Historical Review of Hydrology and Water Quality Data for Leona River Segment 2109

Prepared for:

Texas State Soil & Water Conservation Board
Project 11-50

Prepared by:

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Todd Adams

Texas Institute for Applied Environmental Research
Tarleton State University
Stephenville, Texas

TR1204

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Cover photograph is Leona River south of Uvalde taken by TIAER on September 8, 2010.

Table of Contents

List of Figures

List of Tables

SECTION 1

Introduction

The Leona River (Segment 2109) is a tributary of the Frio River within the Nueces River Basin in southwest Texas. Segment 2109, as defined by the Texas Commission on Environmental Quality (TCEQ), stretches 91 miles from the confluence of the Leona River with the Frio River about six miles north of the City of Dilley in Frio County, through the City of Batesville in Zavala County and the City of Uvalde in Uvalde County, to the crossing of the Leona River with U.S. 83 just north of Uvalde, Texas (Figure 1). Assessment of water quality along the Leona River indicates that Segment 2109 meets most criteria and screening levels, but that the Leona River contains elevated bacteria and nitrate concentrations (TCEQ, 2011). The Texas Water Quality Inventory first noted concerns for nitrates along Segment 2109 in 2002. In 2006, Segment 2109 was first included on the Texas 303(d) List as impaired for the contact recreation standard due to elevated bacteria concentrations (TCEQ, 2007a).

The Texas Water Quality Inventory is a biennial report that presents the status of the State's waters based on historical surface and groundwater data and is prepared in response to Section 305(b) of the Federal Clean Water Act. The 303(d) List is developed from the water quality inventory, as required under Sections 303(d) and 304(a) of the Federal Clean Water Act, and identifies waterbodies within Texas that do not meet water quality standards. The main mechanism for addressing pollutants on the 303(d) List is through development of a Total Maximum Daily Load (TMDL), which indicates the maximum amount of a pollutant that can enter a waterbody and still allow that waterbody to meet water quality standards.

In Texas, other actions may be needed prior to development of a TMDL, and these actions are indicated by the subcategory assigned to the waterbody. All waterbodies on the 303(d) List are considered a category 5, indicating that the waterbody does not meet applicable water quality standards or is threatened for one or more designated uses by one or more pollutants.

- Category 5a indicates a TMDL is underway, scheduled, or will be scheduled.
- Category 5b indicates a review of the water quality standard for the waterbody will be conducted before a TMDL is scheduled.
- Category 5c indicates that additional data and information will be collected before a TMDL is scheduled.

In the 2010 Texas 303(d) List, the bacteria impairment for the Leona River is classified as category 5c indicating that additional data and information are needed to determine whether or not a TMDL or some other type of action is needed for the Leona River (TCEQ, 2011b). Other types of actions may include verification of use attainment, revision of the designated use category for recreation, or development of a watershed protection plan (WPP).

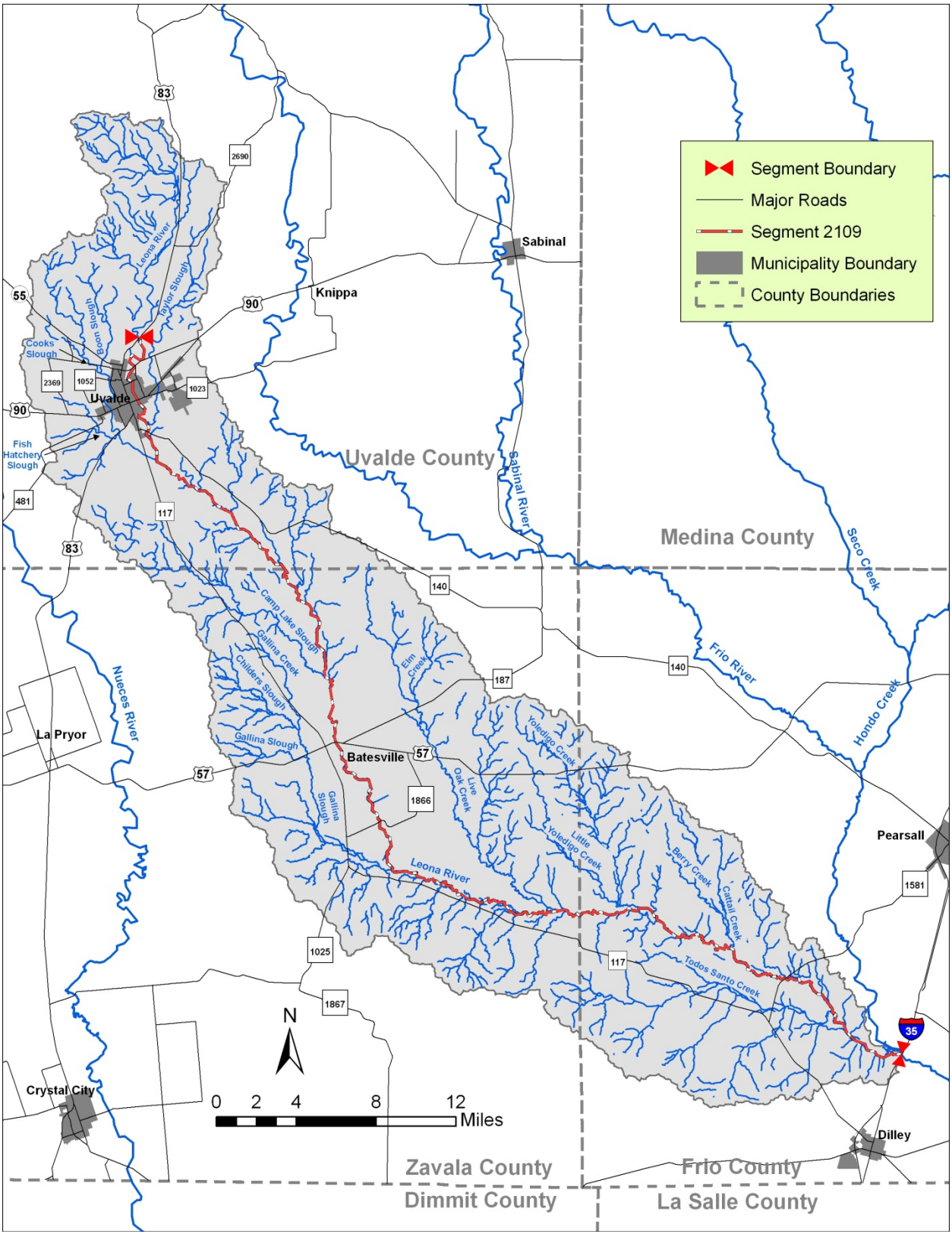


Figure 1 Map of Leona River watershed, Segment 2109

Of note, the 2010 Texas Water Quality Inventory was based on two categories of recreation use, contact and noncontact. In June 2010, the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TSWQS) that expanded the designation of contact recreation into three categories based on varying degrees of interaction with the water, while maintaining a forth category of noncontact recreation. These revisions were codified in the Texas Administrative Code (TAC), Title 30, Chapter 307 and became effective as a state rule on July 22, 2010 (TCEQ, 2010a). As a result of these revisions to the TSWQS, all waterbodies listed as impaired based on bacteria for contact recreation may undergo a standards review to determine if primary contact recreation is appropriate or if a revision to the use category for recreation should be considered.The purpose of this report is to provide an overview of historical hydrologic and water quality data for the Leona River as an aid in assessing and characterizing trends and variability in bacteria and nitrate concentrations. Other aspects of this project will address a recreational use attainability assessment (RUAA) and evaluate potential sources of bacteria and nitrates to the Leona River.

