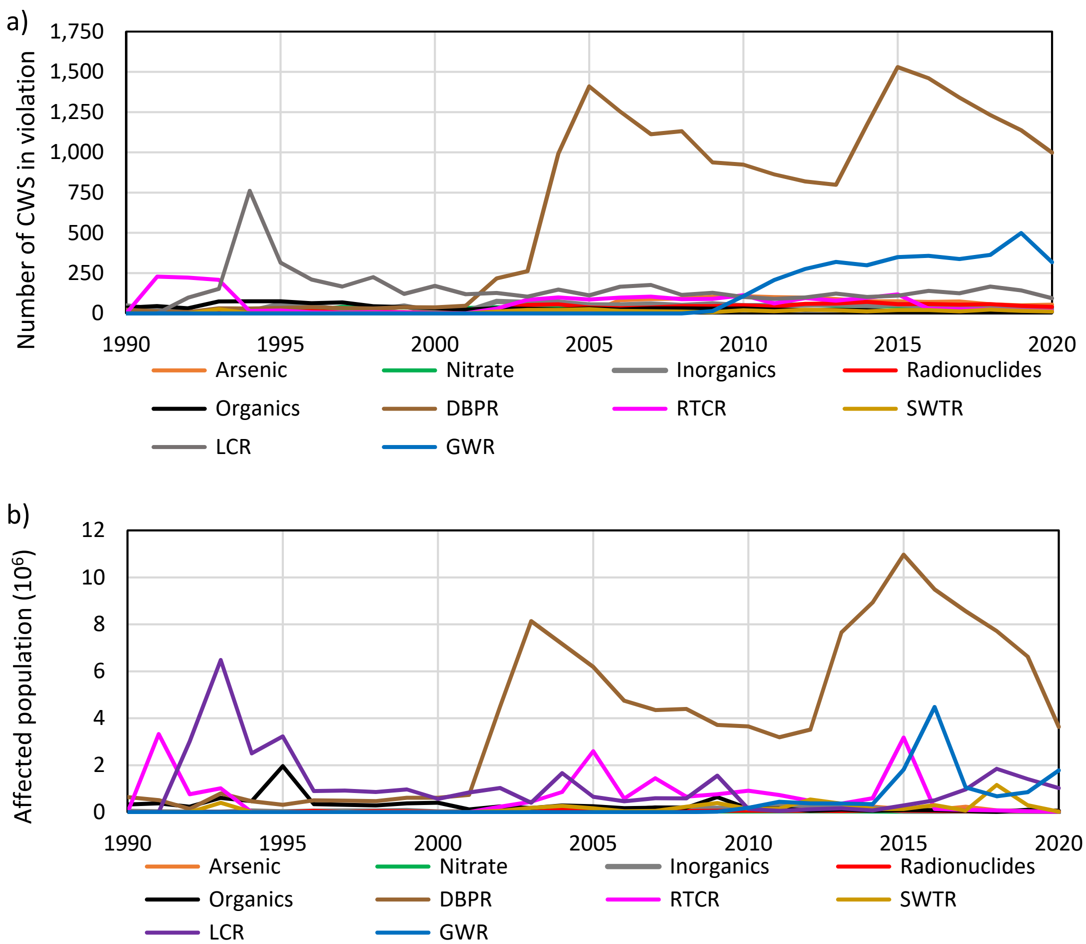

Figure 9. Summary time-series of Texas Community Water System (CWS) health-based violations for the various EPA water quality rules based on the SWDIS database including a) the annual number of violations and b) the total annual affected populations. (SDWIS database, https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting). Annual data are shown in

Table 6a and Table 6b, respectively. DBPR: Disinfection Byproducts Rule, RTCR: Revised Total Coliform Rule, SWTR: Surface Water Treatment Rules, LCR: Lead and Copper Rule, GWR: Groundwater Rule.

Separating fluoride MCL violations from the rest of the Inorganic Rule constituents indicates that the number of CWSs with violations peaked in 2002 (54 systems) and declined gradually to about half as many systems in 2020 (23 systems) (Figure 10a). In terms of affected population, the period from 2007 to 2014 had the highest number (167,000 to 183,000 people), markedly declining in 2015 to 41,000 (Figure 10b). Since then, the affected population decreased gradually to 8,700 in 2020. Comparing the two graphs emphasizes that the CWSs that are currently in violation with respect to fluoride are dominated by small systems, having a median system population of about 240 people.

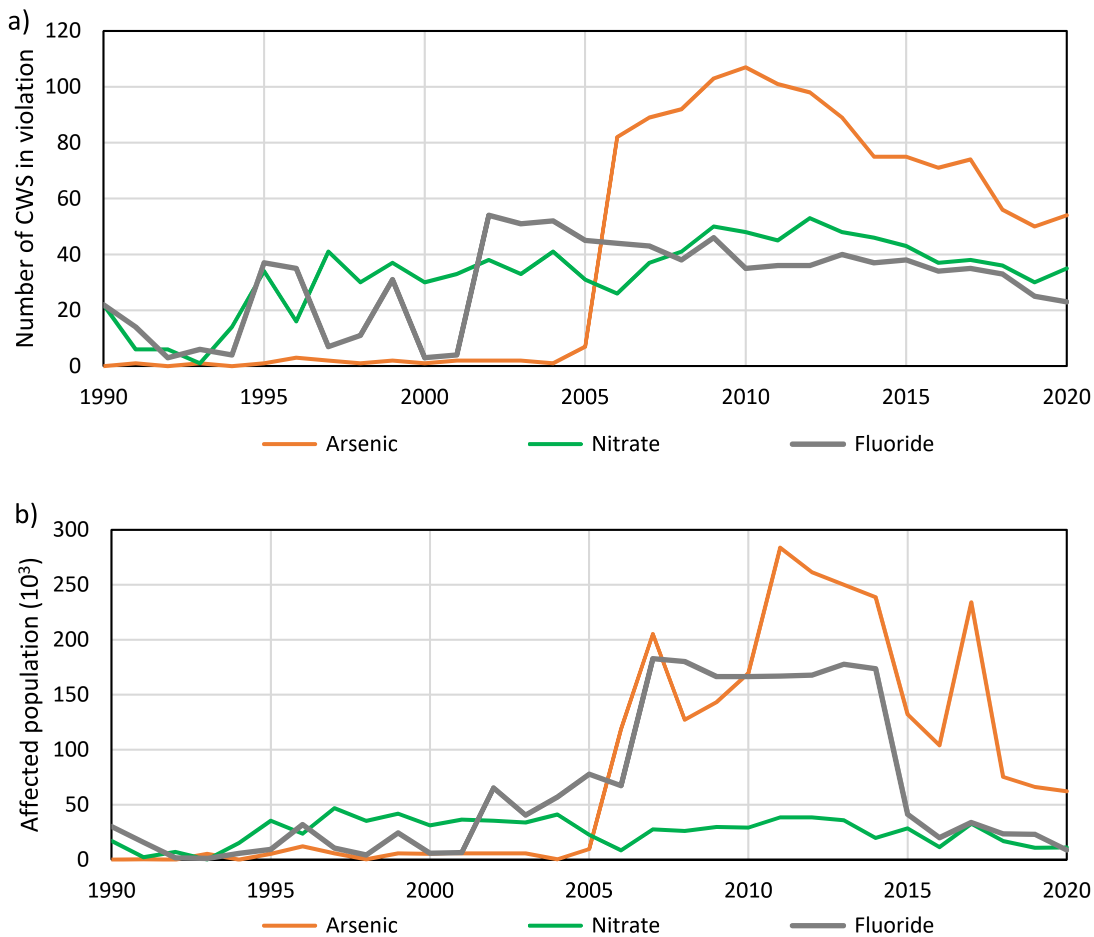

Figure 10. Time-series of the primary inorganic constituent health-based violations including arsenic, nitrate, and fluoride violations for Texas Community Water Systems (CWSs) based on the SWDIS database including a) annual number of system violations and b) total annual affected populations. Annual data are shown in Table 6a and Table 6b, respectively.

Table 6a. Time series of the numbers of CWSs in Texas with health-based violations for the different EPA water quality standards shown in Figure 9a and Figure 10a.

Year	*Fluoride*	*Arsenic Rule*	*Nitrates Rule*	*Inorganics Rule*	*Radionuclides Rule*	*Organics Rule*	*DBPR*	*RTCR*	*SWTR*	*LCR*	*GWR*
1990	22	0	22	46	4	35	22	0	0	0	0
1991	14	1	6	22	9	45	13	228	0	0	0
1992	3	0	6	8	2	31	9	222	0	97	0
1993	6	1	1	7	2	74	31	208	26	152	0
1994	4	0	14	12	5	75	30	15	1	761	0
1995	37	1	34	57	5	75	33	18	1	315	0
1996	35	3	16	46	17	63	38	7	0	210	0
1997	7	2	41	21	5	68	33	5	1	167	0
1998	11	1	30	20	9	44	30	8	1	225	0
1999	31	2	37	45	8	39	38	6	0	121	0
2000	3	1	30	10	3	32	37	2	1	171	0
2001	4	2	33	12	6	23	47	1	0	119	0
2002	54	2	38	74	23	32	217	29	12	127	0
2003	51	2	33	68	52	28	262	84	21	104	0
2004	52	1	41	70	56	23	992	99	21	148	0
2005	45	7	31	52	36	31	1410	86	26	112	0
2006	44	82	26	52	32	24	1254	98	16	166	0
2007	43	89	37	58	36	31	1112	104	14	176	0
2008	38	92	41	49	45	31	1131	88	12	115	0
2009	46	103	50	59	45	29	938	90	8	128	15
2010	35	107	48	47	50	30	924	113	19	102	107
2011	36	101	45	49	42	23	863	62	14	90	207
2012	36	98	53	53	59	21	819	95	22	99	276
2013	40	89	48	57	61	22	798	79	19	123	320
2014	37	75	46	50	71	20	1170	97	13	102	299
2015	38	75	43	54	57	16	1529	118	20	110	349
2016	34	71	37	45	58	14	1460	29	20	140	357
2017	35	74	38	49	54	10	1340	26	13	125	337
2018	33	56	36	43	57	8	1232	24	23	167	363
2019	25	50	30	36	46	14	1137	18	16	143	499
2020	23	54	35	33	40	11	998	15	12	94	318

DBPR: Disinfectant and Disinfection Byproducts Rule, RTCR: Revised Total Coliform Rule, SWTR: Surface Water Treatment Rules (includes SW Treatment, Long Term 1, and Long Term 2 Rules), LCR: Lead and Copper Rule, GWR: Groundwater Rule

Table 6b. Time series of the CWS populations in Texas with health-based violations for the different EPA water quality standards shown in Figure 9b and Figure 10b.

Year	*Fluoride*	*Arsenic Rule*	*Nitrates Rule*	*Inorganics Rule*	*Radionuclides Rule*	*Organics Rule*	*DBPR*	*RTCR*	*SWTR*	*LCR*	*GWR*
1990	30,147	-	17,105	39,279	1,011	329,757	639,910	-	-	-	-
1991	15,796	350	2,210	17,242	10,420	376,815	512,494	3,325,901	-	-	-
1992	1,685	-	7,056	2,138	586	231,929	135,362	766,022	-	3,013,969	-
1993	1,087	5,300	126	1,087	549	610,083	798,849	1,016,290	397,853	6,481,002	-
1994	5,681	-	15,096	51,477	4,440	470,828	465,199	4,949	168	2,500,811	-
1995	9,400	5,300	35,337	16,314	1,005	1,962,058	312,823	7,363	324	3,224,805	-
1996	31,919	12,104	23,534	40,061	56,306	344,293	507,408	1,572	-	903,726	-
1997	10,466	5,650	46,790	53,262	4,426	316,364	493,605	615	90	921,117	-
1998	4,259	350	35,281	47,208	32,969	290,281	472,939	847	645	862,181	-
1999	24,314	5,650	41,721	67,191	45,044	379,736	617,492	843	-	966,861	-
2000	5,874	5,300	31,182	5,874	8,210	406,394	615,557	-	645	569,479	-
2001	6,467	5,650	36,371	6,467	13,326	118,428	735,046	-	-	839,137	-
2002	65,230	5,650	35,315	66,989	58,447	246,992	4,508,976	235,049	53,909	1,031,453	-
2003	40,534	5,650	33,782	41,912	187,563	176,299	8,136,193	442,106	186,898	406,503	-
2004	56,991	350	41,030	58,297	142,353	286,391	7,162,636	862,881	267,655	1,665,900	-
2005	77,789	9,551	22,619	78,230	54,505	253,840	6,191,837	2,595,571	163,134	656,409	-
2006	67,274	118,712	8,409	67,274	27,170	169,755	4,747,157	583,606	41,373	467,047	-
2007	182,799	205,243	27,581	183,648	37,581	190,352	4,347,362	1,449,488	55,329	595,872	-
2008	180,229	127,268	26,026	180,718	55,421	193,677	4,398,863	661,553	233,926	587,933	-
2009	166,538	143,285	29,687	167,027	54,936	644,397	3,717,758	764,710	388,849	1,553,313	24,277
2010	166,563	169,610	29,124	167,412	57,552	159,323	3,651,440	915,929	147,572	140,054	184,282
2011	166,907	283,774	38,368	300,808	59,293	165,733	3,189,411	731,229	149,103	57,050	442,583
2012	167,852	261,439	38,505	301,264	65,704	63,847	3,517,682	479,904	539,547	121,693	375,130
2013	177,699	250,061	35,771	318,705	46,603	114,658	7,654,769	360,292	361,128	164,073	371,267
2014	173,602	238,683	19,733	174,032	79,551	66,470	8,925,443	595,848	134,805	77,095	339,982
2015	41,180	132,017	28,443	48,771	58,171	91,433	10,966,708	3,175,946	136,961	289,067	1,814,346
2016	20,020	103,991	11,401	53,039	63,213	82,600	9,488,496	136,324	301,491	503,402	4,481,763
2017	33,801	234,094	32,632	47,149	42,339	53,991	8,559,092	96,315	67,711	968,948	1,053,311
2018	23,451	75,232	16,915	32,428	51,403	17,425	7,712,920	79,127	1,159,914	1,847,013	675,523
2019	23,004	66,067	10,843	32,410	51,991	102,471	6,626,154	40,217	296,214	1,415,660	857,000
2020	8,702	62,156	11,139	10,248	36,944	60,672	3,633,691	25,455	21,115	1,024,313	1,779,029

DBPR: Disinfection Byproducts Rule, RTCR: Revised Total Coliform Rule, SWTR: Surface Water Treatment Rules (includes SW Treatment, Long Term 1, and Long Term 2 Rules), LCR: Lead and Copper Rule, GWR: Groundwater Rule.

Current Texas Community Water System Violations

Currently there are 34 CWS with fluoride violations in Texas based in SDWIS data download in April 15 2021 (Table 7). Texas ranked number 1 of all states in the CONUS in terms of CWSs with fluoride violations and number 3 in terms of population served based on 2018 – 2020 data (Table 8). Most violations are for systems that obtain their water from the Ogallala Aquifer (29/34). The range in maximum fluoride concentrations for all violating CWSs is low (4.1 – 7.4 mg/L). The populations served by the fluoride violating CWSs ranges from 33 to 14,109 (City of Andrews); however, the majority of the CWSs with fluoride violations are very small (< 500 people, 28/34 systems, ~80% of CWSs). Four of the remaining systems are classified as small in size (501 – 3,300 people) with the remaining two systems classified as medium in size (10,949 people, JBSA-Randolph; 14,109 people, City of Andrews).

A few (3) of the fluoride violating CWSs only recorded one health-based violation over the three-year period (2018 – 2020, 12 quarters); however, many of the CWSs had multiple health-based violations, with up to 48 violations recorded in a single CWS.

Many of these violating CWSs had co-contaminants, in addition to fluoride. The most common co-contaminant is arsenic, with 20/34 systems having arsenic concentrations ranging from 11 to 31 ug/L. Selenium violations were also found in two of the CWSs with fluoride violations, ranging from 60 – 90 ug/L. The MCL for selenium is 50 ug/L, similar to the original arsenic MCL prior to 2003. Nitrates violations were found in three of the CWSs, ranging from 18 – 26 mg/L. Combined uranium was found in five CWSs, ranging from 39 – 130 pCi/L. Co-contaminants with fluoride were found in wells drilled in the Ogallala aquifer.

We also considered related health-based violations in Texas, including the Arsenic Rule (Table 9), Nitrates Rule (Table 10), any inorganic (including arsenic, nitrates, and inorganics rules) (Table 11), and Radionuclides Rule (Table 12). Texas ranked 2nd in terms of CWS violations of the Arsenic Rule and 2nd in terms of population served within the CONUS, both following California ranked 1st (Table 8). Texas ranked 1st in terms of CWS violations of the Nitrates Rule and 2nd in terms of population served within the CONUS (Table 8). Texas ranked 2nd in terms of CWS violations of any inorganic violation after California, including arsenic, nitrate, and inorganics rules and also 2nd in terms of population served, after New York which had a high number related to asbestos violations. Texas also ranked 1st in terms of CWS violations of radionuclides, and 3rd in terms of population served.

Treatment of Community Water System Violations

Data on treatment of CWSs for various health-based violations are limited. A total of 7 out of the 34 systems with fluoride violations between 2018 and 2020 list some type of treatment for inorganic removal, including reverse osmosis (3 systems), filtration (2 systems), use of activated alumina (1 system) and innovative technology (1 system) (Table 13). One system with fluoride violation also lists treatment with fluoridation. Additional details about treatment of specific CWSs for fluoride are provided in Appendix A.

Table 7. Numbers of reported health-based (HB) violations and maximum concentrations of fluoride, arsenic, selenium, nitrate-N, and combined uranium for CWSs in Texas having fluoride MCL violation(s) during the period 2018-2020.

PWS ID	*PWS Name*	*Population Served*	*Aquifer*	*Any HB*	*Fluoride (mg/L)*	*Arsenic (µg/L)*	*Selenium (µg/L)*	*Nitrate-N (mg/L)*	*Combined Uranium (pCi/LL)*
TX0020001	City of Andrews	14,109	Ogallala	7	4.2	20	0	0	0
TX0150115	JBSA - Randolph	10,949	Edwards BFZ	1	4.9	0	0	0	0
TX0830001	City of Seagraves	2,417	Ogallala	24	4.8	36	0	0	0
TX0400001	City of Morton	2,006	Ogallala	4	4.2	11	0	0	0
TX2510002	City of Plains	1,481	Ogallala	18	4.5	14	0	0	0
TX1150010	Esperanza WS	849	HMB	9	5.1	0	0	0	0
TX1100010	City of Smyer	474	Ogallala	22	5.4	20	0	0	0
TX1100004	City of Ropesville	428	Ogallala	12	5.7	0	0	0	0
TX1520199	Wolfforth Place	400	Ogallala	24	5.8	14	0	0	0
TX1100030	City of Opdyke West	376	Ogallala	10	7.0	12	0	0	0
TX1520217	Southwest Garden Water	375	Ogallala	12	5.7	0	0	0	0
TX1520094	Town North Village WS	360	Ogallala	11	4.3	11	60	0	0
TX1530004	City of New Home	345	Ogallala	23	4.4	20	0	0	0
TX0170010	Borden County WS	300	Ogallala	14	5.6	13	0	0	0
TX0830011	Loop WSC	300	Ogallala	3	4.1	20	0	0	0
TX0580025	Klondike ISD	264	Ogallala	19	4.6	41	0	18	39
TX1520188	Seven Estates	260	Ogallala	32	6.0	0	0	0	0
TX1520152	Town North Estates	216	Ogallala	10	4.7	14	0	0	37
TX1520062	Plott Acres	204	Ogallala	11	4.3	0	0	0	0
TX1100011	Whitharral WSC	200	Ogallala	14	4.5	0	0	26	0
TX2230003	City of Wellman	200	Ogallala	24	7.4	37	0	0	0
TX1300008	Foothills MHP	182	Trinity	7	4.7	0	0	0	0
TX1910024	Umbarger Community WS	180	Ogallala	2	4.1	0	0	0	0
TX1520067	114th St MHP	125	Ogallala	9	5.0	0	0	0	0
TX1520106	Cox Addition WS	114	Ogallala	5	5.3	0	0	0	0
TX0700054	Howard Water Coop	90	Woodbine	2	4.5	0	0	0	0
TX1520039	Lubbock MH Community	81	Ogallala	36	4.9	19	0	0	67
TX1520064	Ft Jackson Mobile Estates	72	Ogallala	24	6.0	0	0	0	69
TX1520198	Valley Estates	70	Ogallala	48	5.0	17	90	0	52
TX1520192	Terrells MHP	60	Ogallala	24	5.9	14	0	0	0
TX1530005	Grassland WSC	55	Ogallala	36	5.4	15	0	18	0
TX1520149	Stormlight MHP	54	Ogallala	46	5.4	17	0	0	0
TX1520247	Country View MHP	54	Ogallala	40	4.3	18	0	0	130
TX0180041	Shuler Point	33	Trinity	1	4.1	0	0	0	0

Table 8. Numbers of systems, total populations, and state ranking for CWSs having any health-based violation for **fluoride** under the **Inorganics Rule** in the continental US for the period 2018-2020.

State	*Systems*		*Population*		*State*	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*		*Number*	*Rank*	*Total*	*Rank*
TX	34	1	37,683	2	MA	-	15	-	15
CA	7	2	9,284	5	MD	-	15	-	15
VA	6	3	696	8	ME	-	15	-	15
AZ	4	4	629	9	MI	-	15	-	15
MO	3	5	11,070	3	MN	-	15	-	15
NM	3	5	3,406	6	MS	-	15	-	15
DE	1	7	9,800	4	NC	-	15	-	15
ID	1	7	78	12	ND	-	15	-	15
MT	1	7	50	14	NE	-	15	-	15
NH	1	7	53	13	NJ	-	15	-	15
NY	1	7	100	10	NN	-	15	-	15
OK	1	7	2,000	7	NV	-	15	-	15
UT	1	7	99,750	1	OH	-	15	-	15
WY	1	7	85	11	OR	-	15	-	15
AR	-	15	-	15	PA	-	15	-	15
CO	-	15	-	15	RI	-	15	-	15
CT	-	15	-	15	SC	-	15	-	15
FL	-	15	-	15	SD	-	15	-	15
GA	-	15	-	15	TN	-	15	-	15
IA	-	15	-	15	VT	-	15	-	15
IL	-	15	-	15	WA	-	15	-	15
IN	-	15	-	15	WI	-	15	-	15
KS	-	15	-	15	WV	-	15	-	15
LA	-	15	-	15					

Table 9. Numbers of systems, total populations, and state ranking for CWSs having any health-based violation under the **Arsenic Rule** in the continental US for the period 2018-2020.

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
CA	94	1	114,839	1
TX	71	2	110,363	2
AZ	42	3	71,216	3
NH	26	4	13,715	8
NM	15	5	47,393	5
OR	15	5	8,886	10
IL	13	7	5,590	12
NV	13	7	4,440	15
ID	9	9	3,035	17
MN	9	9	1,850	24
LA	8	11	17,835	7
OK	8	11	60,678	4
WA	8	11	1,004	29
NY	7	14	2,895	18
ME	6	15	3,801	16
MI	6	15	1,338	27
MT	6	15	2,186	22
CO	5	18	1,560	25
IA	5	18	539	30
IN	5	18	1,471	26
KS	5	18	2,131	23
NN	5	18	5,029	13
NE	4	23	24,091	6
PA	4	23	2,661	19

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
CT	3	25	2,626	20
SD	3	25	1,106	28
AR	2	27	2,501	21
FL	2	27	178	33
GA	2	27	112	35
ND	2	27	4,475	14
OH	2	27	108	36
WI	2	27	10,118	9
MA	1	33	40	38
MD	1	33	164	34
MS	1	33	388	31
NJ	1	33	270	32
UT	1	33	90	37
WY	1	33	6,225	11
DE	-	39	-	39
MO	-	39	-	39
NC	-	39	-	39
RI	-	39	-	39
SC	-	39	-	39
TN	-	39	-	39
VA	-	39	-	39
VT	-	39	-	39
WV	-	39	-	39

Table 10. Numbers of systems, total populations, and state ranking for CWSs having any health-based violation under the **Nitrates Rule** in the continental US for the period 2018-2020.

State	*Systems*		*Population*		*State*	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*		*Number*	*Rank*	*Total*	*Rank*
TX	33	1	11,139	2	NM	1	20	222	18
CA	31	2	8,291	3	WV	1	20	65	25
OK	20	3	12,883	1	WY	1	20	70	23
KS	15	4	6,932	6	AR	-	28	-	28
AZ	10	5	3,521	9	GA	-	28	-	28
NE	10	5	4,202	8	LA	-	28	-	28
WA	8	7	4,570	7	MA	-	28	-	28
CO	4	8	2,375	10	MD	-	28	-	28
ID	4	8	7,686	4	ME	-	28	-	28
MT	4	8	1,165	12	MO	-	28	-	28
MN	3	11	369	16	MS	-	28	-	28
PA	3	11	805	14	NC	-	28	-	28
SD	3	11	243	17	ND	-	28	-	28
WI	3	11	1,671	11	NJ	-	28	-	28
IA	2	15	682	15	NN	-	28	-	28
IN	2	15	1,097	13	NV	-	28	-	28
MI	2	15	89	21	NY	-	28	-	28
OR	2	15	172	19	OH	-	28	-	28
UT	2	15	7,350	5	RI	-	28	-	28
CT	1	20	36	27	SC	-	28	-	28
DE	1	20	60	26	TN	-	28	-	28
FL	1	20	70	23	VA	-	28	-	28
IL	1	20	150	20	VT	-	28	-	28
NH	1	20	80	22					

Table 11. Numbers of systems, total populations, and state ranking for CWSs having any health-based violation under any inorganic violation, (includes combined violations of the (**Arsenic Rule, Nitrate Rule, or Inorganics Rule)** in the continental US for the period 2018-2020.

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
CA	127	1	132,092	3
TX	115	2	143,375	2
AZ	55	3	75,068	5
NH	29	4	14,019	11
OK	27	5	73,464	6
KS	22	6	9,647	17
NM	20	7	51,477	7
NE	17	8	35,905	8
OR	17	8	9,058	18
WA	16	10	5,574	20
IL	15	11	9,740	16
ID	13	12	10,756	14
NV	13	12	4,440	24
MN	12	14	2,219	31
MT	11	15	3,401	26
NY	11	15	1,103,345	1
PA	9	17	3,539	25
CO	8	18	3,095	27
IA	8	18	1,487	32
LA	8	18	17,835	10
MI	8	18	1,427	33
IN	7	22	2,568	30
ME	7	22	4,751	22
SD	6	24	1,349	34

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
VA	6	24	696	35
NN	5	26	5,029	21
WI	5	26	11,789	12
AR	-	28	20,526	9
CT	4	28	2,662	29
FL	4	28	2,863	28
UT	4	28	107,190	4
MO	3	32	11,070	13
WY	3	32	6,380	19
DE	2	34	9,860	15
GA	2	34	112	39
ND	2	34	4,475	23
OH	2	34	108	40
MA	1	38	40	42
MD	1	38	164	38
MS	1	38	388	36
NJ	1	38	270	37
WV	1	38	65	41
NC	-	43	-	43
RI	-	43	-	43
SC	-	43	-	43
TN	-	43	-	43
VT	-	43	-	43

Table 12. Numbers of systems, total populations, and state ranking for CWSs having any health-based violation under the **Radionuclides Rule** in the continental US for the period 2018-2020.

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
TX	170	1	195,657	3
CA	153	2	142,137	4
AZ	61	3	79,877	6
CO	48	4	28,939	13
NH	43	5	16,617	17
OK	34	6	76,078	7
MN	33	7	69,558	9
KS	28	8	16,416	18
IL	27	9	36,115	12
NM	27	9	56,840	10
NE	21	11	36,653	11
WI	21	11	202,282	2
ID	17	13	11,129	21
OR	17	13	9,058	24
GA	16	15	15,570	19
NV	16	15	5,169	30
NY	16	15	1,104,510	1
WA	16	15	5,574	29
PA	15	19	6,206	27
SD	14	20	9,390	23
IA	13	21	6,392	26
MO	12	22	15,161	20
MT	12	22	4,501	32
MI	11	24	2,760	35

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
FL	10	25	3,781	34
ME	10	25	5,579	28
NC	10	25	70,979	8
VA	9	28	1,027	39
LA	8	29	17,835	16
IN	7	30	2,568	37
NJ	6	31	22,764	15
VT	6	31	639	40
AR	5	33	24,176	14
CT	5	33	2,730	36
NN	5	33	5,029	31
UT	4	36	107,190	5
WY	4	36	6,425	25
DE	3	38	10,116	22
MA	3	38	215	43
SC	3	38	2,564	38
MD	2	41	253	42
ND	2	41	4,475	33
OH	2	41	108	45
MS	1	44	388	41
RI	1	44	154	44
WV	1	44	65	46
TN	-	47	-	47

Table 13. Numbers of water treatment plants for Texas CWS that incurred a health-based violation for fluoride during 2018-2020 by treatment objective. Inorganics removal objective also lists the treatment technology applied. Only six of the violating systems have active inorganics removal systems during this period. *Esperanza WS implemented inorganics removal in early 2021.

PWS ID	*PWS Name*	*Inorganics Removal*				*Corrosion Control*	*Disinfection*	*Other*
		RO	*Filt*	*Alum*	*Innov*			
TX0020001	City of Andrews						1	
TX0150115	JBSA - Randolph					2	2	Fluoridation (2)
TX0170010	Borden County WS		1				1	Iron Removal (1)
TX0180041	Shuler Point						1	
TX0400001	City of Morton						2	
TX0580025	Klondike ISD						1	Particulates (1)
TX0700054	Howard Water Coop						1	
TX0830001	City of Seagraves						1	
TX0830011	Loop WSC	1					1	
TX1100004	City of Ropesville						1	
TX1100010	City of Smyer						1	
TX1100011	Whitharral WSC						1	
TX1100030	City of Opdyke West						1	
TX1150010	Esperanza WS*	(1)					1	
TX1300008	Foothills MHP						3	
TX1520039	Lubbock MH Community						1	
TX1520062	Plott Acres						2	
TX1520064	Ft Jackson Mobile Estates						1	
TX1520067	114th St MHP						1	
TX1520094	Town North Village WS		1				1	
TX1520106	Cox Addition WS						1	
TX1520149	Stormlight MHP	1					3	
TX1520152	Town North Estates			1			1	
TX1520188	Seven Estates						3	
TX1520192	Terrells MHP						1	
TX1520198	Valley Estates						1	
TX1520199	Wolfforth Place						1	
TX1520217	Southwest Garden Water						1	
TX1520247	Country View MHP						1	
TX1530004	City of New Home						1	
TX1530005	Grassland WSC						1	
TX1910024	Umbarger Community WS						1	
TX2230003	City of Wellman				1		1	
TX2510002	City of Plains						1	

RO: Reverse Osmosis, Filt: Filtration, Alum: Activated Alumina, Innov: Innovative, Corrosion control uses hexametaphosphate inhibitor, Disinfection uses either gaseous chlorination or hypochlorination.

General Results

A total of ~39,500 samples were analyzed for fluoride in the state between 1929 through July 2021. This dataset includes all raw water samples from various sectors from the TWDB database, including those from public water systems. Most of the data (80%, 31,603 samples) represent the major aquifers while the rest (20%, 7,942 samples) represent the minor aquifers (Table 14). A total of 7,630 samples (19% of all groundwater fluoride data in this study) exceed the secondary MCL of 2 mg/L threshold while 1,806 samples (5%) had fluoride concentrations above the primary MCL of 4 mg/L (Table 1).

Table 14. Summary of Fluoride analyses in the TWDB database. Values represent the latest sample for wells sampled between 1929 and 2019.

Aquifer Group	*Samples*	*Detects*	*Non-detects*	*F >0.7 mg/L*		*F >2 mg/L*		*F >4 mg/L*	
				Samples	*% of Total*	*Samples*	*% of Total*	*Samples*	*% of Total*
Majors	31,603	31,054	549	16,455	52.1	6,372	20.2	1,543	4.9
Minors	7,942	7,629	313	3,845	48.4	1,254	15.8	263	3.3
All	39,545	38,683	862	20,300	51.3	7,630	19.3	1,806	4.6

Among the major aquifers, 1,535 samples (4.9%) had fluoride >4 mg/L and all of the major aquifers had at least one sample above the MCL (Table 15, Figure 11). The Ogallala had by far the greatest percentage of samples exceeding the MCL (18.5%), followed by the Edwards (Balcones Fault Zone) (5.0%), Trinity (3.8%), and Pecos Valley (2.5%) aquifers. The remaining major aquifers had from 0.1% to 1.7% of samples above the MCL.

Table 15. Numbers of fluoride samples from the major aquifers in Texas. Values are based on the latest samples from the TWDB groundwater database and wells completed in multiple aquifers were excluded.

Major Aquifer	*Total Number of Samples*	*Number of Detects*	*Number of Non-detects*	*F >2 mg/L*		*F >4 mg/L*	
				Number	*%*	*Number*	*%*
Carrizo-Wilcox	3,943	3,675	268	59	1.5	5	0.1
Edwards BFZ	1,414	1,369	45	246	17.4	70	5.0
Edwards-Trinity Plateau	4,910	4,878	32	1,059	21.6	27	0.5
Gulf Coast	6,299	6,174	125	288	4.6	30	0.5
Hueco-Mesilla Bolson	571	567	4	35	6.1	6	1.1
Ogallala	6,151	6,123	28	3,239	52.7	1,135	18.5
Pecos Valley	556	552	4	177	31.8	14	2.5
Seymour	2,091	2,081	10	269	12.9	35	1.7
Trinity	5,613	5,550	63	988	17.6	213	3.8
All Majors	31,548	30,969	579	6,360	20.2	1,535	4.9

Among the minor aquifers, 1,250 samples (16% of all fluoride data from minor aquifers) had fluoride > 2 mg/L (SMCL) and 263 samples had fluoride levels > 4 mg/L (primary MCL, 3.3% of samples) (Table 16, Figure 11). A total of 17 of the minor aquifers had at least one sample above the MCL of 4 mg/L. The data are relatively sparse among the minor aquifers as compared to the major aquifers, with the numbers of samples mostly ranging from 33 samples (Marathon) to 837 samples (Dockum), and one with 2,256 samples (Cross Timbers). Four of the minor aquifers have fewer than 50 samples and several aquifers lack spatial representation in some area. The Edwards-Trinity High Plains had by far the greatest percentage of samples exceeding the MCL (52%), followed by the Rita Blanca (18%), the West Texas Bolson (8.9%), the Bone Spring-Victorio Peak (7.7%), and the Woodbine (6.8%) aquifers. The remaining minor aquifers had from 0% to 5.4% of samples above the MCL.

Table 16. Numbers of fluoride samples from the minor aquifers in Texas. Values are based on the latest samples from the TWDB groundwater database. Samples from wells completed in multiple aquifers are not included.

