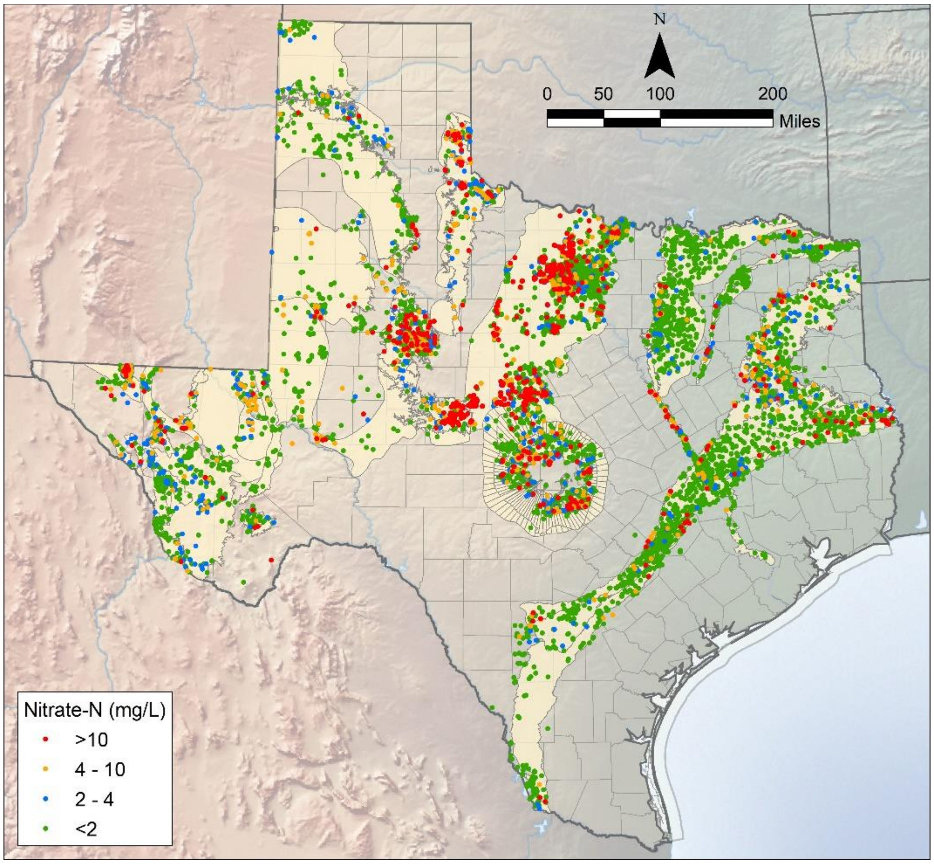
Updated Assessment of Nitrate in Groundwater and Public Water Supply Systems in Texas



by

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List of Abbreviations

BFZ	Balcones Fault Zone
CWS	Community Water System
EPA	Environmental Protection Agency
GW	Groundwater
HB	Health-Based
ISD	Independent School District
MCL	Maximum contaminant level
NCWS	Non-Community Water System
NTNCWS	Non-Transient Non-Community Water System
PWS	Public Water System
SDWIS	Safe Drinking Water Information System
SW	Surface Water
TCEQ	Texas Commission on Environmental Quality
TNCWS	Transient Non-Community Water System
TWDB	Texas Water Development Board
WHO	World Health Organization
WSC	Water Supply Corporation
WS	Water Supply

Executive Summary

This report provides an update to the 2022 report on groundwater nitrate distribution in major aquifers and noncompliant systems based on 2018 – 2020 data. The objectives of this study were to quantify the distribution of groundwater nitrate in the minor aquifers of Texas and to analyze the nature and persistence of nitrate-N Maximum Contamination Level (MCL) exceedances for Community Water Systems (CWSs) in Texas. Groundwater nitrate data were compiled from the Texas Water Development Board database. Drinking water data for all CWSs were compiled from Texas Commission on Environmental Quality and EPA Safe Drinking Water Information System databases.

Where sufficient data were available, the spatial distribution of elevated nitrate concentrations was mapped by aquifer using indicator kriging based on two threshold concentrations: 4 mg/L representing the upper limit of background nitrate-N levels and 10 mg/L, the primary MCL set by the US EPA for health purposes. EPA data were used in the analysis of MCL historical violation persistence during 2003 – 2022 and currently noncompliant CWSs during Jan 2022 – Jun 2023.

Results show that a total of 747 groundwater wells completed in minor aquifers exceeded the nitrate-N MCL of 10 mg/L based on the TWDB groundwater database. This represents 9.1% of the most recent nitrate analyses from minor aquifer wells throughout the state. The exceedance rate for the collective minor aquifer wells is similar to that of major aquifer wells (7.8%), though excluding the Seymour major aquifer, which has an exceedance rate of 54.7%, the exceedance rate for the remaining major aquifers is 4.4% (Malito et al., 2022).

The median nitrate-N concentration was highest in the Lipan Aquifer (8.05 mg/L), followed by the Bone Spring – Victorio Peak (median 4.33 mg/L), Blaine (3.78 mg/L), and the Rustler (3.66 mg/L) aquifers. A total of 1,474 minor aquifer samples exceeded the background level of 4 mg/L nitrate-N, representing 18% of all samples. Concentrations at the 95th percentile exceeded 4 mg/L for all minor aquifers except the Woodbine and Rita Blanca aquifers. Aquifers with the highest exceedance rates for the 4 mg/L background level include the Lipan (61%), Bone Spring – Victorio Peak (46%), Blaine (35%), Edwards-Trinity (High Plains) (35%), and Rustler (34%) aquifers.

We analyzed annual CWS data for 2003 – 2022 to characterize the nature and persistence of historical MCL violations and compared system characteristics with those that are currently out of compliance, i.e. during Jan 2022 – Jun 2023. There were 147 CWSs that were historically out of compliance during at least one year and 21 systems are no longer active. The 126 currently active noncompliant systems collectively serve ~255,000 people, though historically during any one year, about 40,000 people were affected by MCL violations. Of the currently active systems, 107 (85%) serve populations ≤3,300 people. The persistence of violations is greatest among the 74 smallest systems serving ≤500 people, for which violation periods average 5.8 years.

There are 50 systems that are currently out of compliance (Jan 20022 – Jun 2023) and they tend to be smaller and have more persistent violations than the historical group of CWSs. While the current affected population (45,000 people) is similar to the historical average, 96% of the affected systems serve ≤3,300 people and violation periods average 8.3 years for the smallest systems serving ≤500 people. Most of the affected systems (88%) report groundwater as their primary source, while the remaining report only surface water or a combination of surface water and groundwater.

Introduction

Nitrate contamination is widely distributed in groundwater throughout the U.S. (Burow et al., 2010). Nitrate-N levels in drinking water are important because of their negative health impacts, such as blue bay syndrome, cancers, and thyroid disease (Ward et al., 2018). The upper limit of nitrate-N of 10 mg/L (Maximum Contaminant Level) was established to reduce negative health impacts related to nitrate-N toxicity. Results from a recent study indicate that Community Water Systems (CWSs) serving 5.6 million Americans have nitrate-N concentrations exceeding 5 mg/L based on data from the Safe Drinking Water Information System (SDWIS) database for 2010 – 2014 (Schaider et al., 2019).

Public water systems (PWSs) are regulated by the EPA. Many studies show widespread groundwater nitrate contamination across the U.S., especially in shallow or unconfined aquifers beneath agricultural land with high fertilizer application rates and well-drained soils (Pennino et al., 2017). Application of random forest modeling to groundwater nitrate violations shows that percent cropland, agricultural drainage, irrigation to precipitation and nitrogen surplus and surplus precipitation were the dominant drivers of nitrate contamination (Pennino et al., 2020). Analysis of trends in drinking water nitrate violations shows that the proportion of nitrate violating systems only varied slightly from 0.28% to 0.42% of all systems (1994 – 2009) followed by a decrease to 0.32% by 2016 (Pennino et al., 2017). The number of people served by violating systems decreased from 1.5 million in 1997 to 0.20 million in 2014. Occasional spikes in people served were often linked to a single large system in violation. Nebraska and Delaware ranked in the top in terms of proportion of violating systems (2.7% and 2.4%, respectively), while Ohio and California ranked top in terms of mean annual number of people served by violating systems (278,374 and 139,149 people, respectively) (Pennino et al., 2017).

The most recent study on groundwater nitrate conducted by the Bureau of Economic Geology examined nitrate contamination in public water systems and in major aquifers in the state to assess spatial distribution of nitrate levels (Malito et al., 2022). Results from that analysis showed that about 8% of the most recent analyses from wells throughout the state exceeded the nitrate-N MCL of 10 mg/L based on TWDB data. Nitrate violations in CWSs were found primarily in the Ogallala (51%) and Seymour (26%) aquifers with lower percentages in other aquifers. Analysis of CWSs throughout the US indicated that Texas ranked number 1 in terms nitrate-N violations, primarily (34) in major aquifers and 1 in a minor aquifer based on 2018 – 2020 data. The population impacted by nitrate-N MCL exceedances from CWSs totaled ~32,116 people (0.11% of the 2020 population) whereas domestic wells with nitrate-N > 10 mg/L accounted for ~46,069 people (0.16 % of the 2020 population).

A variety of approaches are available to return CWSs to compliance with respect to nitrate, including non-treatment options (new well, connecting to nearby system) or treatment options, blending, ion exchange, reverse osmosis, electrodialysis, and engineered biological treatment (WSDOH, 2018; EPA, 2021). There are advantages and disadvantages to the various treatment options. Different levels of pretreatment may be required for various approaches. Raw water quality may also affect the performance of different options, such as competing ions. Ion exchange resins work like tiny magnets that adsorb nitrate from water in the treatment system. Reverse osmosis involves pushing nitrate-contaminated raw water through a semi-permeable membrane that stops nitrate from passing through. Electrodialysis systems involve application of a direct electric current to transport ions through membranes, which retain nitrate. Biological denitrification involves engineered systems that use of bacteria to convert nitrate to nitrogen gas under anoxic conditions.

This report has two broad objectives:

1) map spatial probabilities of nitrate contamination in the minor aquifers of Texas to supplement similar maps of primarily major aquifers in a previous report, and

2) analyze the nature and persistence of nitrate contamination in community water systems.

In the previous nitrate study in 2022 we mapped the spatial probability of nitrate in groundwater exceeding the MCL in the nine major aquifers of Texas and additionally one minor aquifer, the Lipan, which has ubiquitous elevated concentrations of nitrate (Malito et al., 2022). In the current report, we extend that mapping to include 17 of the remaining 21 minor aquifers in Texas that have sufficient data for the kriging methodology. Elevated groundwater nitrate-N levels represent a public health risk because groundwater is the primary source of water in Texas, accounting for 55% of the 14.7 million acre-feet of water used in the state in 2020. Managing high nitrate-N groundwater is challenging for small municipal CWSs because treatment is often the only option for mitigating noncompliance and most of these small CWSs have limited financial, managerial, and technical capacity to manage violations.

This report additionally characterizes the occurrence and persistence of all nitrate MCL violations in Texas CWSs over the 20-year historical period 2003 – 2022 and compares those systems with the systems that are currently in violation, i.e., systems with recent violations during the period Jan 2022 through Jun 2023. This analysis is limited primarily to systems that are currently active and excludes some information relating to a number of historically active CWSs that are now private or inactive systems and are no longer regulated.

Summary of Recent Public Water Supply System Changes in Texas

Public Water Systems (PWS) 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 nitrate-N. This report focuses on Community Water Systems (CWSs), which serve generally stable community populations, including both residential and commercial enterprises, generally within or related to a city, town, or other community.

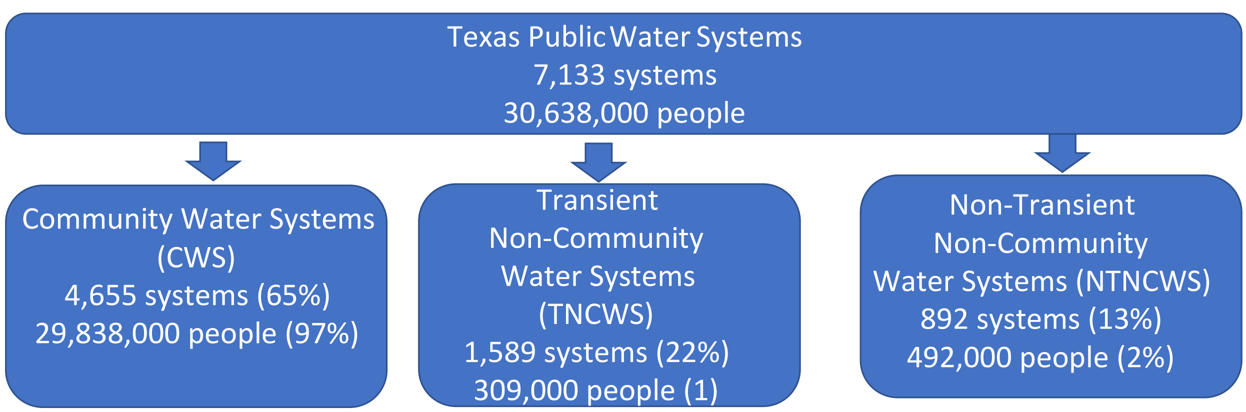


Figure 1. Types, numbers, and total populations served by Texas PWSs in the SDWIS database as of 18 July 2023. Percentages are relative to the combined total number of PWSs and populations served in the database (https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting). The numbers of currently active systems and their corresponding populations served are compared with those from 2021 in the previous report in Table 1.

There were 4,655 active CWSs in Texas serving 29,838,000 people based on SDWIS data downloaded on July 18, 2023 (Figure 1). Additionally, there were 2,478 PWSs that served non-communities, including those with non-transient populations (892 systems) and transient populations (1,586 systems). The non-community water systems are not included in this study to avoid double counting of overlapping populations. The SDWIS database was used to characterize CWSs with nitrate-N concentrations >10 m/L.

Table 1a. Changes between April 2021 and July 2023 in the numbers of active public water supply systems in Texas by population category and PWS type based on the SDWIS database.

Region	*System Type*	*Numbers of Systems by System Size Category*					
		≤500	*501 – 3,300*	*3,301 – 10,000*	*10,001 – 100,000*	*>100,000*	*All*
Texas Apr 2021	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
Texas Jul 2023	CWS	1,997	1,542	731	343	42	4,655
	NTNCWS	754	125	12	-	1	892
	TNCWS	1,477	107	2	-	-	1,586
	All	4,228	1,774	745	343	43	7,133
Net CWS Change		-2.6%	+0.2%	+4.4%	+6.2%	+2.1%	+0.04%

Table 1b. Changes between April 2021 and July 2023 in the total populations served by all active public water systems in Texas population category and PWS type based on the SDWIS database. Note that total populations for system types other than CWS likely include populations from the CWS category in part.

Region	*System Type*	*Populations Served by System Size Category*					
		≤500	*501 – 3,300*	*3,301 – 10,000*	*10,001 – 100,000*	*>100,000*	*All*
Texas Apr 2021	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
Texas Jul 2021	CWS	380,377	2,318,381	4,152,165	8,748,278	14,238,835	29,838,036
	NTNCWS	96,078	155,654	62,154	-	177,673	491,559
	TNCWS	201,573	99,336	7,896	-	-	308,805
	All	678,028	2,573,371	4,222,215	8,748,278	14,416,508	30,638,400
Net CWS Change		-2.2%	-0.9%	+3.8%	+7.3%	+2.7%	+3.8%

Compared to the previous report, the total number of CWSs remained virtually constant while the total population served by all system types increased by about 1.1 million people, representing a net relative increase of 3.8% (Table 1). While the total numbers of CWSs remained essentially constant, the total number of systems serving populations ≤500 people decreased by 2.6% and the numbers of larger systems increased, particularly those serving 10,001 to 100,00 people which saw an increase of 6.2%. The corresponding changes in populations served followed a similar trend, with a net decrease of 1.1% for systems serving ≤3,300 people and net increases for larger systems, particularly those serving 10,001 to 100,000 people which saw a 7.3% increase.

Methods

Maximum Contamination Limit (MCL) concentrations are established under the National Primary Drinking Water Regulations (NPDWR) administered by the US Environmental Protection Agency (EPA). Two inorganic nitrogen ion compounds are regulated, including nitrate (NO_3^-) and nitrite (NO_2^-). Both exist as unassociated charged anions in water and MCLs are expressed as nitrogen equivalent concentrations, i.e. 10 mg/L nitrate-N and 1.0 mg/L nitrite-N.

Data Sources

Concentrations of nitrate and nitrite were obtained from three sources, including the Groundwater Database (GWDB) maintained by the Texas Water Development Board (TWDB), the Public Water Supply (PWS) database maintained by the Texas Commission on Environmental Quality (TCEQ), and the Safe Drinking Water Information System (SDWIS) database maintained by the US EPA.

The TWDB database was queried on July 12, 2023. The database contains groundwater quality analyses for a wide range of well uses, including public water system wells, domestic wells, irrigation wells, etc. Water quality data begin in the early 1900s. The data represent entirely raw water samples obtained adjacent to or directly from the wellhead prior to any treatment, and are useful for characterizing ambient groundwater conditions.

The SDWIS database was queried on July 18, 2023 and includes data on public water systems administrative information, populations served, number of connections, physical facilities, and drinking water rule violations through time. Water quality samples were obtained from the distribution network at a point downstream of any associated treatment processes, usually termed an Entry Point (EP) sample where the water enters the distribution network. Thus, this database does not contain any information on raw, untreated source water.

The TCEQ database was provided on June 13, 2023 via request. The database contains data similar to the SDWIS database, but additionally includes water sample analytical results for general water quality parameters and concentrations of regulated contaminants that do not exceed their respective MCLs. Water quality data begin in 2002. The data primarily represent EP water quality samples, though there are additionally a limited number of raw water samples collected from locations upstream of any treatment facilities. A subset of the TCEQ data are regularly provided to the national SDWIS database.

SDWIS Database Definitions

The SDWIS database includes several system attributes of interest to this study, including estimates of the populations served by Public Water Systems (PWSs) 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 nomenclature and 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 fifteen 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 camp ground 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

- *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."*

This study focuses on health-based violations of the Nitrates Rule by Community Water Systems (CWSs). Collectively, CWSs serve by far the largest population and those served are potentially vulnerable to repeated and/or persistent exposure to contaminants from a consistent drinking water source. Non-community water systems serve either non-transient or transient populations that as a group are generally much smaller than CWSs and were not part of this analysis to avoid potential double counting of overlapping populations.

Data Analysis – Ambient Nitrate Levels in Minor Aquifers

Nitrate-N concentrations from the TWDB database were used to characterize ambient groundwater conditions in the minor aquifers in Texas. All of the wells in the TWDB database have individually been associated with one or more producing aquifer. Only samples from wells that were completed in a single aquifer, which represent most of the wells in the database, were used in this study. The aquifers represented in this study include 18 of the 22 minor aquifers of Texas that have been named by the TWDB (Figure 2). We include the Lipan aquifer for completeness though it was also analyzed in the previous report (Malito et al., 2022). There were insufficient data for four of the remaining aquifers as discussed below.

Samples from 8,220 groundwater wells in Texas are represented in this study, including 5,865 samples with detected nitrate-N concentrations (Table 14). The TWDB groundwater database samples analyzed for nitrate-N were collected between 1930 and 2023 (Figure 2). Analytical detection limits for nitrate-N varied based on the laboratory and method used. Analytical results for samples with undetectable nitrate-N concentrations are deemed "non-detects" and results are characterized with the "<" symbol followed by the method detection limit.

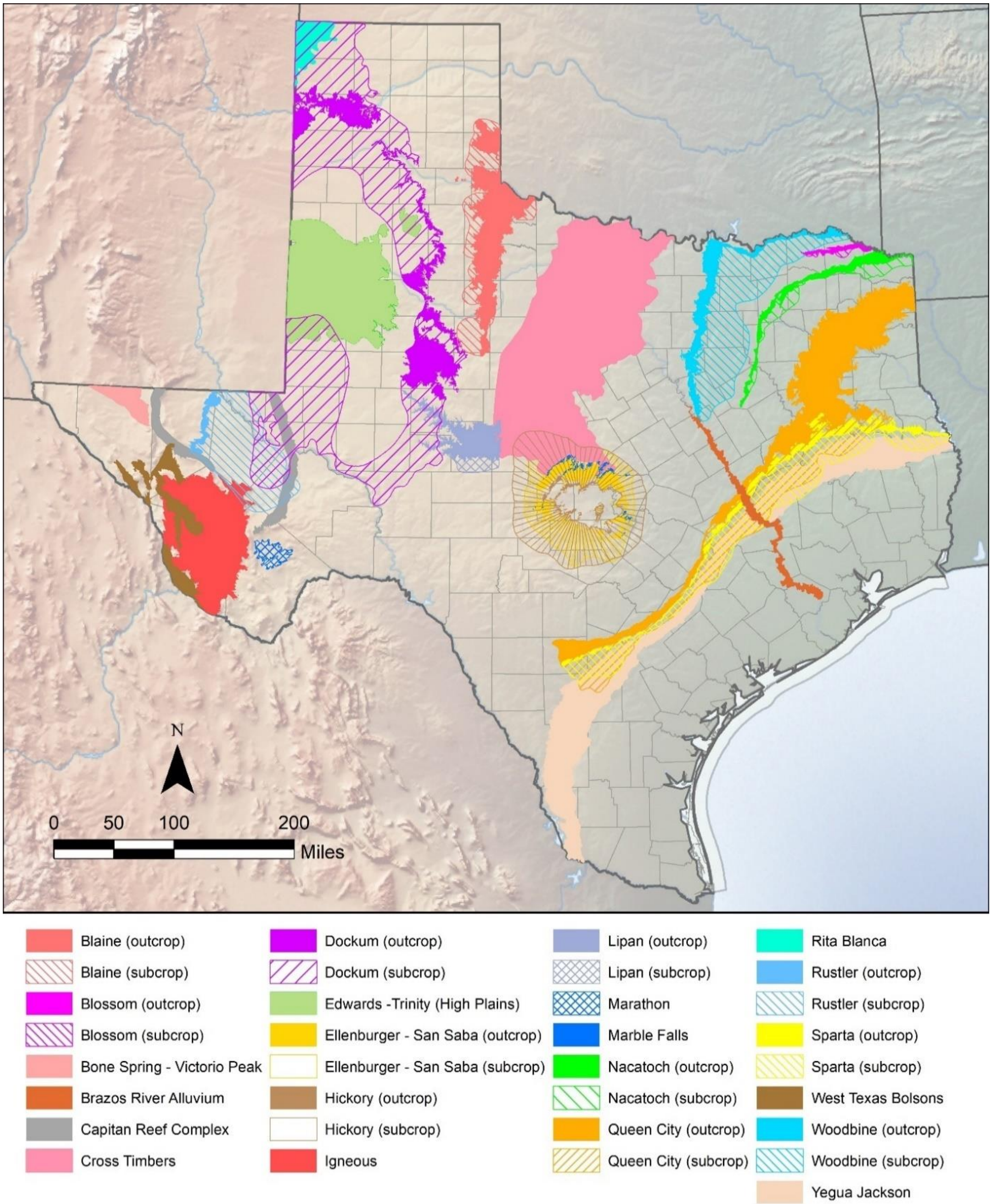


Figure 2. Minor Aquifers of Texas.

Nitrate-N 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 1930 through June 2023. 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 nitrate-N spatial distribution in the different aquifers. Indicator Kriging 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 nitrate-N concentrations exceeding a selected threshold value. Two threshold values were used for the analyses. The threshold of 4 mg/L represents the background level based on literature estimates (Gurdak and Qi, 2006). A higher threshold value of 10 mg/L was used to identify areas where the likelihood that groundwater nitrate-N concentrations exceed the EPA primary MCL for drinking water.

Maps for the minor aquifers were based on the latest sample for a given well during the period 1930 through 2023 focusing on the background (>4 mg/L) and the EPA MCL (>10 mg/L) levels. As a general rule-of-thumb, it is desirable to have 100 or more data points and 50 is considered the bare 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.

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 data points. The resulting output is a grid map of predicted probability (or likelihood) values that nitrate-N concentrations exceed the threshold value. In this study a uniform grid cell size of 1 km x 1 km was used to construct the aquifer probability maps.

The resulting maps depict the estimated spatial distribution of the probability or likelihood of exceeding the threshold value on a scale between 0% and 100%. For this study we characterized predicted probability ranges using five descriptive categories, including very low (<10%), low (10-40%), moderate (40-60%), high (60-90%), and very high (>90%) ranges.

The maps should be interpreted in part with consideration given to the spatial distribution of the underlying data as they 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 graphics in Appendix I for the reader's convenience.

Data Analysis – Persistence

We examined water sample results for CWSs during two periods, including 1) 2003 – 2022, representing the past 20 years to characterize the nature and persistence of nitrate violations and 2) Jan 2022 – Jun 2023 representing current conditions in relation to the 20-yr analysis.

To characterize persistence, we ranked CWSs based on the number of years during the period 2003-2022 that a given system was in violation of the nitrate MCL concentration. Samples are normally collected and analyzed on at least a quarterly basis, though sometimes more frequently. In a given year, a system was considered to be in violation if a single sample exceeded the MCL, regardless of the number of samples that may actually have exceeded the MCL. We examined two time periods. The first includes historical violations for all CWSs having any violation during the 20-yr period (2003 – 2022) and the second includes only systems with a current violation, defined as any violation during the period Jan 2022 – Jun 2023. Thus, the overall occurrence of annual nitrate violations for each CWS is represented on a scale of 0 to 20 for the 20-year period and 0 to 21 for current violators. We next determined the number of consecutive year violation periods for each PWS system, i.e., the number of continuous years in violation separated by non-violating years. To characterize the mean persistence for each CWS, we divided the number of violation years by the number of violation periods.

Results

Minor Aquifer Ambient Nitrate Levels

Based on the TWDB database, a total of 8,220 wells that were completed in minor aquifers were sampled and analyzed for nitrate-N in the state between 1930 and July 2023. A total of 1,474 samples, representing 17.9% of all groundwater nitrate-N data in this study, exceeded the secondary threshold of 4 mg/L while 747 samples (9.1%) had nitrate-N concentrations above the primary EPA MCL of 10 mg/L (Table 2).

Table 2. Summary of nitrate-N analyses in the minor aquifers of Texas. Values represent the latest samples from the TWDB groundwater database for wells sampled between 1930 and 2023. The highlighted aquifers did not have sufficient data for kriging methodology requirements.

Aquifer	*Total Number of Samples*	*Number of Detects*	*Number of Non-Detects*	*Nitrate-N > 4 mg/L*		*Nitrate-N > 10 mg/L*	
				Samples	*% of Total*	*Samples*	*% of Total*
Blaine	282	208	74	100	35.5	37	13.1
Blossom	76	49	27	6	7.9	2	2.6
Bone Spring-Victorio Peak	161	145	16	74	46.0	30	18.6
Brazos River Alluvium	216	167	49	27	12.5	12	5.6
Capitan Reef Complex	64	46	18	5	7.8	1	1.6
Cross Timbers	2,252	1,588	664	530	23.5	336	14.9
Dockum	889	680	209	198	22.3	90	10.1
Edwards-Trinity (High Plains)	71	60	11	25	35.2	6	8.5
Ellenburger-San Saba	376	317	59	64	17.0	24	6.4
Hickory	476	390	86	110	23.1	42	8.8
Igneous	206	182	24	13	6.3	5	2.4
Lipan	147	64	3	90	61.2	64	43.5
Marathon	44	40	4	4	9.1	2	4.5
Marble Falls	47	36	11	7	14.9	3	6.4
Nacatoch	204	113	91	9	4.4	7	3.4
Queen City	651	456	195	80	12.3	27	4.1
Rita Blanca	34	30	4	1	2.9	-	-
Rustler	53	39	14	18	34.0	6	11.3
Sparta	362	254	108	21	5.8	6	1.7
West Texas Bolson	260	246	14	26	10.0	9	3.5
Woodbine	685	410	275	15	2.2	4	0.6
Yegua-Jackson	664	409	255	51	7.7	34	5.1
Total	8,220	5,929	2,211	1,474	17.9	747	9.1

The maximum nitrate-N concentration in the TWDB database for all minor aquifers was 596 mg/L. There were 38 samples with nitrate-N concentrations >100 mg/L and 31 of these were in the Cross Timbers aquifer. These samples were not considered outliers as the concentrations lie within 3 standard deviations of the mean of the $\log_{10}$ transformed data. The non-detect samples had a mean detection limit of 0.28 mg/L and range from 0.002 mg/L to 2.3 mg/L.

Most of the samples used in this study (92%) were collected during or after the 1960s (Figure 3a). The concentration distribution of the sample population collected prior to the median sample date (11/13/1978) was compared to that of samples collected on or after the median sample date (Figure 3b). The distributions are nearly similar above ~0.4 mg/L, while improved sampling technology (lower detection limits) cause deviation between the two datasets below ~0.4 mg/L. At higher concentrations, the newer samples tend to have slightly lower values above about 2 mg/L and the older samples may result in slightly exaggerated exceedances at the 4 mg/L and 10 mg/L values. The slight difference in distributions below 0.5 mg/L is inconsequential to the overall results and is primarily related to lowering of detection limit concentrations as analytical technology improved over time.

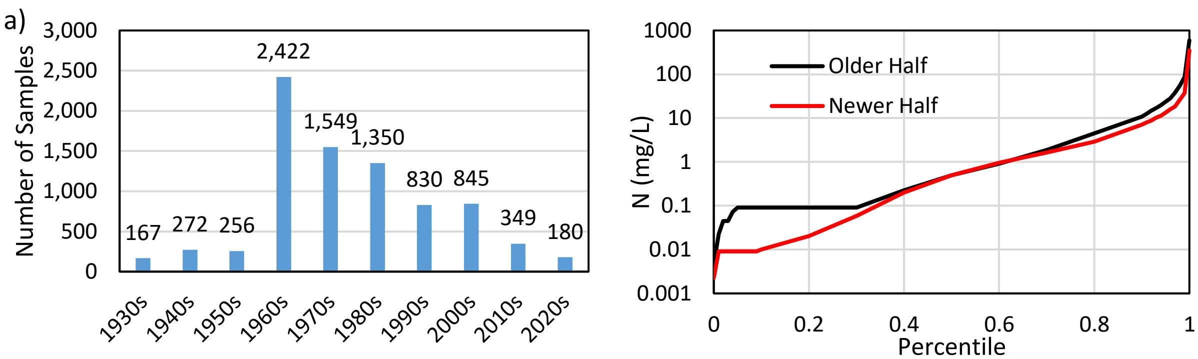


Figure 3. Distributions of a) number of groundwater nitrate-N samples collected by decade and b) percentile distribution of nitrate-N concentrations for samples collected prior to and on or after the median sample date (11/13/1978). (TWDB groundwater database, 1930-2023).

The numbers of samples per minor aquifer are generally quite small relative to the major aquifers while the percentages of samples with nitrate-N >10 mg/L are generally much higher. Aquifers with the largest percentages of samples exceeding the MCL include the Lipan (43.5%), the Bone Spring – Victorio Peak (18.6%), and the Cross Timbers aquifers (14.9%), followed by the Blaine (13.1%), Rustler (11.3%), and Dockum (10.1%) aquifers (Table 2). The remaining minor aquifers had from 0.6% to 8.8% of samples above the MCL and the average for all minor aquifer samples was 9.1%. This is similar to but slightly larger than the exceedance rate of major aquifer samples (7.8%, Malito et al., 2022). Excluding the Seymour aquifer, which has an exceedance of 54.7%, the major aquifers have a collective mean MCL exceedance of 4.4%, less than half that of the collective minor aquifers.

The aquifers mapped include 18 of the 22 minor aquifers in Texas. Nitrate-N data were insufficient to meet kriging requirements for four minor aquifers, including the Marathon, Marble Falls, Rita Blanca, and Rustler aquifers, which variously had between 34 and 53 well locations sampled. Three minor aquifers, including the Blossom, Capitan Reef Complex, and Edwards-Trinity (High Plains) aquifers, were mapped though they had marginal data with 64 to 76 well locations sampled. The remaining minor aquifers had sufficient data, including fourteen that had from 147 to 889 well locations and one aquifer, the Cross Timbers, had 2,252 well locations.

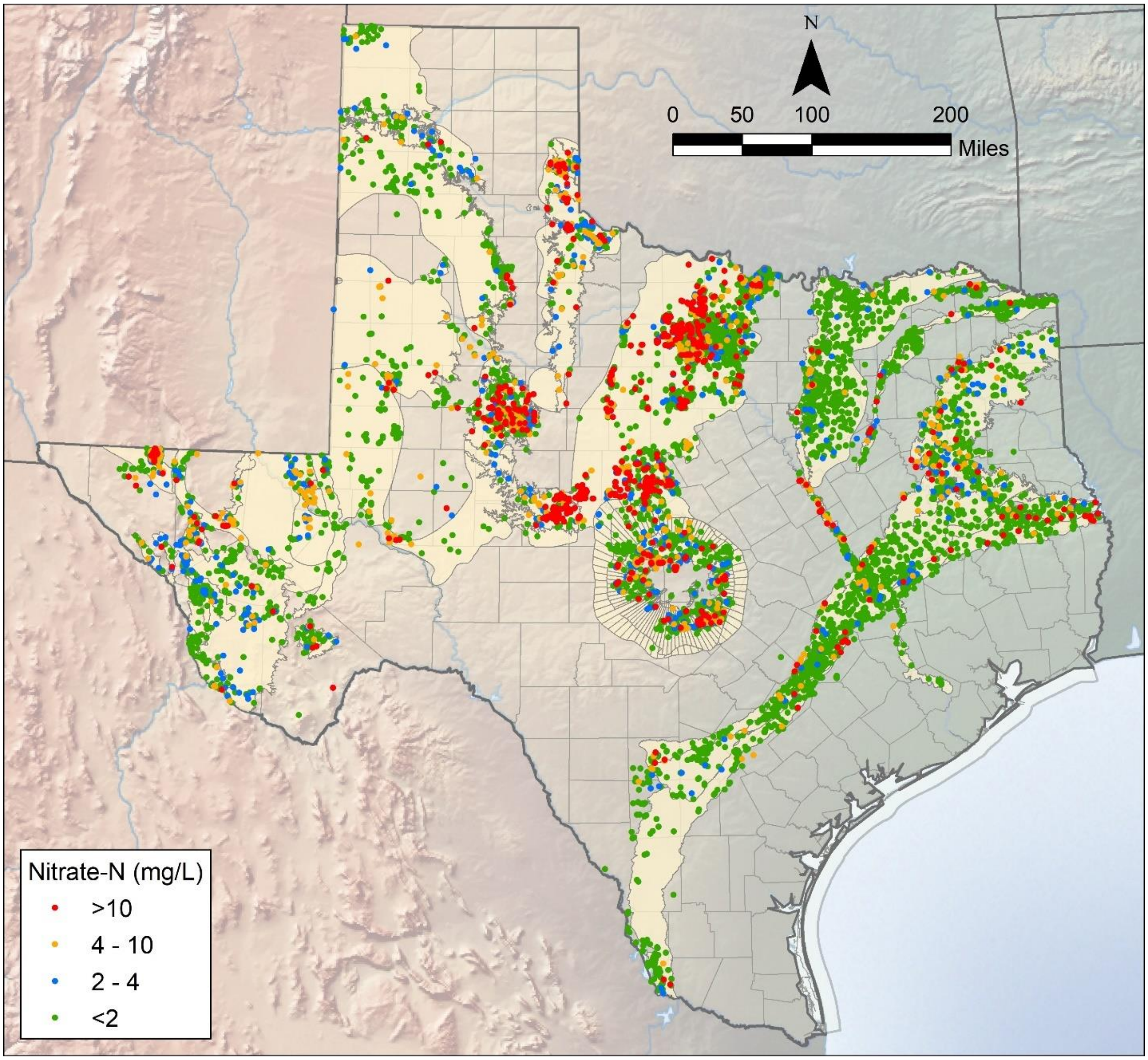


Figure 4. Spatial distribution of nitrate-N concentrations in the minor aquifers of Texas. Values represent the latest sample for each location collected from 1930 – 2023. Samples from wells completed in more than one aquifer are not included.