Watershed Description

The Leona River watershed covers about 429,000 acres and includes the cities of Uvalde (estimated population 16,000) and Batesville (estimated population 1,100). The upper reaches of the Leona River include Hoag Dam south of Uvalde by the Fort Inge Historical Park and three Public Law 566 (PL566) reservoirs north of the City of Uvalde (Figure 2). The Leona River is fairly well delineated in its upper portion, although some tributary channels in areas are difficult to define as water sometimes flows underground while crossing limestones associated with the Balcones Fault Zone (BFZ). The BFZ is associated with the Edwards Aquifer and underlies most of the Leona River watershed within Uvalde County (Figure 3). These porous or fractured limestones of the BFZ are a conduit for recharge of the Edwards Aquifer, and when groundwater levels are high, springs at times feed streamflow. Several groups of springs have been noted along the Leona River in Uvalde County (Brune, 1975), but these springs can be difficult to locate as they often flow beneath the surface of the river or do not flow when extended dry conditions occur due to lowering aquifer water levels. While the upper third of the Leona River watershed largely overlays the Edwards Aquifer, the lower two-thirds overlays the Carizo-Wilcox Aquifer (George, et al., 2011). The Carizo-Wilcox Aquifer is predominantly composed of sand locally interbedded with gravel, silt, clay, and lignite, so percolation of surface water into groundwater is slower than within the region of the Edwards Aquifer (Ashworth and Hopkins, 1995). Along its lower reaches, the Leona River flows through fairly flat terrain and often appears only as shallow depressions in the landscape as it nears its confluence with the Frio River.

The Leona River is part of the Southern Texas Plains Ecoregion (level III; Griffith et al., 2007), which was once covered with grassland and savanna vegetation, while thorny brush, such as mesquite (*Prosopis glandulosa*), now dominate much of the landscape. As part of the Southern Texas Plains, the Leona River watershed falls within the Northern Nueces Alluvial Plains (level IV ecoregion), which differs from much of the Southern Texas Plains by having a higher annual precipitation (generally 22 to 28 inches) and deeper soils. Large parts of the watershed are

rangeland with honey mesquite, plateau live oak (*Quercus fusiformis*), guajillo (*Acacia berlandieri*), and blackbrush (*Acacia rigidula*) as dominate woody species.

The Leona River watershed is largely rural with cropland and pastureland as major land uses. Wheat (*Triticum sp.*), sorghum (*Sorghum bicolor*), cotton (*Gossypium sp*.), vegetables, and corn (*Zea mays*) are among the leading crops in all three counties (USDA-NASS, 2011). Frio County is distinct from Uvalde and Zavala Counties in that peanut (*Arachis hypogaea*) production is also a major crop. Most cropland areas are irrigated, and with the production of winter vegetables, Frio and Zavala Counties are included in what is commonly referred to as the Winter Garden Region of south Texas (Odintz, 2012). Large amounts of land in all three counties are also used as pasture for hay or grazing of primarily beef cattle, although sheep production is also prominent in Uvalde County. Another notable feature in the upper portion of the watershed is the U.S. Fish and Wildlife Service National Fish Hatchery located in Uvalde, Texas (Figure 2), which raises imperiled fishes, such as the fountain darter (*Etheostoma fonticola*), Comanche Springs pupfish (*Cyprinodon elegans*), and Devils River minnow (*Cryprindodon elegans*).

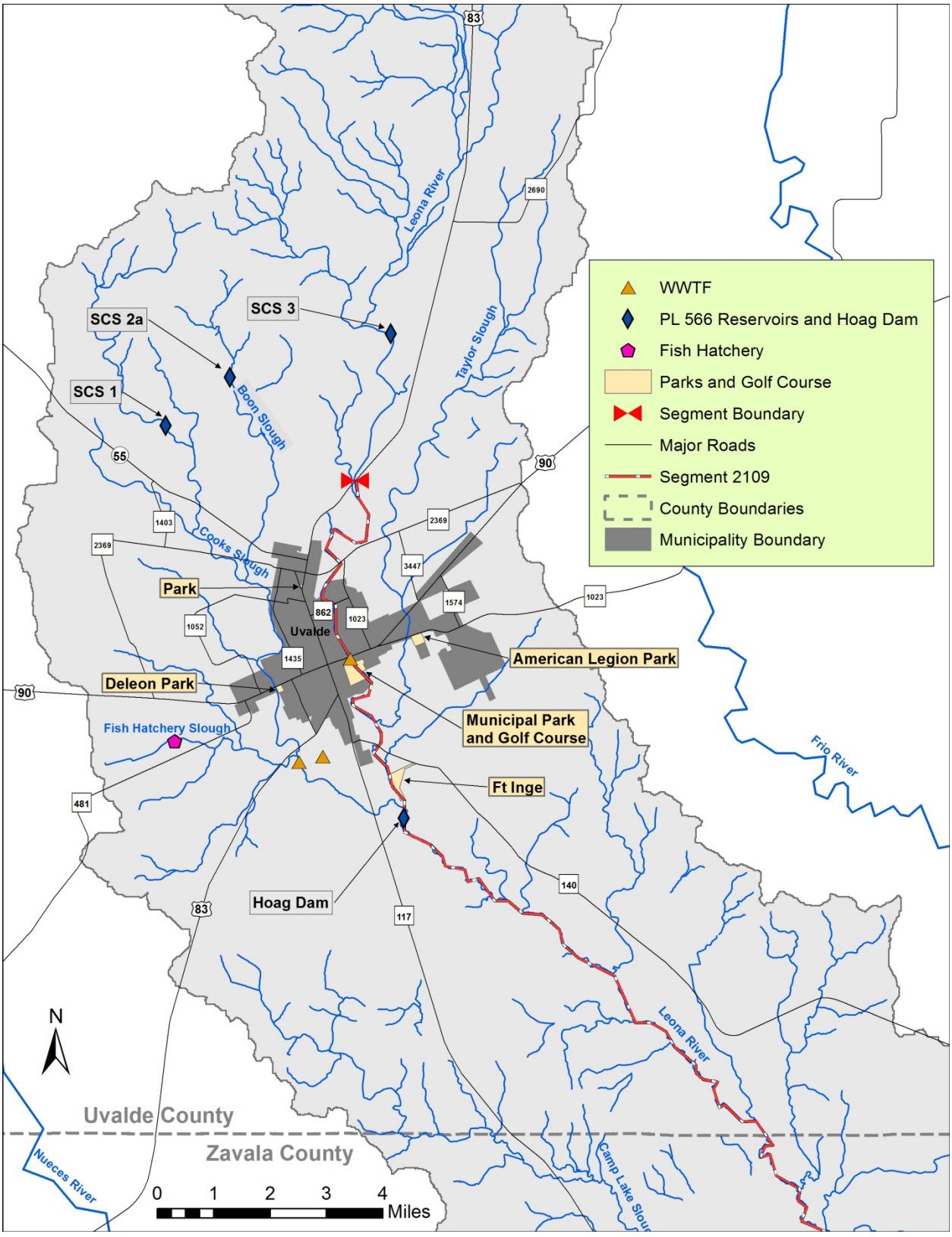


Figure 2 Map showing PL-566 reservoirs and Hoag Dam in the upper portion of the Leona River watershed showing major aquifers of Texas