Minor Aquifer	*Kriged*	*Number of Samples*	*Number of Detects*	*Number of Non-detects*	*Detects >2 mg/L*		*Detects >4 mg/L*	
					Number	*%*	*Number*	*%*
Blaine	N	196	190	6	2	1.0	0	0.0
Blossom	N	75	63	12	8	10.7	0	0.0
Bone Spring-Victorio Peak	Y	155	155	0	62	40.0	12	7.7
Brazos River Alluvium	N	258	256	2	1	0.4	0	0.0
Capitan Reef Complex	N	63	59	4	13	20.6	1	1.6
Cross Timbers	Y	2,256	2,246	10	358	15.9	70	3.1
Dockum	Y	837	824	13	259	30.9	35	4.2
Edwards-Trinity High Plains	Y	71	71	0	62	87.3	37	52.1
Ellenburger-San Saba	Y	318	287	31	21	6.6	9	2.8
Hickory	Y	459	441	18	16	3.5	4	0.9
Igneous	Y	198	198	0	58	29.3	3	1.5
Lipan	N	158	154	4	5	3.2	1	0.6
Marathon	N	33	33	0	2	6.1	1	3.0
Marble Falls	N	41	39	2	3	7.3	0	0.0
Nacatoch	Y	203	193	10	39	19.2	11	5.4
Queen City	N	636	501	135	7	1.1	1	0.2
Rita Blanca	N	34	33	1	10	29.4	6	17.6
Rustler	N	43	42	1	19	44.2	0	0.0
Sparta	N	348	315	33	11	3.2	1	0.3
West Texas Bolson	Y	224	224	0	82	36.6	20	8.9
Woodbine	Y	723	716	7	199	27.5	49	6.8
Yegua-Jackson	N	589	559	30	13	2.2	2	0.3
All Minors	Y:10 N:12	7,918	7,599	319	1,250	15.8	263	3.3

With the large number of samples available, two statewide maps were made representing the probability of fluoride exceeding the 2 mg/L and 4 mg/L fluoride threshold concentrations. The results are generally consistent with the individual aquifer maps with the added benefit of gaining an overall impression of the fluoride distribution in Texas groundwater. The difference between the two maps shows that if the fluoride MCL was reduced from 4 to 2 mg/L, the probability of exceeding the MCL would substantially increase and the areas impacted would expand.

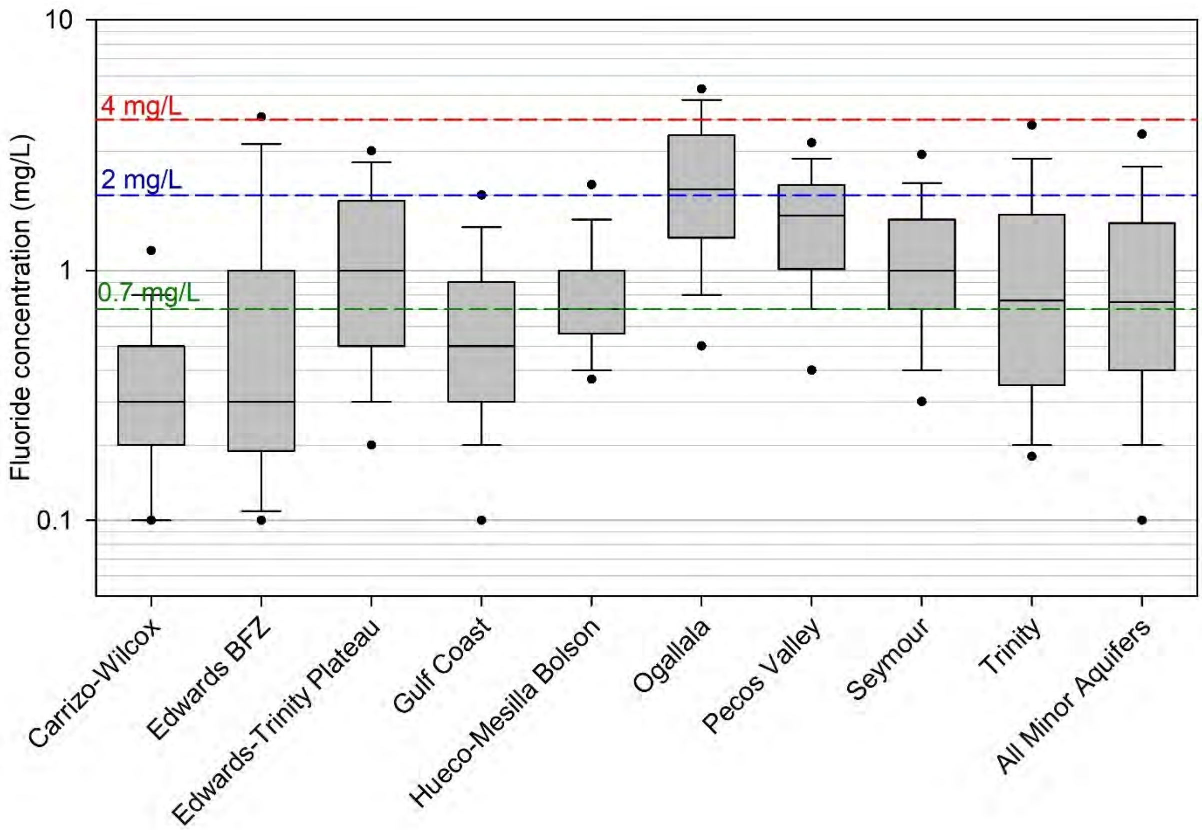

Figure 11. Distribution of detected groundwater fluoride concentrations in the individual major aquifers (31,548 samples, 80% of data, Table 15) and in the combined minor aquifers (7,918 samples, 20% of data, Table 16) of Texas. The lines inside the shaded boxes represent the 50th percentiles (medians), 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. Reference lines are shown for 0.7 mg/L, 2 mg/L, and 4 mg/L threshold values.

Based on the EPA database, 34 CWS were not compliant with the MCL of 4 mg/L, 32 in major aquifers (Table 17) and 2 in minor aquifers (Table 18). Most noncompliant systems were sourced from the Ogallala aquifer (34, 76% of total). A total of 205,875 people are served by 44 PWSs that have been non-compliant with respect to the fluoride MCL (4 mg/L) in at least one of the last 14 quarters (Jan 2017 – June 2020) representing 0.7% of the 2020 Texas total population (29,900,000, Figure 13, Table 3). Most (98%, 202,563 people, Table 17) are associated with PWSs that source their water from one of the major aquifers while the remaining (2%, 3,312 people, Table 18) are associated with minor aquifer PWSs. The major aquifers include the Ogallala (183,183 people), Edwards BFZ (17,795 people), Trinity (877 people), and Hueco-Mesilla Bolson (708 people) (

Table 17). Minor aquifers include the Woodbine (3,312 people) (Table 18). There were no systems identified as having serious violations.

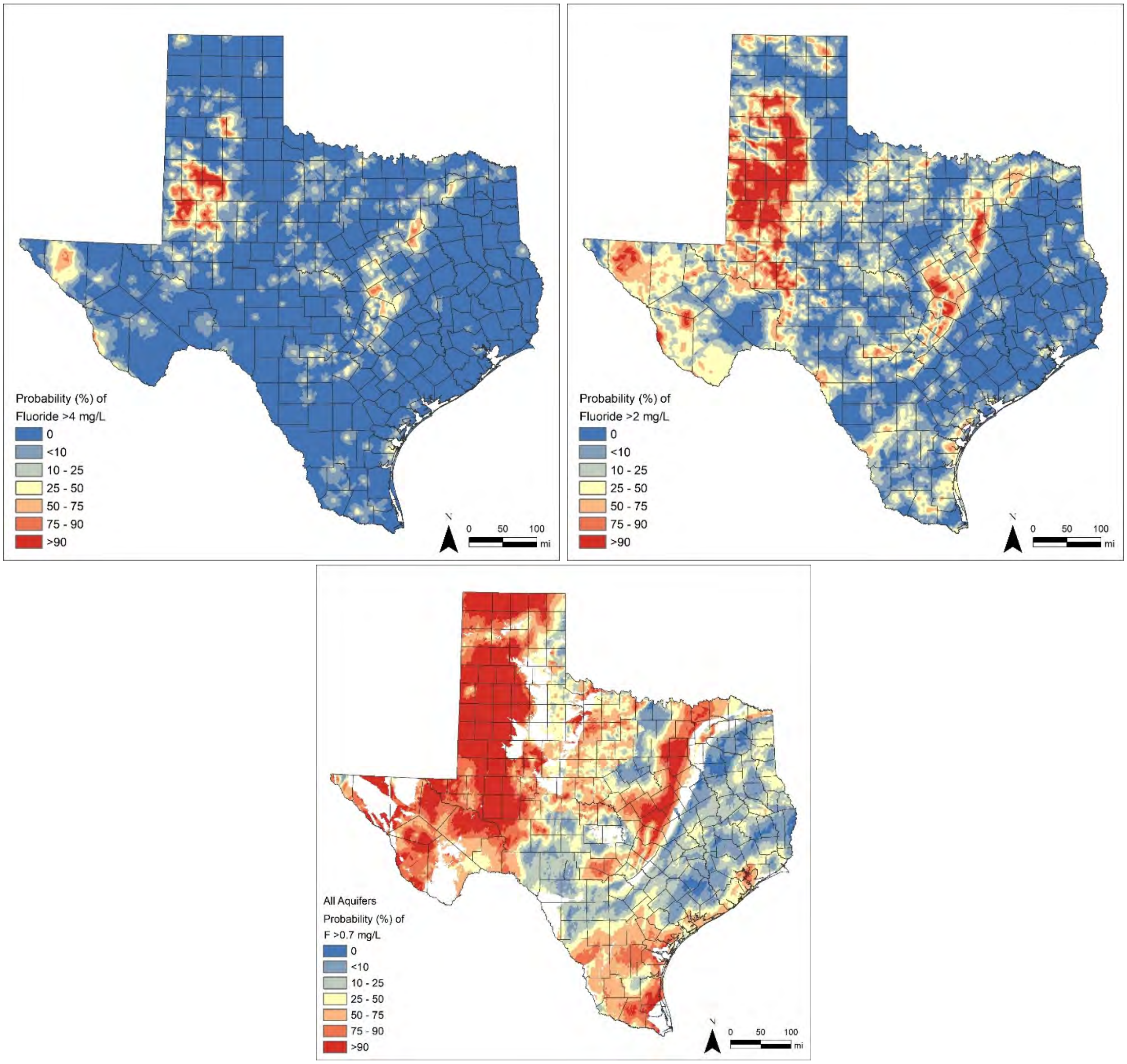

Figure 12. Statewide probability of groundwater fluoride a) >4 mg/L, b) >2 mg/L, and c) >0.7 mg/L based on the latest concentration data by well from the original study (1929 – 2019), including 39,466 samples TWDB data. The images are a composite of data from all named major and minor aquifers in the state, with results for major aquifers shown where they may locally overlie minor aquifers.

Table 17. Numbers of major aquifer PWSs with fluoride concentrations greater than the secondary MCL (>2 mg/L) and greater than the primary MCL (>4 mg/L). The populations shown are those associated with Community Water Systems (CWSs). The numbers of non-community water systems are also shown.

Aquifer	*TCEQ Database CWS Systems Fluoride >2 mg/L*			*EPA Non-compliant CWS Systems Fluoride >4 mg/L*	
	Number of NCWS	*CWS*	*CWS At-risk Population*	*CWS*	*Population*
Carrizo-Wilcox	-	7	11,876	-	-
Edwards BFZ	4	18	207,024	1	10,949
Edwards-Trinity Plateau	11	8	11,868	-	-
Gulf Coast	10	35	160,693	-	-
Hueco-Mesilla Bolson	1	1	708	1	849
Ogallala	38	94	292,928	29	25,580
Pecos Valley	1	3	8,906	-	-
Trinity	55	78	292,068	2	215
Total Major Aquifers	120	244	986,071	41	36,834
Percent of 2020 population			3.43		0.13

Table 18. Numbers of minor aquifer PWSs with fluoride concentrations greater than nominal background (>2 mg/L) and greater than the MCL (>4 mg/L) The populations shown are those associated with community water systems (CWSs). The numbers of non-community water systems (NCWSs) are also shown.

Aquifer	*TCEQ Database PWS Fluoride >2 mg/L*			*EPA Non-compliant CWS Fluoride >4 mg/L*	
	NCWS	*CWS*	*CWS At-risk Population*	*CWS*	*CWS Population*
Cross Timbers	1	-	-	-	-
Dockum	3	9	17,724	-	-
Edwards	2	1	25	-	-
Hickory	-	1	3,987	-	-
Igneous	4	5	10,282	-	-
Nacatoch	-	4	3,690	-	-
West Texas Bolson	-	2	2,833	-	-
Woodbine	-	16	44,226	1	90
Yegua-Jackson	-	1	332	-	-
Other	12	9	3,717	-	-
Total Minor Aquifers	22	48	86,816	1	90

Based on the aquifer GIS analyses coupled with the USGS county water use population data for 2015, an estimated total of 77,921 people, representing about 0.27% of the estimated 2020 Texas total population (29,146,000), are served by non-PWSs with fluoride concentrations above the 4 mg/L MCL threshold (Table 19). As with the PWSs, these are predominantly major aquifer non-PWSs (73%, 57,269 people), with generally smaller populations associated with minor aquifer systems (27%, 20,652 people). Thus, the Texas population served by either PWS or non-PWSs with fluoride concentrations above the MCL is estimated at about 115,604 people, representing about 0.40% of the 2020 Texas total population.

A total of 293 PWS had fluoride levels greater than the SMCL of 2 mg/L, more than eight times greater than the 34 PWSs exceeding 4 mg/L. Most (83%) of the SMCL PWS violations (244) are sourced from major aquifers. The population served by these SMCL noncompliant PWSs is ~ 1 million people, ~ 3.4% of the estimated 2020 population. A total of 309,000 people outside of the PWSs have water sources that exceed the SMCL of 2 mg/L, 72% sourced from major aquifers. Based on the TCEQ database and the rural supply analysis, a total of 1,384,271 people (about 4.74% of the estimated 2020 Texas total population) have water with fluoride concentrations above the secondary MCL of 2 mg/L (this includes the MCL violations). Again, most (88%) represent water sourced from one of the major aquifers while the remaining 12% are sourced from minor aquifers.

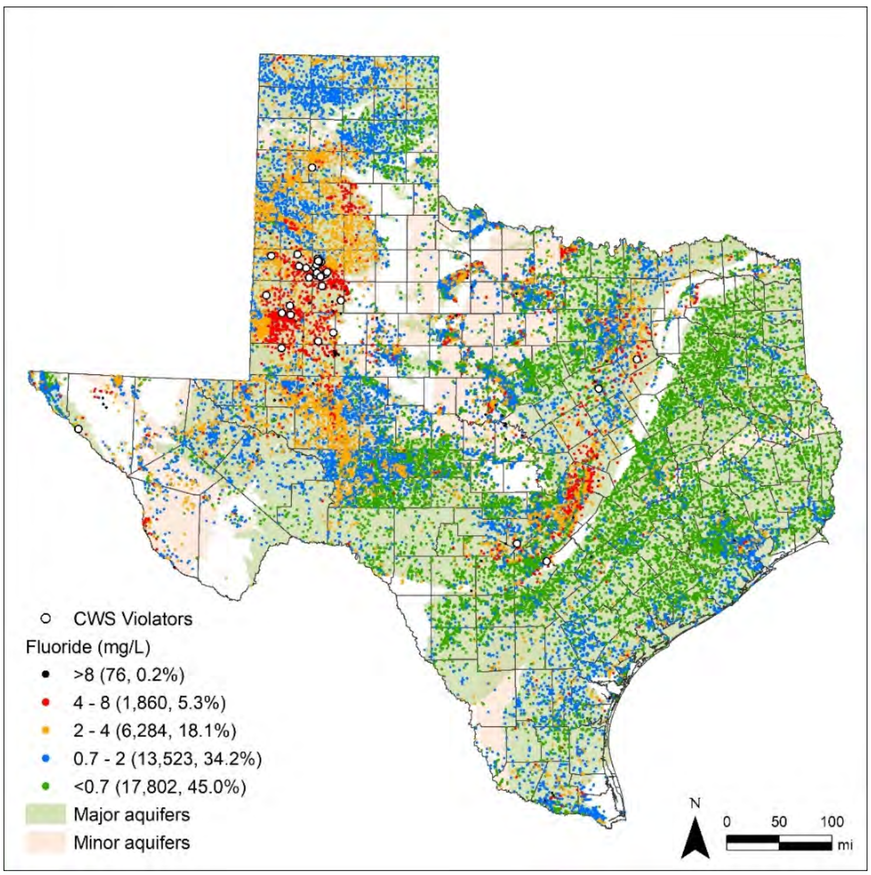

Figure 13. Locations of 34 community water systems that have health-based non-compliance violations for fluoride concentrations in distributed water based on the EPA SDWIS database (12 quarters, Jan 2018 – Dec 2020). The violating systems are located primarily in the southern Ogallala, Trinity, Edwards BFZ, and Woodbine aquifers.

Table 19. Texas populations served by PWS (community water systems) and non-PWSs with fluoride (F) concentrations >2 mg/L and >4 mg/L MCL. The percent of the 2020 US Census population is also provided (29,146,000 people).

Water Source	*CWS population*		*Non-PWS population*		*PWS & Non-PWS population*	
	F >2 mgl/L	*F >4 mg/L*	*F >2 mgl/L*	*F >4 mg/L*	*F >2 mgl/L*	*F >4 mg/L*
All Major Aquifers	986,071	37,593	223,904	57,269	1,209,975	94,103
All Minor Aquifers	86,816	90	85,063	20,652	171,879	20,742
Total	1,072,887	37,683	308,967	77,921	1,381,854	114,845
% of 2020 pop.	3.68	0.13	1.06	0.27	4.74	0.39

Major Aquifers Results

There were sufficient data to perform indicator kriging on fluoride concentrations for all nine of the major aquifers in Texas. There were 31,548 samples in the major aquifers, representing 80% of all TWDB samples included in this study (Table 15). Of the major aquifer samples, 98% (30,969) had detectable concentrations while only 2% (579) had non-detectable concentrations (<1 mg/L or lower). A total of 20% (6,360) of the major aquifer samples exceeded the threshold fluoride concentration of 2 mg/L and 4.9% (1,535) samples exceeded the MCL of 4 mg/L. All of the major aquifers had at least five samples with fluoride >4 mg/L. Median detected fluoride concentrations ranged from 0.3 mg/L in the Carrizo-Wilcox and Edwards BFZ aquifers to 2.11 mg/L in the Ogallala aquifer (Table 20). Median detected concentrations were ≤2 mg/L in all but the Ogallala aquifer.

Table 20. Distributions of fluoride concentrations above detection limits for the major aquifer samples in Texas. Values are based on the latest samples from the TWDB groundwater database and samples from wells completed in multiple aquifers were excluded.

Major Aquifer	*Samples*	*Mean (mg/L)*	*Percentile (mg/L)*								
			Min	*0.05*	*0.1*	*0.25*	*0.50*	*0.75*	*0.90*	*0.95*	*Max*
Carrizo-Wilcox	3,675	0.41	0.01	0.10	0.10	0.20	0.30	0.50	0.80	1.20	9.60
Edwards BFZ	1,369	0.97	0.02	0.10	0.11	0.19	0.30	1.00	3.20	4.10	11.20
Edwards-Trinity Plateau	4,878	1.26	0.01	0.20	0.30	0.50	1.00	1.90	2.69	3.00	9.63
Gulf Coast	6,174	0.78	0.01	0.10	0.20	0.30	0.50	0.90	1.49	2.00	350.00
Hueco-Mesilla Bolson	567	0.92	0.01	0.38	0.40	0.57	0.70	1.00	1.60	2.18	6.10
Ogallala	6,123	2.52	0.01	0.50	0.80	1.35	2.11	3.47	4.80	5.30	16.00
Pecos Valley	552	1.80	0.08	0.40	0.70	1.02	1.66	2.20	2.80	3.20	38.70
Seymour	2,081	1.25	0.02	0.30	0.40	0.70	1.00	1.60	2.22	2.90	9.80
Trinity	5,550	1.20	0.01	0.18	0.20	0.35	0.76	1.67	2.80	3.80	12.70
Total	30,969										

The TCEQ database lists 7,065 active PWSs in Texas, including 4,657 community water systems and 1,533 non-community water systems. During the period Jan 2017 – Jun 2017, a total of 363 systems (5.1%) with distribution water derived at least in part from one of the major aquifers had fluoride >2 mg/L. This includes 244 community water systems and 120 non-community water systems with an associated population of about 1 million people (Table 17).

Based on the EPA database, 41 community water systems had non-compliant water samples with fluoride >4 mg/L in major aquifers, with a total associated population of about 200,000 people (Table 17). The most affected populations are located in the Southern High Plains area (Ogallala aquifer, 34 CWSs with 183,183 people), and in parts of Williamson and Bell counties (Edwards BFZ aquifer, 2 systems with 17,795 people).

Table 21. Estimated non-PWS populations at risk of groundwater fluoride concentrations >2 mg/L and >4 mg/L US EPA MCL in the Major Aquifers. The populations shown are estimated from the GIS map mean county-by-county probability multiplied by the estimated non-PWS population.

Aquifer	*Total Non-PWS Population*	*At-risk Population >2 mg/L*	*At-risk Population >2 mg/L % of Total*	*At-risk Population >4 mg/L*	*At-risk Population >4 mg/L % of Total*
Carrizo-Wilcox	332,651	5,585	1.68	217	0.07
Edwards	188,446	4,992	2.65	1,445	0.77
Edwards-Trinity Plateau	152,877	17,456	11.42	586	0.38
Gulf Coast	449,786	9,219	2.05	1,249	0.28
Hueco-Mesilla Bolson	16,413	1,846	11.25	171	1.04
Ogallala	154,377	82,880	53.69	32,837	21.27
Pecos Valley	36,571	4,901	13.40	466	1.27
Seymour	19,727	800	4.05	146	0.74
Trinity	486,408	96,225	19.78	20,152	4.14
Total Major Aquifers	1,837,256	223,904	12.19	57,269	3.12
Percent of 2020 population	6.14	0.75		0.19	

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 1, Figure 14). 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 3,985 samples analyzed for fluoride with only 310 samples (7.8%) having non-detectable concentrations. The probability of fluoride exceeding 2 mg/L is zero over most (72%) of the aquifer area with only (18%) of the aquifer area primarily in south and south-central Texas down-dip reaches having a generally low to moderate probability of fluoride >2 mg/L with the highest probability region in the extreme south end of the aquifer. The median concentration of samples with detectable concentrations is 0.3 mg/L and the 5th-95th percentile range is 0.1–1.2 mg/L. Only four samples exceeded the MCL with a concentration of 4 mg/L.

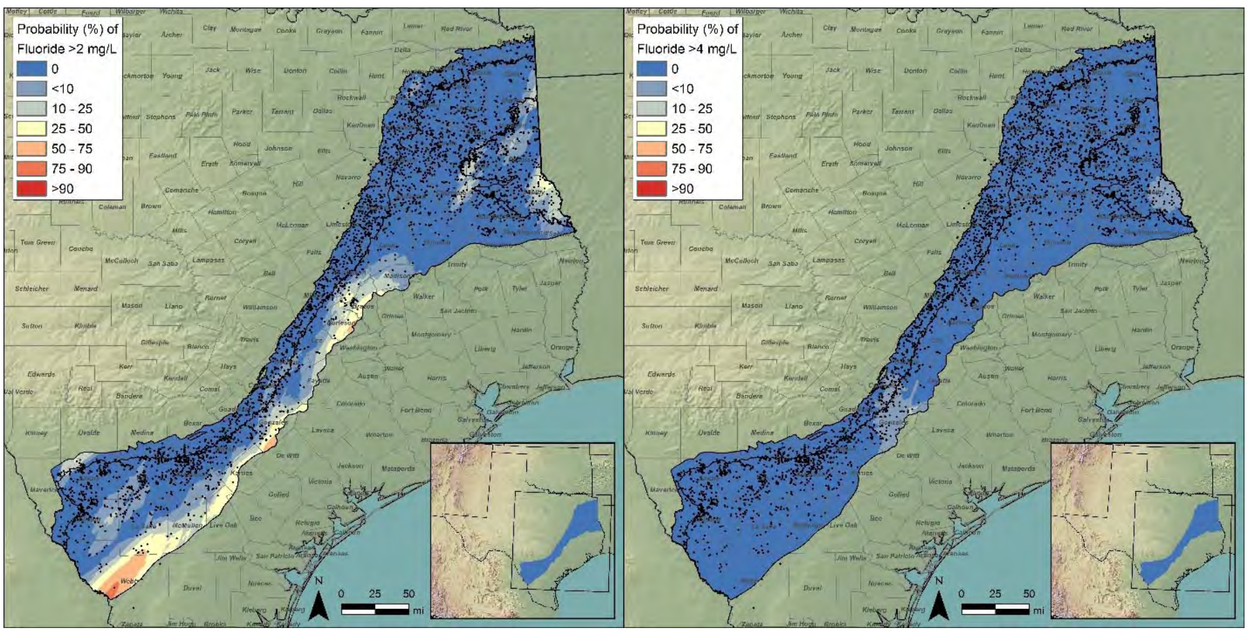

Figure 14. Carrizo-Wilcox aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 7 PWSs had fluoride concentrations >2 mg/L, all of which are community water systems, with a population of 11,876 people. Based on the EPA PWS database, there were no community water systems that were non-compliant for fluoride. The non-PWSs at-risk population of > 4 mg/L fluoride is very low at 217, located in southern Maverick County along the international border with Mexico and along the extreme down-dip extents.

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 1, Figure 15). 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 1,418 samples analyzed for fluoride during the study period with only 49 samples (3.5%) having non-detectable concentrations. Most (82%) of the aquifer area has no probability of fluoride >2 mg/L with 14% of the area having low to moderate and 2% having elevated probabilities in the down-dip edges in confined regions of the aquifer. The median concentration of samples with detectable concentrations is 0.3 mg/L and the 5th-9th percentile range is 0.1–4.1 µg/L. A total of 70 samples (4.9%) exceeded the MCL with a range of concentrations from 4.1 to 11.2 mg/L, mostly in the far down-dip regions in the north.

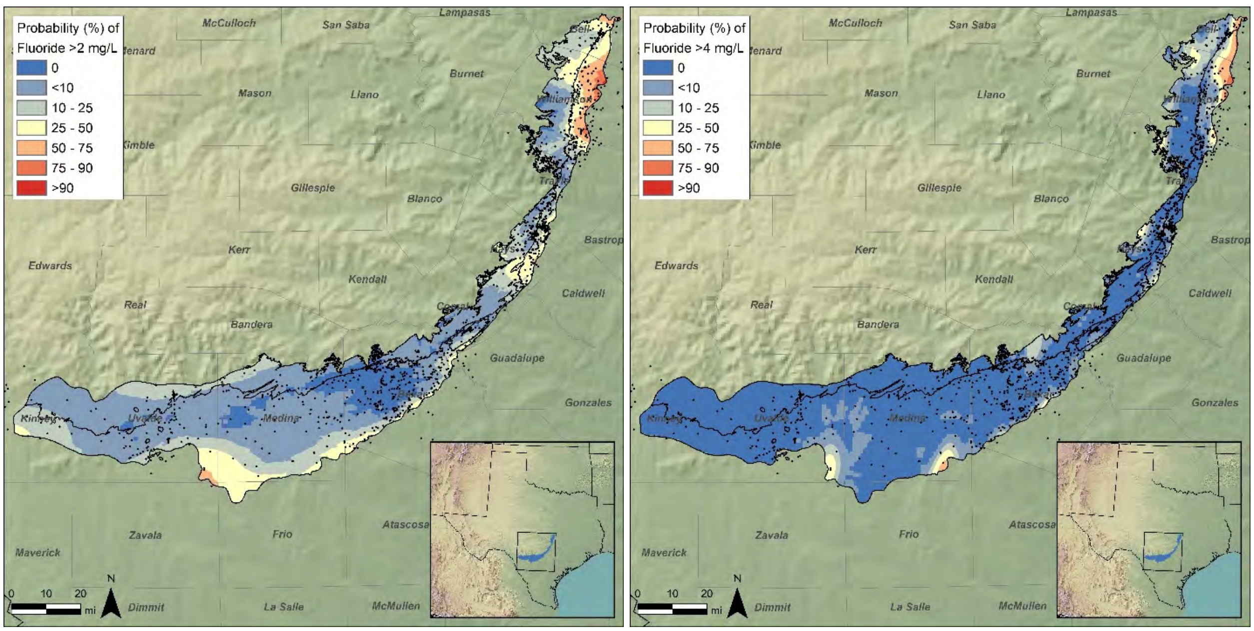

Figure 15. Edwards (BFZ) aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Table 22. Edwards (BFZ) aquifer PWSs with violations for fluoride concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
0150115	JBSA – Randolph	CWS	GW	1	1-2018	10,949

Based on the TCEQ PWS database, a total of 22 PWSs are impacted by fluoride concentrations >2 mg/L, including 18 community water systems and 4 non-community water systems. The community water systems are associated with an estimated population of 207,024 people. Based on the EPA PWS database, there are 2 community water systems that are non-compliant for fluoride (Table 22). The non-PWS at-risk population of fluoride >4 mg/L is 1,445 people located primarily in the furthest down-dip areas of the aquifer in Williamson, Bell, and Medina 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 1, Figure 16). 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 4,913 samples analyzed for fluoride with 35 samples (0.7%) having non-detectable concentrations. About 73% of the aquifer area has no to moderate probability of fluoride >2 mg/L. About 22% of the area has elevated to high probability and 5% has high to very high probability, primarily located in a north-south trending band through the middle of the aquifer. The median concentration of samples with detectable concentrations is 1.0 mg/L and the 5th-9th percentile range is 0.2–3.0 mg/L. A total of 27 samples (0.5%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 9.6 mg/L that are located in generally isolated areas.

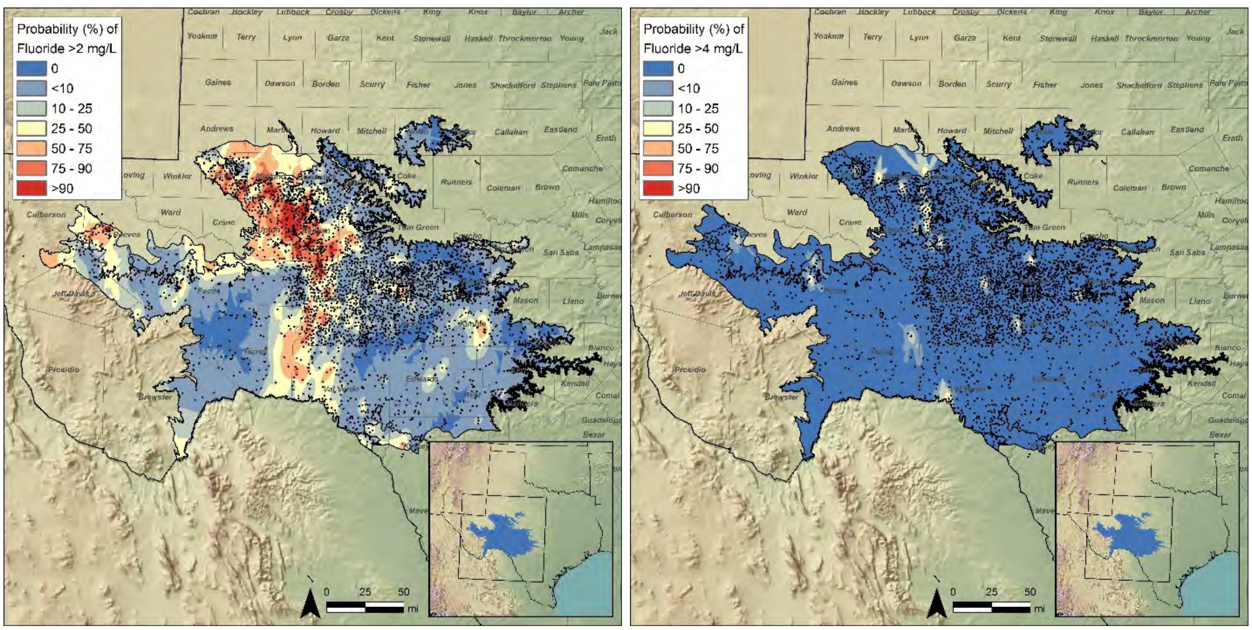

Figure 16. Edwards-Trinity Plateau aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 19 PWSs are impacted by fluoride concentrations >2 mg/L, including 11 non-community water systems and 8 community water systems with a population of 11,868 people. Based on the EPA PWS database, there no community PWSs impacted by fluoride concentrations >4 mg/L. The estimated non-PWS at-risk population of fluoride >4 mg/L is 586 people.

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 1, Figure 17). 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 6,371 samples analyzed for fluoride during the study period with 197 samples (3.1%) having non-detectable concentrations. Fluoride occurrence in the Gulf Coast aquifer is generally located in the south and near the coast, with isolated inland areas in the north. About 81% of the aquifer area has no to very low probability of fluoride >2 mg/L and a further 18% with low to moderate probability. Only about 1% of the aquifer has probabilities that exceed 50%. The median of samples with detectable concentrations is 0.5 mg/L and the 5^{th}-9^{th} percentile range is 0.1–2.0 mg/L. A total of 30 samples (0.5%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 30 mg/L.

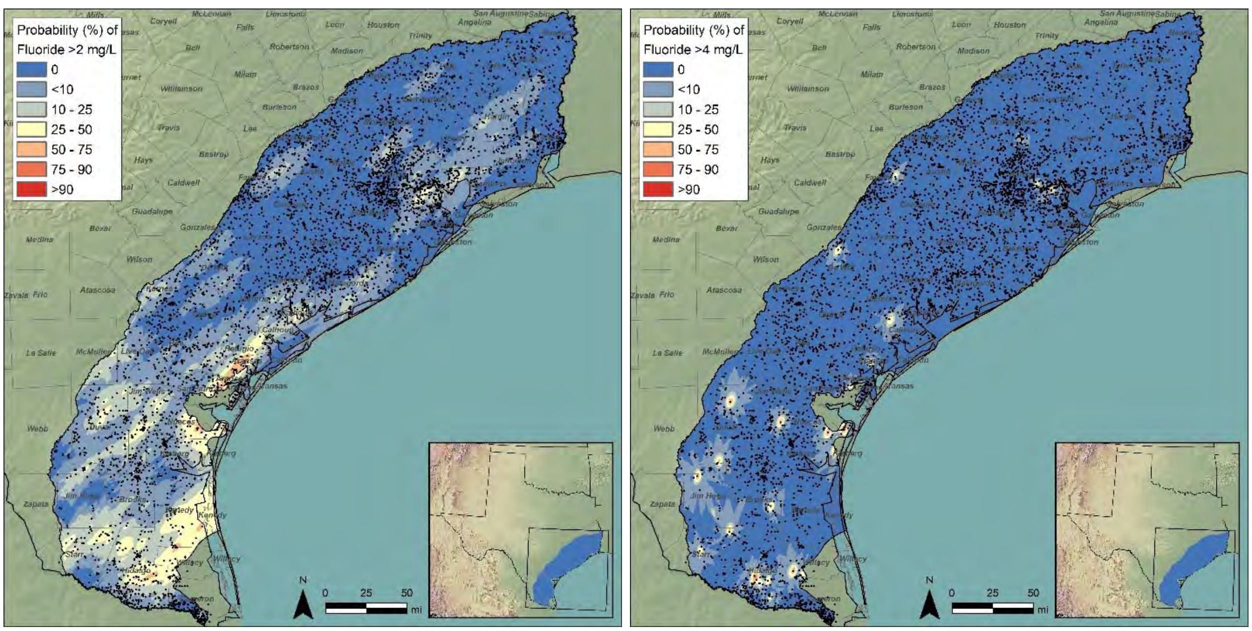

Figure 17. Gulf Coast aquifer system probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 44 PWSs are impacted by fluoride concentrations >2 mg/L, including 10 non-community water systems and 35 community water systems with a population of 160,693 people. Based on the US EPA database, there are no PWSs that are impacted by fluoride concentrations >4 mg/L. The non-PWSs at-risk population of fluoride >4 mg/L is 1,249 located primarily in isolated areas of the southern part of the aquifer.

