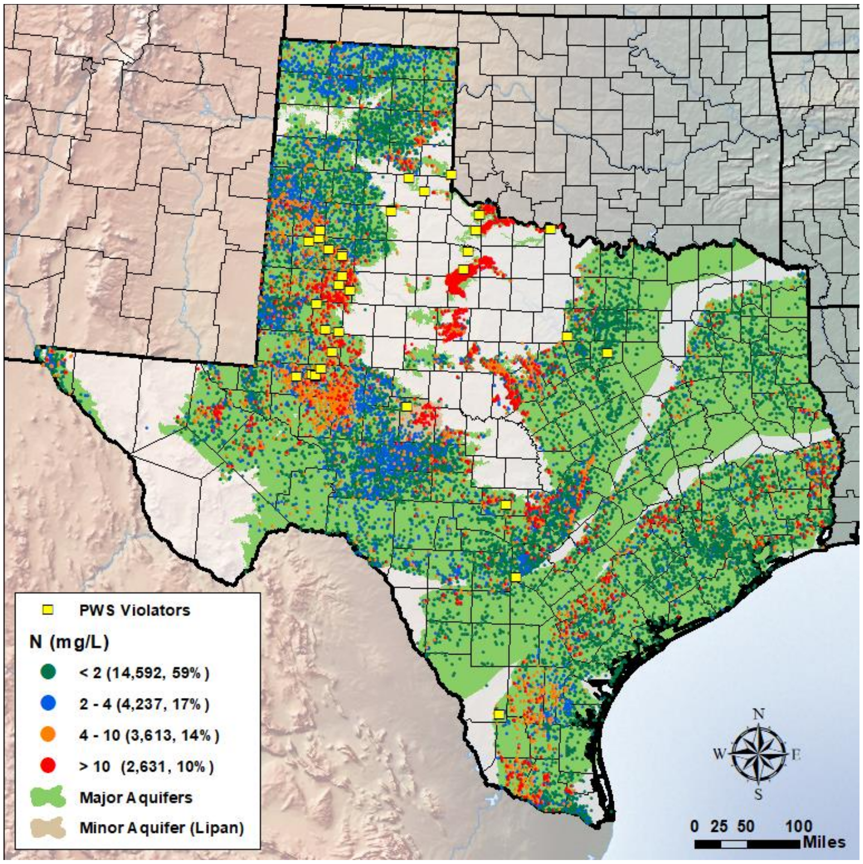
Assessment of Nitrate in Groundwater and Public Water Supply Systems in Texas



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List of Abbreviations

ACS	US Census Bureau American Community Survey
BFZ	Balcones Fault Zone
CDC	Center for Disease Control
CONUS	Continental United States
CWS	Community Water System
DBPR	Disinfectant Byproduct Rule
EPA	Environmental Protection Agency
GIS	Geographic Information System
GW	Groundwater
GWR	Groundwater Rule
HB	Health-Based
ISD	Independent School District
LCR	Lead-Copper Rule
MCL	Maximum contaminant level
MH	Mobile Home
NCWS	Non-Community Water System
NN	Navajo Nation
NRC	National Resource Council
NTNCWS	Non-Transient Non-Community Water System
PWS	Public Water System
RO	Reverse Osmosis
RTCR	Revised Total Coliform Rule
SDWIS	Safe Drinking Water Information System
SOVI	Social Vulnerability Index
SW	Surface Water
SWTR	Surface Water Treatment Rule
TCEQ	Texas Commission on Environmental Quality
TNCWS	Transient Non-Community Water System
TWDB	Texas Water Development Board
USGS	United States Geological Survey
WHO	World Health Organization
WSC	Water Supply Corporation
WS	Water Supply

Executive Summary

Understanding the spatial distribution of elevated groundwater nitrate levels is an important issue because of adverse health effects of high nitrate (>10 mg/L nitrate-N, EPA primary Maximum Contaminant Level, MCL).

The objectives of this study were to quantify the distribution of groundwater nitrate in major aquifers and one minor aquifer (Lipan) in Texas and assess linkages to Community Water Systems (PWSs) and their associated populations that use this water. The Lipan minor aquifer was included because it is known to have elevated nitrate levels in groundwater. Groundwater nitrate data were compiled from the Texas Water Development Board database for 33,167 wells based on the most recent samples by well from 1930 through 2021**.** The spatial distribution of elevated nitrate concentrations was mapped for the state and by aquifer using indicator kriging based on two threshold concentrations: 4 mg/L representing the upper limit of background nitrate levels and 10 mg/L, the primary MCL set by the US EPA for health purposes. The current number of non-compliant PWSs and associated populations were obtained from EPA listings based on 2018 through 2020 data. Although domestic wells are not regulated by EPA, populations served by domestic (rural) water wells that exceed these threshold levels were estimated from the U.S. Geological Survey water use data (2015 data).

Results show that a total of 2,631 groundwater samples from the TWDB database exceeded the nitrate-N MCL of 10 mg/L, representing ~8% of the most recent nitrate analyses from wells throughout the state. Nitrate rule violations by PWSs were primarily from the Ogallala (51%) and Seymour (26%) aquifers with much lower percentages for the remaining aquifers. The median nitrate-N concentration was highest in the Seymour Aquifer (10.8 mg/L) with the 95th percentile of 33.9 mg/L, followed by the Lipan (median 7.7 mg/L), Ogallala (1.8 mg/L), and Edwards-Trinity Plateau (1.6 mg/L) aquifers. A much larger percentage (20%) of samples (6,554 samples) from the TWDB database exceeded the background level of 4 mg/L nitrate-N. Concentrations at the 95th percentile generally exceeded 4 mg/L for all aquifers except the Carrizo-Wilcox Aquifer. Of all samples exceeding the 4 mg/L background level, 28% were from the Seymour aquifer, 20% from the Ogallala, 16% from the Gulf Coast, and 15% from the Edwards-Trinity Plateau aquifers. The Seymour aquifer had 84% of its groundwater samples exceed 4 mg/L. The Lipan aquifer, though more sparsely sampled than the major aquifers, had 61% of its groundwater samples exceed 4 mg/L.

Texas has the largest number of active PWSs of any state in the U.S. (4,653 systems, 2020). The majority of the population has access to PWSs (28.7 million in 2020; 98.6% of the total census population of 29.1 million) with a much lower number of people relying on domestic or non-Public Water Systems (PWSs) (0.4 million, 1.4% of total population). Texas ranks number 1 in terms of the number of PWSs with any health-based violation (545 PWSs) and number 1 in terms of nitrate-N violations relative to all of the states in the Continental U.S. (CONUS). A total of 35 PWSs exceeded the nitrate-N MCL in Texas, mostly (34) in major aquifers and only 1 in minor aquifers based on 2018 – 2020 data. The population impacted by nitrate-N MCL exceedances from PWSs totaled ~32,116 people (0.09% of the 2020 population) whereas domestic wells (non-PWSs) with nitrate-N >10 mg/L accounted for ~46,069 people (0.16 % of the 2020 census population). These percentages are much higher for the background nitrate-N level of 4 mg/L (PWSs, 0.99% of 2020 population, non-PWSs, 0.47%).

Three of the major aquifers accounted for the majority of the population impacted by primary MCL violations in terms of population served by PWSs (), the Edwards Balcones Fault Zone (BFZ) (11,007 people, 34% of total impacted population), Ogallala (6,817 people, 21%), and Trinity (6,631, 21%) aquifers. Some of the PWSs with nitrate-N exceedances also have co-contaminant concentrations above their MCL, such as arsenic (23), fluoride (29) and radionuclides (2), primarily in the Ogallala and Seymour Aquifers. Of these, five systems have reported treatment for inorganics removal, including reverse osmosis (2), filtration (1), and innovative techniques (2), yet violations persist. PWSs that exceed nitrate-N MCL are generally persistent, with 8 PWSs exceeding the MCL for ≥9 out of 12 quarters within a three-year period (2018 – 2020). While the State has been making considerable progress towards bringing PWSs that are out of compliance with respect to nitrate-N into compliance, there are still a number of non-compliant PWSs. The number of nitrate-N non-compliant PWSs decreased from 31 in 2018 to 21 in 2020. There are a variety of approaches for managing nitrate-N contamination in small PWSs.

Introduction

Nitrate is the most pervasive contaminant in groundwater in Texas and in the U.S. (Burow et al., 2010). Groundwater nitrate-N levels in drinking water are of great interest because of adverse health impacts, including blue bay syndrome, cancers, and thyroid disease (Ward et al., 2018). The upper nitrate-N limit of 10 mg/L (Maximum Contaminant Level) was established to minimize adverse health impacts related to nitrate-N toxicity. Previous studies show that 5.6 million Americans have nitrate-N concentrations ≥5 mg/L in their Community Water Systems based on 2010 – 2014 data from the Safe Drinking Water Information System (SDWIS) database (Schaider et al., 2019).

The EPA regulations only apply to public water systems (PWSs) and not to private domestic-supply wells. Previous studies show that the dominant sources of nitrate in groundwater include fertilizer application and manure. Conditions resulting in elevated nitrate levels were found to be oxic conditions (low iron and manganese and high dissolved oxygen) and high nitrogen inputs (Burow et al., 2010). GIS overlay analyses and logistic regression have been used to assess different sources and controls on nitrate contamination at regional and national scales (Nolan et al., 1997; 2002; Squillace et al., 2002).

Previous studies conducted by the University of Texas Bureau of Economic Geology evaluated linkages between nitrogen loading and aquifer susceptibility parameters (Scanlon et al., 2004). Nitrogen loading included rainfall, atmospheric deposition, fertilizers (inorganic and organic), land use (proxies for sewage and septic input), population density, and irrigation. Aquifer vulnerability to nitrate contamination considered clay content, organic matter content, percent land surface slope, and percent well drained soils. Multivariate logistic regression showed that rainfall, percent agricultural land, low density residential land, and soil organic matter were the most important variables. The inverse relationship between precipitation and nitrate concentration was attributed to dilution in high rainfall areas and possibly evapoconcentration in low rainfall areas. Percent agricultural land may provide a proxy for agricultural nitrogen loading and low-density residential land use may reflect septic tank effluent. Percent organic matter may represent denitrification in some regions. This study helped highlight major controls on elevated groundwater nitrate concentrations in Texas.

The most recent study on groundwater nitrate conducted by the Bureau of Economic Geology examined nitrate contamination in public water systems and in major and minor aquifers in the state to assess spatial distribution of nitrate levels (Reedy et al., 2017). Factors influencing groundwater nitrate contamination were examined, including nitrate-N inputs, soil types, unconfined versus confined aquifer systems, and water table depths in unconfined aquifers. Results showed that the highest nitrogen loading did not necessarily correspond to groundwater nitrate contamination hotspots. Discrepancies between nitrate loading and groundwater nitrate contamination suggested that soil texture, aquifer status (confined vs unconfined), and water table depths are more important factors controlling nitrate contamination. High levels of groundwater nitrate, particularly in the Seymour, Lipan, and southern Ogallala aquifers, were attributed primarily to natural sources and fertilizer inputs, coarse soils, unconfined aquifers, and shallow water tables.

A variety of approaches are available to treat groundwater nitrate contamination, including ion exchange, reverse osmosis, and electrodialysis (EPA, 2021). Ion exchange resins work like tiny magnets that adsorb nitrate from water in the treatment system. Reverse osmosis involves forcing nitrate-contaminated raw water through a semi-permeable membrane that does not allow nitrate to pass through. Electrodialysis involves use of a direct electric current to transport ions through membranes, where it holds nitrate.

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

- What is the spatial variability in groundwater nitrate-N concentrations in major aquifers in Texas?
- What is the potential population served by domestic wells and public water systems with nitrate-N exceedances of 4 and 10 mg/L?

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

Methods

Terminology

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

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

The National Primary Drinking Water Regulations (NPDWR) are applied to public water systems to limit the levels of contaminants in drinking water, thus preserving public health. Nitrate rule violations fall under the inorganics portion of the Chemical Contaminants Rule, in which the MCL for nitrate-N is 10 mg/L. This rule was enacted to prevent illness in infants. Nitrates are generally sourced from agricultural fertilizers, leaks from septic tanks, sewage, and erosion of natural deposits om addition to natural geochemical processes. Nitrites have similar sources and impacts as nitrates, but have an MCL of 1 mg/L. As most of the PWS systems are supplied by aquifers under oxidizing conditions in Texas, this study focused on nitrate-N. Most of the groundwater well samples in Texas include nitrate-N, with < 1% of the samples including nitrite-N.

Data from the Texas Water Development Board (TWDB) groundwater database were used to characterize statewide groundwater nitrate-N concentrations to develop estimates of county rural populations at risk of exposure to nitrate-N at threshold concentrations of 4 mg/L and >10 mg/L. The threshold of 4 mg/L was based on previous studies that suggested nitrate-N levels exceeding this level reflect anthropogenic nitrate inputs in the High Plains aquifer (Gurdak and Qi, 2006). Analysis of nitrate levels in groundwater in Texas aquifers includes all well use categories in the state. Data from the TCEQ PWS database were used to characterize PWS populations at risk of exposure to nitrate-N concentrations >10 mg/L based on water quality analyses of distribution system water samples. Data from the SDWIS database were used primarily to characterize CWS populations at risk of exposure to nitrate-N >10 mg/L, though non-PWSs are also mentioned.

TWDB Groundwater Data Analysis

Data on groundwater nitrate-N concentrations for this study were obtained from the TWDB groundwater database. The TWDB database contains analyses of groundwater sampled at the well head prior to any treatment processes and the results are considered representative of groundwater conditions at that location at the time of sampling. The original version of this report used data from groundwater samples collected between 1929 and 2019. The current report uses data from groundwater samples collected between 1930 and 2021 for the statewide maps only.

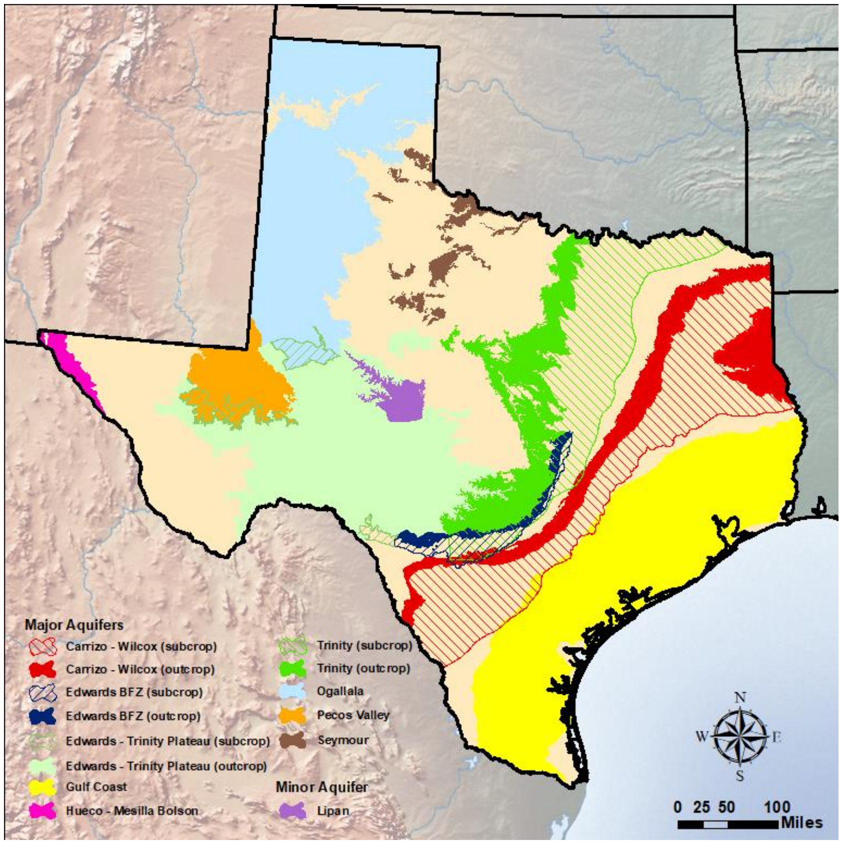

Figure 1. Texas Major Aquifers, and the Lipan Aquifer (Minor) evaluated in this study.

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

Samples from 33,167 groundwater wells in Texas are represented in this study, including 25,422 samples with detected nitrate-N concentrations (Table 14). The TWDB groundwater database samples analyzed for nitrate-N were collected between 1930 and 2021 (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. The highest non-detect nitrate-N concentration measured in the TWDB dataset was 4.5 mg/L from 311 samples taken in DeWitt County in the 1930's. Non-detect samples were not used to construct the probability maps or other well data analyses presented in this study.

The maximum concentration was found to be 505 mg/L, and a total of 44 samples had concentrations greater than 100 mg/L. These samples were not considered outliers as these 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 0.24 mg/L and range from 0.001 mg/L to 4.5 mg/L.

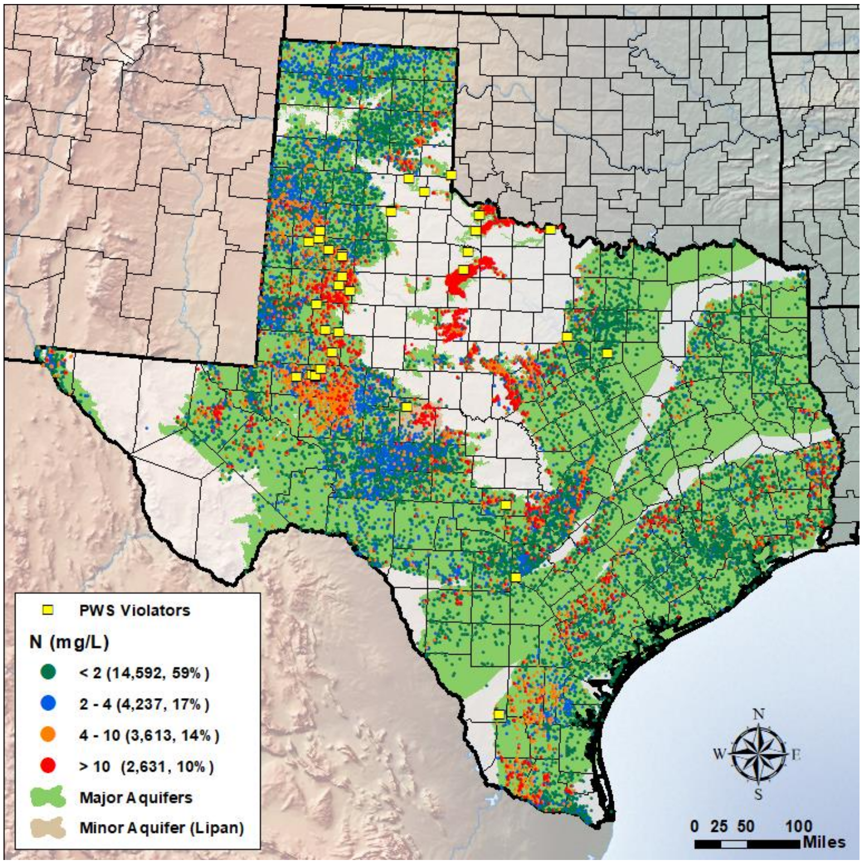

Figure 2. Spatial distribution of nitrate-N concentrations in Texas groundwater, including samples collected from 1930 – 2021 with detected concentrations (25,422). The numbers of samples and percentages of all samples within the stated concentration ranges are shown in parenthesis. Samples with non-detect concentrations and samples from wells that were not completed in single named major aquifer (or Lipan aquifer) are not included. The locations of 35 public water systems (PWSs) that had any nitrate-N MCL violation during the period 2018-2020 are also shown.

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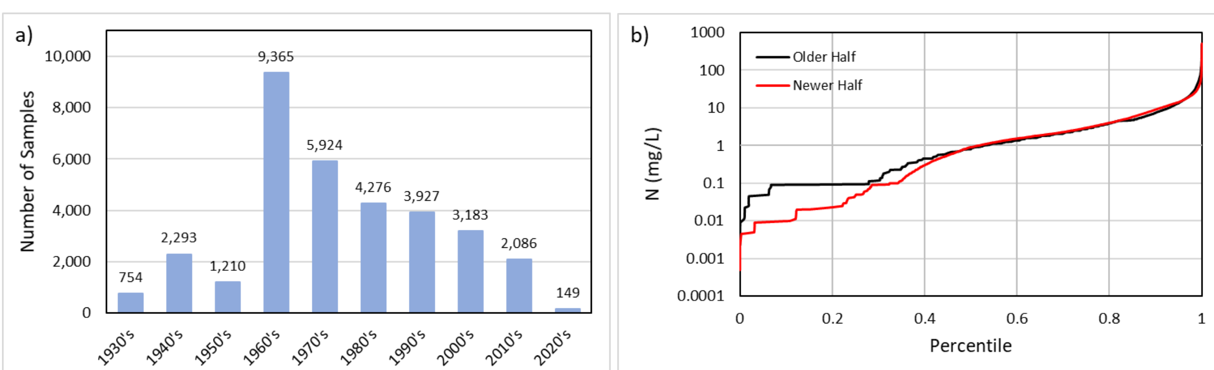

Figure 3. Distributions of a) number of groundwater nitrate-N samples collected by decade and b) percentile distribution of nitrate-N concentrations for samples collected prior to and on or after the median sample date (10/8/1975). (TWDB groundwater database, 1930-2021).

The concentration distribution of the sample population collected prior to the median sample date (10/8/1975) was compared to that of samples collected on or after the median sample date (Figure 3b). The distributions are nearly identical above ~0.5 mg/L, while improved sampling technology (lower detection limits) cause deviation between the two datasets below ~0.5 mg/L. As this study is primarily focused on nitrate-N concentration threshold values of 4 mg/L and 10 mg/L, the slight difference in distributions below 0.5 mg/L is inconsequential to the overall results. This indicates that there is little significant bias in the analytical precision of nitrate-N over the sampled time period and that "older" data can be reliably incorporated to maximize spatial coverage. The data used include only the most recent analysis for each well.

TWDB Data Analysis – Groundwater Conditions and Rural Populations

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 2021. 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 rural population 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. Separate state-wide maps were generated for data over the period 1930 to 2021 at threshold nitrate-N concentrations of 4 mg/L, and 10 mg/L.

Maps for each aquifer based on the period 1930 through 2021 focused on the background level (>4 mg/L) and the EPA MCL (>10 mg/L), including all major aquifers and the Lipan minor aquifer. As a general rule-of-thumb, it is desirable to have 100 or more data points and 50 is considered the minimum required to obtain a statistically stable and meaningful result using kriging methods. Further consideration must also be given to the spatial distribution of data point locations within the modeled area, i.e., whether the data are overly clustered in one area and sparse or absent in others. There were more than sufficient data for all nine of the major aquifers and for the Lipan minor aquifer.

The indicator kriging procedure begins with a binary transformation of the concentration data as either 0 (zero) for all data points less than or equal to the threshold value or 1 (one) for all data points greater than the threshold value. A semi-variogram is created that represents the average variance between data locations as a function of the separation distance between the data points. The semi-variogram may include directional anisotropy components if the variance displays structure based on azimuthal direction within the data. A mathematical model is then fit to the semi-variogram points and this model is used to predict values at locations between the data points. The resulting output is a grid map of predicted probability (or likelihood) values that 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 and state-wide probability maps.

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

The maps should be interpreted in part with consideration given to the spatial distribution of the underlying data as data may be clustered in some areas and relatively sparse elsewhere. Some artifacts are present in the maps that arise primarily in regions with little or no data and/or the results of directional anisotropy in the underlying semi-variogram structure.

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

Safe Drinking Water Information System and TCEQ Public Water System Data Analysis – Public Water System Conditions and Populations

Public water systems (PWSs) in Texas are regulated under the Safe Drinking Water Act with primacy transferred from EPA to TCEQ and must provide distribution system water sample analyses to monitor system performance with regard to various potential contaminants of concern, including nitrate-N. There was a total of 7,055 active PWSs in Texas serving 28,747,517 people based on SDWIS data downloaded in April 15, 2021 (Figure 3a). PWSs serve stable year-round populations and accounted for 66% of the PWSs serving most of the PWS population (97%, 28,747,517 people). This study focuses on PWSs. Non-PWSs (those with transient or non-transient populations) are not included to avoid double counting of overlapping populations. The SDWIS database was used to characterize CWSs with nitrate-N concentrations >10 m/L.

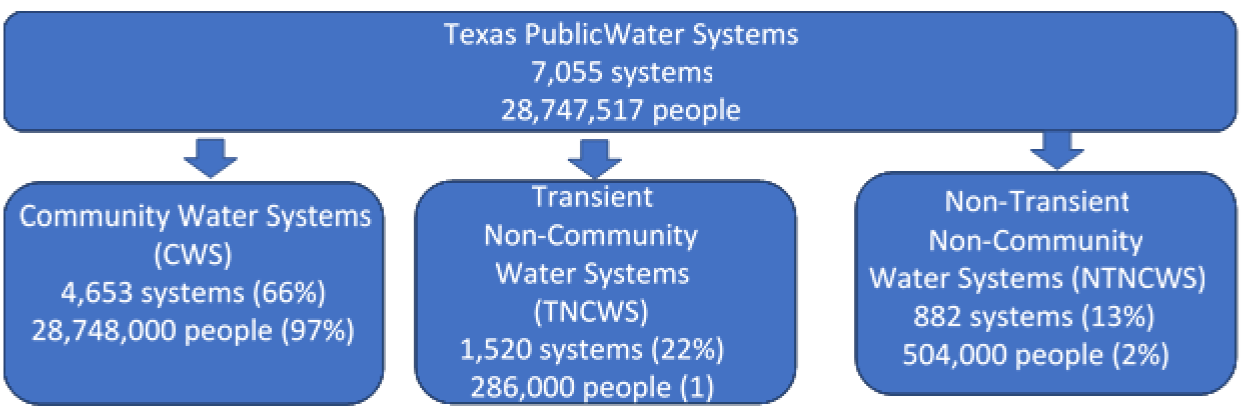

Figure 4. Types, numbers, and total populations served by Texas PWSs in the SDWIS database as of 15 April 2021. Percentages are relative to the combined total number of PWSs and populations served in the database (https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting). The numbers of systems and corresponding populations served are summarized in Table 1.

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

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

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

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

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

Because sample results with nitrate-N levels below 10 mg/L are not routinely included in the SDWIS database, data from the TCEQ PWS database were used to estimate the at-risk CWS populations for nitrate-N concentrations exceeding the background level of 4 mg/L in the distribution systems. These assessments are based on whether the CWS had at least one distribution water sample with nitrate-N >4 mg/L during the period from January 2018 through July 2020.

SDWIS Database Definitions

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

Public Water System Type

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

- *Community water system - A PWS that serves at least fifteen service connections used by year-round residents or regularly serves at least 25 year-round residents (e.g., homes, apartments and condominiums that are occupied year-round as primary residences).*
- *Non-community water system*
    - *Transient non-community water system - A non-community water system that does not regularly serve at least 25 of the same persons over six months per year. A typical example is a 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

- *"Serious Violator*
    - *'Yes' indicates a public water supply system with unresolved serious, multiple, and/or continuing violations that is designated as a priority candidate for formal enforcement, as directed by EPA's Drinking Water Enforcement Response Policy.*
    - *EPA designates systems as serious violators so that the drinking water system and primacy agency will act quickly to resolve the most significant noncompliance. Many public water supply systems with violations, however, are not serious violators. Operators and the primacy agencies are expected to correct the violations at non-serious violators as well, but without the more strict requirements and deadlines applicable to serious violators. If the violations at a non-serious violator are left uncorrected, that system may become a serious violator. When a serious violator has received formal enforcement action or has returned to compliance, it is no longer designated a serious violator. EPA updates its serious violator list on a quarterly basis.*
- *Health-Based Violations*

- *Violations of maximum contaminant levels (MCLs) or maximum residual disinfectant levels (MRDLs), which specify the highest concentrations of contaminants or disinfectants, respectively, allowed in drinking water; or of treatment technique (TT) rules, which specify required processes intended to reduce the amounts of contaminants in drinking water. MCLs, MRDLs, and treatment technique rules are all health-based drinking water standards."*

Compliance Points

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

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

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

Non-Public Water Systems

Domestic and self-supplied systems are not regulated by the TCEQ or EPA. These systems are generally located in rural areas or are otherwise not connected to a regulated PWS and are referred to in this study as non-PWSs. Estimates of the at-risk non-PWS populations were made by aquifer using the kriging probability maps discussed earlier coupled with estimates of the non-PWS county populations from the United States Geological Survey (USGS, 2015, https://water.usgs.gov/watuse/). The USGS report provides total populations and populations relying on PWSs. This study uses the difference between those two populations to estimate the rural (non-PWS) population in each county of Texas.

The spatial mean probabilities of exceeding both the 4 mg/L background level and 10 mg/L nitrate-N MCL threshold level were estimated for each unique aquifer-county intersecting area based on the GIS probability maps. The spatial probability of exceedance mean values were multiplied by the non-PWS population estimates for each county to obtain initial estimates of the at-risk populations. The initial estimates were finally adjusted to remove populations in those county areas not underlain by the given aquifers. The final county results were summed across each aquifer.