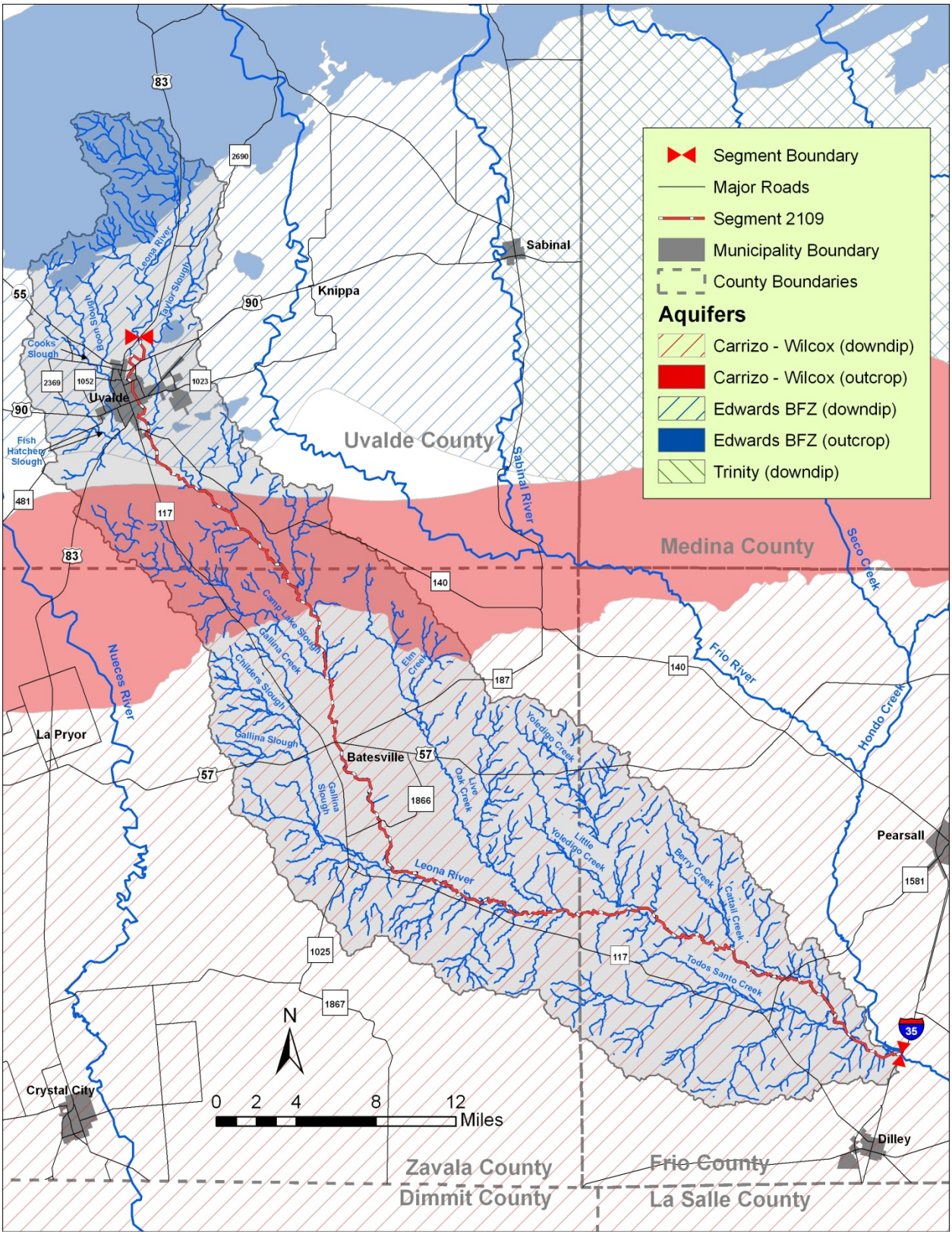


Figure 3 Map of Leona River watershed showing major aquifers of Texas. Source for aquifer data TWDB

SECTION 2

Inventory of Historical Data

Historical Water Quality Data

Historical water quality data through December 2010 were obtained through TCEQ's publicly available online Surface Water Quality Monitoring Information System (SWQMIS) for stations within Segment 2109 (TCEQ, 2011c)[1]. Of note, when queried, no data for 2011 were available in SWQMIS. Of the 14 stations with data within SWQMIS for Segment 2109 (Table 1 and Figure 4), only 5 stations (12985, 12987, 12988, 12989, and 18418) had more than 2 observations for nitrates, fecal coliform, or *E. coli* (Table 2). The Nueces River Authority (NRA) website for water quality data was separately queried, and for the parameters of interest, available data were found to match those from the SWQMIS database.

Table 1 SWQMIS stations within Leona River, Segment 2109

TCEQ Station No.	Station Location Description	Station Type (mainstem, tributary or pond)	Latitude	Longitude
12956	Cooks Slough at FM 117	Tributary	29.171288	-99.772269
12957	Cooks Slough downstream Uvalde WWTF	Tributary	29.180994	-99.792311
12958	Fish Hatchery Slough at US 83	Tributary	29.177324	-99.783421
12959	Cooks Slough at US HWY 83	Tributary	29.189423	-99.792541
12985	Leona River at FM 1581	Mainstem	28.793011	-99.241125
12986	Leona River at Loma Vista Road	Mainstem	28.840500	-99.407627
12987	Leona River at US 57	Mainstem	28.963631	-99.614258
12988	Leona River SE of Uvalde	Mainstem	29.153347	-99.740833
12989	Leona River at Hoags Dam	Mainstem	29.170088	-99.763183
12990	Leona River at FM 140	Mainstem	29.188787	-99.770980
12991	Leona River Uvalde Golf Course	Mainstem	29.208355	-99.777177
12992	Leona River at Highway 90 west	Mainstem	29.211790	-99.779766
17980	Lake El Caballo NFTS 0196	Pond	28.906500	-99.649390
18418	Leona River upstream of FM 140	Mainstem	29.191935	-99.770508

[1] Data from SWQMIS was downloaded for this report from the TCEQ website on November 16, 2011.

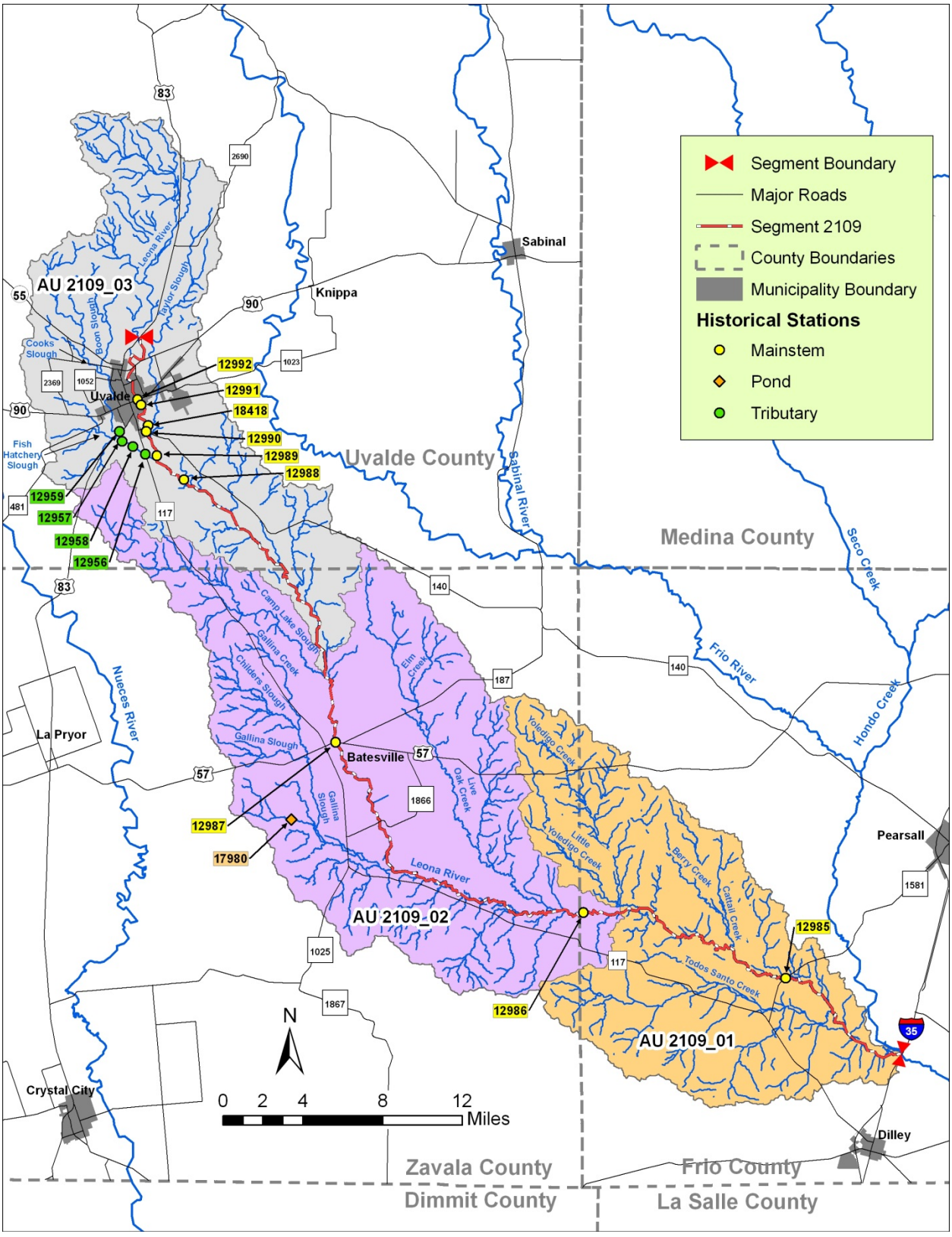


Figure 4 Location of historical TCEQ stations within the Leona River watershed. AU indicates assessment unit

Of the 14 sampling stations, 4 are currently included in routine monitoring conducted by the TCEQ and NRA. Stations 12985, 12987, and 12989 are monitored quarterly by TCEQ, while station 18418 is monitored quarterly by the NRA. Of note, station 12989 is in fairly close proximity to station 12988 and replaced station 12988 as a routine monitoring location in 1990 (see Figure 4); thus, data for stations 12988 and 12989 were combined for evaluation in this report. Data from 1974 through 1989 are from station 12988, while data from 1990 through 2010 are from station 12989.