The distributions of the 5,929 samples with detected nitrate-N concentrations indicate that the median concentrations range from 0.32 mg/L (Nacatoch) to 8.05 mg/L (Lipan) among the minor aquifers (Table 3). At their respective 90th percentile concentrations, 7 of the minor aquifers exceed the nitrate-N MCL and 14 minor aquifers exceed the MCL at their 95th percentile concentrations. All but one minor aquifer, the Rita Blanca, had maximum nitrate-N concentrations that exceeded the MCL.

Table 3. Distributions of nitrate-N concentrations above detection limits for the minor 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.

Aquifer	*Total Number of Detects*	*Mean (mg/L)*	*Percentile (mg/L)*								
			Min	*5*	*10*	*25*	*50*	*75*	*90*	*95*	*Max*
Blaine	208	6.0	0.01	0.29	0.68	1.76	3.78	7.70	13.60	18.91	37.27
Blossom	49	1.4	0.01	0.01	0.02	0.09	0.56	1.50	4.11	5.88	11.30
Bone Spring-Victorio Peak	145	7.8	0.09	0.43	0.62	1.41	4.33	9.04	22.41	34.23	51.96
Brazos River Alluvium	167	2.6	0.01	0.03	0.05	0.18	0.56	1.71	6.71	11.29	74.77
Capitan Reef Complex	46	1.5	0.02	0.04	0.09	0.25	0.77	1.65	3.80	4.71	12.20
Cross Timbers	1,588	11.8	0.00	0.04	0.09	0.27	1.25	7.45	26.14	57.50	596.37
Dockum	680	4.8	0.01	0.05	0.11	0.52	1.41	5.09	12.40	19.29	110.69
Edwards-Trinity (High Plains)	60	4.4	0.01	0.36	0.55	1.09	2.94	6.25	9.51	12.33	16.00
Ellenburger-San Saba	317	4.0	0.01	0.06	0.19	0.68	1.49	2.94	8.46	12.89	159.26
Hickory	390	4.5	0.01	0.09	0.18	0.52	1.78	4.52	10.53	17.03	159.26
Igneous	182	1.8	0.01	0.15	0.24	0.49	0.96	1.96	3.20	4.96	28.10
Lipan	64	14.9	.002	0.09	0.12	1.66	8.05	21.11	37.67	42.57	85.26
Marathon	40	1.8	0.02	0.04	0.10	0.35	0.62	2.15	3.46	4.94	14.50
Marble Falls	36	5.8	0.01	0.10	0.13	0.41	1.19	2.94	7.07	19.91	95.90
Nacatoch	113	3.2	0.01	0.01	0.01	0.04	0.32	1.17	3.13	12.70	125.75
Queen City	456	2.7	.002	0.02	0.05	0.20	0.68	2.46	6.58	10.90	72.29
Rita Blanca	30	1.1	0.03	0.15	0.26	0.43	0.65	1.57	2.72	2.81	4.07
Rustler	39	5.6	.005	0.12	0.22	0.60	3.66	7.09	15.43	17.73	27.11
Sparta	254	2.2	0.01	0.02	0.04	0.10	0.43	1.19	3.39	6.56	224.77
West Texas Bolson	246	2.3	0.02	0.11	0.30	0.96	1.54	2.29	4.24	6.89	22.14
Woodbine	410	1.2	.002	0.03	0.05	0.18	0.50	0.90	1.71	2.39	66.41
Yegua-Jackson	409	3.0	0.00	0.02	0.04	0.09	0.34	1.11	6.41	16.08	109.79
Total	5,959	5.9	.002	0.04	0.09	0.29	1.07	3.84	12.65	24.69	596.4

Blaine

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

There were 282 samples analyzed for nitrate during the study period with 208 samples (74%) having detectable nitrate concentrations. Most of the samples are located in the northern half of the aquifer so the kriging results are skewed toward that region. About 65% of the area has moderate to very high probability of nitrate-N >4 mg/L (Table 4). About 99% of the area has very low to low probability of nitrate-N >10 mg/L. The median concentration of samples with detectable concentrations is 3.8 mg/L and the 5th-95th percentile range is 0.3–18.9 mg/L. There were 37 samples (13%) that exceeded the MCL ranging from 10.4 mg/L to 37.3 mg/L with a median of 14.5 mg/L.

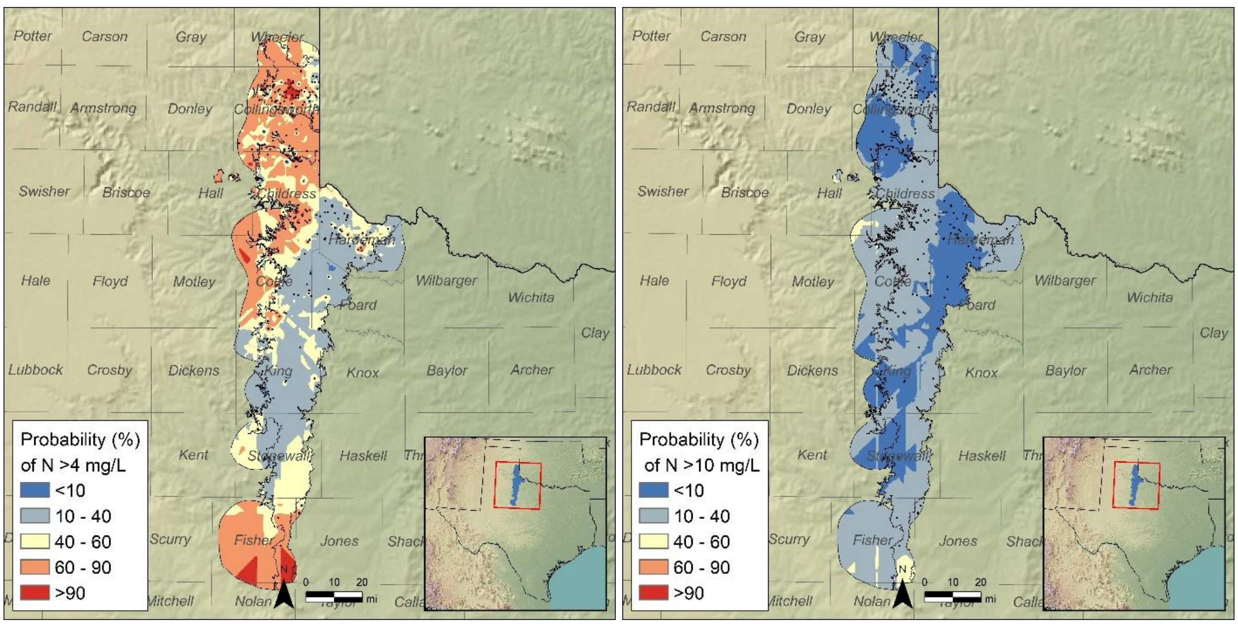


Figure 5. Blaine aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 4. Blaine aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	0.5	34.5	60.5	31.9	2.6
Nitrate-N >10 mg/L	37.4	61.2	1.3	0.0	0.0

Blossom

The Blossom aquifer occupies 280 mi^2 in a narrow band across parts of three counties in northeast Texas (Figure 6). The aquifer is comprised of alternating sand and clay sequences of the Cretaceous Blossom Sand Formation. The freshwater saturated thickness averages about 25 ft. Water quality is generally fair in the outcrop areas with TDS concentrations generally <1,000 mg/L. Locally, the water is high in sodium, bicarbonate, iron, and fluoride.

There were 76 samples analyzed for nitrate during the study period with 49 samples (64%) having detectable nitrate concentrations. This is a marginal number of samples for kriging purposes, though in this case the area is relatively small. All of the area (100%) has very low to low probability of nitrate-N >4 mg/L and >10 mg/L (Table 5). The median concentration of samples with detectable concentrations is 0.6 mg/L and the 5th-95th percentile range is 0.01–5.9 mg/L. There were only 2 samples (3%) that exceeded the MCL, at 10.3 mg/L and 11.3 mg/L.

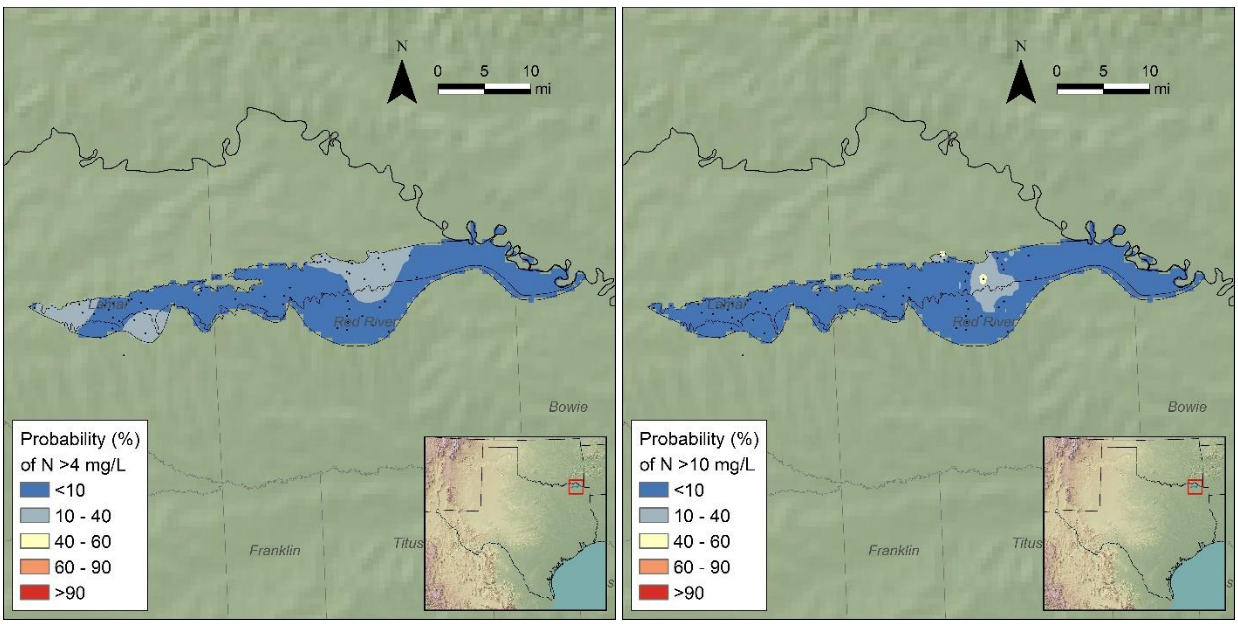


Figure 6. Blossom aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 5. Blossom aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	80.7	19.3	0.0	0.0	0.0
Nitrate-N >10 mg/L	91.7	7.8	0.3	0.1	0.0

Bone Spring – Victorio Peak

The Bone Spring - Victorio aquifer is located entirely in northern Hudspeth County and covers 710 mi^2 (Figure 7). The aquifer consists of Permian limestones. Water quality is generally fair to poor with concentrations generally between 1,000 and 10,000 mg/L TDS.

There were 161 samples analyzed for nitrate during the study period with 145 samples (90%) having detectable nitrate concentrations. Most of the sampled wells are located in a small area of intensive irrigation around the town of Dell City near the New Mexico border. The southern area of the aquifer is sparsely sampled and the western area has no samples. Some samples lie outside the aquifer boundary to the southwest. About 20% of the aquifer has a moderate to high probability of nitrate-N >4 mg/L (Table 6), centered on the most densely sampled agricultural region. Only about 3% of the aquifer has a moderate to high probability of nitrate-N >10 mg/L. The median concentration of samples with detectable concentrations is 4.3 mg/L and the 5^{th}-95^{th} percentile range is 0.43–34.2 mg/L. There were 30 samples (19%) that exceeded the MCL ranging from 10.4 mg/L to 52.0 mg/L with a median of 22.1 mg/L.

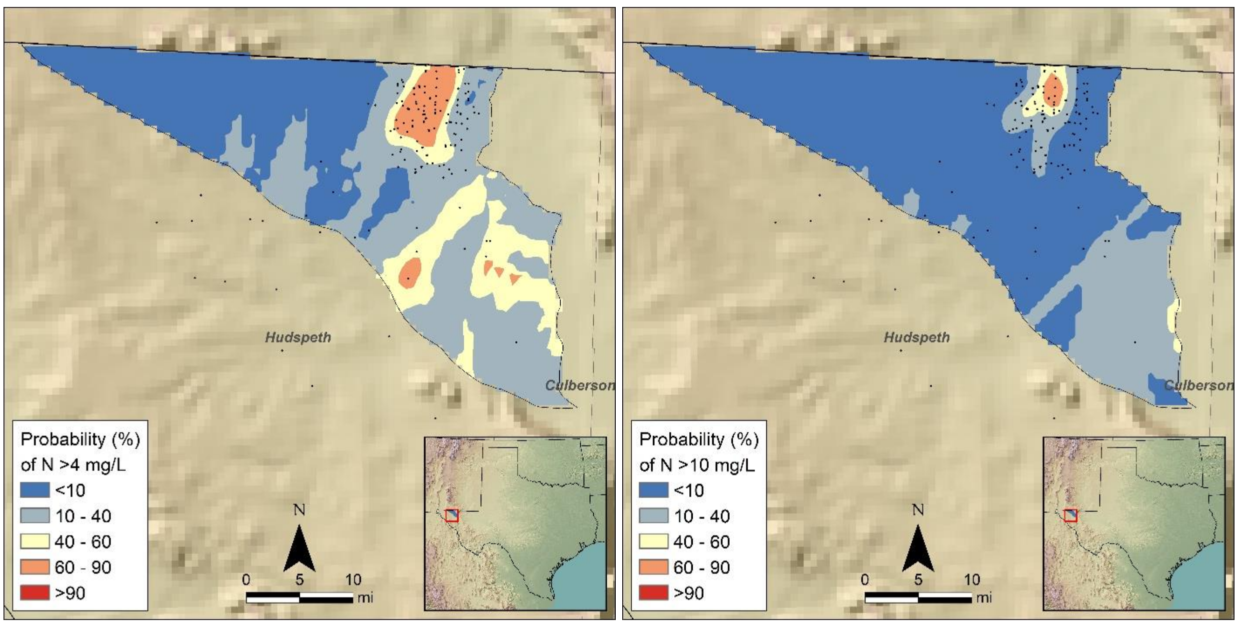


Figure 7. Bone Spring – Victorio Peak aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 6. Bone Spring – Victorio Peak aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	38.9	41.7	14.8	4.6	0.0
Nitrate-N >10 mg/L	74.5	23.1	1.8	0.6	0.0

Brazos River Alluvium

The Brazos River Alluvium aquifer occupies 1,060 mi2 across 13 counties in eastern Texas. The aquifer consists of Quaternary floodplain deposits of sand, gravel, silt and clay along a 350-mile stretch of the Brazos River and is generally less than about 7 miles wide (Figure 8). The aquifer is generally thin, averaging about 50 ft and ranging up to about 150 ft thick. Water quality is generally good with TDS concentrations <1,000 mg/L but locally ranging as high as 10,000 mg/L.

There were 216 samples analyzed for nitrate during the study period with 167 samples (77%) having detectable nitrate concentrations. Most of the sampled wells are located in approximately the northern 50% of the aquifer area. About 14% of the aquifer has a moderate to high probability of nitrate-N >4 mg/L (Table 7), located almost entirely in the northern most two counties. Throughout the aquifer, there is a very low to low probability nitrate-N >10 mg/L. The median concentration of samples with detectable concentrations is 0.6 mg/L and the 5th-95th percentile range is 0.03–11.3 mg/L. There were 12 samples (6%) that exceeded the MCL ranging from 10.4 mg/L to 74.8 mg/L with a median of 14.1 mg/L. These samples are located in close proximity to samples with very low nitrate-N primarily in the northern most area discussed above with three additional samples located at the extreme lateral margins of the aquifer in the central reach.

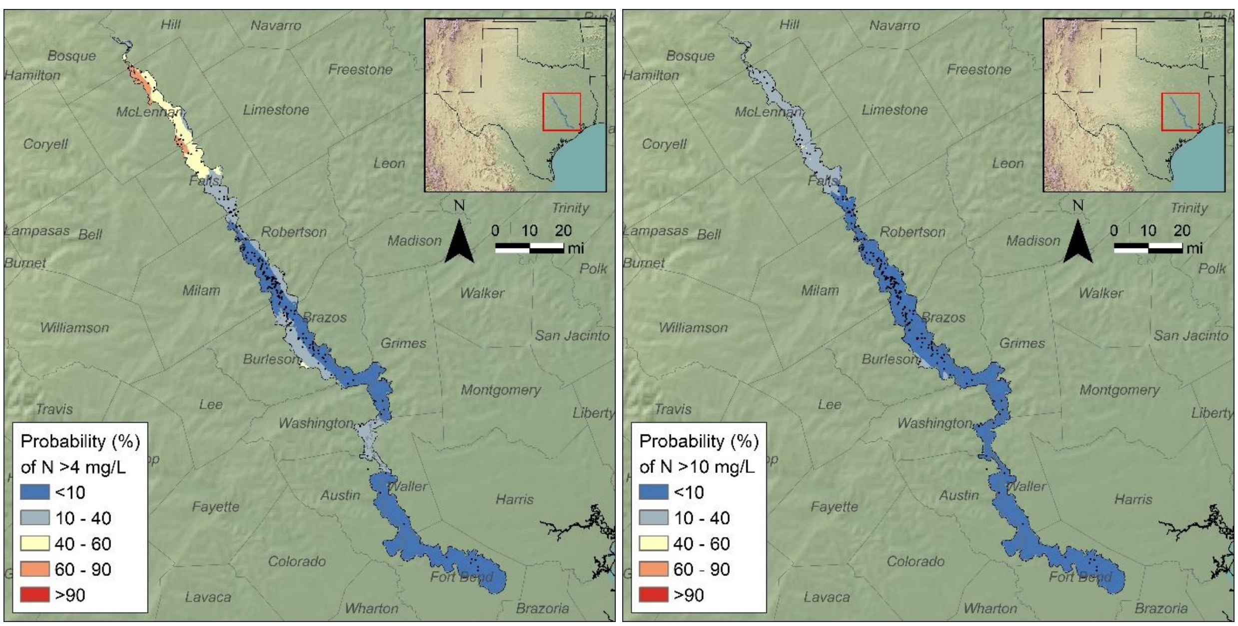


Figure 8. Brazos River Alluvium aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 7. Brazos River Alluvium aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	62.0	23.8	11.7	2.5	0.0
Nitrate-N >10 mg/L	81.3	18.5	0.1	0.0	0.0

Capitan Reef Complex

The Capitan Reef Complex aquifer occupies 1,850 mi^2 across 6 counties in west Texas and also extends into southeast New Mexico (Figure 9). The aquifer consists of Permian limestones and dolomites of the Capitan Limestone, Goat Seep Dolomite, and several formations of the Artesia Group that formed in an arcuate band surrounding the Delaware Basin. The aquifer ranges up to 2,400 ft thick. Water quality is generally moderate to poor with TDS concentrations of 1,000 mg/L to >5,000 mg/L.

There were only 64 samples analyzed for nitrate during the study period with 46 samples (72%) having detectable nitrate concentrations. The sampled wells are located primarily in several clusters across the region. All but 2% of the aquifer has a very low to low probability of nitrate-N >4 mg/L and 95% of the aquifer has a very low probability of nitrate-N >10 mg/L (Table 8). The median concentration of samples with detectable concentrations is 0.8 mg/L and the 5th-95th percentile range is 0.04–4.7 mg/L. There was only one sample (2%) that exceeded the MCL at 12.2 mg/L.

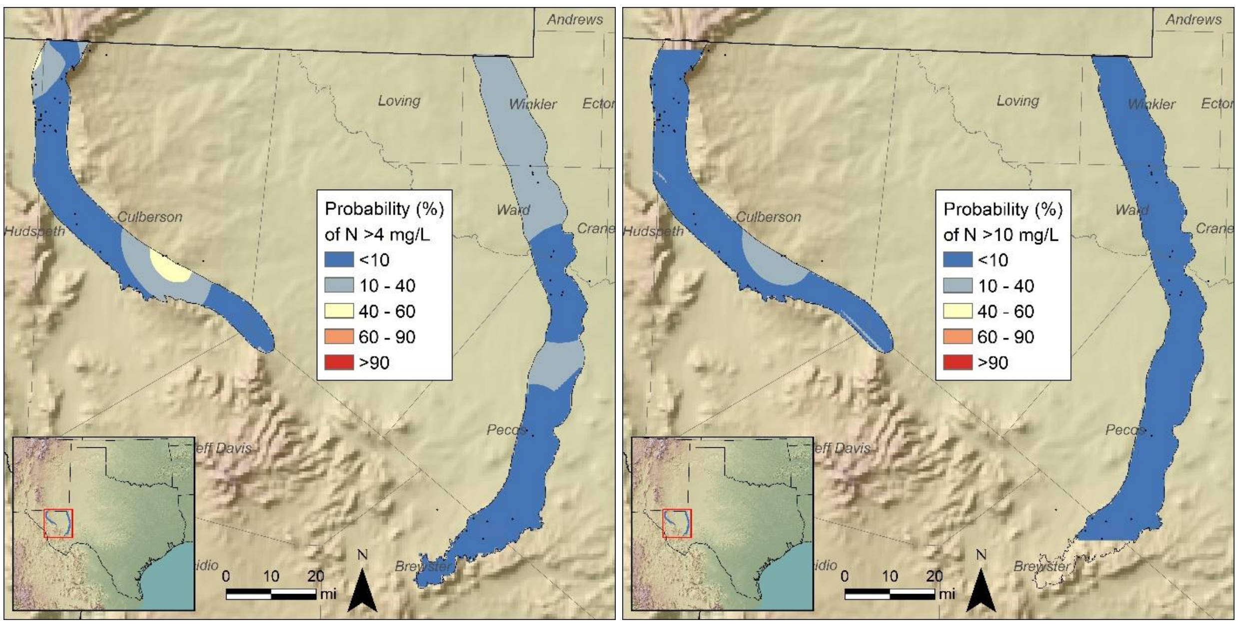


Figure 9. Capitan Reef Complex aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 8. Capitan Reef Complex aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	64.1	33.9	1.9	0.0	0.0
Nitrate-N >10 mg/L	94.9	5.1	0.0	0.0	0.0

Cross Timbers

The Cross Timbers aquifer occupies 17,800 mi^2 parts of 30 counties from north-central to central Texas (Figure 10). The aquifer consists of limestone, shale, and sandstone units of the Paleozoic Strawn, Canyon, Cisco, and Wichita groups. Water quality is generally fair to poor with TDS concentrations generally between 1,000 and 10,000 mg/L.

There were 2,252 samples analyzed for nitrate with 1,588 samples (71%) having detectable concentrations and 664 samples (29%) with non-detectable concentrations. About 63% of the area has no to very low probability of nitrate-N >4 mg/L and a further 35% has moderate to high probability (Table 9). Only about 1% of the total aquifer area has high probability of nitrate-N >2 mg/L. The spatial pattern of probabilities displays artifacts reflecting limited data density in some regions while most of the samples tend to be located in clusters throughout the aquifer. The median concentration of samples with detectable concentrations is 1.5 mg/L and the 5th-9th percentile range is 0.04–57.5 mg/L.

A total of 336 samples (15%) exceeded the MCL with concentrations ranging from 10.01 mg/L to 596 mg/L and a median of 25.1 mg/L. Samples in this aquifer have some of the highest exceedances in the state, though the kriged probability maps to not reflect many of the exceedance locations because they are surrounded by many more wells that do not exceed the threshold, thus lowering the overall probability in that area. This indicates that much of the nitrate contamination in this aquifer represents point sources.

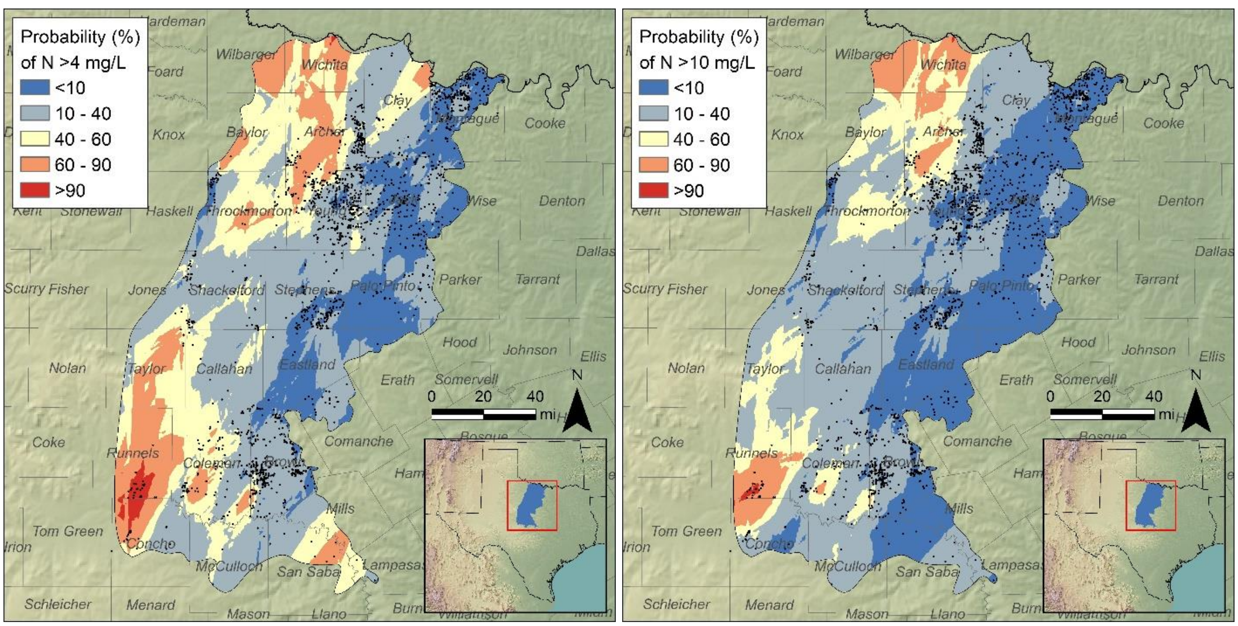


Figure 10. Cross Timbers aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 9. Cross Timbers aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	19.1	44.4	23.3	12.5	0.7
Nitrate-N >10 mg/L	33.1	47.4	13.7	5.6	0.1

Dockum

The Dockum aquifer occupies 25,300 mi^2 extending across parts of 46 counties from the Oklahoma border in the northwestern Panhandle south to the general area of Midland, Texas (Figure 11). The aquifer includes stratigraphic components of the Late Triassic Dockum Group, which includes 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 marginal to the High Plains escarpment. The Dockum underlies the Ogallala, Pecos Valley, Edwards-Trinity Plateau, and Edwards-Trinity (High Plains) aquifers.

There were 889 samples analyzed for nitrate during the study period with 680 samples (76%) having detectable concentrations. About 73% of the area has very low to low probability of nitrate-N > 4 mg/L (Table 10). Only about 0.5% of the total aquifer area has high to very high probabilities of nitrate-N >10 mg/L. The spatial pattern of probabilities displays artifacts of limited data density, particularly in the confined regions of the central area. The median concentration of samples with detectable concentrations is 1.4 mg/L and the 5th-95th percentile range is 0.05–19.3 µg/L. A total of 90 samples (10%) exceeded the MCL with a range of concentrations from 10.1 mg/L to 110 mg/L with a median of 17.5 mg/L. These tend to be located in the outcrop areas along the southeast margin of the aquifer.

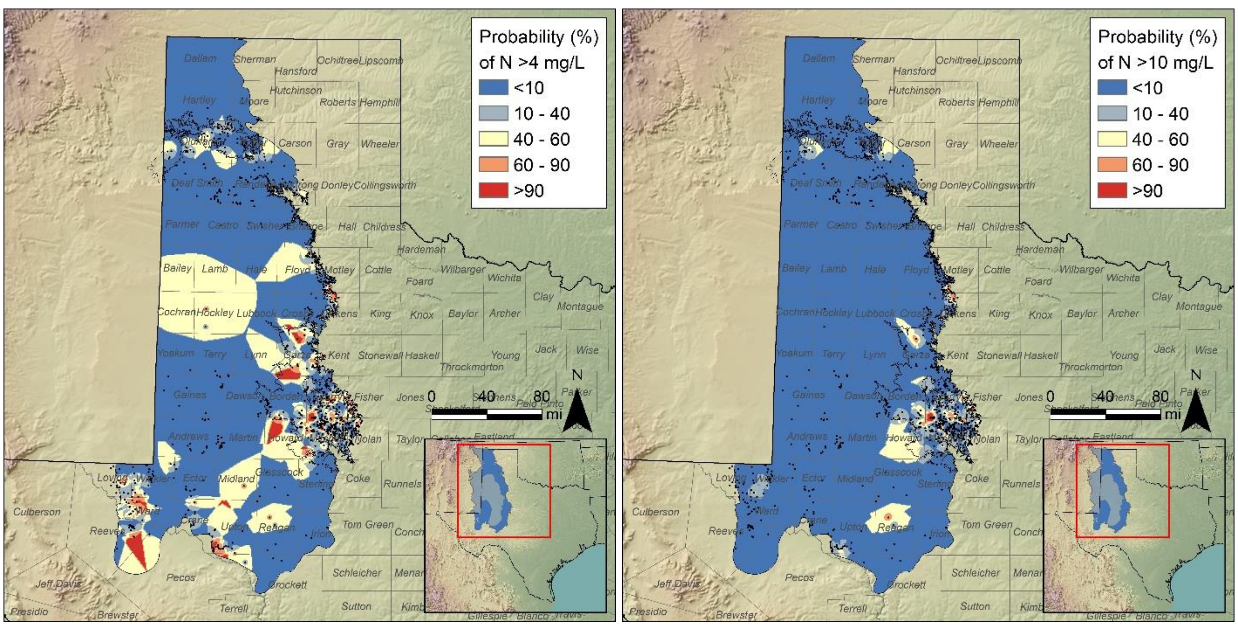


Figure 11. Dockum aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right). The aquifer extends into Oklahoma and New Mexico. The formal aquifer region in Texas is reflected by the darker shade of blue in the map insets. Other regions that are not part of the formal aquifer are shown by lighter shade.

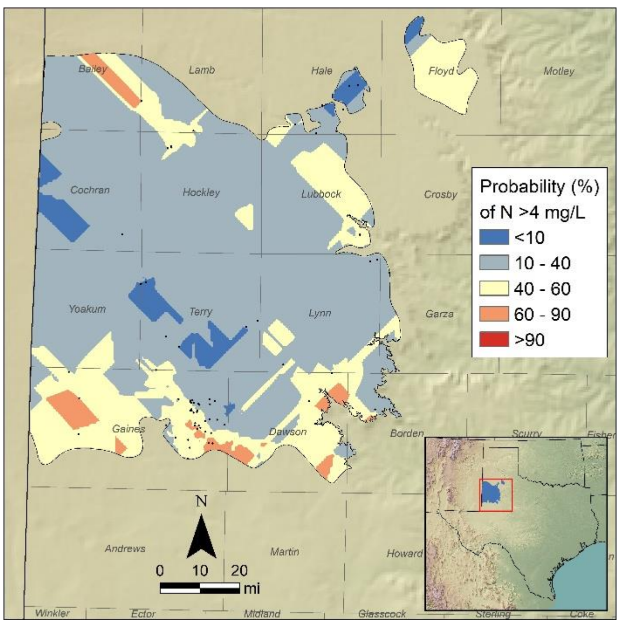
Table 10. Dockum aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	66.7	6.3	24.1	1.6	1.3
Nitrate-N >10 mg/L	91.5	4.2	3.8	0.4	0.1

Edwards-Trinity (High Plains)

The Edwards-Trinity aquifer occupies 9,000 mi^2 in parts of 13 counties in the Southern High Plains of Texas (Figure 12). The aquifer underlies the Ogallala aquifer and overlies the Dockum Formation. The aquifer is composed of a Cretaceous limestones and sandstones of the Comanche Peak, Edwards, and Antlers formations of the Trinity Group. 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 nitrate during the study period with 60 samples (85%) having detectable concentrations. About 76% of the area has very low to low probability of nitrate >4 mg/L and 21% has moderate probability (Table 11). Only 3.4% of the total aquifer area has moderate to high probabilities of nitrate-N >10 mg/L. The kriging results display artifacts of limited data across most of the central areas of the aquifer. The median concentration of samples with detectable concentrations is 2.9 mg/L and the 5^{th}-9^{th} percentile range is 0.36–12.3 mg/L. There were 6 samples (8%) that exceed the 10 mg/L MCL, mostly located along the southern margin of the aquifer, ranging from 10.8 mg/L to 16 mg/L with a median of 13.5 mg/L



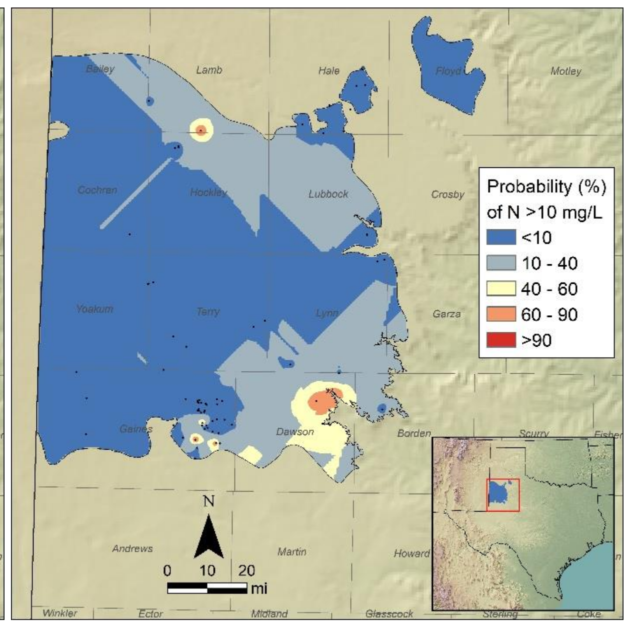


Figure 12. Edwards-Trinity (High Plains) aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 11. Edwards-Trinity (High Plains) aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	4.7	71.4	21.2	2.6	0.0
Nitrate-N >10 mg/L	67.1	29.6	2.8	0.5	0.0

Ellenburger – San Saba

The Ellenburger-San Saba aquifer occupies 5,400 mi^2 across parts of 16 counties surrounding the Llano Uplift in central Texas (Figure 13). The aquifer is composed of a limestones and dolomites, including the Tanyard, Gorman, and Honeycut formations of the Ellenburger Group and the San Saba limestone of the Wilberns Formation. Total thickness locally 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 the aquifer is compartmentalized by regional block faulting.