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 1, Figure 18). 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 580 samples analyzed for fluoride during the study period with 13 samples (2.2%) having non-detectable concentrations. The Hueco-Mesilla Bolson aquifer is poorly sampled in its southern reaches in Hudspeth County, but available samples indicate that fluoride concentrations tend to increase toward the south. Only about 34% of the area has no to very low probability of fluoride >2 mg/L. About 38% of the total aquifer area has elevated to very high probabilities of fluoride >2 mg/L. The median concentration of samples with detectable concentrations is 0.7 mg/L and the 5th-9th percentile range is 0.38–2.18 µg/L. A total of 6 samples (1%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 6.1 mg/L.

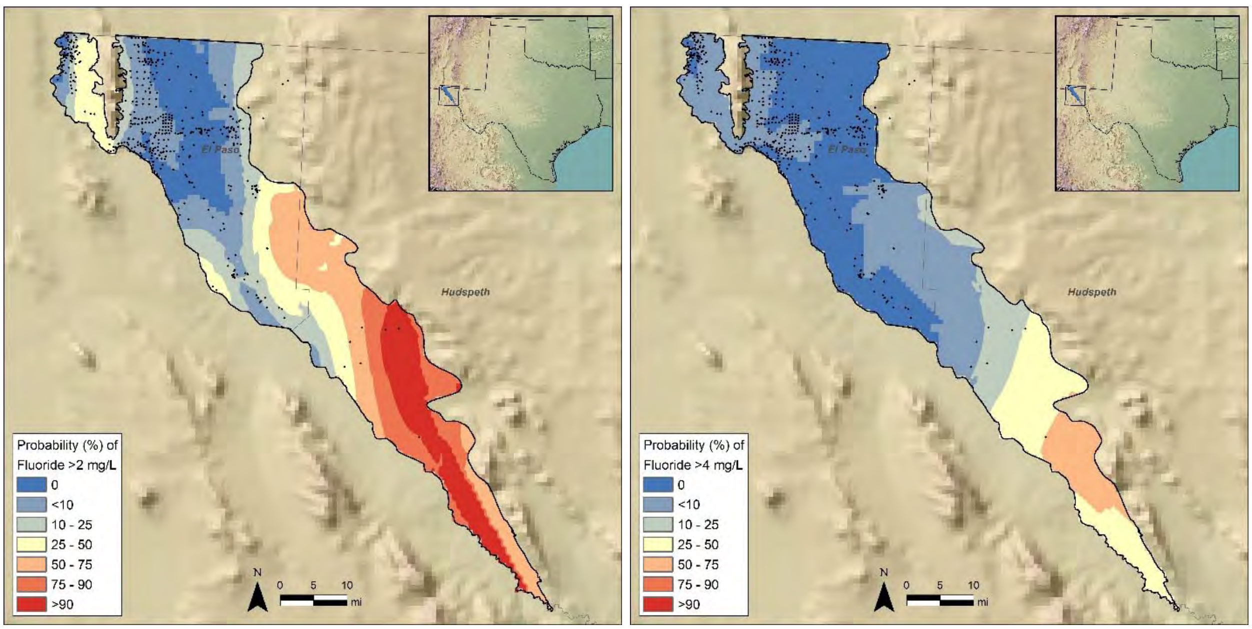

Figure 18. Hueco-Mesilla Bolson aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 2 PWSs are impacted by fluoride concentrations >2 mg/L, including 1 non-community water system and 1 community water system with a population of 708 people. Based on the EPA PWS database, there is 1 community system impacted by fluoride concentrations >4 mg/L (Table 23). The non-PWSs at-risk population of fluoride >4 mg/L is low at 171 people located primarily in Hudspeth County.

Table 23. Hueco-Mesilla Bolson aquifer PWS systems with violations for fluoride concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
1150010	Esperanza Water Service	CWS.	GW	9	3-2020	849

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 1, Figure 19). 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 6,163 samples analyzed for fluoride during the study period with 40 samples (0.6%) having non-detectable concentrations. Fluoride occurrence is widespread in the Ogallala aquifer and concentrations are notably higher in the southern areas. About 17% of the area has no to very low probability of fluoride >2 mg/L and a further 31% has low to moderate probability. About 20% of the total aquifer area has elevated to high probabilities and fully 28% of the aquifer area has a very high probability. The median concentration of samples with detectable concentrations is 2.11 mg/L and the 5th-9th percentile range is 0.5–5.3 mg/L. A total of 1,134 samples (18.4%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 16 mg/L.

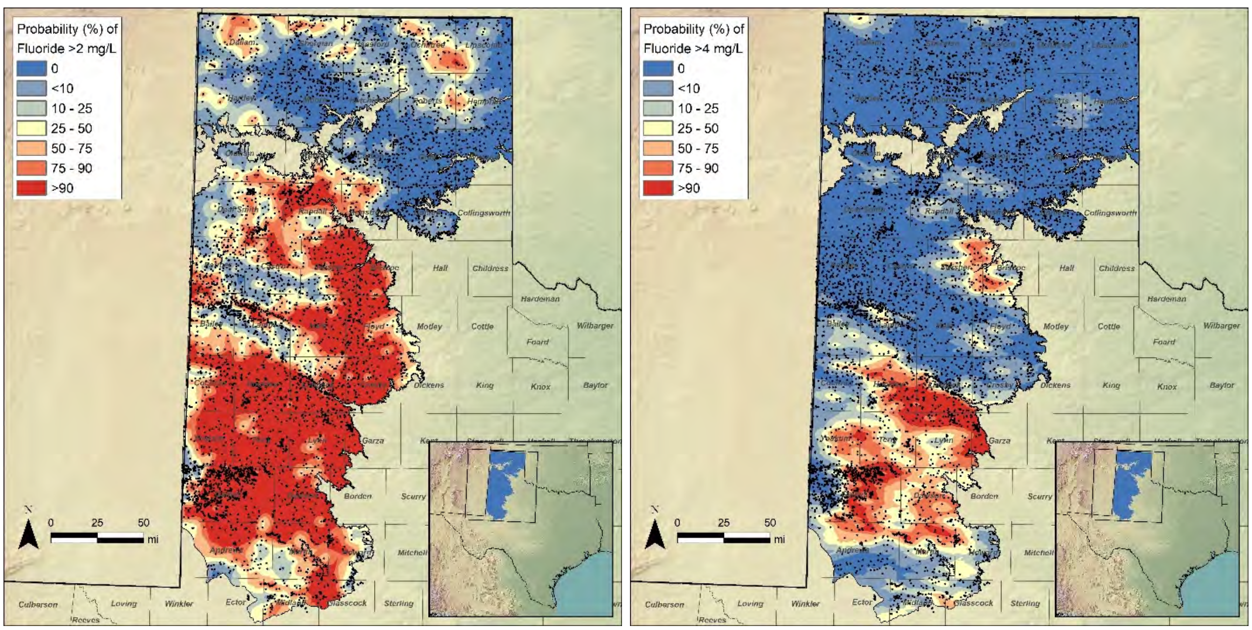

Figure 19. Ogallala aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 132 PWSs are impacted by fluoride concentrations >2 mg/L, including 38 non-community water systems and 94 community water systems with a population of 292,928 people. Based on the EPA PWS database, there are a total of 29 community systems that are impacted by fluoride concentrations >4 mg/L with a total population of 25,580 people (Table 24). The non-PWS at-risk population of fluoride >4 mg/L is the highest in the state at 32,837 located primarily in the areas of the aquifer south of Lubbock.

Table 24a. Ogallala aquifer CWSs with MCL violations for fluoride concentrations based on the US EPA database (Jan 2018-Dec 2020, 12 quarters). Persistence of violations is shown by number of quarters with violations out of a total of 12 quarters (2018 – 2020). All of the listed systems use groundwater as their primary source. Co-contaminants include: none, Arsenic (As), Selenium (Se), Nitrate (NO3), and Uranium (U).

PWS ID	*Name*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*	*Co-contaminants*
TX0020001	City of Andrews	1	1-2019	14,109	As
TX0170010	Borden County WS	12	4-2020	300	As
TX0400001	City of Morton	3	3-2018	2,006	As
TX0580025	Klondike ISD	4	4-2018	264	As, NO3, U
TX0830001	City of Seagraves	12	4-2020	2,417	As
TX0830011	Loop WSC	1	1-2018	300	As
TX1100004	City of Ropesville	12	4-2020	428	none
TX1100010	City of Smyer	12	4-2020	474	As
TX1100011	Whitharral WSC	4	4-2018	200	NO3
TX1100030	City of Opdyke West	6	2-2019	376	As
TX1520039	Lubbock MH Community	12	4-2020	81	As, U
TX1520062	Plott Acres	11	2-2019	204	none
TX1520064	Ft Jackson Mobile Estates	12	4-2020	72	U
TX1520067	114th St MHP	9	1-2020	125	none
TX1520094	Town North Village WS	4	2-2018	360	As, Se
TX1520106	Cox Addition WS	5	4-2020	114	none
TX1520149	Stormlight MHP	12	4-2020	54	As
TX1520152	Town North Estates	4	3-2020	216	As, U
TX1520188	Seven Estates	12	4-2020	260	none
TX1520192	Terrells MHP	12	4-2020	60	As
TX1520198	Valley Estates	12	4-2020	70	As Se, U
TX1520199	Wolfforth Place	12	4-2020	400	As
TX1520217	Southwest Garden Water	12	4-2020	375	none
TX1520247	Country View MHP	12	4-2020	54	As, U
TX1530004	City of New Home	11	4-2020	345	none
TX1530005	Grassland WSC	11	4-2020	55	As, NO3
TX1910024	Umbarger Community WS	2	2-2018	180	none
TX2230003	City of Wellman	12	4-2020	200	As
TX2510002	City of Plains	6	3-2020	1,481	As

Quarters: number of quarters with violations in the 14-quarter period from Jan 2018 to Dec 2020.

Table 24b. Ogallala aquifer Non-CWS PWSs with MCL violations for fluoride concentrations based on the US EPA database (Jan 2017-Jun2020). All of the listed systems use groundwater as their primary source.

PWS ID	*Name*	*System Type*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*
TX0850002	Southland ISD	NTNC	12	2020-4
TX1100040	Worley Welding Works	NTNC	4	2018-4
TX1520147	Short Road Water Supply	NTNC	12	2020-4
TX1520241	Managed Care Center	NTNC	6	2019-2
TX1520250	Scott Manufacturing	NTNC	12	2020-4
TX1520265	Cash Register Services	NTNC	12	2020-4
TX1520279	1585 & Frankford Discount RV Storage	NTNC	12	2020-4
TX1520301	TEGA Kids Superplex	NTNC	12	2020-4
TX2510023	Wasson CO2 Recovery Plant	NTNC	6	2019-2

System Type: Non-Transient non-community (NTNC)

Primary Source: Groundwater (GW)

Quarters: number of quarters with violations in the 12-quarter period from Jan 2018 to Dec 2020.

Pecos Valley Aquifer

The Pecos Valley aquifer covers 6,800 mi^2 extending across parts of 12 counties in west Texas (Figure 1, Figure 20). 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 556 samples analyzed for fluoride during the study period with 4 samples (0.7%) having non-detectable concentrations. Elevated fluoride concentrations are wide spread in the eastern half of the Pecos Valley Aquifer. About 19% of the area has no or very low probability of fluoride >2 mg/L and a further 47% has low to moderate probability. About 32% of the total aquifer area has elevated to high probabilities and 2% very high probabilities. The spatial pattern of probabilities displays artifacts of limited data density in some areas. The median concentration of samples with detectable concentrations is 1.66 mg/L and the 5^{th}-9^{th} percentile range is 0.4–3.2 mg/L. A total of 14 samples (2.5%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 38 mg/L.

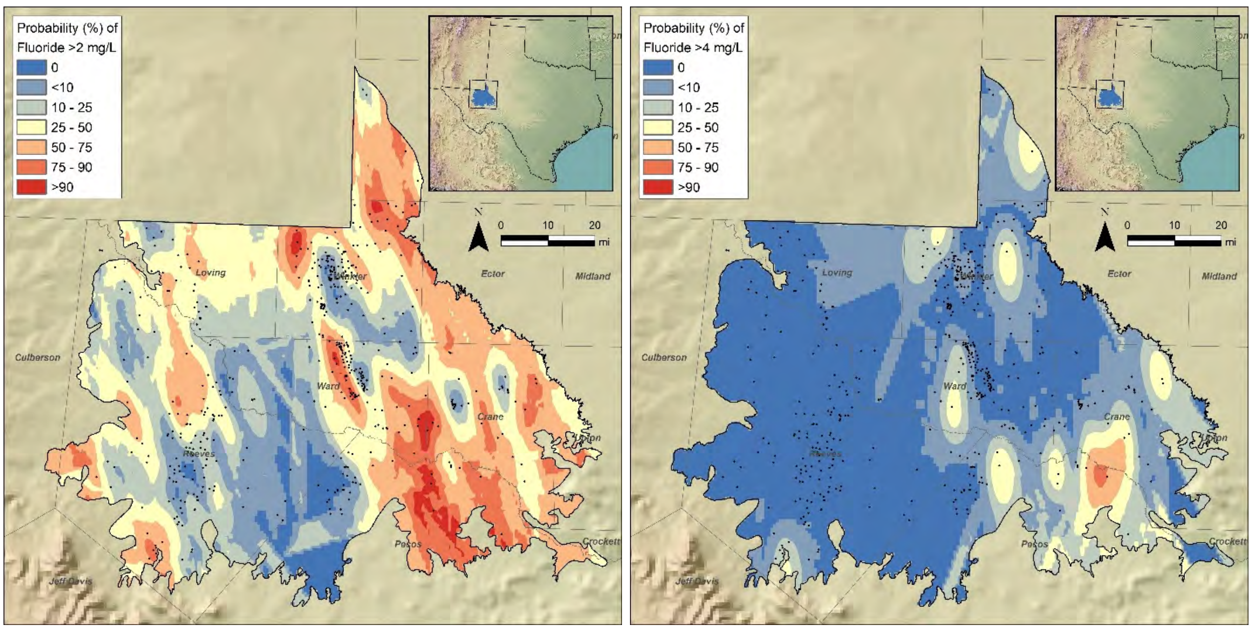

Figure 20. Pecos Valley aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 4 PWSs are impacted by fluoride concentrations >2 mg/L, including 1 non-community water system and 3 community water systems with a population of 8,906 people. Based on the EPA PWS database, there are no PWSs impacted by fluoride concentrations >4 mg/L. The non-PWS at-risk population of fluoride >4 mg/L is low at 466 located primarily in the eastern half of the aquifer.

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 1, Figure 21). 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 2,091 samples analyzed for fluoride with 10 samples (0.5%) having non-detectable concentrations. About 63% of the area has no or very low probability of fluoride >2 mg/L and a further 33% has low to moderate probability of. Only about 4% of the total aquifer area has elevated to high probabilities of fluoride >2 mg/L. The spatial pattern of probabilities displays artifacts of limited data density, particularly in some areas with the higher concentrations in the south in the Fisher-Jones county area. The median concentration of samples with detectable concentrations is 1.0 mg/L and the 5th-9th percentile range is 0.3–2.9 mg/L. A total of 35 samples (1.7%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 9.8 mg/L.

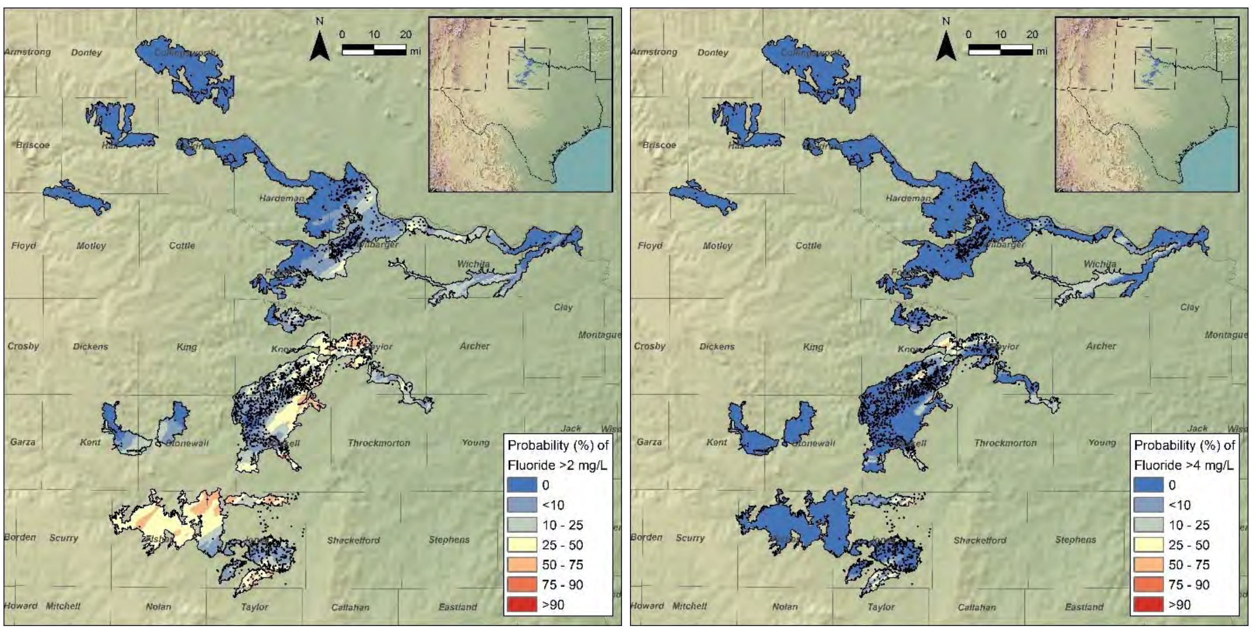

Figure 21. Seymour aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, no public supply distribution systems are impacted by fluoride concentrations >2 mg/L. Based on the EPA PWS database, there are no PWSs that are impacted by fluoride concentrations >4 mg/L. The non-PWS at-risk population of >4 mg/L is very low at 146 located primarily in the southern aquifer pods. However, samples are sparse in most of the highest probability areas and the results may not be reliable.

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 1, Figure 22). 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 5,624 samples analyzed for fluoride during the study period with 74 samples (1.3%) having non-detectable concentrations. About 35% of the area has no to very low probability of fluoride >2 mg/L and a further 48% has low to moderate probability. Only about 18% of the total aquifer area has elevated to high probabilities and 1% with very high probability. The spatial pattern of probabilities displays artifacts of limited data density in the down-dip confined areas of both the far north and south areas. The median concentration of samples with detectable concentrations is 0.76 mg/L and the 5^{th}-9^{th} percentile range is 0.18–3.8 mg/L. A total of 213 samples (3.8%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 12.7 mg/L.

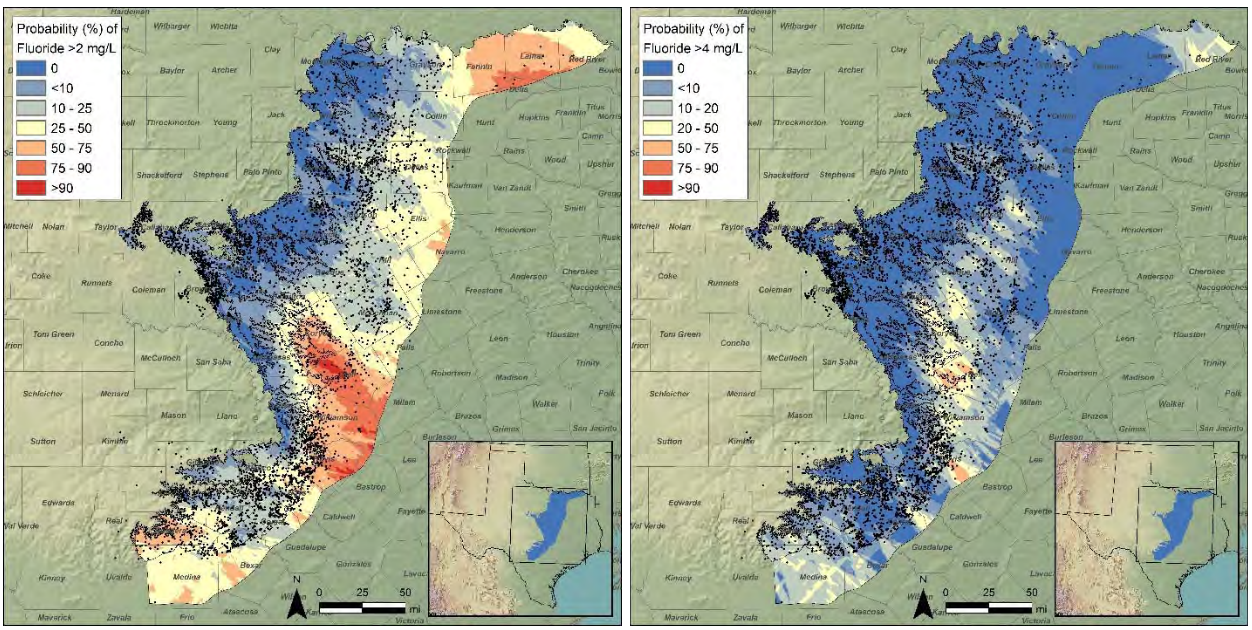

Figure 22. Trinity aquifer probability distribution of fluoride >2 mg/L (left) and >4 µg/L (right).

Based on the TCEQ PWS database, a total of 133 public supply systems are impacted by fluoride concentrations >2 mg/L, including 55 non-community water systems and 78 community water systems with a population of 292,068 people. Based on the EPA PWS database, there are 2 community water supply systems that are impacted by fluoride concentrations >4 mg/L with a population of 215 people (Table 25). The non-PWS at-risk population of fluoride >4 m/L is the second highest in the state at 20,152 located primarily in Bell, Coryell, and Travis counties.

Table 25. Trinity aquifer CWSs with violations for fluoride concentrations based on the US EPA database. All of the listed systems use groundwater as their primary source. (Based on SDWIS Database).

PWS ID	*Name*	*System Type*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Pop. Served*
0180041	Shuler Point	CWS	1	4-2019	33
1300008	Foothills MH Ranch	CWS	7	4-2020	182

System Type: Community water system (CWS)

Quarters: number of quarters with violations in the 12-quarter period from Jan 2018 to Dec 2020.

Minor Aquifer Results

Indicator kriging of fluoride concentrations was performed for ten of the minor aquifers in Texas. Maps were not generated for the remaining ten minor aquifers because they had either <50 data points, very low percentages of samples exceeding the threshold values, or very poor spatial coverage (Table 16). Data for the minor aquifers represent 7,918 samples, representing 20% of all samples included in this study. Of all the minor aquifer samples, 96% (7,599) had detectable concentrations while only 4% (319) had non-detectable concentrations (). A total of 16% (1,250) of all the minor aquifer samples exceeded the 2 mg/L threshold and 3.3% (263) of samples exceeded the MCL of 4 mg/L. Seventeen of the minor aquifers had at least one sample with fluoride >4 mg/L, though six of these had only 1 or 2 such samples. Median detected fluoride concentrations ranged from 0.2 mg/L in the Queen City aquifer to 4.1 mg/L in the Edwards-Trinity High Plains aquifer (Table 26).

Table 26. Distributions of detected fluoride concentrations for the minor aquifer samples in Texas. Values are based on the latest samples from the TWDB groundwater database. Samples from wells completed in multiple aquifers are not included.

Minor Aquifer	*Detect Samples*	*Mean (mg/L)*	*Percentile (mg/L)*								
			Min	*0.05*	*0.1*	*0.25*	*0.50*	*0.75*	*0.90*	*0.95*	*Max*
Blaine	190	0.71	0.05	0.21	0.30	0.46	0.66	0.82	1.20	1.60	2.75
Blossom	63	0.81	0.10	0.10	0.20	0.30	0.60	0.90	2.10	2.60	3.10
Bone Spring - Victorio Peak	155	2.27	0.50	1.12	1.26	1.60	1.90	2.40	3.00	5.28	9.00
Brazos River Alluvium	256	0.37	0.05	0.18	0.20	0.27	0.30	0.40	0.50	0.61	3.00
Capitan Reef Complex	59	1.35	0.10	0.19	0.30	0.78	1.10	1.93	2.51	2.94	4.12
Cross Timbers	2,246	1.18	0.10	0.20	0.30	0.40	0.80	1.50	2.70	3.60	22.00
Dockum	824	1.77	0.10	0.40	0.59	0.98	1.50	2.30	3.09	3.78	10.00
Edwards-Trinity HP	71	4.05	1.00	1.83	2.00	2.58	4.10	5.10	6.00	6.75	10.00
Ellenburger - San Saba	287	0.80	0.04	0.10	0.10	0.20	0.45	0.78	1.67	2.40	11.10
Hickory	441	0.84	0.05	0.25	0.30	0.43	0.62	1.00	1.50	2.00	9.20
Igneous	198	1.58	0.10	0.37	0.50	0.81	1.40	2.20	2.92	3.31	4.90
Lipan	154	0.86	0.10	0.32	0.40	0.53	0.80	1.02	1.35	1.64	4.20
Marathon	33	1.16	0.40	0.44	0.49	0.80	1.00	1.29	1.93	2.08	4.20
Marble Falls	39	0.71	0.12	0.20	0.20	0.29	0.40	0.89	1.29	2.50	3.90
Nacatoch	193	1.28	0.01	0.17	0.20	0.40	0.78	1.80	3.20	4.28	5.80
Queen City	501	0.34	0.01	0.03	0.05	0.10	0.20	0.40	0.70	1.00	4.96
Rita Blanca	33	2.14	0.79	0.89	0.93	1.19	1.60	2.50	4.36	5.04	6.02
Rustler	42	1.84	0.08	0.40	0.81	1.34	2.00	2.42	2.70	2.80	2.87
Sparta	315	0.51	0.01	0.06	0.10	0.11	0.30	0.60	1.09	1.71	4.30
West Texas Bolson	224	2.04	0.29	0.57	0.71	1.20	1.72	2.25	3.84	5.05	10.00
Woodbine	716	1.58	0.06	0.24	0.30	0.60	1.20	2.20	3.50	4.40	6.10
Yegua-Jackson	559	0.51	0.02	0.10	0.10	0.20	0.40	0.60	1.00	1.40	5.00

Table 27. Estimated non-PWS at-risk populations with groundwater fluoride concentrations >2 mg/L and >4 mg/L in the Minor Aquifers. The populations shown are estimated from the GIS map mean county-by-county probability multiplied by the estimated non-PWS population.

Aquifer	*Total Population*	*At-risk Population >2 mg/L*	*At-risk Population >2 mg/L % of Total*	*At-risk Population >4 mg/L*	*At-risk Population >4 mg/L % of Total*
Bone Spring-Victorio Peak	155	12	7.90	2	1.44
Cross Timbers	110,253	4,690	4.25	547	0.50
Dockum*	121,810	40,402	33.17	12,340	10.13
Ellenburger-San Saba	64,279	1,224	1.90	439	0.68
Edwards-Trinity High Plains	65,240	29,237	44.81	7,010	10.75
Hickory	140,540	6,629	4.72	3,552	2.53
Igneous	10,722	316	2.95	13	0.12
Nacatoch	35,547	2,299	6.47	1,078	3.03
West Texas Bolsons	1,580	58	3.66	10	0.64
Woodbine	115,783	40,598	35.06	8,001	6.91
Minor Aquifers**	544,099	85,063	15.63	20,652	3.80
Percent of 2020 population	1.82	0.28		0.07	

* The Dockum mostly underlies the Ogallala in the study area and it is unlikely that domestic wells utilize the aquifer.

** Excludes Dockum values

Bone Spring – Victorio Peak

The Bone Spring - Victorio aquifer covers 710 mi^2 located in northern Hudspeth County (Figure 2, Figure 23). The aquifer consists of limestones of Permian age. Water quality is generally fair to poor with concentrations generally between 1,000 and 10,000 mg/L TDS.

There were 155 samples analyzed for fluoride with no samples having non-detectable fluoride concentrations. There were 62 samples (40%) with fluoride >2 mg/L and there were 12 samples (7.7%) that exceed the MCL. Most of the samples are clustered around the City of Dell Valley.

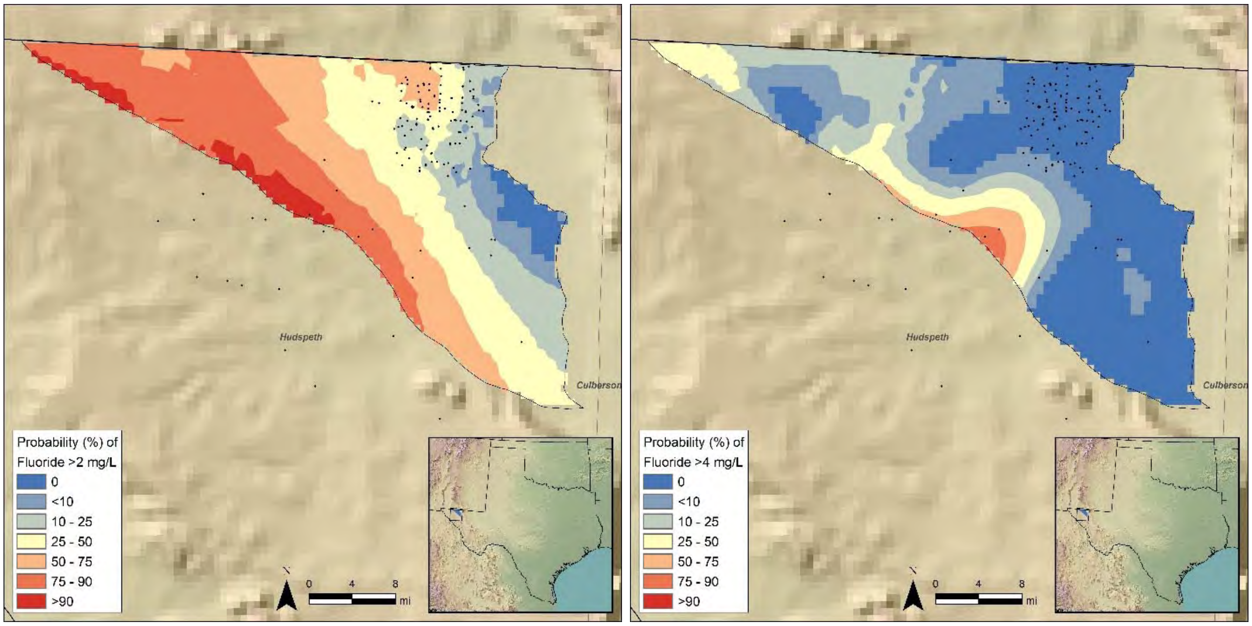

Figure 23. Bone Spring – Victorio Peak aquifer probability distributions of fluoride >2 mg/L (left) and of fluoride >4 mg/L (right).

There are no PWSs impacted by fluoride concentrations >2 ml/L and therefore no PWSs are impacted by fluoride concentrations >4 mg/L. The non-PWS at-risk population of fluoride >2 mg/L very small at 12, representing about 12% of the rural population.

Cross Timbers

The Cross Timbers aquifer covers 17,800 mi^2 located in north-central Texas (Figure 2, Figure 24). The aquifer consists of Paleozoic age limestone, shale, and sandstone units of the Strawn, Canyon, Cisco, and Wichita groups. Water quality is generally fair to poor with concentrations generally between 1,000 and 10,000 mg/L TDS.

There were 2,256 samples analyzed for fluoride with 2,246 samples (99.6%) having detectable concentrations and only 10 samples (0.4%) with non-detectable concentrations. About 48% of the area has no to very low probability of fluoride >2 mg/L and a further 50% has low to moderate probability. Only about 2% of the total aquifer area has elevated to high probabilities of fluoride >2 mg/L. The spatial pattern of probabilities displays artifacts limited data density in some regions while most of the samples form clusters throughout the aquifer. The occurrence of fluoride in the clustered areas might indicate a similar pattern in other areas of the aquifer that are less densely sampled. The median concentration of samples with detectable concentrations is 0.8 mg/L and the 5th-9th percentile range is 0.2–3.6 mg/L. A total of 70 samples (3.1%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 22 mg/L.

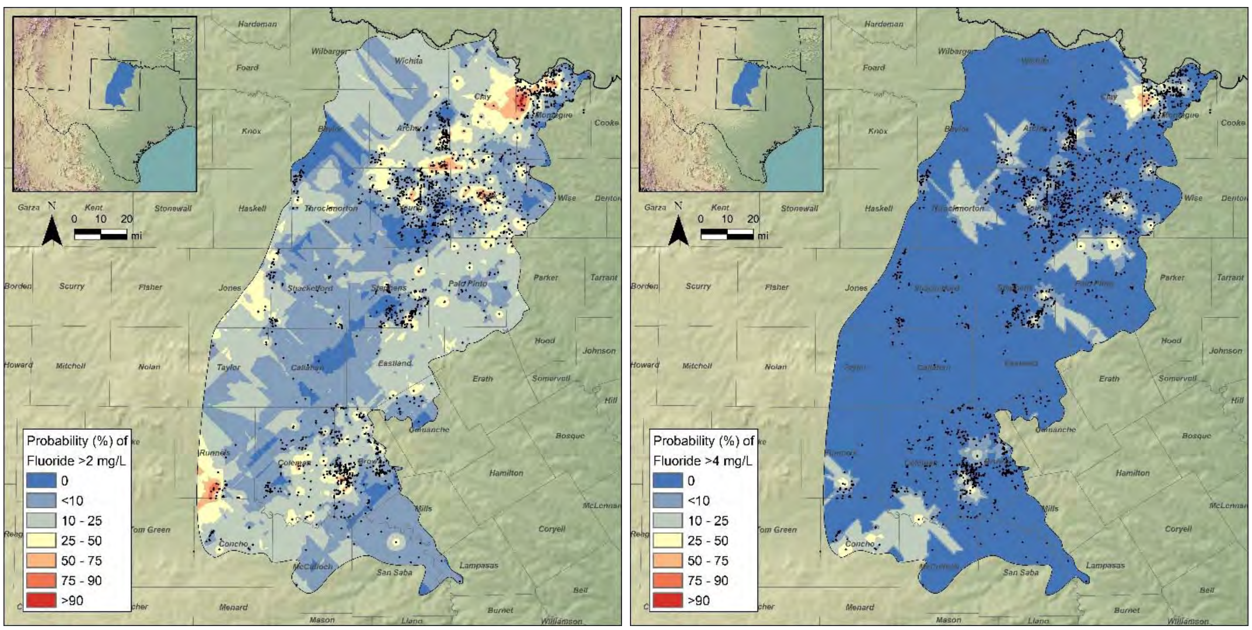

Figure 24. Cross Timbers aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, one public water supply system is impacted by fluoride concentrations >2 mg/L, represented by a non-community water system. There are no PWSs impacted by fluoride concentrations >4 ml/L. The non-PWS at-risk population of fluoride >2 mg/L is moderate at 4,690, representing about 4% of the rural population.

Dockum Aquifer

The Dockum aquifer covers 25,300 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 2, Figure 25). 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.

There were 837 samples analyzed for fluoride with 3 samples (1.6%) having non-detectable concentrations. About 18% of the area has no or very low probability of fluoride > 2 mg/L and a further 49% has low to moderate probability. Only about 31% of the total aquifer area has elevated to high probability of fluoride >2 mg/L and 2% has very high probability. The median concentration of samples with detectable concentrations is 1.5 mg/L and the 5th-9th percentile range is 0.4–3.78 µg/L. A total of 35 samples (4.2%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 10 mg/L.