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

Social Vulnerability Index

The US Centers for Disease Control (CDC) periodically publishes a national dataset characterizing what they term the Social Vulnerability Index (SoVI). The dataset is based on data at the US Census Tract level and is made available at that resolution and also at the US County level. The dataset contains several components. For this study we used the current Social Vulnerability Index (i.e., SoVI) statistic which is based on the US Census Bureau American Community Survey (ACS) for the period 2016-2020 (Figure 5), adapted for use in water-quality analyses.

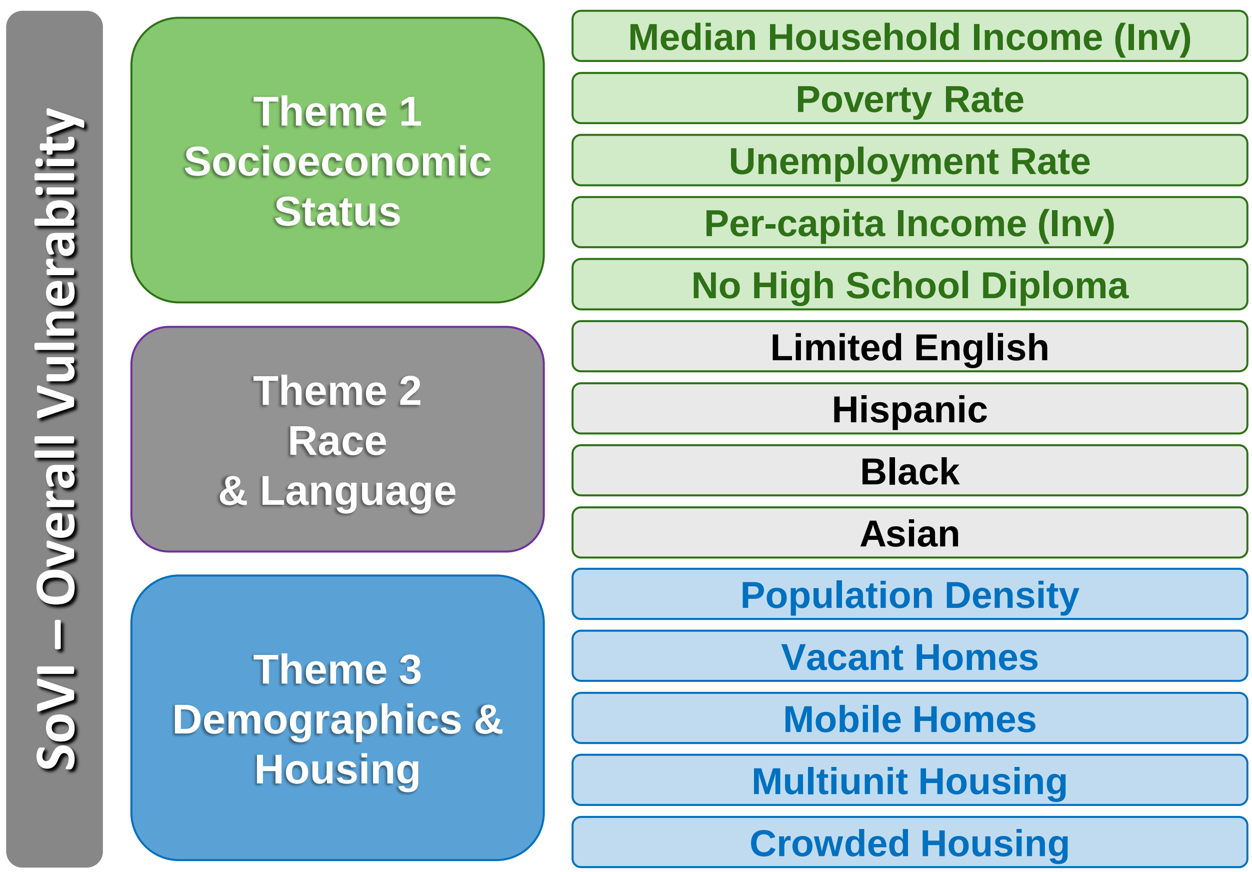

Figure 5. Components of the Centers for Disease Control (CDC) Social Vulnerability Index (SoVI) adapted for use in this water quality analysis.

The CDC SoVI is designed for disaster management. We modified the CDC SoVI by excluding social parameters not considered directly relevant to drinking water quality and including some additional parameters. The CDC SoVI includes 15 parameters within four themes: Socioeconomic status, Household composition & disability; Minority status and language, and Housing type and transportation. We omitted the Household composition & disability theme and vehicle transport from Housing Type and transportation. We included per-capita income and vacant homes (proxy for depopulating systems) and also subdivided the Minority class to include Hispanic, Black, and Asian groups. The modified SoVI statistic is based on 14 US census variables that are grouped into three themes, including (1) socioeconomic status, (2) race and language, and (3) demographics and housing (Fig. 5). Theme 1 variables shown with (Inv) indicate those data that were inverted or flipped about their median values so that they correlate positively with increased social vulnerability. Crowded housing refers to occupied housing units with more than one person per room. The analysis was based on the 2016 – 2020 five-year US Census data published in 2022 by the American Community Survey data.

Values of SoVI range from zero (0, least vulnerable) to one (1, most vulnerable) and represent the normalized sums of the individual variables for a given county. The SoVI values were summarized at the US county level for the CONUS and for Texas in this study.

Results

Populations served by Public Water Systems and non-Public Water Systems

The total population of Texas increased by a factor of about 3 between 1960 (9.6 million) and 2015 (27.5 million) and further to the population of ~29.1 million in 2020 (Figure 6). The percentage of the population served by PWSs has varied between about 80-95% during that time and was estimated at 26.2 million in 2015 (Table 3). The population served by non-PWSs generally fluctuated between about 0.4 to 2.7 million people during that time and was estimated to be 0.4 million in 2020. As a percentage of the total population, the non-PWS population ranged from 10% to 22% between 1960 and 1980 and decreased to 2% in 2020.

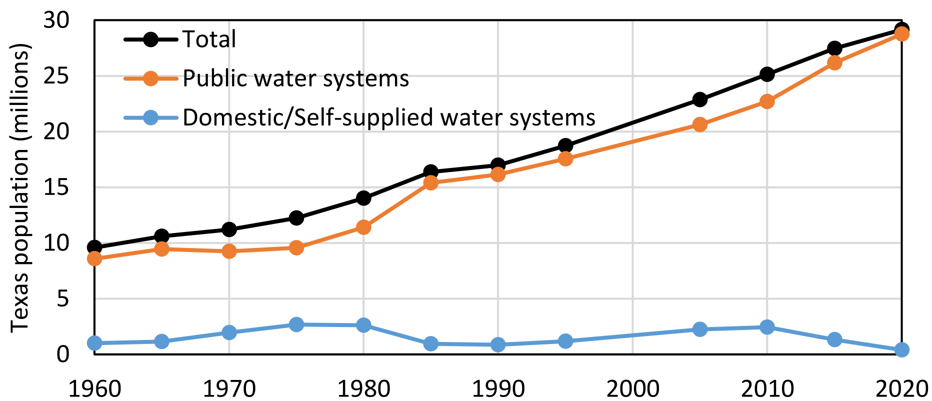

Figure 6. Historical evolution of Texas population relying on Public (CWS) vs Domestic/Self-supplied (non-PWSs) (USGS, https://water.usgs.gov/watuse/data/) for 1990-2015. Values for 2020 are based on the SDWIS database. Values are summarized in Table 3. (https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting)

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

Year	*Total Population*	*PWS Population*	*Non-PWS Population*	*PWS (%)*	*Non-PWS (%)*
1960	9,580,000	8,580,000	1,000,000	89.6	10.4
1965	10,591,000	9,450,000	1,141,000	89.2	10.8
1970	11,197,000	9,240,000	1,957,000	82.5	17.5
1975	12,236,000	9,560,000	2,676,000	78.1	21.9
1980	14,013,000	11,390,000	2,623,000	81.3	18.7
1985	16,361,330	15,403,760	957,570	94.1	5.9
1990	16,986,410	16,129,900	856,510	95.0	5.0
1995	18,723,940	17,550,400	1,173,540	93.7	6.3
2005	22,859,968	20,628,993	2,230,975	90.2	9.8
2010	25,145,561	22,704,975	2,440,586	90.3	9.7
2015	27,469,114	26,154,041	1,315,073	95.2	4.8
2020*	29,536,915	28,747,517	397,988	98.4	1.6

*PWS values based on 2020 SDWIS database.

Texas CWS National Rankings for Rule Violations

The state of Texas shows large variability in the distribution of counties with PWSs having any health-based violation relative to Social Vulnerability Index (SoVI), with many counties with any health-based violations (2018 – 2020 SDWIS data), particularly in the High Plains (Figure 7). However, counties in the Rio Grande Valley and East Texas fall into the highest category of SoVI and health-based violations. Populations in Texas with higher SoVI generally increase with higher terciles of any health-based violation (Table 5). For example, ~ 9,000 people are classified within the lowest SoVI tercile and lowest tercile of health-based violation whereas almost 746,000 people fall into the category with the highest SoVI tercile and highest tercile of health-based violations. Within the top tercile of health-based violations, SoVI populations peaked within the middle SoVI tercile. These results indicate that higher SoVI populations are more at risk of health-based violations.

Texas ranks variously among the top five states with regard to numbers of PWSs that had recent (2018-2020) health-based violations (Table 4). Texas ranks number 1 of all states in terms of number of PWSs with any health-based violation and ranks within the top 2 for many of the other health-based violations. Only violations of Surface Water Treatment Rule, Groundwater Rule, and organics rules rank lower in Texas relative to other states. Texas ranking in terms of CWS populations served ranges from 2 to 8 for different health-based violations. The rankings reflect in part that Texas has both the largest number of PWSs of any state (4,653) and the second largest state population served by PWSs (~28.7 million) after California. Accordingly, for total affected populations expressed as percentages of the state-wide total populations served by all PWSs, Texas ranks variously between 6 and 24 among other continental US (CONUS) states with nitrate-N violations regulated separately. For nitrate-N violations, Texas ranks number 1 in terms of number of PWSs, number 2 in terms of population served, and number 5 on a per-capita basis.

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

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

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

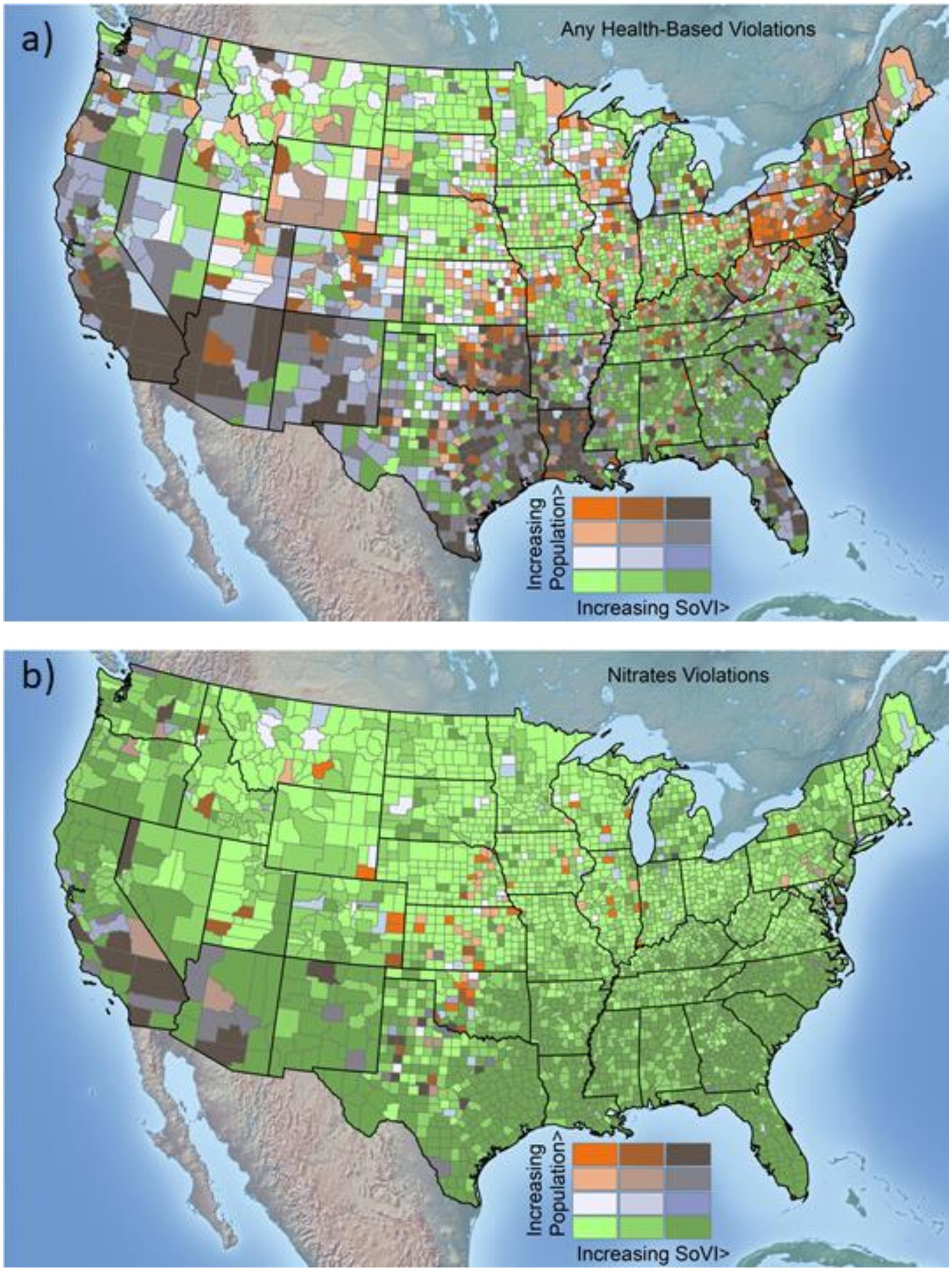

Figure 7. National county-level map comparing terciles of CWS populations having any health-based violation (a) or nitrate rule (b) violation for the period 2018 – 2020 vs terciles of SoVI (Social Vulnerability Index, 2018). The choropleth map is similar to that used by Fedinick et al., 2019. Green tinted areas represent SoVI terciles for counties having no health-based violation for any CWS in that county. The SoVI is a normalized score with values ranging from 0 (least vulnerable) to 1 (most vulnerable) as described in the Methods Section of this report. Values for CONUS and Texas are summarized in Table 5a and 5b.

Table 5a. Populations and percentages of total CWS populations associated with terciles of US and Texas county level SoVI (normalized) values and terciles of CWS populations with any health-based violation in the SDWIS database during the period 2018-2020. Percentages of total values are relative to the US CWS population of 304,379,434 and to the Texas CWS population of 28,747,430. Cell colors correspond to the legend in Figure 5a. Values reflect violating CWS populations in each category except (none, green) which represents the total population in each category.

Region	Affected Population Tercile	*County SoVI Percentile Range*					
		1		*2*		*3*	
		People	*% CWS Total*	*People*	*% CWS Total*	*People*	*% CWS Total*
CONUS	3	3,168,302	1.04	6,093,369	2.00	15,909,384	5.23
	2	421,814	0.14	468,233	0.15	542,774	0.18
	1	63,527	0.02	68,072	0.02	45,404	0.01
	0	27,415,585	9.01	85,627,754	28.13	164,764,283	54.13
Texas	3	131,855	0.46	1,507,049	5.24	745,773	2.59
	2	41,595	0.14	74,113	0.26	76,683	0.27
	1	9,121	0.03	9,857	0.03	6,750	0.02
	0	2,977,497	10.36	6,672,524	23.21	16,494,613	57.38

Table 5b. Populations and percentages of total CWS populations associated with terciles of US and Texas county level SoVI (normalized) values and terciles of CWS populations with nitrate rule violations in the SDWIS database during the period 2018-2020.

Region	Affected Population Tercile	*County SoVI Percentile Range*					
		1		*2*		*3*	
		People	*% CWS Total*	*People*	*% CWS Total*	*People*	*% CWS Total*
CONUS	3	45,829	0.015	62,242	0.020	72,285	0.024
	2	11,261	0.004	5,344	0.002	6,894	0.002
	1	2,160	0.001	2,185	0.001	867	0.000
	0	31,009,978	10.188	92,187,657	30.287	181,181,799	59.525
Texas	3	131,855	0.46	1,507,049	5.24	745,773	2.59
	2	41,595	0.14	74,113	0.26	76,683	0.27
	1	9,121	0.03	9,857	0.03	6,750	0.02
	0	2,977,497	10.36	6,672,524	23.21	16,494,613	57.38

Historical Texas Community Water System Violations

Time series of PWSs with health-based violations in Texas shows that system violations of the DBP Rule (DBPR) were highest since early 2000s, peaking in 2005 and 2015 (Figure 8a). Total affected populations are also dominated by DBPR violations since early 2000s (Figure 8b). The Lead and Copper Rule (LCR) violations peaked in the early 1990s, in terms of number of systems and populations served. System violations of the Ground Water Rule (GWR) increased from ~ 2010 peaking in 2019 and ranked 2nd after DBPR violations (Fig. 8a).

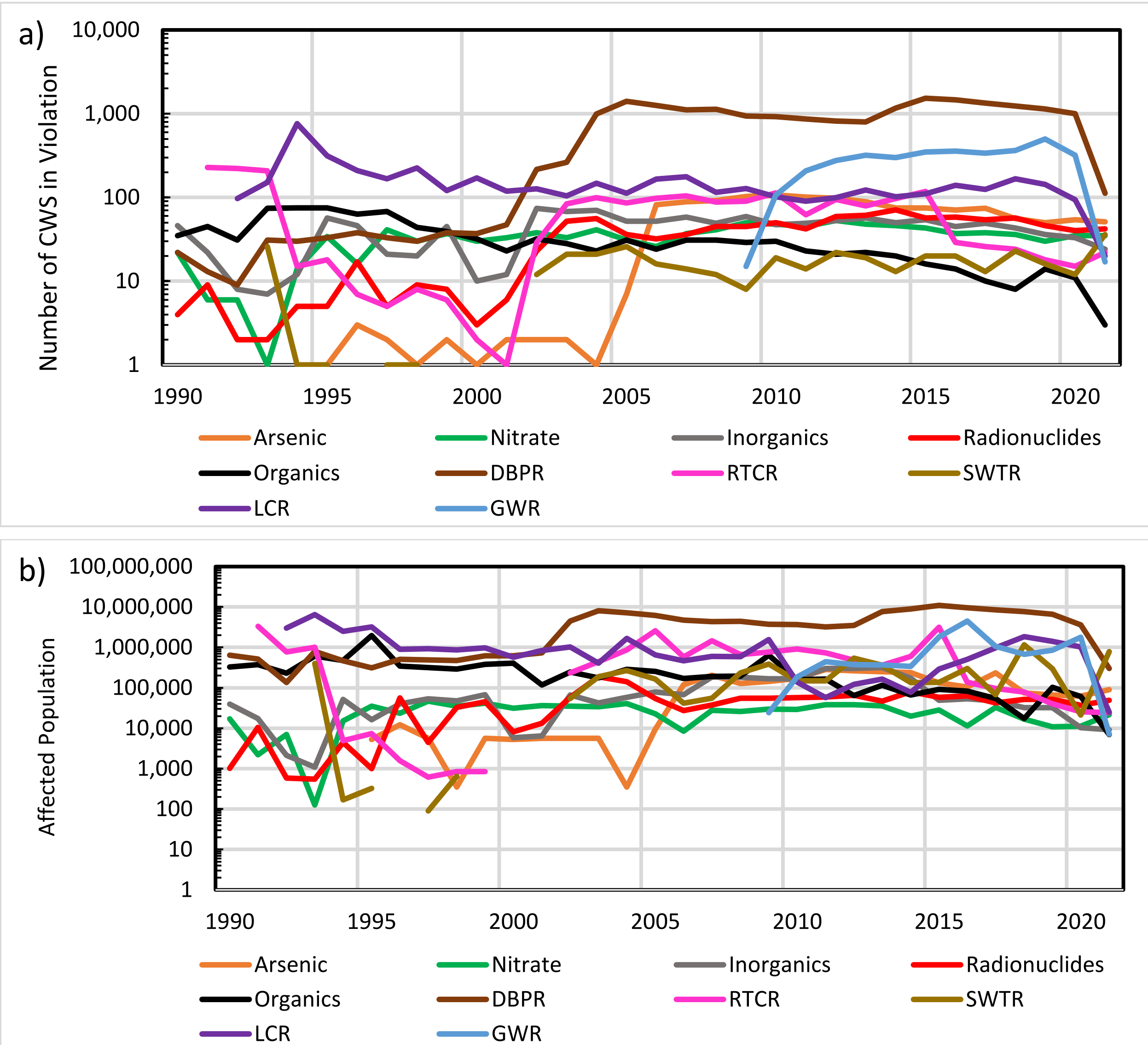

Figure 8. Summary time-series of Texas Community Water System (CWS) health-based violations for the various EPA water quality rules based on the SDWIS database including a) the annual number of violations and b) the total annual affected populations. (SDWIS database, https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting). Annual data are shown in Table 6a and Table 6b, respectively. DBPR: Disinfection Byproducts Rule, RTCR: Revised Total Coliform Rule, SWTR: Surface Water Treatment Rules, LCR: Lead and Copper Rule, GWR: Groundwater Rule.

PWSs with nitrate-N violations varied in the early to mid-1990s and gradually increased peaking in 2012 (53) and then declined to a minimum of 30 in 2019 (Fig. 9a). In terms of affected population, the period from 1995 – 2005 had the highest number of people impacted with an average of 34,815, declining slightly to a local minimum of 10,843 in 2019 (Figure 9b). Comparing the two graphs emphasizes that the PWSs that are currently in violation with respect to nitrate-N are dominated by small systems, having a median system population of about 200 people.

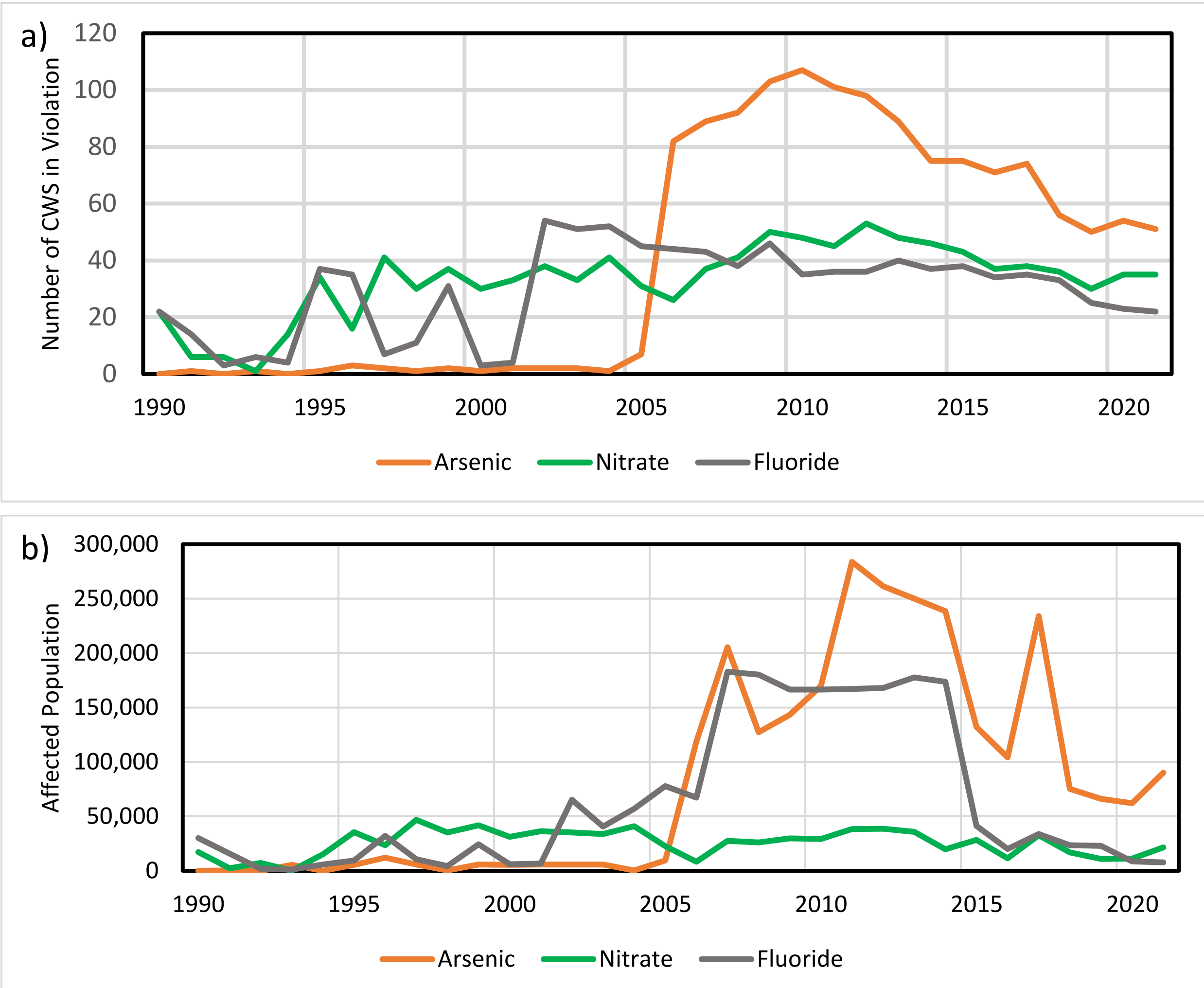

Figure 9. Time-series of the primary inorganic constituent health-based violations including arsenic, nitrate, and nitrate-N violations for Texas Community Water Systems (PWSs) based on the SDWIS database including a) annual number of system violations and b) total annual affected populations. Annual data are shown in

Table 6a and Table 6b, respectively.

Table 6a. Time series of the numbers of PWSs in Texas with health-based violations for the different EPA water quality standards shown in Figure 8a and Figure 9a.

Year	*Nitrates Rule*	*Arsenic Rule*	*Radionuclides Rule*	*Fluoride*	*Inorganics Rule*	*Organics Rule*	*DBPR*	*RTCR*	*LCR*	*SWTR*	*GWR*
1990	22	0	4	22	46	35	22	0	0	0	0
1991	6	1	9	14	22	45	13	228	0	0	0
1992	6	0	2	3	8	31	9	222	97	0	0
1993	1	1	2	6	7	74	31	208	152	26	0
1994	14	0	5	4	12	75	30	15	761	1	0
1995	34	1	5	37	57	75	33	18	315	1	0
1996	16	3	17	35	46	63	38	7	210	0	0
1997	41	2	5	7	21	68	33	5	167	1	0
1998	30	1	9	11	20	44	30	8	225	1	0
1999	37	2	8	31	45	39	38	6	121	0	0
2000	30	1	3	3	10	32	37	2	171	1	0
2001	33	2	6	4	12	23	47	1	119	0	0
2002	38	2	23	54	74	32	217	29	127	12	0
2003	33	2	52	51	68	28	262	84	104	21	0
2004	41	1	56	52	70	23	992	99	148	21	0
2005	31	7	36	45	52	31	1410	86	112	26	0
2006	26	82	32	44	52	24	1254	98	166	16	0
2007	37	89	36	43	58	31	1112	104	176	14	0
2008	41	92	45	38	49	31	1131	88	115	12	0
2009	50	103	45	46	59	29	938	90	128	8	15
2010	48	107	50	35	47	30	924	113	102	19	107
2011	45	101	42	36	49	23	863	62	90	14	207
2012	53	98	59	36	53	21	819	95	99	22	276
2013	48	89	61	40	57	22	798	79	123	19	320
2014	46	75	71	37	50	20	1170	97	102	13	299
2015	43	75	57	38	54	16	1529	118	110	20	349
2016	37	71	58	34	45	14	1460	29	140	20	357
2017	38	74	54	35	49	10	1340	26	125	13	337
2018	36	56	57	33	43	8	1232	24	167	23	363
2019	30	50	46	25	36	14	1137	18	143	16	499
2020	35	54	40	23	33	11	998	15	94	12	318
2021	35	51	42	22	24	3	112	22	20	36	17

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

Table 6b. Time series of the CWS populations in Texas with health-based violations for the different EPA water quality standards shown in Figure 8b and Figure 9b.