There were 376 samples analyzed for nitrate during the study period with 317 samples (84%) having detectable concentrations. About 74% of the area has low to very low probability of nitrate-N > 4 µg/L and 23% has moderate probability (Table 12). About 3% of the total aquifer area has high to very probabilities of nitrate-N >4 µg/L. The kriging results display artifacts of limited data in large areas of the aquifer, particularly down-dip, and the higher probability areas are primarily located in very small areas around the offending wells, potentially due to the fault compartmentalization. The median concentration of samples with detectable concentrations is 1.5 mg/L and the 5th-95th percentile range is 0.06–12.9 mg/L. There were 24 samples (6%) that exceed the 10 mg/L MCL, ranging from 10.3 mg/L to 159 m/L with a median of 16.5 mg/L.

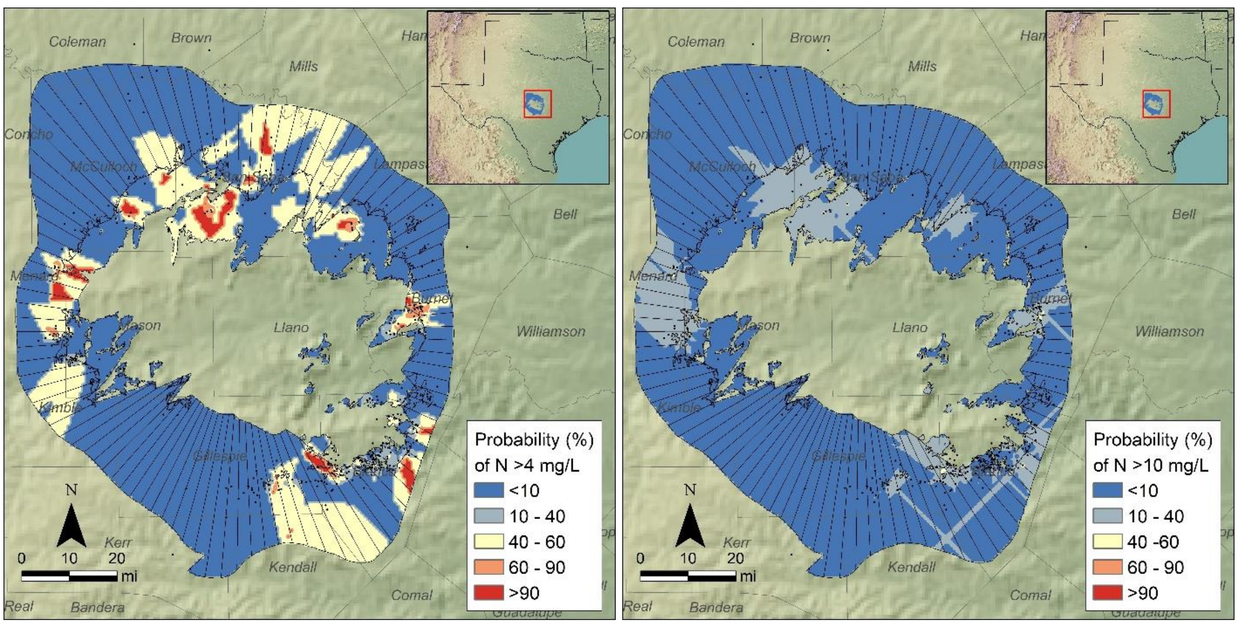


Figure 13. Ellenburger – San Saba aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 12. Ellenburger – San Saba aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	72.3	2.0	22.7	0.8	2.2
Nitrate-N >10 mg/L	83.8	16.1	0.1	0.0	0.0

Hickory

The Hickory aquifer occupies 8,600 mi^2 across parts of 19 counties surrounding the Llano Uplift in central Texas (Figure 14) and is composed of parts of the Hickory Sandstone Member of the Riley Formation. Total thickness ranging up to 480 ft thick and water quality is generally good with TDS <1,000 mg/L. The primary contaminants of concern are radium and associated radon and gross alpha radiation.

There were 476 samples analyzed for nitrate during the study period with 390 samples (82%) having detectable concentrations. The kriging results display artifacts resulting from limited data in large areas of the aquifer and the high probability areas are confined to very small areas around the offending wells, potentially due to fault compartmentalization similar to the Ellenburger-San Saba aquifer. About 99% of the Hickory area has very low to low probability of nitrate-N > 4 mg/L (Table 13). The median concentration of samples with detectable concentrations is 1.8 mg/L and the 5th-95th percentile range is 0.09–17.0 mg/L.

A total of 42 samples (9%) exceeded the MCL with concentrations ranging from 10.2 mg/L to 159 mg/L with a median of 16.9 mg/L. The kriged probability maps to not reflect the exceedance locations because they are surrounded by wells that do not exceed the threshold, thus lowering the overall probability in that area. This indicates that much of the nitrate contamination in this aquifer likely represents localized point sources.

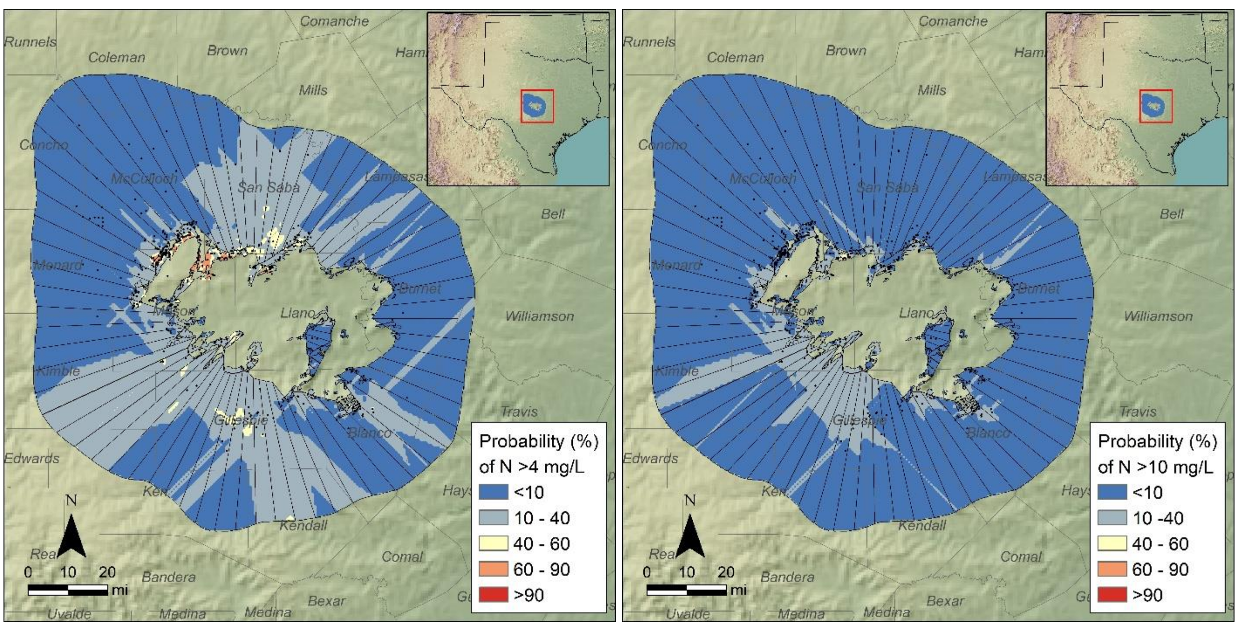


Figure 14. Hickory aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 13. Hickory aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	60.4	38.1	1.1	0.3	0.0
Nitrate-N >10 mg/L	88.1	11.8	0.0	0.0	0.0

Igneous

The Igneous aquifer occupies 6,100 mi^2 extending cross parts of 6 counties in western Texas and is primarily located in Presidio, Jeff Davis, and Brewster counties with smaller areas in Culberson, Reeves, and Pecos counties (Figure 15). The aquifer is composed of a complex series of pyroclastic and volcanoclastic sediments up to 6,000 ft thick. The Igneous aquifer locally underlies parts of another minor aquifer, the West Texas Bolsons. Freshwater saturated thickness averages 1,800 ft and water quality is generally good with TDS <1,000 mg/L. Table 14

There were 206 samples analyzed for nitrate during the study period with 182 samples (88%) having detectable concentrations. About 95% of the area has a very low probability of nitrate-N > 4 mg/L (Table 14). About 0.5% of the total aquifer area has moderate to very high probabilities of nitrate-N >10 mg/L. There are limited data particularly in the central region where probabilities are the highest. The median concentration of samples with detectable concentrations is 1.0 mg/L and the 5th-95th percentile range is 0.15 – 5.0 mg/L. A total of 5 samples (2%) exceeded the MCL with a range of concentrations from 11.6 mg/L to 28.1 mg/L with a median of 13.5 mg/L.

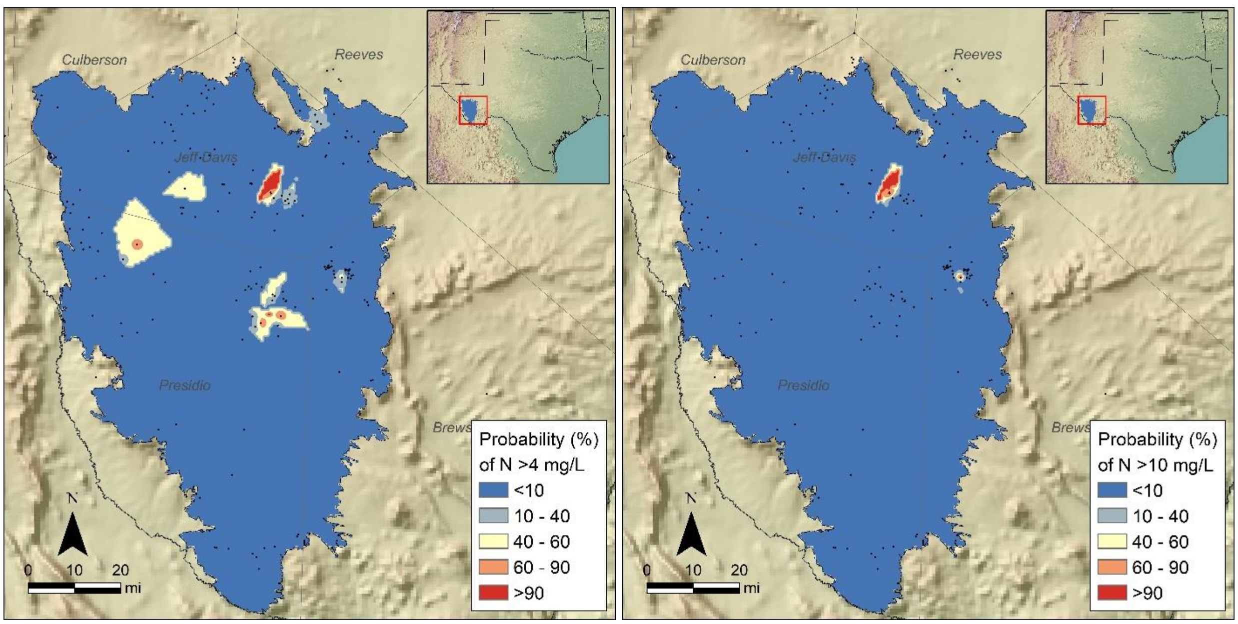


Figure 15. Igneous aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 14. Igneous aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	95.3	0.9	3.4	0.2	0.3
Nitrate-N >10 mg/L	99.4	0.1	0.2	0.1	0.2

Lipan

The Lipan aquifer covers 1,994 mi^2 and extends across all or parts of 8 counties of the Edwards Plateau region of west-central Texas (Figure 16). The stratigraphic components of the Lipan include the San Angelo Sandstone (Pease River Group) and the Choza Formation, Bullwagon Dolomite, Vale Formation, Standpipe Limestone, and Arroyo Formation of the Clear Fork Group. Groundwater is found in water-bearing alluvium comprised of saturated sediments from the Quaternary Leona formation. The groundwater tends to be hard and ranges from fresh to slightly saline.

There were 147 samples analyzed for nitrate during the study period with 144 samples (98%) having detectable concentrations. There are very limited data in the southern region where the aquifer is confined and no data in the unconfined distant west and northwest areas. About 62% of the area has a very low to low probability of nitrate-N >4 mg/L ((Table 15). About 26% of the total aquifer area has moderate to very high probabilities of nitrate-N >10 mg/L. The median concentration of samples with detectable concentrations is 8.1 mg/L and the 5^{th}-95^{th} percentile range is 0.09 – 42.6 mg/L. A total of 64 samples (44%) exceeded the MCL with a range of concentrations from 10.3 mg/L to 85.3 mg/L with a median of 28.3 mg/L.

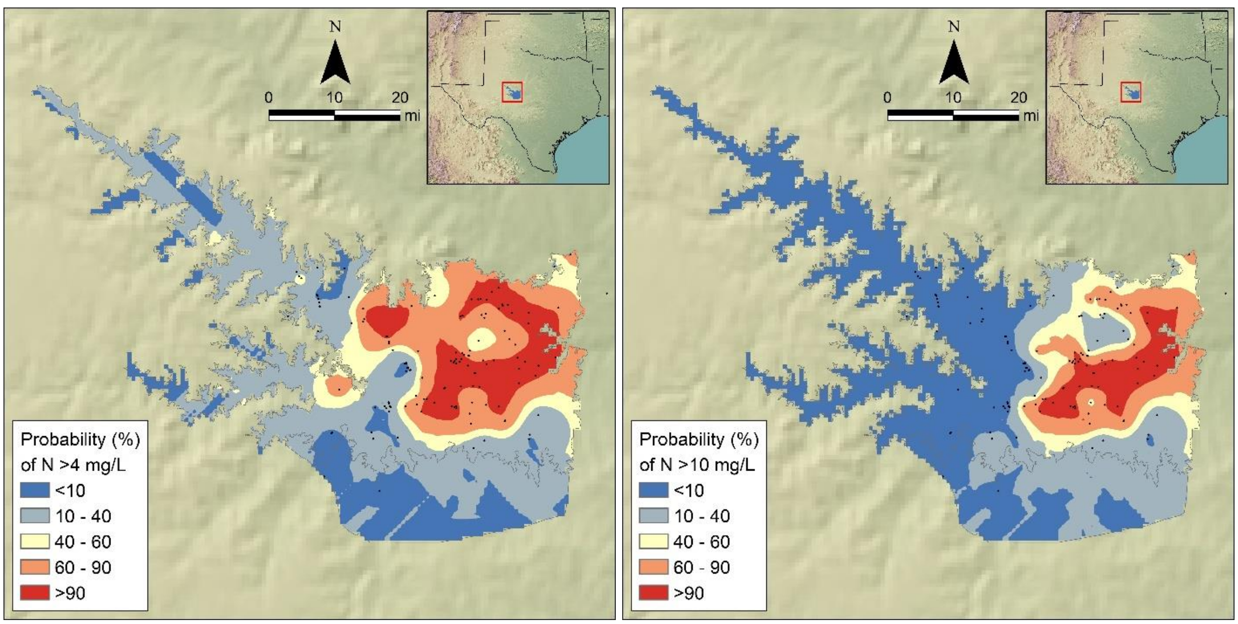


Figure 16. Lipan aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 15. Lipan aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	20.3	41.7	9.4	18.4	10.2
Nitrate-N >10 mg/L	51.5	22.9	8.3	11.0	6.3

Nacatoch

The Nacatoch aquifer occupies 1,800 mi^2 in a narrow band extending across parts of 15 counties in northeast Texas (Figure 17). The aquifer is composed of Cretaceous sandstones with an average saturated thickness of 50 ft. Water quality generally 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 204 samples analyzed for nitrate with 113 samples (55%) having detectable concentrations. About 99% of the area has very low to low probability of nitrate-N >4 mg/L (Table 16). The median concentration of samples with detectable concentrations is 0.3 mg/L and the 5^{th}-9^{th} percentile range is 0.01–12.7 mg/L.

A total of 7 samples (3%) exceeded the MCL with concentrations ranging from 10.6 mg/L to 126 mg/L and a median of 30.7 mg/L. The kriged probability maps reflect the exceedance locations as areas of low to moderate exceedance probability. The wells in violation are surrounded by wells that do not exceed the threshold, thus lowering the overall probability in those areas. This indicates that the nitrate contamination in this aquifer likely represents localized point sources.

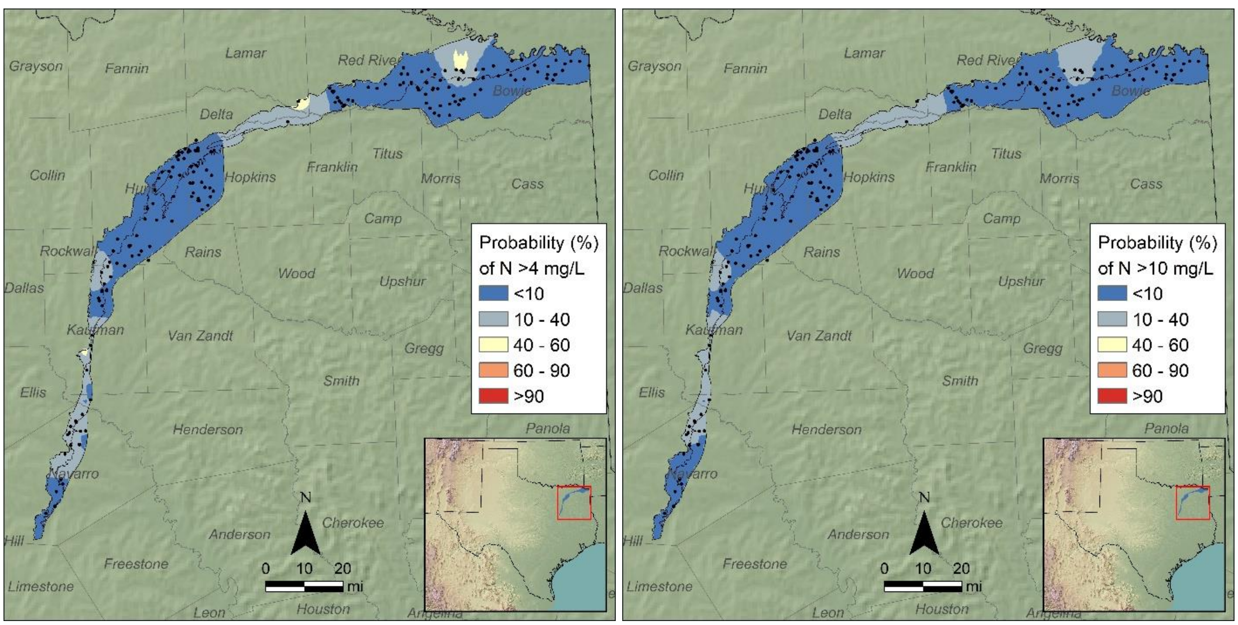


Figure 17. Nacatoch aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 16. Nacatoch aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	76.1	22.7	1.1	0.0	0.0
Nitrate-N >10 mg/L	79.4	20.6	0.0	0.0	0.0

Queen City

The Queen City aquifer occupies 15,800 mi^2 extending across parts of 42 counties in the upper coastal plain of Texas from Arkansas to South Texas (Figure 18). The aquifer is composed of Middle Eocene sands and loosely cemented sandstones. The average fresh water saturated thickness is 140 ft and water quality in generally good with TDS <1,000 mg/L.

There were 651 samples analyzed for nitrate with 456 samples (70%) having detectable concentrations. About 99% of the area has very low to low probability of nitrate-N >4 mg/L (Table 17). The median concentration of samples with detectable concentrations is 0.7 mg/L and the 5th-9th percentile range is 0.02–10.9 mg/L.

A total of 27 samples (4%) exceeded the MCL with concentrations ranging from 10.2 mg/L to 72.3 mg/L and a median of 17.2 mg/L. The kriged probability maps reflect the exceedance locations as areas of low to moderate exceedance probability. The wells in violation are surrounded by wells that do not exceed the threshold, thus lowering the overall probability in those areas. This indicates that the nitrate contamination in this aquifer likely represents localized point sources.

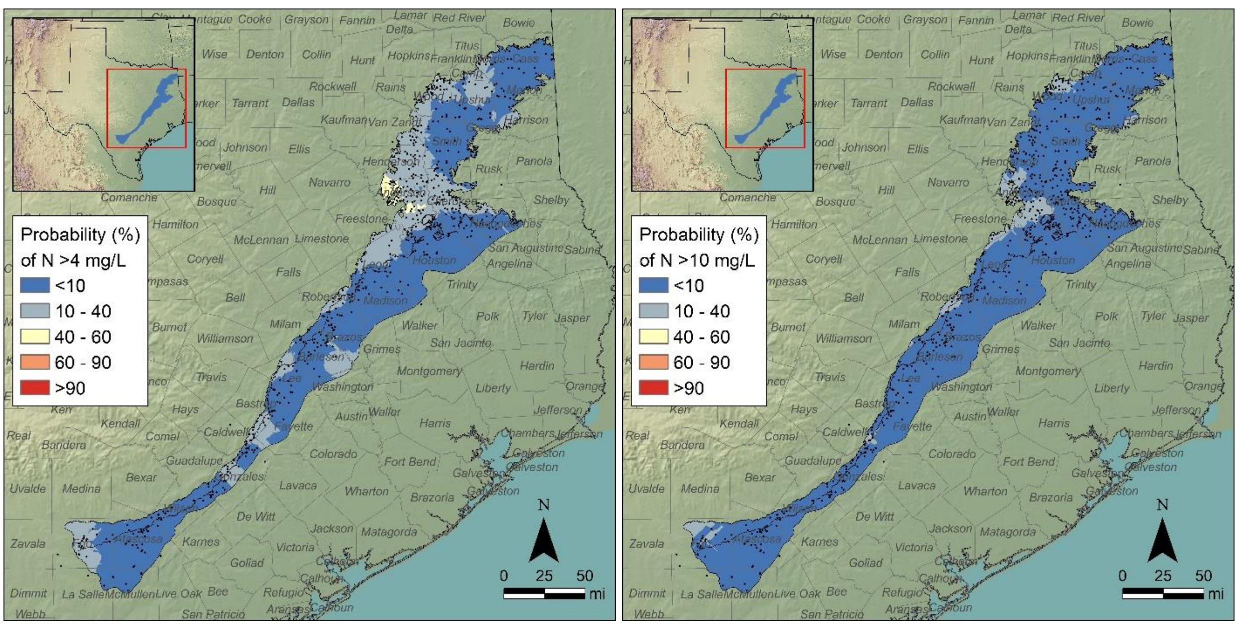


Figure 18. Queen City aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 17. Queen City aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	72.0	26.9	1.1	0.0	0.0
Nitrate-N >10 mg/L	95.2	4.8	0.0	0.0	0.0

Sparta

The Sparta aquifer occupies 7,900 mi^2 and extends across parts of 25 counties in the upper coastal plain of Texas (Figure 19). The aquifer is represented by the Middle Eocene Sparta Formation of the Claiborne Group. The freshwater saturated thickness is about 120 ft and water quality in the Sparta is generally good with TDS <1,000 mg/L.

There were 362 samples analyzed for nitrate with 254 samples (70%) having detectable concentrations. About 87% of the area has very low to low probability of nitrate-N >4 mg/L (Table 18). The median concentration of samples with detectable concentrations is 0.4 mg/L and the 5th-9th percentile range is 0.02–6.6 mg/L.

A total of 6 samples (2%) exceeded the MCL with concentrations ranging from 11.2 mg/L to 225 mg/L and a median of 16.6 mg/L. The kriged probability maps reflect the exceedance locations as areas of low to moderate exceedance probability. The wells in violation are surrounded by wells that do not exceed the threshold, thus lowering the overall probability in those areas. This indicates that the nitrate contamination in this aquifer likely represents localized point sources.

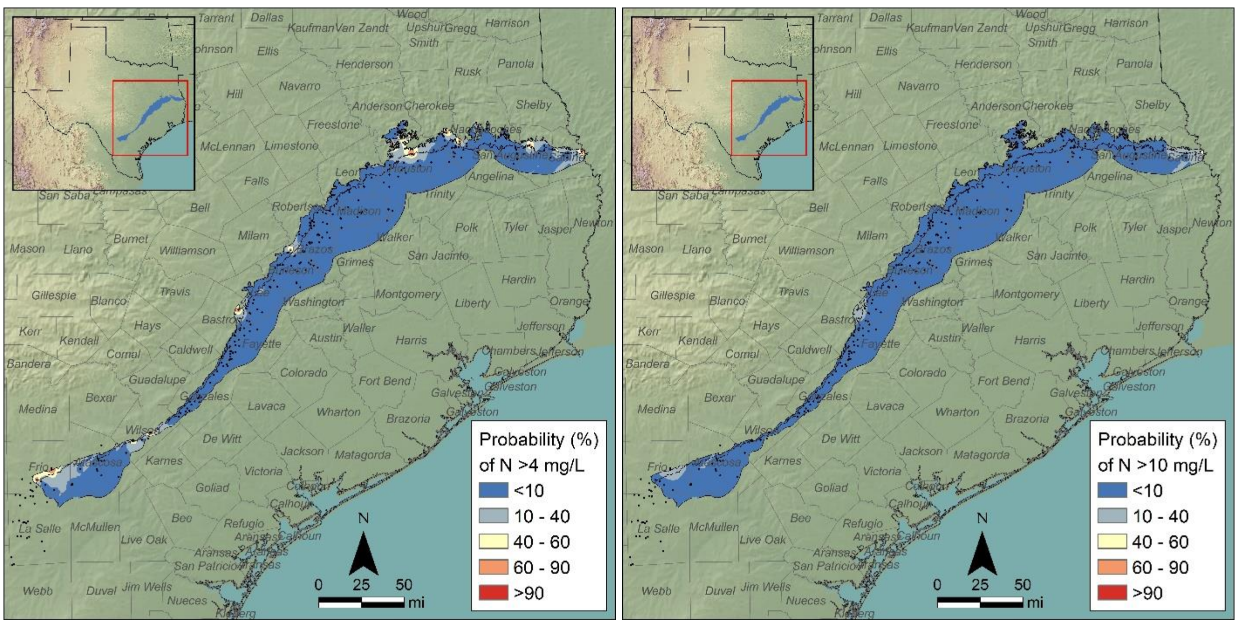


Figure 19. Sparta aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 18. Sparta aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	86.4	10.6	2.2	0.8	0.0
Nitrate-N >10 mg/L	95.8	4.1	0.0	0.0	0.0

West Texas Bolsons

The West Texas Bolsons aquifer occupies 1,200 mi^2 across parts of 5 counties in west Texas along the international border with Mexico (Figure 20). The aquifer is composed of Quaternary basin-fill deposits ranging up to 3,000 ft thick. The average freshwater saturated thickness is 580 ft. Water quality is locally <1,000 mg/L TDS but ranges up to 4,000 mg/L TDS.

There were 260 samples analyzed for nitrate with 246 samples (95%) having detectable concentrations. About 93% of the area has very low to low probability of nitrate-N >4 mg/L (Table 19). The median concentration of samples with detectable concentrations is 1.5 mg/L and the 5th-9th percentile range is 0.11–6.9 mg/L.

A total of 9 samples (3%) exceeded the MCL with concentrations ranging from 10.6 mg/L to 22.1 mg/L and a median of 12.9 mg/L. The kriged probability maps reflect the exceedance locations as areas of moderate to high exceedance probability. The wells in violation are not located nearby to wells that do not exceed the threshold. This indicates that the nitrate contamination in this aquifer may represent more than localized point sources.

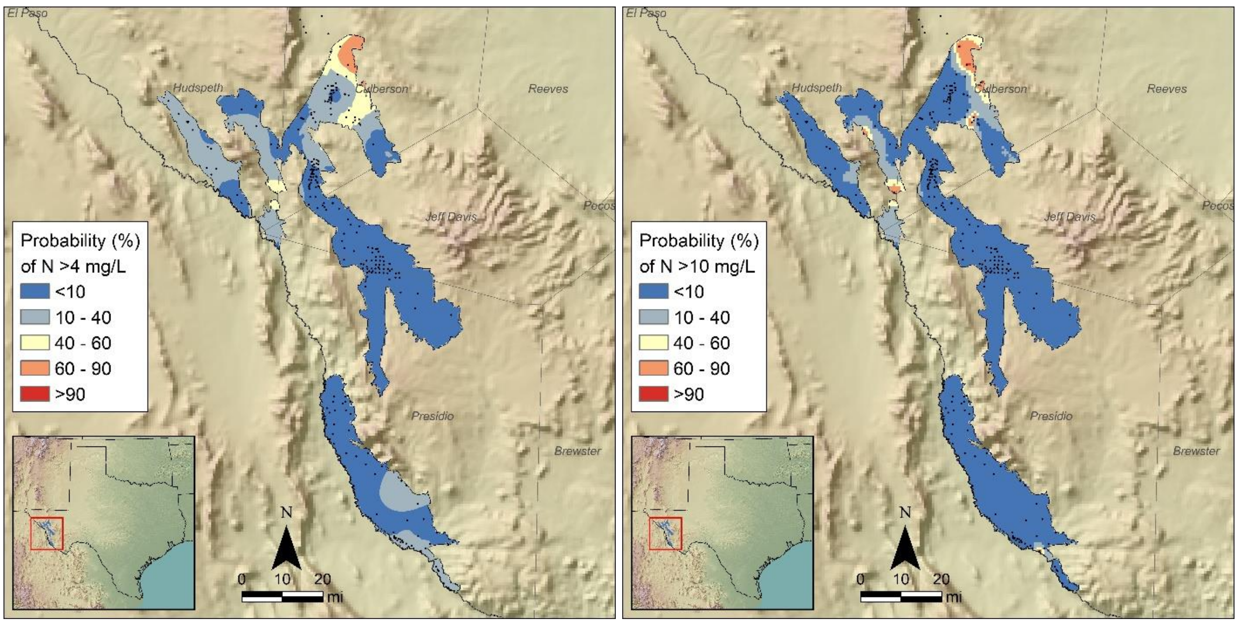


Figure 20. West Texas Bolsons aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 19. West Texas Bolsons aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	63.7	29.4	5.0	1.8	0.0
Nitrate-N >10 mg/L	86.1	9.2	2.5	2.1	0.1

Woodbine

The Woodbine aquifer occupies 7,300 mi^2 across parts of 17 counties in north central Texas (Figure 21). The aquifer is composed of interbedded Cretaceous sandstones, shales, and clays up to 600 ft thick. The average freshwater saturated thickness is 160 ft. Water quality generally decreases with increasing depth from <1,000 mg/L TDS in the shallower portions down to about 1,500 ft and ranging up to 4,000 mg/L TDS at greater depths.

There were 685 samples analyzed for nitrate with 410 samples (60%) having detectable concentrations. About 92% of the area has very low probability of nitrate-N >4 mg/L (Table 20). The median concentration of samples with detectable concentrations is 0.5 mg/L and the 5th-9th percentile range is 0.03–2.4 mg/L.

A total of 4 samples (1%) exceeded the MCL with concentrations ranging from 12.7 mg/L to 66.4 mg/L and a median of 33.1 mg/L. The kriged probability maps reflect the exceedance locations as areas of moderate to high exceedance probability. The wells in violation are surrounded by wells that do not exceed the threshold, thus lowering the overall probability in those areas. This indicates that the nitrate contamination in this aquifer likely represents localized point sources.

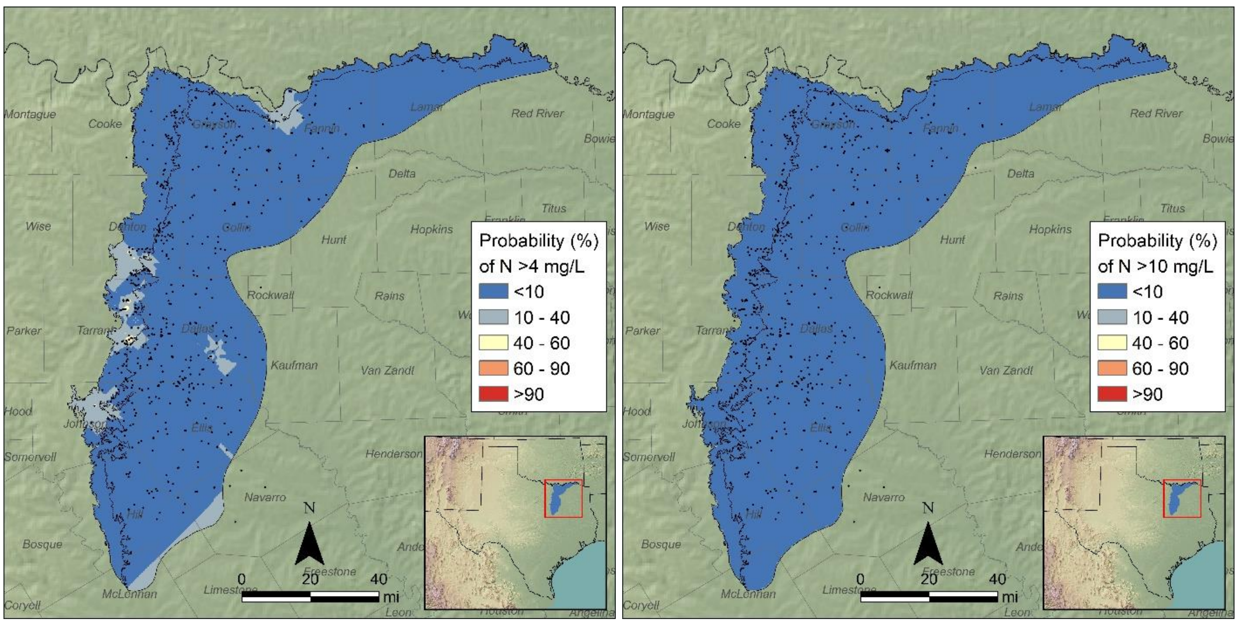


Figure 21. Woodbine aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 20. Woodbine aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	92.4	7.5	0.1	0.0	0.0
Nitrate-N >10 mg/L	100.0	0.0	0.0	0.0	0.0

Yegua – Jackson

The Yegua-Jackson aquifer occupies 10,900 mi^2 in parts of 34 counties across in the Texas Coastal Plain (Figure 22). The aquifer is composed of interbedded sands, silts, and clays of the Eocene Yegua Formation and Jackson Group. Freshwater saturated thickness averages 170 ft. Water quality is highly variable, ranging from <1,000 mg/L TDS in the shallower regions up to 10,000 mg/L TDS at greater depths.