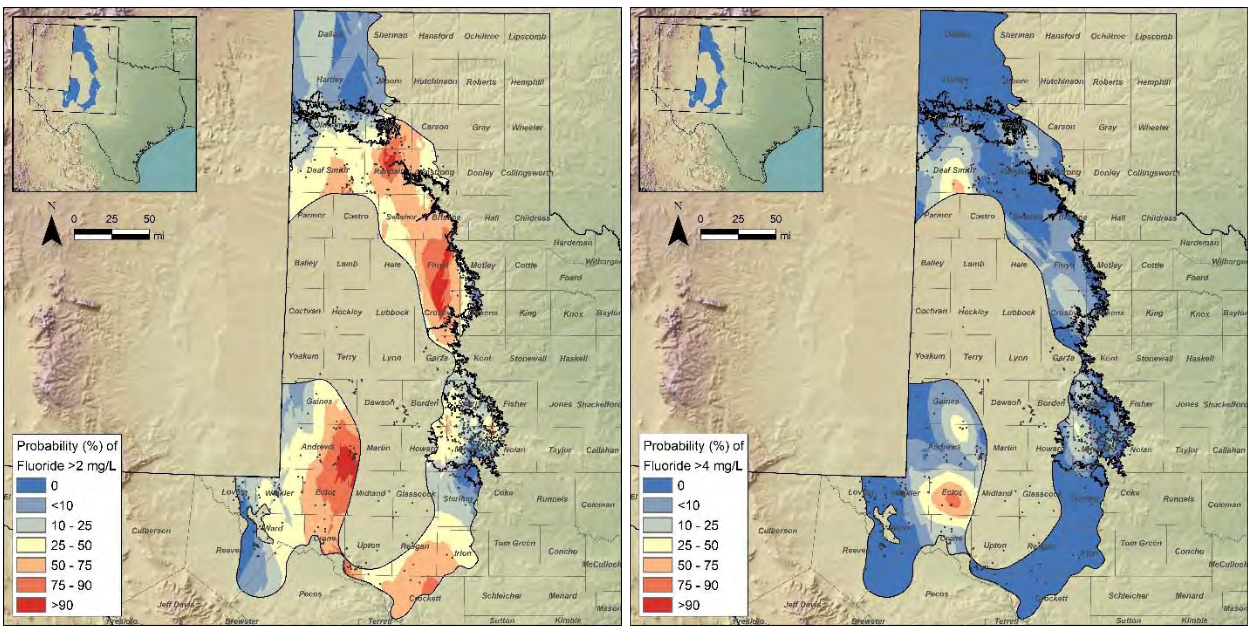

Figure 25. Dockum aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right). While the Dockum is continuous and present in the central "empty" region of the figure, the TWDB limits the extents of the defined aquifer to regions that have water with total dissolved solids (TDS) <3000 mg/L.

Based on the TCEQ PWS database, a total of 12 PWSs are impacted by fluoride concentrations >2 mg/L, including 3 non-community water systems and 9 community water systems with a population of 17,724 people. Based on the EPA PWS database, there are no PWSs that are impacted by fluoride concentrations >4 mg/L. The non-PWS at-risk population of fluoride >2 µg/L is high at 40,402 people, representing about 33% of the rural population. However, these areas also lie within the limits of the Ogallala aquifer and the numbers of domestic wells in the Dockum is likely very small. Accordingly, the estimated non-PWS at-risk population is estimated at zero.

Edwards-Trinity High Plains

The Edwards-Trinity aquifer covers 9,000 mi^2 and extends across parts of 13 counties in the Southern High Plains of Texas and lies just beneath the Ogallala aquifer and above the Dockum (Figure 2, Figure 26). The aquifer is composed of a limestones and sandstones of the Comanche Peak, Edwards, and Antlers formations of the Trinity Group and the freshwater saturated thickness averages about 125 ft. Water quality is generally more saline than the overlying Ogallala aquifer, with TDS generally ranging from 1,000 up to 3,000 mg/L.

There were 71 samples analyzed for fluoride, all with detectable concentrations. Only about 9% of the area has no to very low probability of fluoride >2 mg/L and a further 45% has low to moderate probability. About 31% of the total aquifer area has elevated to high probabilities of fluoride >4 mg/L and 14% has very high probability. The kriging results display artifacts limited data in large areas of the aquifer. The median concentration of samples with detectable concentrations in 4.10 m/L and the 5th-9th percentile range is 1.83–6.75 µg/L. There 37 samples (52%) that exceed the 4 mg/L MCL, almost all of them located in a cluster in eastern Gaines County.

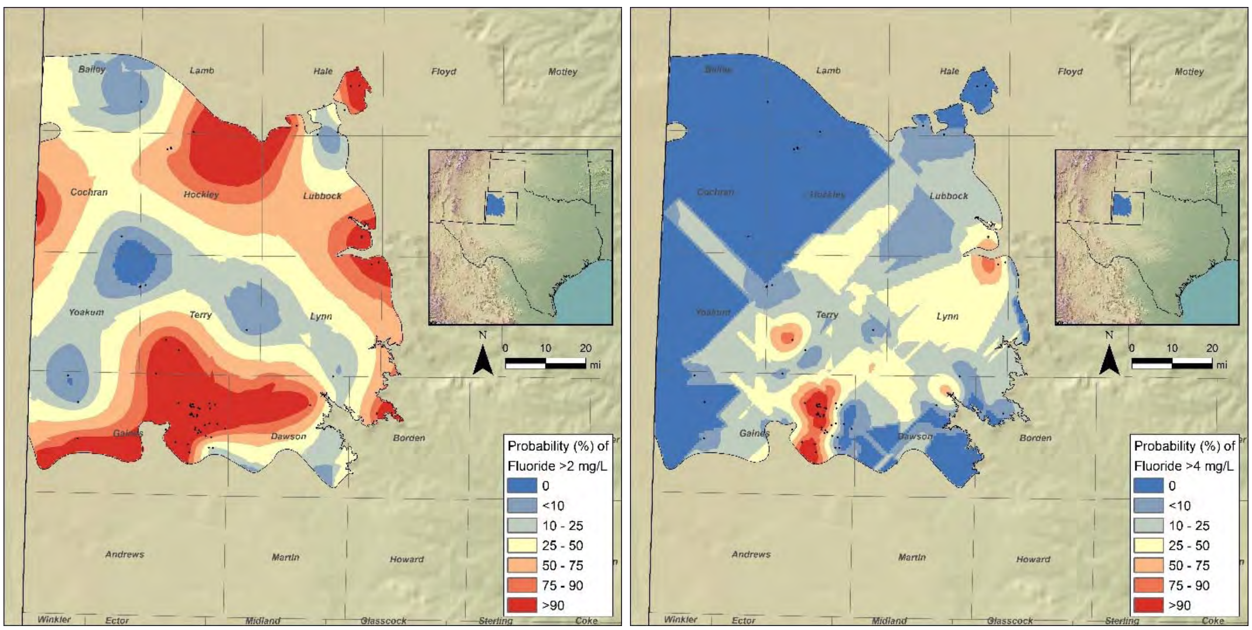

Figure 26. Edwards-Trinity High Plains aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, there are no PWSs are impacted by fluoride concentrations >2 mg/L, and therefore no PWS are impacted by fluoride concentrations >4 mg/L. The non-PWS at-risk population of fluoride >2 µg/L is high at 29,237 people, representing about 45% of the rural population. This aquifer immediately underlies the Ogallala aquifer and wells are frequently completed in both aquifers, therefore no adjustment has been made as with the Dockum aquifer.

Ellenburger-San Saba Aquifer

The Ellenburger-San Saba aquifer covers 5,400 mi^2 and extends across parts of 16 counties surrounding the Llano Uplift in central Texas (Figure 2, Figure 27). 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.

There were 318 samples analyzed for fluoride with 31 samples (9.7%) having non-detectable concentrations. About 70% of the area has no or very low probability of fluoride >2 mg/L and a further 21% has low to moderate probability. Only about 9% of the total aquifer area has elevated to high probabilities of fluoride >2mg/L and 1% with very high probability. The high probability areas are located in the far down-dip northern reaches of the aquifer. The median concentration of samples with detectable concentrations is 0.45 mg/L and the 5th-9th percentile range is 0.1–2.4 µg/L. There were 9 samples (2.8%) with fluoride concentrations greater than the MCL.

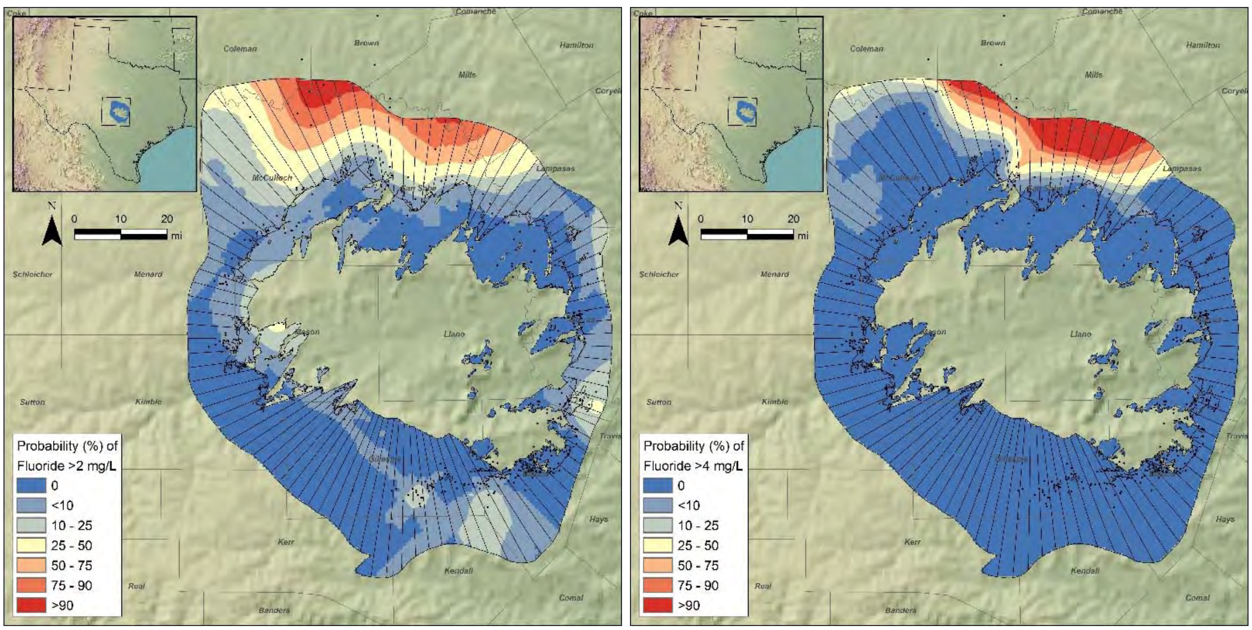

Figure 27. Ellenburger-San Saba aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

There are no PWSs impacted by fluoride concentrations >2 mg/L and therefore no PWSs are impacted by fluoride concentrations >4 mg/L. The non-PWS at-risk population of fluoride >2 mg/L is low at 1,224, representing 1.9% of the rural population.

Hickory Aquifer

The Hickory aquifer covers 8,600 mi^2 and extends across parts of 19 counties in and surrounding the Llano Uplift in central Texas (Figure 2, Figure 28). 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.

There were 459 samples analyzed for fluoride with only 18 samples (3.9%) having non-detectable concentrations. The kriging results display artifacts resulting from limited data in many areas of the aquifer as most of the samples are located in the central outcrop areas. As with the adjacent Ellenburger-San Saba aquifer, the high probability areas are located in the far down-dip northern reaches of the aquifer. About 61% of the Hickory area has no to very low probability of fluoride >2 mg/L and a further 35% has low to moderate probability of fluoride >4 mg/L. About 5% of the area has elevated probability. The median concentration of samples with detectable concentrations is 0.62 mg/L and the 5th-9th percentile range is 0.25–2.0 mg/L. Only 4 samples (0.9%) exceed the 4 mg/L MCL.

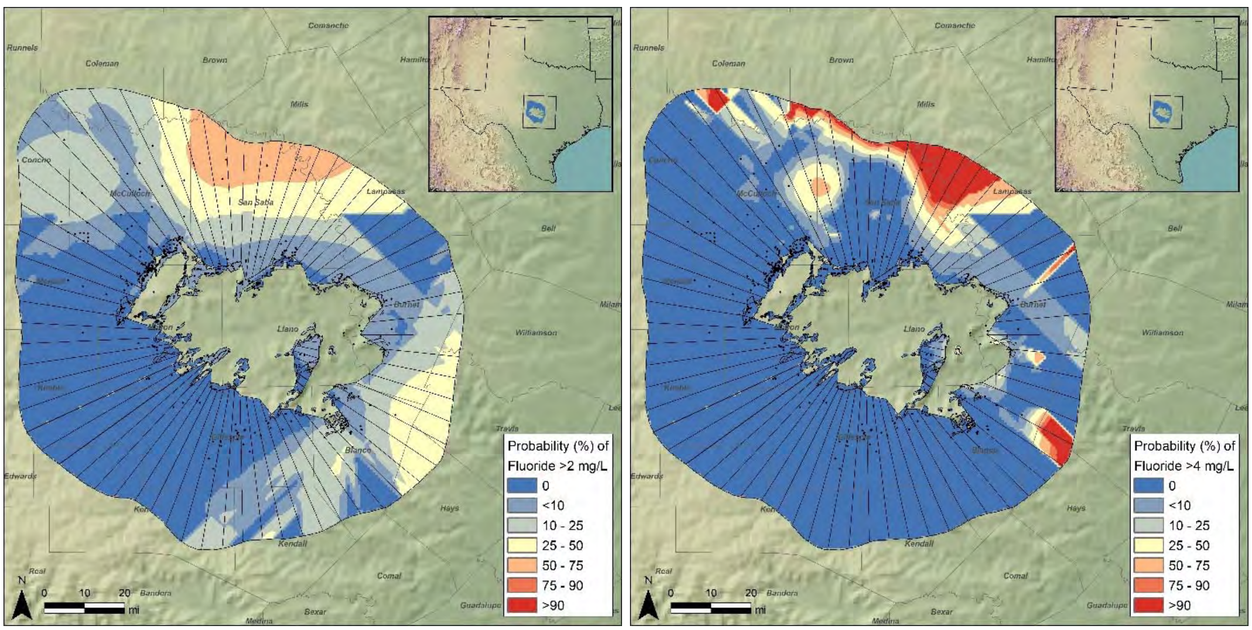

Figure 28. Hickory aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, a single public supply system is impacted by fluoride concentrations >2 mg/L, represented by a PWS community water system serving 3,987 people. There are no PWSs impacted by fluoride concentrations >4 ml/L. The non-PWS at-risk population of fluoride >2 mg/L is moderate at 6,629, representing about 5% of the rural population.

Igneous Aquifer

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 2, Figure 29). 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.

There were 198 samples analyzed for fluoride, all having detectable concentrations. About 22 % of the area has no or very low probability of fluoride >2 mg/L and a further 56% has low to moderate probability. About 20% of the total aquifer area has elevated to high probability of fluoride >2 mg/L and 2% has very high probability. The highest concentrations are generally located in the central area of the aquifer. The median concentration of samples with detectable concentrations is 1.4 mg/L and the 5th-9th percentile range is 0.37–3.31 mg/L. Only 3 samples (1.5%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 4.9 mg/L.

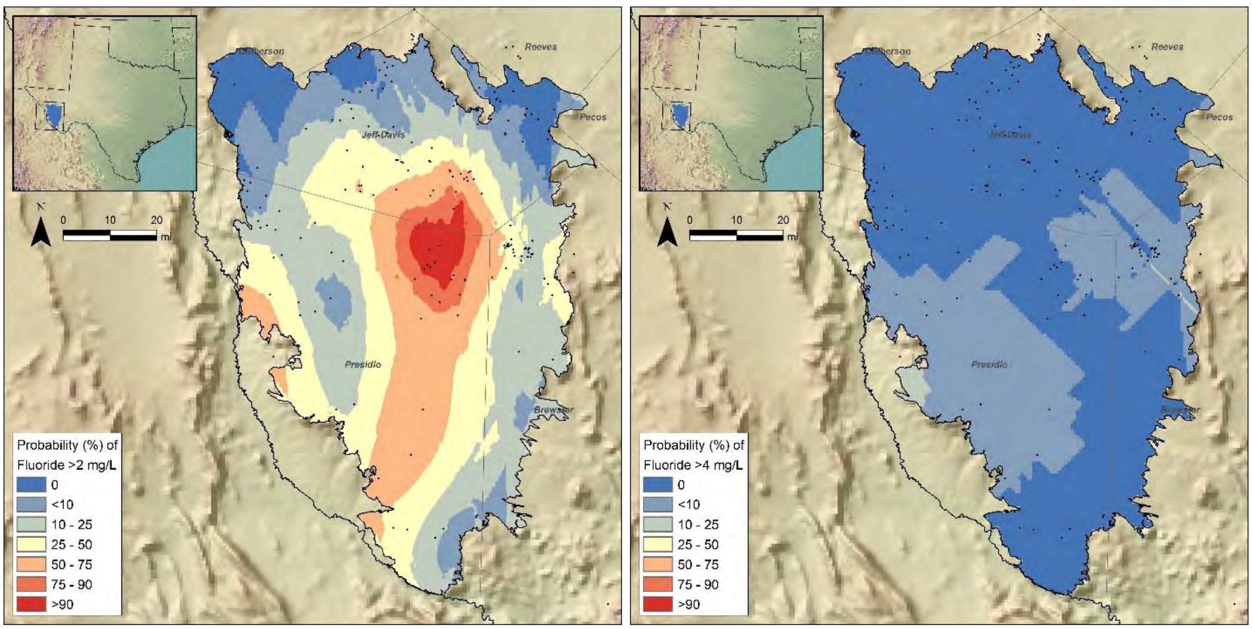

Figure 29. Igneous aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, a total of 9 PWSs are impacted by fluoride concentrations >2 mg/L, including 4 non-community water systems and 5 community water systems with a total population of 10,282 people. Based on the EPA PWS database, there are no PWS impacted by fluoride concentrations >4 mg/L. The estimated non-PWS at-risk population of fluoride >2 mg/L is small at 316, representing about 3% of the rural population. The estimated non-PWS at-risk population of fluoride >4 mg/L is very small at 13, representing about 0.1% of the rural population.

Nacatoch Aquifer

The Nacatoch aquifer covers 1,800 mi^2 in a narrow band that extends across parts of 15 counties in northeast Texas (Figure 2, Figure 30). The aquifer is composed of sandstones with an average of about 50 ft of saturated thickness. General water quality ranges from 350 mg/L to 3,000 mg/L TDS. The primary water quality issue of concern in the aquifer is high alkalinity due to high concentrations of sodium bicarbonate.

There were 203 samples analyzed for fluoride with 10 samples (4.9%) having non-detectable concentrations. About 54% of the area has no or very low probability of fluoride >2 mg/L and a further 27% has low to moderate probability. About 15% of the total aquifer area has elevated to high probability of fluoride >2 mg/L and 4% has very high probability. The highest concentrations are generally located in the down dip regions of the central and far north extents of the aquifer. The median concentration of samples with detectable concentrations is 0.78 mg/L and the 5th-9th percentile range is 1.7–4.28 mg/L. There are no samples that exceeded the 10 µg/L MCL.

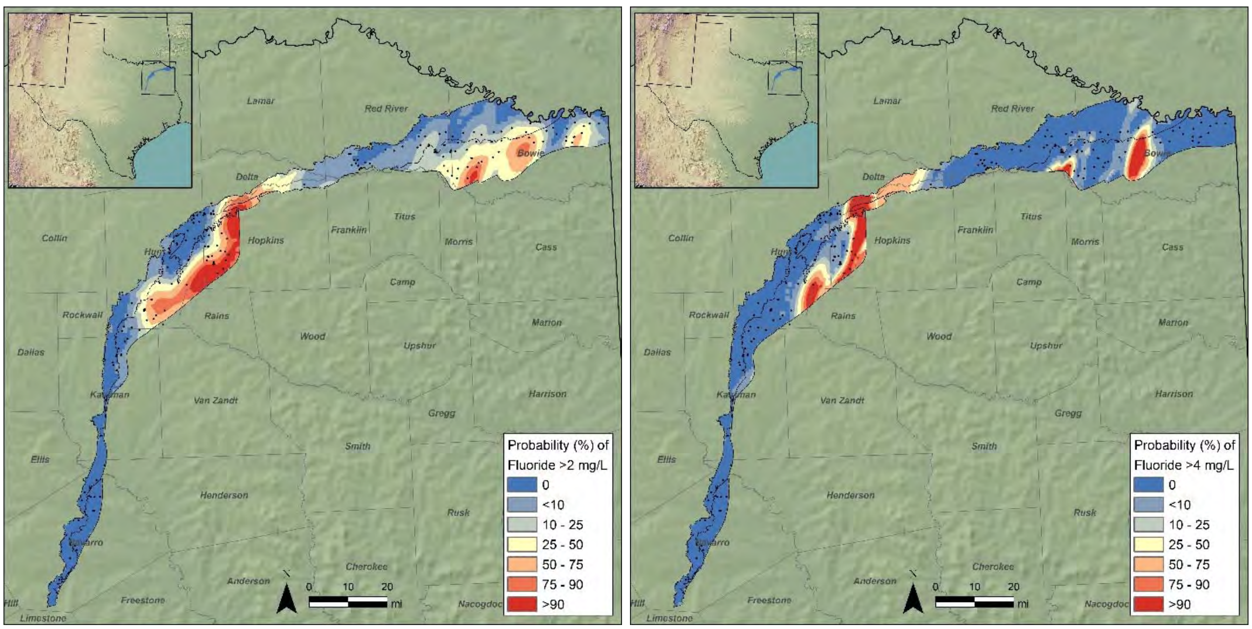

Figure 30. Nacatoch aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, a total of 4 PWSs are impacted by fluoride concentrations >2 mg/L with a total population of 3,690 people. Based on the EPA PWS database, there are no PWS impacted by fluoride concentrations >4 mg/L. The estimated non-PWS at-risk population of fluoride >2 mg/L is moderate at 2,299, representing about 6.5% of the rural population. The estimated non-PWS at-risk population of fluoride >4 mg/L is also moderate at 1,078, representing about 3% of the rural population.

West Texas Bolsons Aquifer

The West Texas Bolsons aquifer covers 1,200 mi^2 and extends across parts of 5 counties in west Texas along the international border with Mexico (Figure 2, Figure 31). 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.

There were 224 samples analyzed for fluoride, all having detectable concentrations. Only about 11% of the area has no to very low probability of fluoride >2 mg/L with a further 54% having low to moderate probability. About 28% of the total aquifer area has elevated to high probability of fluoride >2 mg/L and 8% has very high probability. The highest concentrations are located in the southern-most basin adjacent to the Rio Grande River. The median concentration of samples with detectable concentrations is 1.72 mg/L and the 5^{th}-9^{th} percentile range is 0.57–5.05 mg/L. A total of 20 samples (8.9%) exceeded the MCL with a range of concentrations from 4.1 mg/L to 10 mg/L.

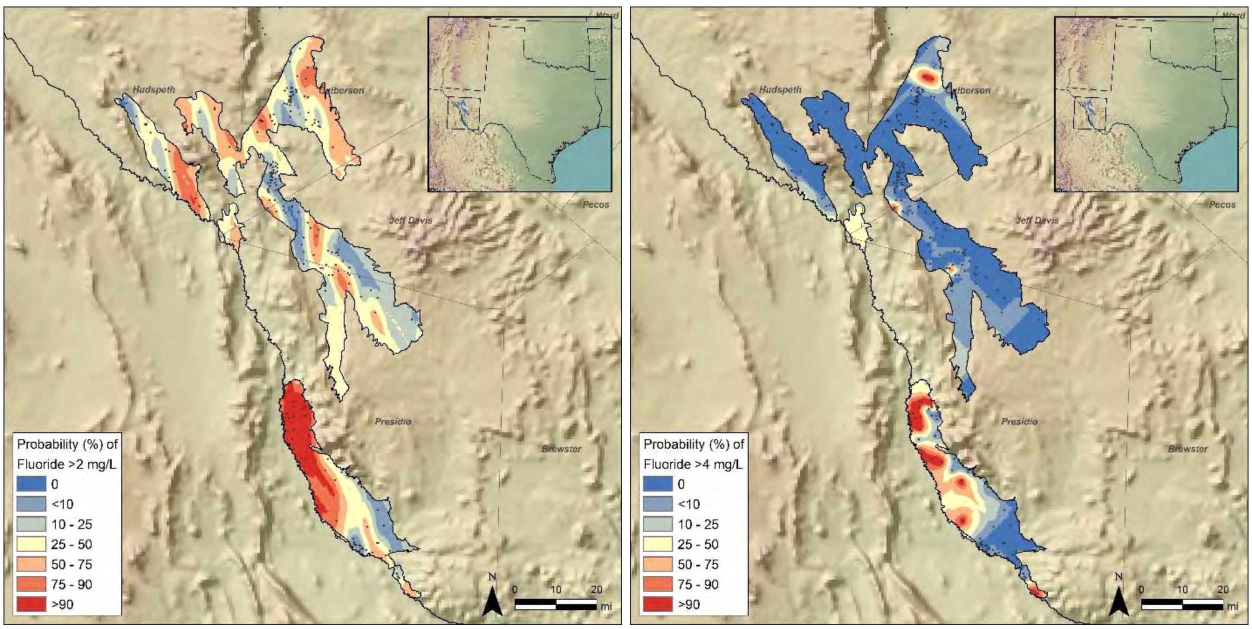

Figure 31. West Texas Bolsons aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, a total of 2 PWS are impacted by fluoride concentrations >2 mg/L with a total population of 2,833 people. Based on the EPA PWS database, there are no PWS impacted by fluoride concentrations >4 mg/L. The estimated non-PWS at-risk population of fluoride >2 mg/L is small at 58, representing about 3.7% of the rural population. The estimated non-PWS at-risk population of fluoride >4 mg/L is very small at 10, representing about 0.6% of the rural population.

Woodbine Aquifer

The Woodbine aquifer covers 7,300 mi^2 and extends across parts of 17 counties in north central Texas (Figure 2, Figure 32). 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.

There were 723 samples analyzed for fluoride with only 7 samples (1.0%) having non-detectable concentrations. About 39% of the area has no to very low probability of fluoride >2 mg/L with a further 34% having low to moderate probability. About 18% of the total aquifer area has elevated to high probability of fluoride >2 mg/L and 9% has very high probability. The median concentration of samples with detectable concentrations is 1.20 mg/L and the 5^{th}-9^{th} percentile range is 0.24–4.4 mg/L. There are 49 samples (6.8%) that exceed the 4 mg/L MCL.

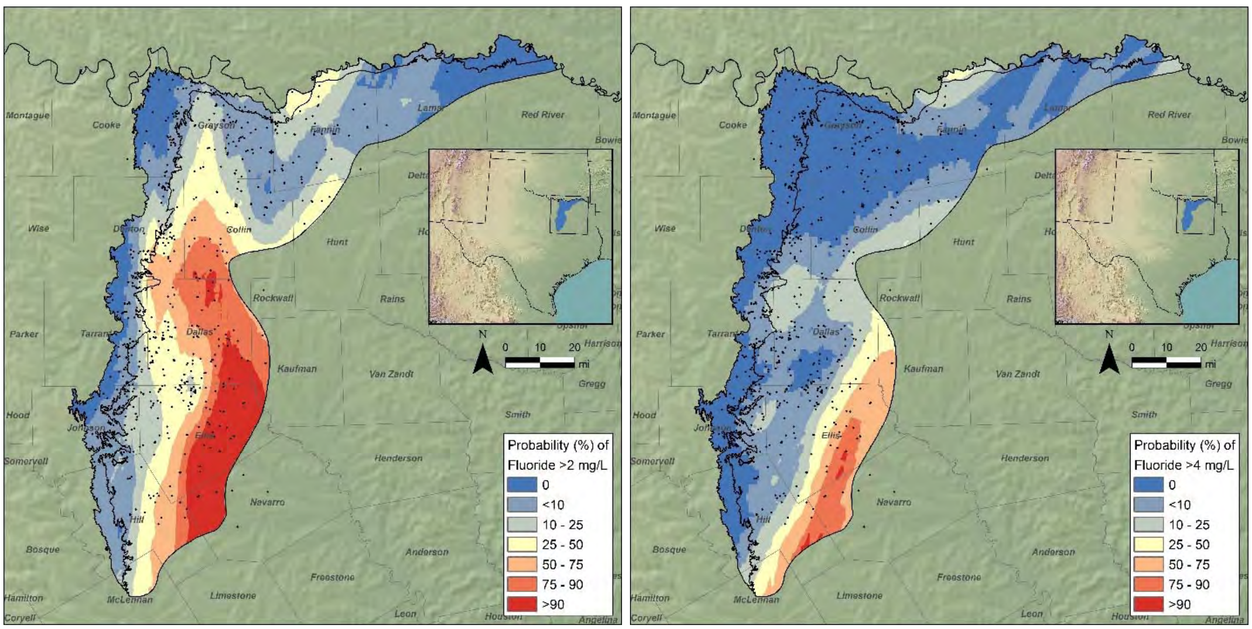

Figure 32. Woodbine aquifer probability distribution of fluoride >2 mg/L (left) and >4 mg/L (right).

Based on the TCEQ PWS database, a total of 16 PWS are impacted by fluoride concentrations >2 mg/L with a total population of 44,226 people. Based on the EPA PWS database, there us 1 PWS impacted by fluoride concentrations >4 mg/L with a total population of 90 (Table 28). The estimated non-PWS at-risk population of fluoride >2 mg/L is very high at 40,598, representing about 35% of the rural population. The estimated non-PWS at-risk population of fluoride >4 mg/L is moderate at 8,001, representing about 7% of the rural population.

Table 28. Woodbine aquifer CWSs with violations for fluoride concentrations based on the US EPA database. The listed system uses groundwater as the primary source.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Pop. Served*
0700054	Howard Water Coop	CWS	GW	2	4-2020	90

Other Aquifers

For completeness, there were no community or non-community water systems that were impacted by fluoride concentrations >4 mg/L that use unmapped (other) aquifers as their source.

Summary

Most of the Texas population is served with water from PWSs, totaling 28.7 million in 2020 (98.6% of population of 29.1 million) whereas the number of people relying on domestic water supplies totaled 0.4 million in 2020 (1.4% of population).

Quantifying the spatial distribution of groundwater fluoride concentrations in aquifers in Texas is important for managing groundwater resources in the state. Previous studies show that the fluoride hotspot in the southern High Plains aquifer originates from geologic sources. This study evaluated the probability of groundwater fluoride levels exceeding the primary MCL of 4 mg/L, the secondary MCL of 2 mg/L, and the recommended dental care minimum of 0.7 mg/L using ~39,500 analyses from 1929 through 2021. Results of the study indicate that 4.6% (1,800) of samples exceed the primary MCL of 4 mg/L, mostly (3.9%) from major aquifers.

Of the CWSs that were noncompliant with respect to fluoride during 2018-2020, the majority (29/34 85%) are located in the southern High Plains, reflecting the Ogallala Aquifer. The percentage of samples exceeding the secondary MCL of 2 mg/L was about 4 times higher than that for the primary MCL, totaling 19% of all samples, divided between major (16%) and minor (3%) aquifers. A total of 34 CWS exceeded the primary MCL, 33 systems sourced by major aquifers. In contrast 293 PWS exceeded the secondary MCL of 2 mg/L, 83% sourced from major aquifers. Results suggest that an estimated 115,600 people may have been exposed to fluoride concentrations exceeding the primary MCL of 4 mg/L, with 33% (~37,700 people) from PWS systems and the 67% (~78,000) from non-PWSs. The population impacted by the secondary MCL is estimated to be 1.38 million, 4.6% of the estimated 2020 population. The majority of the impacted population is served by PWSs (78%, ~ 1 million people). A total of 21,743 groundwater samples throughout Texas exceeded 0.7 mg/L (55% of total); therefore, 45% were less than the recommended threshold established by the USPHS to minimize tooth decay. TCEQ is working with PWSs to bring them into compliance with the fluoride regulations using either nontreatment or treatment options. Domestic supply systems are not regulated and home owners need to assess their vulnerability, particularly in the southern High Plains fluoride hotspot.

Acknowledgements

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Appendix I – Treatment of Community Water Systems

Two systems that were in violation of the 4 mg/L fluoride MCL standard during 2018-2020 have since come into compliance for fluoride, including Plott Acres (TX1520062) located in Lubbock County and Esperanza Water Service (TX1150010) located in Hudspeth County (Table 29). Both systems are small, with populations served of 204 and 849 people, respectively. Both systems have a history of fluoride, arsenic, and selenium violations beginning in the early 80s when such were initially analyzed, though neither system had any arsenic and selenium MCL violations since before 2018. Fluoride has historically alternated between periods of compliance and non-compliance for both systems.

Table 29. Texas CWS systems that have come into compliance since 2020.

System ID	System Name	Population Served	Number of Violations	Violations Period	Return to Compliance	Violations
TX1520062	Plott Acres	204	142	3/14/1980 – 4/1/2019	3/4/2020	F, As, Se
TX1150010	Esperanza WS	849	28	1/19/1983 – 7/1/2020	2/3/2021	F, As, Se, Coliform

Of these two systems, only the Esperanza WS has a treatment plant listed in the SDWIS database which uses reverse osmosis technology with a stated treatment objective of removing fluoride (and arsenic and selenium). It is unclear what approach or technology Plott Acres has employed to come into compliance as there are no treatment plants for the removal of inorganic constituents listed in the database.

A third system is currently studying an innovative coagulation approach to achieve compliance with respect to fluoride and arsenic, which commonly affects water supplies in the Southern High Plains region. In 2020, The City of Seagraves and their consulting engineer contacted WwaterTech, the Texas representative for Purifics (https://www.purifics.com), to request a pilot treatment study on their groundwater supply, which is source from five groundwater wells. The study the Purifics Ceramic Ultrafiltration (Cuf) platform. TCEQ has shown the City's water to consistently exceed the primary MCLs for arsenic (10 μg/L) and fluoride (4 mg/L). A Purifics pilot treatment skid was shipped to the city and began operation in 2021. At present, two rounds of treatment and testing have been completed.

Treatment results using a dose of 150-200 mg/L alum coagulant consistently reduced fluoride concentrations to below the 4 mg/L primary MCL and using doses of 40-50 mg/L consistently under the 2 mg/L secondary MCL for raw water that ranged from 3.33 mg/L to 4.34 mg/L. Treatment results for arsenic using a treatment dose of 5 mg/l reduced arsenic concentrations to below detection limits for raw water that ranged from 16 μg/L to 19.7 μg/L.