Year	*Nitrates Rule*	*Arsenic Rule*	*Radionuclides Rule*	*Fluoride*	*Inorganics Rule*	*Organics Rule*	*DBPR*	*RTCR*	*LCR*	*SWTR*	*GWR*
1990	17,105	-	1,011	30,147	39,279	329,757	639,910	-	-	-	-
1991	2,210	350	10,420	15,796	17,242	376,815	512,494	3,325,901	-	-	-
1992	7,056	-	586	1,685	2,138	231,929	135,362	766,022	3,013,969	-	-
1993	126	5,300	549	1,087	1,087	610,083	798,849	1,016,290	6,481,002	397,853	-
1994	15,096	-	4,440	5,681	51,477	470,828	465,199	4,949	2,500,811	168	-
1995	35,337	5,300	1,005	9,400	16,314	1,962,058	312,823	7,363	3,224,805	324	-
1996	23,534	12,104	56,306	31,919	40,061	344,293	507,408	1,572	903,726	-	-
1997	46,790	5,650	4,426	10,466	53,262	316,364	493,605	615	921,117	90	-
1998	35,281	350	32,969	4,259	47,208	290,281	472,939	847	862,181	645	-
1999	41,721	5,650	45,044	24,314	67,191	379,736	617,492	843	966,861	-	-
2000	31,182	5,300	8,210	5,874	5,874	406,394	615,557	-	569,479	645	-
2001	36,371	5,650	13,326	6,467	6,467	118,428	735,046	-	839,137	-	-
2002	35,315	5,650	58,447	65,230	66,989	246,992	4,508,976	235,049	1,031,453	53,909	-
2003	33,782	5,650	187,563	40,534	41,912	176,299	8,136,193	442,106	406,503	186,898	-
2004	41,030	350	142,353	56,991	58,297	286,391	7,162,636	862,881	1,665,900	267,655	-
2005	22,619	9,551	54,505	77,789	78,230	253,840	6,191,837	2,595,571	656,409	163,134	-
2006	8,409	118,712	27,170	67,274	67,274	169,755	4,747,157	583,606	467,047	41,373	-
2007	27,581	205,243	37,581	182,799	183,648	190,352	4,347,362	1,449,488	595,872	55,329	-
2008	26,026	127,268	55,421	180,229	180,718	193,677	4,398,863	661,553	587,933	233,926	-
2009	29,687	143,285	54,936	166,538	167,027	644,397	3,717,758	764,710	1,553,313	388,849	24,277
2010	29,124	169,610	57,552	166,563	167,412	159,323	3,651,440	915,929	140,054	147,572	184,282
2011	38,368	283,774	59,293	166,907	300,808	165,733	3,189,411	731,229	57,050	149,103	442,583
2012	38,505	261,439	65,704	167,852	301,264	63,847	3,517,682	479,904	121,693	539,547	375,130
2013	35,771	250,061	46,603	177,699	318,705	114,658	7,654,769	360,292	164,073	361,128	371,267
2014	19,733	238,683	79,551	173,602	174,032	66,470	8,925,443	595,848	77,095	134,805	339,982
2015	28,443	132,017	58,171	41,180	48,771	91,433	10,966,708	3,175,946	289,067	136,961	1,814,346
2016	11,401	103,991	63,213	20,020	53,039	82,600	9,488,496	136,324	503,402	301,491	4,481,763
2017	32,632	234,094	42,339	33,801	47,149	53,991	8,559,092	96,315	968,948	67,711	1,053,311
2018	16,915	75,232	51,403	23,451	32,428	17,425	7,712,920	79,127	1,847,013	1,159,914	675,523
2019	10,843	66,067	51,991	23,004	32,410	102,471	6,626,154	40,217	1,415,660	296,214	857,000
2020	11,139	62,156	36,944	8,702	10,248	60,672	3,633,691	25,455	1,024,313	21,115	1,779,029
2021	21,548	90,108	49,502	7,583	9,137	6,968	303,370	24,143	24,954	780,970	7,134

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

Current Texas Community Water System Violations

Currently there are 35 CWS with nitrate violations in Texas based in SDWIS data downloaded in April 15 2021 (Table 7). Texas ranked number 1 of all states in the CONUS in terms of PWSs with nitrate violations and number 2 in terms of population served based on 2018 – 2020 data (Table 8). Most violations are for systems that obtain their water from the Ogallala (18/35) or Seymour aquifers (9/35). The range in maximum nitrate-N concentrations for all violating PWSs is 10 to 26 mg/L. The populations served by the nitrate violating PWSs ranges from 50 to 11,007 (Atascosa Rural WSC); however, the majority of the PWSs with nitrate violations are very small (< 500 people, 28/35 systems, ~75% of CWSs). Four of the systems are classified as small in size (501 – 3,300 people) with the remaining three systems classified as medium in size (City of Keene, 6,310 people; Concho Rural Water Grape Creek, 4,569 people; Atascosa Rural WSC, 11,007 people).

Several (9) of the nitrate-N violating CWSs only recorded one health-based violation over the three-year period (2018 – 2020, 12 quarters); however, many of the CWSs had multiple health-based violations, with up to 39 violations recorded in a single CWS (Franklin Water System III).

Many of these violating CWSs had co-contaminants, in addition to nitrate-N (Table 7). The most common co-contaminant is arsenic, with 32/35 systems having measured arsenic concentrations ranging from 8.3 to 19.6 µg/L. Fluoride concentrations exceeding the primary EPA MCL of 4 mg/L were also found in 29 of the CWSs with nitrate-N violations, ranging from 8.72 – 25.6 mg/L (from TCEQ entry point data). Two PWSs had radionuclide rule violations in addition to nitrate violations (Country View MHP and Klondike ISD), both drawing groundwater from the Ogallala aquifer.

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

Treatment of Community Water System Violations

Data on treatment of CWSs for various health-based violations are limited. A total of 5 out of the 35 systems with nitrate violations between 2018 and 2020 list some type of treatment for inorganic removal, including reverse osmosis (2 systems), filtration (1 system), and innovative technology (2 systems) (Table 13). Additional details about treatment of specific PWSs for nitrate, including those with corrosion control, iron removal, taste/odor control, and particulate removal are provided in Table 13.

Table 7. Numbers of reported health-based (HB) violations and maximum concentrations of nitrate-N, arsenic, and fluoride, and number of radionuclides violations for PWSs in Texas having nitrate-N MCL violation(s) during the period 2018-2020. Co-contaminant concentration data were collected from the TCEQ PWS entry point dataset.

PWS ID	*PWS Name*	*Population Served*	*Aquifer Name*	*No. of Rule Violations*		*Max. Concentrations*		
				Any HB	*Radionuclides*	*Arsenic (µg/L)*	*Fluoride (mg/L)*	*Nitrate-N (mg/L)*
TX1520080	FRANKLIN WATER SYSTEMS 3	159	Ogallala	39		14.4		22
TX1530005	GRASSLAND WSC	55	Ogallala	37		9.93	9.93	16
TX1520247	COUNTRY VIEW MHP	54	Ogallala	35	10			11
TX0580013	WELCH WSC	315	Ogallala	27		15.3	9.93	18
TX0580025	KLONDIKE ISD	264	Ogallala	24	4	15.8	19.6	18
TX1650111	COUNTRY VILLAGE MOBILE HOME ESTATES	138	Ogallala	23		18.9	19.6	16
TX1100011	WHITHARRAL WSC	200	Ogallala	16		13.7	19.6	26
TX1650077	SOUTH MIDLAND COUNTY WATER SYSTEMS	165	Ogallala	15				19
TX0990001	CITY OF CHILLICOTHE	707	Seymour	14		17.2	18.9	13
TX1650084	WARREN ROAD SUBDIVISION WATER SUPPLY	195	Edwards-Trinity Plateau	14				12
TX0680051	CANYON DAM MOBILE HOME PARK	108	Trinity	13		8.76	9.93	20
TX1650048	GREENWOOD TERRACE MOBILE HOME SUBDIVISIO	120	Ogallala	13		15.3	8.78	20
TX0390003	CITY OF BYERS	496	Seymour	12		15.3	8.78	18
TX1650057	TWIN OAKS MHP MIDLAND	234	Ogallala	11		15.3	8.76	16
TX1590002	MARTIN COUNTY FWSD 1	54	Ogallala	10		10.8	0.012	12
TX0780013	THALIA WSC	135	Seymour	9		9.86	8.76	15
TX1380011	CITY OF BENJAMIN	258	Seymour	7		9.93	9.93	20
TX0440002	CITY OF DODSON	109	Seymour	5		8.76	9.93	20
TX1380006	RRA TRUSCOTT GILLILAND WATER SYSTEM	176	Seymour	4		11	0.0029	17
TX1520046	WILDWOOD MOBILE HOME VILLAGE	672	Ogallala	4		15.3	13.7	14
TX0860080	ROYAL OAKS APARTMENTS	57	Trinity	3		8.76	9.93	11
TX0960014	LAKEVIEW WSC	98	Seymour	3		8.3	9.85	13
TX1530003	CITY OF WILSON	489	Ogallala	3		13.9	18.9	11
TX0580011	CITY OF ACKERLY	245	Ogallala	2		19.6	11	11
TX1530002	CITY OF TAHOKA	2585	Ogallala	2		10.8	17.8	14
TX1650024	PECAN GROVE MOBILE HOME PARK	336	Ogallala	2		10.8	10.8	11
TX0150040	ATASCOSA RURAL WSC	11007	Edwards (BFZ)	1		10.6	18.9	11
TX0960001	RRA ESTELLINE TURKEY WATER SYSTEM	250	Seymour	1		9.93	9.92	11
TX1100001	CITY OF ANTON	1126	Ogallala	1		15.8	9.98	11

TX1260008	CITY OF KEENE	6310	Trinity	1		17.8	15.3	10
TX1400010	SPADE WSC	125	Ogallala	1		15.3	8.78	11
TX1730003	FLOMOT WATER ASSOCIATION	50	Seymour	1		8.72	8.72	14
TX1840018	LAZY BEND ESTATES	171	Trinity	1		9.85	9.85	11
TX2260008	CONCHO RURAL WATER GRAPE CREEK	5049	Lipan	1		19.4	25.6	11
TX2400025	MIRANDO CITY WSC	460	Gulf Coast	1		10.3	15.3	11

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

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
TX	33	1	11,139	2
CA	31	2	8,291	3
OK	20	3	12,883	1
KS	15	4	6,932	6
AZ	10	5	3,521	9
NE	10	5	4,202	8
WA	8	7	4,570	7
CO	4	8	2,375	10
ID	4	8	7,686	4
MT	4	8	1,165	12
MN	3	11	369	16
PA	3	11	805	14
SD	3	11	243	17
WI	3	11	1,671	11
IA	2	15	682	15
IN	2	15	1,097	13
MI	2	15	89	21
OR	2	15	172	19
UT	2	15	7,350	5
CT	1	20	36	27
DE	1	20	60	26
FL	1	20	70	23
IL	1	20	150	20
NH	1	20	80	22

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
NM	1	20	222	18
WV	1	20	65	25
WY	1	20	70	23
AR	-	28	-	28
GA	-	28	-	28
LA	-	28	-	28
MA	-	28	-	28
MD	-	28	-	28
ME	-	28	-	28
MO	-	28	-	28
MS	-	28	-	28
NC	-	28	-	28
ND	-	28	-	28
NJ	-	28	-	28
NN	-	28	-	28
NV	-	28	-	28
NY	-	28	-	28
OH	-	28	-	28
RI	-	28	-	28
SC	-	28	-	28
TN	-	28	-	28
VA	-	28	-	28
VT	-	28	-	28

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

State	*Systems*		*Population*		*State*	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*		*Number*	*Rank*	*Total*	*Rank*
TX	35	1	37,683	2	MA	-	15	-	15
CA	7	2	9,284	5	MD	-	15	-	15
VA	6	3	696	8	ME	-	15	-	15
AZ	4	4	629	9	MI	-	15	-	15
MO	3	5	11,070	3	MN	-	15	-	15
NM	3	5	3,406	6	MS	-	15	-	15
DE	1	7	9,800	4	NC	-	15	-	15
ID	1	7	78	12	ND	-	15	-	15
MT	1	7	50	14	NE	-	15	-	15
NH	1	7	53	13	NJ	-	15	-	15
NY	1	7	100	10	NN	-	15	-	15
OK	1	7	2,000	7	NV	-	15	-	15
UT	1	7	99,750	1	OH	-	15	-	15
WY	1	7	85	11	OR	-	15	-	15
AR	-	15	-	15	PA	-	15	-	15
CO	-	15	-	15	RI	-	15	-	15
CT	-	15	-	15	SC	-	15	-	15
FL	-	15	-	15	SD	-	15	-	15
GA	-	15	-	15	TN	-	15	-	15
IA	-	15	-	15	VT	-	15	-	15
IL	-	15	-	15	WA	-	15	-	15
IN	-	15	-	15	WI	-	15	-	15
KS	-	15	-	15	WV	-	15	-	15
LA	-	15	-	15					

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

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

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

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

State	*Systems*		*Population*		*State*	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*		*Number*	*Rank*	*Total*	*Rank*
CA	127	1	132,092	3	VA	6	24	696	35
TX	115	2	143,375	2	NN	5	26	5,029	21
AZ	55	3	75,068	5	WI	5	26	11,789	12
NH	29	4	14,019	11	AR	-	28	20,526	9
OK	27	5	73,464	6	CT	4	28	2,662	29
KS	22	6	9,647	17	FL	4	28	2,863	28
NM	20	7	51,477	7	UT	4	28	107,190	4
NE	17	8	35,905	8	MO	3	32	11,070	13
OR	17	8	9,058	18	WY	3	32	6,380	19
WA	16	10	5,574	20	DE	2	34	9,860	15
IL	15	11	9,740	16	GA	2	34	112	39
ID	13	12	10,756	14	ND	2	34	4,475	23
NV	13	12	4,440	24	OH	2	34	108	40
MN	12	14	2,219	31	MA	1	38	40	42
MT	11	15	3,401	26	MD	1	38	164	38
NY	11	15	1,103,345	1	MS	1	38	388	36
PA	9	17	3,539	25	NJ	1	38	270	37
CO	8	18	3,095	27	WV	1	38	65	41
IA	8	18	1,487	32	NC	-	43	-	43
LA	8	18	17,835	10	RI	-	43	-	43
MI	8	18	1,427	33	SC	-	43	-	43
IN	7	22	2,568	30	TN	-	43	-	43
ME	7	22	4,751	22	VT	-	43	-	43
SD	6	24	1,349	34					

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

State	*Systems*		*Population*	
	Number	*Rank*	*Total*	*Rank*
TX	170	1	195,657	3
CA	153	2	142,137	4
AZ	61	3	79,877	6
CO	48	4	28,939	13
NH	43	5	16,617	17
OK	34	6	76,078	7
MN	33	7	69,558	9
KS	28	8	16,416	18
IL	27	9	36,115	12
NM	27	9	56,840	10
NE	21	11	36,653	11
WI	21	11	202,282	2
ID	17	13	11,129	21
OR	17	13	9,058	24
GA	16	15	15,570	19
NV	16	15	5,169	30
NY	16	15	1,104,510	1
WA	16	15	5,574	29
PA	15	19	6,206	27
SD	14	20	9,390	23
IA	13	21	6,392	26
MO	12	22	15,161	20
MT	12	22	4,501	32
MI	11	24	2,760	35
FL	10	25	3,781	34
ME	10	25	5,579	28
NC	10	25	70,979	8
VA	9	28	1,027	39
LA	8	29	17,835	16
IN	7	30	2,568	37
NJ	6	31	22,764	15
VT	6	31	639	40
AR	5	33	24,176	14
CT	5	33	2,730	36
NN	5	33	5,029	31
UT	4	36	107,190	5
WY	4	36	6,425	25
DE	3	38	10,116	22
MA	3	38	215	43
SC	3	38	2,564	38
MD	2	41	253	42
ND	2	41	4,475	33
OH	2	41	108	45
MS	1	44	388	41
RI	1	44	154	44
WV	1	44	65	46
TN	-	47	-	47

Table 13. Numbers of water treatment plants for Texas CWS that incurred a health-based violation for nitrates-N during 2018-2020 by treatment objective. Inorganics removal objective also lists the treatment technology applied. Only six of the violating systems have active inorganics removal systems during this period.

PWSID	*PWS Name*	*Inorganics Removal*				*Corrosion Control*	*Disinfection*	*Other*
		RO	*Filt*	*Alum*	*Innov*			
TX0150040	ATASCOSA RURAL WSC						2	Iron Removal (1)
TX0230002	CITY OF QUITAQUE						1	
TX0270021	SILVER CREEK VILLAGE WSC		1				2	Taste/Odor Control (1)
TX0270047	CASSIE WS						2	
TX0270065	RIVER OAKS WS						1	
TX0390003	CITY OF BYERS						2	
TX0440001	WELLINGTON MUNICIPAL WS						1	
TX0440002	CITY OF DODSON						1	
TX0440018	RRA DODSON WS						2	
TX0480011	EOLA WSC				1		1	
TX0570082	D BAR B MOBILE HOME RANCH						2	
TX0580011	CITY OF ACKERLY						1	
TX0580013	WELCH WSC						1	
TX0580025	KLONDIKE ISD						1	Particulate Removal (1)
TX0680051	CANYON DAM MOBILE HOME PARK						1	
TX0680163	HUBER GARDEN ESTATES						1	
TX0780013	THALIA WSC						1	
TX0860080	ROYAL OAKS APARTMENTS						1	
TX0860136	BERNHARD TRAILER PARK						1	
TX0960001	RRA ESTELLINE TURKEY WS						1	
TX0960003	TURKEY MUNICIPAL WS						1	
TX0960014	LAKEVIEW WSC						1	Particulate Removal (1)
TX0990001	CITY OF CHILLICOTHE						2	
TX1100001	CITY OF ANTON						1	
TX1100011	WHITHARRAL WSC						1	

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

Table 13 (continued)

PWSID	PWS Name	Inorganics Removal				Corrosion Control	Disinfection	Other
		RO	Filt	Alum	Innov			
TX1260008	CITY OF KEENE						2	
TX1350001	RRA GUTHRIE DUMONT WS						1	
TX1380006	RRA TRUSCOTT GILLILAND WS						1	
TX1380011	CITY OF BENJAMIN	1					1	
TX1400010	SPADE WSC						1	
TX1520046	WILDWOOD MOBILE HOME VILLAGE						1	
TX1520080	FRANKLIN WSS 3						1	
TX1520247	COUNTRY VIEW MHP						1	
TX1520308	CHIPPER POINT APARTMENTS						1	
TX1530002	CITY OF TAHOKA						1	
TX1530003	CITY OF WILSON						1	
TX1530005	GRASSLAND WSC						1	
TX1590002	MARTIN COUNTY FWSD 1						1	
TX1650024	PECAN GROVE MOBILE HOME PARK						1	
TX1650048	GREENWOOD TERRACE MOBILE HOME						1	
TX1650057	TWIN OAKS MHP MIDLAND				1		1	
TX1650077	SOUTH MIDLAND COUNTY WSS						1	
TX1650084	WARREN ROAD SUBDIVISION WS						1	
TX1650111	COUNTRY VILLAGE MOBILE HOME ESTATES						1	Particulates (1)
TX1730003	FLOMOT WATER ASSOCIATION						1	
TX1770001	CITY OF ROSCOE	1				1	1	
TX1840018	LAZY BEND ESTATES						1	
TX2000002	CITY OF MILES						2	
TX2260008	CONCHO RURAL WATER GRAPE CREEK						1	
TX2400025	MIRANDO CITY WSC						1	
TX2440003	NORTHSIDE WSC						2	
TX2440005	RRA HINDS WILDCAT WS						2	

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

General Results

A total of 33,167 samples were analyzed for nitrate-N in the state between 1930 and July 2021. This dataset includes all raw water samples from various sectors from the TWDB well database, including those from public water systems. Data points overlying the major aquifers plus the Lipan minor aquifer were analyzed in this study. A total of 6,554 samples (20% of all groundwater nitrate-N data in this study) exceeded the secondary threshold of 4 mg/L while 2,631 samples (8%) had nitrate-N concentrations above the primary EPA MCL of 10 mg/L (Table 14).

Table 14. Summary of nitrate-N analyses in the TWDB database. Values represent the latest sample for wells sampled between 1930 and 2021.

Aquifer	*Aquifer Group*	*Total Number of Samples*	*Detects*	*Non-Detects*	*Nitrate-N >4 mg/L*		*Nitrate-N >10 mg/L*	
					Samples	*% of Total*	*Samples*	*% of Total*
Carrizo-Wilcox	Major	3868	1619	2249	156	4.03	71	1.84
Edwards BFZ	Major	1465	1235	230	138	9.42	24	1.64
Edwards-Trinity Plateau	Major	5162	4482	680	1013	19.62	176	3.41
Gulf Coast	Major	6916	4641	2275	1030	14.89	315	4.55
Hueco-Mesilla Bolson	Major	547	479	68	45	8.23	7	1.28
Ogallala	Major	6439	6224	215	1326	20.59	419	6.51
Pecos Valley	Major	661	592	69	137	20.73	59	8.93
Seymour	Major	2199	2149	50	1840	83.67	1202	54.66
Trinity	Major	5763	3860	1903	779	13.52	294	5.10
Lipan	Minor	147	141	6	90	61.22	64	43.54
Total		33167	25422	7745	6554	19.76	2631	7.93

The Seymour and Lipan aquifers had the greatest percentages of samples exceeding the EPA MCL (54.66% and 43.54%, respectively), followed by the Pecos Valley (8.93%), and Ogallala (6.51%) aquifers. The remaining aquifers had from 0.07% to 0.53% of samples above the MCL. Similarly, the Seymour and Lipan aquifers had by far the greatest percentage of their samples exceeding the secondary nitrate-N threshold of 4 mg/L, with 83.67% and 61.22%, respectively. The Pecos Valley, Ogallala, and Edwards-Trinity Plateau all had exceedance percentages of approximately 20%.

With the large number of samples available, two statewide maps were made representing the probability of nitrate-N exceeding the 4 mg/L and 10 mg/L nitrate-N threshold concentrations (Figure 11). The results are generally consistent with the individual aquifer maps with the added benefit of gaining an overall impression of the nitrate-N distribution in Texas groundwater.

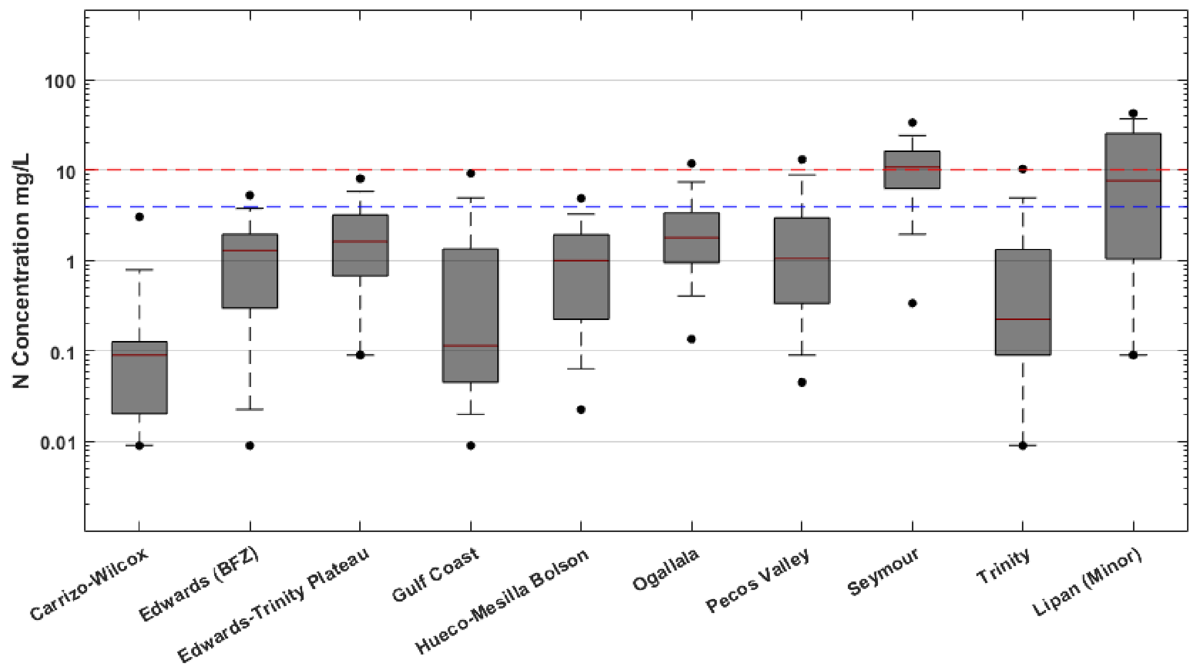

Figure 10. Distribution of groundwater nitrate-N concentrations in the individual major aquifers (plus Lipan) of Texas. The lines inside the shaded boxes represent the 50th percentiles (medians), the shaded boxes represent the 25th to 75th percentile ranges, the upward and downward lines extending from the boxes are terminated by horizontal lines at the 10th and 90th percentiles, and the points represent the 5th and 95th percentiles. Reference lines are shown at the 4 mg/L and 10 mg/L threshold values.

Based on the EPA database, 35 CWS were not compliant with the MCL of 10 mg/L, 34 in major aquifers (nitrate-N violations Table 16) and 1 in the Lipan minor aquifer. Most noncompliant systems were sourced from the Ogallala aquifer (18, 51% of total).

A total of 32,116 people are served by 35 PWSs that have been non-compliant with respect to the nitrate-N MCL (10 mg/L) in at least one of the last 12 quarters (Jan 2018 – Dec 2020) representing 0.11% of the 2020 Texas total population (28,747,430, Figure 12, Table 3). Most (91%, 29,024 people, Table 16) are associated with PWSs that source their water from the Ogallala, Trinity, or Edwards BFZ, or Lipan aquifers, while the Seymour supplies a further 2,237 people (7%). Furthermore, ~287,518 people are served by PWSs we consider at-risk for nitrate-N >4 mg/L, representing nearly 1% of the Texas population (Table 16).

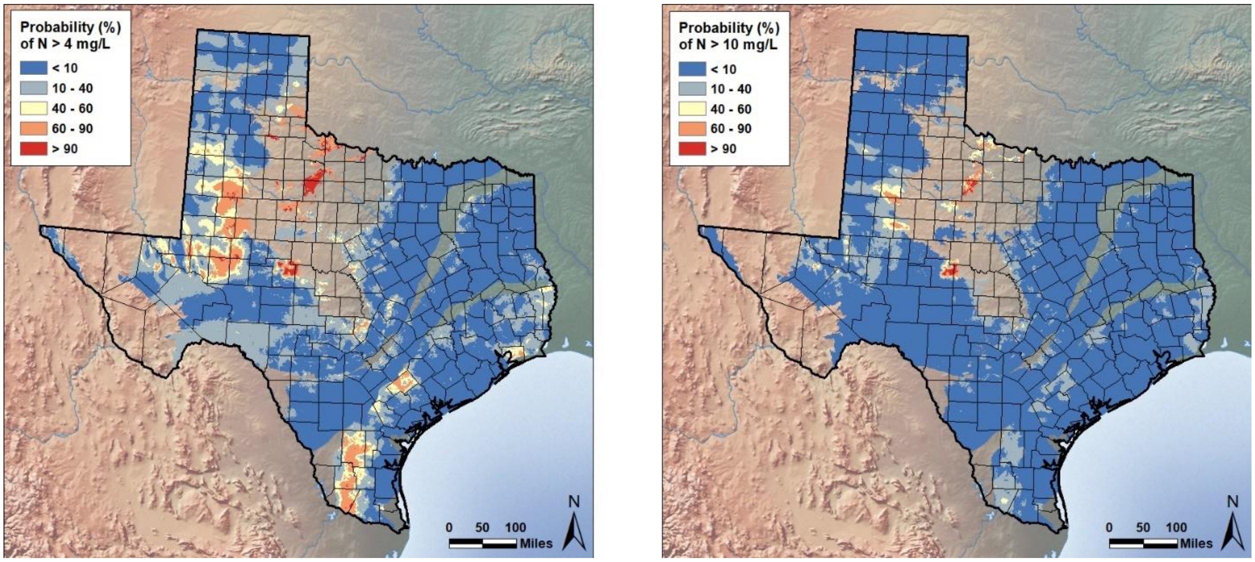

Figure 11. Statewide probability of groundwater N a) >4 mg/L, b) >10 mg/L based on the latest concentration data by well from the original study (1930 – 2021), including 33,167 samples TWDB data. The images are a composite of data from all named major aquifers in Texas and the Lipan aquifer.

Table 15. Summary of CWSs with a nitrate-rule violation between 2018-2020 with persistence of nitrate rule violations per quarter. No. of quarters refers to quarters that CWSs are noncompliant.