There were 664 samples analyzed for nitrate with 409 samples (62%) having detectable concentrations. About 99% of the area has very low to low probability of nitrate-N >4 mg/L (Table 21). The median concentration of samples with detectable concentrations is 0.3 mg/L and the 5th-9th percentile range is 0.02–16.1 mg/L.

A total of 34 samples (5%) exceeded the MCL with concentrations ranging from 10.2 mg/L to 110 mg/L and a median of 18.9 mg/L. The kriged probability maps reflect the exceedance locations as localized areas of moderate to high exceedance probability in the far eastern regions of the aquifer near the Louisiana border.

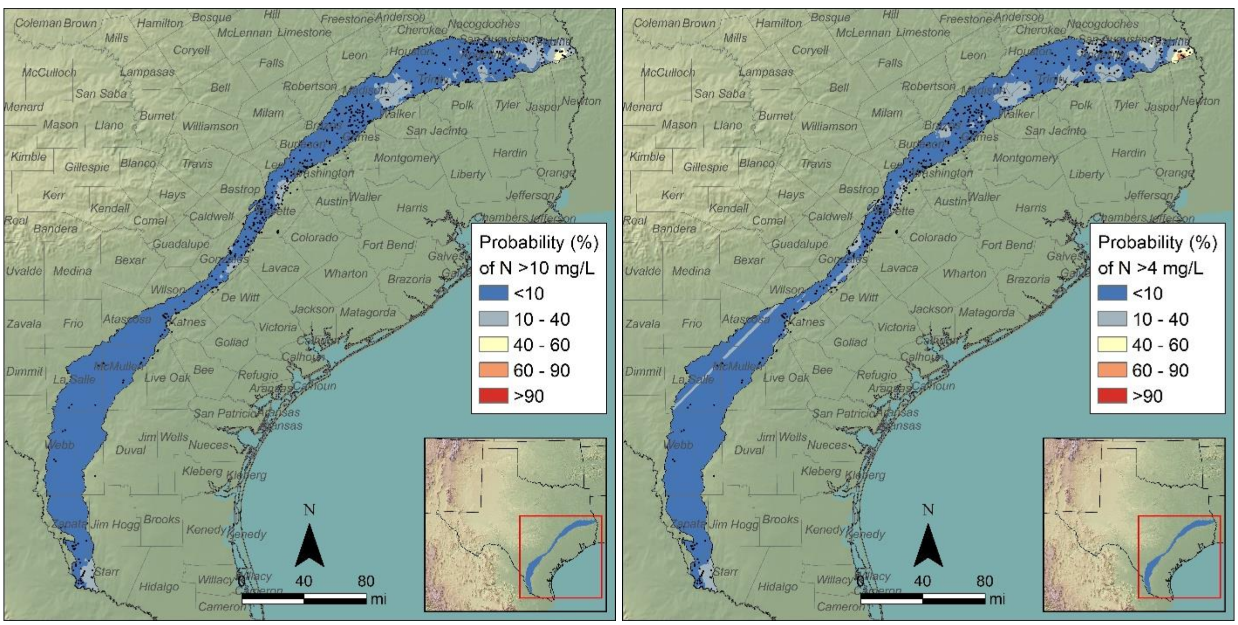


Figure 22. Yegua – Jackson aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 21. Yegua – Jackson aquifer areas at risk of exceeding 4 or 10 mg/L nitrate-N.

Exceedance Concentration	*Percent of aquifer area at risk of exceedance*				
	Very Low (<10%)	*Low (10%–40%)*	*Moderate (40%–60%)*	*High (60%–90%)*	*Very High >90%*
Nitrate-N >4 mg/L	84.6	14.7	0.6	0.1	0.0
Nitrate-N >10 mg/L	90.7	98.0	0.3	0.0	0.0

Persistence of Nitrate Contamination

Historical Nitrate-N Violations in Community Water Systems

Over the 20-year period 2003 – 2022, there were 147 CWSs in Texas that had at least one nitrate-N MCL violation (Figure 23). Of these, there are 126 systems that are currently active (Table 24), though not all are currently out of compliance. Almost half (61, 48%) of the currently active systems had violations during only 1 to 3 years, while the remaining systems had more persistent violation occurrences ranging from 4 to 20 years (Figure 24a).

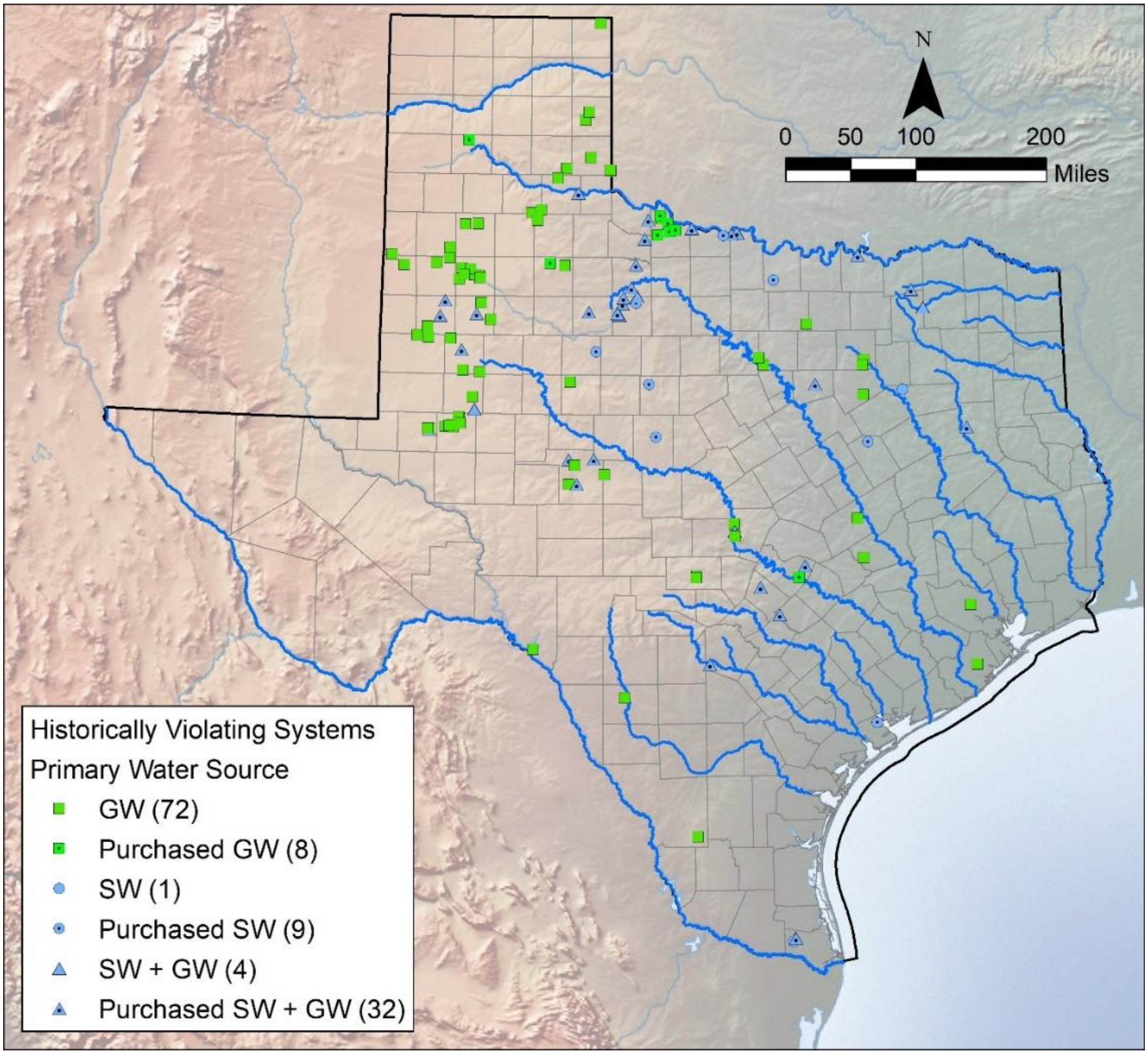


Figure 23. Locations of CWSs with historical Nitrates Rule violations during 2003 – 2022 symbolized by reported primary water source. Sources include groundwater (GW) and surface water (SW) and additionally water purchased water from another CWS system. There are many systems that indicate surface water as their primary source (purchased or not) that also include one or more active groundwater wells as a listed facility.

There were 21 systems that changed from public water systems to non-public water systems or became inactive altogether at some time during 2003 – 2022 (Table 25). These systems are no longer regulated by TCEQ and data on the original populations served are now mostly absent from the database. However, the original numbers of connections associated with most of these systems ranged from 1 to 42, with one having 105 connections. In all cases, each system was classified as serving ≤500 people. Based on the numbers of connections, these now private or inactive systems likely served very small populations, probably no more than ~100 people each.

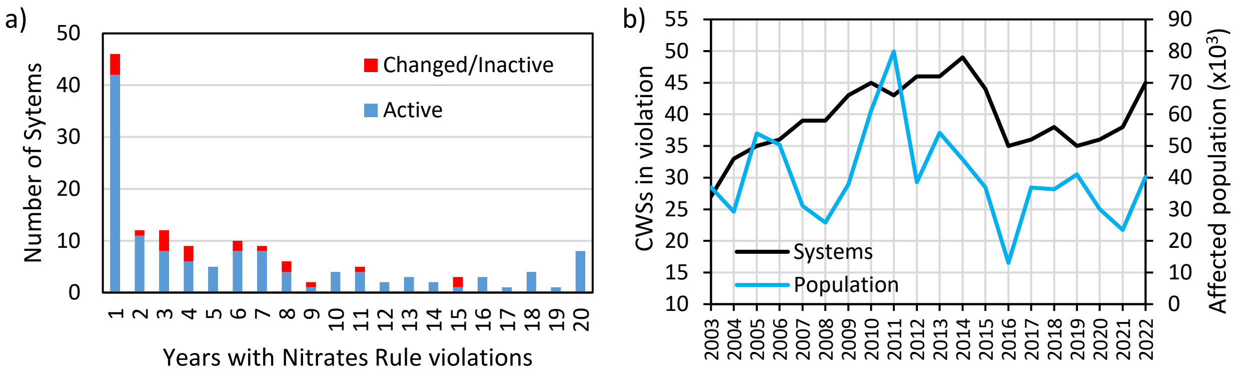


Figure 24. a) Years of Nitrate Rule violations for CWSs in Texas and b) time series of violating systems and associated populations for currently active systems during 2003 – 2022.

The total population served by all 126 currently active CWSs with violations during 2003 – 2022 is 255,053 persons, though some system populations likely increased or decreased during the period (Table 22). This represents 0.85% of the 2023 total CWS population in Texas.

Table 22. Persistence of Texas CWS Nitrate Rule violations during 2003-2022.

System Population	*Number of Systems*	*Total Population*	*Years in Violation*		*Years/ Period*
			Average	*Maximum*	
≤500	74	14,107	8.0	20	5.82
501 – 3,300	33	50,792	4.4	16	2.06
>3,300	13	83,123	2.7	11	1.48
24 – 39,648	126	255,053	6.3	20	4.18

The sizes of these CWSs range from 24 to 39,648 persons, with a median of 326 persons. There are distinct differences in both the mean frequency and persistence of violations by system size category, particularly for the smallest systems (Figure 25). Based on the last 20 years, the persistence of violations for the smallest systems (≤500 people) averages 3× to 4× greater than that of larger systems. There are 29 CWSs with violations of the Nitrates Rule during more than 10 of the past 20 years. Of these, 25 (86%) were CWSs that serve populations of ≤500 people.

Most (64%) of the CWSs with violations during 2003 – 2022 currently list groundwater as their primary source, representing about 60,000 people served. The remaining systems (36%) indicate that surface water is currently their primary source, though 27% also have active groundwater wells in their list of system facilities (147,300 people) while 9% do not list any active groundwater wells (47,800 people). Where groundwater is listed as a source, the Ogallala and Seymour aquifers are the most prevalent major aquifer sources, with a few occurrences of the Gulf Coast, Edwards, and Edwards-Trinity Plateau aquifers.

Several minor aquifers are also listed as sources for different violating systems, including the Blaine, Dockum, Lipan, Woodbine, and Nacatoch aquifers.

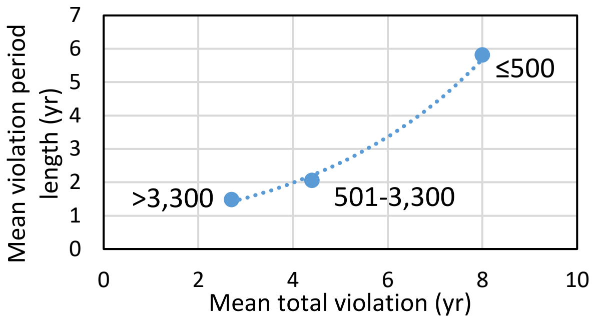


Figure 25. Relationship between the mean total number of violation years vs the mean violation period duration for three CWS population size groups.

Current Nitrate Violations in Community Water Systems.

For this study, we defined current violations as those occurring between Jan 2022 and Jun 2023. There are 50 CWSs that are currently out of compliance with regards to Nitrate Rule MCL concentrations (Figure 26).

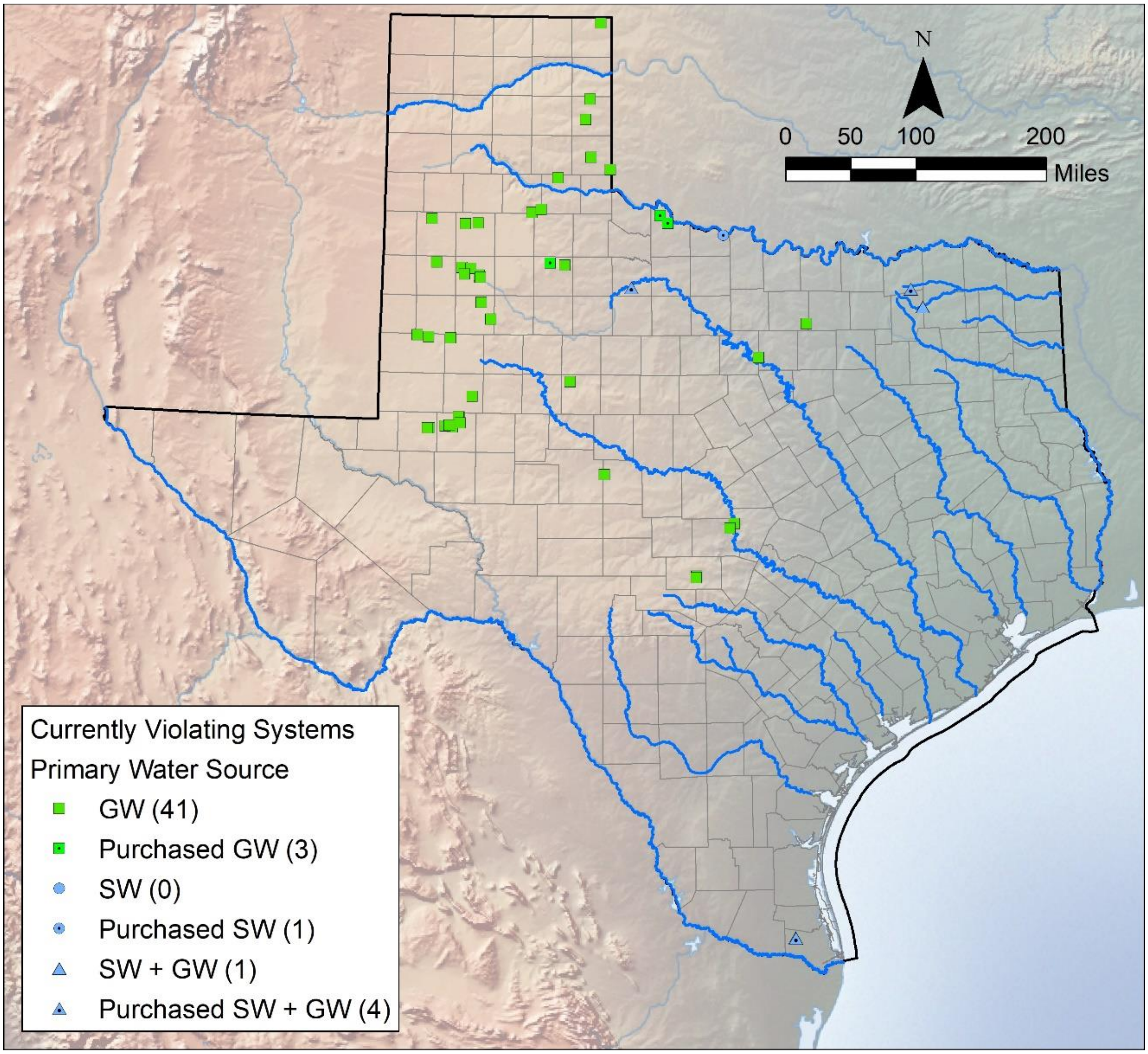


Figure 26. Locations of CWSs with current Nitrates Rule violations during Jan 2022 – Jun 2023 symbolized by reported primary water source. Sources include groundwater (GW) and surface water (SW) and additionally water purchased water from another CWS system. There are many systems that indicate surface water as their primary source (purchased or not) that also include one or more active groundwater wells as a listed facility.

This includes an additional five systems that were not included in the 20-yr analysis as these had no violations in 2022 but did report violations in 2023. The mean historical frequency and persistence by size category of the currently violating systems is generally similar to that of the systems in the 20-yr analysis, though currently violating systems are more heavily weighted toward smaller size systems having more frequent and persistent violations (Table 23, Figure 27). The overall affected population of ~45,000 people is similar to the annual mean affected population during the 20-yr period (40,000).

Table 23. Texas CWSs with current Nitrate Rule violations during 2003-2023.

System Population	*Number of Systems*	*Total Population*	*Years in Violation*		*Years/ Period*
			Average	*Maximum*	
≤500	39	7,881	10.7	21	8.34
501 – 3,300	8	13,152	6.6	16	1.68
>3,300	3	23,727	6.3	11	1.58
24 – 10,978	50	44,760	9.3	21	4.18

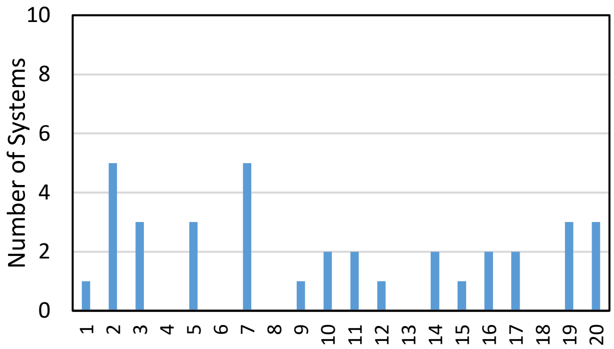


Figure 27. Years of Nitrate Rule violations during 2003 – 2023 for CWSs in Texas with current violations.

Most (88%) of the CWSs with current violations list groundwater as their primary source (Figure 26), representing about 17,700 people served. The remaining systems (12%) indicate that surface water is currently their primary source though 8% have active groundwater wells in their list of system facilities (serving 24,000 people), while 4% do not list any active wells (serving 3,100 people). Where groundwater is listed as a source, the Ogallala and Seymour aquifers together account for most (30) systems while the remaining systems variously obtain their water from one of ten other major and minor aquifers. The surface water sources include the Rio Grande River, Sabine River, Brazos River, and reservoirs along the Little Wichita River.

Table 24. List of 129 currently active systems with any Nitrate Rule MCL violations during either the historical period 2003-2022 or current period 2022-2023 by primary source, including groundwater (GW), purchased groundwater (GWP), surface water (SW), and purchased surface water (SWP).

PWSID	System Name	Primary Source	Population Served	Source Aquifer	Surface Water Source
Primary Groundwater or Purchased Groundwater Sources Only					
TX0090011	Maple WSC	GW	55	Edwards -Trinity HP	none
TX0200011	City of Danbury	GW	1,745	Gulf Coast	none
TX0230002	City of Quitaque	GW	385	Permian Age	none
TX0260014	Deanville WSC	GW	3,192	Queen City	none
TX0270021	Silver Village WSC	GW	312	Hickory	none
TX0270065	River Water System	GW	300	Precambrian Age	none
TX0400001	City of Morton	GW	1,690	Ogallala	none
TX0440001	Wellington Water System	GW	2,191	Seymour	none
TX0440002	City of Dodson	GW	109	Seymour	none
TX0440018	Rra Water System	GW	300	Blaine	none
TX0480011	Eola Eola WSC	GW	165	Lipan	none
TX0510001	City of Paducah	GW	1,186	Seymour	none
TX0570082	D Bar B Mobile Home Ranch	GW	240	Alluvial	none
TX0570094	Cottonwood Ck MHP	GW	225	Woodbine	none
TX0580011	City of Ackerly	GW	245	Ogallala	none
TX0580013	Welch Welch WSC	GW	315	Ogallala	none
TX0580025	Klondike ISD	GW	264	Ogallala	none
TX0680051	Canyon Home Park	GW	108	Edwards - Trinity Plateau	none
TX0680163	Huber Garden Estates	GW	200	Dockum	none
TX0700020	City of Bardwell	GW	747	Woodbine	none
TX0830001	City of Seagraves	GW	2,417	Ogallala	none
TX0830011	Loop Loop WSC	GW	300	Ogallala	none
TX0860080	Royal Oaks Apartments	GW	57	Trinity	none
TX0860136	Bernhard Trailer Park	GW	60	HIckory	none
TX0860144	Vineyard Ridge WS	GW	195	Ellenburger-San Saba	none
TX0950016	Halfway Halfway WSC	GW	110	Ogallala	none
TX0950059	Loma Alta WSC	GW	72	Ogallala	none
TX0950064	Ebeling WSC	GW	51	Ogallala	none
TX0960002	City of Memphis	GW	2,290	Alluvial	none
TX0960003	Turkey Water System	GW	421	Permian Age	none
TX0960014	Lakeview Lakeview WSC	GW	98	Seymour	none
TX1010826	Pin Oak MHP	GW	345	Gulf Coast (Chicot)	none
TX1100001	City of Anton	GW	1,126	Ogallala	none
TX1100011	Whitharral WSC	GW	200	Ogallala	none
TX1350001	RRA Water System	GW	408	Permian Age	none
TX1400002	City of Earth	GW	1,160	Ogallala	none

PWSID	System Name	Primary Source	Population Served	Source Aquifer	Surface Water Source
TX1400010	Spade WSC	GW	125	Ogallala	none
TX1480003	Follett Water System	GW	450	Ogallala	none
TX1500033	Lake Front Buchanan	GW	69	Precambrian Age	none
TX1520026	Family Community Center MHP	GW	86	Ogallala	none
TX1520039	Peaceful Lane Village	GW	90	Ogallala	none
TX1520046	Wildwood Home Village	GW	672	Ogallala	none
TX1520080	Franklin Water System	GW	159	Ogallala	none
TX1520094	Town Water System	GW	360	Ogallala	none
TX1520159	North University Estates	GW	600	Ogallala	none
TX1520232	West Roosevelt MHP	GW	95	Ogallala	none
TX1520292	Heartland Heartland House	GW	24	Ogallala	none
TX1520308	Chipper Point Apartments	GW	29	Ogallala	none
TX1530003	City of Wilson	GW	444	Ogallala	none
TX1530005	Grassland Grassland WSC	GW	55	Ogallala	none
TX1590002	Martin County FWSD	GW	54	Ogallala	none
TX1650024	Pecan Home Park	GW	336	Ogallala	none
TX1650048	Greenwood H Subdivision	GW	120	Ogallala	none
TX1650057	Twin MHP Midland	GW	234	Ogallala	none
TX1650066	Spring Home Park	GW	163	Edwards - Trinity Plateau	none
TX1650077	South Midland County WS	GW	165	Ogallala	none
TX1650084	Warren Road Subdivision WS	GW	195	Edwards - Trinity Plateau	none
TX1650111	Country Home Estates	GW	138	Ogallala	none
TX1650197	Margies Margies MHP	GW	60	Ogallala	none
TX1660011	North Milam WSC	GW	1,713	Carrizo-Wilcox	none
TX1730003	Flomot Water Assoc	GW	55	Seymour	none
TX1770001	City of Roscoe	GW	1,271	Dockum	none
TX1840018	Lazy Bend Estates	GW	171	Trinity	none
TX1840077	Rjr Rjr Water	GW	387	Alluvial	none
TX2230003	City of Wellman	GW	200	Ogallala	none
TX2260022	Browns Pool and Park	GW	70	Lipan	none
TX2260052	Tom Green County FWSD	GW	960	Alluvial	none
TX2330013	Tierra Del Lago	GW	81	Edwards - Trinity Plateau	none
TX2400025	Mirando City WSC	GW	460	Gulf Coast	none
TX2420001	Shamrock Water System	GW	1,946	Ogallala	none
TX2420002	Wheeler MWS	GW	1,651	Ogallala	none
TX2420006	Fort Wlliott CISD Briscoe	GW	155	Ogallala	none
TX2440001	City of Vernon	GW	10,078	Seymour	none
TX2490031	Singing Meadows Subdivision	GW	120	Trinity	none
TX2540003	Zavala County WCID	GW	2,043	Carrizo-Wilcox	none
TX0630014	Patton Springs ISD	GWP	130	Ogallala	none

PWSID	System Name	Primary Source	Population Served	Source Aquifer	Surface Water Source
TX1910005	Country Estates MHP	GWP	262	Ogallala	none
TX2270255	Austins Colony	GWP	9,987	Alluvial	none
TX2440003	Northside Northside WSC	GWP	200	Seymour	none
TX2440005	Rra Water System	GWP	228	Seymour	none
TX2440006	RRA Box CWS	GWP	144	Seymour	none
TX2440008	RRA Lockett WS	GWP	843	Seymour	none
TX2440009	Oklaunion WSC	GWP	95	Seymour	none
Primary Surface Water or Purchased Surface Water Sources Only					
TX1070190	West Creek MUD	SW	20,379	none	Cedar Creek Reservoir
TX0290002	City of Port Lavaca	SWP	11,854	none	Port Lavaca West Reservoir
TX0300015	Callahan County WSC	SWP	3,747	none	Lake Baird
TX0310027	City Palm Valley	SWP	1,310	none	Lake Harlingen
TX0420034	Coleman County SUD	SWP	5,000	none	Lake Coleman
TX0760013	D P & R WSC	SWP	570	none	Unknown
TX1040004	City of Weinert	SWP	157	none	Millers Creek Reservoir
TX1470001	City of Coolidge	SWP	955	none	Navarro Mills Lake
TX1690023	Amon G Carter Lake WSC	SWP	750	none	Lake Amon G Carter
TX2430005	City of Burkburnett	SWP	10,978	none	Wichita River
TX0310021	Town of Combs	SWP	2,895	none	Rio Grande River
TX0310145	Carefree Valley Resort	SWP	197	none	Rio Grande River
Primary Surface Water or Purchased Surface Water Sources with Additional Groundwater Sources					
TX0270047	Cassie Water System	SW	106	Precambrian Age	Lake Buchanan
TX1160003	City of Commerce	SW	8,240	Nacatoch	Sabine River
TX1380009	North Central Texas MWA	SW	132	Seymour	Millers Creek Reservoir
TX1590001	City of Stanton	SW	2,492	Ogallala	Colorado River
TX0150040	Atascosa Rural WSC	SWP	13,905	Edwards BFZ	Unknown
TX0280013	Martindale WSC	SWP	3,045	Alluvial	San Marcos River
TX0370016	Craft Turney WSC Main	SWP	5,577	Carrizo-Wilcox	Lake Jacksonville
TX0390003	City of Byers	SWP	496	Seymour	Lake Kickapoo
TX0390016	Charlie WSC	SWP	100	Seymour	Red River
TX0390019	Dean Dale SUD	SWP	3,747	Seymour	Lake Kickapoo
TX0580001	City of Lamesa	SWP	9,442	Ogallala	Lake Alan Henry
TX0680013	Northgate MHP	SWP	126	Dockum	Odessa Reservoir North
TX0780013	Thalia WSC	SWP	135	Seymour	Unknown
TX0910052	Tanglewood on Texoma	SWP	3,687	Antlers	Lake Texoma
TX0960001	RRA Estelline Turkey WS	SWP	250	Seymour	Greenbelt Reservoir
TX0990001	City of Chillicothe	SWP	707	Seymour	Greenbelt Reservoir
TX1040002	City of Rochester	SWP	248	Seymour	Millers Creek Reservoir
TX1040003	City of Rule	SWP	687	Seymour	Millers Creek Reservoir
TX1040005	City of Obrien	SWP	102	Seymour	Millers Creek Reservoir

PWSID	System Name	Primary Source	Population Served	Source Aquifer	Surface Water Source
TX1050013	Dripping Springs WSC	SWP	8,037	Trinity	Lake Travis
TX1160039	North Hunt SUD	SWP	4,509	Nacatoch	Sabine River
TX1260008	City of Keene	SWP	6,310	Trinity	Brazos River
TX1380006	RRA Truscott Gilliland WS	SWP	243	Seymour	Greenbelt Reservoir
TX1380011	City of Benjamin	SWP	258	Seymour	Brazos River
TX1530002	City of Tahoka	SWP	2,760	Ogallala	Canadian River
TX2000002	City of Miles	SWP	920	Lipan	Lake E V Spence
TX2170001	City of Aspermont	SWP	1,015	Seymour	Millers Creek Reservoir
TX2170002	Swenson WSC	SWP	32	Seymour	Millers Creek Reservoir
TX2230001	City of Brownfield	SWP	9,800	Ogallala	Canadian River
TX2230002	City of Meadow	SWP	593	Ogallala	Canadian River
TX2260008	Concho Rural Water Grape Creek	SWP	5,049	Lipan	Lake E V Spence
TX2260057	Concho Rural Water Pecan Creek	SWP	1,275	Lipan	Lake E V Spence
TX2270033	Manville WSC	SWP	39,648	Edwards BFZ	Unknown
TX2430002	City of Electra	SWP	2,715	Alluvial	Lake Iowa Park

Table 25. List of 21 historically active systems with any Nitrate Rule MCL violations during 2003-2022 by primary source, including groundwater (GW), purchased groundwater (GWP), surface water (SW), and purchased surface water (SWP). These systems have converted to non-public systems or are no longer active.

PWSID	System Name	Primary Source	System Connections	Source Aquifer	Surface Water Source
Primary Groundwater or Purchased Groundwater Sources Only					
TX0680069	Devilla MHP	GW	14	Ogallala	none
TX0680126	Williams Trailer Court	GW	24	Ogallala	none
TX0680148	Gardendale MHP	GW	29	Ogallala	none
TX0940089	River Ridge Apartments	GW	17	Edwards BFZ	none
TX1080238	Sol Y Mar	GW	29	Gulf Coast	none
TX1520009	Hidden Tree Ranch	GW	30	Ogallala	none
TX1520064	Fort Jackson Mobile Estates	GW	12	Ogallala	none
TX1520142	Country Squire HMP	GW	13	Ogallala	none
TX1520211	Texin Enterprises WS	GW	12	Ogallala	none
TX1520225	Red Rader RV Park	GW	42	Ogallala	none
TX1520257	J&G Rentals	GW	16	Ogallala	none
TX1650022	Sherwood Estates	GW	1	Ogallala	none
TX1650043	Peak Properties	GW	11	Ogallala	none
TX1700058	Rolling Hills Oaks Subdivision	GW	39	Gulf Coast	none
TX2080022	Colorado River MWD Snyder Well Field	GW	1	Ogallala	none
TX2320056	Newell MHP	GW	22	ET Plateau	none
TX2420003	Allison Volunteer WS	GW	22	Ogallala	none
TX2490052	Diamond Ridge	GW	37	Unknown	none
TX1650105	Water Tech	GWP	2	Ogallala	none
Primary Surface Water or Purchased Surface Water Sources Only					
TX1500117	Rio Vista Resort	SW	2	none	Lake LBJ - Colorado River
TX0130018	Blueberry Hills Waterworks	SWP	105	none	Lake Corpus Chisti

Summary

Most of the Texas population is served with water from CWSs, totaling 29.8 million in 2023 (95.5% of population of 31.2 million). Quantifying the spatial distribution of groundwater nitrate-N concentrations in aquifers in Texas is important for managing groundwater resources in the state. In this study 18 of the 22 minor aquifers of Texas were evaluated for the probability of groundwater nitrate-N levels exceeding 4 mg/L background level and 10 mg/L EPA nitrate-N MCL, using the latest samples collected from 8,220 groundwater wells between 1930 and 2023.

A total of 747 groundwater wells completed in minor aquifers exceeded the nitrate-N MCL of 10 mg/L based on the TWDB groundwater database. This represents 9.1% of the most recent nitrate analyses from minor aquifer wells throughout the state. The exceedance rate for the collective minor aquifer wells is similar to that of major aquifer wells (7.8%), though excluding the Seymour major aquifer, which has an exceedance rate of 54.7%, the exceedance rate for the remaining major aquifers is 4.4% (Malito et al., 2022).

The median nitrate-N concentration was highest in the Lipan Aquifer (8.05 mg/L), followed by the Bone Spring – Victorio Peak (median 4.33 mg/L), Blaine (3.78 mg/L), and the Rustler (3.66 mg/L) aquifers. A total of 1,474 minor aquifer samples exceeded the background level of 4 mg/L nitrate-N, representing 18% of all samples. Concentrations at the 95^{th} percentile exceeded 4 mg/L for all minor aquifers except the Woodbine and Rita Blanca aquifers. Aquifers with the highest exceedance rates for the 4 mg/L background level include the Lipan (61%), Bone Spring – Victorio Peak (46%), Blaine (35%), Edwards-Trinity (High Plains) (35%), and Rustler (34%) aquifers. The exceedance rates for the 10 mg/L MCL level are >10% in six minor aquifers, including the Lipan (43.5%), Bone Spring – Victorio Peak (18.6%), Cross Timbers (14.9%), Blaine (13.1%), Rustler (11.3%), and Dockum (10.1%) aquifers.

Annual CWS data for 2003 – 2022 indicate there were 147 CWSs that were historically out of compliance during at least one year and 21 systems are no longer active. The 126 currently active systems collectively serve ~255,000 people, though historically during any one year, about 40,000 people were affected by MCL violations. Of the currently active systems, 107 (85%) serve populations ≤3,300 people. The persistence of violations is greatest among the 74 smallest systems (≤500 people) which have an average violation period of 5.8 years.

There are 50 systems that are currently out of compliance (Jan 2022 – Jun 2023) and as a group they tend to be smaller and have more persistent violations than the group of 126 historical systems with violations (2003 – 2022). While the current affected population (45,000 people) is similar to the historical average, 96% of the affected systems serve ≤3,300 people and violation periods average 8.3 years for the smallest systems serving ≤500 people. Most of the affected systems (88%) report groundwater as their primary source, while the remaining report only surface water or a combination of surface water and groundwater.