Appendix II – Large Format Aquifer Probability Maps

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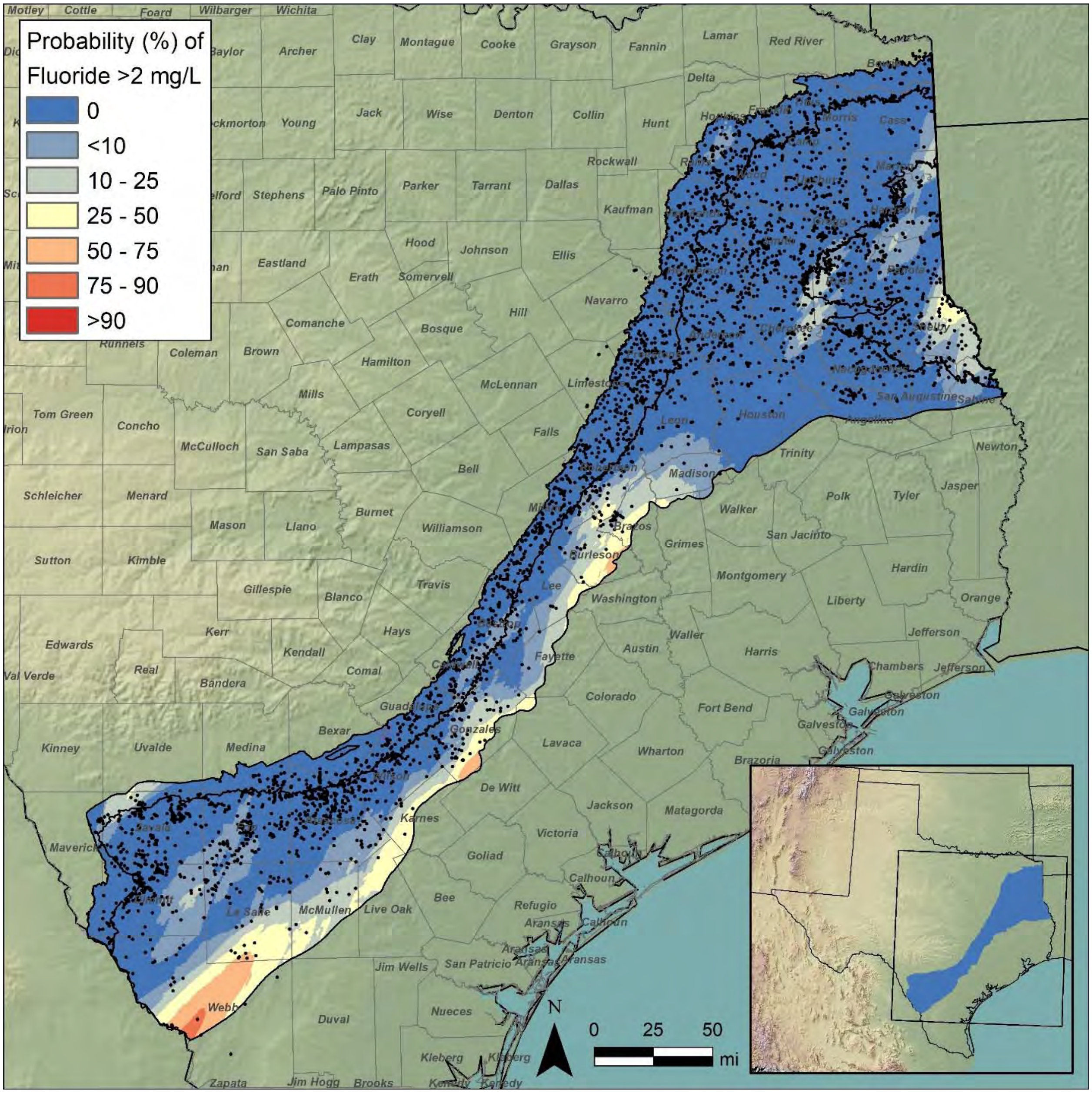
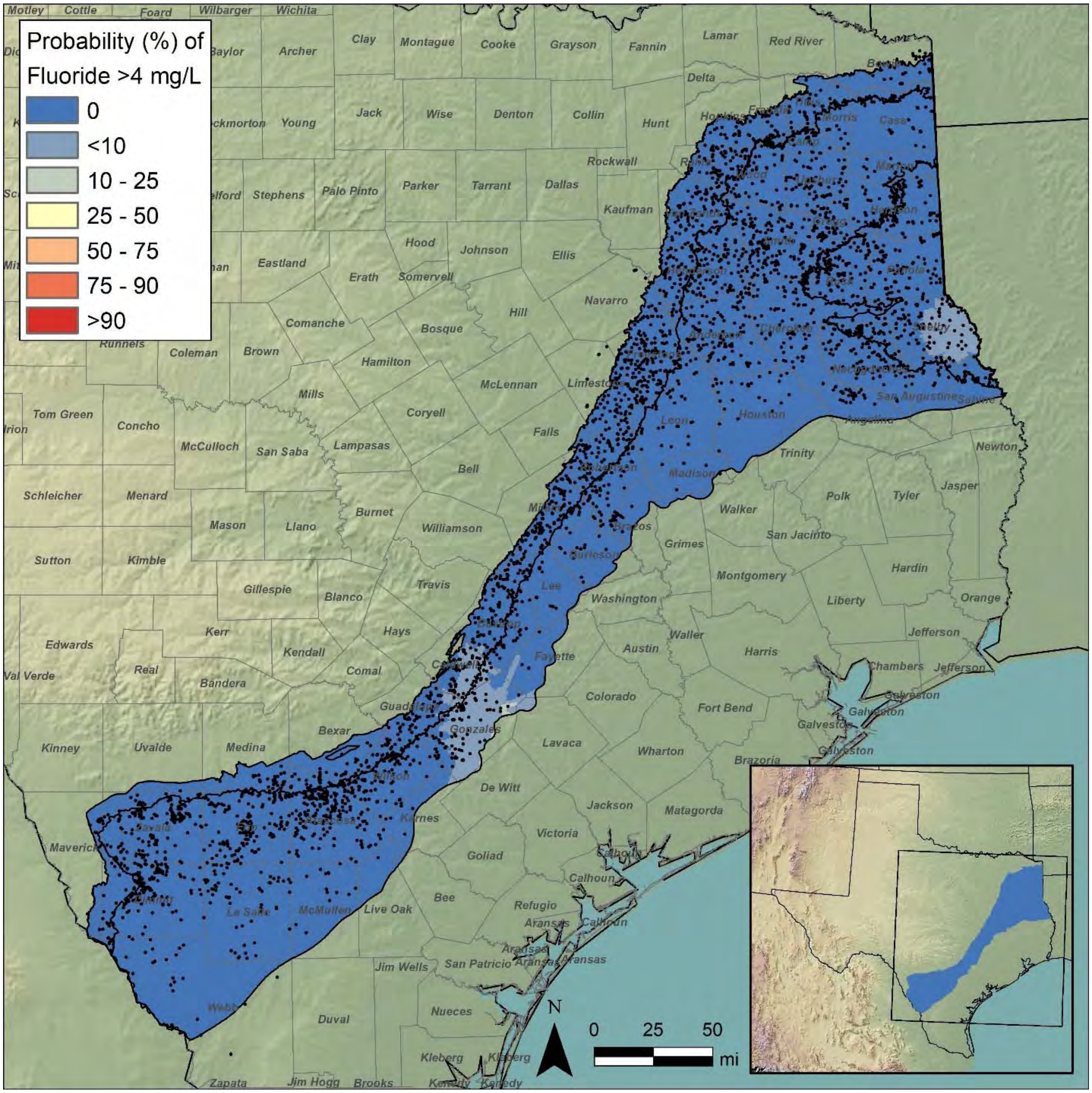


Figure 33. Carrizo-Wilcox aquifer probability distribution of fluoride >2 mg/L.



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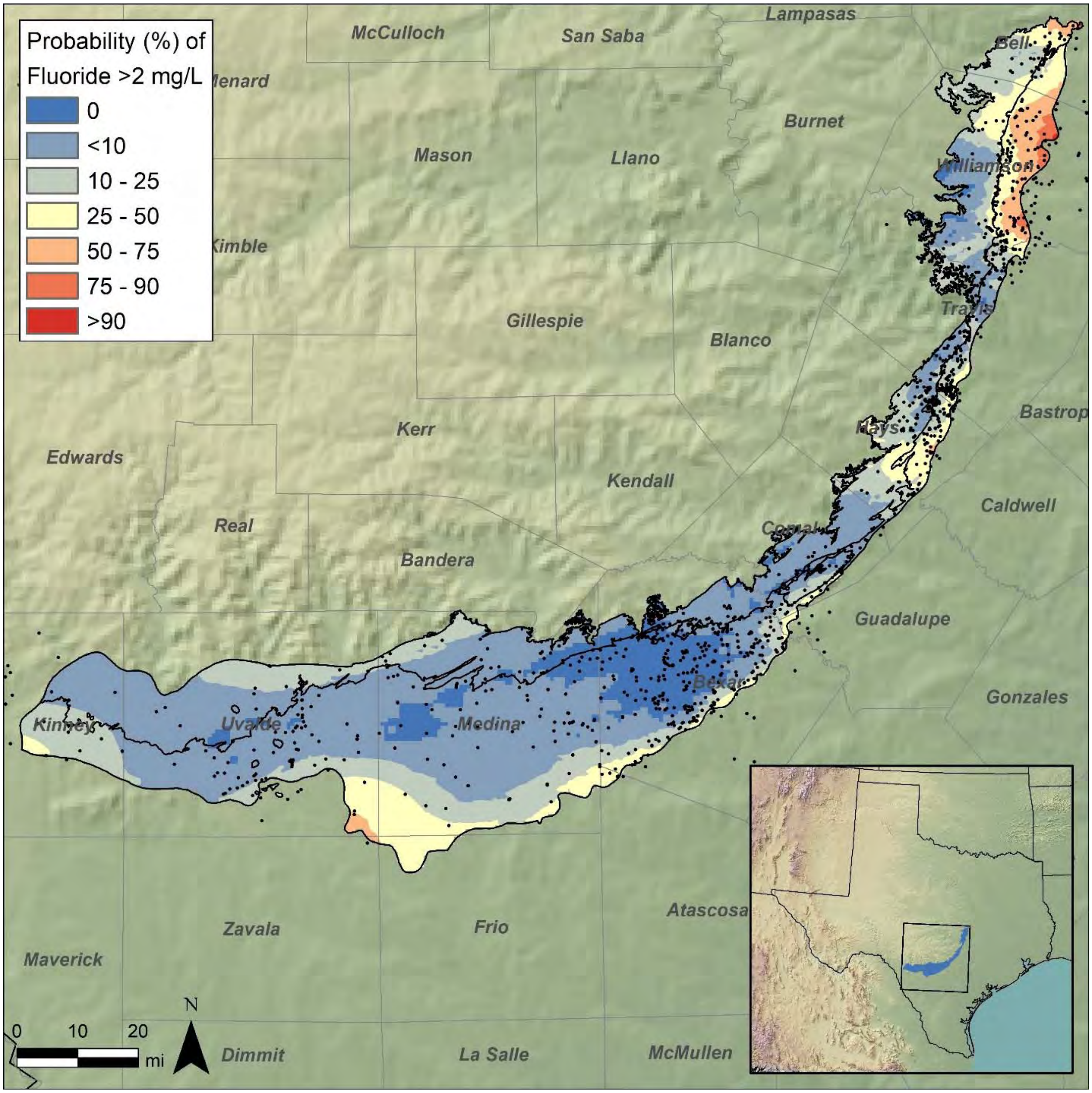
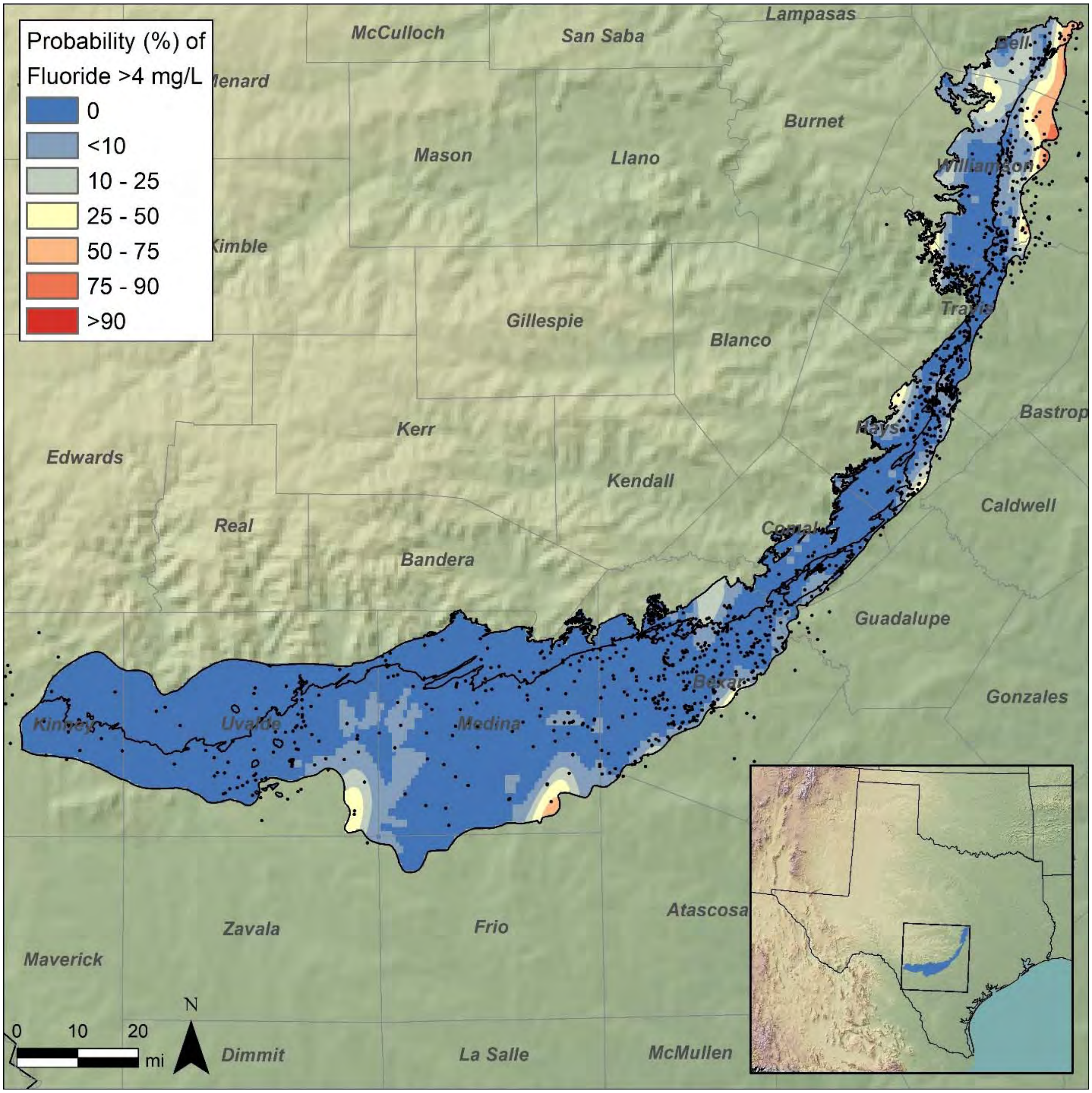


Figure 35. Edward (BFZ) aquifer probability distribution of fluoride >2 mg/L.



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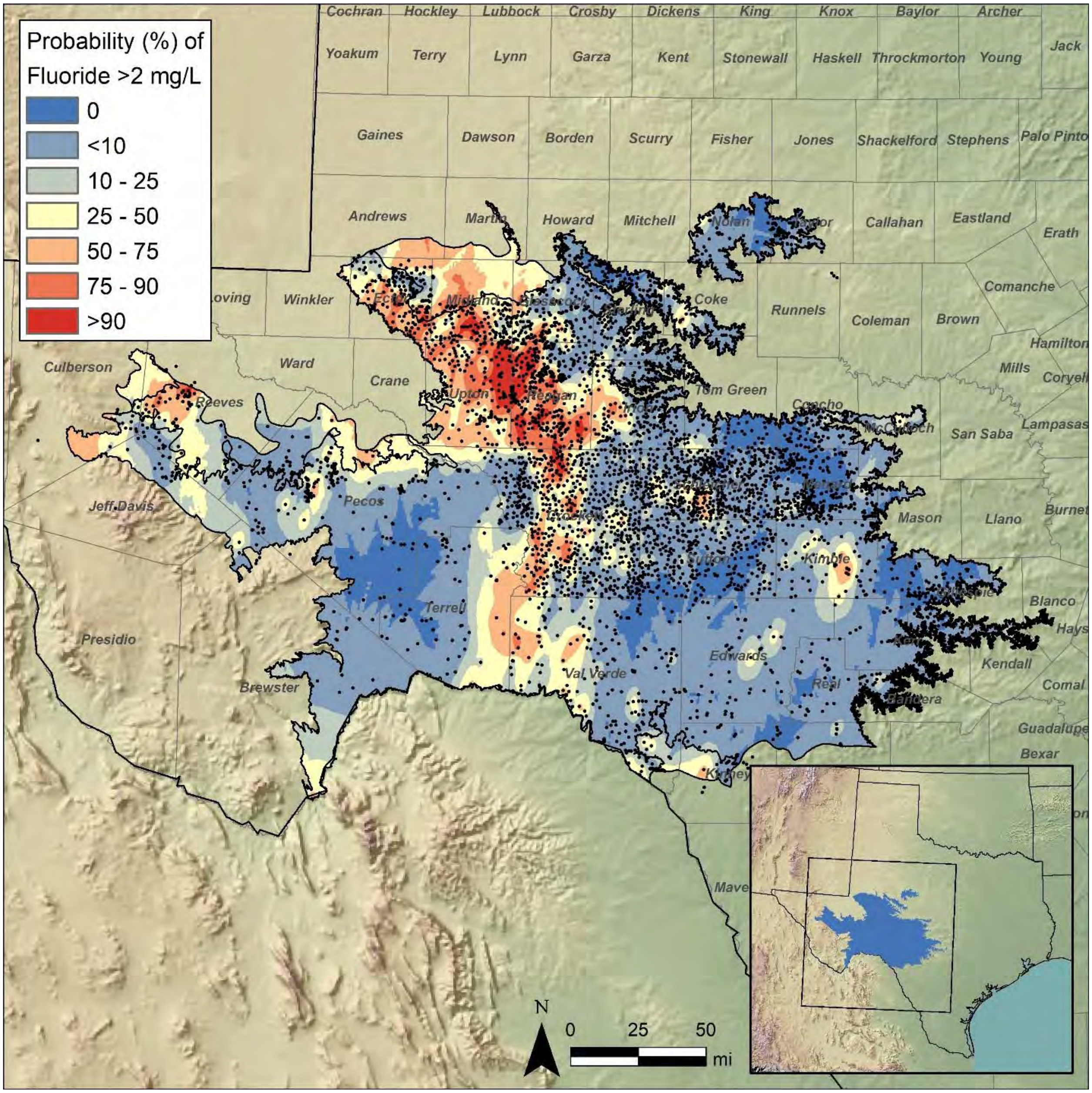
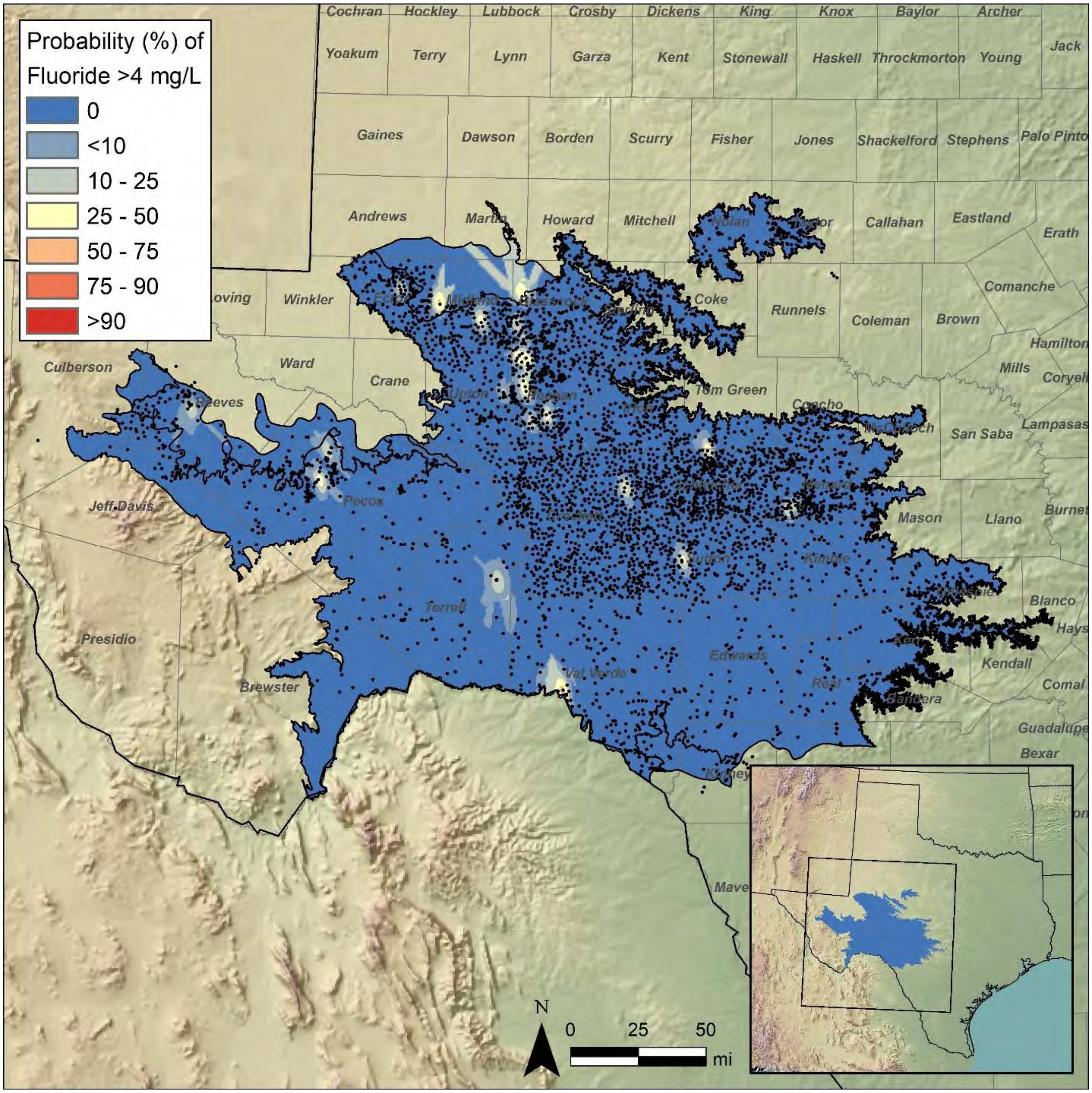


Figure 37. Edwards-Trinity Plateau aquifer probability distribution of fluoride >2 mg/L.



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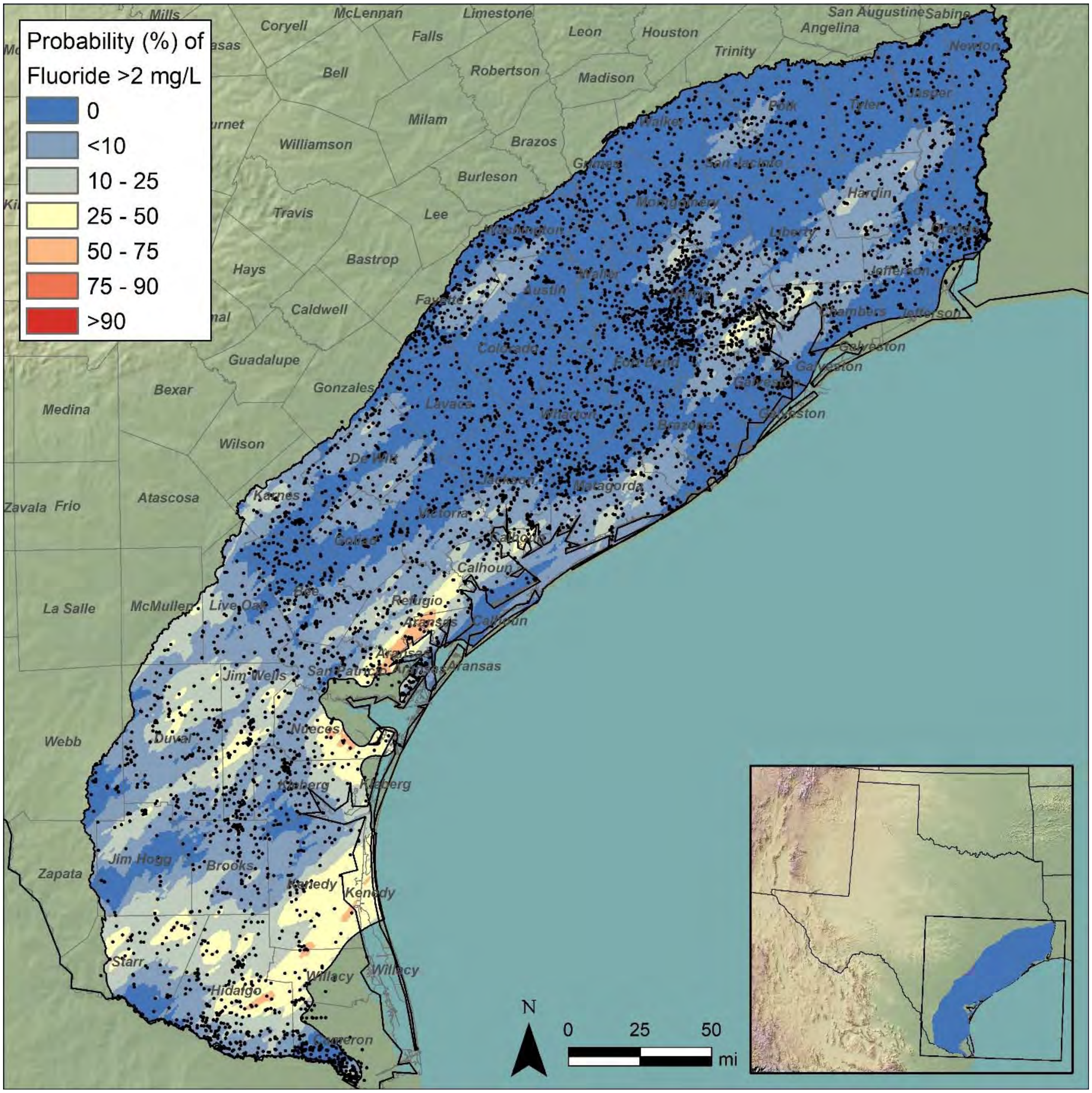

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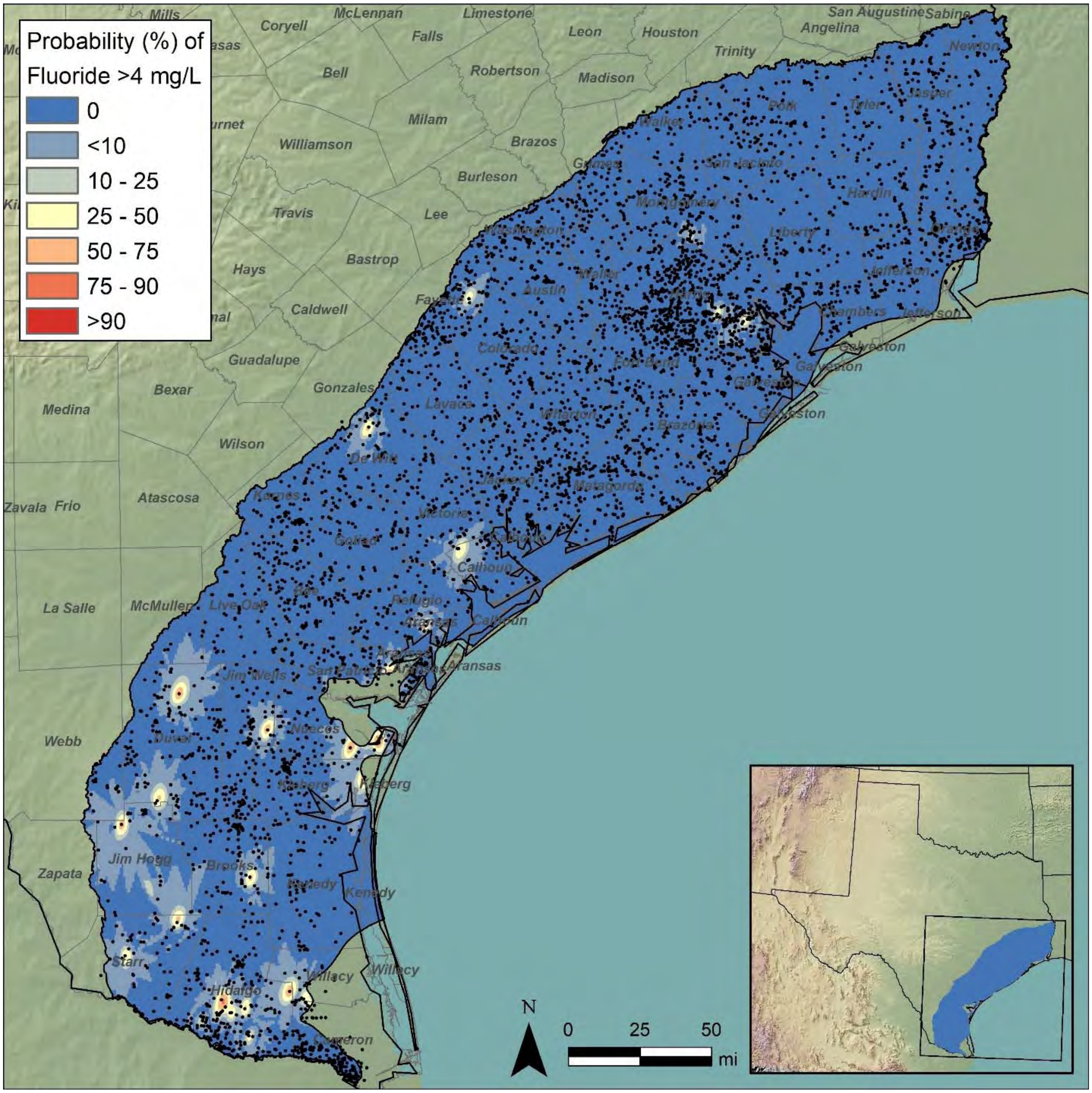

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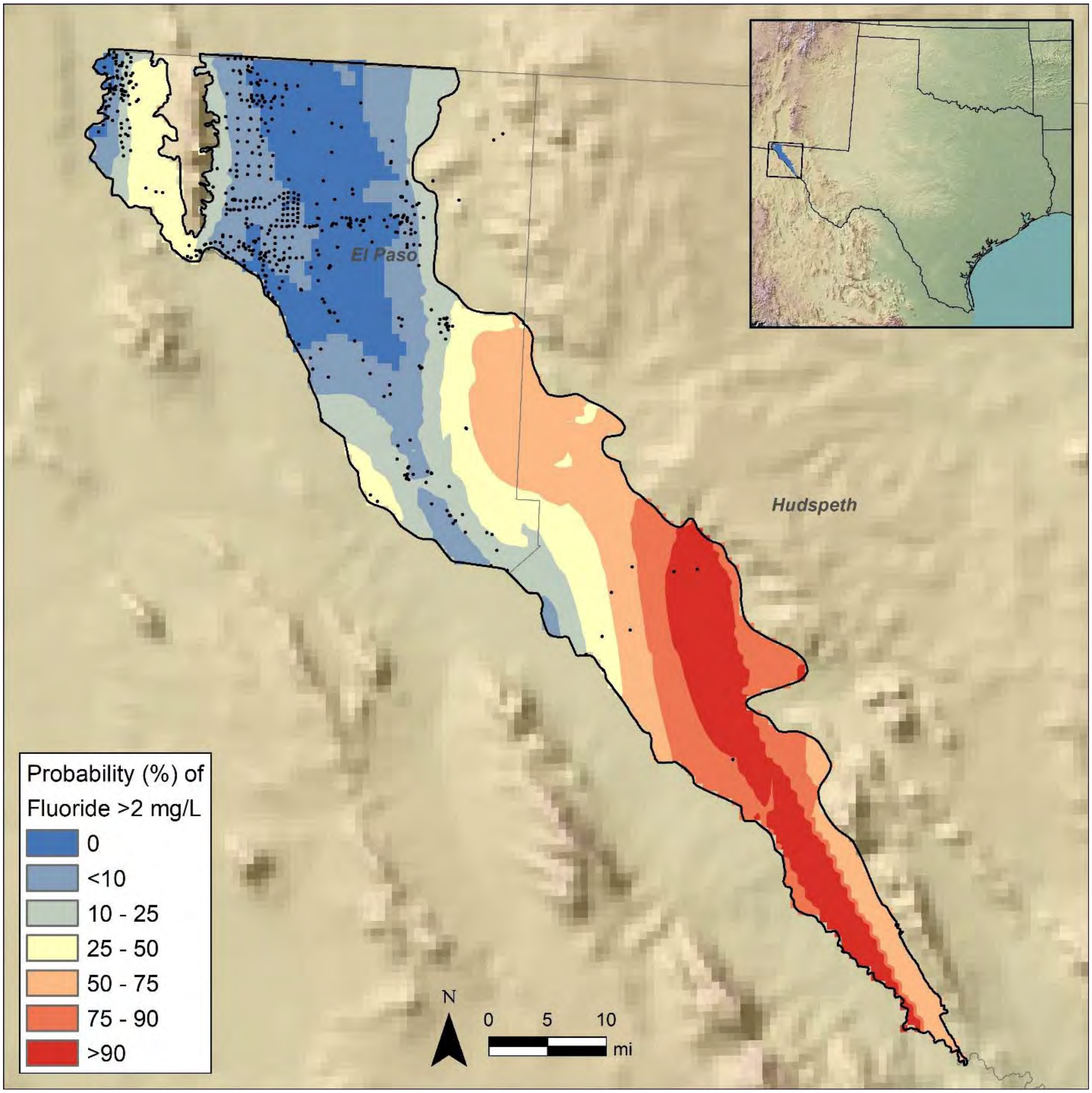
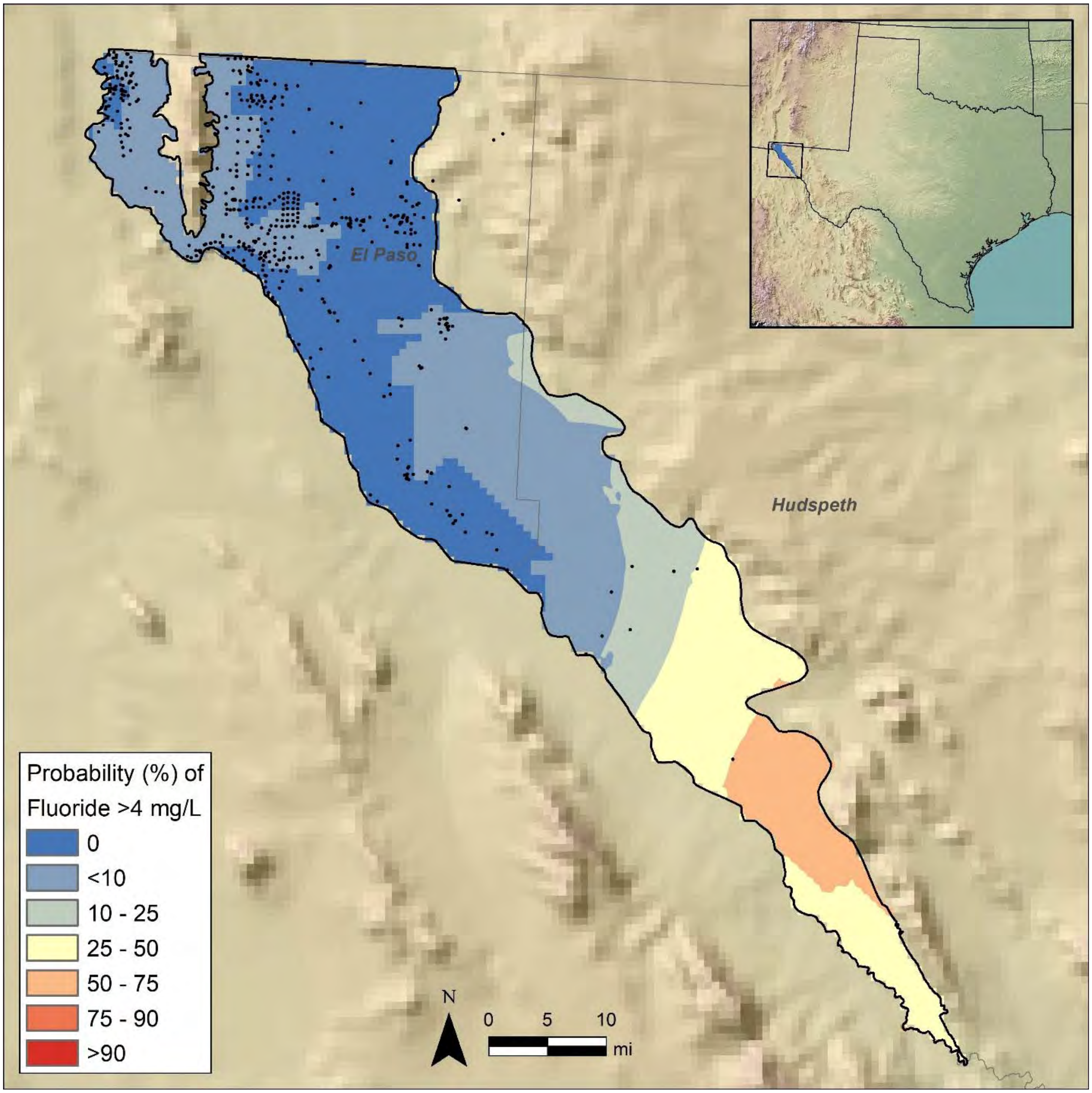