PWS ID	*PWS Name*	*Po. Served*	*Aquifer Name*	*No. of Quarters*	*2018*				*2019*				*2020*			
					1	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
TX1650077	SOUTH MIDLAND COUNTY WSS	165	Ogallala	12	■	■	■	■	■	■	■	■	■	■	■	■
TX1530005	GRASSLAND WSC	55	Ogallala	10	■	■	■	■	■	■		■		■	■	■
TX1650111	COUNTRY VILLAGE MH ESTATES	138	Ogallala	10	■	■	■		■		■	■	■	■	■	■
TX1520080	FRANKLIN WSS 3	159	Ogallala	9	■	■		■	■	■		■	■	■	■	
TX0580013	WELCH WSC	315	Ogallala	9	■		■	■	■	■		■		■	■	■
TX1100011	WHITHARRAL WSC	200	Ogallala	9	■	■		■	■	■		■		■	■	■
TX0680051	CANYON DAM MH PARK	108	Trinity	9	■			■	■		■	■	■	■	■	■
TX1650048	GREENWOOD TERRACE MH Sub.	120	Ogallala	9	■		■		■		■	■	■	■	■	■
TX1650057	TWIN OAKS MHP MIDLAND	234	Ogallala	8	■		■		■		■	■	■	■	■	
TX1590002	MARTIN COUNTY FWSD 1	54	Ogallala	7	■	■	■			■		■			■	■
TX0990001	CITY OF CHILLICOTHE	707	Seymour	6				■	■	■		■	■	■		
TX1380011	CITY OF BENJAMIN	258	Seymour	6				■	■			■	■	■	■	
TX0580025	KLONDIKE ISD	264	Ogallala	4	■	■	■	■								
TX0440002	CITY OF DODSON	109	Seymour	4	■		■	■						■		
TX1520046	WILDWOOD MH VILLAGE	672	Ogallala	4				■	■	■		■				
TX0860080	ROYAL OAKS APARTMENTS	57	Trinity	3										■	■	■
TX1650084	WARREN Rd. SUBDIVISION WS	195	Edwards-Trinity	2		■									■	
TX1380006	RRA TRUSCOTT GILLILAND WS	176	Seymour	2	■		■									
TX0960014	LAKEVIEW WSC	98	Seymour	2	■										■	
TX1530003	CITY OF WILSON	489	Ogallala	2					■							■
TX0580011	CITY OF ACKERLY	245	Ogallala	2	■									■		
TX1530002	CITY OF TAHOKA	2585	Ogallala	2		■									■	
TX1520247	COUNTRY VIEW MHP	54	Ogallala	1	■											
TX0390003	CITY OF BYERS	496	Seymour	1	■											
TX0780013	THALIA WSC	135	Seymour	1	■											
TX1650024	PECAN GROVE MOBILE HOME	336	Ogallala	1	■											
TX0150040	ATASCOSA RURAL WSC	11007	Edwards	1	■											
TX0960001	RRA ESTELLINE TURKEY WS	250	Seymour	1				■								
TX1100001	CITY OF ANTON	1126	Ogallala	1											■	
TX1260008	CITY OF KEENE	6310	Trinity	1		■										
TX1400010	SPADE WSC	125	Ogallala	1								■				
TX1730003	FLOMOT WATER ASSOCIATION	50	Seymour	1											■	
TX1840018	LAZY BEND ESTATES	171	Trinity	1					■							
TX2260008	CONCHO RURAL WATER GRAPE	5049	Lipan	1					■							
TX2400025	MIRANDO CITY WSC	460	Gulf Coast	1	■											

Table 16. Numbers of PWSs with N concentrations greater than 4 mg/L and greater than the primary MCL (>10 mg/L). The populations shown are those associated with Community Water Systems (PWSs). The numbers of non-community water systems are also shown.

Aquifer	*TCEQ Database CWS Systems N >4 mg/L*			*EPA Non-compliant CWS Systems N >10 mg/L*	
	Number of NCWS	*CWS*	*CWS At-risk Population*	*CWS*	*Population*
Carrizo-Wilcox	2	5	42,506	-	-
Edwards BFZ	1	5	20,867	1	11,007
Edwards-Trinity Plateau	21	10	9,089	1	195
Gulf Coast	14	11	54,682	1	460
Hueco-Mesilla Bolson		3	6,109	-	-
Ogallala	71	81	64,670	18	7,017
Pecos Valley	1	-	-	-	-
Seymour	17	12	3,330	9	2,237
Trinity	8	22	70,107	4	6,631
Lipan (Minor)	4	4	16,158	1	4,569
Total		153	287,518	35	32,116
Percent of 2020 pop.			0.99		0.09

Based on the aquifer GIS analyses coupled with the USGS county water use population data for 2015, an estimated total of 46,069 people, representing about 0.16% of the estimated 2020 Texas total population (28,747,430), are served by non-PWSs with nitrate-N concentrations above the 10 mg/L MCL threshold (Table 17). As with the PWSs, these are predominantly major aquifer non-PWSs (91%, 41,928 people), with generally smaller populations associated with the Lipan (minor) aquifer system (9%, 4,141 people). Thus, the Texas population served by either PWS or non-PWSs with nitrate-N concentrations above the MCL is estimated at about 77,985 people, representing about 0.25% of the 2020 Texas total population.

A total of 153 PWSs had nitrate-N levels greater than the secondary concentration threshold of 4 mg/L, more than four times greater than the 35 PWSs exceeding 10 mg/L. Most (97%) of the PWS violations for the secondary threshold (149) are sourced from major aquifers (Table 16). The population served by these secondary threshold noncompliant PWSs is ~ 287,518 people, ~ 1% of the estimated 2020 population. A total of 137,163 people outside of the PWSs have water sources that exceed the secondary threshold of 4 mg/L. Based on the TCEQ database and the rural supply analysis, a total of 424,681 people (about 1.46% of the estimated 2020 Texas total population) have water with nitrate-N concentrations above the secondary threshold of 4 mg/L (this includes the MCL violations).

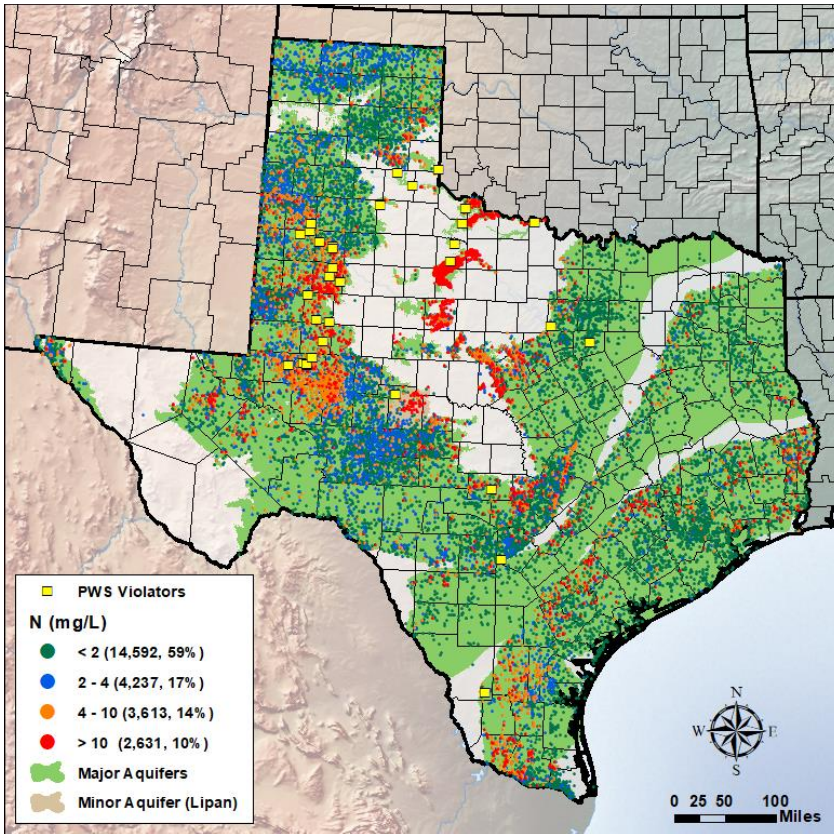

Figure 12. Locations of 35 community water systems that have health-based non-compliance violations for nitrate-N concentrations in distributed water based on the EPA SDWIS database (12 quarters, Jan 2018 – Dec 2020). The violating systems are located primarily in the southern Ogallala, Seymour, and Edwards-Trinity Plateau aquifers.

Table 17. Texas populations served by PWS (community water systems) and non-PWSs with nitrate-N concentrations >4 mg/L and >10 mg/L MCL. The percent of the 2020 US Census population of Texas is also provided (29,536,916 people).

Water Source	*CWS Population*		*Non-PWS Population*		*PWS & Non-PWS Population*	
	N >4 mg/L	*N >10 mg/L*	*N >4 mg/L*	*N >10 mg/L*	*N >4 mg/L*	*N >10 mg/L*
All Major Aquifers	271,360	27,347	131,060	41,928	402,420	69,275
Lipan Aquifer (Minor)	16,158	4,569	6,103	4,141	22,261	8,710
Total	287,518	32,116	137,163	46,069	424,681	77,985
% of 2020 Population	0.99	0.11	0.47	0.16	1.46	0.27

Major Aquifers Results

There were sufficient data to perform indicator kriging on nitrate-N concentrations for all nine of the major aquifers, along with the Lipan Aquifer (minor) in Texas. There were 33,167 groundwater samples in the aquifers and of the major aquifer samples, 77% (25,422) had detectable concentrations while 33% (7,745) had non-detectable concentrations (Table 14). A total of 20% (6,554) of the aquifer samples exceeded nitrate-N concentration of 4 mg/L and 8% (2,631) samples exceeded the MCL of 10 mg/L. All of the studied aquifers had at least seven samples with nitrate-N >4 mg/L. Median detected nitrate-N concentrations ranged from 0.09 mg/L in the Carrizo-Wilcox aquifer to 10.84 mg/L in the Seymour aquifer (Table 18). Median detected concentrations were ≤2 mg/L in all but the Ogallala, Lipan, and Seymour aquifers.

Table 18. Distributions of N concentrations above detection limits for the major + Lipan 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*
Carrizo-Wilcox	1,619	0.90	0.001	0.01	0.01	0.02	0.09	0.13	0.79	3.03	230.41
Edwards BFZ	1,235	1.74	0.002	0.01	0.02	0.30	1.30	1.96	3.80	5.27	26.20
Edwards-Trinity Plateau	4,482	2.83	0.005	0.09	0.09	0.68	1.63	3.21	5.87	8.13	255.26
Gulf Coast	4,641	2.22	0.002	0.01	0.02	0.05	0.12	1.36	4.97	9.26	224.54
Hueco-Mesilla Bolson	479	1.52	0.002	0.02	0.06	0.23	1.00	1.94	3.22	4.89	29.00
Ogallala	6,224	3.33	0.002	0.14	0.41	0.95	1.81	3.39	7.46	11.88	361.43
Pecos Valley	592	3.55	0.002	0.05	0.09	0.34	1.06	2.98	8.58	13.10	174.68
Seymour	2,149	13.82	0.050	0.34	1.99	6.33	10.84	16.26	24.40	33.88	336.59
Trinity	3,860	2.87	0.002	0.01	0.01	0.09	0.23	1.33	4.97	10.37	505.00
Lipan	141	14.61	0.002	0.09	0.09	1.07	7.71	25.37	37.25	42.32	85.26
Total	25,422										

The TCEQ database lists 7,065 active PWSs in Texas, including 4,657 community water systems and 1,533 non-community water systems. During the period Jan 2018 – Dec 2018, a total of 292 community water systems (4.1%) with distribution water derived at least in part from one of the aquifers in this study had nitrate-N >4 mg/L. This includes 153 community water systems with an associated population of about 287,518 people (Table 16).

Based on the EPA database, 35 community water systems had non-compliant water samples with nitrate-N >10 mg/L in the studied aquifers, with a total associated population of about 32,116 people (Table 16). The most affected populations are located in the Southern High Plains area (Ogallala aquifer), the community of Atascosa (Edwards BFZ aquifer), and Johnson County (Trinity aquifer).

Table 19. Estimated non-PWS populations at risk of groundwater N concentrations >4 mg/L and >10 mg/L US EPA MCL in the Major Aquifers. The populations shown are estimated from the GIS map mean county-by-county probability multiplied by the estimated non-PWS population.

Aquifer	*Total Non-PWS Population*	*At-Risk N >4 mg/L*		*At-Risk N >10 mg/L*	
		Population	*% of Total*	*Population*	*% of Total*
Carrizo-Wilcox	332,651	5,875	1.77	2,710	0.81
Edwards (BFZ)	178,918	3,763	2.10	847	0.47
Edwards-Trinity Plateau	152,877	19,239	12.58	3,172	2.07
Gulf Coast	447,168	35,896	8.03	12,503	2.80
Hueco-Mesilla Bolson	16,413	1,427	8.69	97	0.59
Ogallala	154,377	34,013	22.03	8,985	5.82
Pecos Valley	36,571	4,374	11.96	1,952	5.34
Seymour	19,349	2,461	12.72	1,594	8.24
Trinity	486,382	24,011	4.94	10,067	2.07
Lipan (Minor)	37,753	6,103	16.16	4,141	10.97
Total	1,862,459	137,163	7.36	46,069	2.47
% of 2020 Texas Population	6.39	0.47		0.16	

Table 20. Percent of total aquifer area in each probability category for groundwater nitrate-N concentrations to exceed 4 mg/L and 10 mg/L, as estimated by the GIS analysis.

Category	Probability %	*Percent Aquifer Area*																			
		Carrizo-		*Edwards BFZ*		*Edwards-*		*Gulf Coast*		*Hueco-*		*Ogallala*		*Pecos Valley*		*Seymour*		*Trinity*		*Lipan*	
		N > 4 mg/L	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*	*N > 4 mg/L*	*N > 10 mg/L*
Very Low	< 10	90	96	78	96	42	89	56	80	61	99	44	82	20	57	0	4	76	88	17	56
Low	10-40	10	4	18	4	48	11	29	20	37	1	38	15	51	40	2	40	21	11	42	16
Moderate	40-60	0	0	3	0	5	0	9	0	2	0	11	3	21	3	8	28	3	0	10	8
High	60-90	0	0	1	0	4	0	6	0	0	0	8	1	9	0	62	22	1	0	18	12
Very High	> 90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	5	0	0	14	8

Carrizo-Wilcox Aquifer

The Carrizo-Wilcox aquifer covers 36,800 mi^2 in Texas extending from the international border with Mexico in south central Texas to the Arkansas/Louisiana border in northeast Texas (Figure 1, Figure 13 The aquifer underlies all or parts of 65 counties in Texas. It is composed of the Wilcox Group and the overlying Carrizo Formation of the Claiborne Group. The aquifer is up to 3,000 ft in thick locally and the total thickness of sands saturated with fresh water is about 670 ft.

There were 3,868 samples analyzed for N with 2,249 samples (58%) having non-detectable concentrations. The probability of N exceeding 4 mg/L is very low over most (90%) of the aquifer area with only 10% of the aquifer area primarily in south and south-central Texas down-dip reaches generally having a low probability of nitrate-N >4 mg/L (Table 20). The highest probabilities are located in several small hotspots along the northwest (up-dip) boundary. Probabilities of nitrate-N concentrations exceeding 10 mg/L are very low. The median concentration of samples with detectable concentrations is 0.09 mg/L and the 5^{th}-95^{th} percentile range is 0.01–3.03 mg/L. Only 71 total samples exceeded the MCL with a concentration of 10 mg/L, representing <1 % of the total number of samples taken.

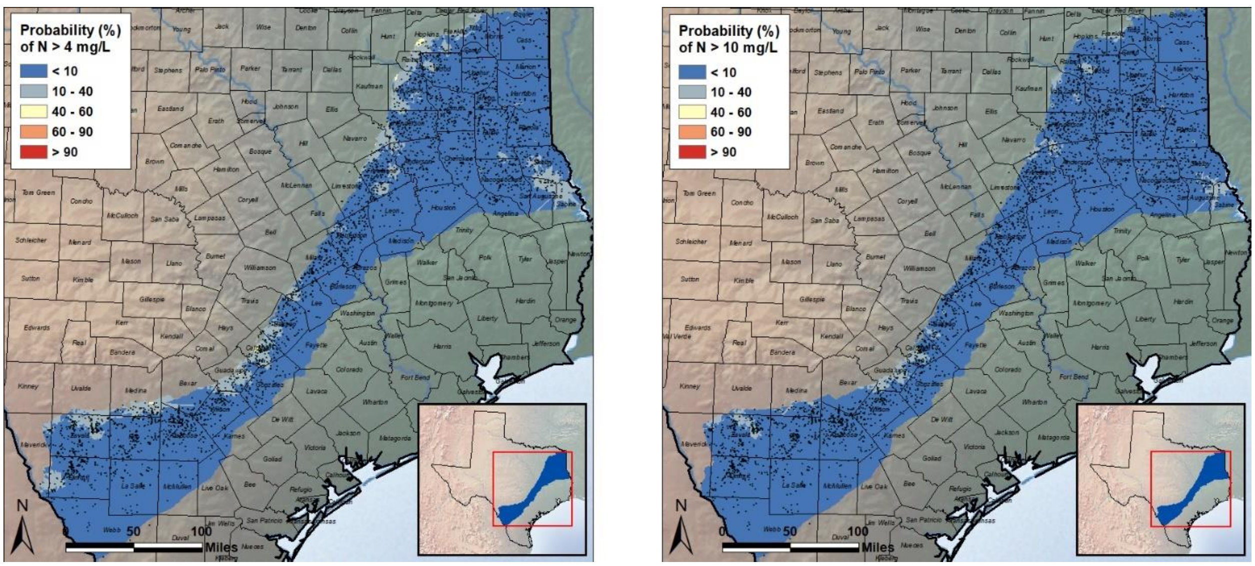

Figure 13. Carrizo-Wilcox aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Based on the TCEQ PWS database, a total of 7 PWSs had nitrate-N concentrations >4 mg/L, 5 of which are community water systems, with a population of 42,506 people. Based on the EPA PWS database, there were no community water systems that were non-compliant for nitrate-N with concentrations above 10 mg/L.

Edwards (Balcones Fault Zone) Aquifer

The Edwards BFZ aquifer covers 4,300 mi^2 in Texas skirting the eastern and southern boundaries of the Llano Uplift in south central Texas (Figure 1, Figure 14). The aquifer underlies parts of 13 counties in Texas. It composed of the Edwards Limestone and is highly permeable due to dissolution of the unit.

There were 1,465 samples analyzed for N during the study period with 230 samples (15%) having non-detectable concentrations. Most (78%) of the aquifer area has a very low probability of nitrate-N >4 mg/L. About 18% of the area having low probabilities and only 4% having moderate to high probabilities in the northern portion of the aquifer. No portion of the aquifer has more than a 40% probability of nitrate-N above the MCL of 10 mg/L (Table 20). The median concentration of samples with detectable concentrations is 1.3 mg/L and the 5th-95th percentile range is 0.01–5.27 mg/L. A total of 24 samples (0.07%) exceeded the MCL with a range of concentrations from 10.1 to 26.4 mg/L, mostly in the far down-dip regions in the north.

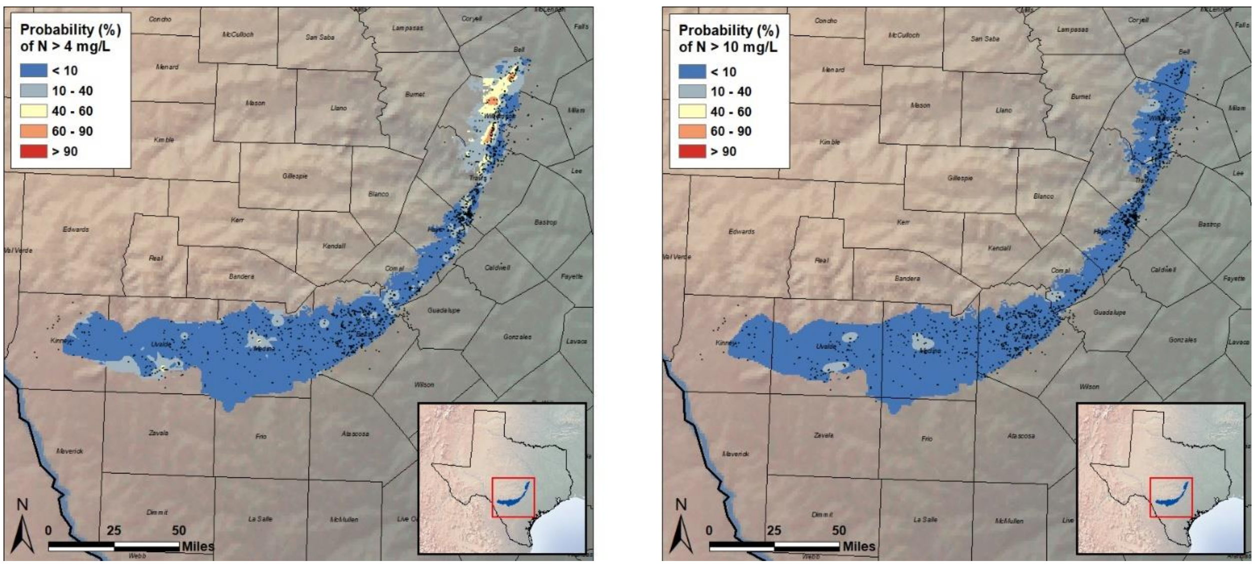

Figure 14. Edwards (BFZ) aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 21. Edwards (BFZ) aquifer PWSs with violations for nitrate-N concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
TX0150040	ATASCOSA RURAL WSC	CWS	SW	1	1-2018	11,007

Based on the TCEQ PWS database, a total of 6 PWSs are impacted by nitrate-N concentrations >4 mg/L, including 5 community water systems and 1 non-community water systems. The community water systems are associated with an estimated population of 20,867 people. Based on the EPA PWS database, there is 1 community water system non-compliant for nitrate-N with concentrations above 10 mg/L with a population of 11,007 people (Table 21).

Edwards-Trinity Plateau Aquifer

The Edwards-Trinity Plateau aquifer covers 35,400 mi^2 in Texas including the southern area of the Llano Uplift in south central Texas west to the Pecos River and south to the international border with Mexico (Figure 1, Figure 15). The aquifer underlies all or parts of 40 counties in Texas. Most of the aquifer area (32,400 mi, 92%) is unconfined. Two areas underlie other major aquifers including 1,500 mi^2 (4%) beneath the Pecos Valley Alluvium aquifer and 1,140 mi^2 (3%) beneath the Ogallala aquifer. The aquifer is composed of limestones and dolomites of the Edwards Group and sands in the underlying Trinity Group. Saturated thickness averages 430 ft and is locally greater than 800 ft.

There were 5,162 samples analyzed for N with 680 samples (13%) having non-detectable concentrations. About 90% of the aquifer has a very low to low probability of nitrate-N >4 mg/L with a localized area of moderate to very high probabilities (40% - 100%) in the north-central portion of the aquifer (Midland, Glasscock, Upland, and Ector counties) that comprises 10% of the aquifer area. Probabilities of nitrate-N concentrations >10 mg/L are generally very low throughout, and no portion of the aquifer has an exceedance probability greater than 40% (Table 20). The median concentration of samples with detectable concentrations is 1.63 mg/L and the 5th-95th percentile range is 0.09–8.13 mg/L. A total of 176 samples (0.53%) exceeded the MCL with a range of concentrations from 10.1 mg/L to 225.26 mg/L that are located primarily in the north-central region of the aquifer.

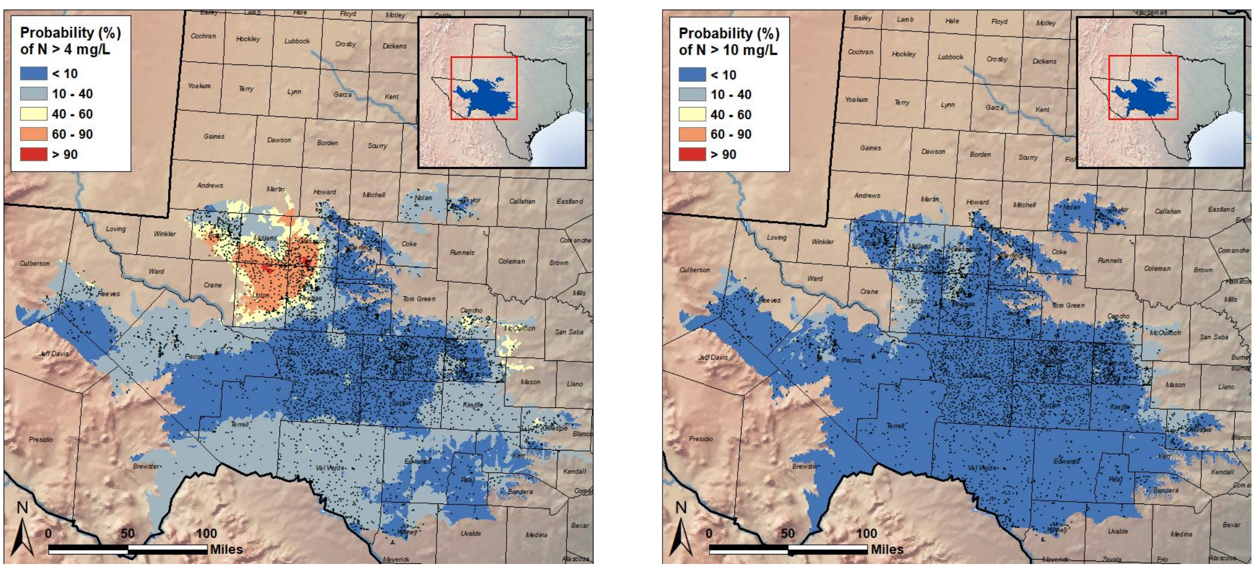

Figure 15. Edwards-Trinity Plateau aquifer probability distribution of nitrate-N >4 mg/L (left) and >10 mg/L (right).

Table 22. Edwards-Trinity Plateau aquifer PWSs with violations for nitrate-N concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
TX1650084	WARREN ROAD SUBDIVISION WATER SUPPLY	CWS	GW	2	3-2020	195

Based on the TCEQ PWS database, a total of 10 PWSs are impacted by nitrate-N concentrations >4 mg/L, including 11 non-community water systems and 10 community water systems with a population of 9,089 people. Based on the EPA PWS database, there is 1 community water system non-compliant for nitrate-N with concentrations above 10 mg/L with a population of 195 people (Table 21).

Gulf Coast Aquifer System

The Gulf Coast aquifer is a complex system that covers 40,500 mi^2 in Texas extending in a 100-120 mile-wide arc along the entire Texas Gulf Coast from the international border with Mexico to Louisiana (Figure 1, Figure 16). The aquifer underlies all or parts of 56 counties in Texas. The Gulf Coast aquifer is composed of three primary subunits, including from oldest to youngest the Jasper, Evangeline, and Chicot aquifers which outcrop in the most inland areas toward the coast, respectively. Conditions in the aquifer range from unconfined to semi-confined to confined in different areas and depths. Fresh water saturated thickness averages about 1,000 ft.

There were 1,465 samples analyzed for N during the study period with 230 samples (16%) having non-detectable concentrations. Nitrate-N occurrence in the Gulf Coast aquifer is generally located in the south and up-dip along the northwest boundary of the aquifer. In addition, a localized area of moderate to high probabilities is located in Chambers County. About 56% of the aquifer area has a very low probability of nitrate-N >4 mg/L and a further 29% with a low probability. Only about 15% of the aquifer area has probabilities that exceed 40%. Probabilities of nitrate-N concentrations of over 10 mg/L are generally very low, with 80% of the aquifer area having no to very low probability (Table 20). The median of samples with detectable concentrations is 0.5 mg/L and the 5th-95th percentile range is 0.01–9.26 mg/L. A total of 71 (0.95%) samples exceeded the MCL of 10 mg/L with a range of concentrations from 10.1 to 224.5 mg/L.

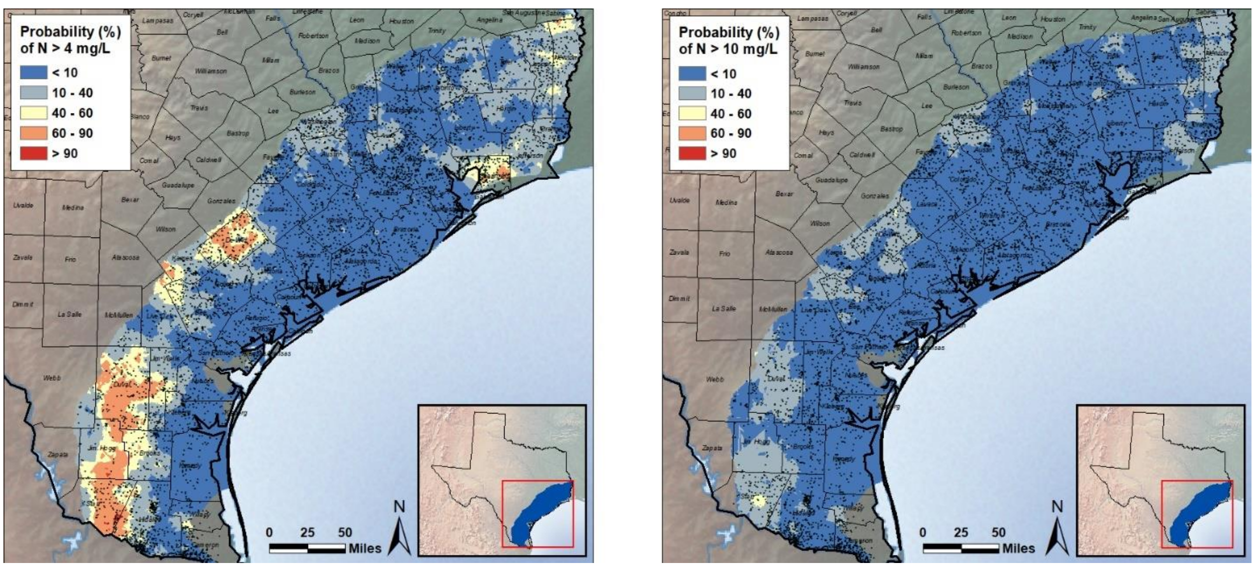

Figure 16. Gulf Coast aquifer system probability distribution of nitrate-N >4 mg/L (left) and >10 mg/L (right).