While water quality for the majority of CWSs is compliant with respect to nitrate-N levels, noncompliant systems are generally based on groundwater and are mostly small systems. The lack of alternative water supplies for many of these systems means that most will require treatment to reach compliance, which is challenging for these small CWSs.

Acknowledgements

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Appendix I – Large Format Aquifer Probability Maps

List of Figures

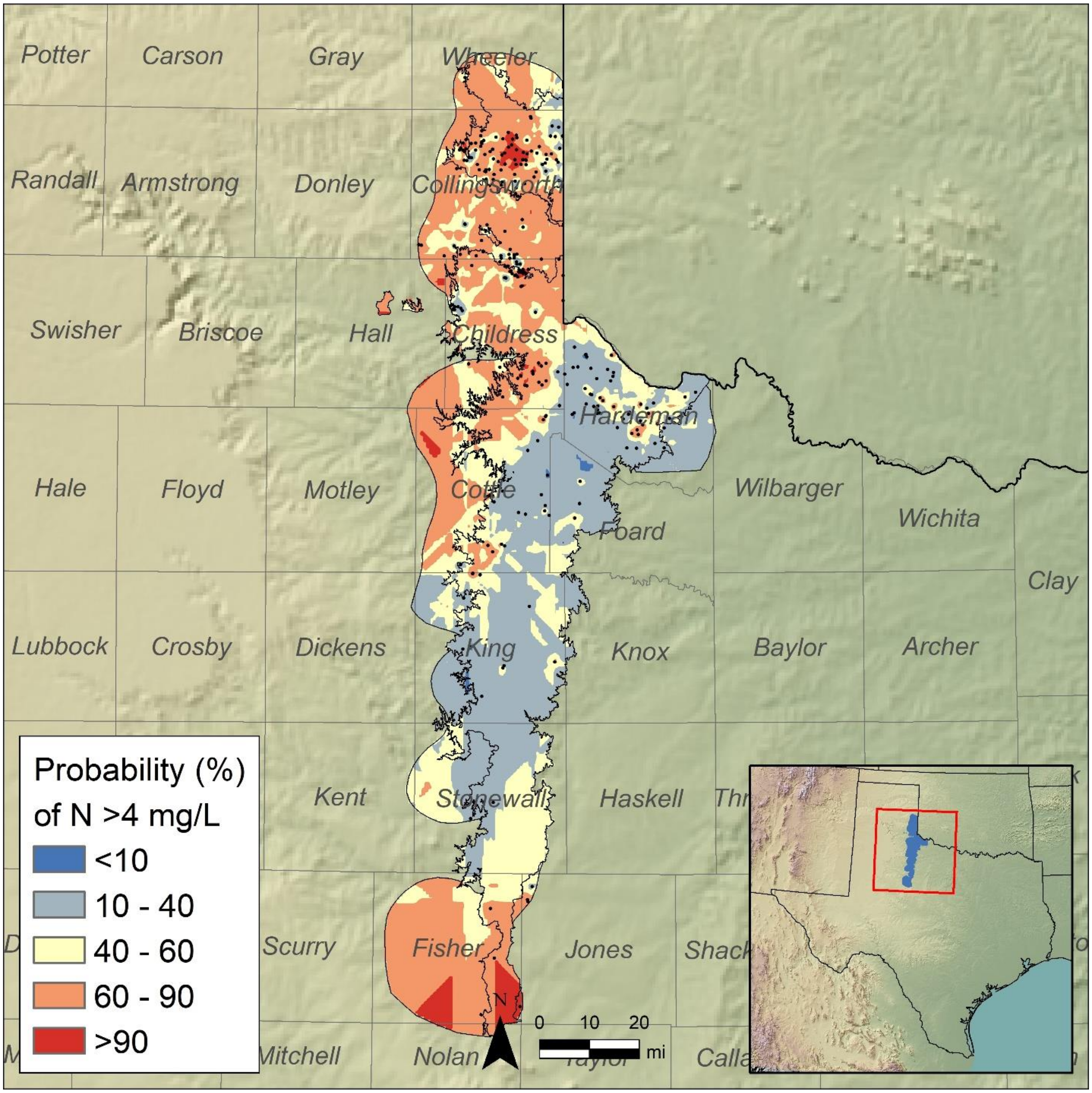


Figure 28. Blaine aquifer probability distribution of N >4 mg/L.

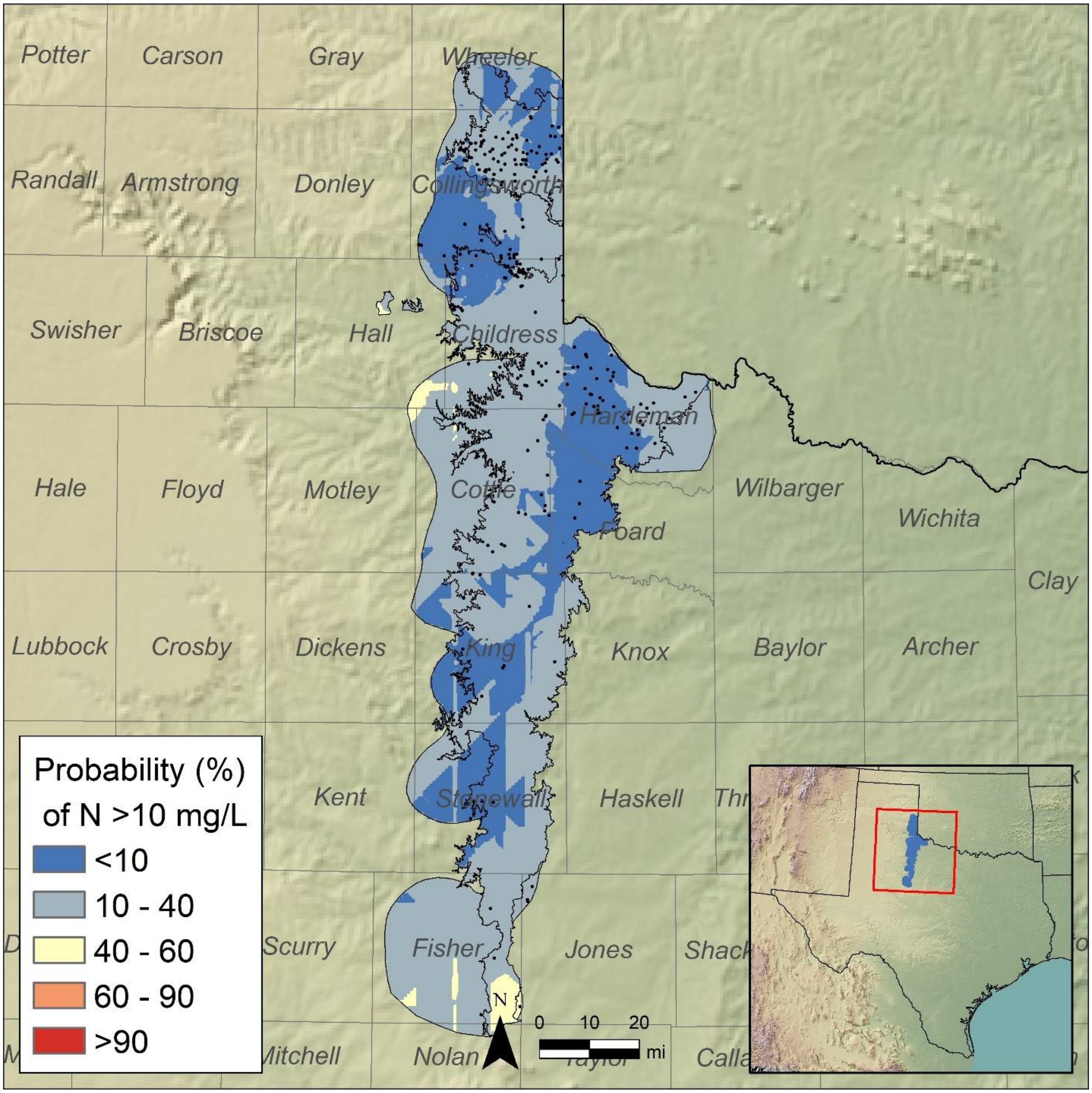


Figure 29. Blaine aquifer probability distribution of N >10 mg/L.

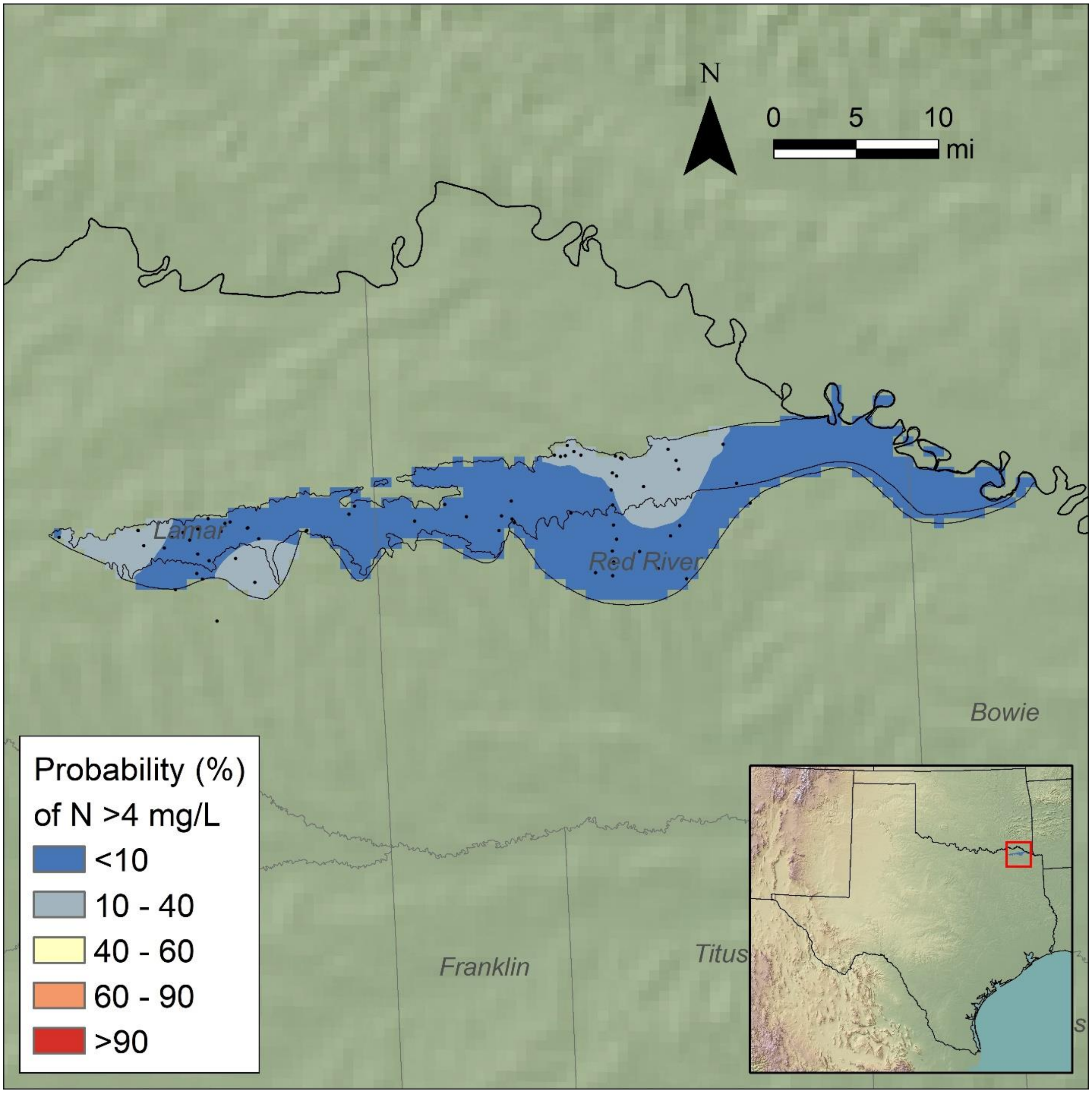


Figure 30. Blossom aquifer probability distribution of N >4 mg/L.

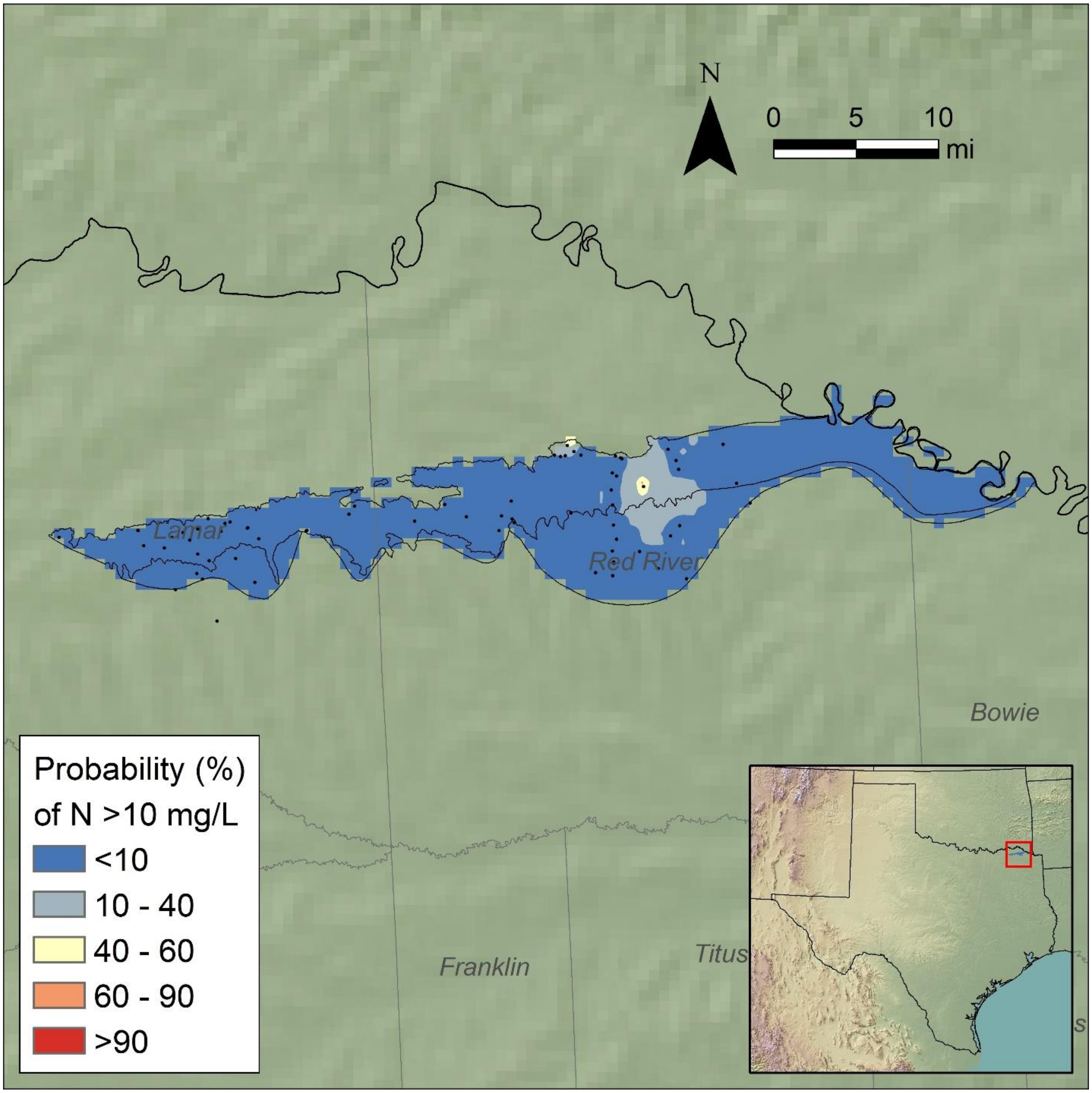


Figure 31. Blossom aquifer probability distribution of N >10 mg/L.

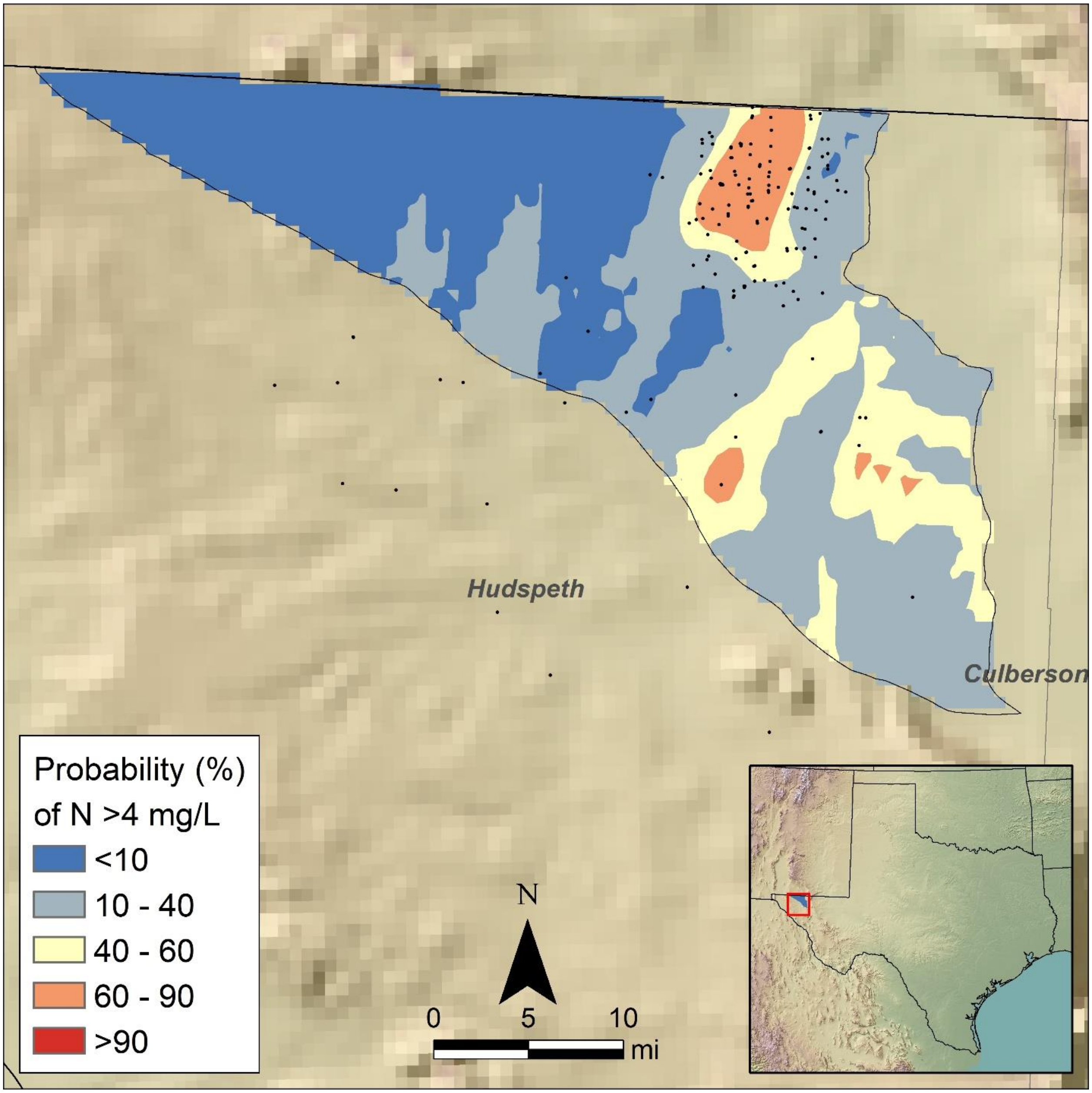


Figure 32. Bone Spring – Victorio Peak aquifer probability distribution of N >4 mg/L.

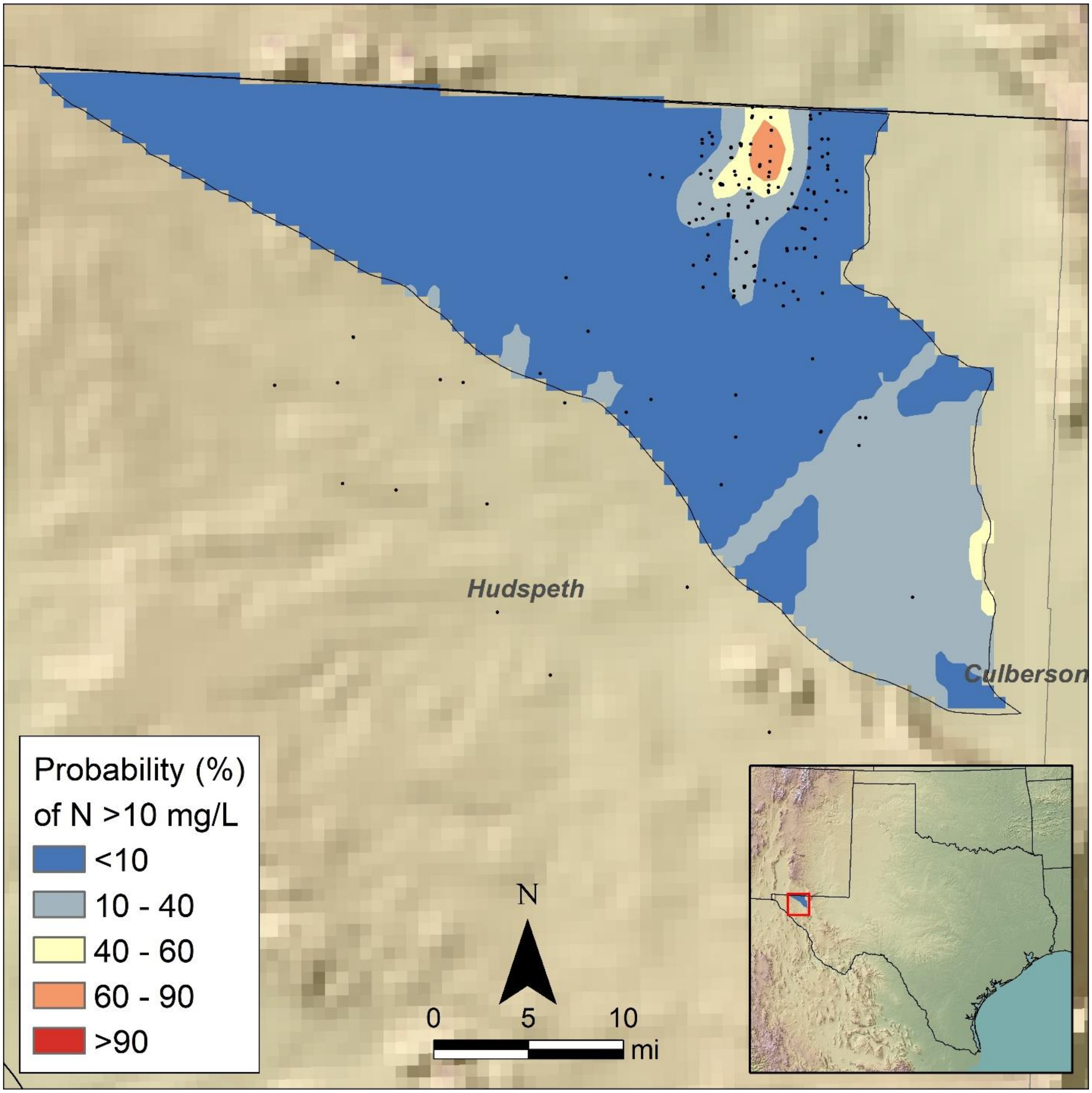


Figure 33. Bone Spring – Victorio Peak aquifer probability distribution of N >10 mg/L.

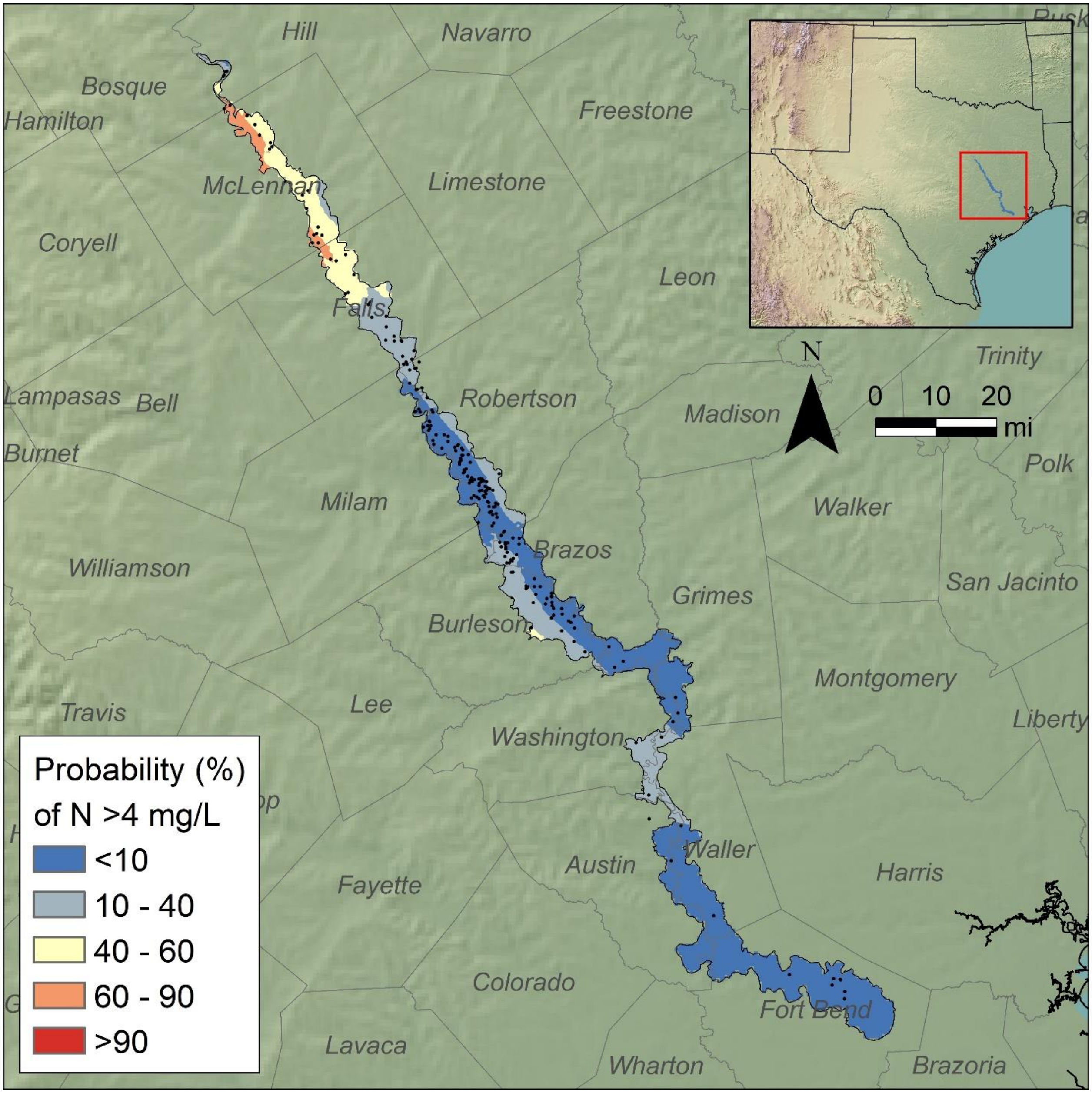


Figure 34. Brazos River Alluvium aquifer probability distribution of N >10 mg/L.

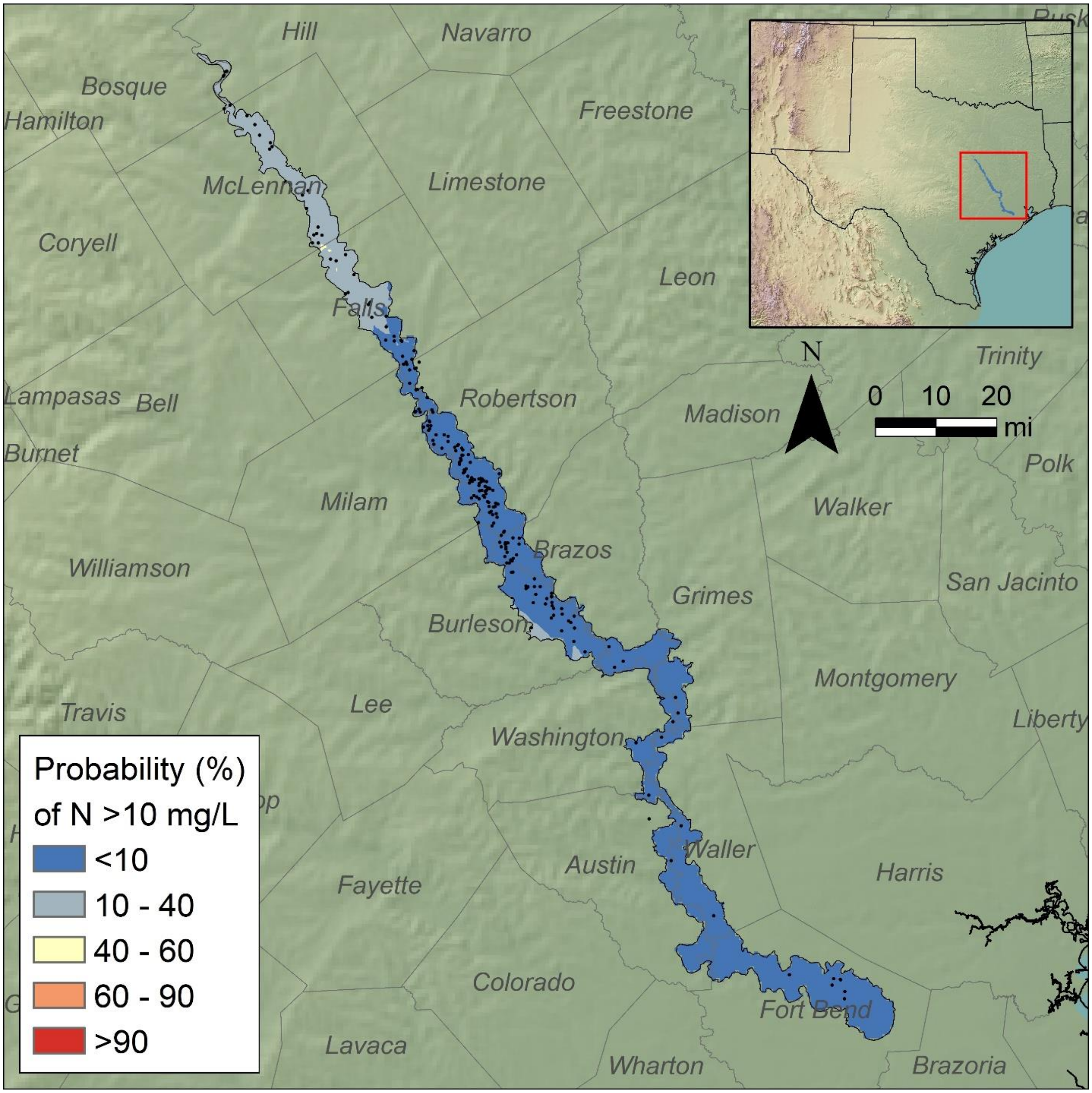


Figure 35. Brazos River Alluvium aquifer probability distribution of N >10 mg/L.

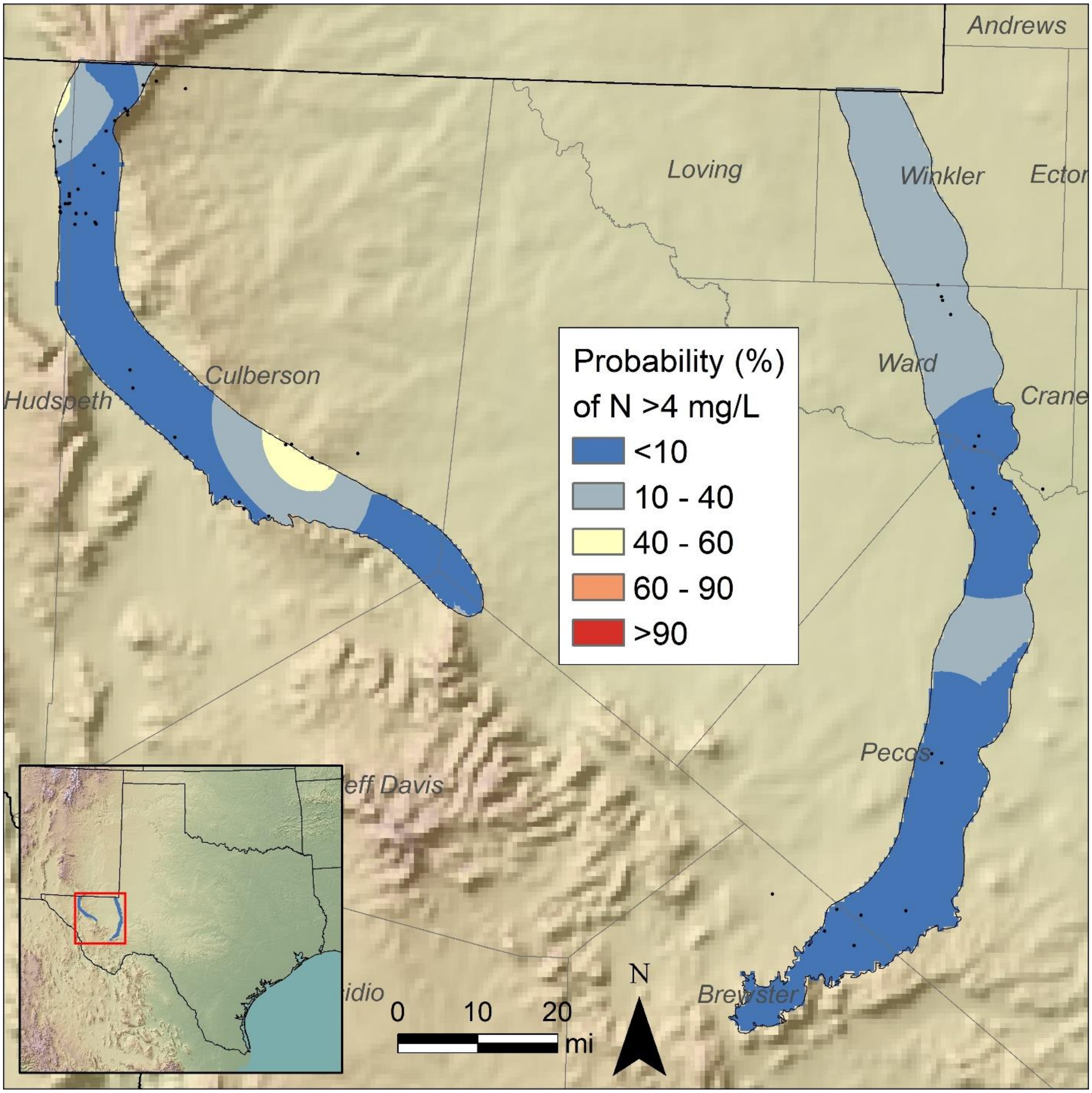


Figure 36. Capitan Reef Complex aquifer probability distribution of N >4 mg/L.