Table 2 Number of bacteria and nitrate samples available through December 2010 for Leona River, Segment 2109. Data obtained from SWQMIS (TCEQ, 2011c).

TCEQ Station No.	Station Location Description	Fecal Coliform[a]	*E. coli*[a]	Nitrate[b]
12956	Cooks Slough at FM 117	2	0	2
12957	Cooks Slough downstream Uvalde WWTF	2	0	2
12958	Fish Hatchery Slough at US 83	2	0	2
12959	Cooks Slough at US HWY 83	0	0	0
12985	Leona River at FM 1581	56	23	83
12986	Leona River at Loma Vista Road	0	0	1
12987	Leona River at US 57	22	29	43
12988	Leona River SE of Uvalde	46	0	49
12989	Leona River at Hoags Dam	2	21	18
12990	Leona River at FM 140	2	0	2
12991	Leona River Uvalde Golf Course	0	0	1
12992	Leona River at Highway 90 west	0	0	0
17980	Lake El Caballo NFTS 0196	0	0	0
18418	Leona River upstream of FM 140	0	21	23

a. For fecal coliform, samples represent parameter code 31616 and for *E. coli*, samples represent parameter code 31699. Parameter codes representing other bacteria methods were reviewed and had only minimal data (two samples or less) in association with all Leona River stations, and, thus, were not included.

b. Nitrate is often measured as nitrite (NO_2-N) plus nitrate (NO_3-N) rather than solely NO_3-N. Because NO_2-N is generally found at low concentrations and easily converts to NO_3-N, parameters codes include 00593 (total NO_2-N + NO_3-N filtered), 00615 (NO_2-N), 00620 (NO_3-N) and 00630 (total NO_2-N + NO_3-N). Where values for NO_2-N and NO_3-N occurred or values for just NO_3-N and no value for total NO_2-N+NO_3-N, the separate values of NO_2-N and NO_3-N were combined for analysis. Other parameters representing variants of nitrite and nitrate were reviewed and had no data in association with Leona River stations.

Water Quality Assessment Findings

Bacteria is listed on the 2010 Texas 303(d) List as an impairment with regard to the use of contact recreation for assessment units 2109_01 (from the downstream end of segment to the confluence of Yoledigo Creek), 2109_02 (from the confluence of Yoledigo Creek to the confluence of Camp Lake Slough), and 2109_03 (from the confluence of Camp Lake Slough to the upper end of segment) of the Leona River (Figure 4).

In assessing the suitability of a waterbody for recreational use, bacteria are generally used as an indicator of the potential for contamination of the water by feces of warm-blooded animals. Fecal coliforms are gram negative, facultative anaerobic, lactose fermenting bacteria that are commonly found in the intestines of homeotherms (Talaro and Talaro, 1999). *Escherichia coli*, a species of coliform bacteria, is often used as an indicator of the possible presence of fecal pathogens in water, because its concentration in water is relatively easy to measure, and it is often the most abundant species of the fecal coliform bacteria (Talaro and Talaro, 1999). *E. coli* concentrations are typically expressed as a most probable number per 100 milliliters of water (MPN/100 mL), while fecal coliform concentrations are typically expressed as the number of colony forming units per 100 milliliters of water (cfu/100 mL). Criteria are expressed as the number of bacteria per 100 mL of water (in terms of colony forming units, most probable number, or other applicable reporting measures), so the units MPN/100 mL and cfu/100 mL are used interchangeably.

Within the 2010 Texas Water Quality Inventory, all classified waterbodies are presumed to support contact recreation and any change in that designation requires a comprehensive study. Contact recreation is defined as recreational activities involving a significant risk of ingestion of water, such as swimming or wading by children. In 2000, Texas adopted a geometric mean of 126 *E. coli* per 100 mL of water as the criterion for assessing the use of contact recreation in freshwaters within the SWQS as recommended by EPA. Prior to this change, a geometric mean of 200 fecal coliform per 100 mL of water had been used as the criterion for contact recreation. With the change in 2000 of the SWQS, fecal coliform temporarily continued to be collected as an indicator to allow a transition period. Of note prior to 2004, most bacteria data were reported as fecal coliform rather than *E. coli* as TCEQ gradually phased from fecal coliform to *E. coli* as the primary indicator of bacteria in freshwaters.

More recently in June 2010, TCEQ adopted further revisions to the criteria for evaluating contact recreation by expanding from two categories (contact and noncontact recreation) to four categories (primary contact recreation [PCR], secondary contract recreation 1 [SCR1], secondary contact recreation 2 [SCR2], and noncontact recreation [NCR]) with corresponding changes to numeric criterion associated with each category (Table 3). These additional categories were made into rules as part of the TSWQS in July 2010, which were reviewed and approved by EPA in June 2011. The default category is primary contact recreation unless it can be demonstrated with a Recreational Use Attainability Analysis (RUAA) that a different category of recreational use is more appropriate.

Table 3 Recreation use categories and numeric criteria. Source: TSWQS (2010a).

Contact Category	Basic Definition	Criteria as Geometric Mean of *E. coli*/100 mL
Primary Contact Recreation (PCR)	Activities that are presumed to involve a significant risk of ingestion of water (e.g. wading by children, swimming, water skiing, diving, tubing, surfing, and the following whitewater activities: kayaking, canoeing, and rafting).	126
Secondary Contact Recreation (SCR1)	Activities that commonly occur but have limited body contact incidental to shoreline activity (e.g. fishing, canoeing, kayaking, rafting and motor boating). These activities are presumed to pose a less significant risk of water ingestion than primary contact recreation but more than secondary contact recreation 2.	630
Secondary Contact Recreation (SCR2)	Activities with limited body contact incidental to shoreline activity (e.g. fishing, canoeing, kayaking, rafting and motor boating) that are presumed to pose a less significant risk of water ingestion than secondary contact recreation 1. These activities occur less frequently than secondary contact recreation 1 due to physical characteristics of the waterbody or limited public access.	1,030
Noncontact Recreation (NCR)	Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity, including birding, hiking, and biking. Noncontact recreation use may also be assigned where primary and secondary contact recreation activities should not occur because of unsafe conditions, such as ship and barge traffic.	2,060

The Leona River (Segment 2109) first appeared on the 2006 Texas 303(d) List due to *E. coli* concentrations that exceeded the geometric mean criteria for contact recreation use (Table 4). Also beginning in 2002, there was a concern noted due to elevated nitrate concentrations that exceeded the screening levels associated with general use (Table 5). Of note, screening levels for nutrients are statistically derived by TCEQ from statewide surface water quality monitoring data and represent the 85^{th} percentile value for each parameter in freshwater streams and are used to indicate concerns with regard to general uses of the water and not impairments (TCEQ, 2010b). While a variety of other parameters were evaluated in assessing water quality, no other impairments or concerns were noted.

Table 4 Bacteria assessment information reported by TCEQ in determining impairment status of Segment 2109

Assessment Year	Period of Record Assessed	Assessment Unit	Number of Fecal Coliform Samples	Fecal Coliform Geometric Mean (cfu/100 mL)	Number of *E. coli* Samples	*E. coli* Geometric Mean (MPN)
2006	01Dec1999 – 30Nov2004	2109_01	8	338	9	168
		2109_02	8	141	11	190
		2109_03	0	NA[a]	1	NA
2008	01Dec1999-30Nov2006	2109_01	8	338	16	232
		2109_02	8	141	19	228
		2109_03	0	NA	16	274
2010	01Dec2001-30Nov2008	2109_01	NR[b]	NR	21	171
		2109_02	NR	NR	23	233
		2109_03	NR	NR	31	202

a. NA indicates that a value is not applicable.
b. NR indicates that a value was not reported.

Table 5 Assessment values reported by TCEQ in determining nitrate concerns for Segment 2109. Nitrate screening level was 2.76 mg/L for the 2002 and 2004 assessments and 1.95 mg/L for the 2006, 2008 and 2010 assessments.