Table 23. Gulf Coast aquifer PWSs with violations for Nitrate-N concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
TX2400025	MIRANDO CITY WSC	CWS	GW	1	1-2018	460

Based on the TCEQ PWS database, a total of 25 PWSs are impacted by nitrate-N concentrations >4 mg/L, including 14 non-community water systems and 11 community water systems with a population of 54,682 people. Based on the EPA PWS database, there is 1 community water system non-compliant for nitrate-N with concentrations above 10 mg/L with a population of 465 people (Table 23).

Hueco-Mesilla Bolson Aquifer

The Hueco-Mesilla Bolson aquifer covers 1,400 mi^2 in Texas adjacent to the international border with Mexico in El Paso and Hudspeth counties (Figure 1, Figure 17). The aquifer is composed of basin fill deposits derived from surrounding uplifted areas including the Franklin Mountains in two bolsons, including the Hueco Bolson with a thickness up to 9,000 ft and the Mesilla Bolson with a thickness up to 2,000 ft.

There were 547 samples analyzed for nitrate-N during the study period with 68 samples (12%) having non-detectable concentrations. The Hueco-Mesilla Bolson aquifer is poorly sampled in its southern reaches in Hudspeth County, but available samples indicate that nitrate-N concentrations tend to be very low in the south. About 99% of the aquifer area has very low probabilities of nitrate-N concentrations >10 mg/L. About 61% of the area has very low to low probabilities of nitrate-N >4 mg/L, with an area of elevated probabilities (>40%) that lay in the east/central portion of El Paso county (Table 20). The median concentration of samples with detectable concentrations is 1.00 mg/L and the 5^{th}-9^{th} percentile range is 0.02–4.89 mg/L. A total of 7 samples (0.02%) exceeded the MCL with a range of concentrations from 10.1 mg/L to 29.0 mg/L.

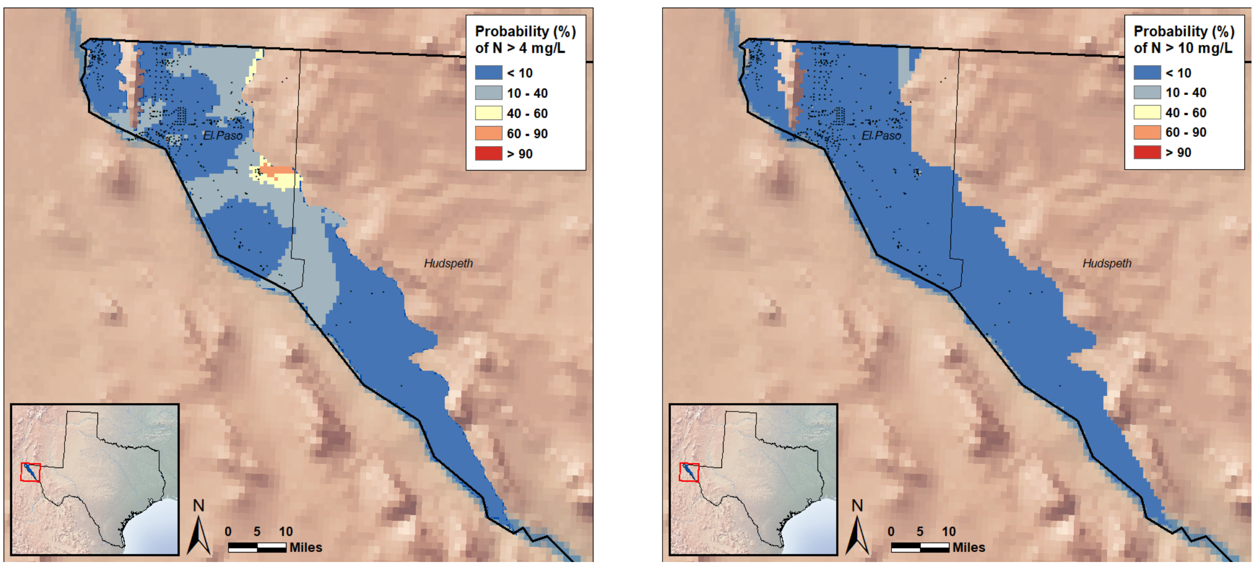

Figure 17. Hueco-Mesilla Bolson aquifer probability distribution of nitrate-N >4 mg/L (left) and >10 mg/L (right).

Based on the TCEQ PWS database, a total of 3 PWSs are impacted by nitrate-N concentrations >4 mg/L, all community water systems with a total population of 6,109 people. Based on the EPA PWS database, there are no community water systems non-compliant for nitrate-N with concentrations above 10 mg/L.

Ogallala Aquifer

The Ogallala aquifer covers 36,300 mi^2 in Texas extending across most of the panhandle and southward to Midland. The aquifer underlies all or parts of 49 counties in Texas (Figure 1, Figure 18). The Ogallala in Texas is part of the High Plains Aquifer System, the largest in the United States. It consists primarily of unconsolidated sediments ranging from clay to gravel and has a thickness up to about 800 ft. Thickness varies by region and the thickness is much less (150-300 ft) in the southern areas. The Ogallala is in hydraulic contact with the Pecos Valley aquifer to the southwest and also with the underlying Edwards-Trinity (High Plains), Dockum, and Rita Blanca aquifers.

There were 6,439 samples analyzed for N during the study period with only 215 samples (3%) having non-detectable concentrations. Nitrate-N occurrence is widespread in the Ogallala aquifer and concentrations are notably higher in the southern areas. About 44% of the area has a very low probability of nitrate-N >4 mg/L and a further 38% has a low probability. About 19% of the total aquifer area has moderate to high probabilities, generally located in the southern region of the aquifer. About 4% of the aquifer area has elevated (>40%) probabilities of nitrate-N exceeding the MCL of 10 mg/L, located primarily in Martin, Howard, Lynn, and Borden counties. The median concentration of samples with detectable concentrations is 1.81 mg/L and the 5th-95th percentile range is 0.14–11.88 mg/L. A total of 419 samples (1.26) exceeded the MCL with a range of concentrations between 10.1 mg/L and 361.43 mg/L.

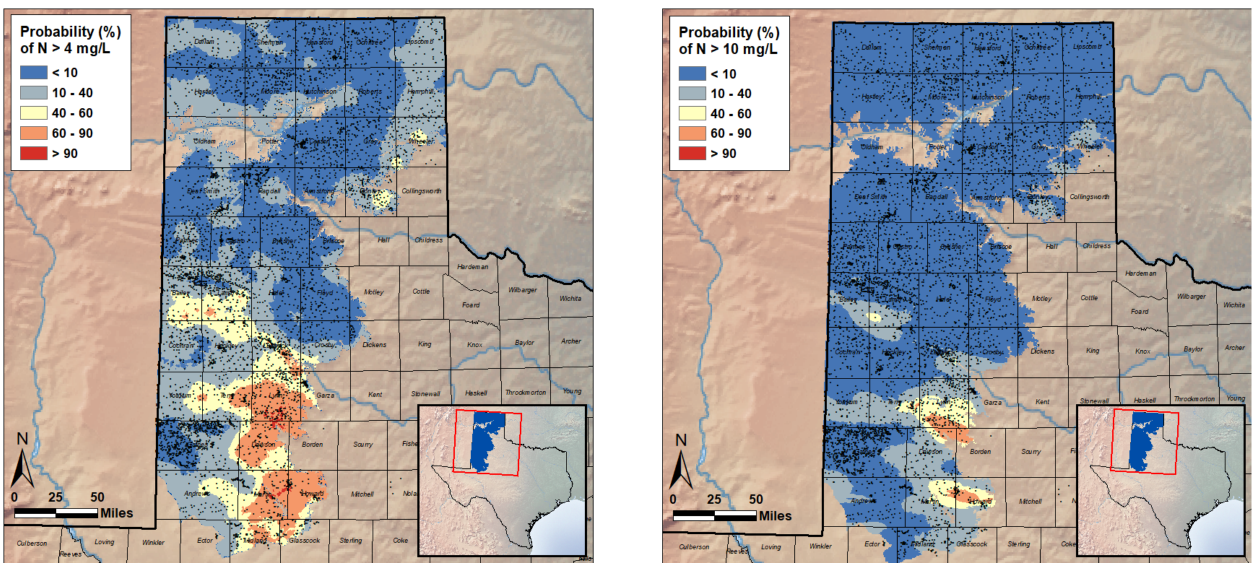

Figure 18. Ogallala aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

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

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*	*Co-Contaminants*
TX1530002	CITY OF TAHOKA	CWS	SW	2	3-2020	2585	none
TX1100001	CITY OF ANTON	CWS	GW	1	3-2020	1126	none
TX1530003	CITY OF WILSON	CWS	GW	2	4-2020	489	none
TX1650024	PECAN GROVE MOBILE HOME PARK	CWS	GW	1	1-2018	336	none
TX0580013	WELCH WSC	CWS	GW	9	4-2020	315	As
TX0580025	KLONDIKE ISD	CWS	GW	4	4-2018	264	As, Ra, F
TX1520046	WILDWOOD MOBILE HOME VILLAGE	CWS	GW	4	4-2019	250	none
TX0580011	CITY OF ACKERLY	CWS	GW	2	2-2020	245	none
TX1650057	TWIN OAKS MHP MIDLAND	CWS	GW	8	3-2020	234	none
TX1100011	WHITHARRAL WSC	CWS	GW	9	4-2020	200	F
TX1650077	SOUTH MIDLAND COUNTY WATER SYSTEMS	CWS	GW	12	4-2020	165	As
TX1520080	FRANKLIN WATER SYSTEMS 3	CWS	GW	9	3-2020	159	none
TX1650111	COUNTRY VILLAGE MOBILE HOME ESTATES	CWS	GW	10	4-2020	138	none
TX1400010	SPADE WSC	CWS	GW	1	4-2019	125	none
TX1650048	GREENWOOD TERRACE MOBILE HOME SUBDIVISIO	CWS	GW	9	4-2020	120	none
TX1520247	COUNTRY VIEW MHP	CWS	GW	1	1-2018	55	As, Ra
TX1530005	GRASSLAND WSC	CWS	GW	10	4-2020	55	As, F
TX1590002	MARTIN COUNTY FWSD 1	CWS	GW	7	4-2020	54	none

System Type: Community water system (CWS)

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

Based on the TCEQ PWS database, a total of 153 PWSs are impacted by nitrate-N concentrations >4 mg/L, including 71 non-community water systems and 81 community water systems with a total population of 64,670 people. Based on the EPA PWS database, there are 18 community water systems non-compliant for nitrate-N with concentrations above 10 mg/L with a total population of 6,817 people (Table 24).

Pecos Valley Aquifer

The Pecos Valley aquifer covers 6,800 mi^2 extending across parts of 12 counties in west Texas (Figure 1, Figure 19). The Pecos Valley consists of alluvial and aeolian deposits that locally reach up to 1,500 thick with an average saturated thickness of about 250 ft.

There were 661 samples analyzed for nitrate-N during the study period with 69 samples (10%) having non-detectable concentrations. Elevated nitrate-N concentrations are widespread around several regional hotspots. About 51% of the aquifer area has a low probability of nitrate-N >4 mg/L, and 9% of the aquifer area has a high probability. For nitrate-N concentrations greater than the MCL of 10 mg/L, 57% of the aquifer area has very low probabilities and 40% of the area has low probabilities, primarily located around regional hotspots. The spatial pattern of probabilities displays artifacts of limited data density in some areas. The median concentration of samples with detectable concentrations is 1.06 mg/L and the 5th-95th percentile range is 0.05–13.1 mg/L. A total of 59 samples (0.18%) exceeded the MCL with a range of concentrations from 10.1 mg/L to 174.7 mg/L.

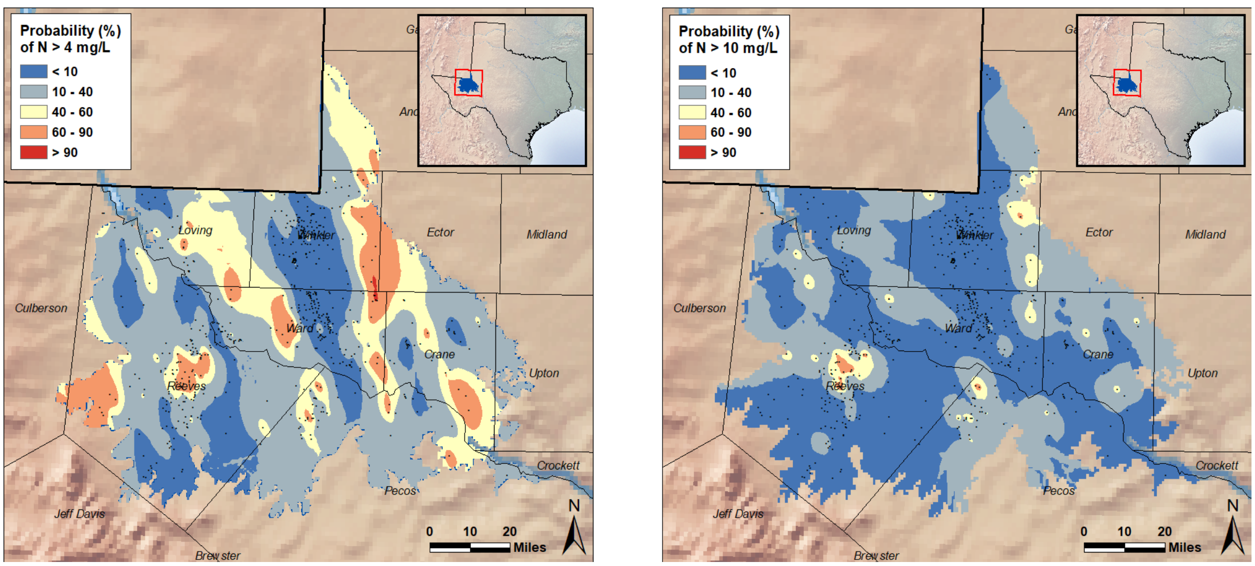

Figure 19. Pecos Valley aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Based on the TCEQ PWS database, only 1 water system is impacted by nitrate-N concentrations >4 mg/L, a non-community water system. Based on the EPA PWS database, there are no PWSs impacted by nitrate-N concentrations >10 mg/L.

Seymour Aquifer

The Seymour aquifer covers 3,400 mi^2 and is present as a series of isolated pods that extending across parts of 23 counties in north central Texas (Figure 1, Figure 20). The aquifer consists of conglomerate, gravel, sands, and silty sands ranging up to 360 ft thick. Most of the aquifer is affected by high nitrate-N concentrations.

There were 2,199 samples analyzed for nitrate-N with only 50 samples (2%) having non-detectable concentrations. Nitrate-N probabilities are elevated throughout the aquifer. About 90% of the aquifer area has greater than high to very high probabilities for nitrate-N >4 mg/L. For nitrate-N concentrations above the MCL of 10 mg/L, 27% of the aquifer area has probabilities greater than 60% (moderate to very high). The highest probabilities tend to occur in the central portion of the aquifer in Knox and Haskell counties (Table 20). The median concentration of samples with detectable concentrations is 10.84 mg/L and the 5^{th}-95^{th} percentile range is 0.34–33.8 mg/L. A total of 1202 samples (3.62%) exceeded the MCL with a range of concentrations from 10.1 mg/L to 336.59 mg/L.

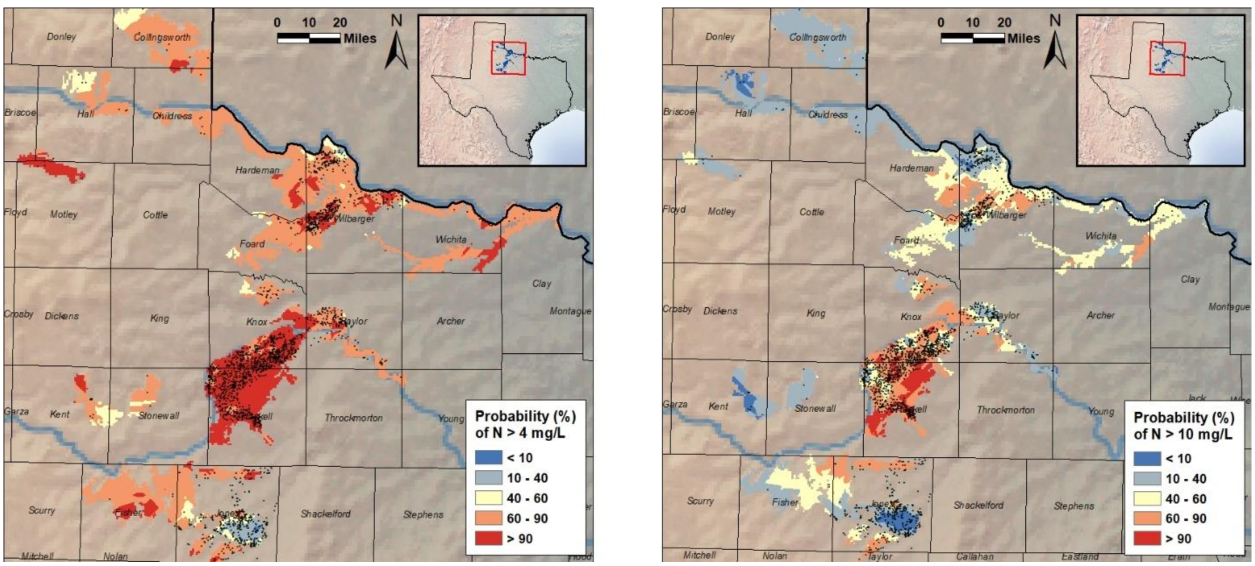

Figure 20. Seymour aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 25. Seymour aquifer PWSs with violations for nitrate-N concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
TX0990001	CITY OF CHILLICOTHE	CWS	SW	6	2-2020	707
TX0390003	CITY OF BYERS	CWS	SW	1	1-2018	496
TX1380011	CITY OF BENJAMIN	CWS	SW	6	3-2020	264
TX0960001	RRA ESTELLINE TURKEY WATER SYSTEM	CWS	SW	1	4-2018	200
TX1380006	RRA TRUSCOTT GILLILAND WATER SYSTEM	CWS	GW	2	3-2018	176
TX0780013	THALIA WSC	CWS	SW	1	1-2018	125
TX0960014	LAKEVIEW WSC	CWS	GW	2	3-2020	110
TX0440002	CITY OF DODSON	CWS	GW	4	2-2020	109
TX1730003	FLOMOT WATER ASSOCIATION	CWS	GW	1	3-2020	50

Based on the TCEQ PWS database, a total of 29 PWSs are impacted by nitrate-N concentrations >4 mg/L, including 17 non-community water systems and 21 community water systems with a total population of 3,330 people. Based on the EPA PWS database, there are 9 community water systems non-compliant for nitrate-N with concentrations above 10 mg/L with a total population of 2,237 people (Table 25).

Trinity Aquifer

The Trinity aquifer covers 32,100 mi^2 and extends across parts of 60 counties from north central to south central Texas (Figure 1, Figure 23). The aquifer includes several units of the Early Cretaceous Trinity Group, including permeable units in the Antlers, Glen Rose, Paluxy, Twin Mountain/Travis Peak, Hensell, and Hosston formations. Total fresh water thickness ranges from 600 ft in North Texas to about 1,900 ft in Central Texas.

There were 5,763 samples analyzed for N during the study period with 1903 samples (33%) having non-detectable concentrations. Probabilities for elevated nitrate-N concentrations are generally low throughout the aquifer area. About 76% of the aquifer area has <10% probability of nitrate-N >4 mg/L. About 4% of the aquifer area has elevated probabilities (>40%) for nitrate-N >4 mg/L. For nitrate-N concentrations greater than the MCL of 10 mg/L, 88% of the aquifer area has a very low probability. Elevated probabilities occur in relatively small areas on the western boundary of the aquifer, with the highest probabilities located in Blanco county (Table 20). Some of the spatial patterns of probabilities display artifacts of limited data density in the down-dip confined areas of both the far north and south areas. The median concentration of samples with detectable concentrations is 0.23 mg/L and the 5th-95th percentile range is 0.01–10.3 mg/L. A total of 294 samples (0.89 %) exceeded the MCL with a range of concentrations from 10.1 mg/L to 505.0 mg/L.

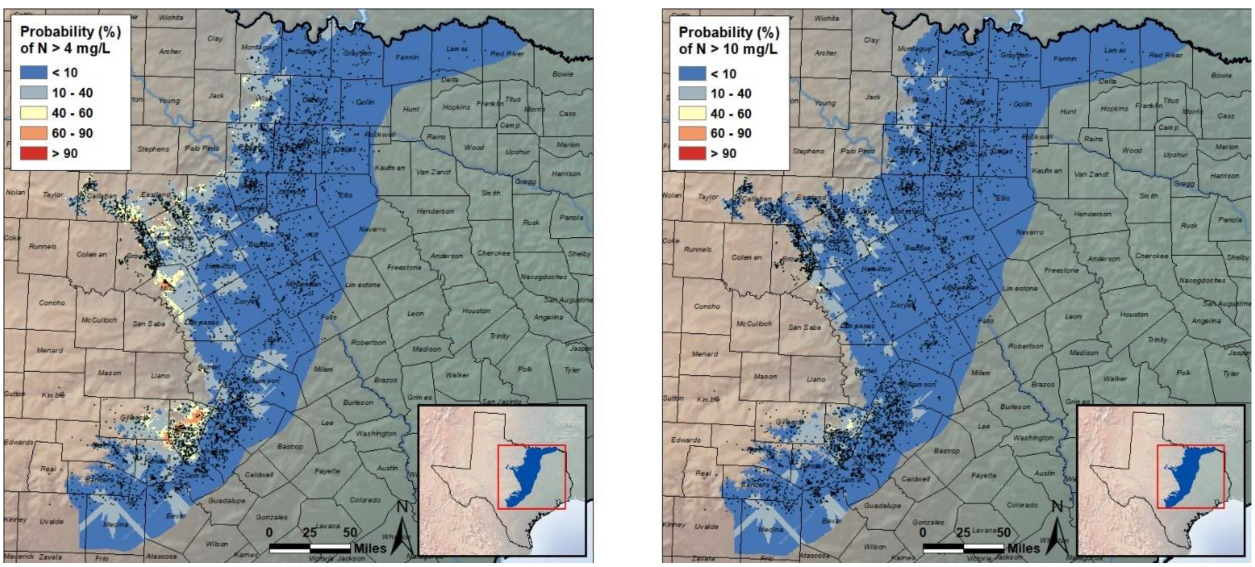

Figure 21. Trinity aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 26. Trinity aquifer PWSs with violations for nitrate-N concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
TX1260008	CITY OF KEENE	CWS	SW	1	2-2018	6310
TX1840018	LAZY BEND ESTATES	CWS	GW	1	1-2019	156
TX0680051	CANYON DAM MOBILE HOME PARK	CWS	GW	9	4-2020	108
TX0860080	ROYAL OAKS APARTMENTS	CWS	GW	3	4-2020	57

Based on the TCEQ PWS database, a total of 30 public supply systems are impacted by nitrate-N concentrations >4 mg/L, including 8 non-community water systems and 22 community water systems with a population of 70,107 people. Based on the EPA PWS database, there are 4 community water supply systems that are impacted by nitrate-N concentrations >4 mg/L with a population of 6,631 people (Table 26).

Lipan Aquifer (Minor)

Indicator kriging of nitrate-N concentrations was performed for the Lipan aquifer in west-central Texas. Maps were not generated for the remaining ten minor aquifers because they had either <50 data points, very low percentages of samples exceeding the threshold values, or very poor spatial coverage.

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, surrounding San Angelo. 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-N, with only 6 (4%) having non-detectable concentrations. The highest probabilities of elevated nitrate-N concentrations are located in Tom Green and Concho counties, in the northeastern portion of the aquifer. About 17% of the area has a very low probability of nitrate-N >4 mg/L and a further 42% has low to moderate probability. About 32% of the total aquifer area has elevated to high probability (>60%) of nitrate-N >4 mg/L. For nitrate-N concentrations greater than the MCL of 10 mg/L, 56% of the aquifer rea has a very low probability, while 8% has a very high probability, primarily located in Concho and Tom Green counties (Table 20). The median concentration of samples with detectable concentrations is 7.71 mg/L and the 5^{th}-95^{th} percentile range is 0.09–42.32 mg/L. Only 64 samples (0.19%) exceeded the MCL with a range of concentrations from 10.1 mg/L to 85.26 mg/L.

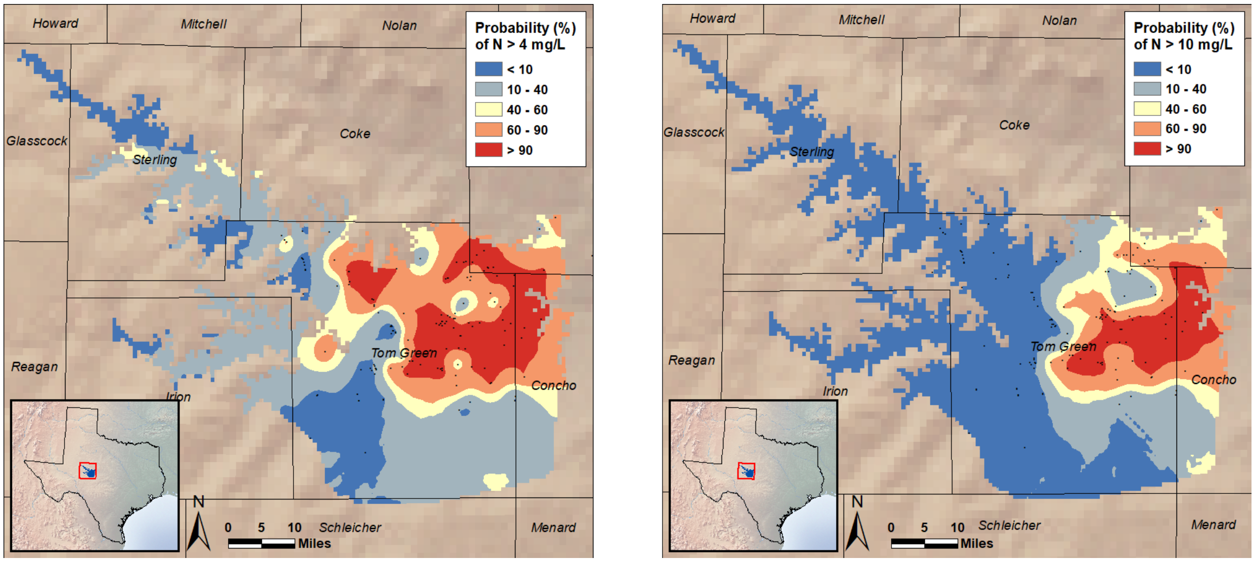

Figure 22. Lipan aquifer probability distribution of N >4 mg/L (left) and >10 mg/L (right).

Table 27. Lipan aquifer PWS with violations for nitrate-N concentrations based on the US EPA database.

PWS ID	*Name*	*System Type*	*Primary Source*	*Quarters w/ Violations*	*Latest Violation Qtr-Yr*	*Population Served*
TX2260008	CONCHO RURAL WATER GRAPE CREEK	CWS	SW	1	1-2019	4569

Based on the TCEQ PWS database, a total of 8 PWSs are impacted by nitrate-N concentrations >4 mg/L, including 4 non-community water systems and 4 community water systems with a total population of 16,158 people. Based on the EPA PWS database, there are no PWS impacted by nitrate-N concentrations >10 mg/L.

Summary

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

Quantifying the spatial distribution of groundwater nitrate-N concentrations in aquifers in Texas is important for managing groundwater resources in the state. In this study all nine major aquifers of Texas, along with the Lipan minor aquifer were evaluated. This study evaluated the probability of groundwater nitrate-N levels exceeding 4 mg/L the and the EPA nitrate-N MCL of 10 mg/L, using ~33,000 analyses from 1930 through 2021. Results of the study indicate that 7.93% (2,631) of samples exceed the MCL of 10 mg/L.