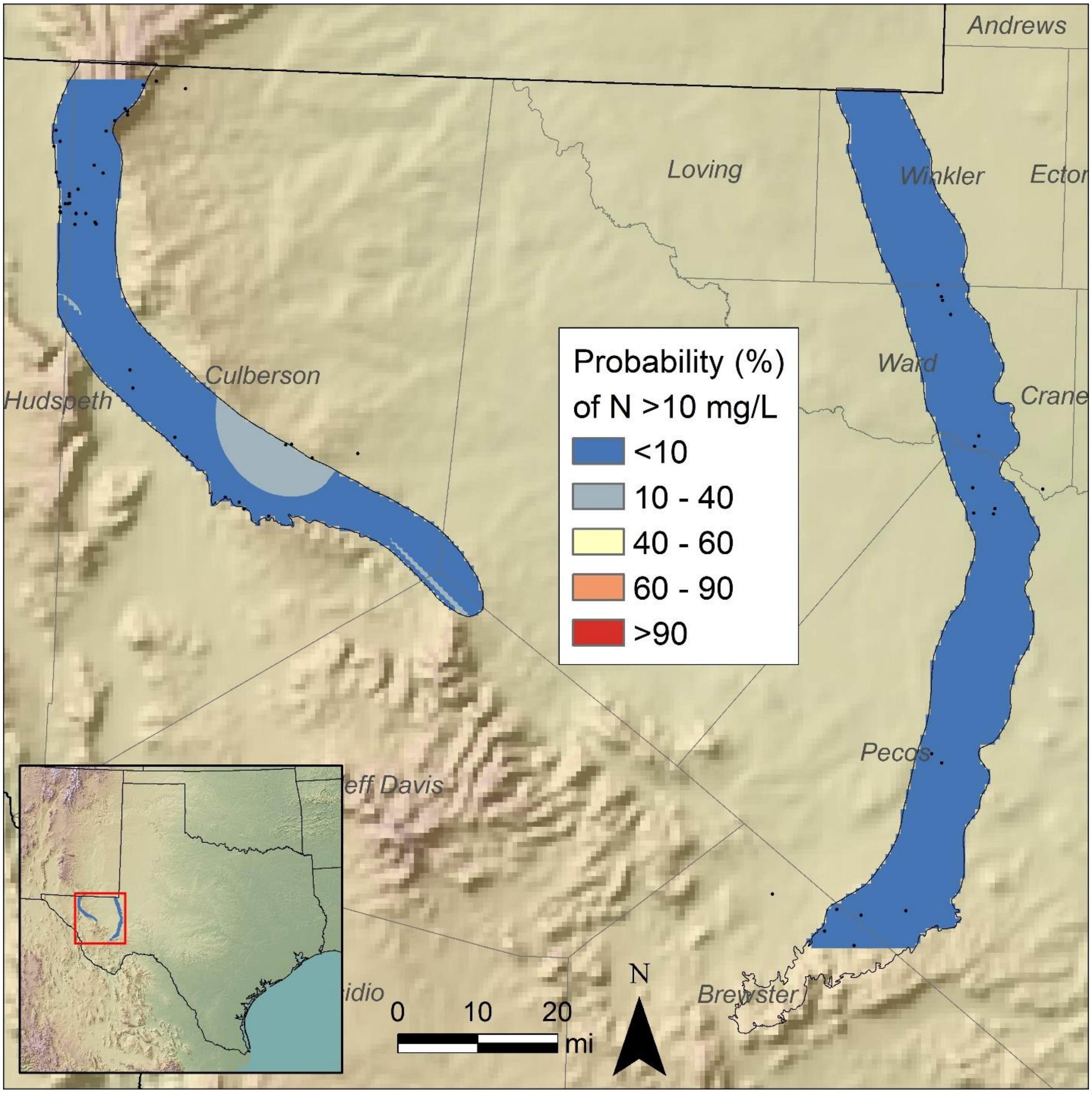
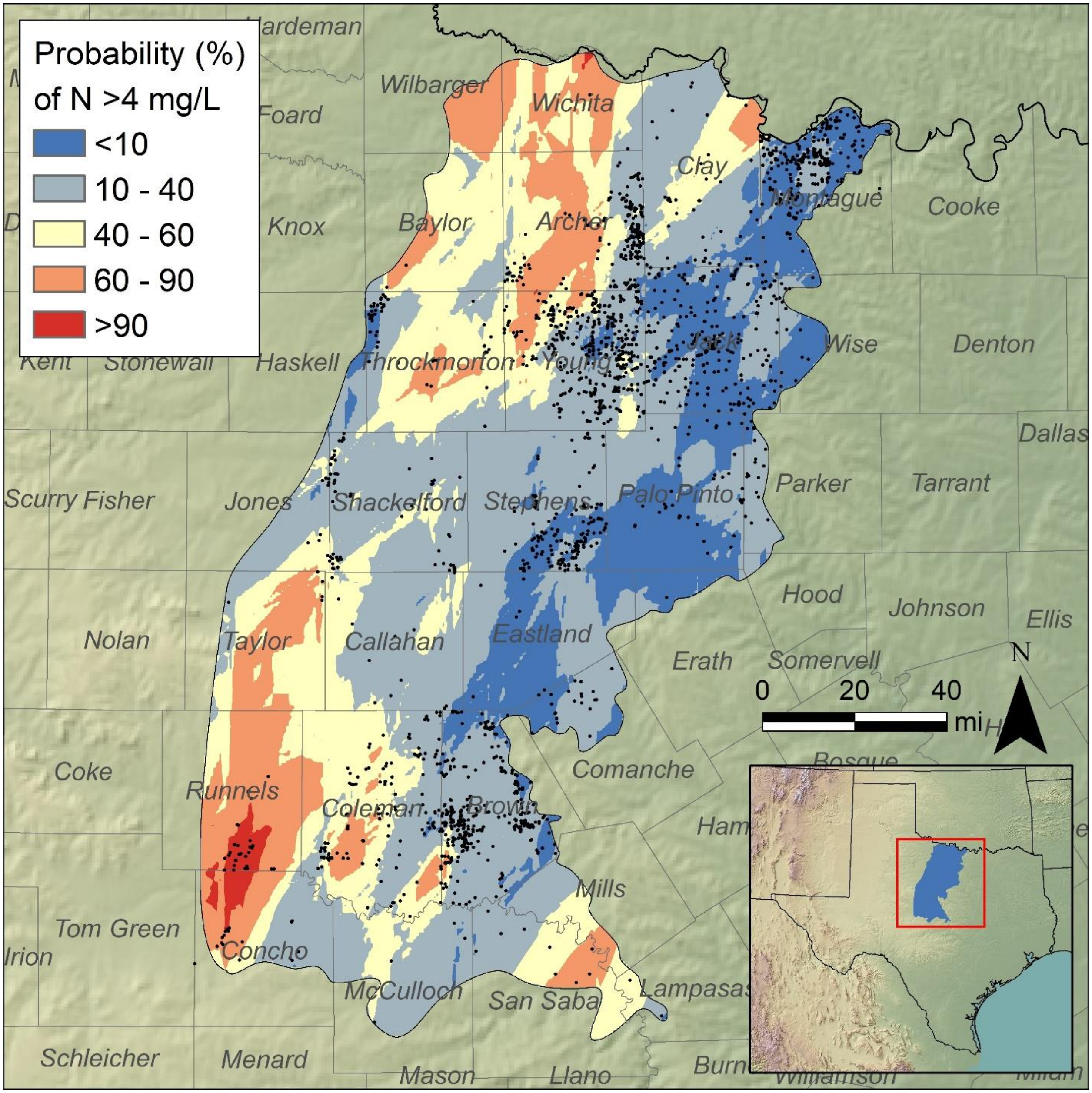


Figure 37. Capitan Reef Complex aquifer probability distribution of N >10 mg/L.



Probability (%)
of N >4 mg/L
<10
10 - 40
40 - 60
60 - 90
>90
Hardeman
Wilbarger
Wichita
Foard
Clay
Montague
Cooke
Knox
Baylor
Archer
Kent
Stonewall
Haskell
Throckmorton
Young
Jack
Wise
Denton
Dallas
Scurry
Fisher
Jones
Shackelford
Stephens
Palo Pinto
Parker
Tarrant
Hood
Johnson
Ellis
Nolan
Taylor
Callahan
Eastland
Erath
Somervell
0
20
40
mi
N
Coke
Runnels
Coleman
Brown
Comanche
Bosque
Mills
Tom Green
Irion
Concho
McCulloch
San Saba
Lampasas
Schleicher
Menard
Mason
Llano
Williamson
Milam

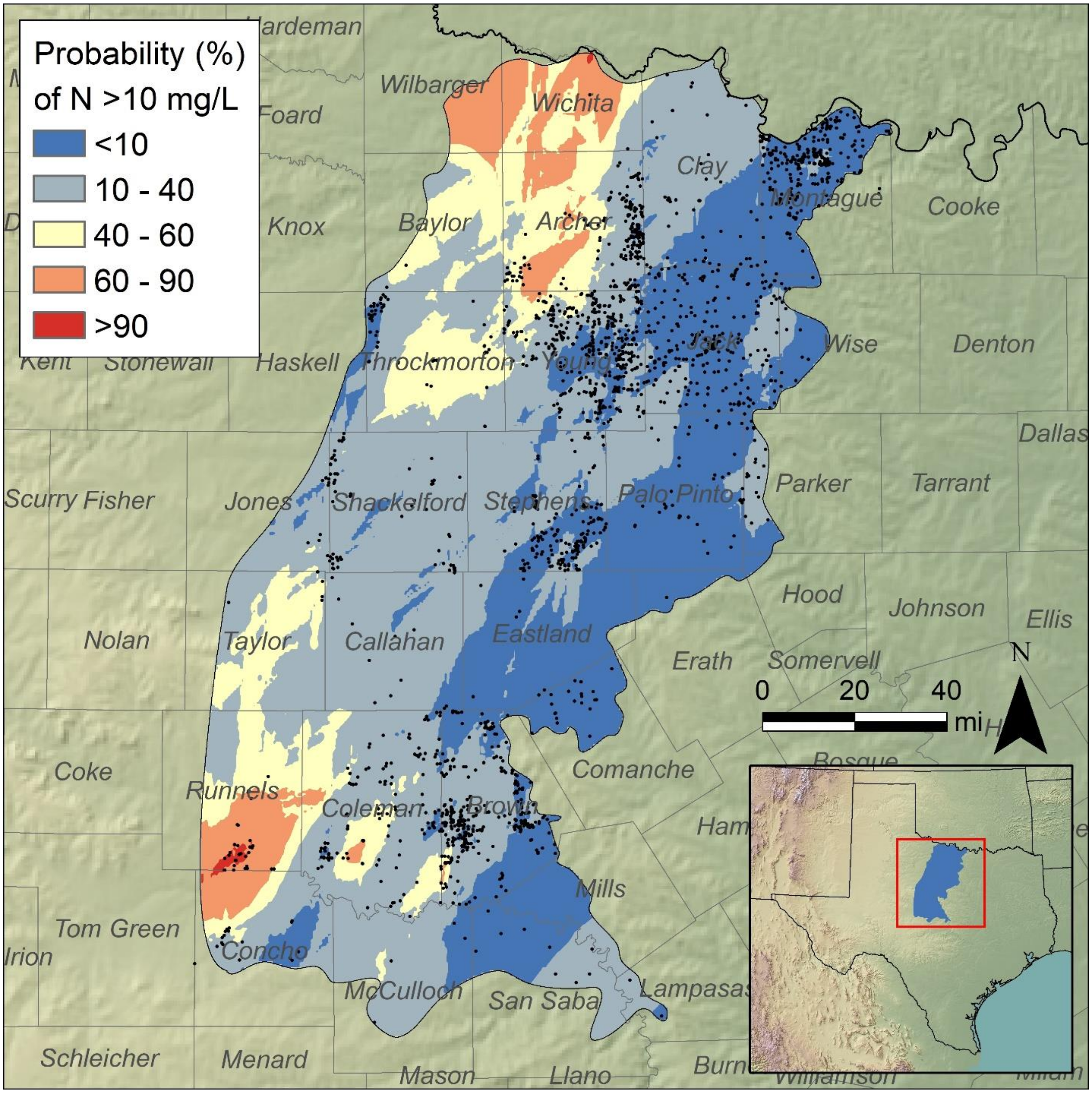


Figure 38. Capitan Reef Complex aquifer probability distribution of N >10 mg/L.

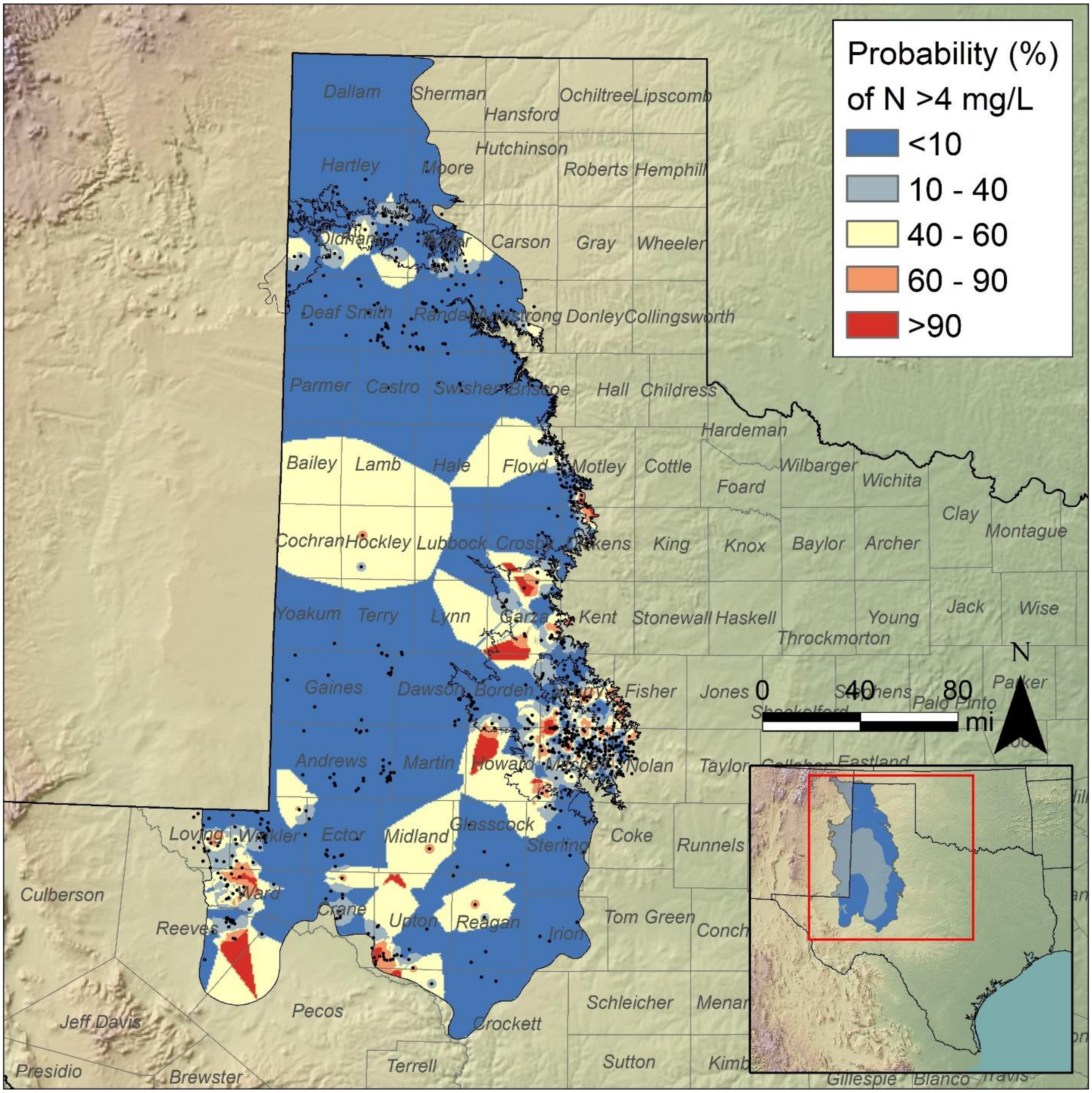


Figure 39. Dockum aquifer probability distribution of N >4 mg/L.

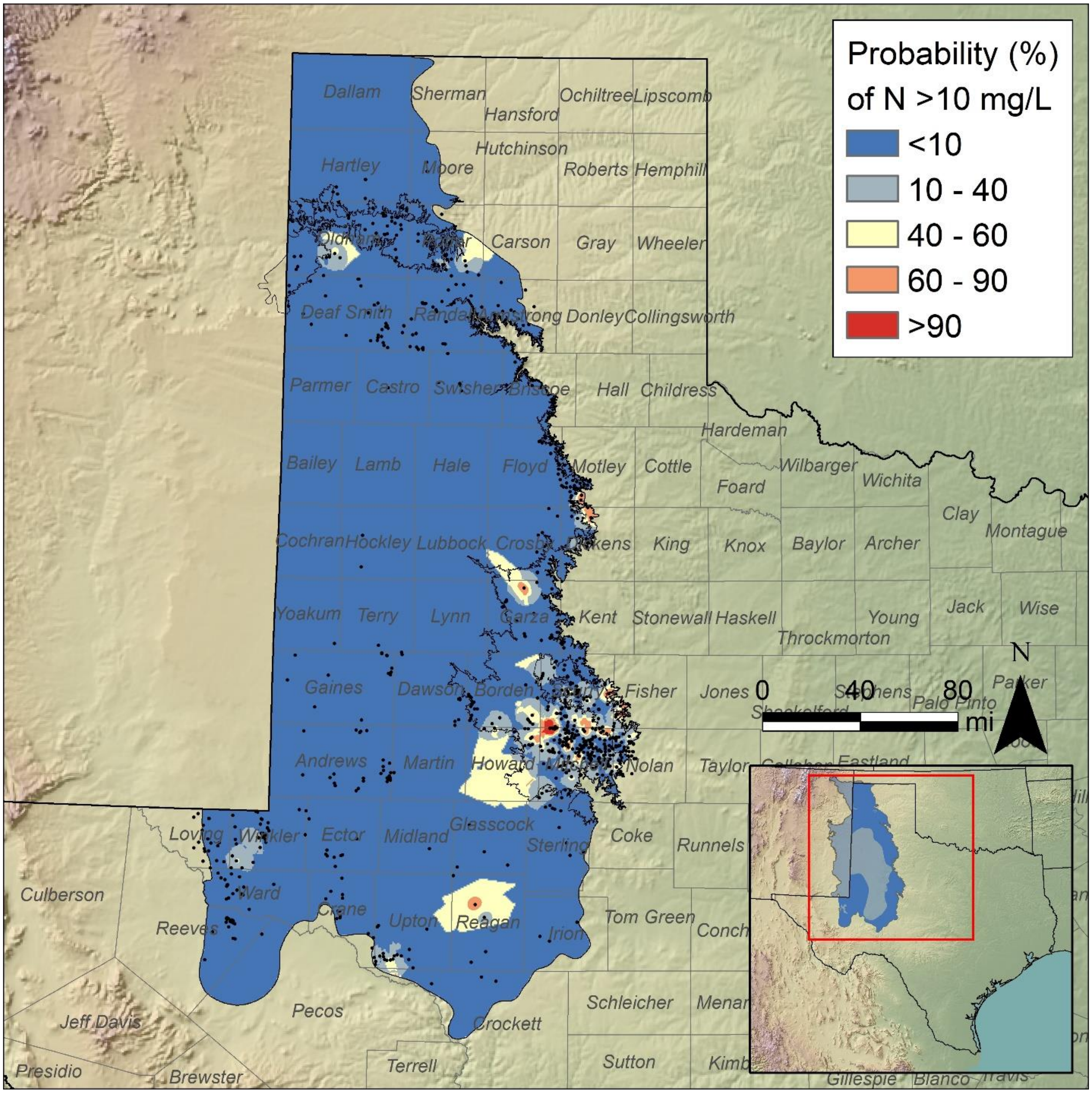


Figure 40. Dockum aquifer probability distribution of N >10 mg/L.

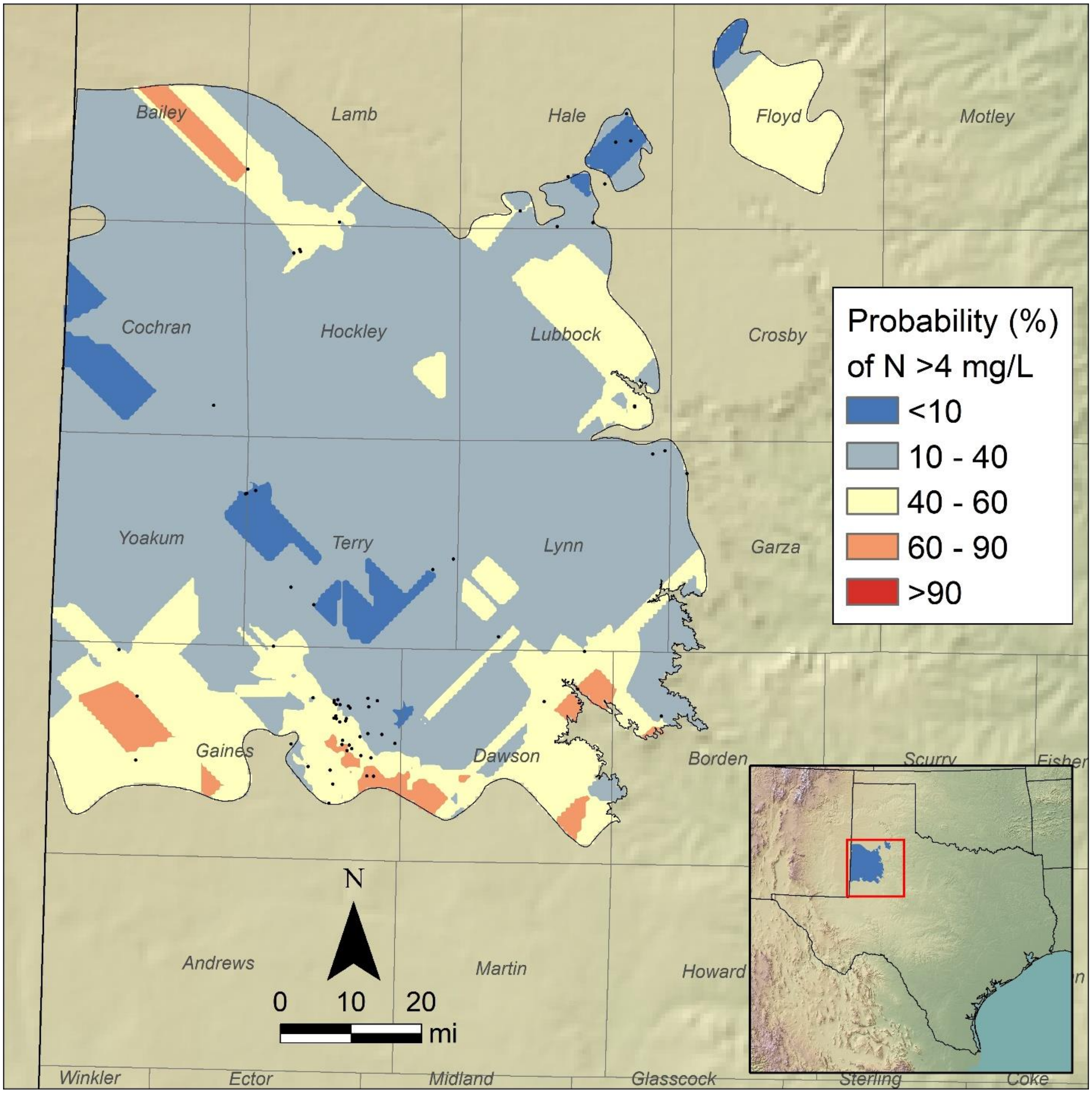


Figure 41. Edwards-Trinity (High Plains) aquifer probability distribution of N >4 mg/L.

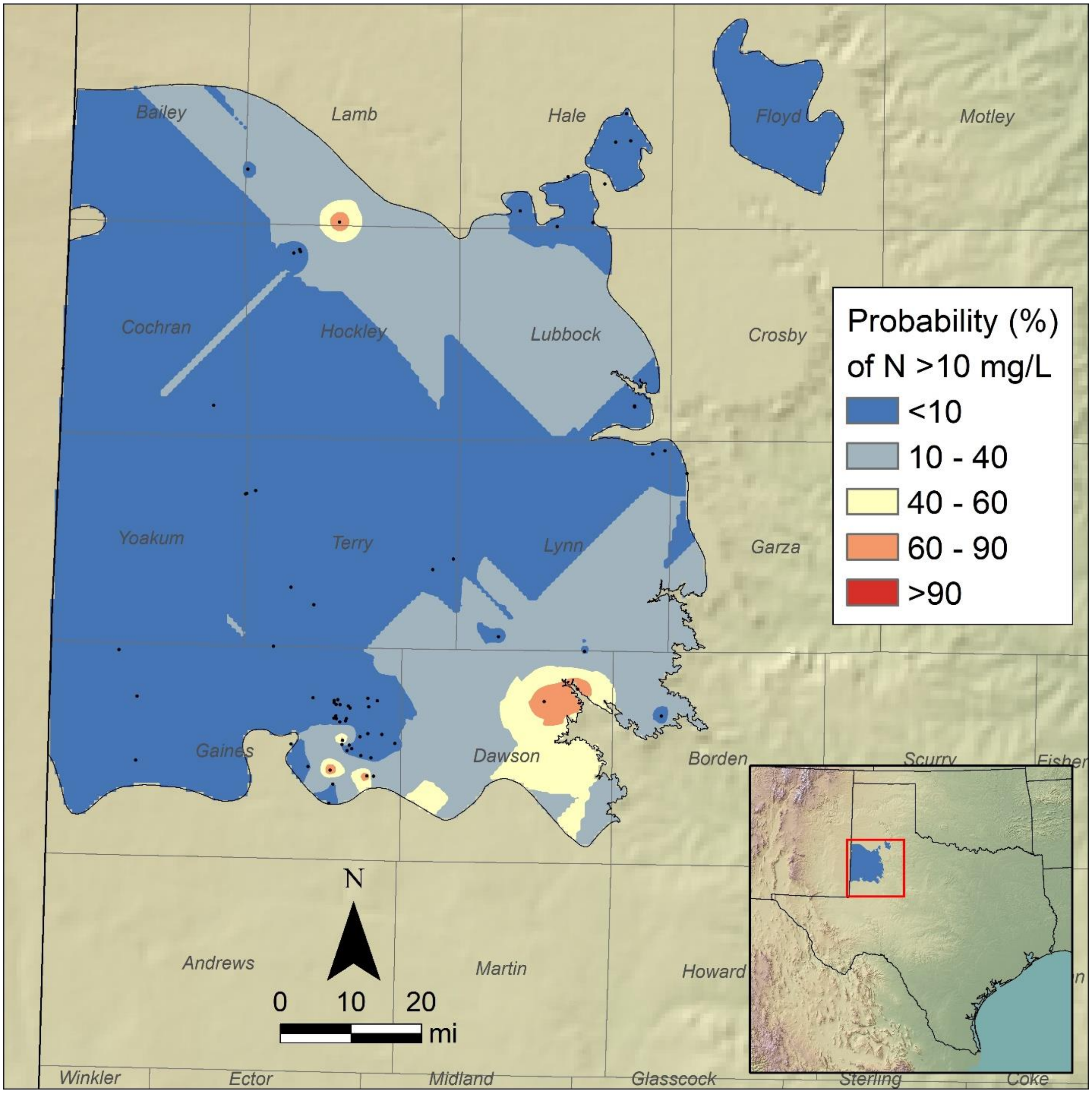


Figure 42. Edwards-Trinity (High Plains) aquifer probability distribution of N >10 mg/L.

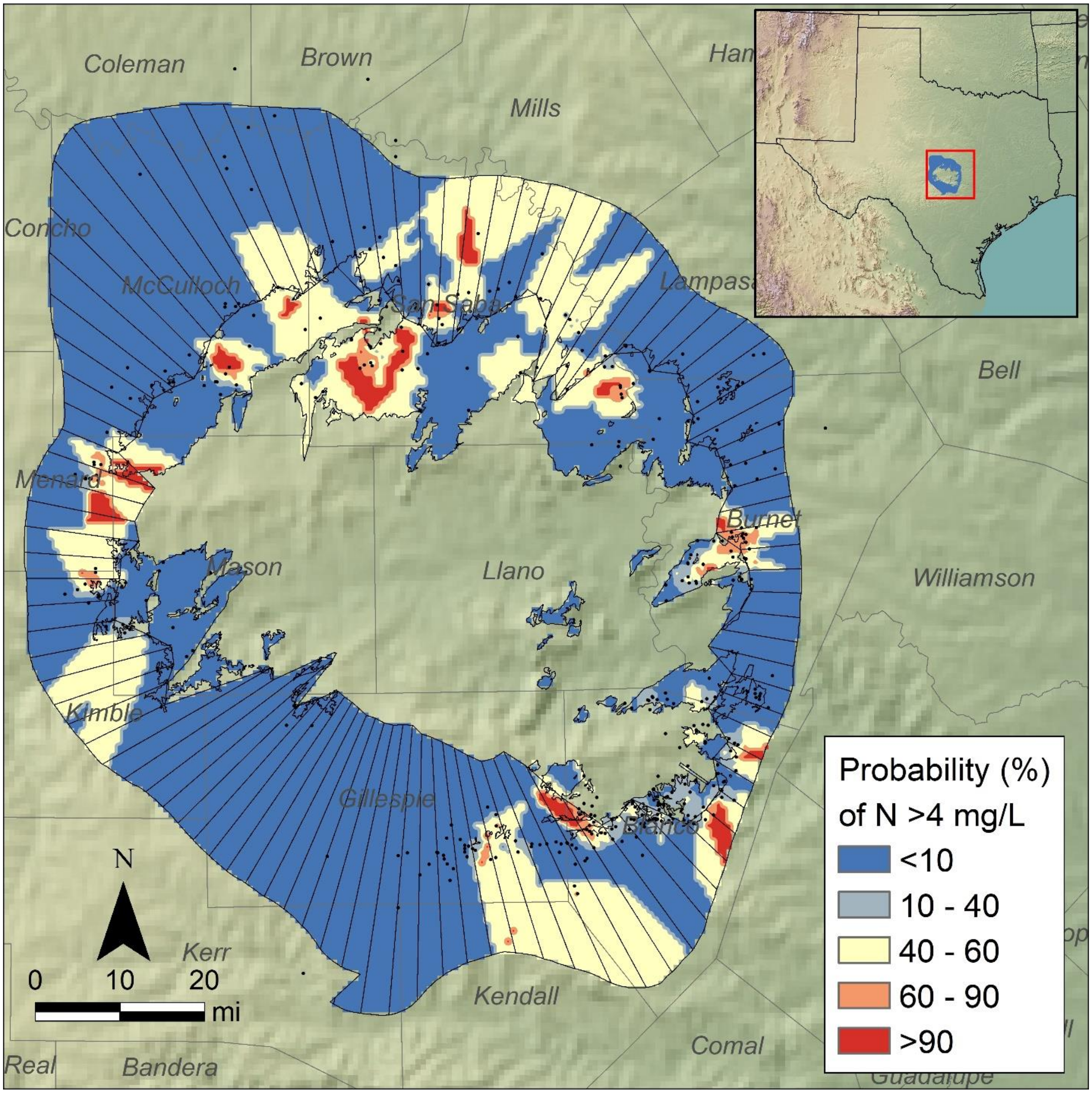


Figure 43. Ellenburger – San Saba aquifer probability distribution of N >4 mg/L.

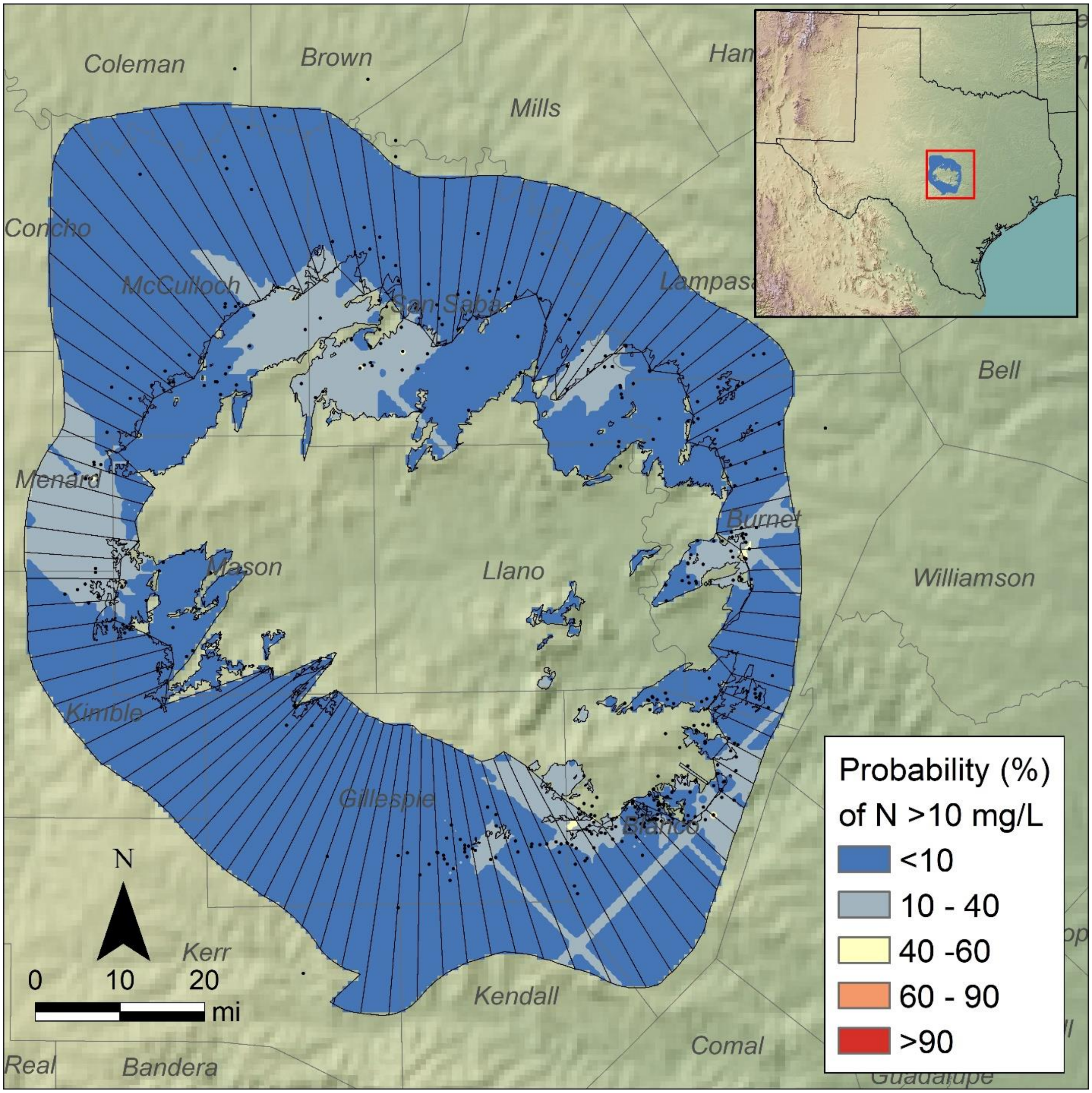


Figure 44. Ellenburger – San Saba aquifer probability distribution of N >10 mg/L.