Assessment Year	Period of Record Assessed	Assessment Unit	Number of Nitrate Samples	Number of Samples That Exceed Screening Level	Mean of Samples That Exceed Screening Level (mg/L)
2002 & 2004[a]	01Mar1996-28Feb2001	2109 (entire segment)	12	12	9.47
2006	01Dec1999 – 30Nov2004	2109_01	17	15	NR[b]
		2109_02	14	14	NR
		2109_03	3	1	NR
2008	01Dec1999-30Nov2006	2109_01	23	21	NR
		2109_02	22	20	NR
		2109_03	17	15	NR
2010	01Dec2001-30Nov2008	2109_01	23	21	8.17
		2109_02	27	23	3.89
		2109_03	28	26	2.60

a. In 2004, a targeted assessment was implemented of parameters and segments and Segment 2109 was not reassessed in 2004, but the assessment from 2002 was carried over into the 2004 Texas Water Quality Inventory.
b. NR indicates that a value was not reported.

Streamflow and Water Level Data

With regard to daily streamflow and water level data, four USGS gaging stations have been located in the watershed (Figure 5; USGS, 2012), but only three have had routine data collected within the last few years (Table 6). Station 8204500 on the Leona River near Divot, Texas has a short history of discharge data from 1924 through 1929, although this location is still used on rare occasions (twice in the last 10 years) by the USGS to collect field measurements of discharge. Divot, Texas is located at the intersection of Farm roads 1581 and 117 and is considered a ghost town with an unknown population, thus, it no longer appears on most maps (Ochoa, 2012). Only two USGS stations are currently operating with data reported real-time. These are station 8204005 on the Leona River south of Uvalde, where discharge and gage height are reported, and station 8203450 north of Uvalde, where only gage height is reported. Station 8204250 on the Leona River near Batesville was discontinued in August 2010 due to funding shortfalls, but for about three years reported both discharge and gage height. Of note, station 8204005 on the Leona River near Uvalde is also in very close proximity and is considered collocated with TCEQ water quality monitoring station 12988. Also at the same location as station 8204005, 572 field measurements of stream stage and discharge were available for station 8204000 (Leona Springs near Uvalde, TX) starting on February 7, 1939 and ending on March 7, 2007. Another field measurement station (8204200) is located on the Leona River at SH 57 near Batesville, Texas, but only two flow measurements have been taken at this location.

Table 6 History of daily discharge and gage height data for USGS stations within the Leona River watershed. Source: USGS (2012).

Station Number	Station Description	Latitude	Longitude	Discharge Data		Gage Height Data	
				Start Date	End Date	Start Date	End Date
8204500	Leona River near Divot, TX	28.792778	99.240833	01May1924	30Sep1929	--	--
8204250	Leona River at FM 1866 near Batesville	28.905833	99.577222	22May2008	03Jan2011	23May2008	03Jan2011
8204005[a]	Leona River near Uvalde, TX	29.154167	99.743056	01Mar2003	Present	01Mar2003	Present
8203450	Leona River at CR 429A near Uvalde, TX	29.345278	99.748889	--	--	22Jan2010	Present

a. Station 8204000, Leona Springs near Uvalde, TX is a USGS station at the same location as 8204005. Station 8204000 has field measurements back to 1939 but not daily data.

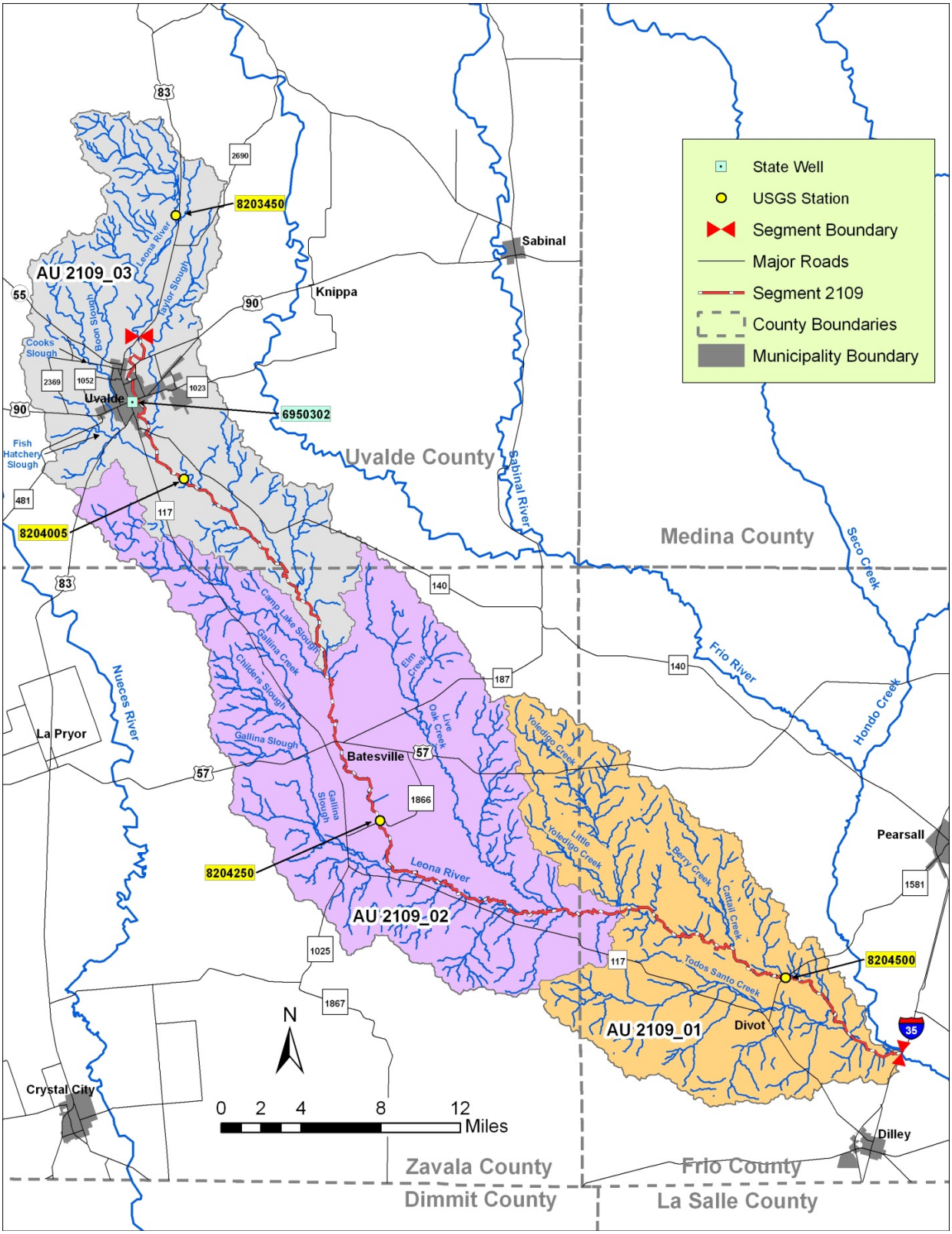


Figure 5 USGS daily stream gaging stations and EAA State Well Index site within the Leona River watershed. (Note: State Well 6950302 is also referenced as Index Well J-27).

Average daily discharge for station 8204005 from 2003 through 2008 often showed flows well above 10 cfs. The years 2009 through 2011 indicate much lower flows with the Leona River often showing zero flow conditions, particularly during the summer months (Figure 6). While the history of flows at station 820425 near Batesville are much more limited, they generally tracked the flows at from the upstream station (8204005) but at a notably lower level.