Figure 41. Hueco-Mesilla Bolsons aquifer probability distribution of fluoride >2 mg/L



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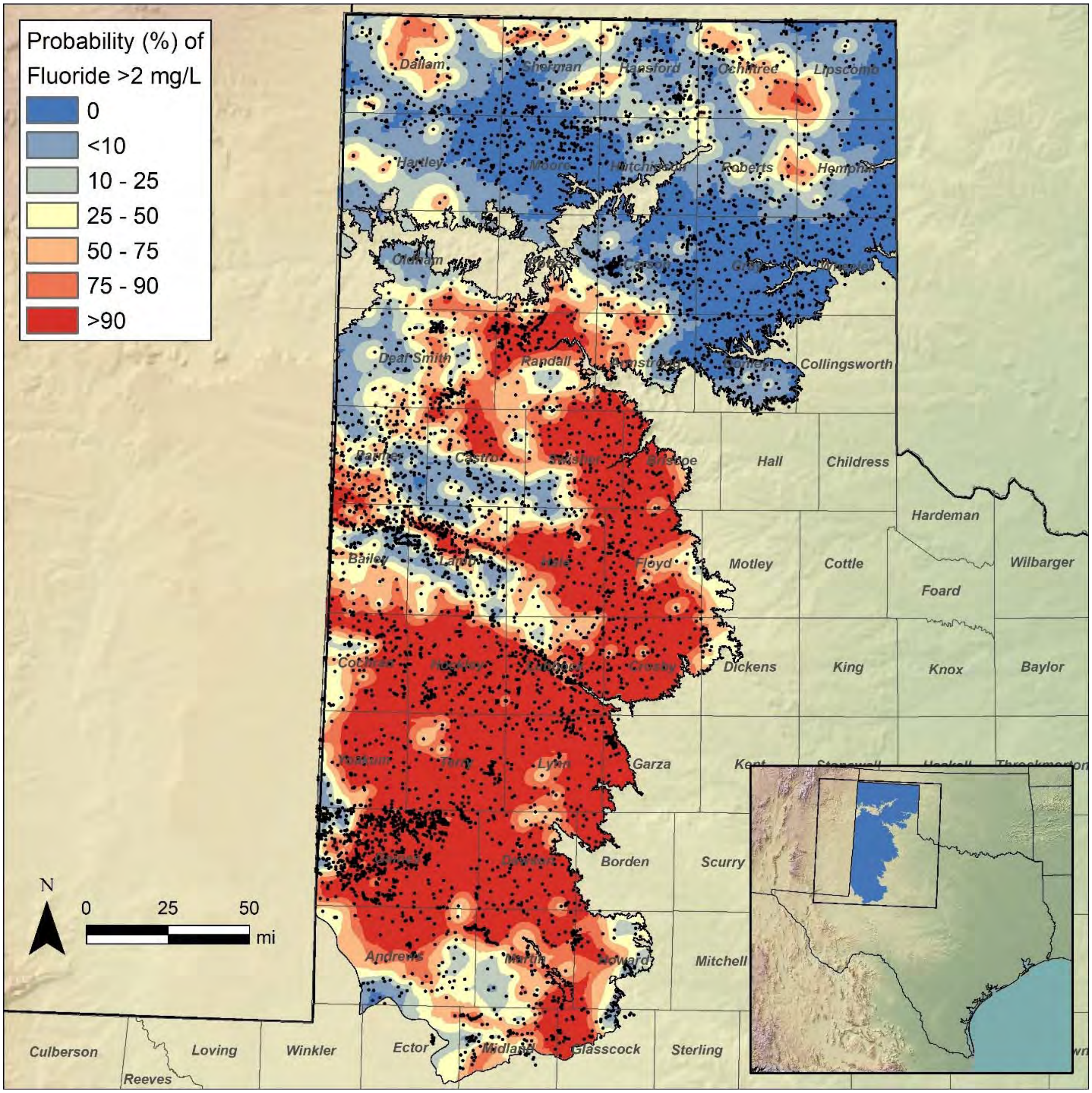
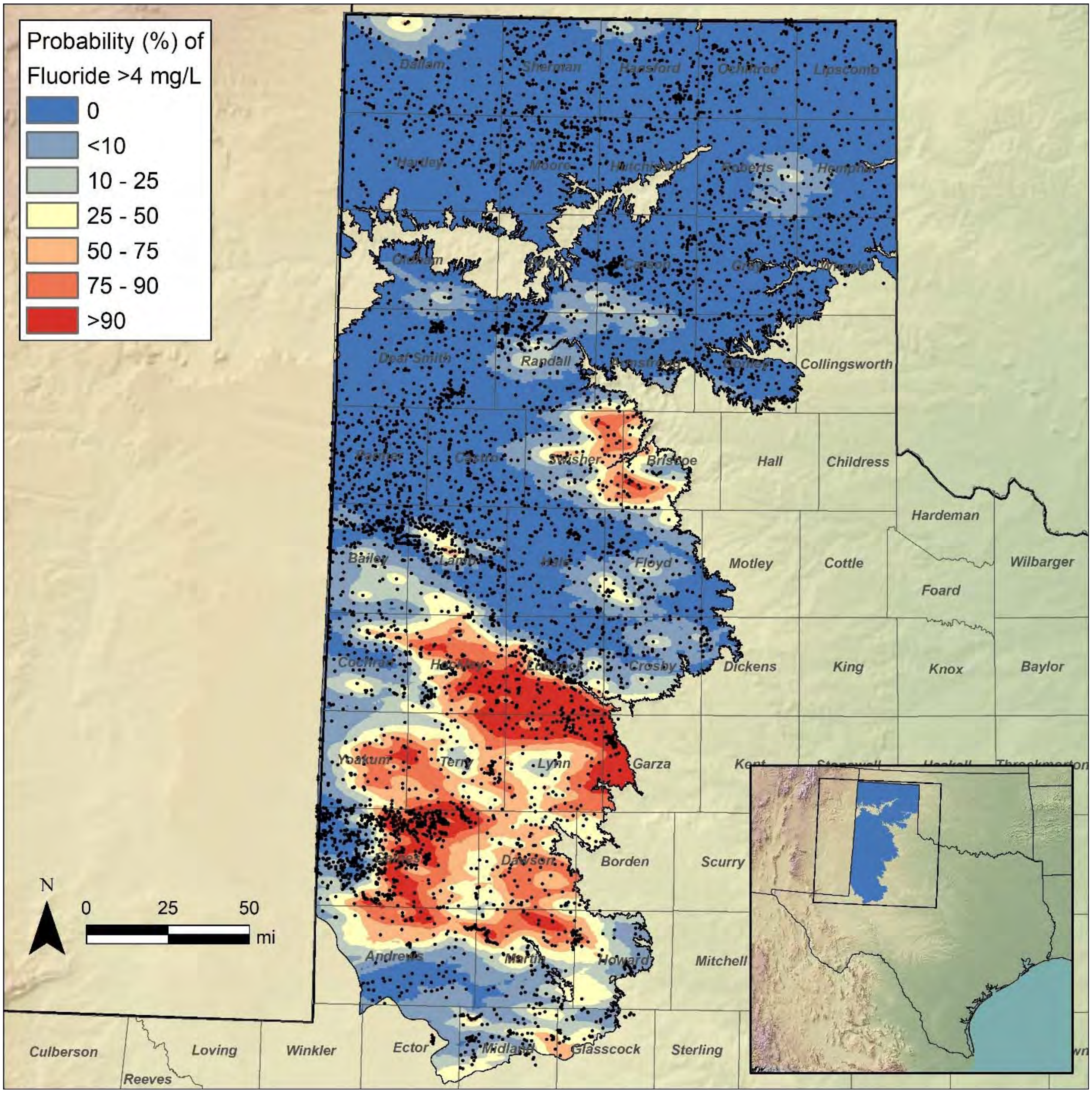


Figure 43. Ogallala aquifer probability distribution of fluoride >2 mg/L



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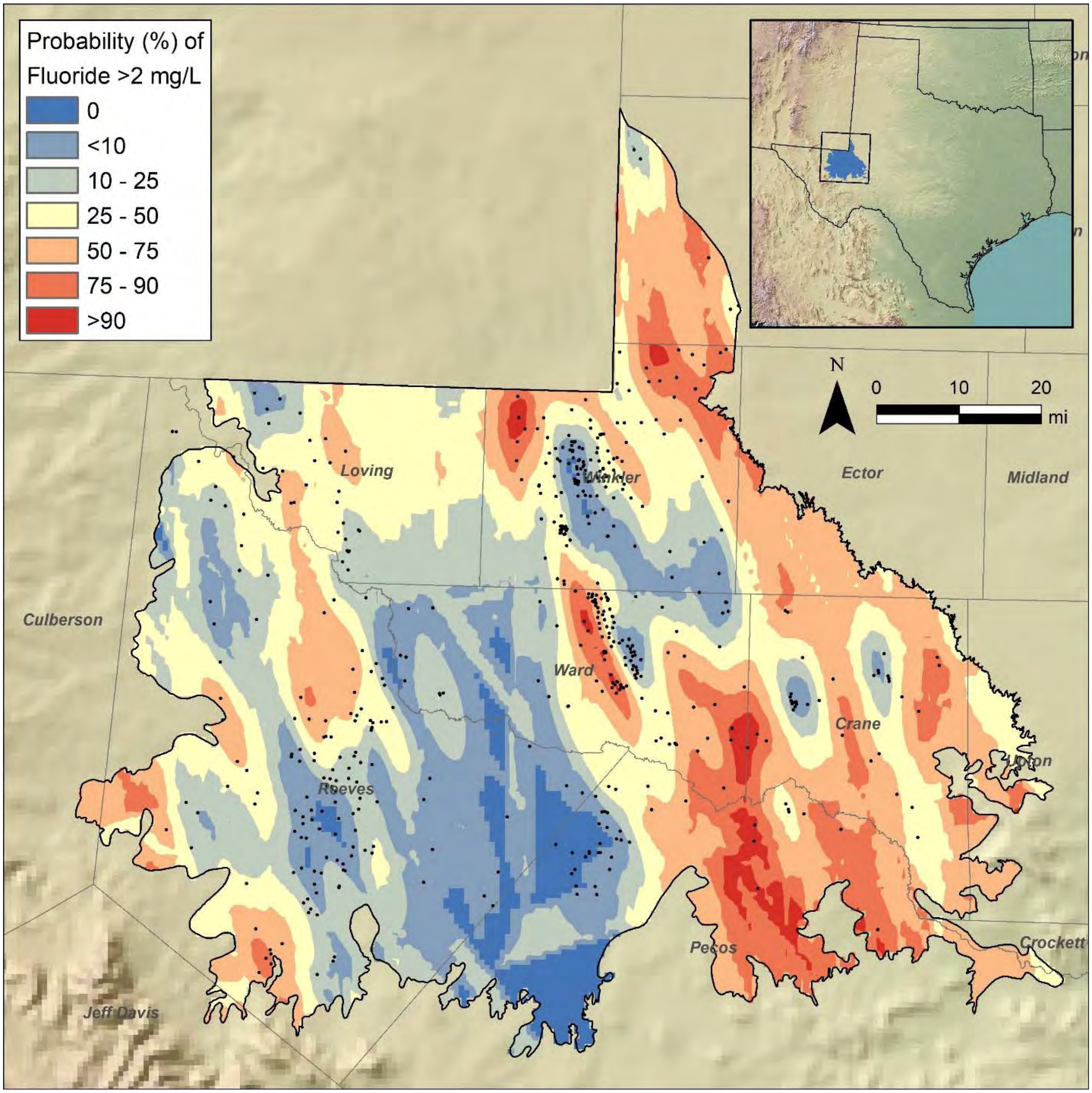

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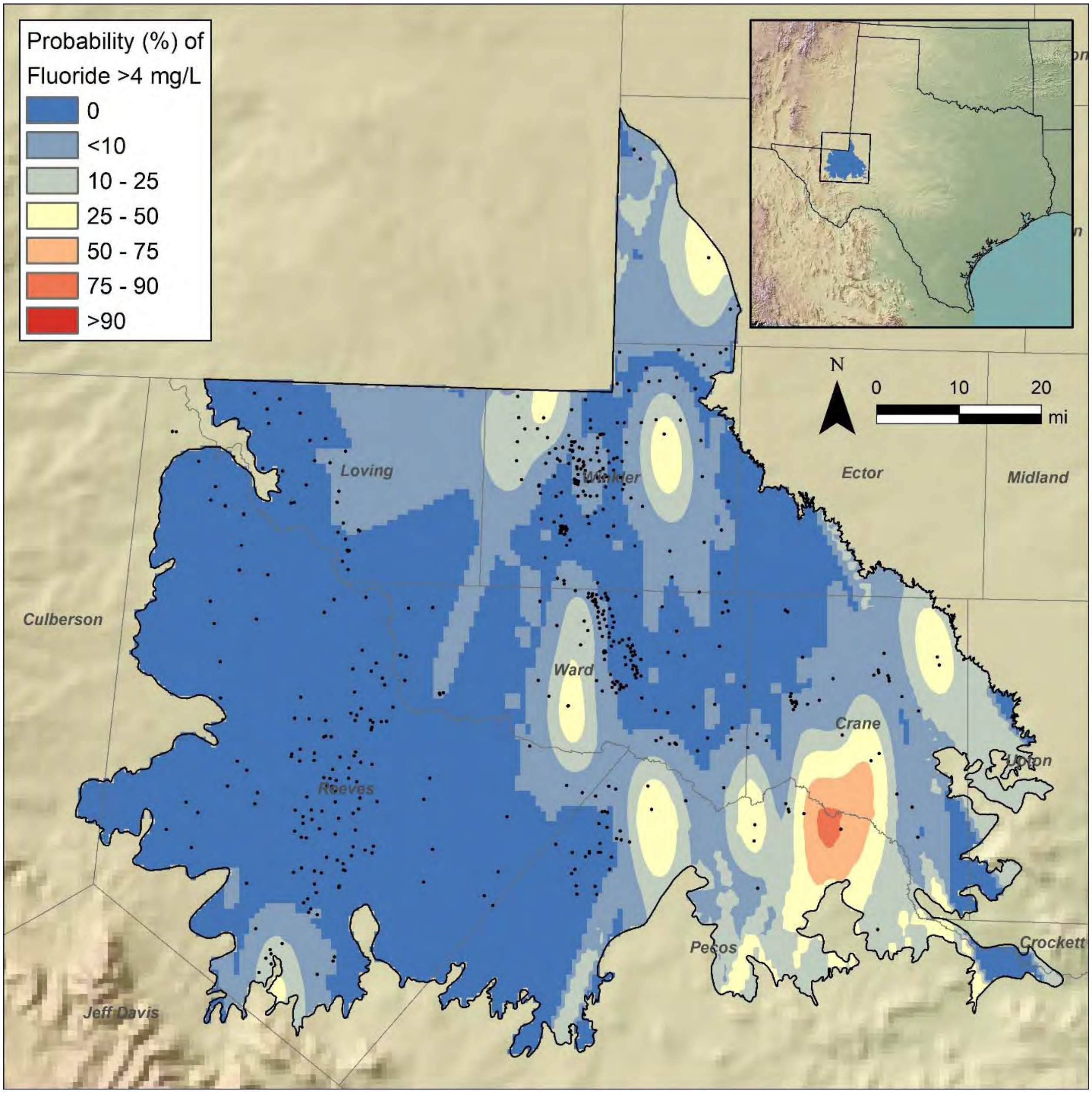

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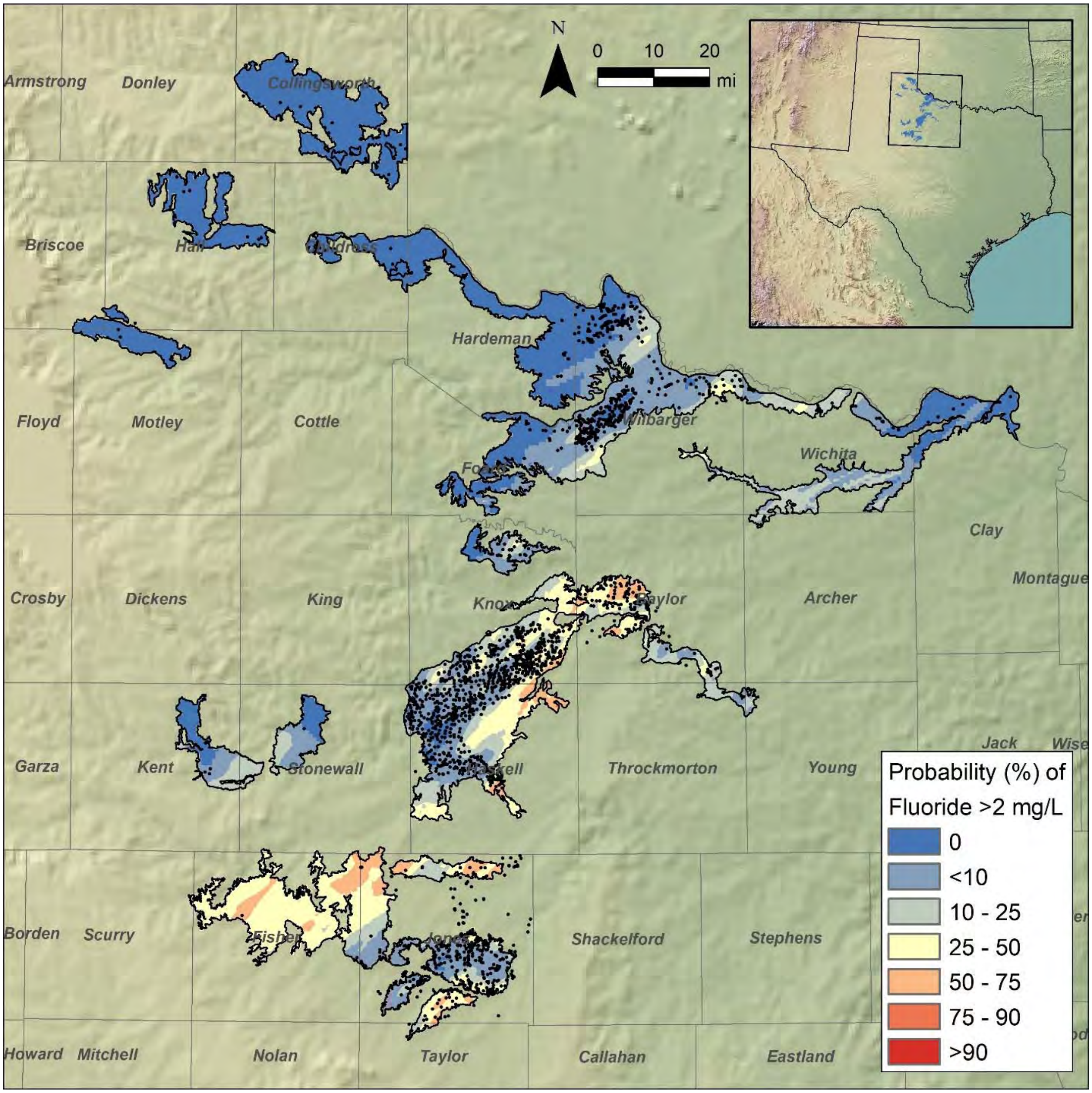

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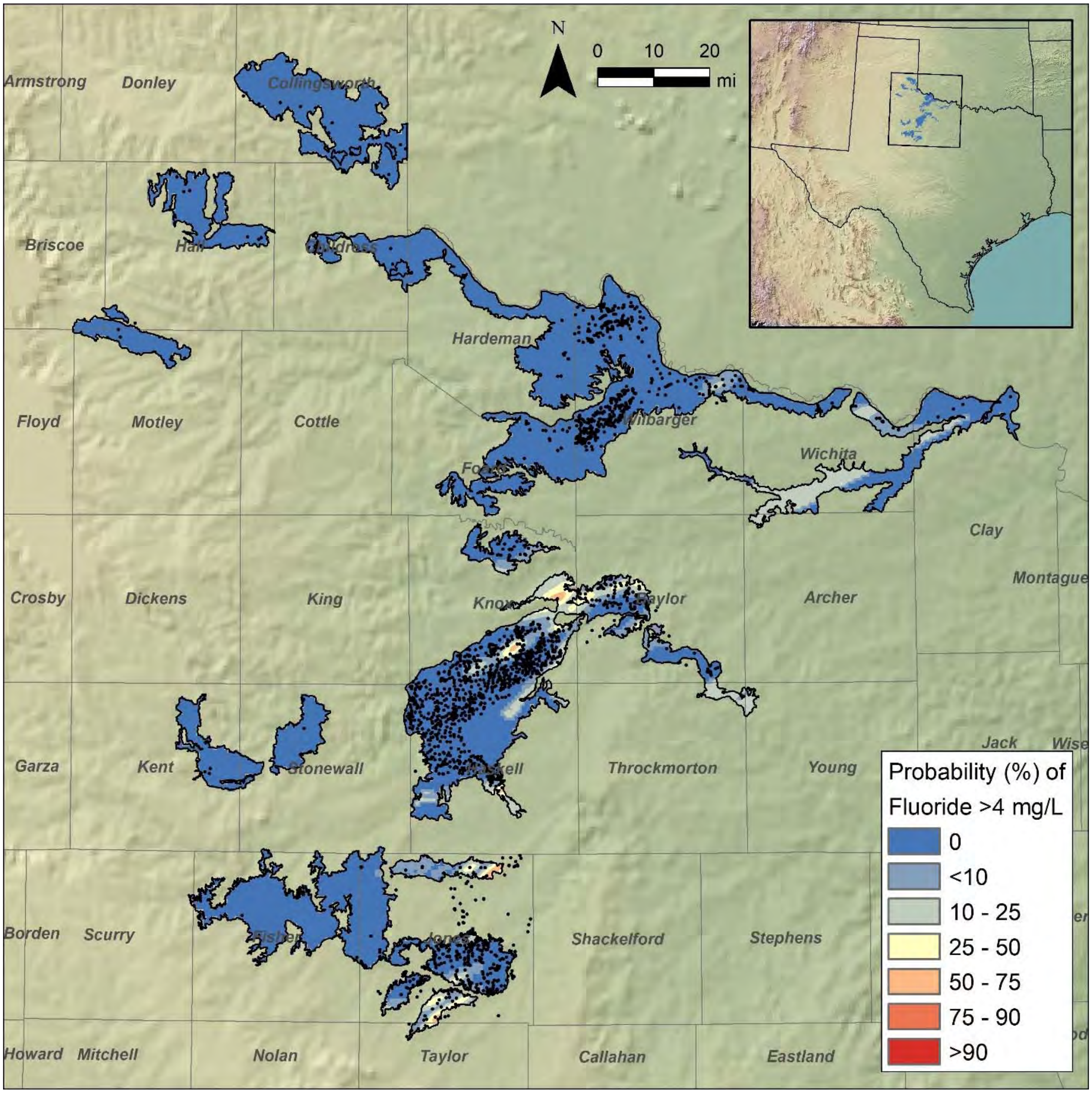

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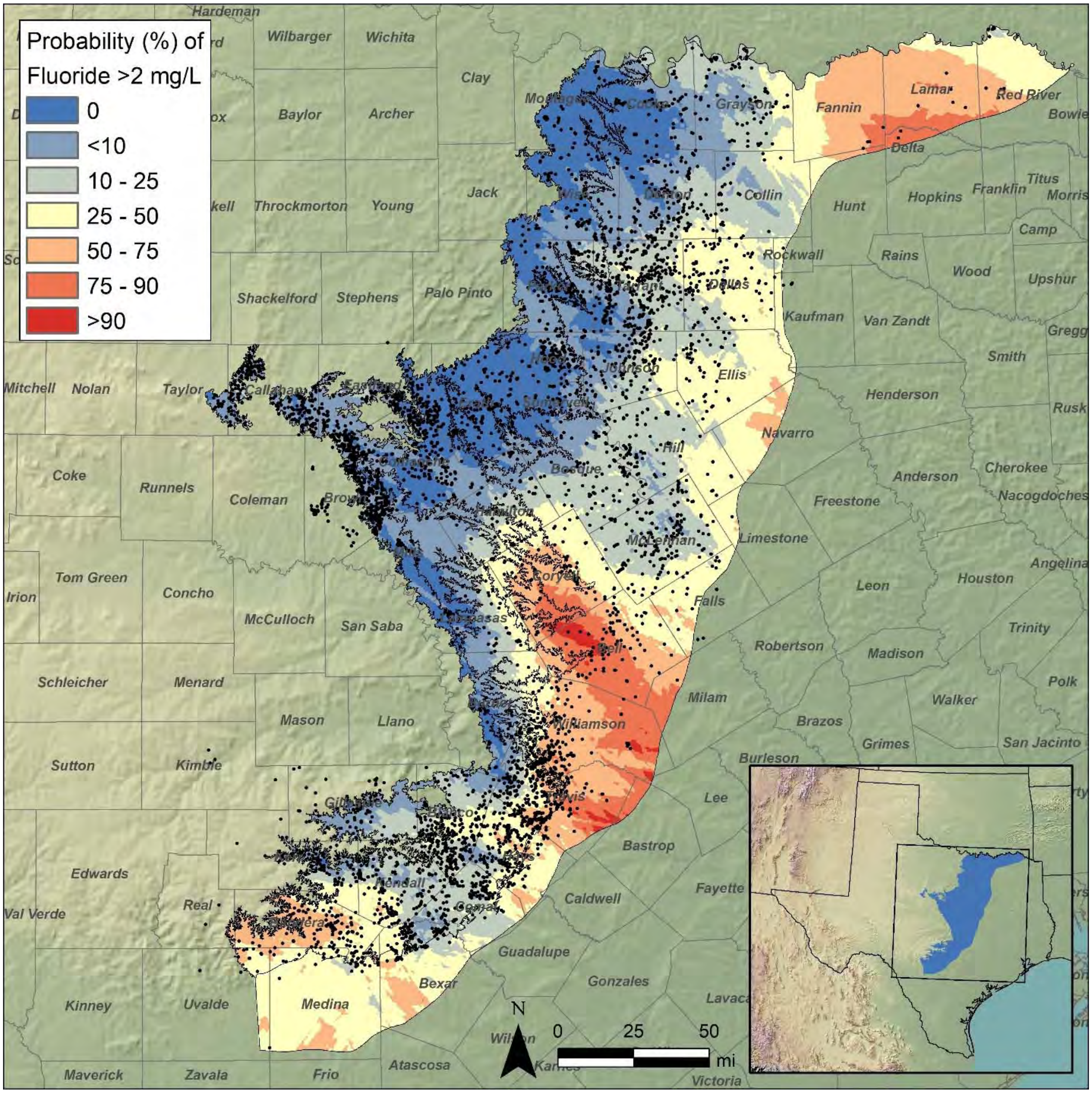
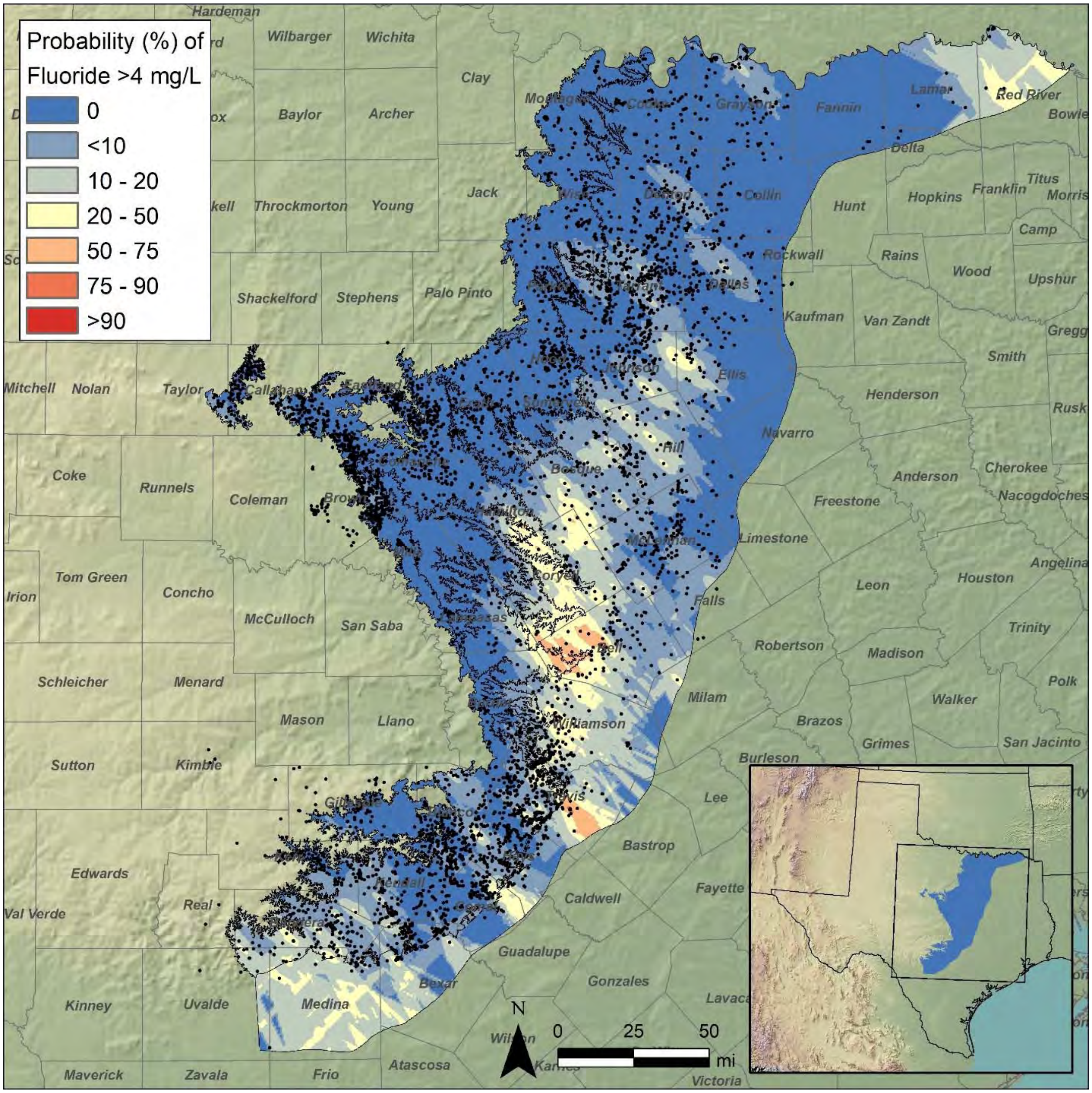


Figure 49. Trinity aquifer probability distribution of fluoride >2 mg/L



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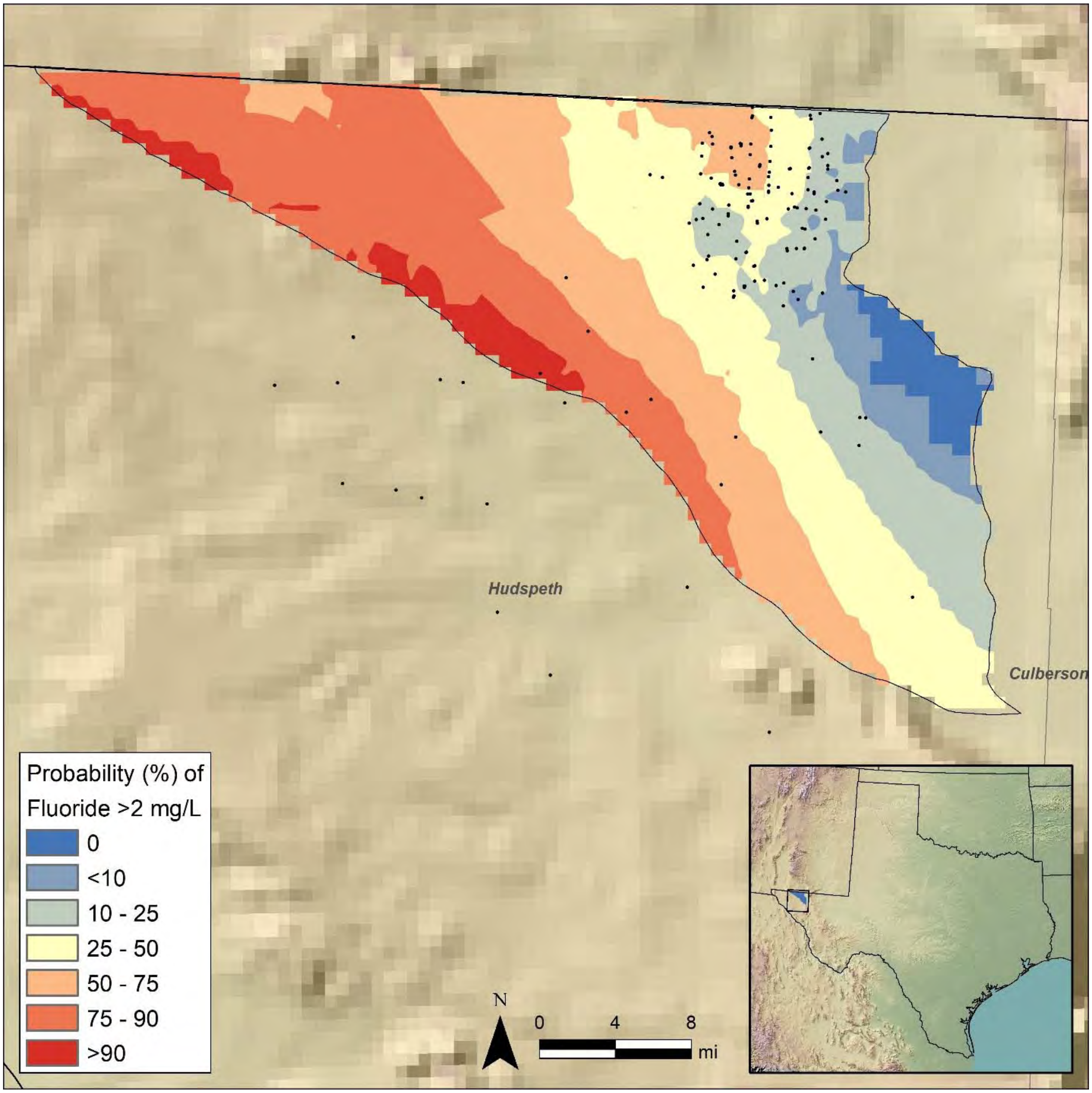