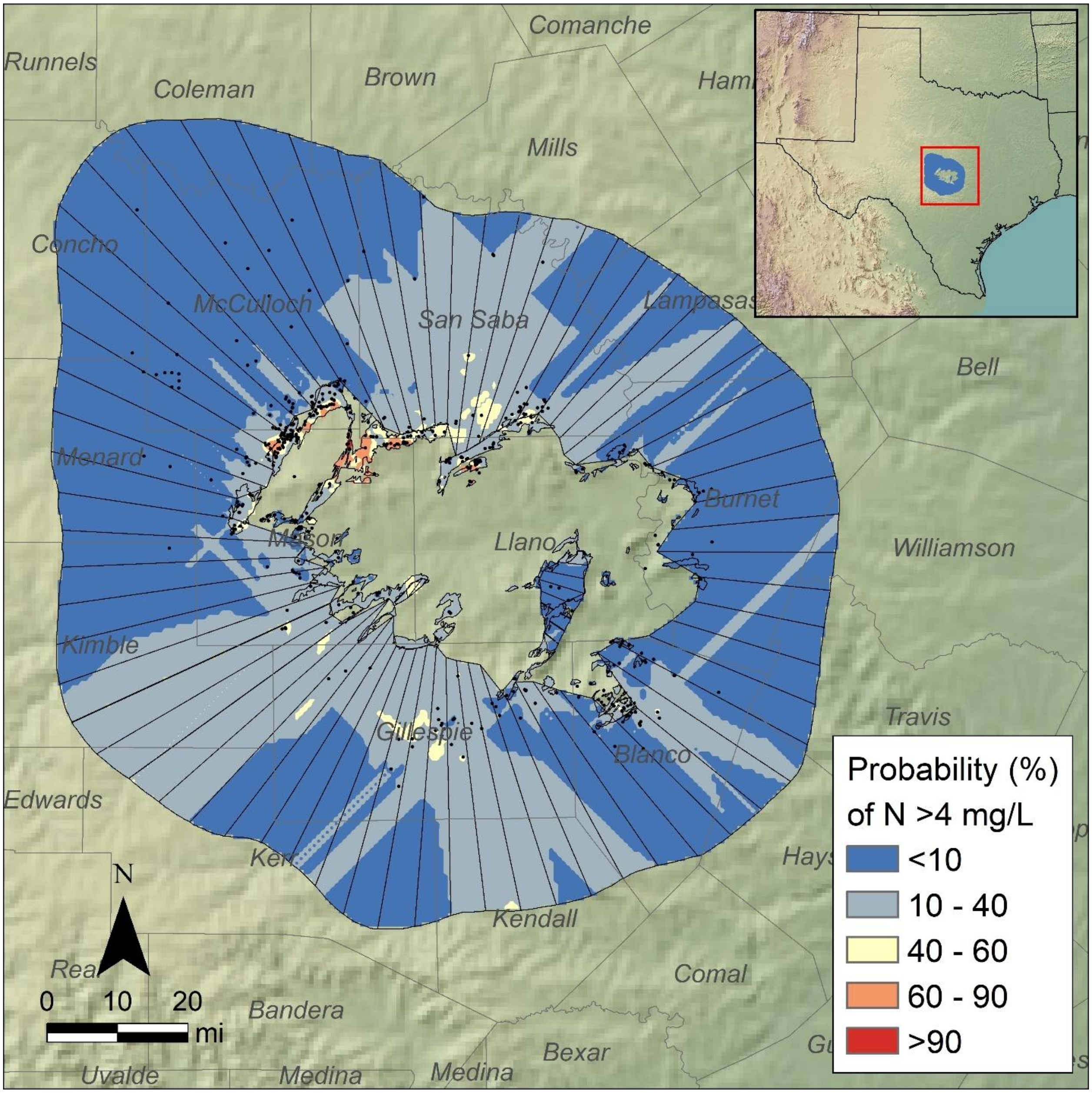


Figure 45. Hickory aquifer probability distribution of N >4 mg/L.

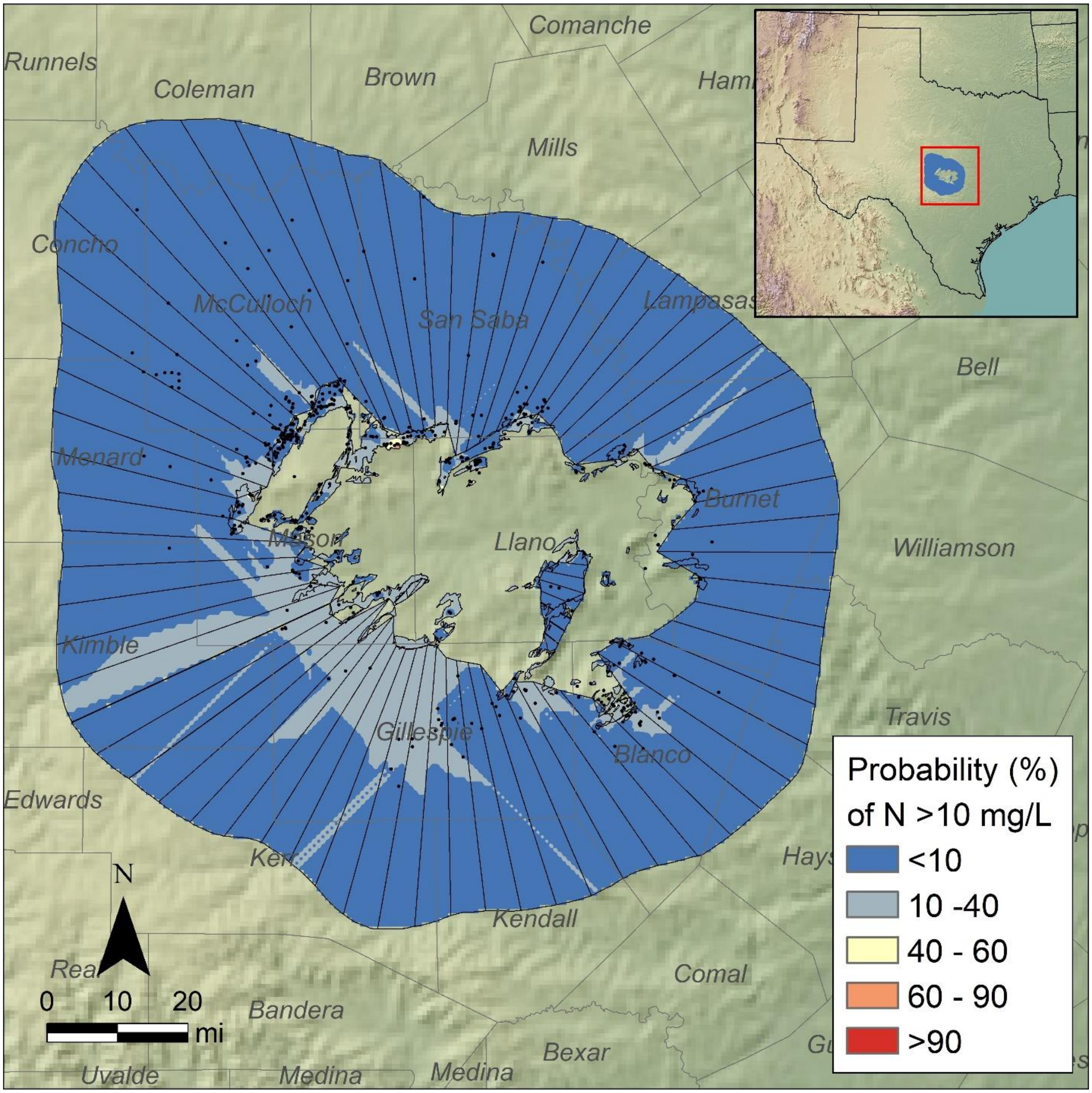


Figure 46. Hickory aquifer probability distribution of N >10 mg/L.

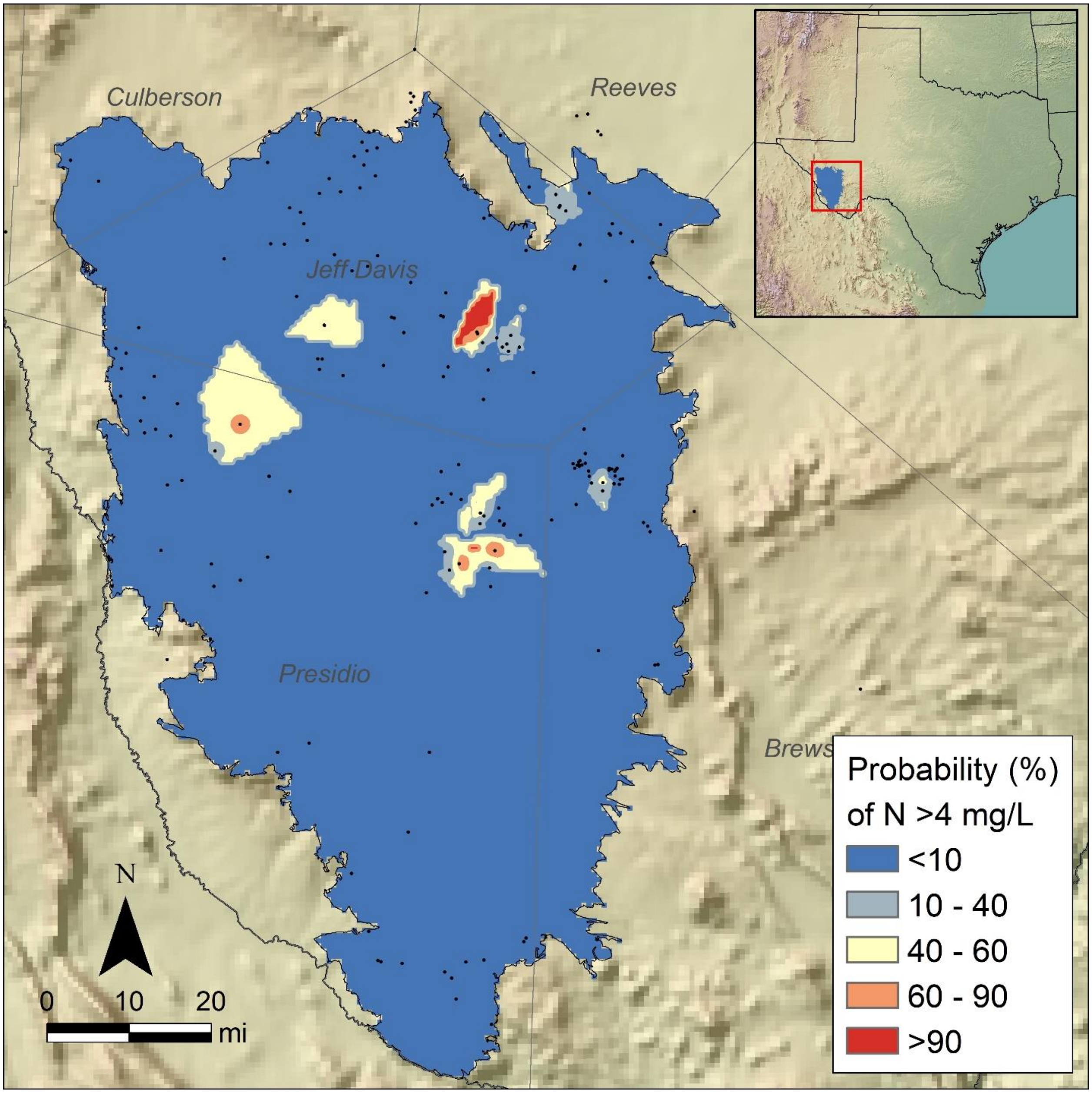


Figure 47. Igneous aquifer probability distribution of N >4 mg/L.

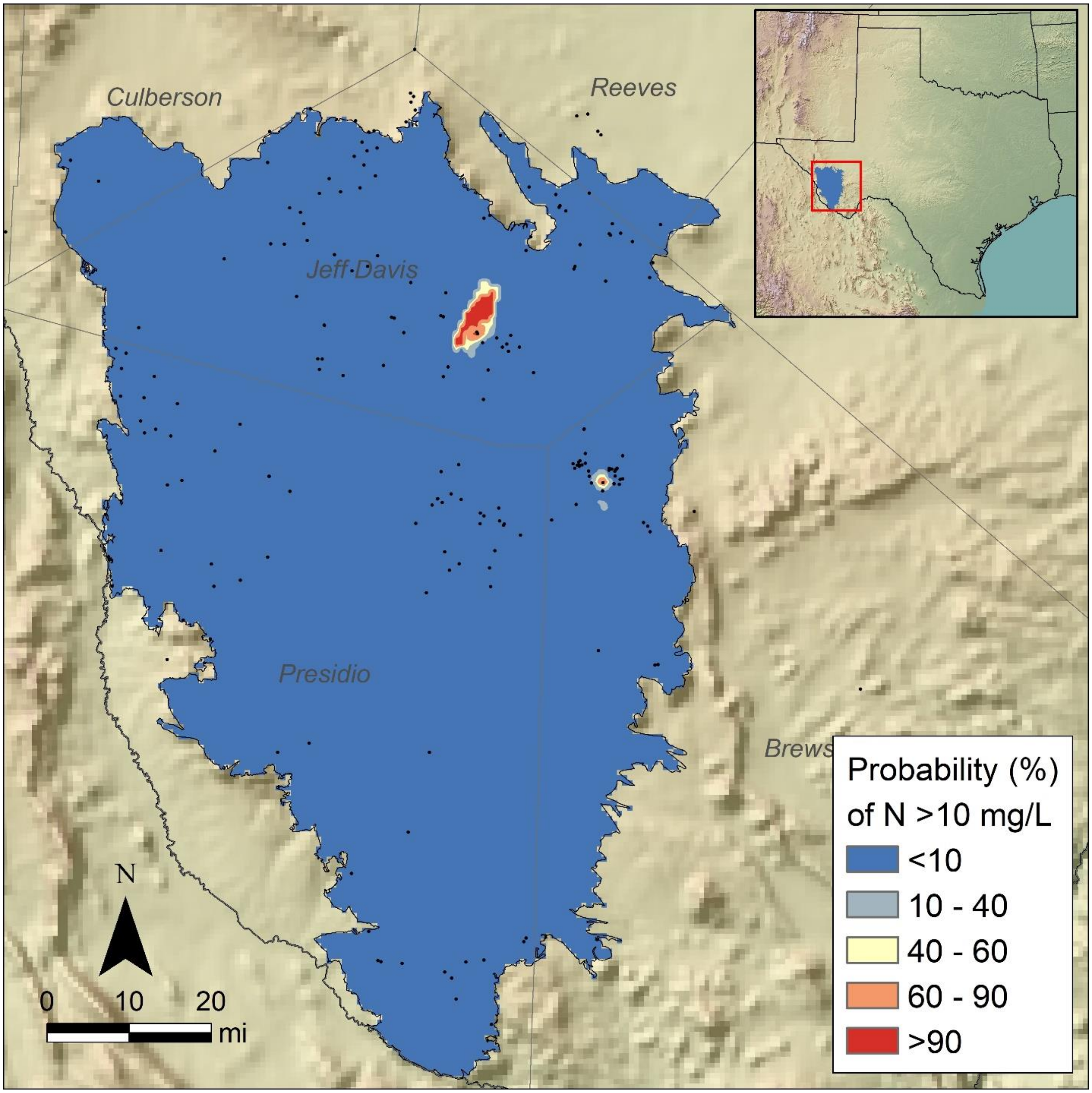


Figure 48. Igneous aquifer probability distribution of N >10 mg/L.

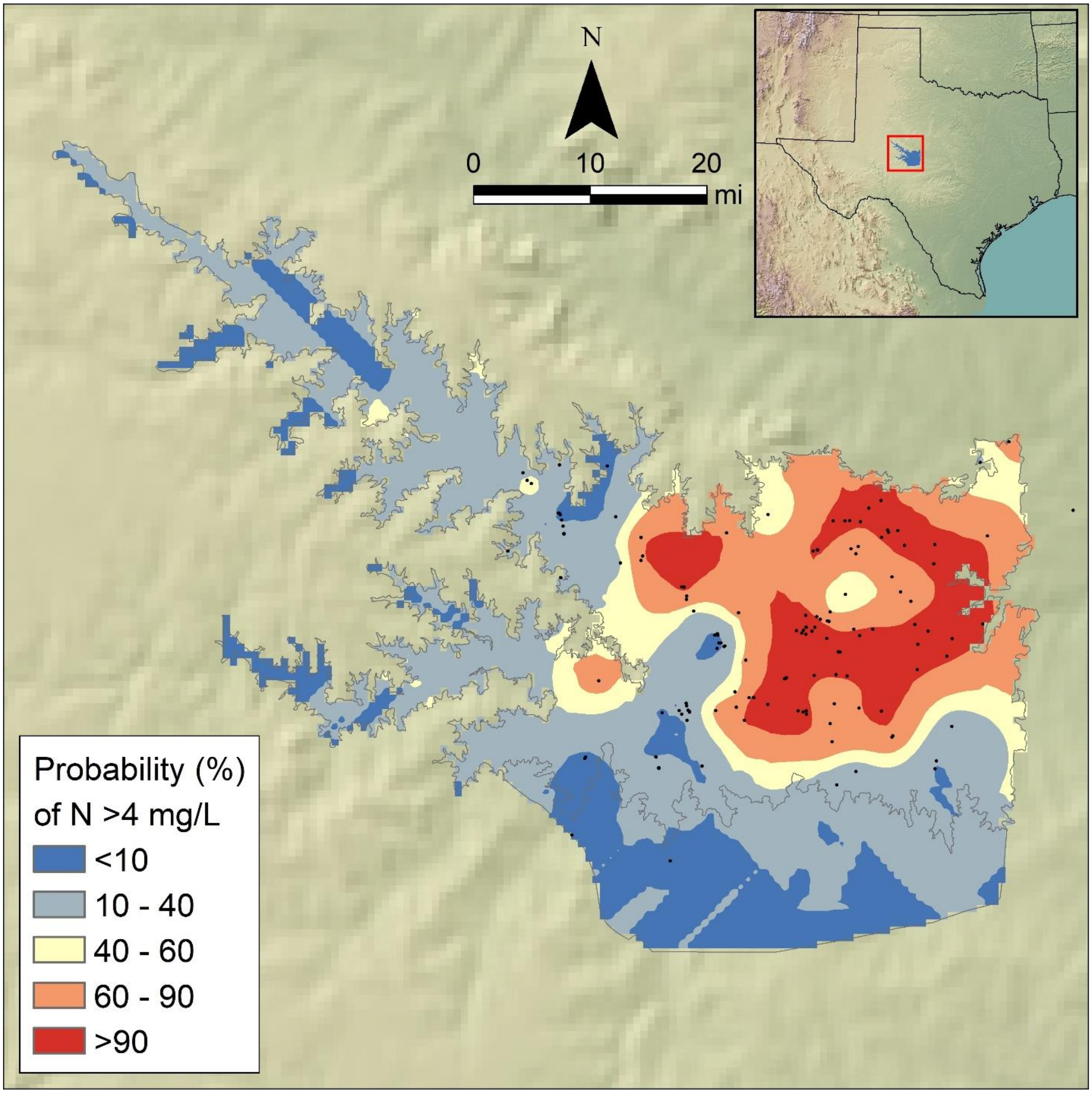


Figure 49. Lipan aquifer probability distribution of N >4 mg/L.

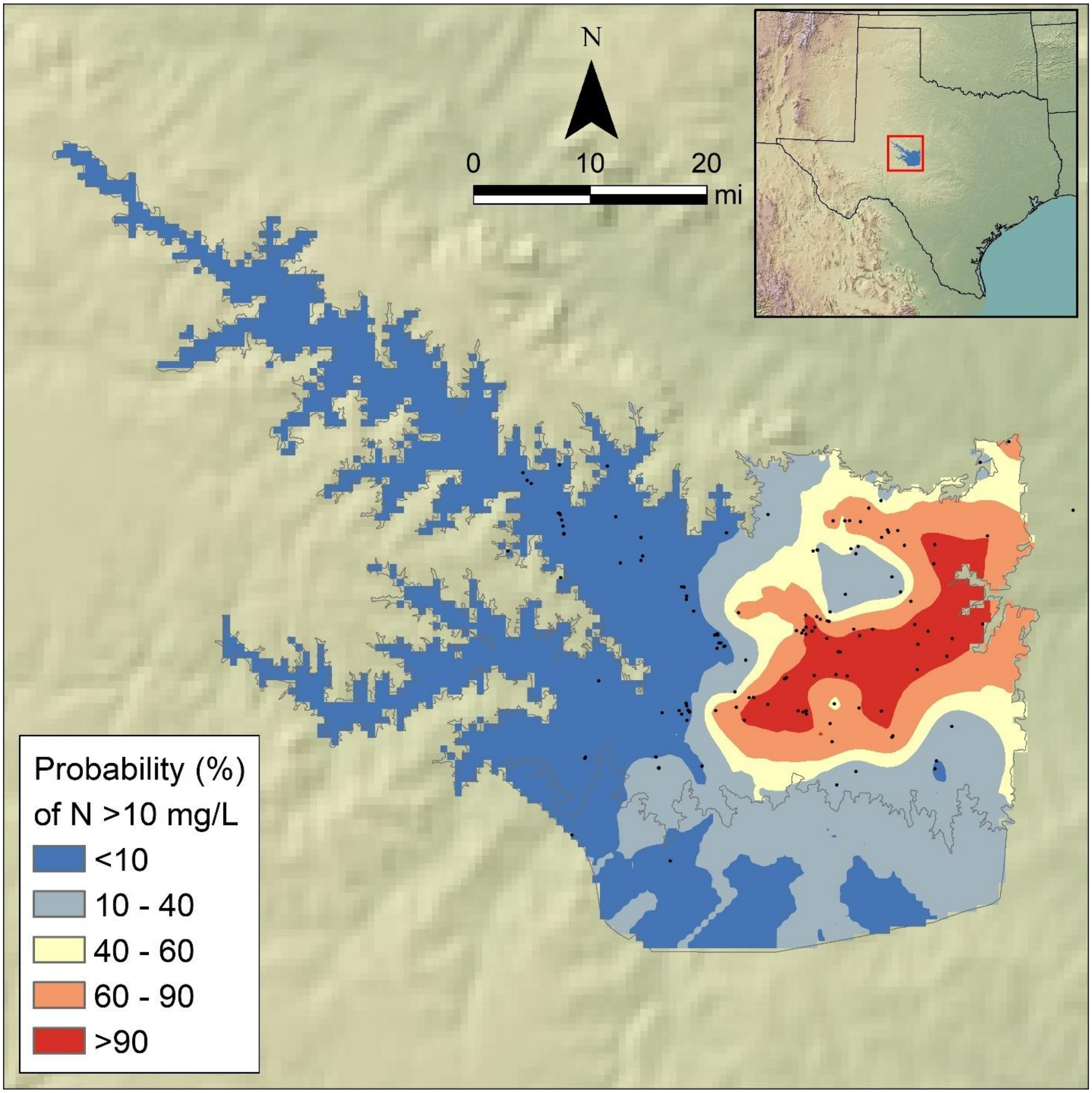


Figure 50. Lipan aquifer probability distribution of N >10 mg/L.

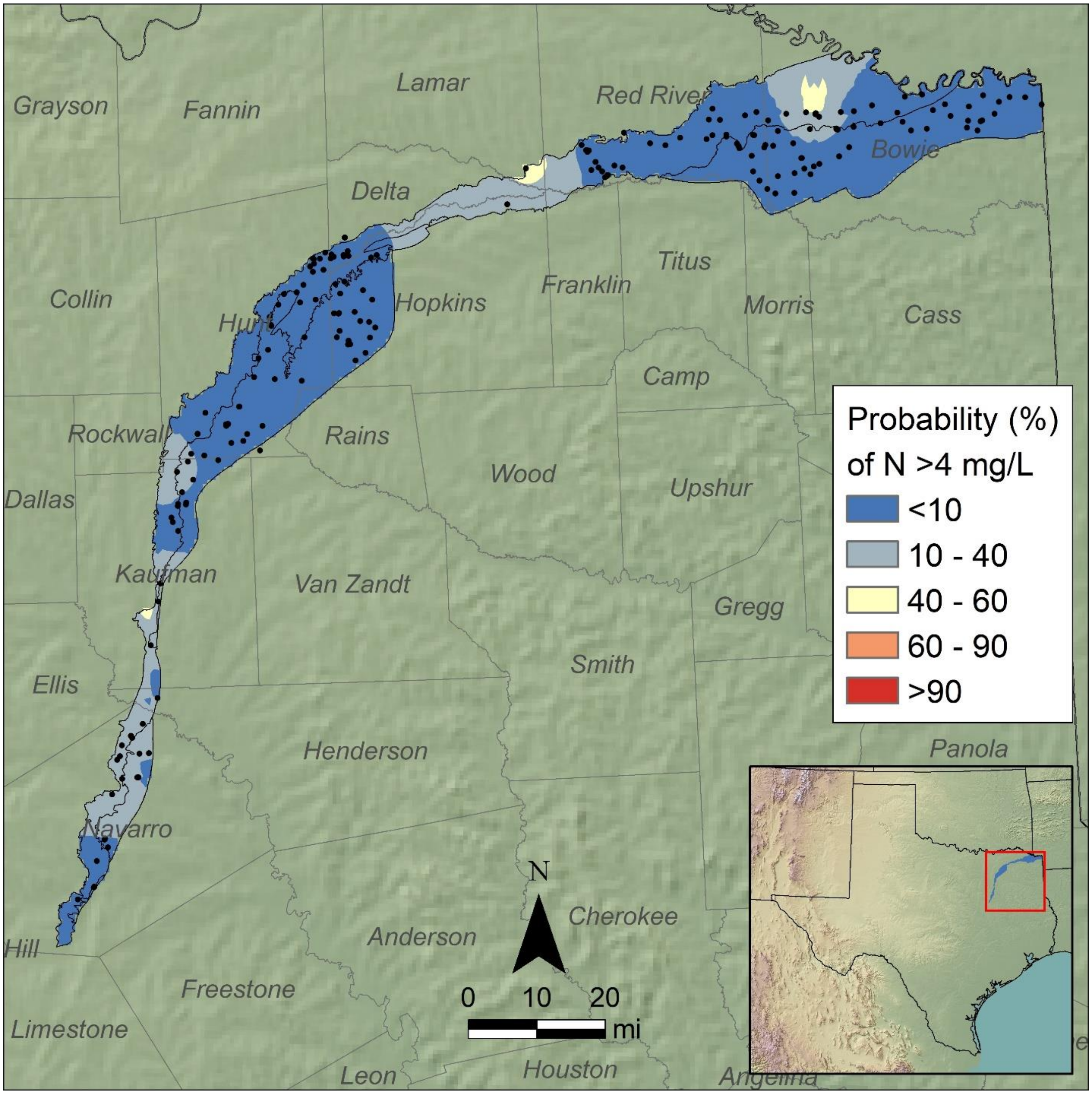


Figure 51. Nacatoch aquifer probability distribution of N >4 mg/L.

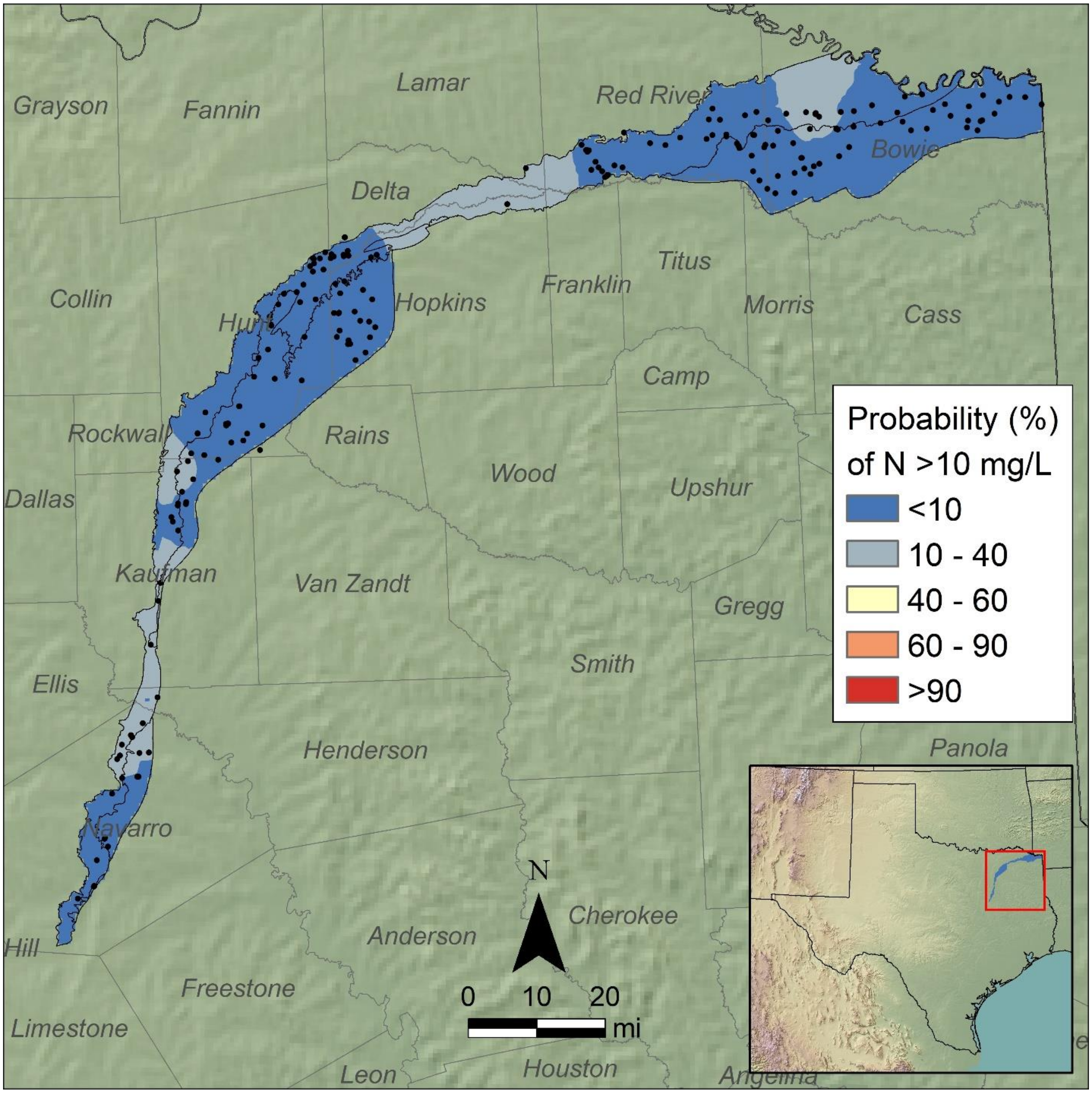


Figure 52. Nacatoch aquifer probability distribution of N >10 mg/L.

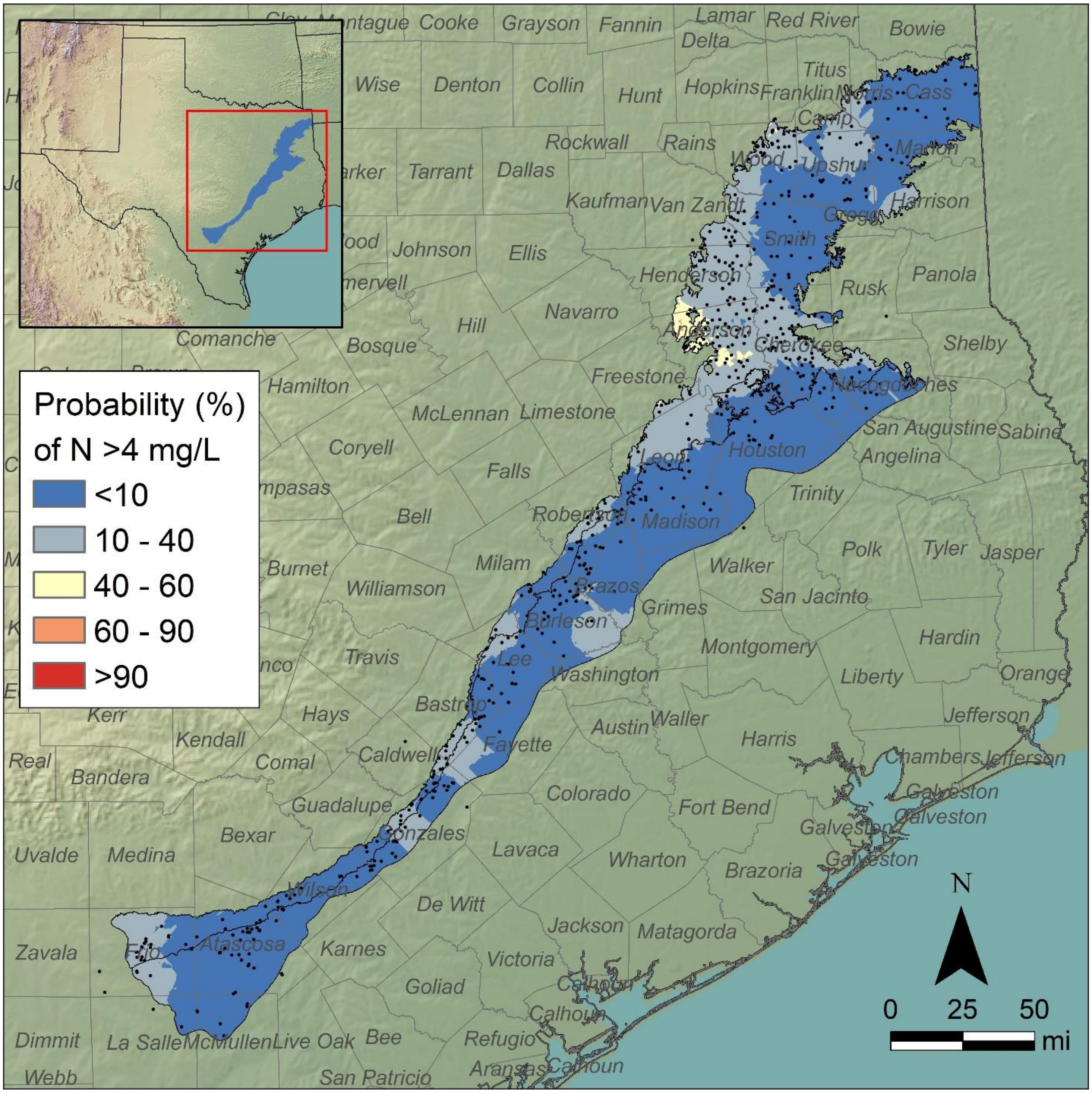


Figure 53. Queen City aquifer probability distribution of N >4 mg/L.