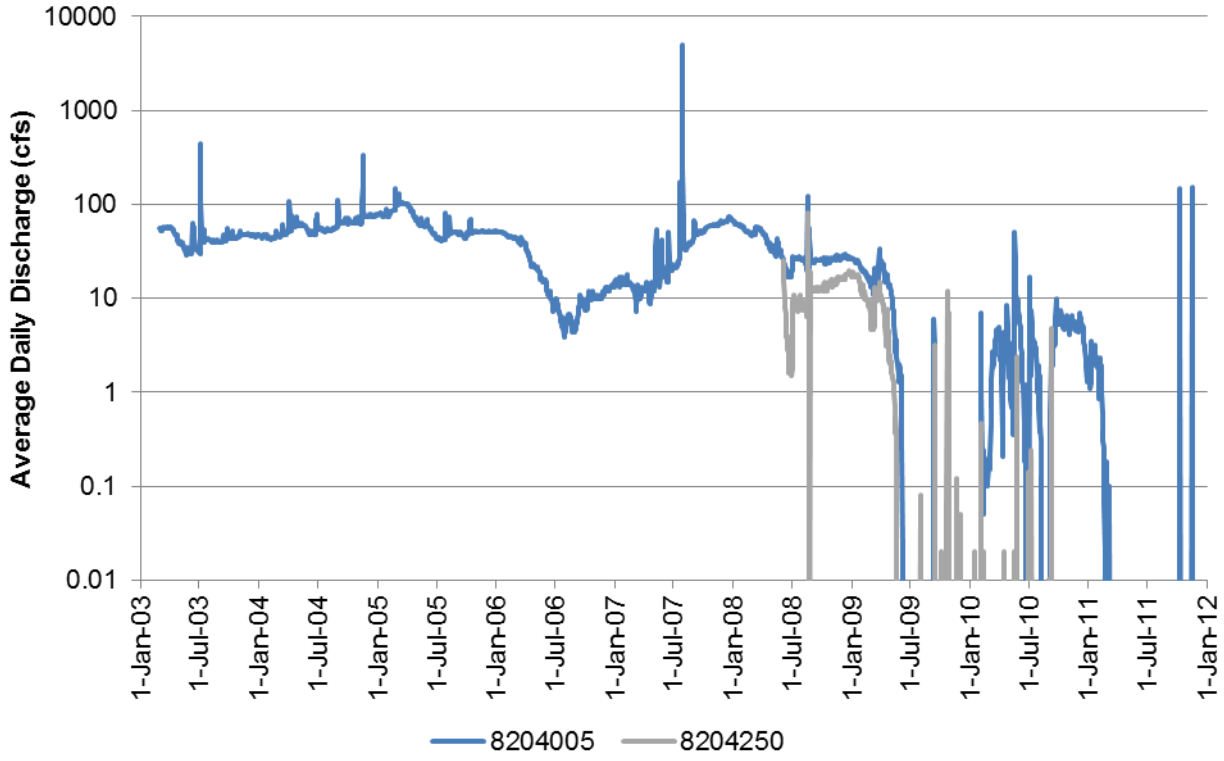


Figure 6 Daily average flow for USGS Stations 8204005 and 8204250 on the Leona River near Uvalde, Texas through December 2011. Source: USGS (2012).

As a comparison of longer-term data, daily flows for 8204005 were also compared to field measurements collected at 8204000 (Figure 7). Of note during the 1950s, several field measurements were made where zero or no flow was recorded that do not show on the log-scale chart. Station 8204000 was named Leona Springs as flows at this location represent surface flows from four known springs in the area, as well as tributary flow from Cooks Slough. Flows in the Leona River at stations 8204000 and 8204005 have been used by the USGS and the EAA to aid in estimating groundwater flows (e.g., Green et al., 2008).

For Segment 2109 within the SWQMIS data, flow (parameter code 00061) and estimated flow (parameter code 74069) were often reported in conjunction with water quality measurements, particularly with more recent sampling events. Flow severity (parameter code 01351), which is reported as 1 (no flow), 2 (low flow), 3 (normal flow), 4 (flood flow), 5 (high flow) and 6 (dry), was also commonly indicated with water quality data. Flow severity is an observational measurement that is highly dependent on the waterbody and the knowledge of the monitoring personnel, but is useful as an indicator of flow conditions at the time water quality samples are collected.

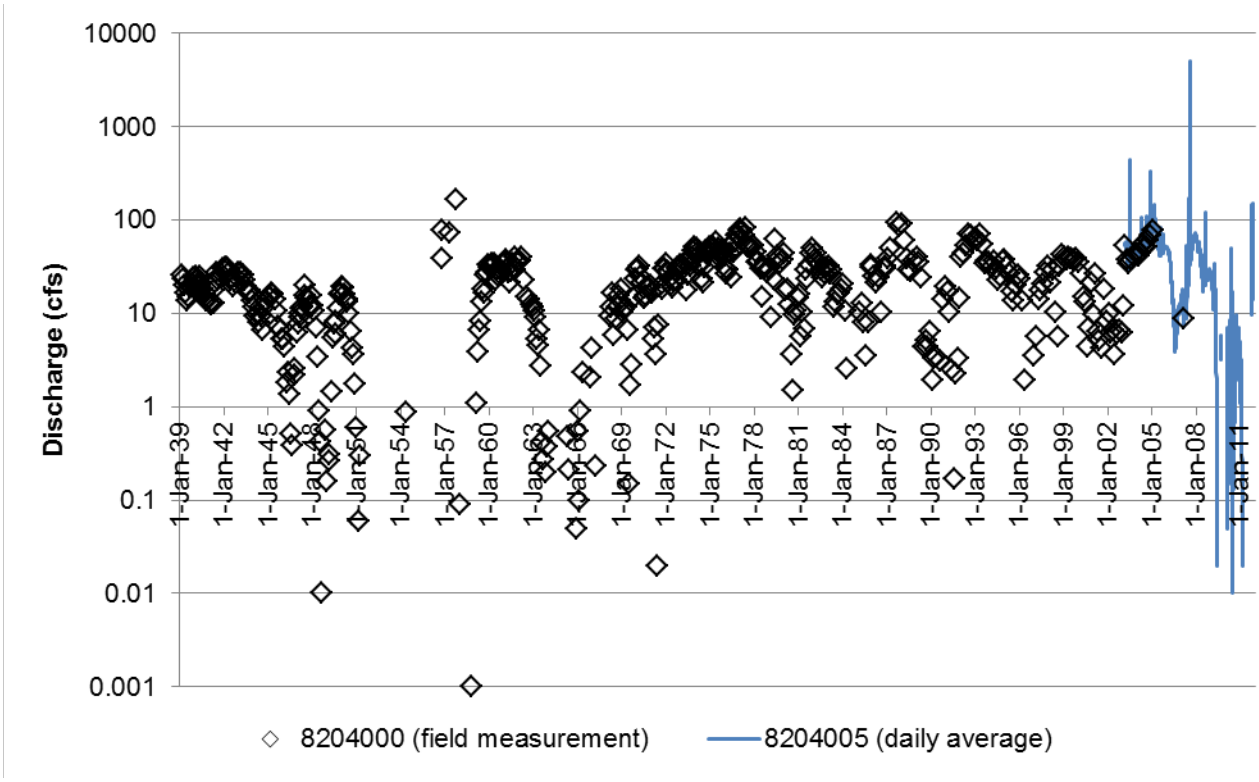


Figure 7 Daily average flow for USGS stations 8204005 compared with field measurements collected at station 8204000

Groundwater Levels and Water Quality Data

Because of the importance of area for recharge to the Edwards Aquifer, the Edwards Aquifer Authority (EAA) maintains a continuous water level monitoring station within the City of Uvalde. This station is State Well number 6950302 (Figure 5) and is also referenced as Index Well J-27 (Uvalde) by the EAA. Data for State Well 6950302 extend back to October 1940 and are generally are available on a daily basis (Figure 8). Levels within State Well 6950302 are used by the EAA to aid in triggering critical periods for reductions in groundwater withdrawals by permitted municipal, industrial and irrigation users of the Edwards Aquifer (EAA, 2012).