Of the PWSs that were noncompliant with respect to nitrate-N during 2018-2020, over half (18/35) are located in the southern High Plains, reflecting the Ogallala Aquifer. The remaining noncompliant PWSs are located in the Seymour (9), Trinity (4), Lipan (1), Gulf Coast (1), Edwards BFZ (1), and Edwards-Trinity Plateau (1). The percentage of samples exceeding 4 mg/L was about 2.5 times higher than that for the MCL of 10 mg/L, totaling 19% of all samples. A total of 35 CWSs exceeded the primary MCL, 34 systems sourced by major aquifers. In contrast 153 PWSs exceeded the secondary threshold of 4 mg/L, with over half sourced from the Ogallala aquifer (81/153, 53%).

Results suggest that an estimated 77,985 people may have been exposed to nitrate-N concentrations exceeding the MCL of 10 mg/L, with 41% (~32,116 people) from PWS systems and the 59% (~46,069) from non-PWSs. The population impacted by the secondary threshold concentration of 4 mg/L is estimated to be 424,681, 1.46% of the estimated 2020 population of Texas. TCEQ is working with PWSs to bring them into compliance with the nitrate-N regulations using either nontreatment or treatment options. Domestic supply systems are not regulated and home owners need to assess their vulnerability, particularly in the southern High Plains nitrate-N hotspot.

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Appendix I – Large Format Aquifer Probability Maps

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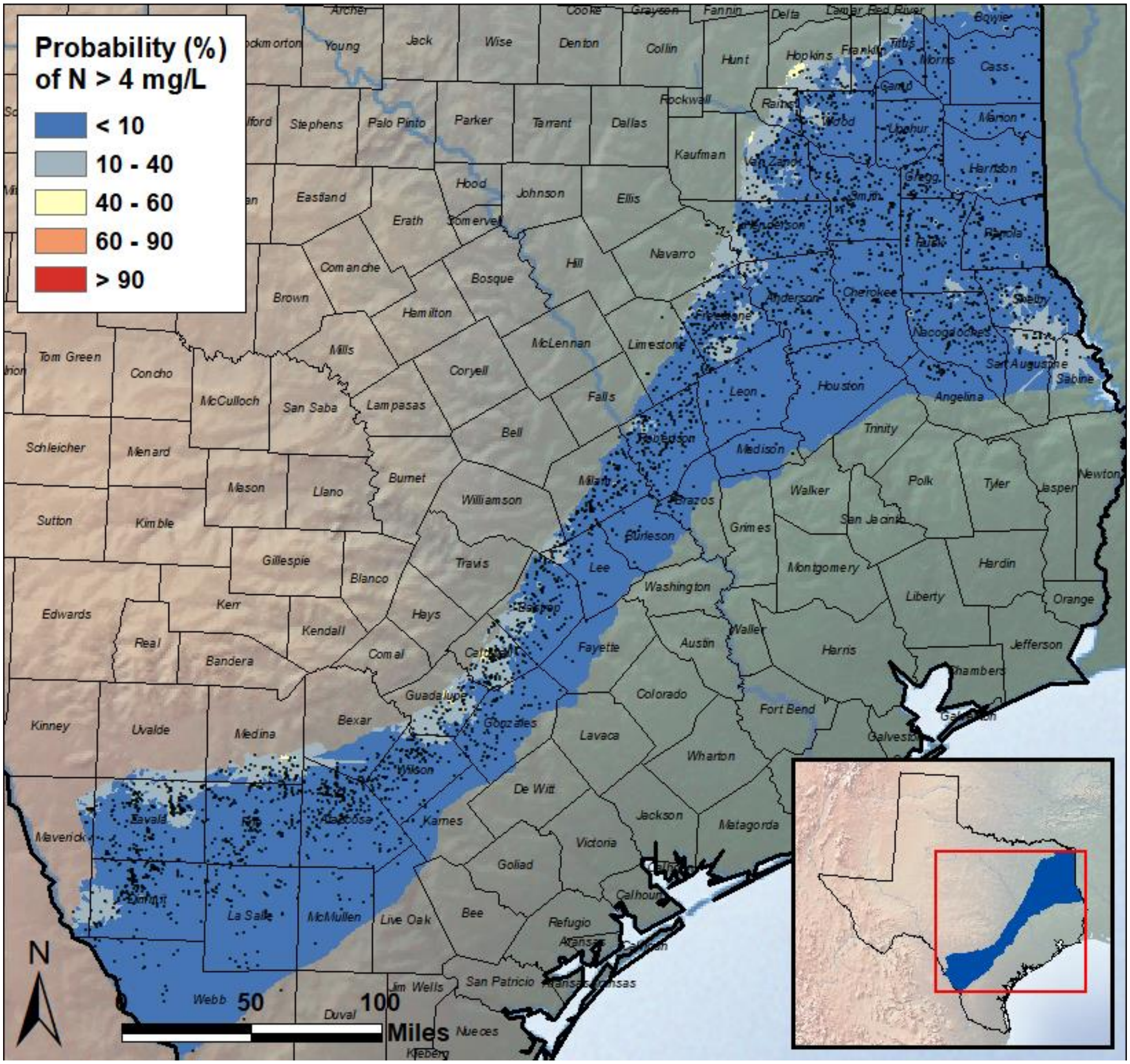
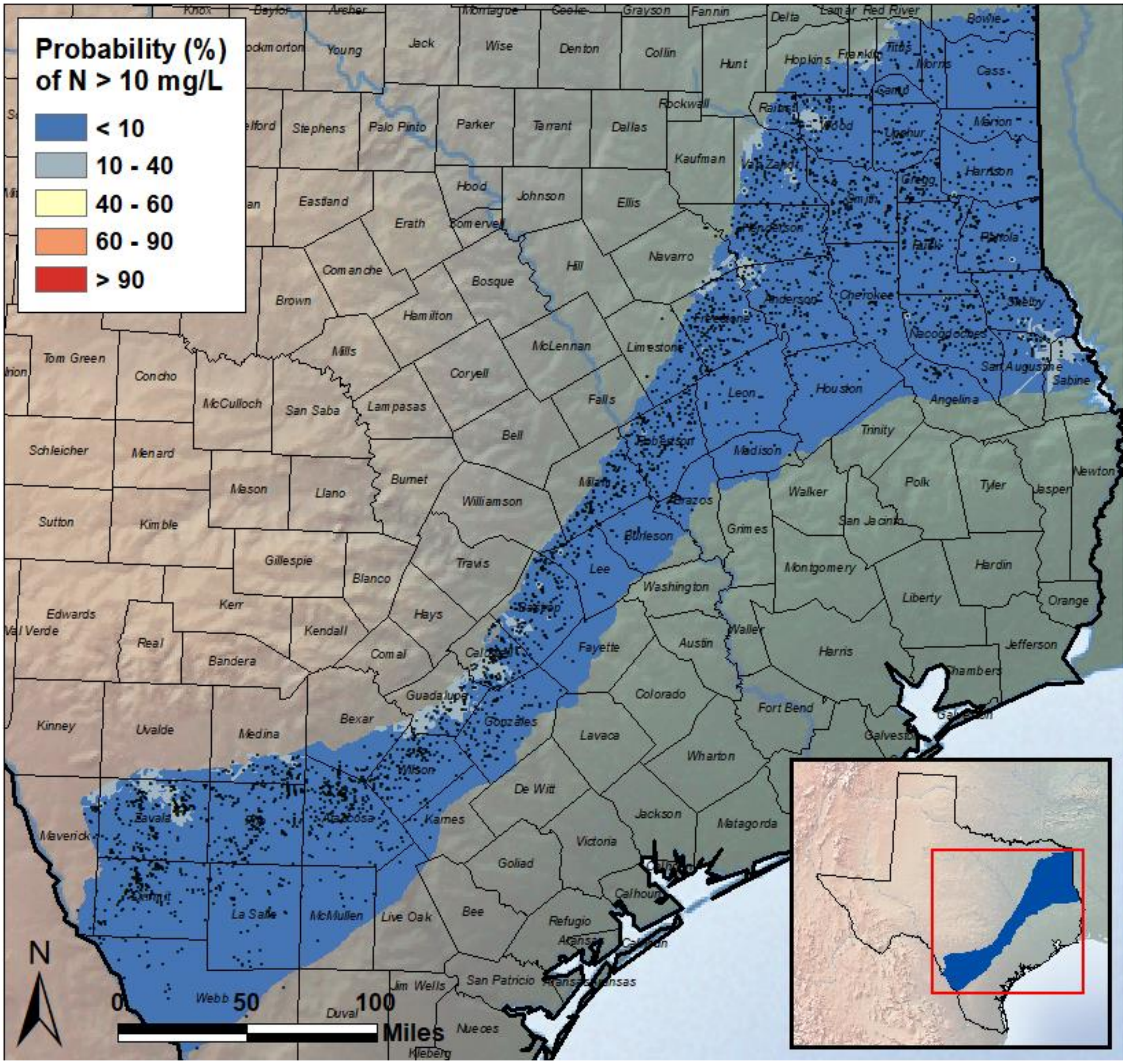


Figure 23. Carrizo-Wilcox aquifer probability distribution of nitrate-N >4 mg/L.



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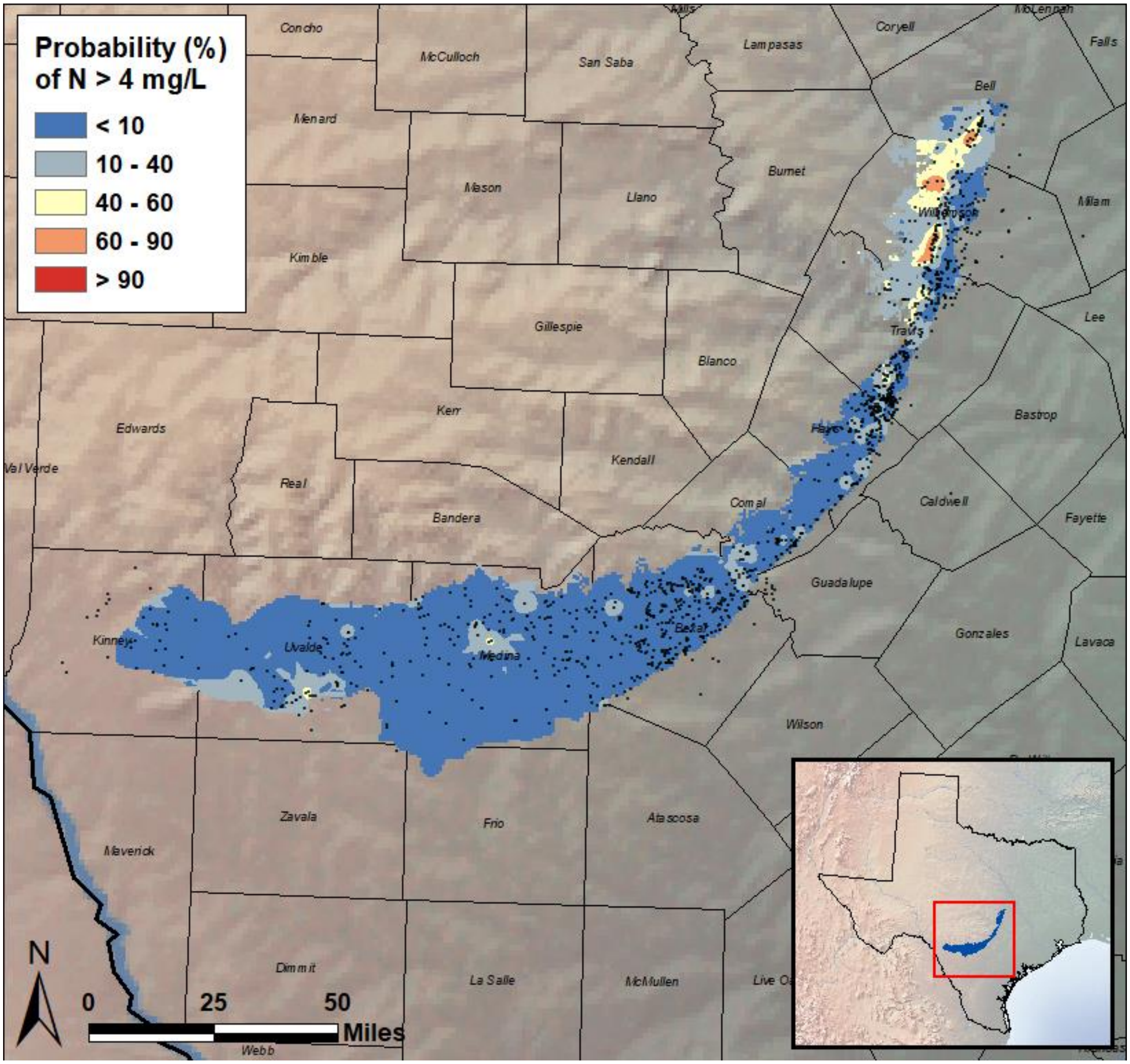

Figure 25. Edwards (Balcones Fault Zone) aquifer probability distribution of nitrate-N >4 mg/L.

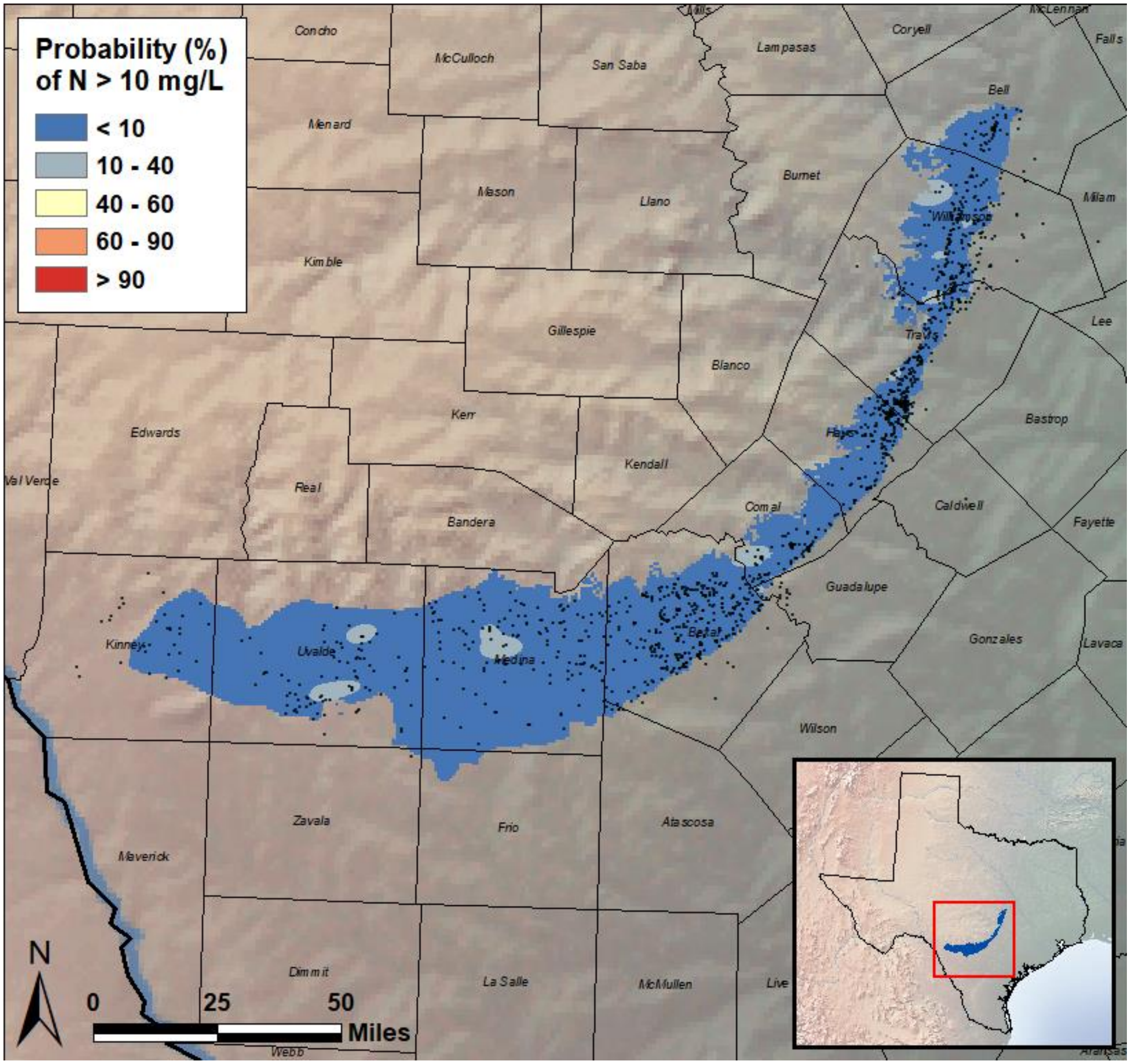

Figure 26. Edwards (Balcones Fault Zone) aquifer probability distribution of nitrate-N >10 mg/L.

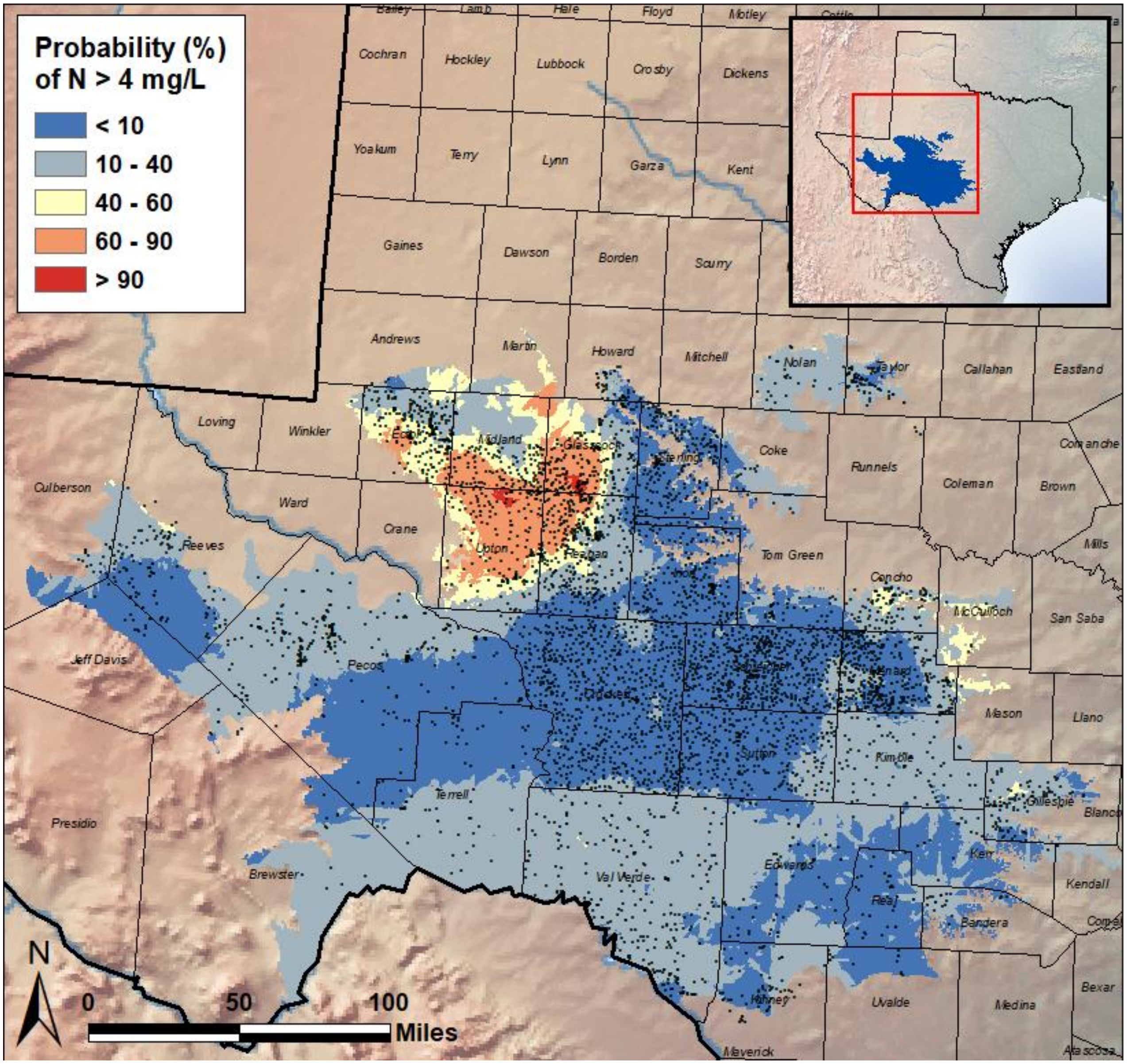

Figure 27. Edwards-Trinity Plateau aquifer probability distribution of nitrate-N >4 mg/L.

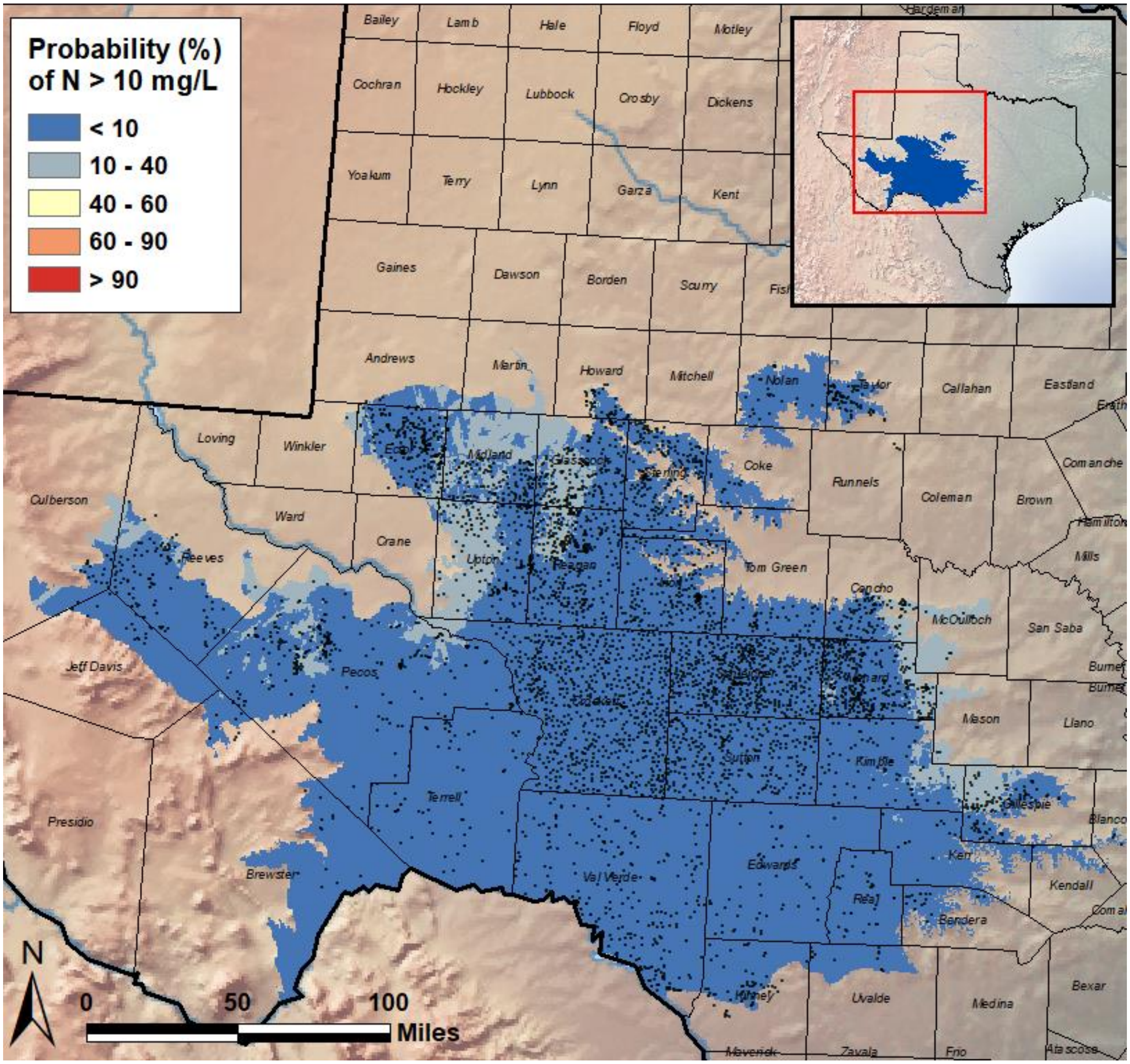

Figure 28. Edwards-Trinity Plateau aquifer probability distribution of nitrate-N >10 mg/L.

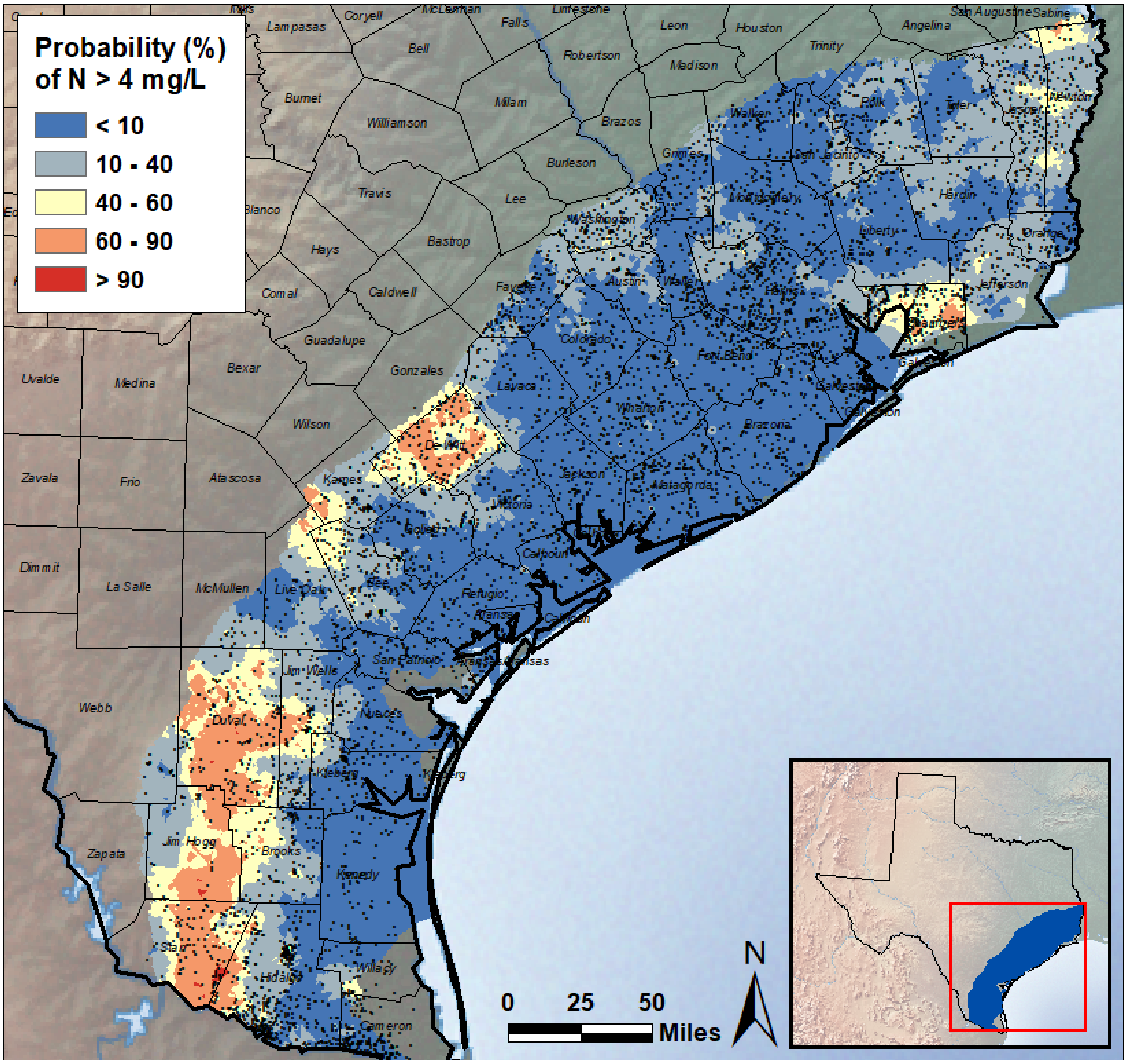

Figure 29. Gulf Coast aquifer probability distribution of nitrate-N >4 mg/L.