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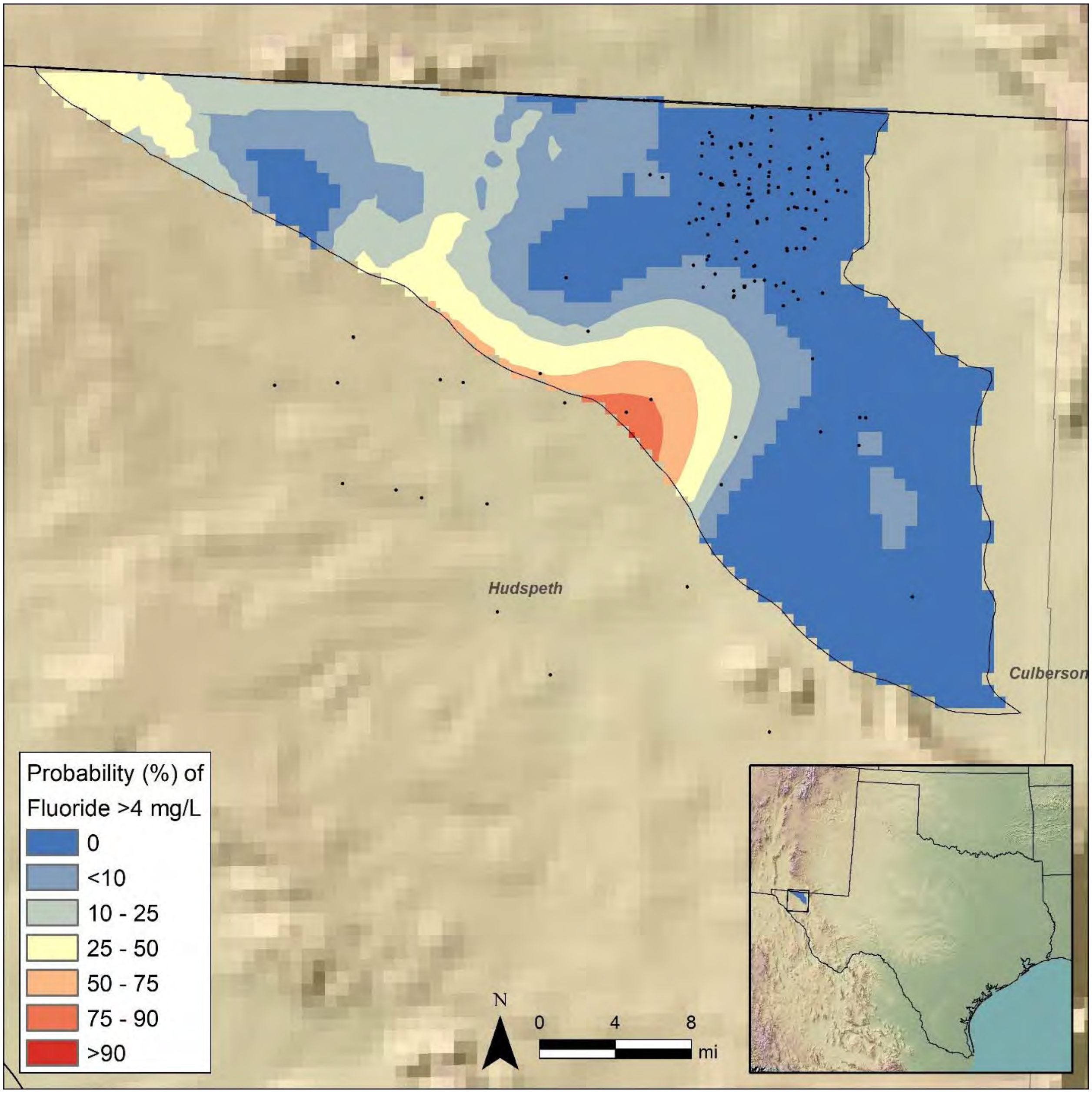
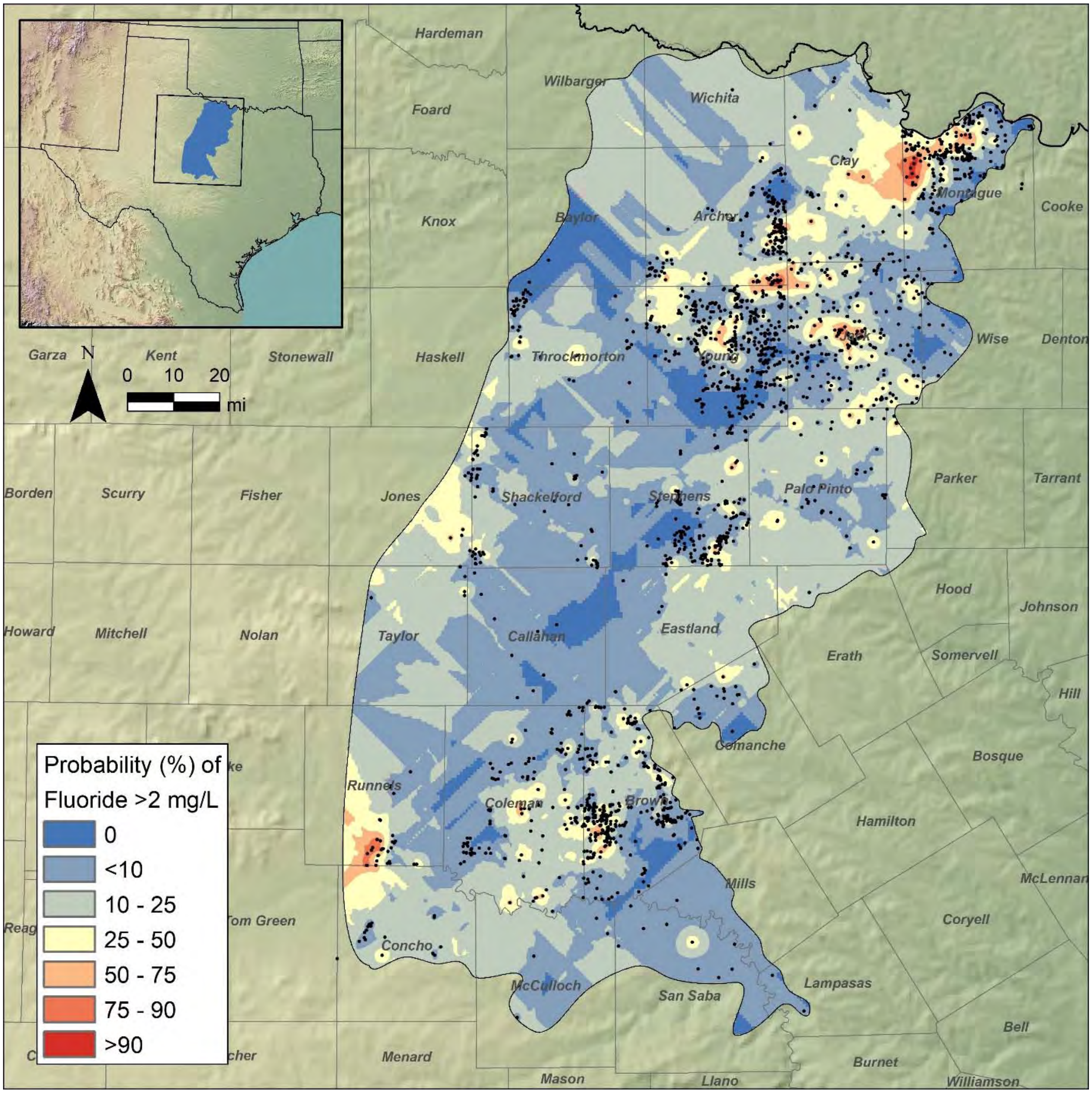


Figure 52. Bone Spring – Victorio Peak aquifer probability distribution of fluoride >4 mg/L.



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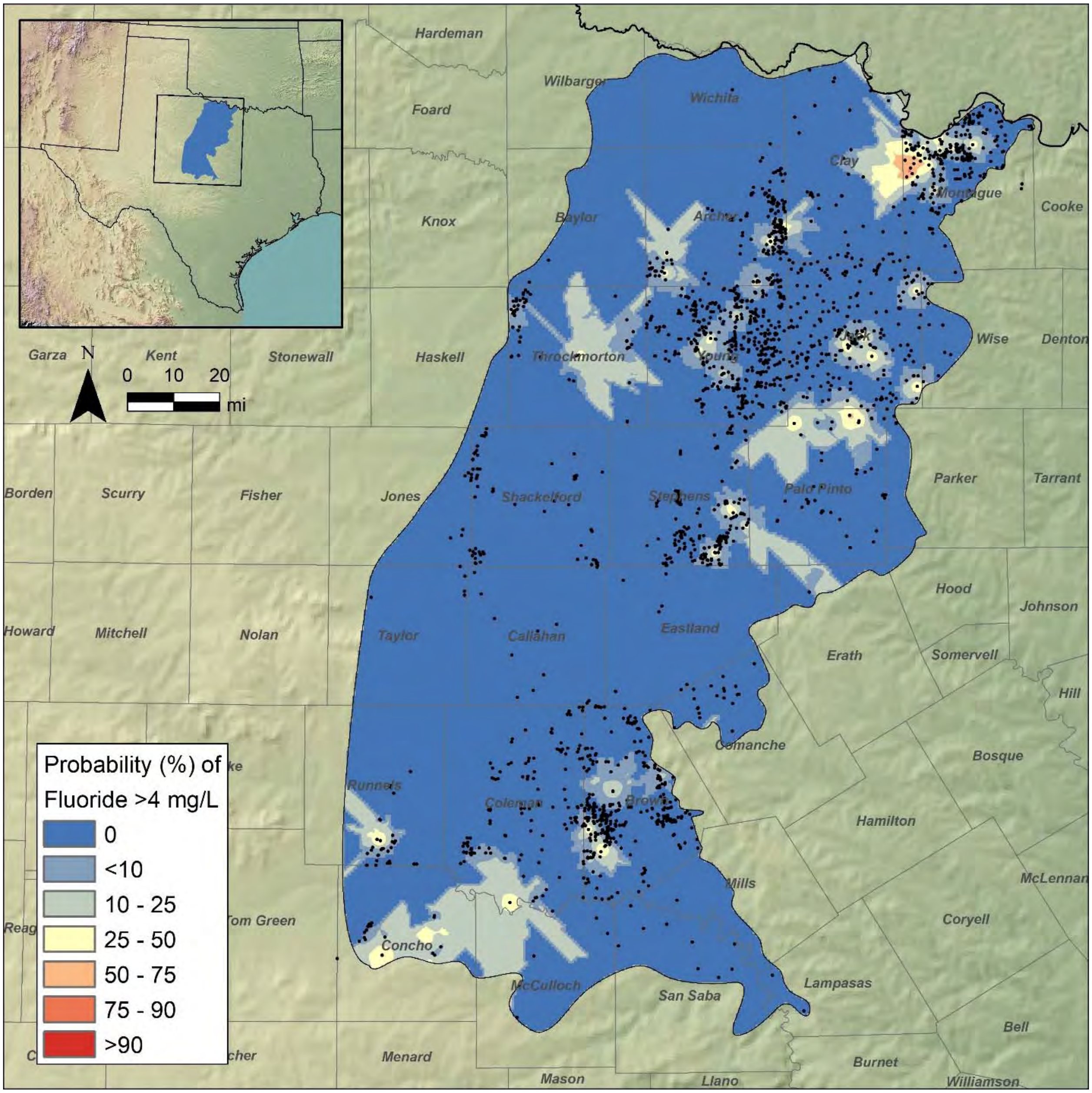

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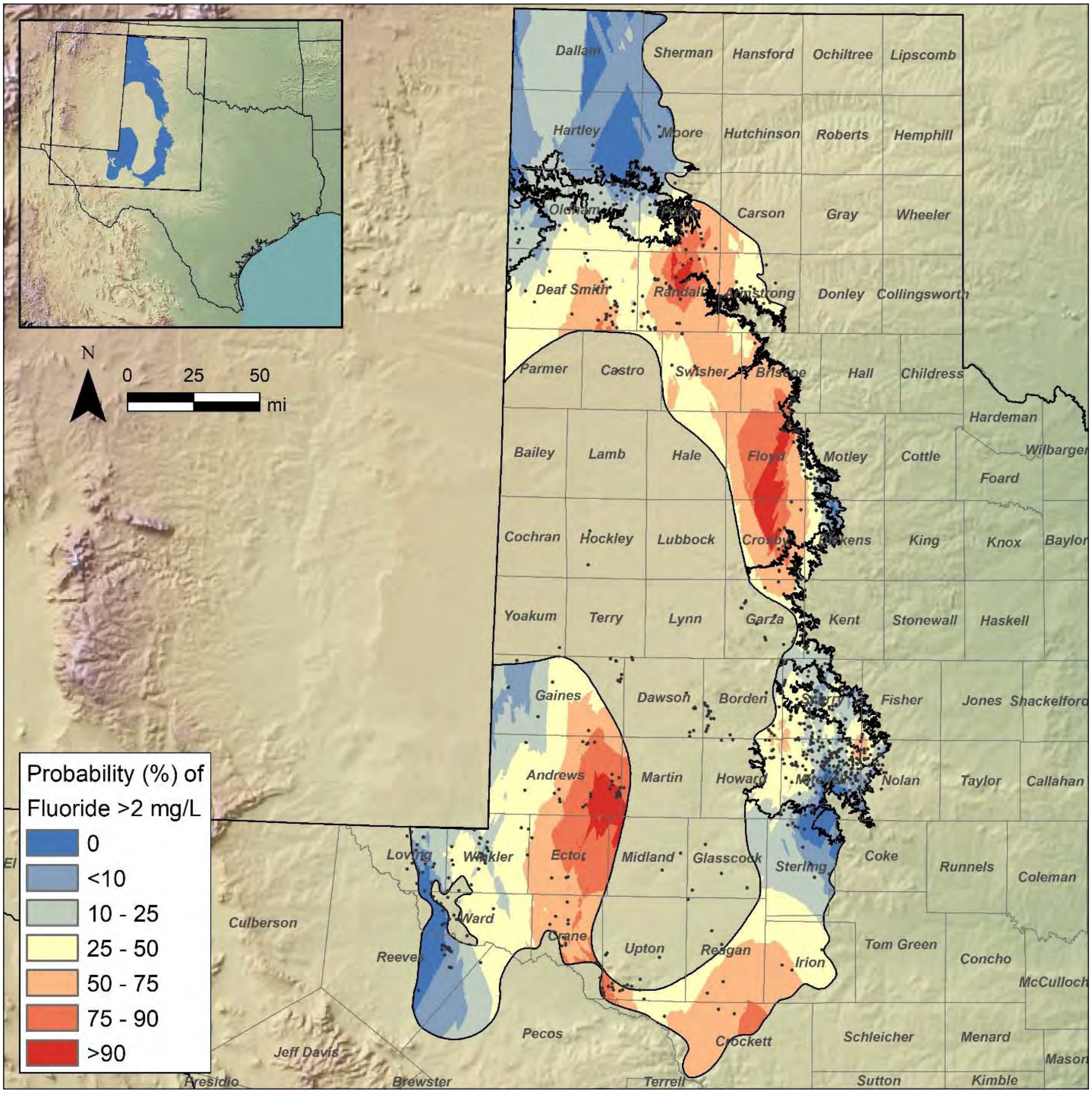

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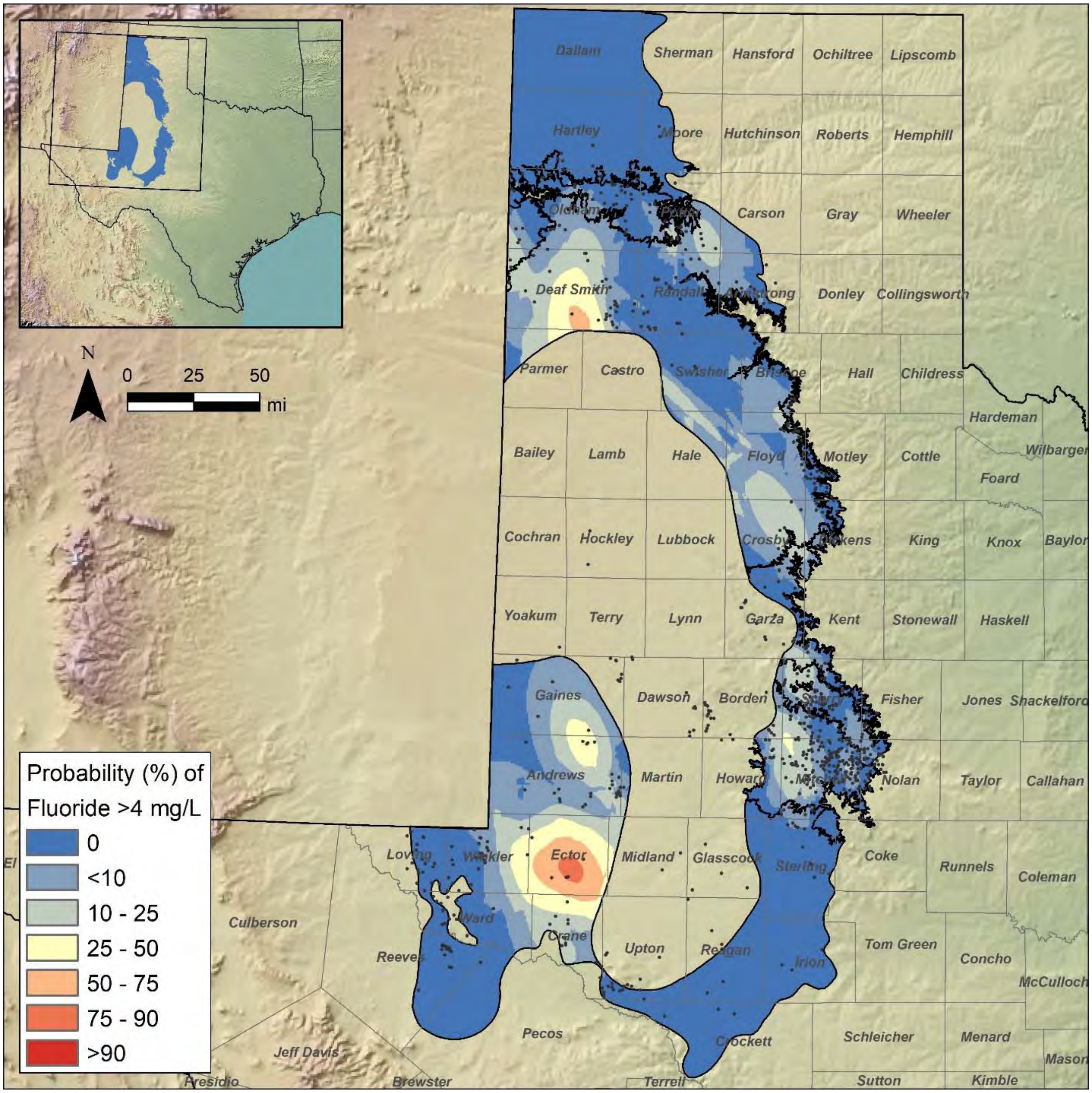

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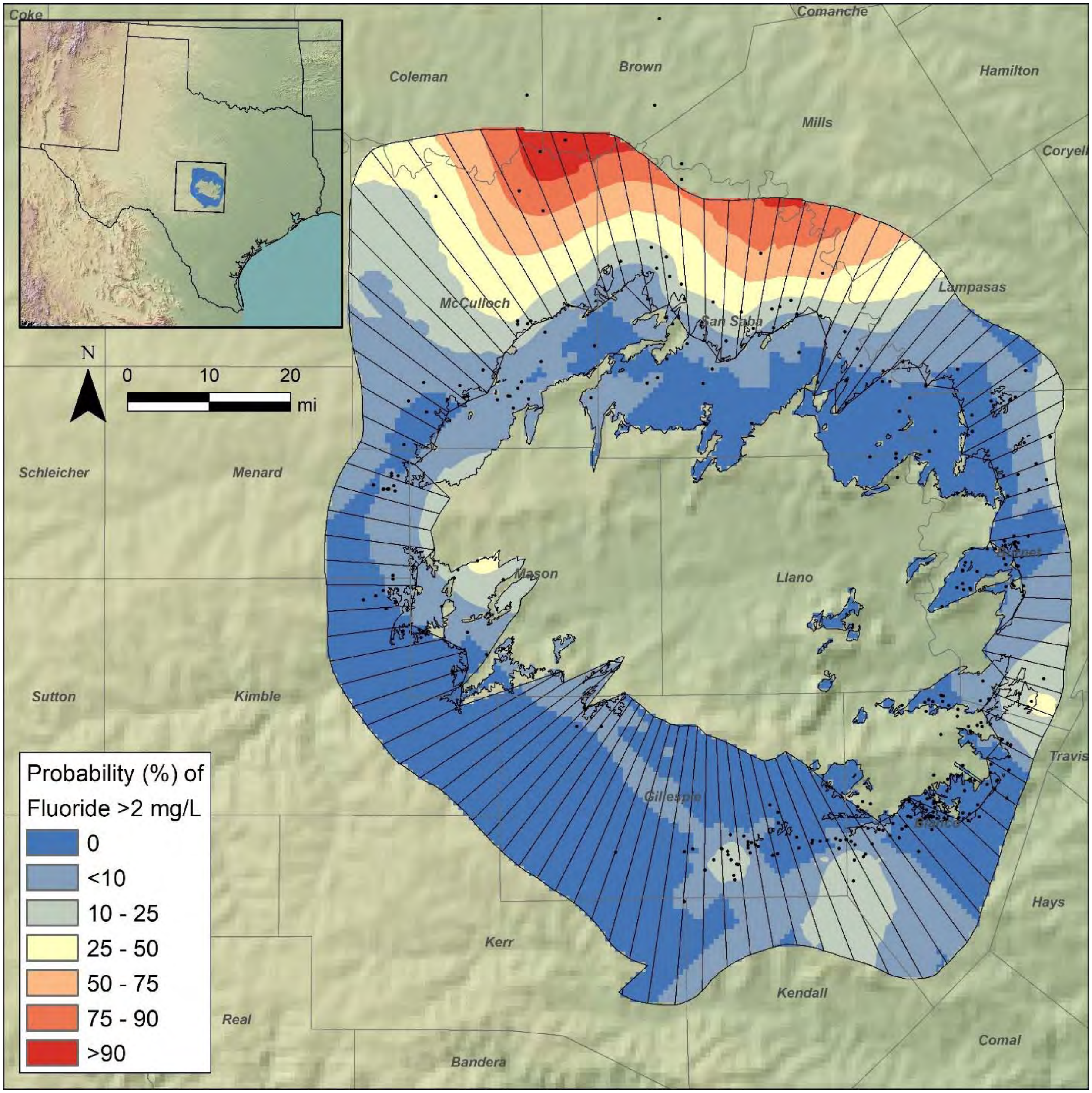

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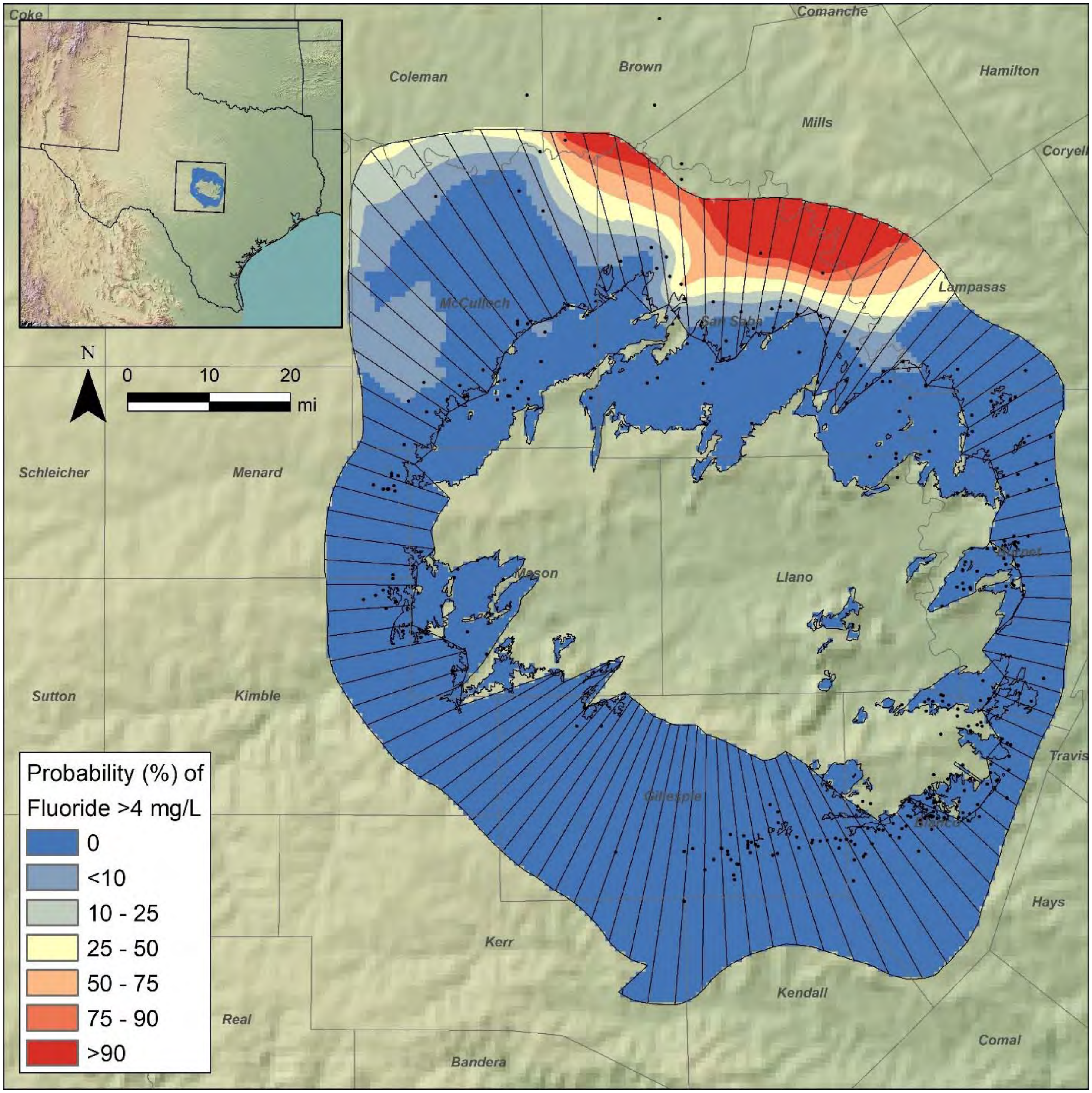

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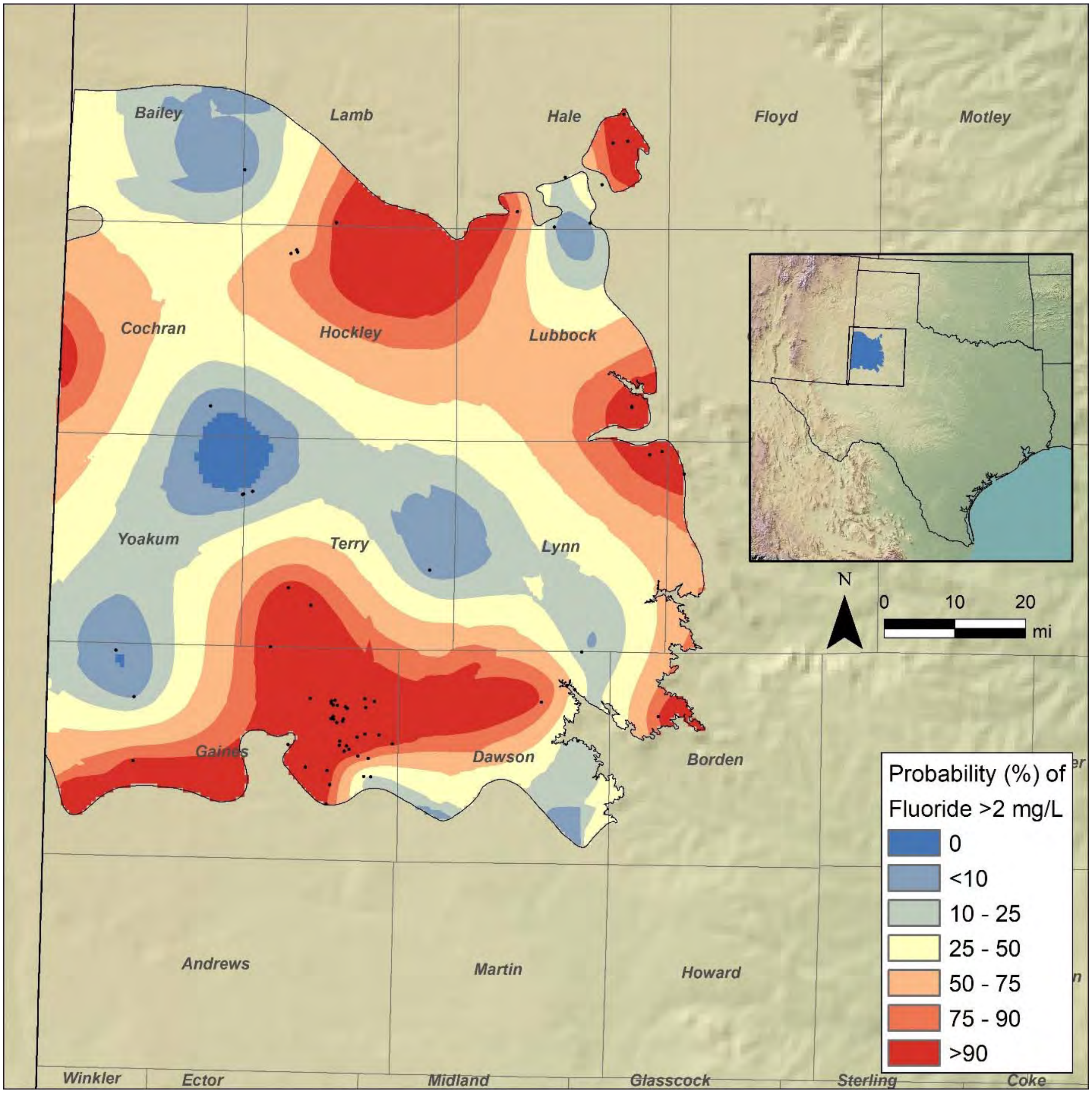

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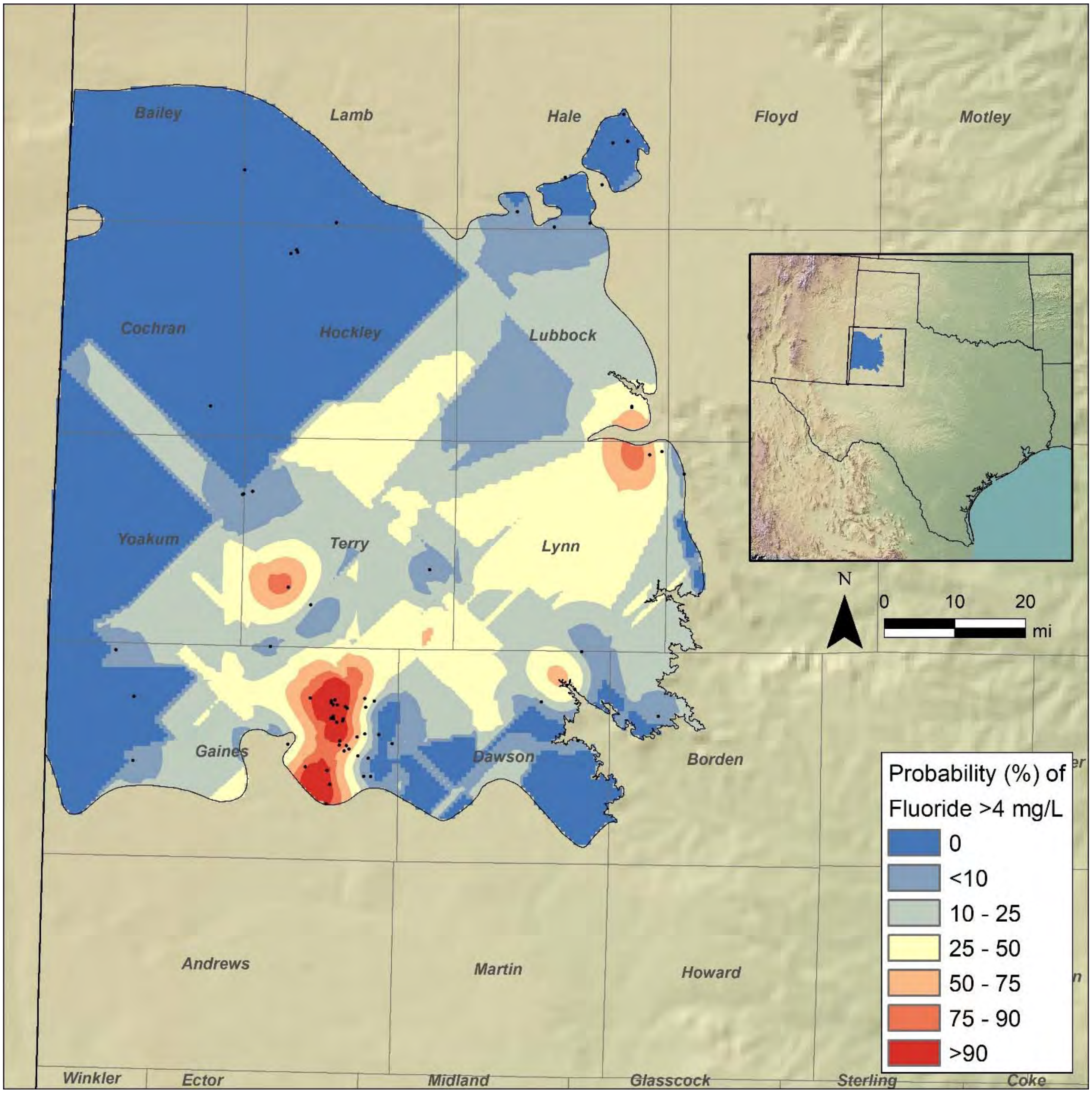

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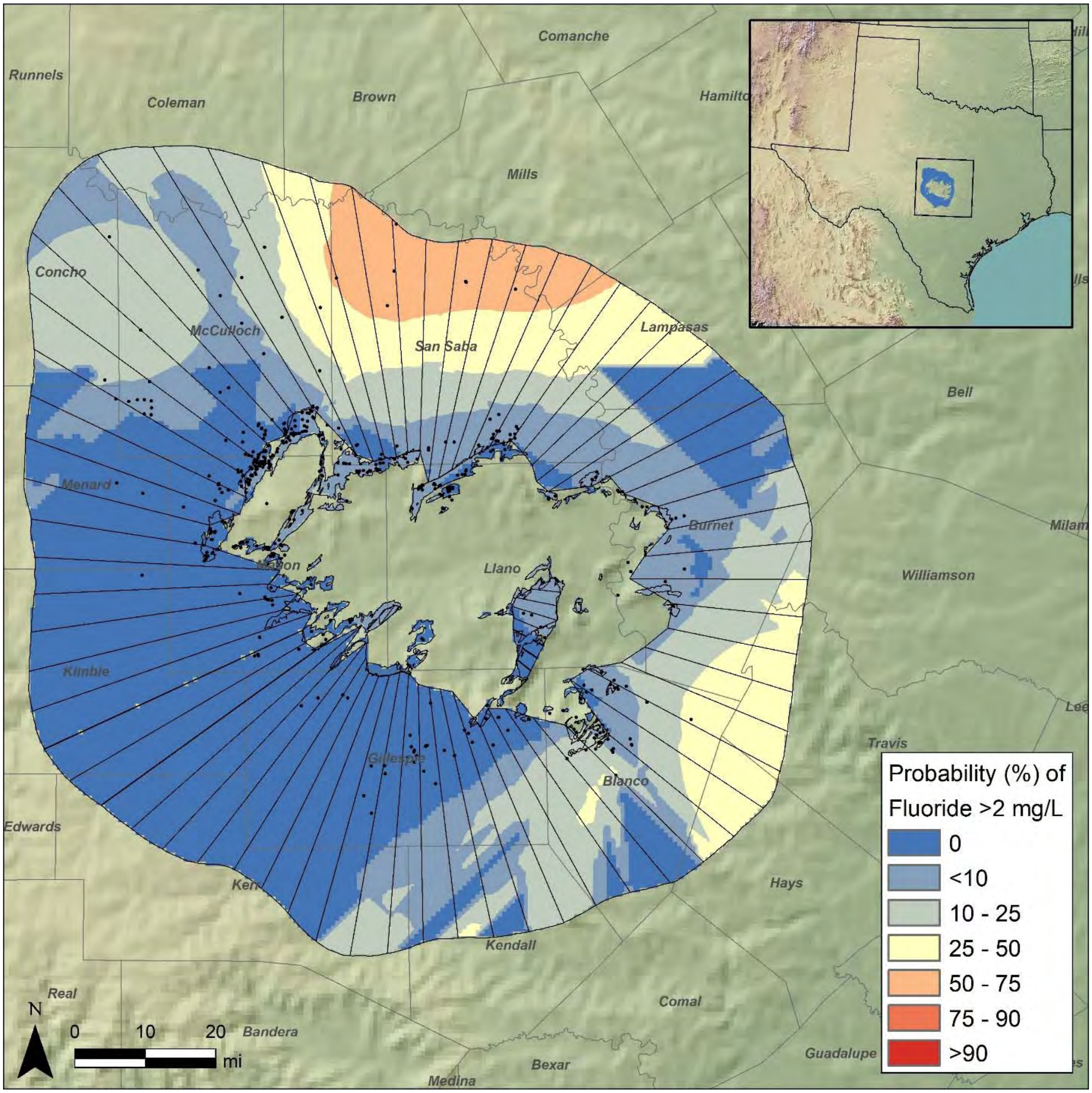