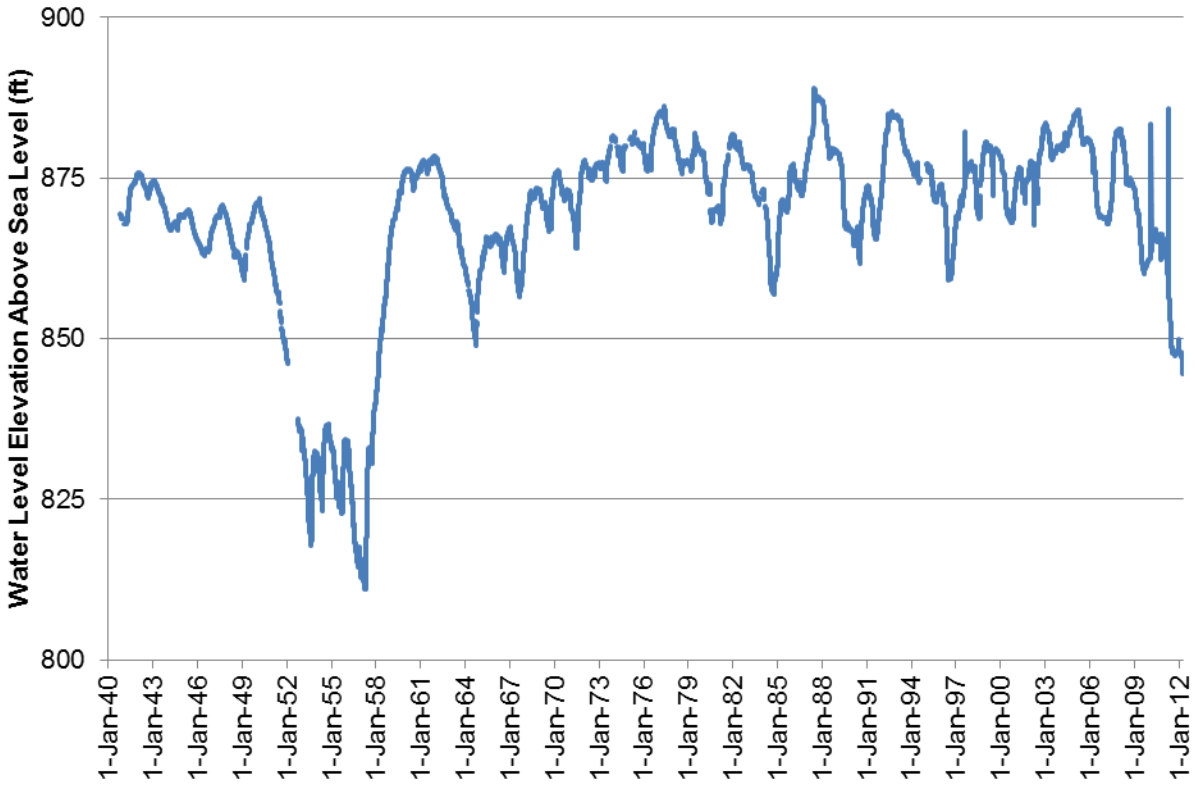


Figure 8 Groundwater levels reported for State Well 6950302 within Uvalde, Texas also referenced as Index Well J-27. Source: San Antonio Water System (2012).

The TWDB maintains a database of statewide well locations by county (TWDB, 2012). Along with this well database is a compilation of groundwater quality reports. The Geographic Information System (GIS) shapefile for well locations was downloaded from the TWDB website and overlaid with the Leona River watershed boundary to determine which wells by county were reported in the watershed area. No bacteria data were within any of the water quality reports, but nitrate-nitrogen data were often reported (Table 7).

Plots of the nitrate data clearly showed elevated values from wells in Uvalde and Zavala since about 1970 (Figure 9). In Frio County, all well nitrate concentrations were well below the 10 mg/L drinking water standard, while in Uvalde and Zavala County, well nitrate concentrations were often greater than 10 mg/L. On note, the majority of wells only had one water quality reading, there were many wells with multiple readings (from 2 to 16). Of the nitrate concentrations over 20 mg/L in Uvalde County, 78 percent of the observations came from just two wells. For Zavala County, 54 percent of the observations with concentrations greater than 20 mg/L nitrate-N came from just five wells.

Table 7 Summary of nitrate-nitrogen data for wells within the Leona River watershed. Source: TWDB Groundwater Quality Reports by County (TWDB, 2012).

Well Information	County		
	Uvalde	Zavala	Frio
Number of Registered Wells within Leona River Watershed	243	241	81
Number of Wells with Nitrate Data	35	83	22
Number of Nitrate Readings	107	138	38
Start Date Nitrate Readings	20-May-1930	9-Feb-1928	17-Jun-1932
End Date Nitrate Readings	12-Jul-2011	13-Jul-2010	22-Jul-2010
Average Nitrate-N (mg/L)	17.4	12.8	0.53
Median Nitrate-N (mg/L)	13.9	0.40	0.40
Standard Deviation Nitrate-N (mg/L)	13.1	25.2	0.81
Minimum Nitrate-N (mg/L)	0.04	0.02	0.02
Maximum Nitrate-N (mg/L)	87.2	121.3	4.50
Number of Readings $\geq$ 20 mg/L Nitrate-N	32	28	0
Number of Wells with Readings $\geq$ 20 mg/L Nitrate-N	7	15	0
Number of Readings < 20 and > 10 mg/L Nitrate-N	49	5	0
Number of Wells with Readings < 20 and > 10 mg/L Nitrate-N	18	5	0

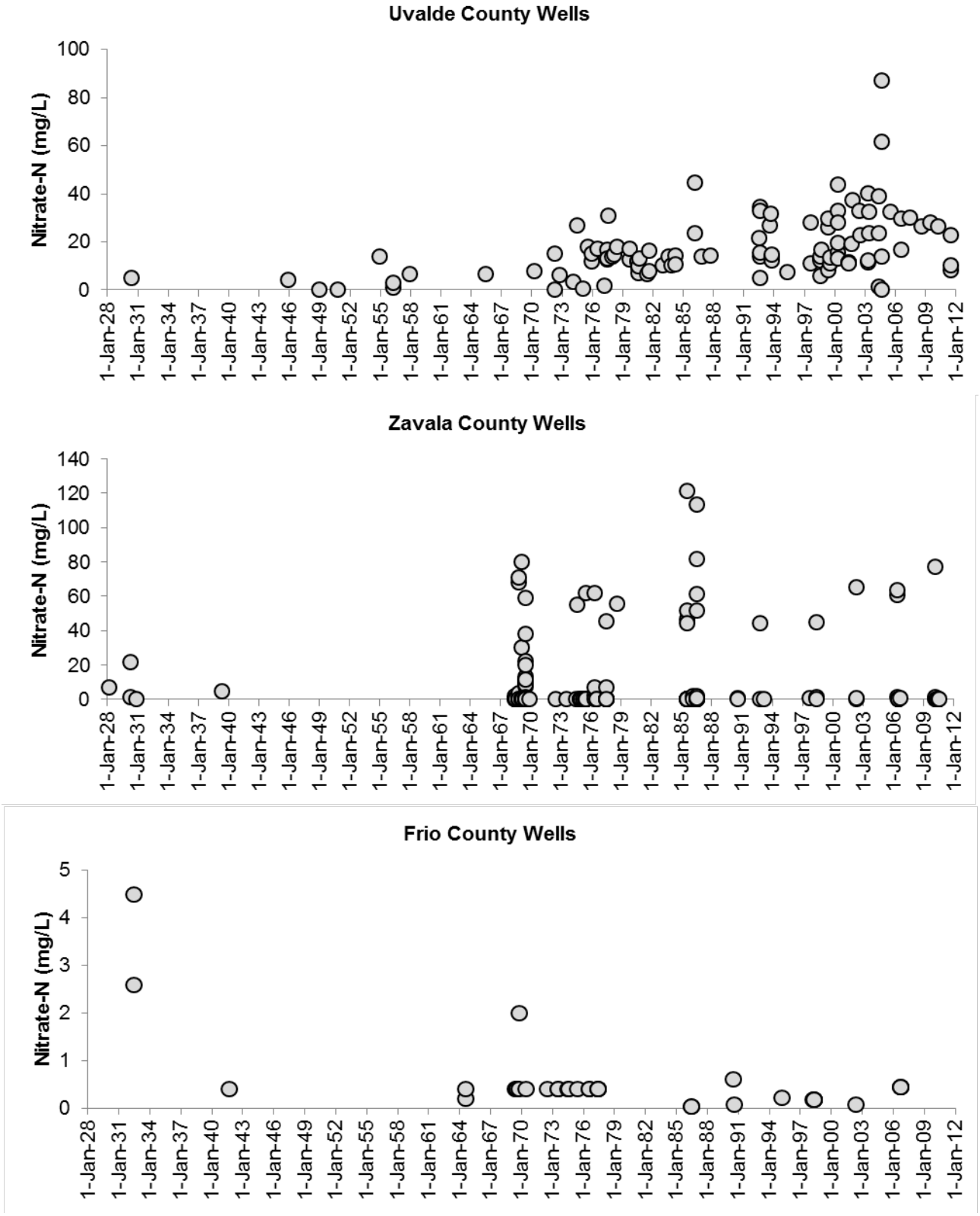


Figure 9 Groundwater nitrate-nitrogen concentrations for wells within the Leona River watershed by county. Source: TWDB (2012).