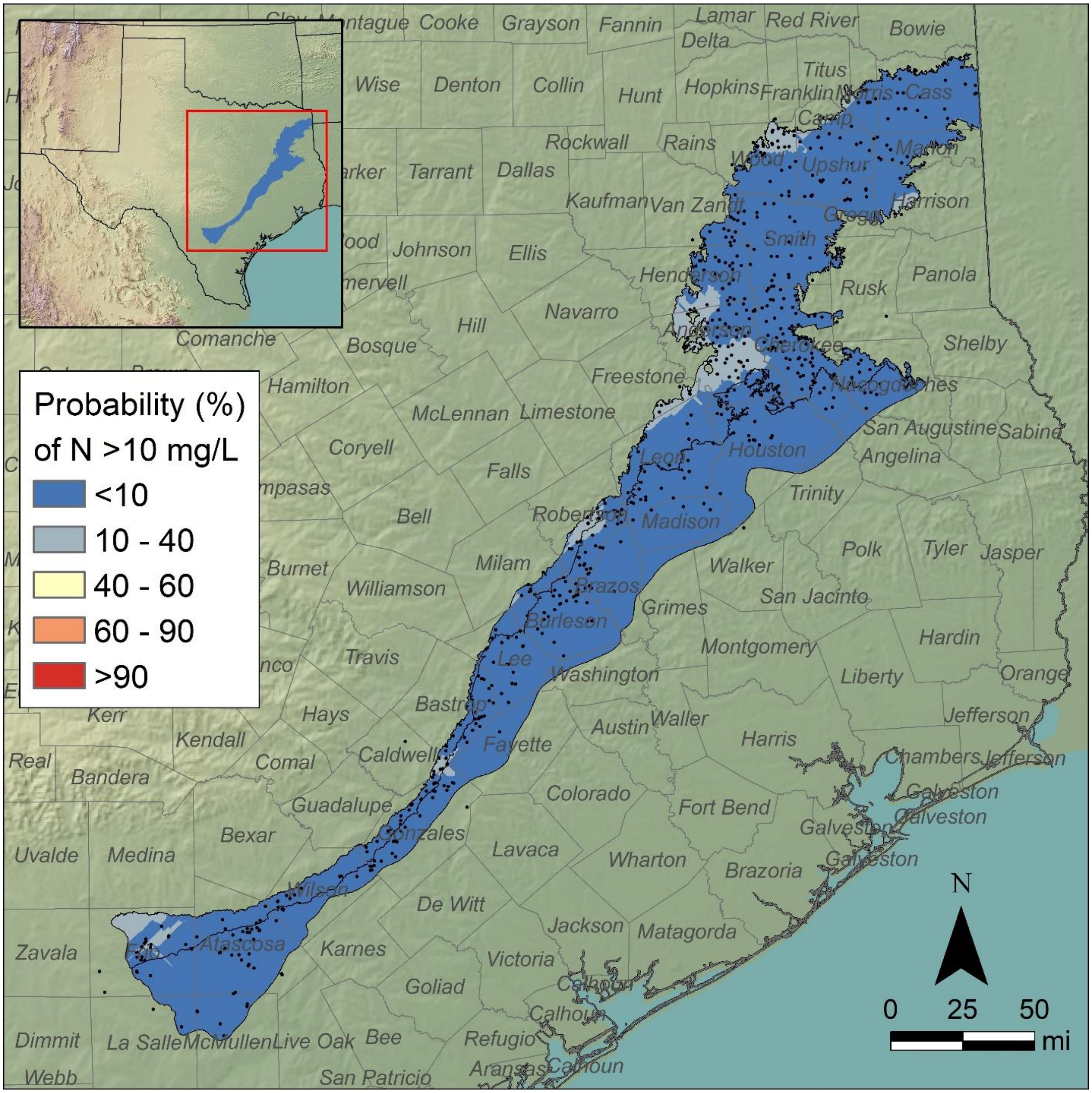


Figure 54. Queen City aquifer probability distribution of N >10 mg/L.

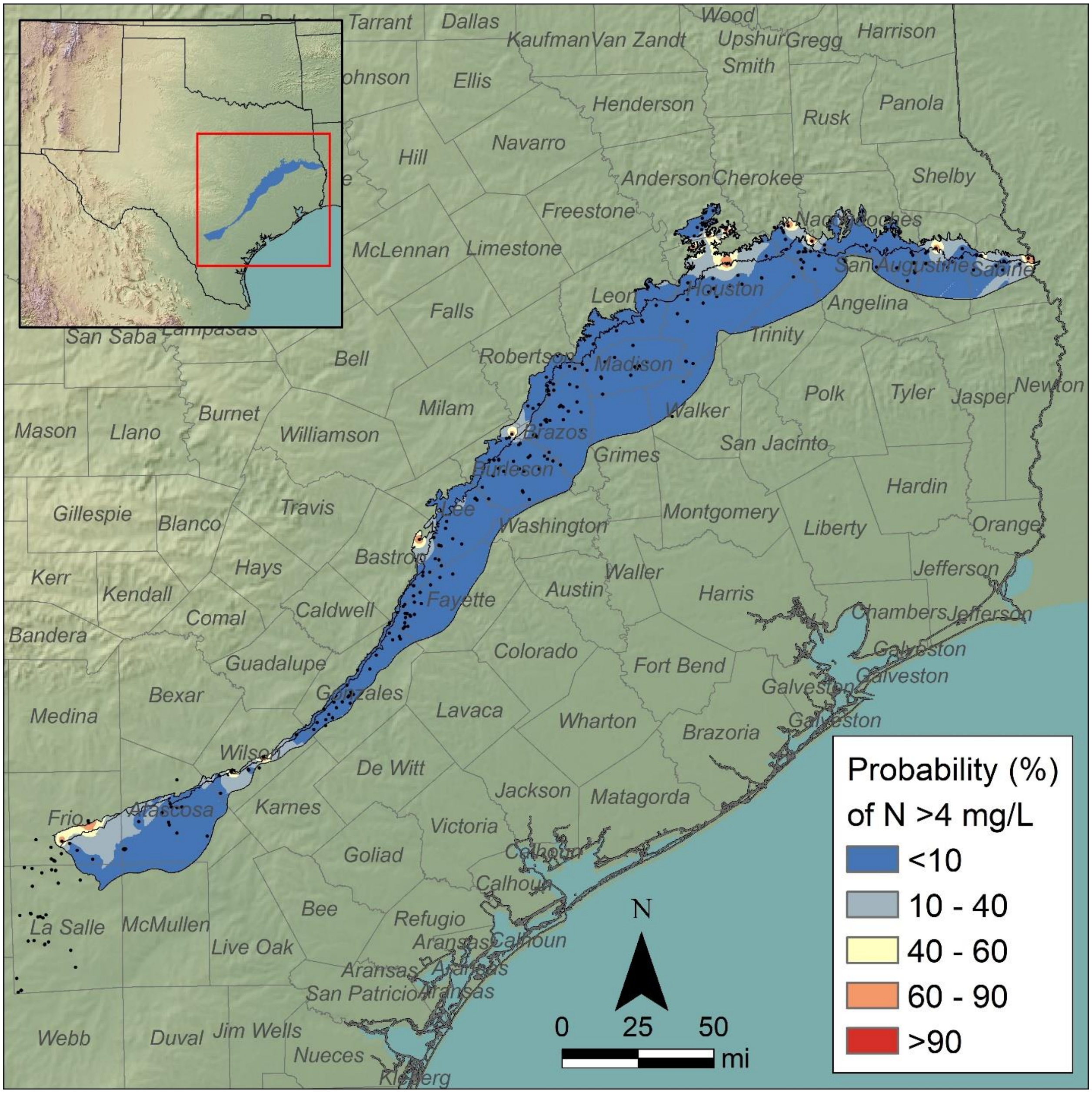


Figure 55. Sparta aquifer probability distribution of N >4 mg/L.

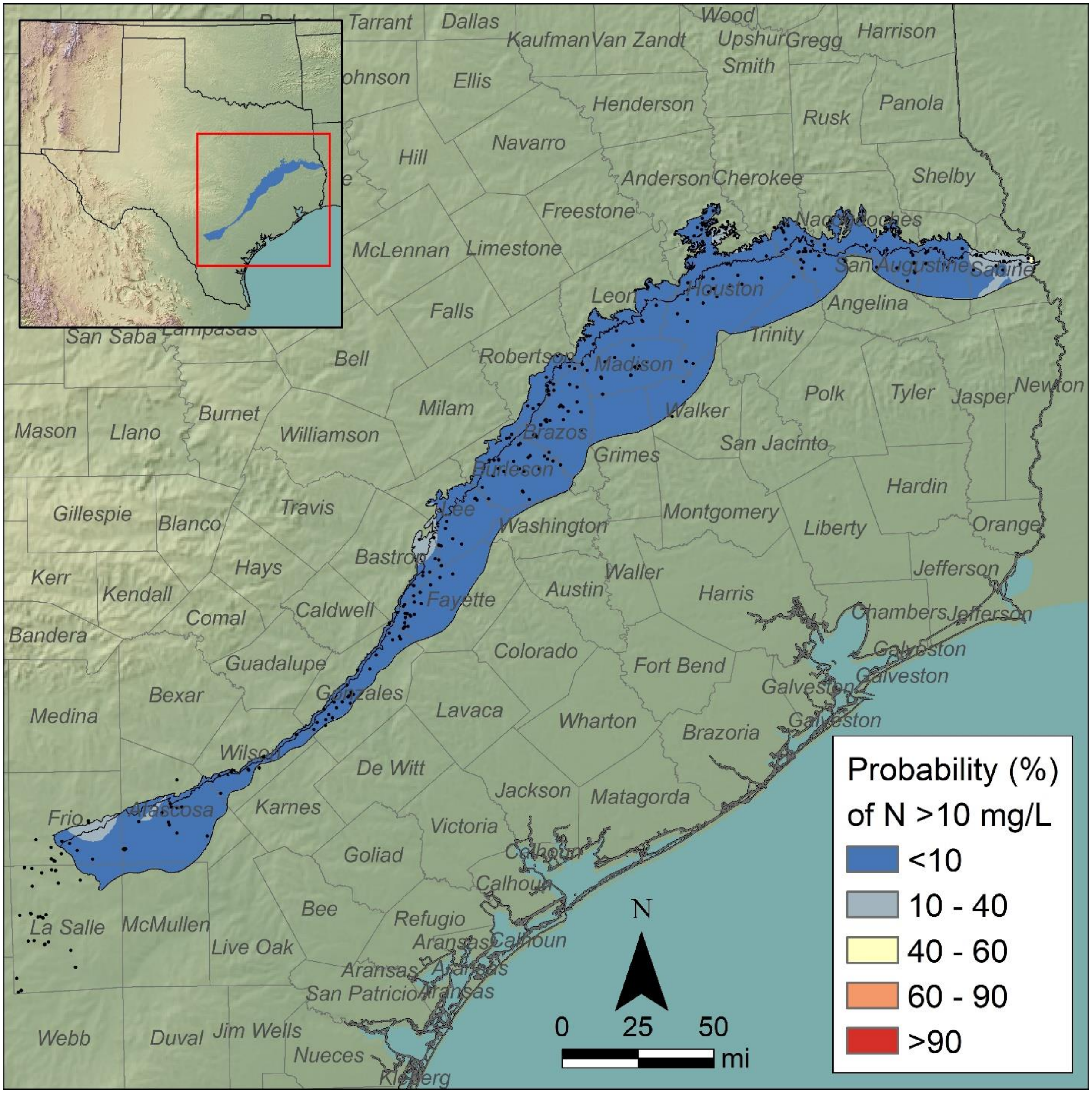


Figure 56. Sparta aquifer probability distribution of N >10 mg/L.

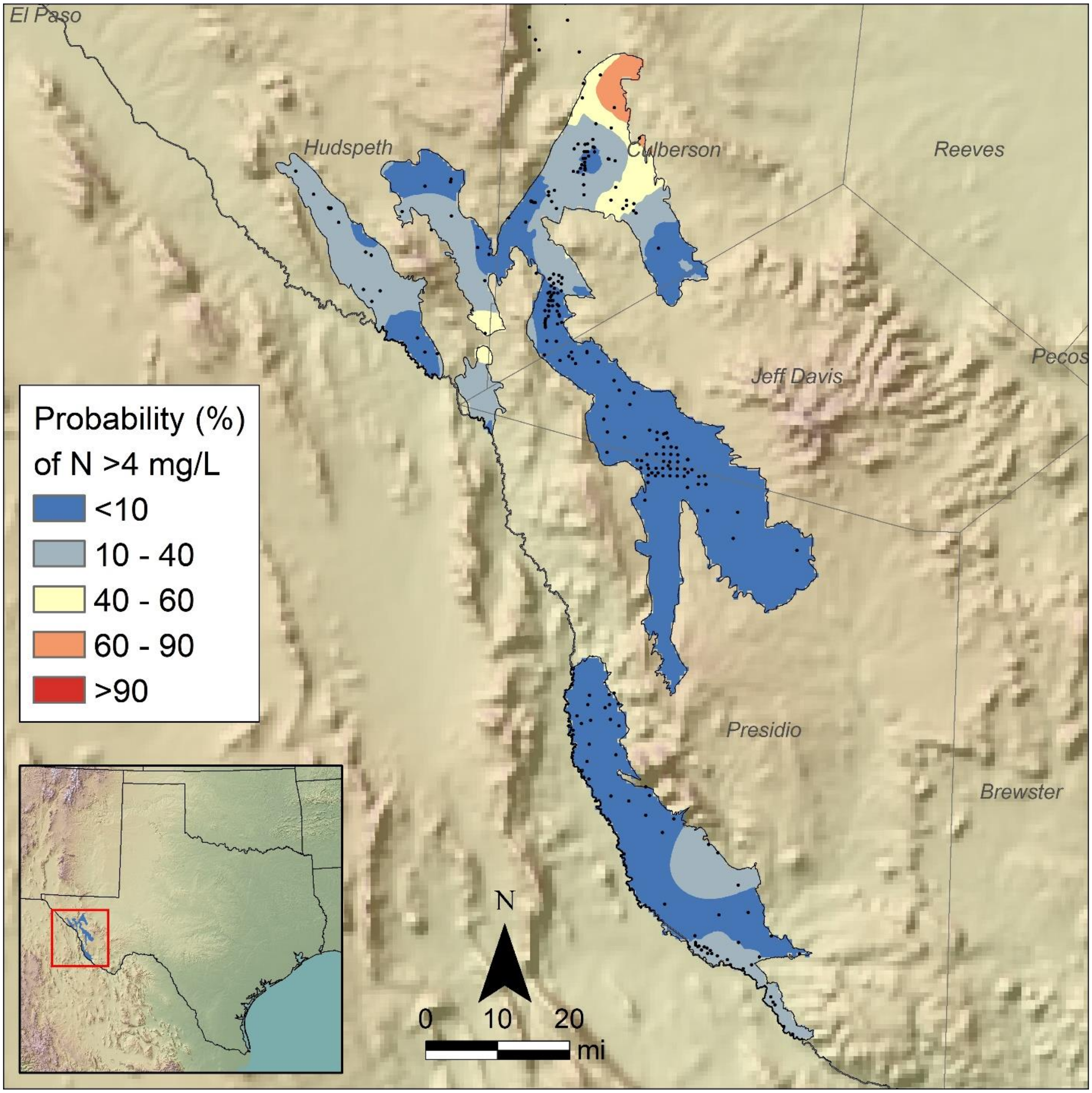


Figure 57. West Texas Bolsons aquifer probability distribution of N >4 mg/L.

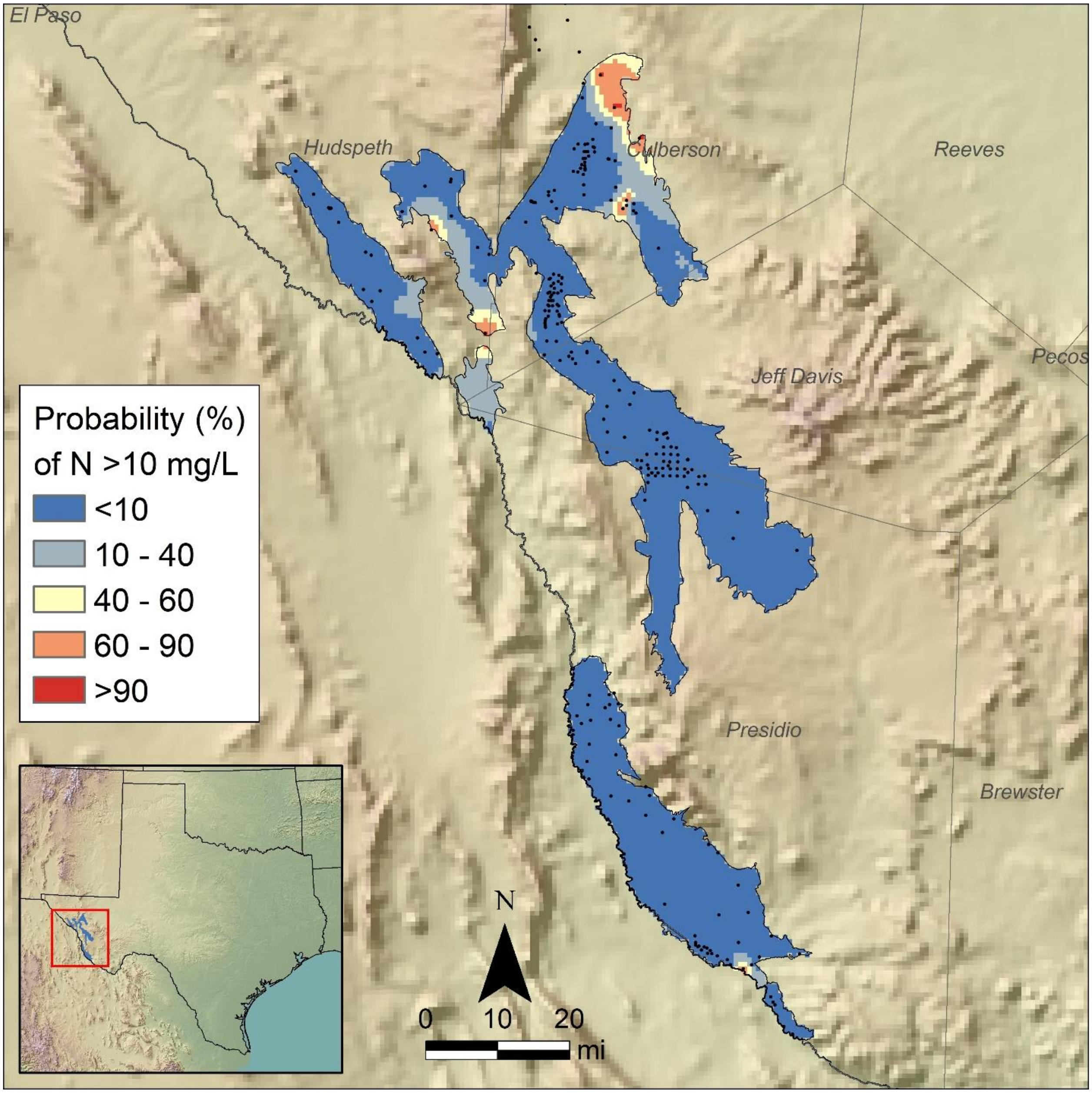


Figure 58. West Texas Bolsons aquifer probability distribution of N >10 mg/L.

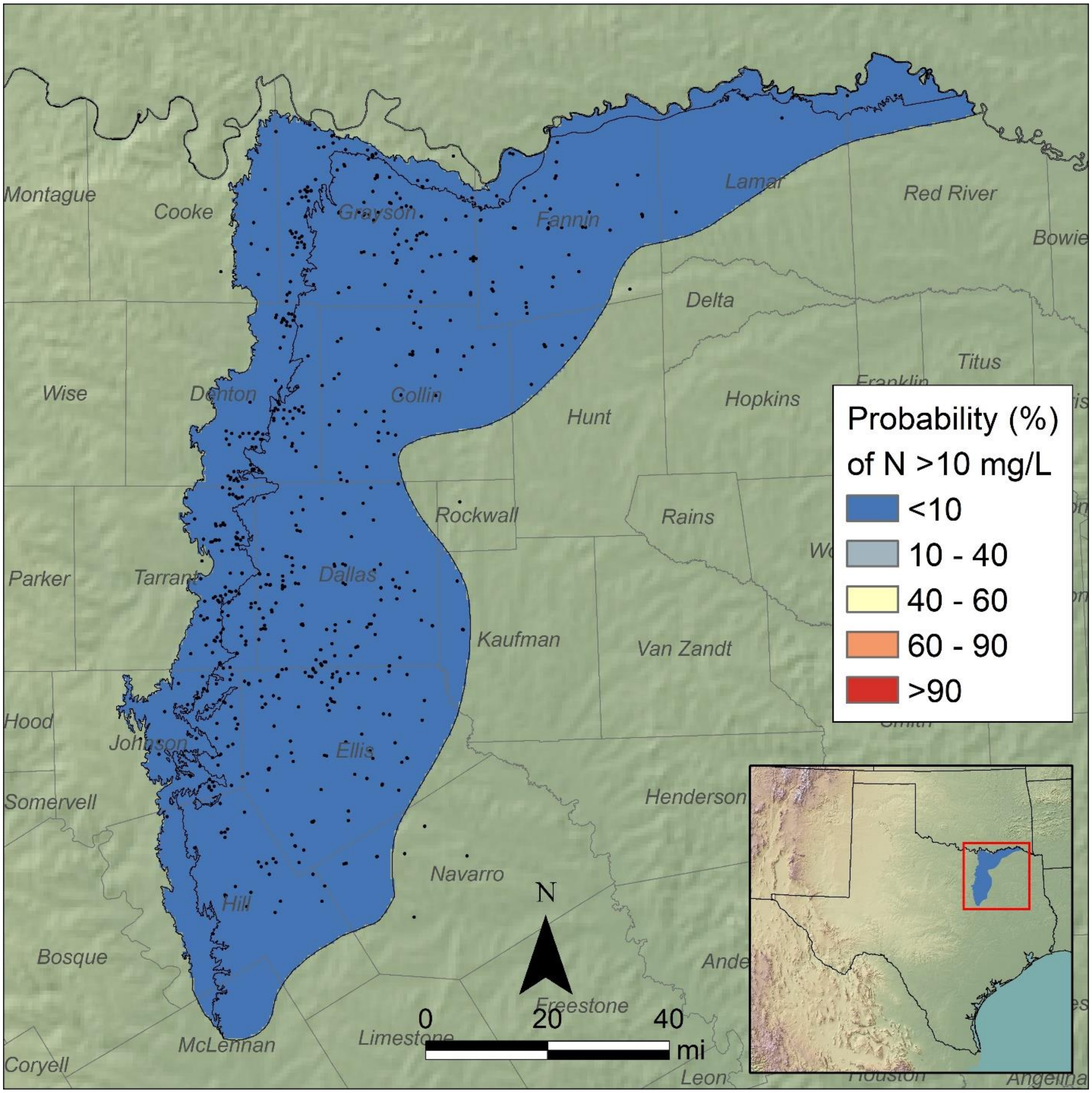


Figure 59. Woodbine aquifer probability distribution of N >4 mg/L.

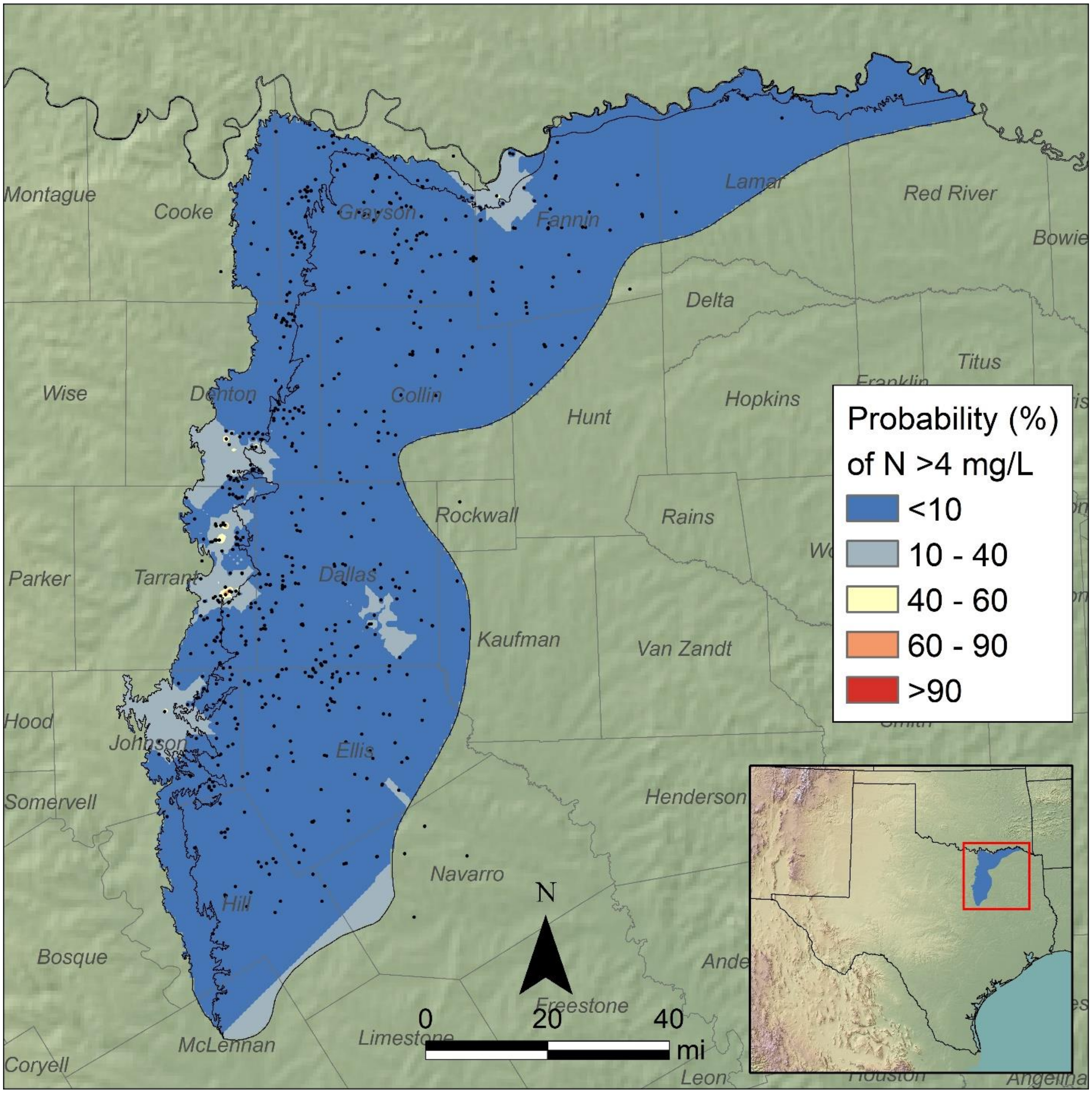


Figure 60. Woodbine aquifer probability distribution of N >10 mg/L.

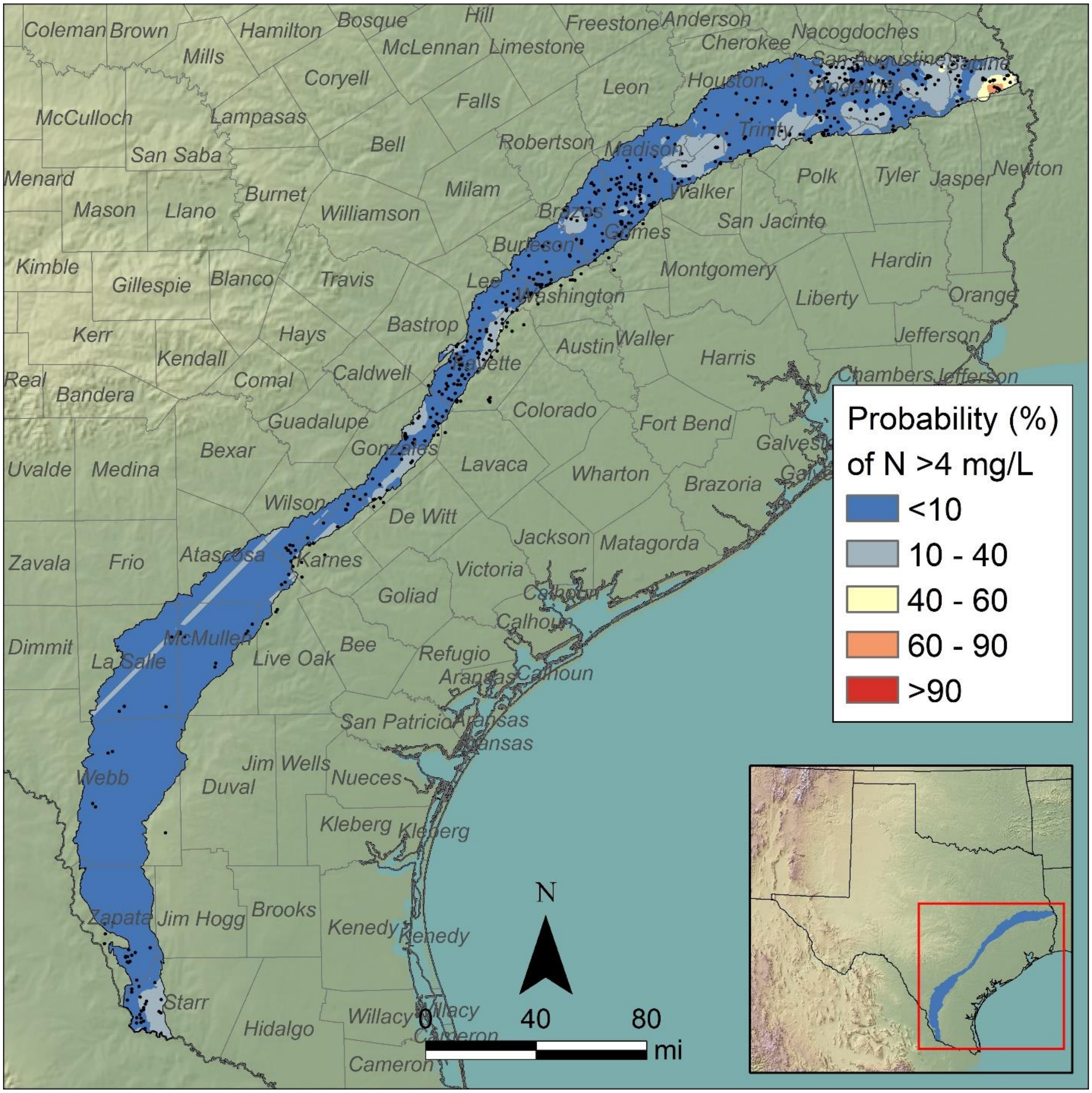


Figure 61. Yegua – Jackson aquifer probability distribution of N >4 mg/L.

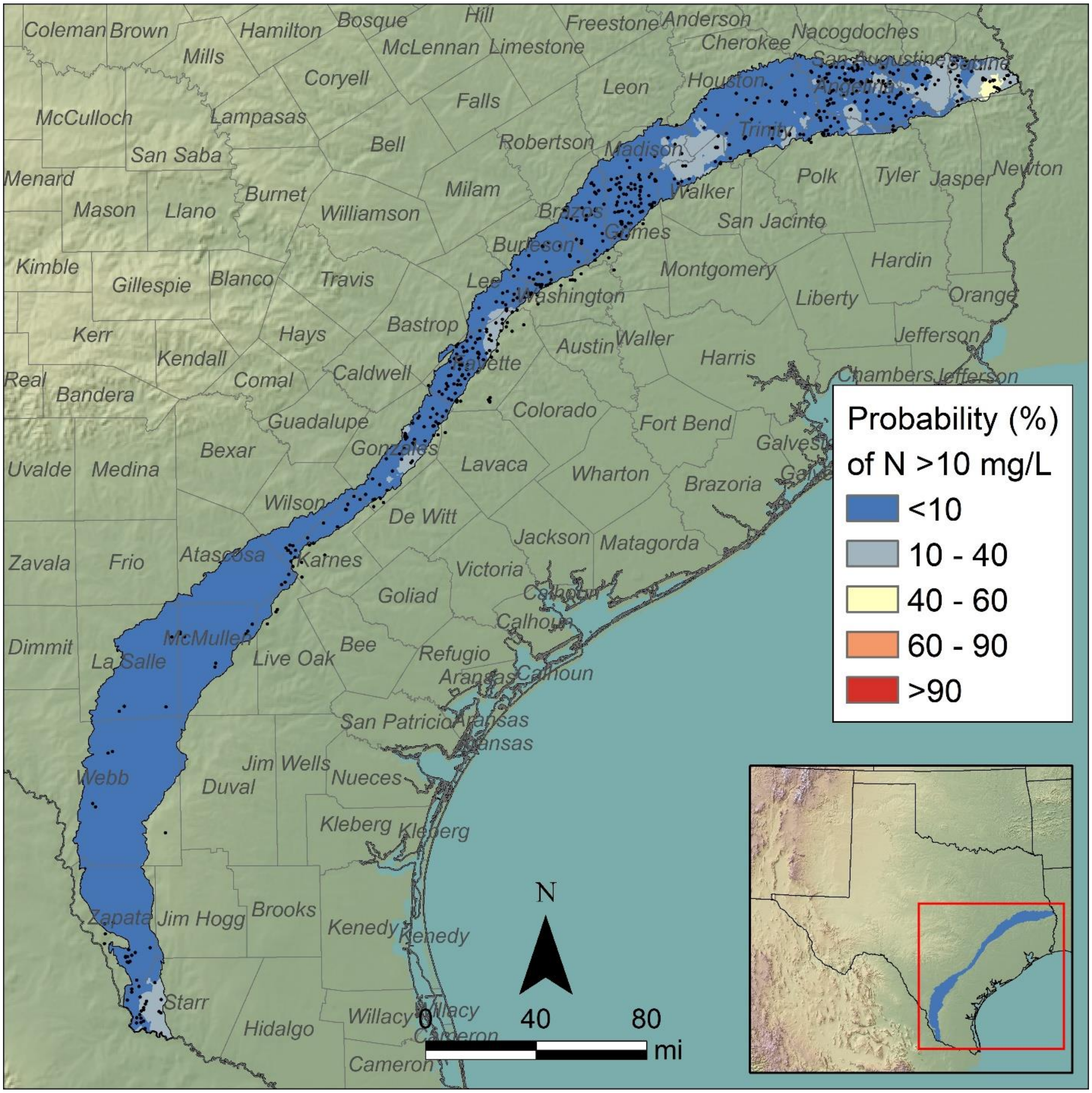


Figure 62. Yegua – Jackson aquifer probability distribution of N >10 mg/L.