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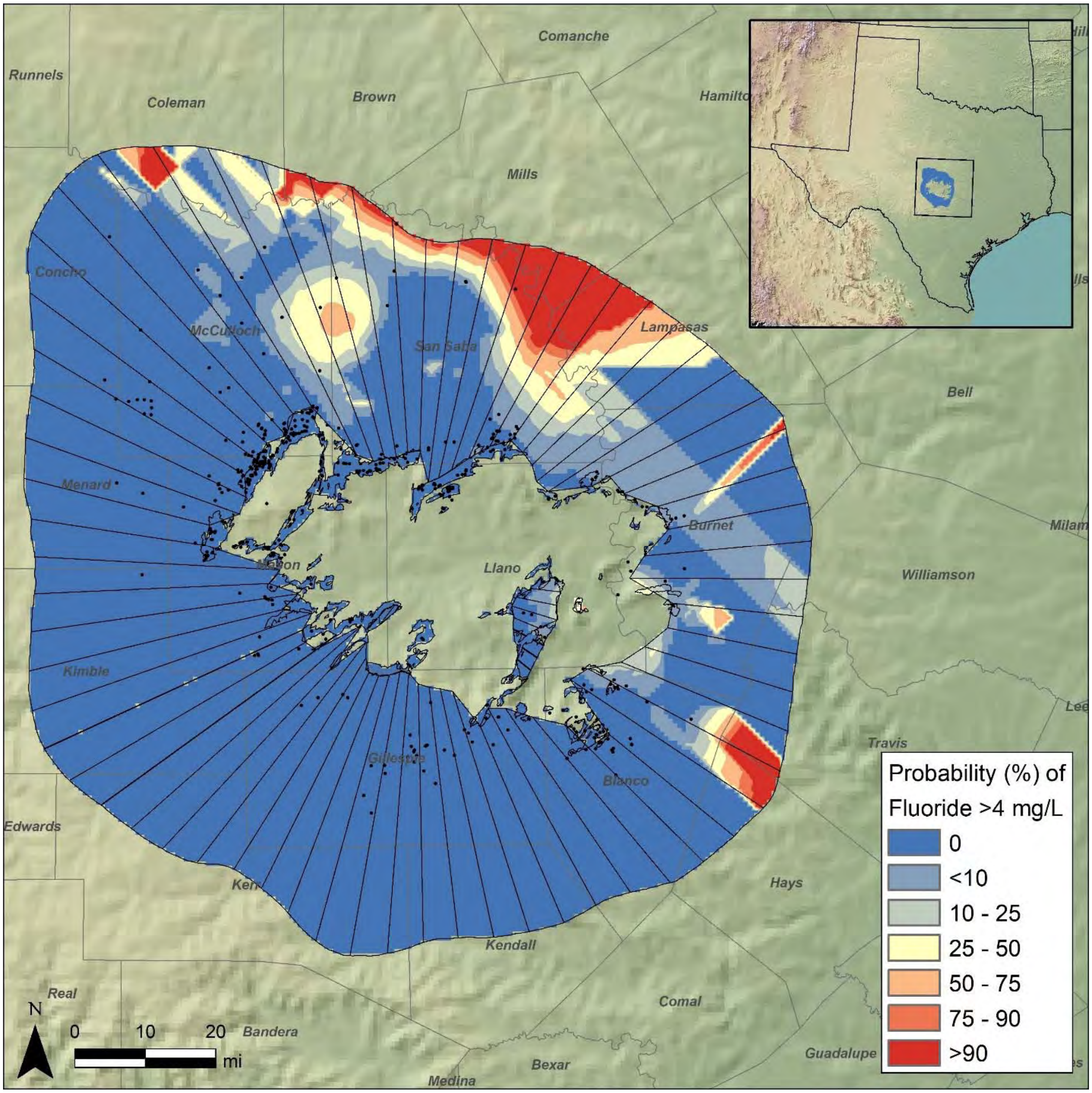

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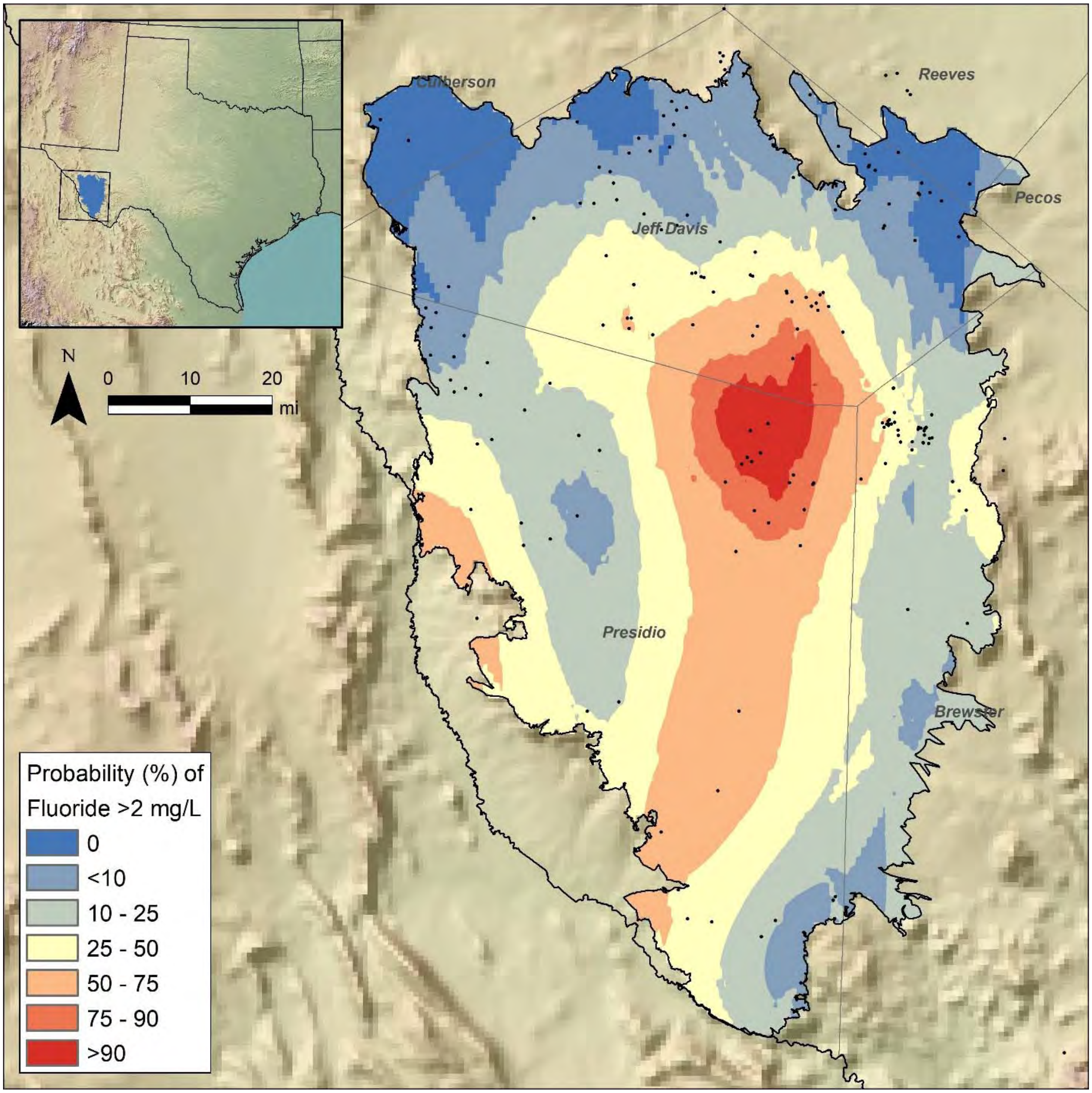

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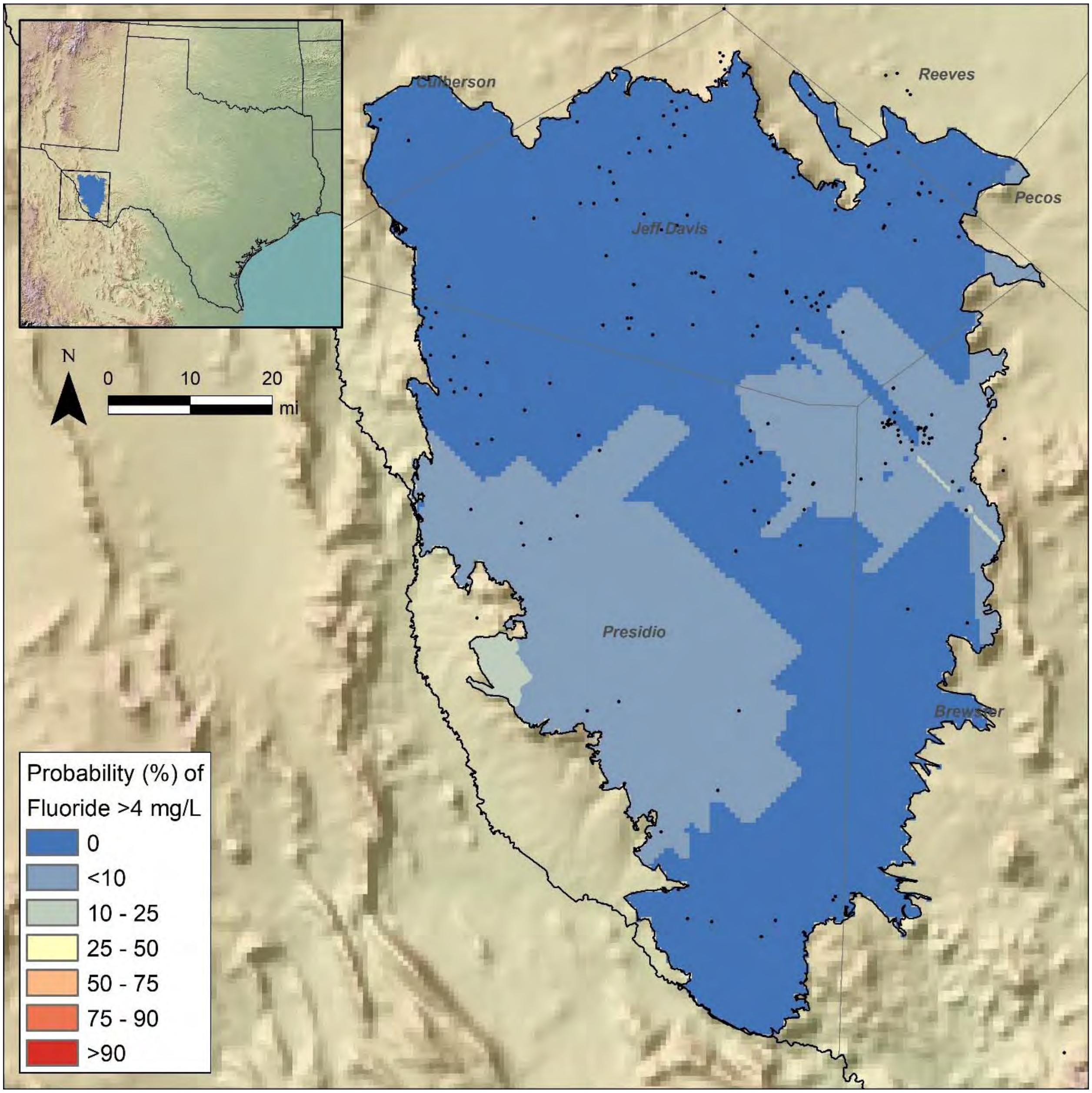

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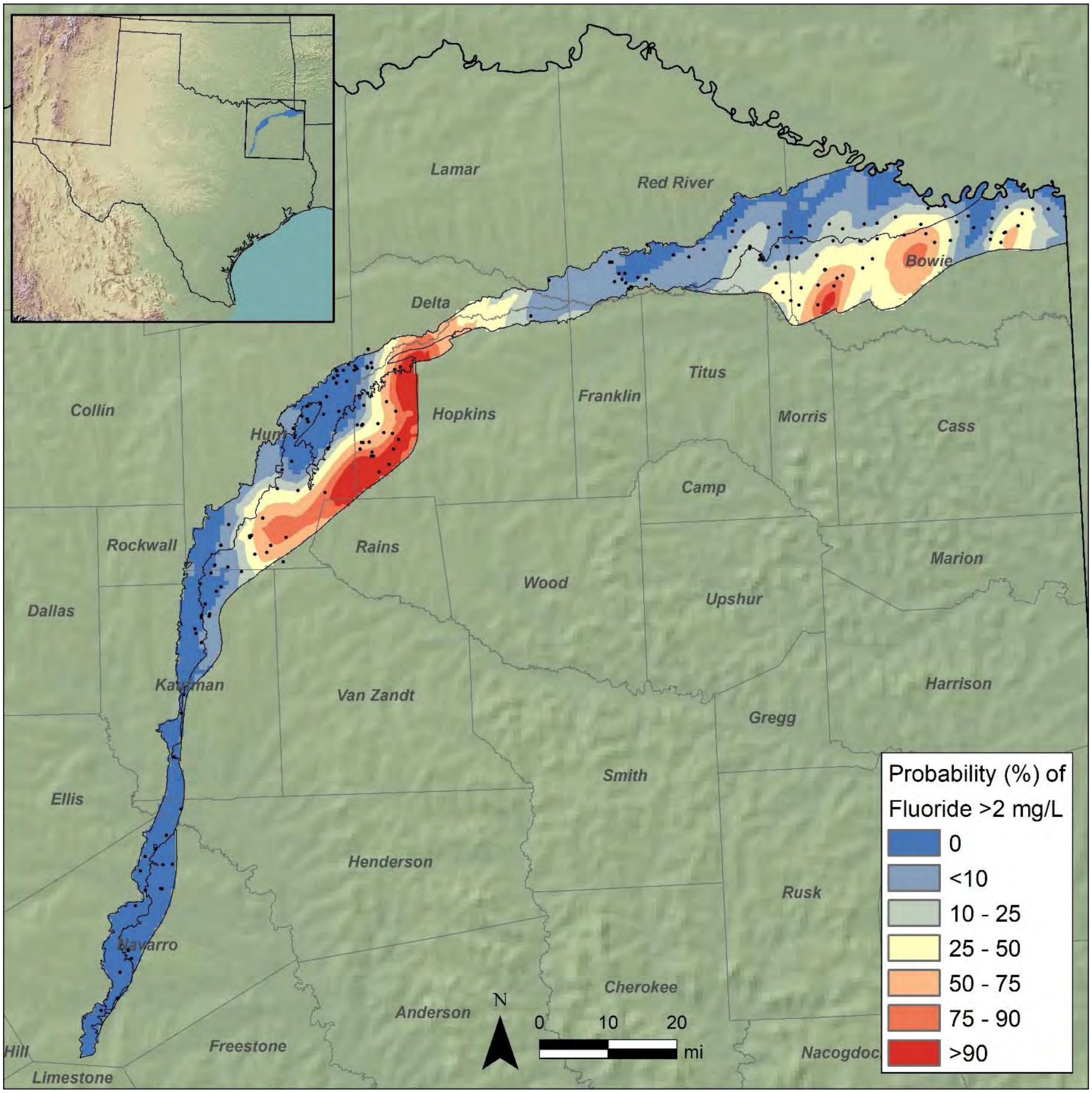

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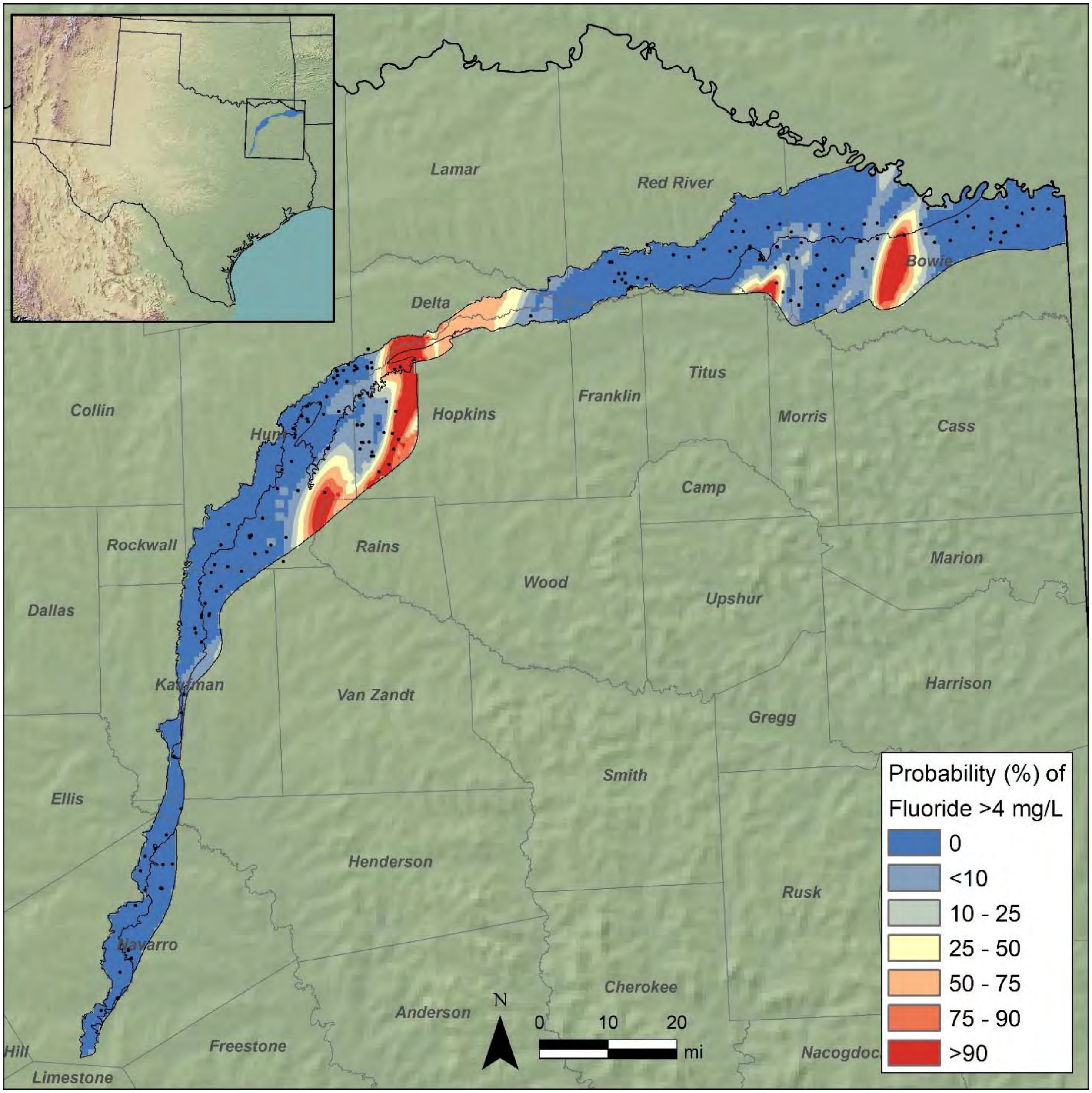

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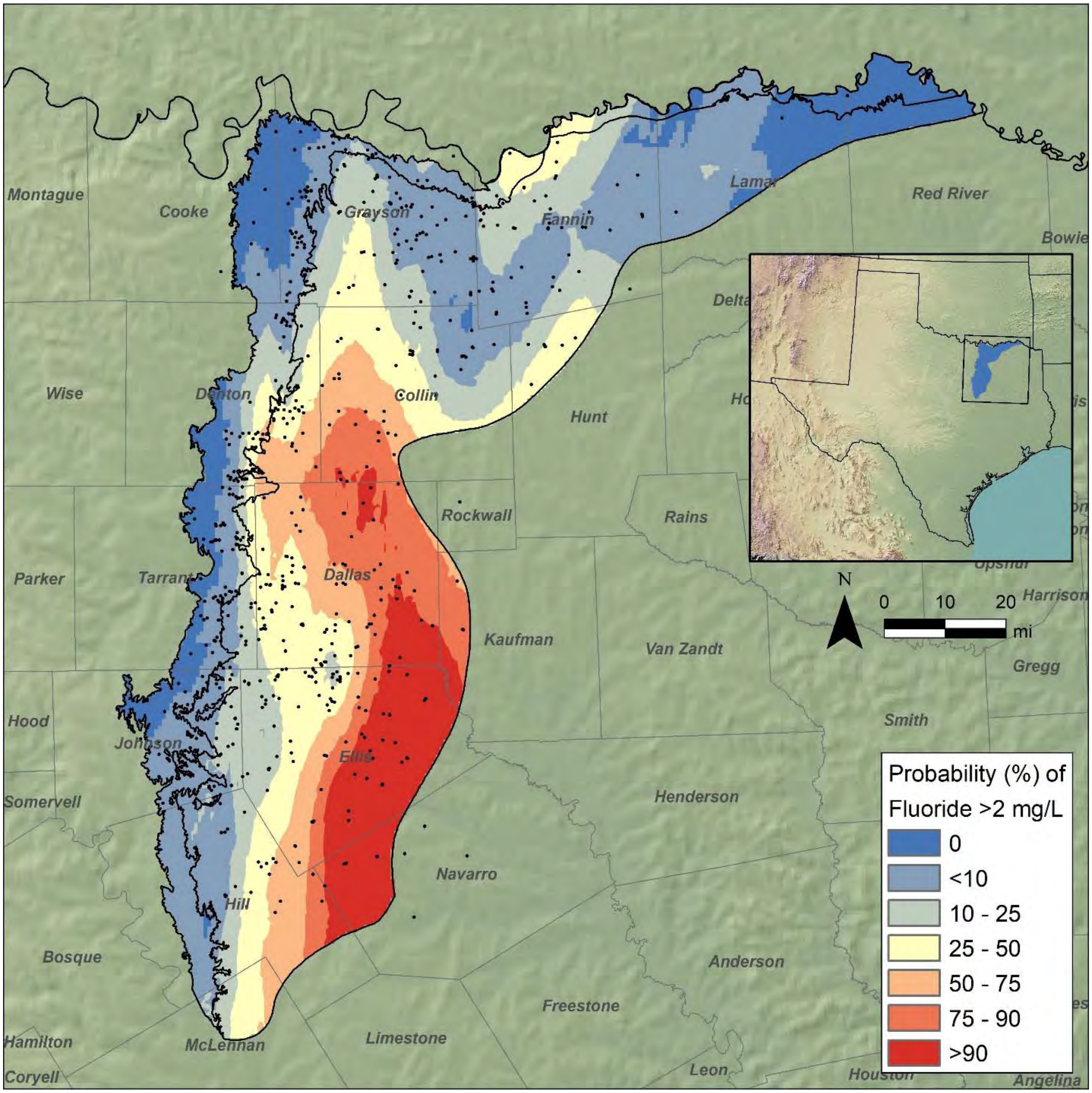


Figure 67. Woodbine aquifer probability distribution of fluoride >2 mg/L.

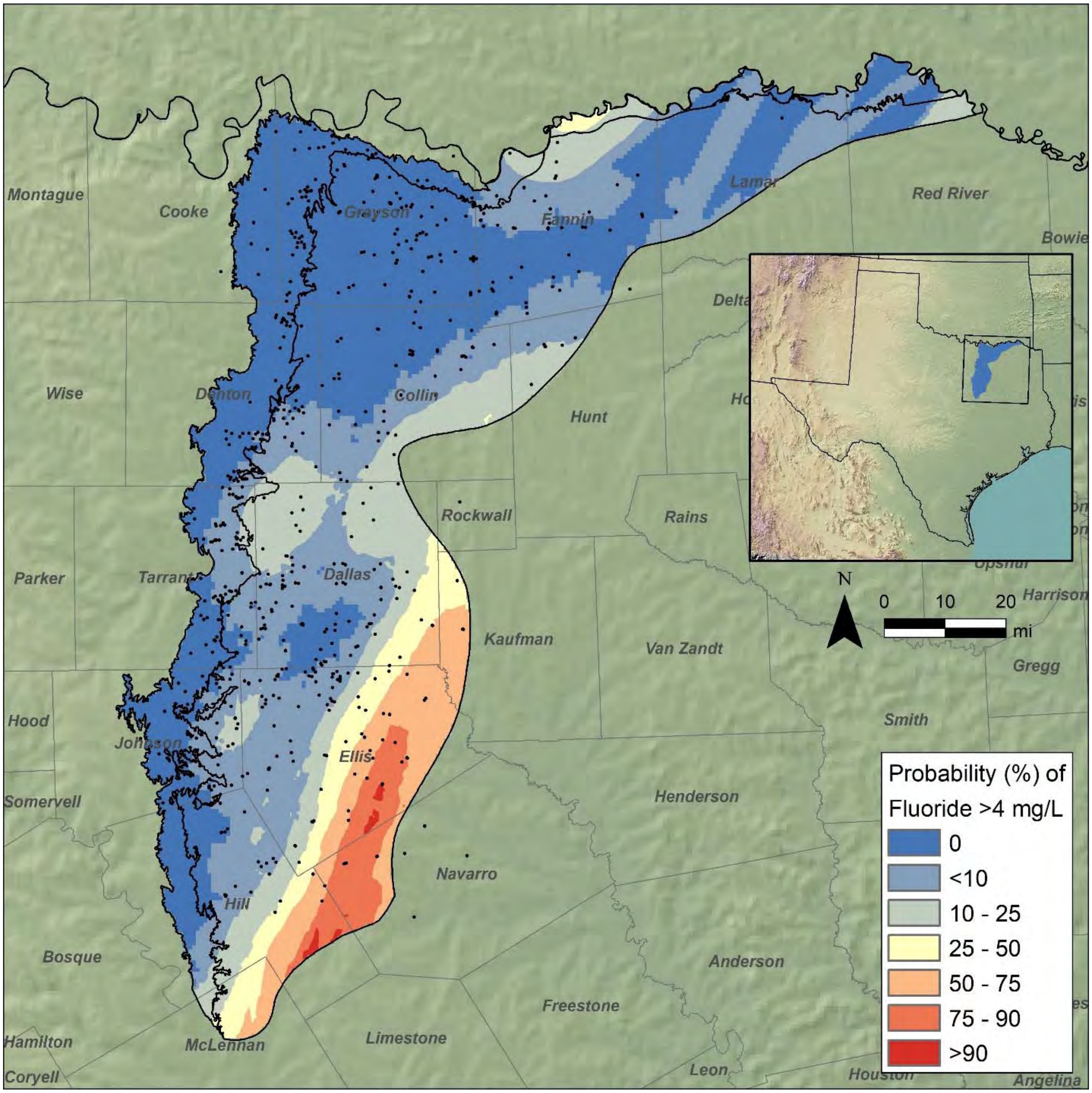
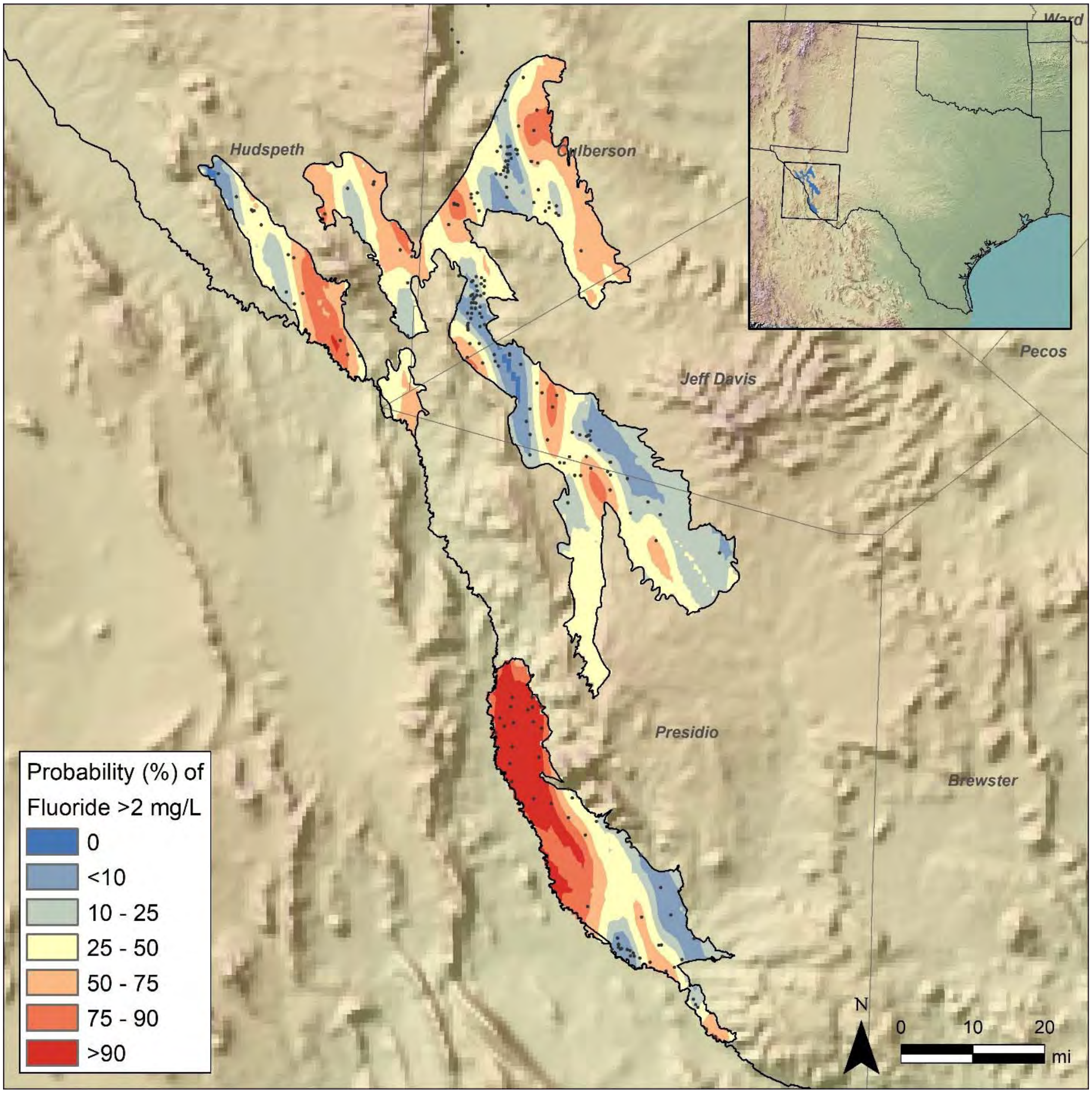


Figure 68. Woodbine aquifer probability distribution of fluoride >4 mg/L.



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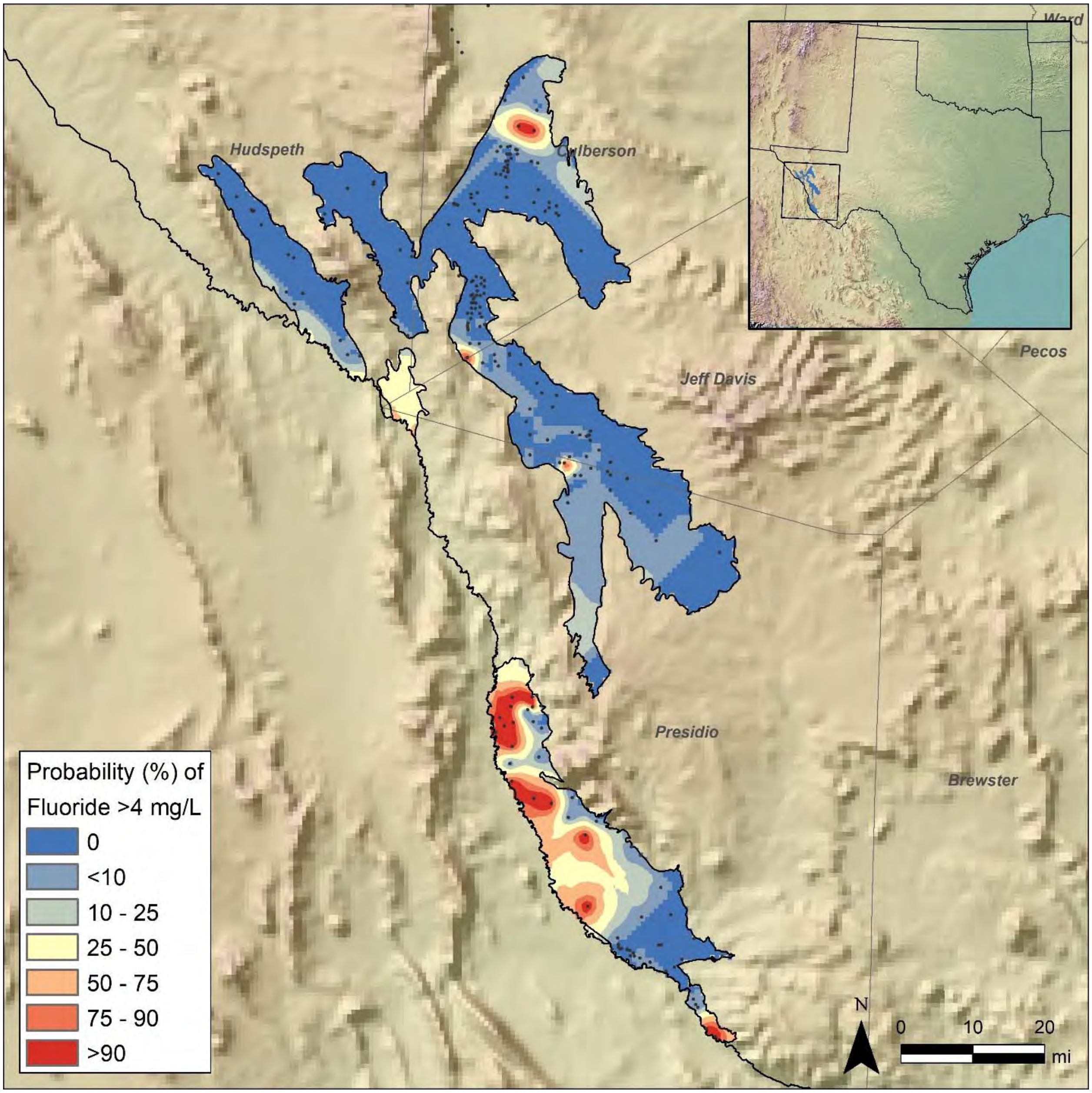

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