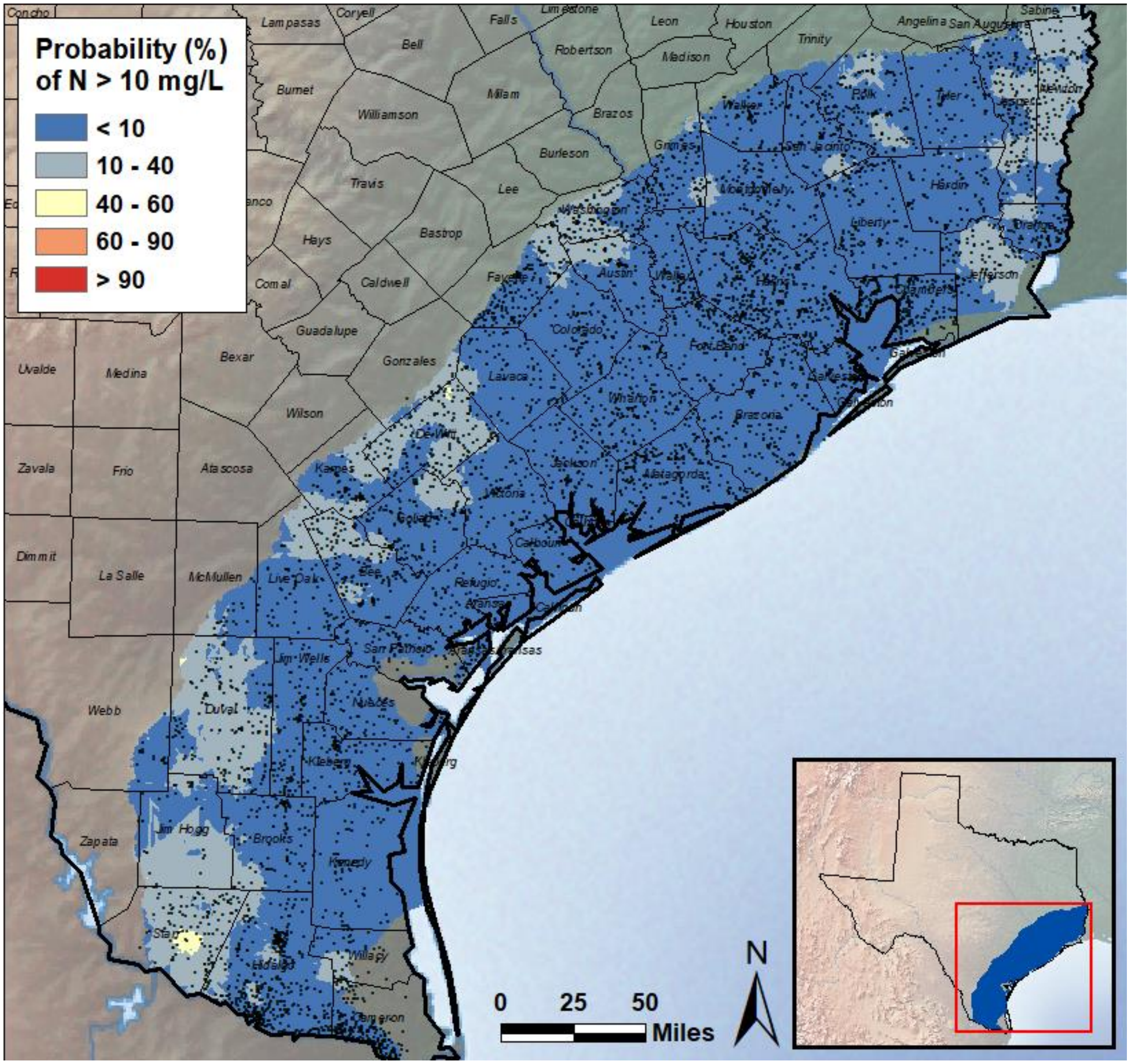

Figure 30. Gulf Coast aquifer probability distribution of nitrate-N >10 mg/L.

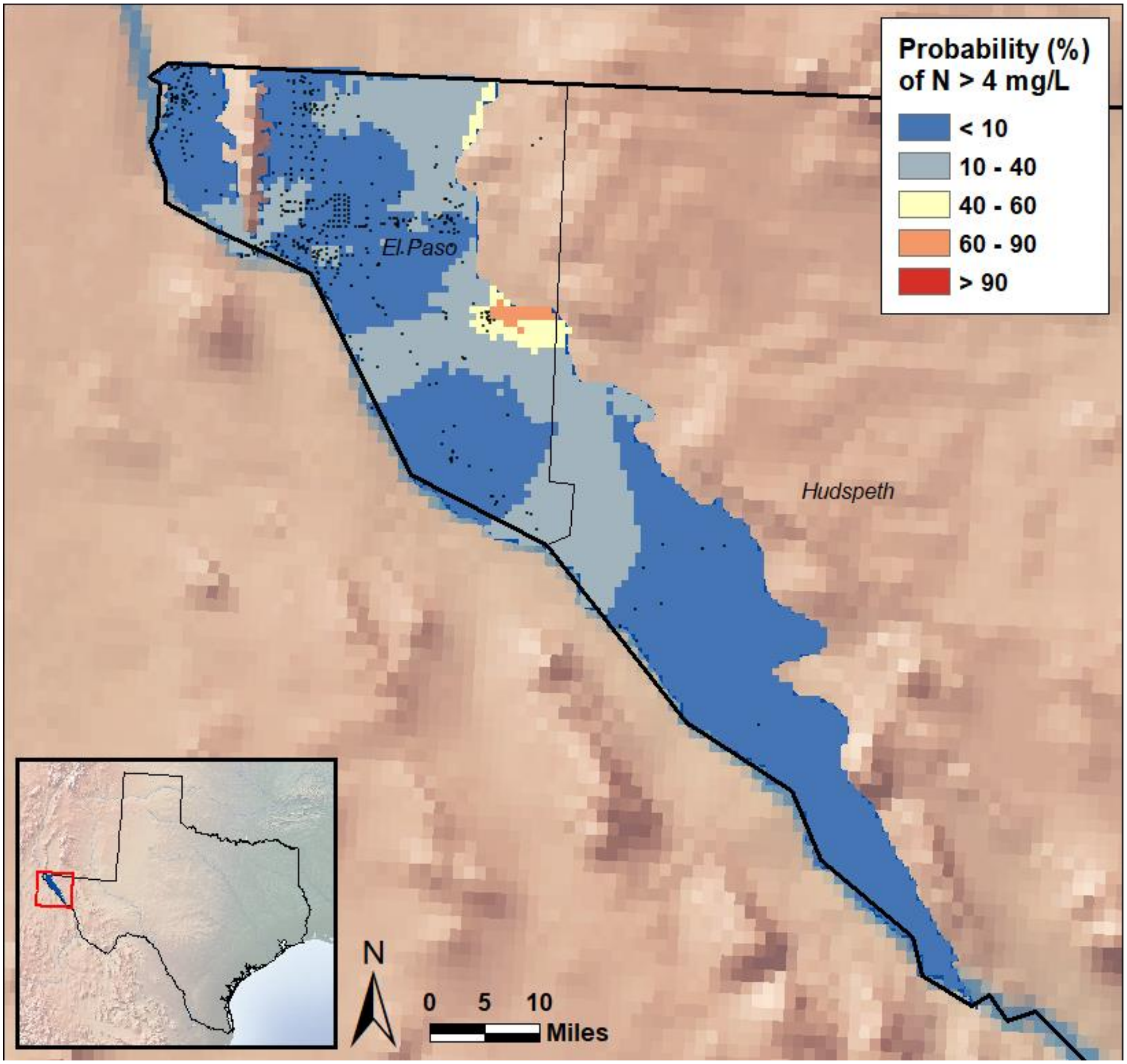

Figure 31. Hueco-Mesilla Bolson aquifer probability distribution of nitrate-N >4 mg/L.

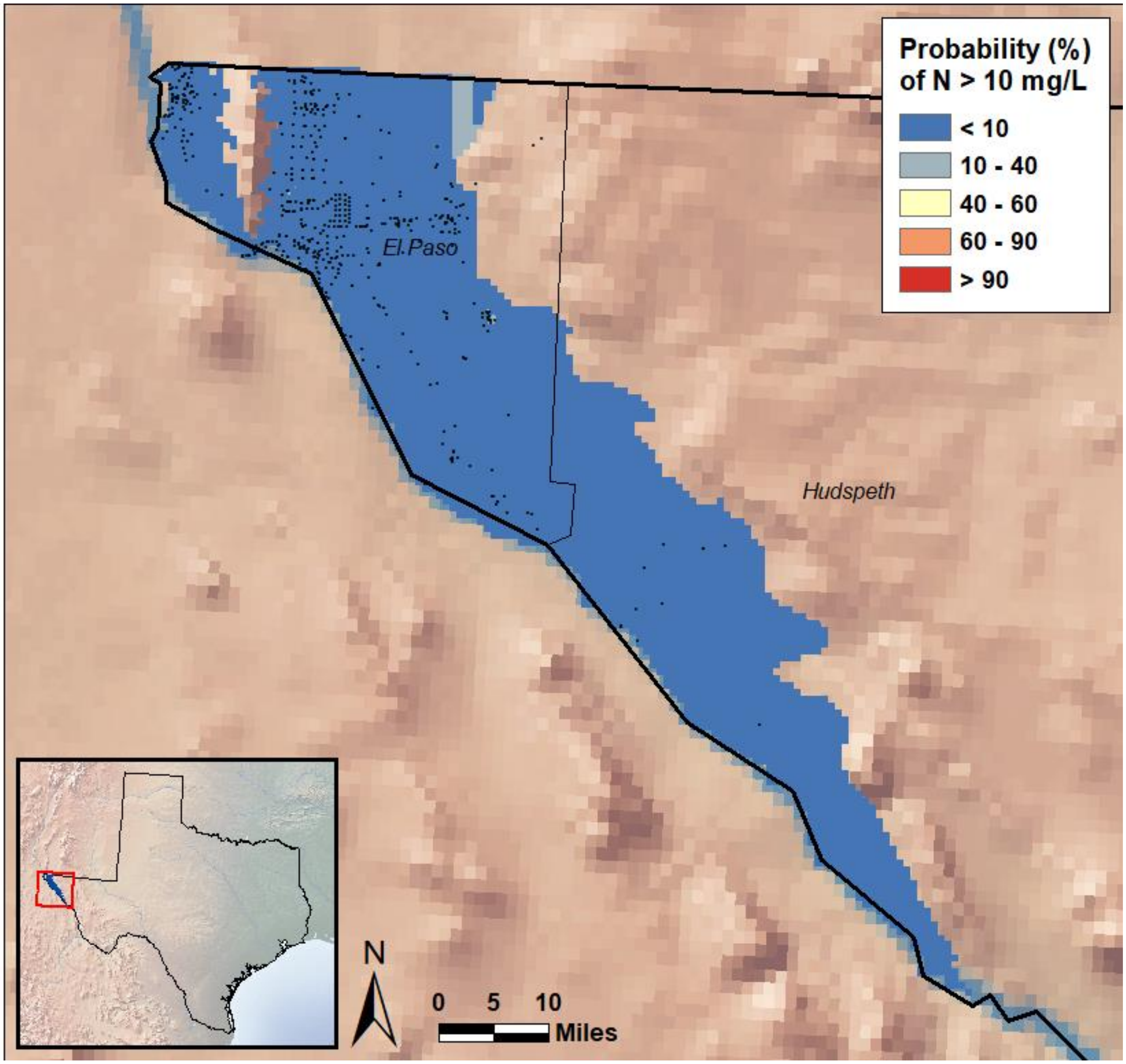

Figure 32. Hueco-Mesilla Bolson aquifer probability distribution of nitrate-N >10 mg/L.

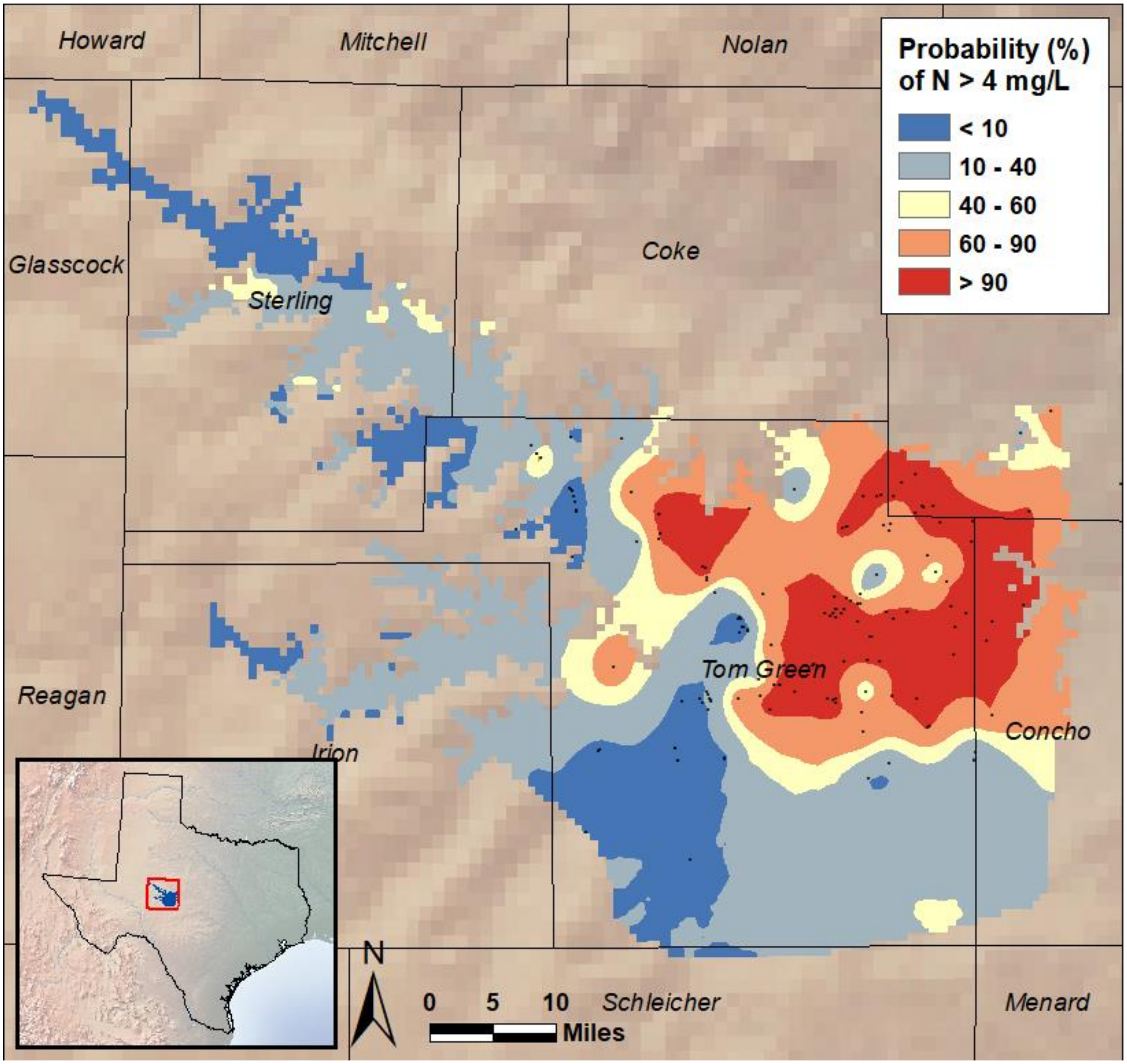

Figure 33. Lipan aquifer probability distribution of nitrate-N >4 mg/L.

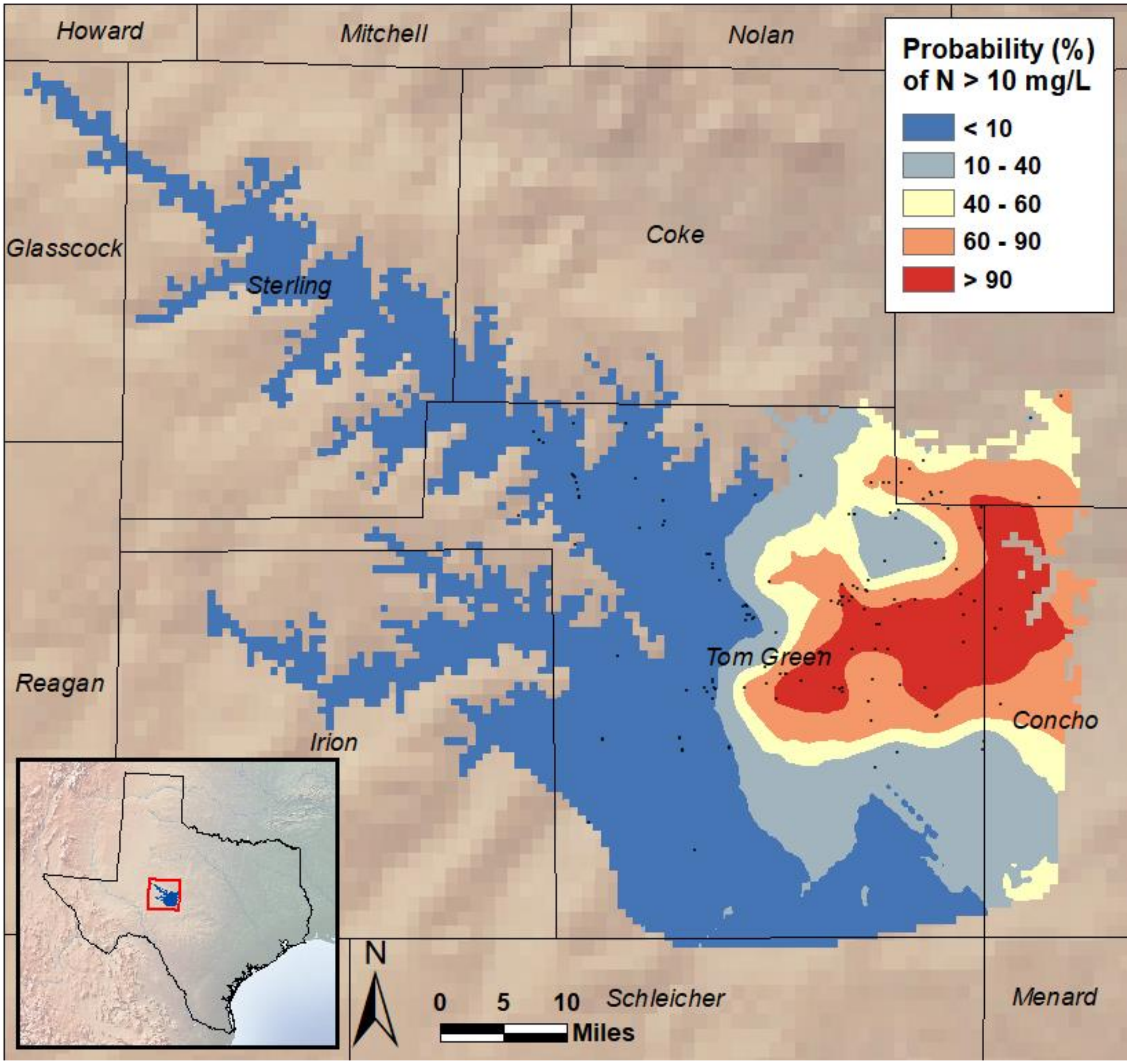

Figure 34. Lipan aquifer probability distribution of nitrate-N >10 mg/L.

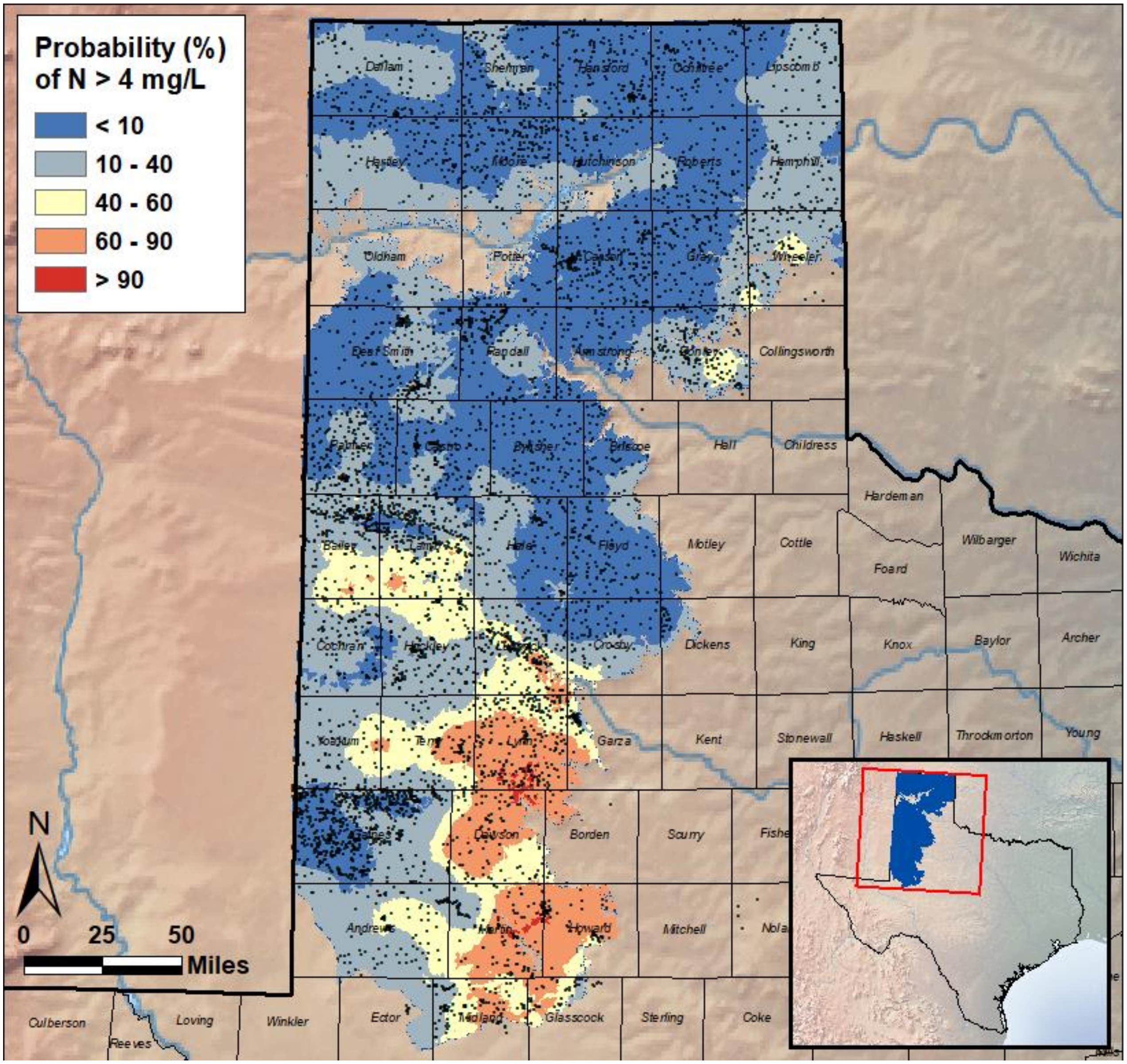

Figure 35. Ogallala aquifer probability distribution of nitrate-N >4 mg/L.

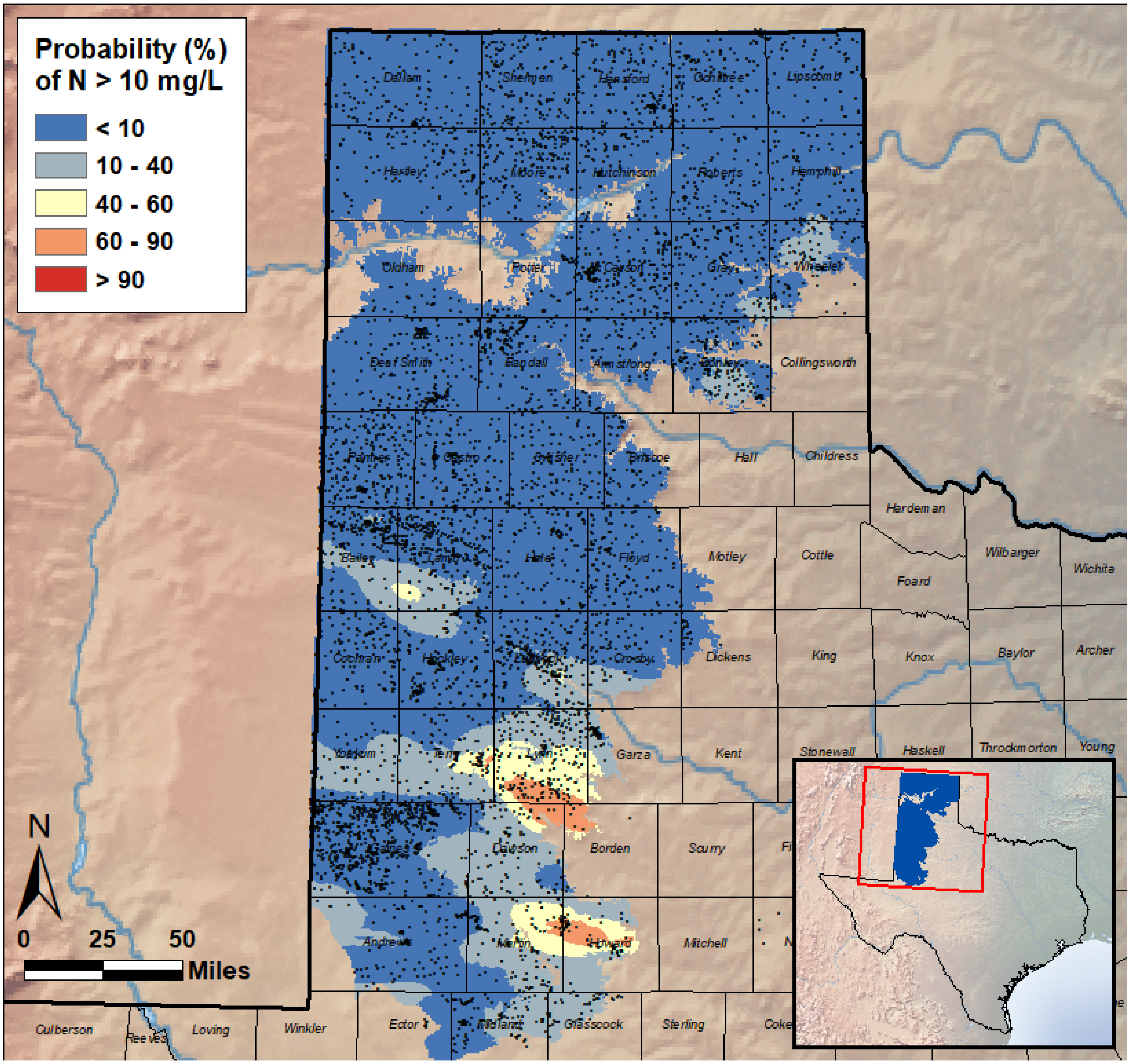

Figure 36. Ogallala aquifer probability distribution of nitrate-N >10 mg/L.

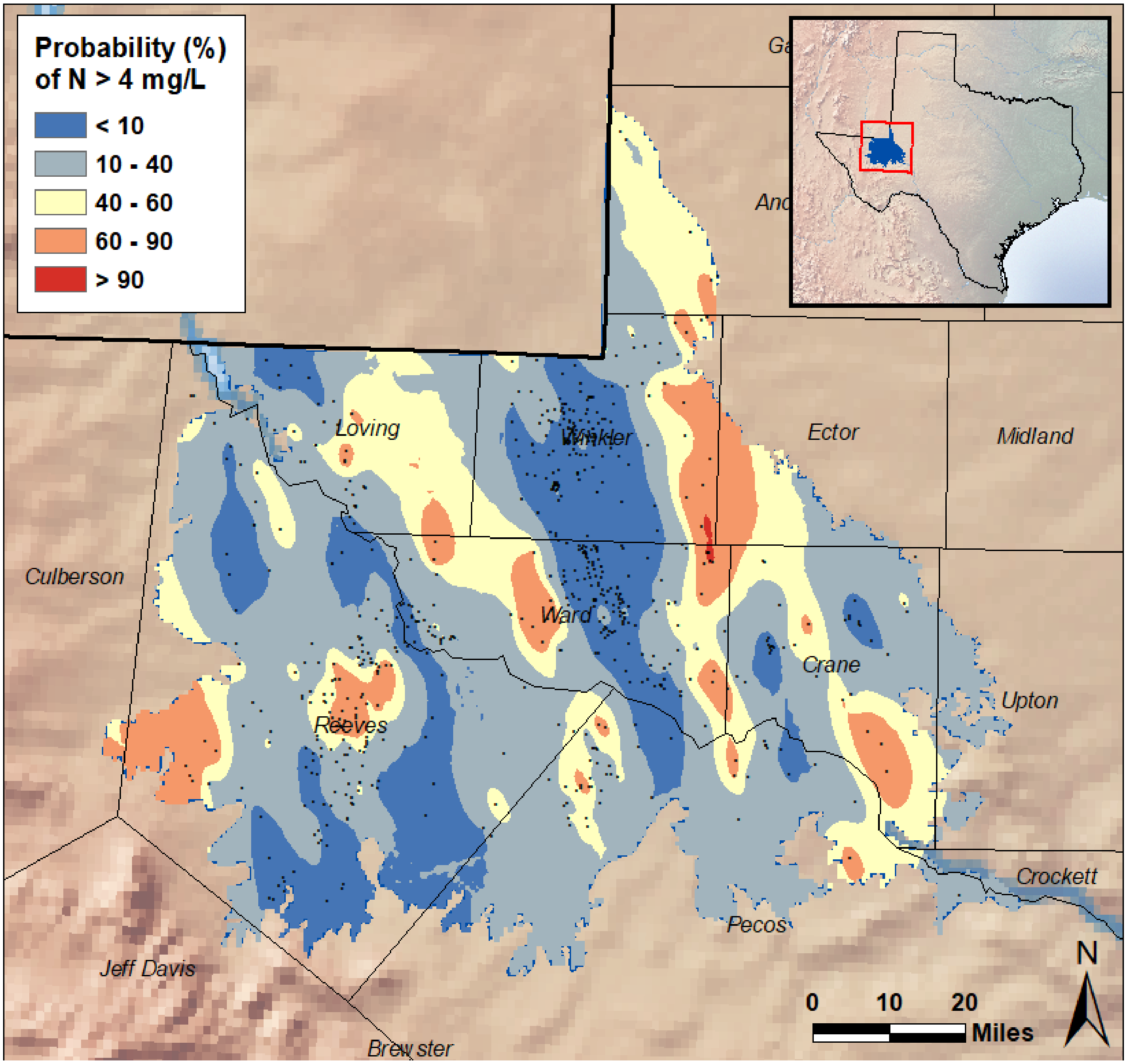

Figure 37. Pecos Valley aquifer probability distribution of nitrate-N >4 mg/L.

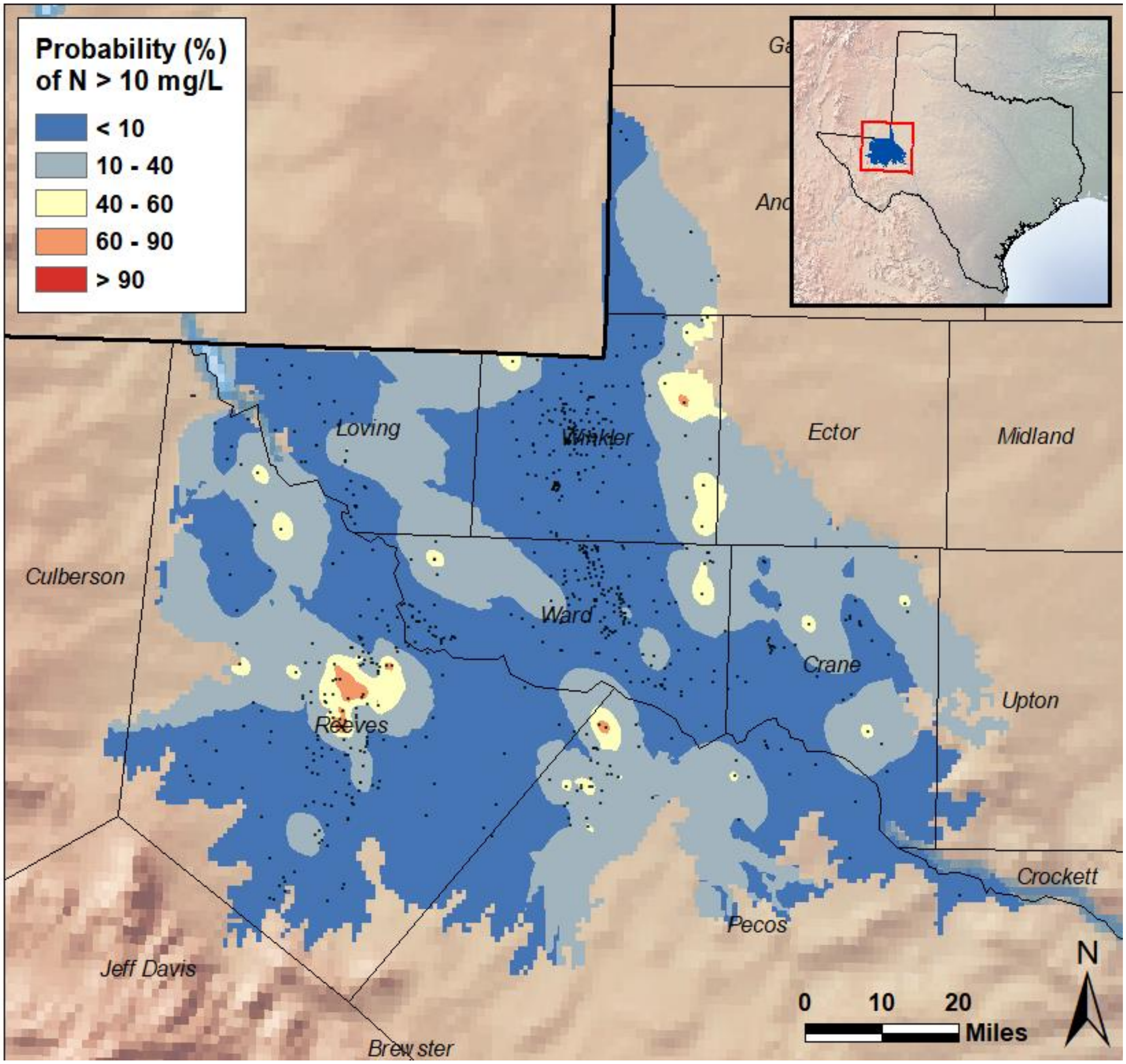

Figure 38. Pecos Valley aquifer probability distribution of nitrate-N >10 mg/L.

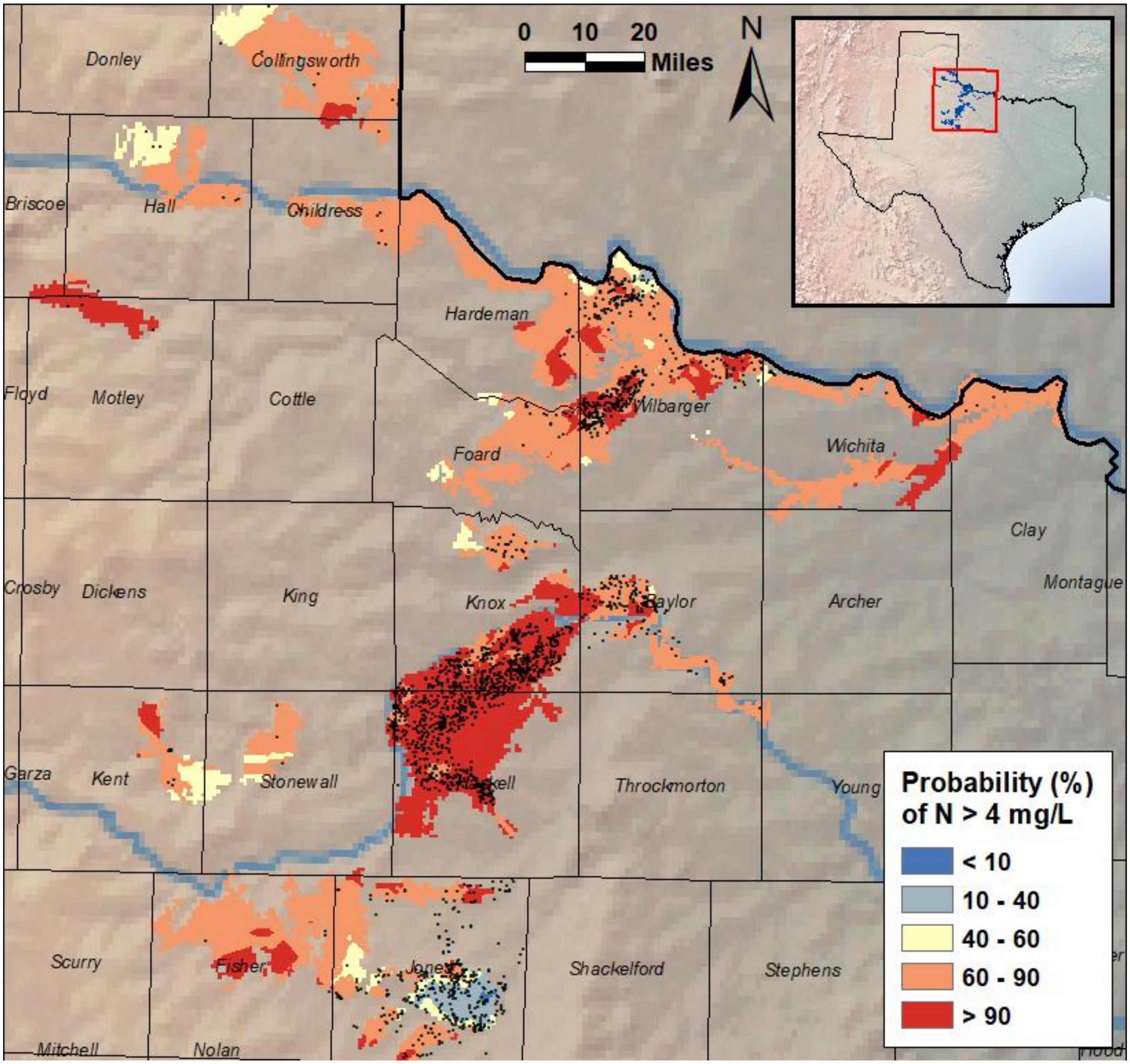

Figure 39. Seymour aquifer probability distribution of nitrate-N >4 mg/L.

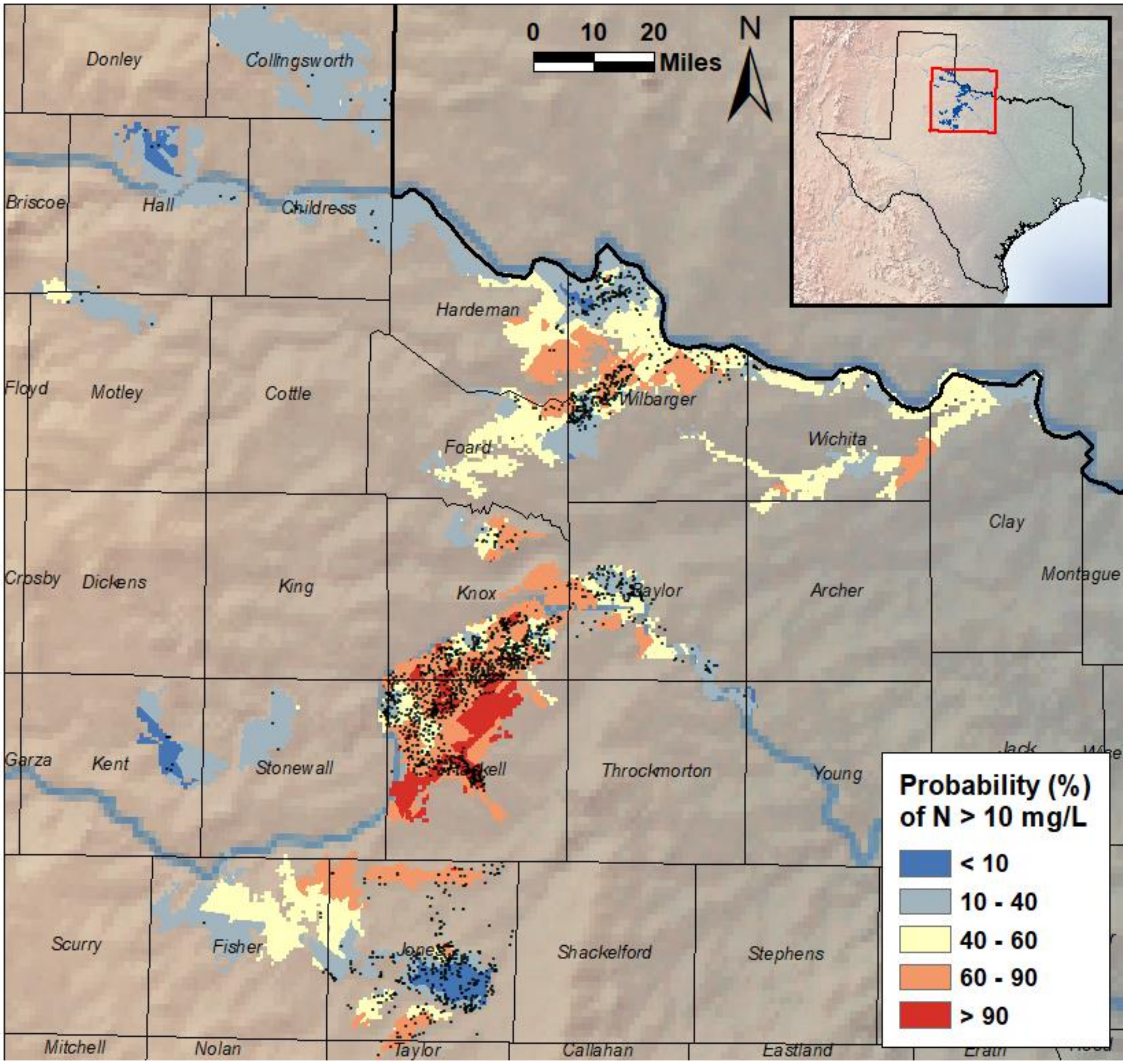

Figure 40. Seymour aquifer probability distribution of nitrate-N >10 mg/L.

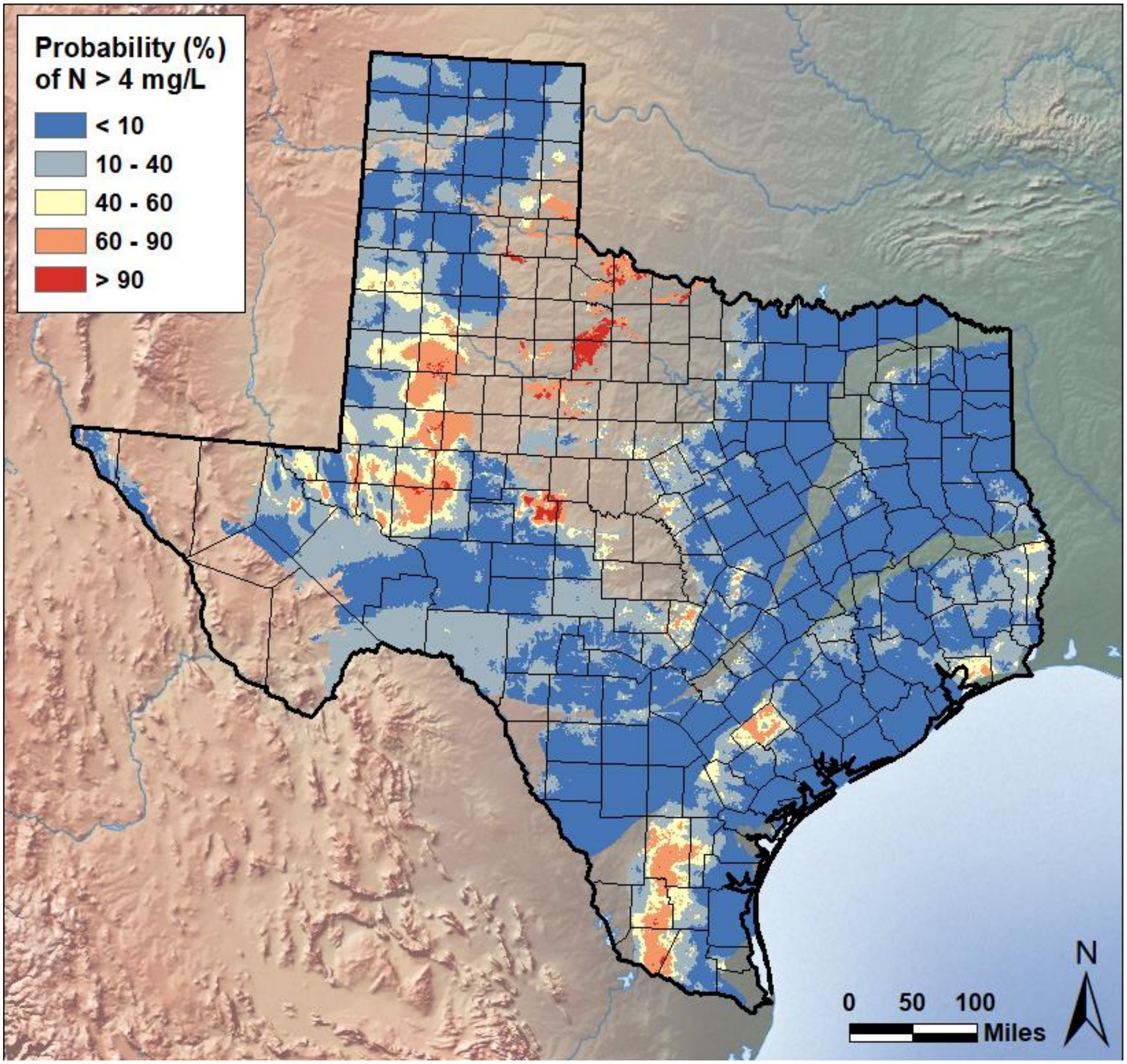

Figure 41. Statewide aquifer probability distribution of nitrate-N >4 mg/L.

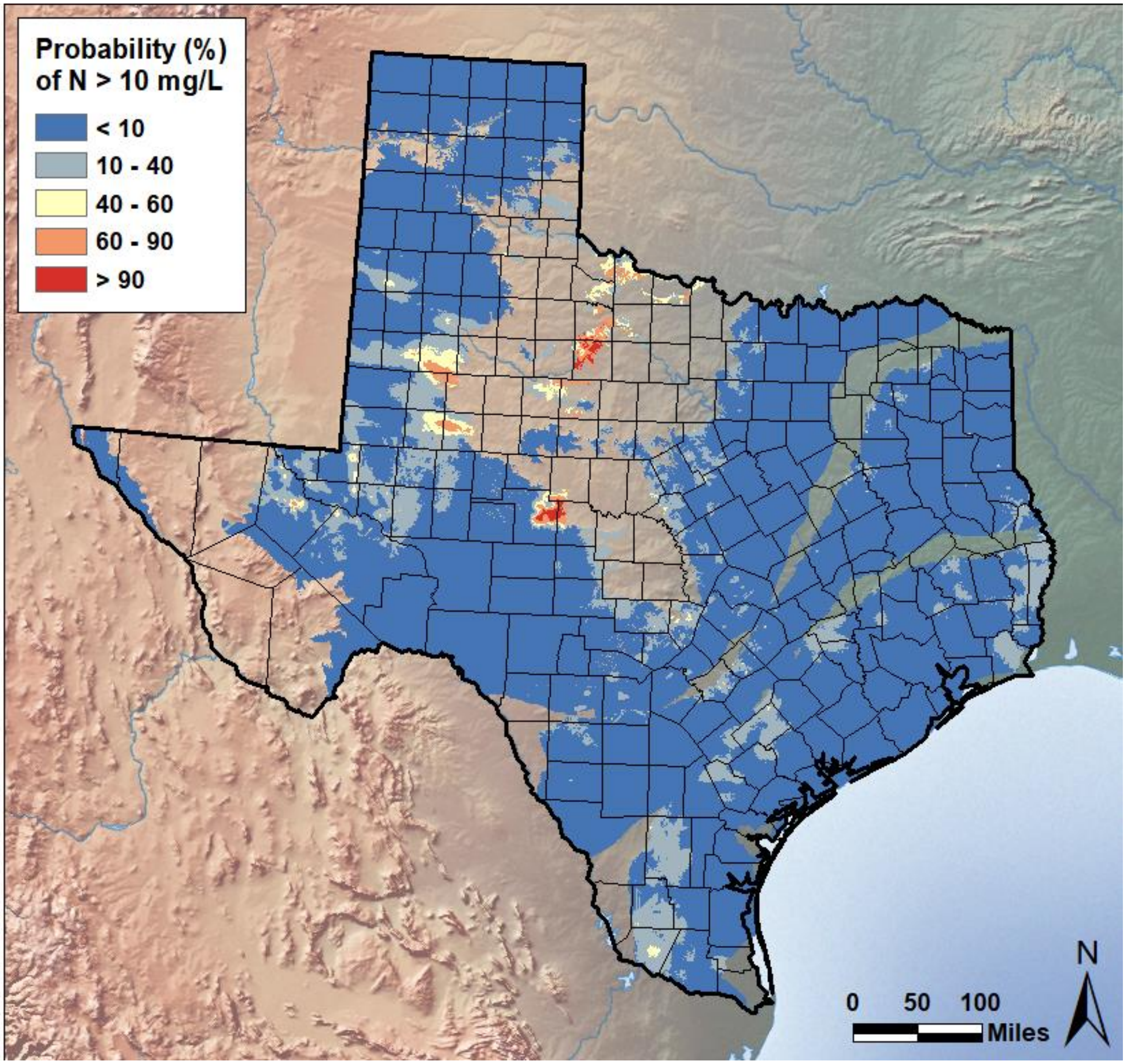

Figure 42. Statewide aquifer probability distribution of nitrate-N >10 mg/L.

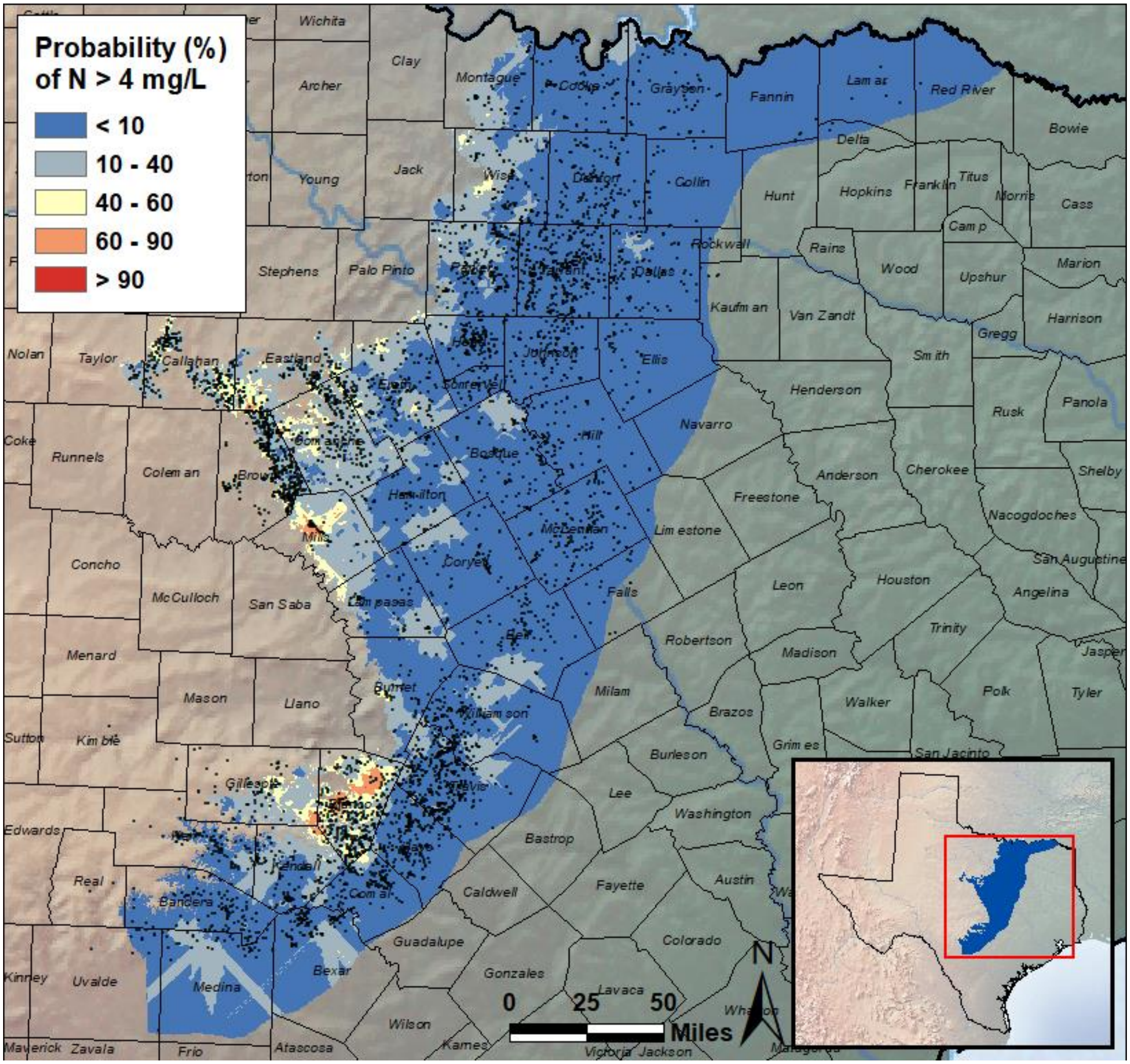

Figure 43. Trinity aquifer probability distribution of nitrate-N >4 mg/L.

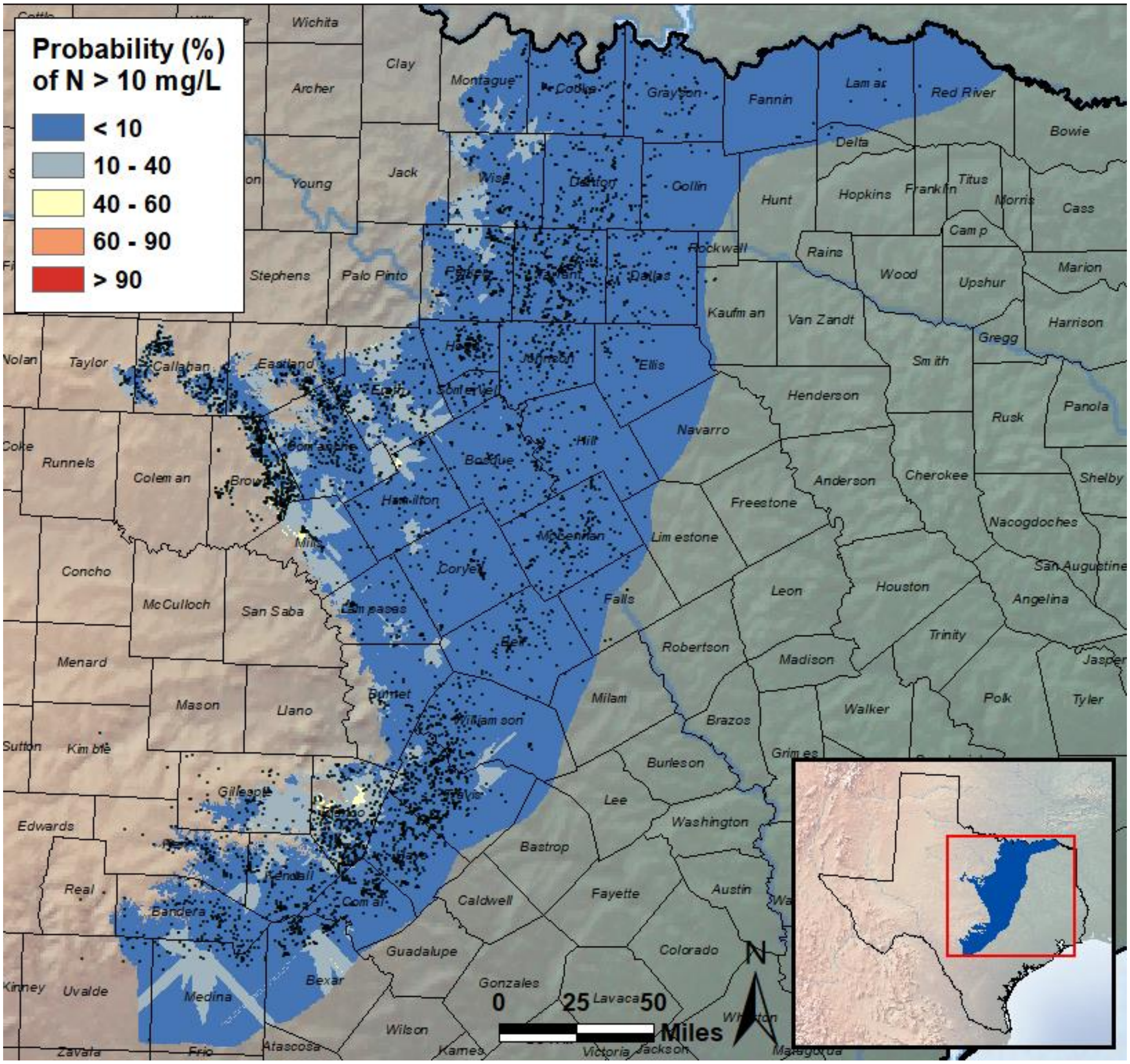

Figure 44. Trinity aquifer probability distribution of nitrate-N >10 mg/L.