There are three Groundwater Conservation Districts (GCDs) within the Leona and representing the upper, middle and lower regions. The Uvalde County Underground Water Conservation District (UWCD) covers Uvalde County and was formed in 1993. The Wintergarden GCD includes the counties of Zavala, Dimmitt and La Salle and was formed in 1998. Frio County is in the Evergreen UWCD, which was formed in 1965, and also includes Atascosa, Wilson and Karnes Counties. Local GCDs are authorized with powers and duties that enable them to manage groundwater resources by providing for the conservation, preservation, protection, recharging, and prevention of waste of the groundwater resources within their jurisdictions. GCDs (Fipps, 2001). The three primary GCD authorities include: permitting water wells; developing a comprehensive management plan; and adopting the necessary rules to implement the management plan. A query of each GCD indicated no additional well water quality data beyond that provided by the TWDB.

Precipitation Records

Precipitation records for locations within or near the Leona River watershed from the National Weather Service (NWS) were accessed via the National Climatic Data Center (NCDC) website (Figure 10). Currently active stations were located in conjunction with the communities of Crystal City, Derby, La Pryor, Pearsall, Sabinal, and Uvalde (Table 8). Other active stations included the Highway 57 Farm west of La Pryor and Palomo Lodge south of La Pryor. Many of the stations have historical precipitation records but have not been active for several years (Table 8). While most years were complete, many years contained only partial annual datasets.

Daily precipitation data for Uvalde stations were combined to obtain annual values from 1905 through 2011 (Figure 11). The 30-year average rainfall for data from 1980 through 1999 was calculated as 25.1 inches. It should be noted that the 30-year average excludes data from the years 1985, 1993, 1998 and 1999 due to significant amounts of missing daily precipitation data during these four years. Of the years considered to have complete records, 60 out of 96 years had precipitation totals below the long-term average. The lowest annual precipitation total was recorded in 1956 with only 9.3 inches and the highest annual total was in 1976 with 45.1 inches.

While rainfall can vary greatly across the watershed for any given storm event, annual totals were compared between the Uvalde and Pearsall stations and annual total were generally comparable (Figure 12), although the most recent year presented, 2011, showed notably higher rainfall amounts at Uvalde than at Pearsall.

Based on the long-term record for Uvalde at station USC00419265, the wettest month on average for the period of record was May with an average of 3.27 inches and the driest month January with an average of 1.13 inches. Precipitation patterns indicated much wetter conditions generally from April through October averaging 2.59 inches per month and notably drier conditions November through March averaging 1.19 inches per month.

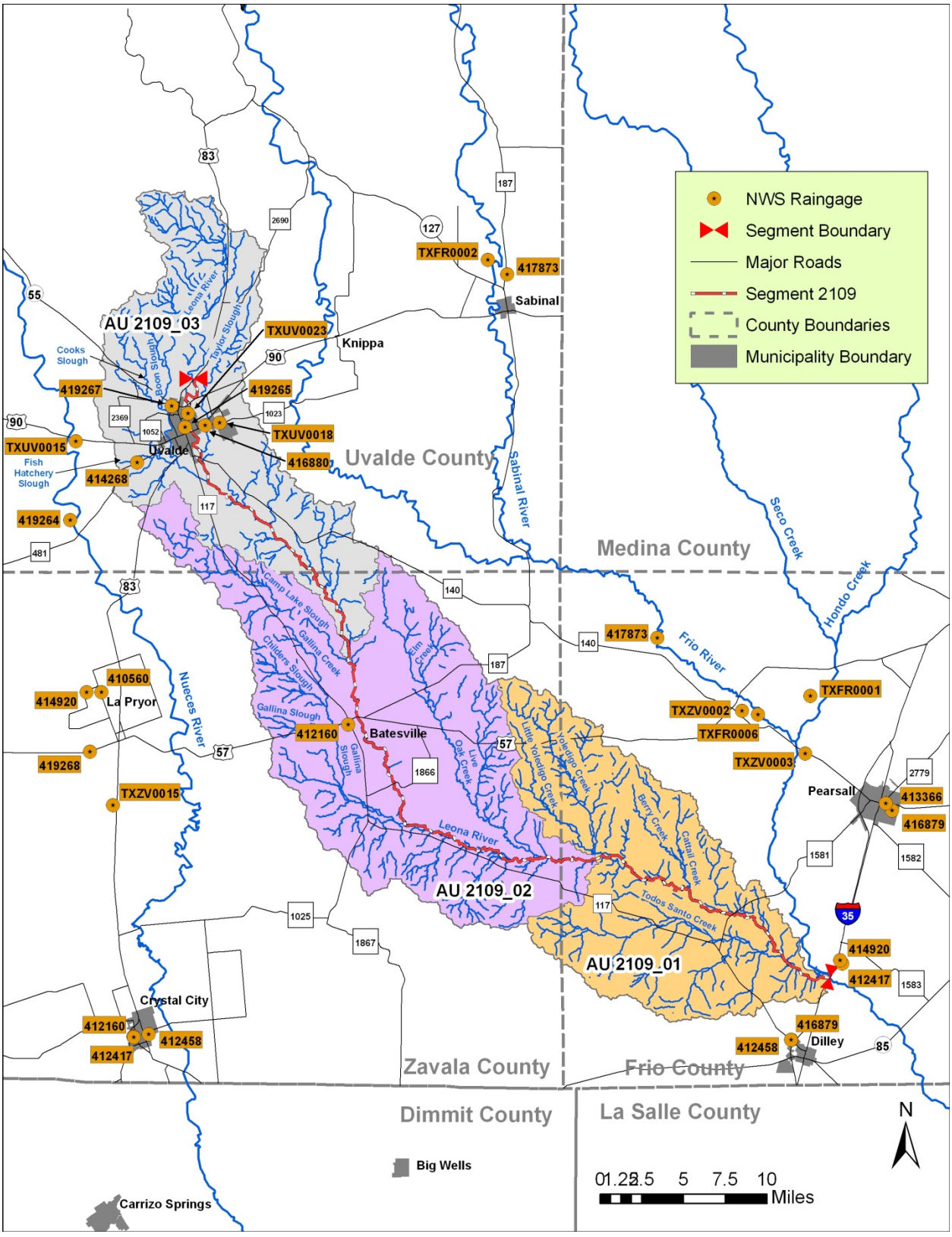


Figure 10 Location of NWS stations with records of daily precipitation data within or near the Leona River watershed. Source: NCDC (2012).

Table 8 History of daily precipitation records through December 2011 for NWS stations within and surrounding the Leona River watershed. Source: NCDC (2012).

Station Name	Station	Years with Complete Daily Data[a]	Years with Partial Data	Total Years	Latitude	Longitude	Date First Observation	Date Last Observation
BATESVILLE	GHCND:USC00410560	27	10	37	28.9567	-99.6228	1-Jun-1965	31-Mar-2001
CRYSTAL CITY	GHCND:USC00412160	62	6	68	28.6833	-99.8333	3-Jan-1941	31-Dec-2008
CRYSTAL CITY 0.5	GHCND:US1TXZV0015	0	4	4	28.6859	-99.8185	22-Aug-2008	31-Dec-2011
DERBY 1 S	GHCND:USC00412417	27	7	34	28.7528	-99.1350	1-Apr-1978	31-Dec-2011
DILLEY	GHCND:USC00412458	90	6	96	28.6833	-99.1833	1-Mar-1910	30-Jun-2008
FRIO TOWN	GHCND:USC00413366	22	6	28	29.0333	-99.3167	1-Sep-1947	30-Nov-1979
HIGHWAY 57 FARM	GHCND:US1TXZV0002	1	3	4	28.9318	-99.8785	24-Jul-2008	31-Dec-2011
LA PRYOR	GHCND:USC00414920	68	25	93	28.9836	-99.8678	1-Apr-1915	31-Dec-2011
PALOMO LODGE	GHCND:US1TXZV0003	1	3	4	28.8853	-99.8555	24-Jul-2008	31-Dec-2011
PEARSALL	GHCND:USC00416879	88	20	108	28.8894	-99.0897	1-Mar-1902	31-Dec-2011
PEARSALL 10.2 NW	GHCND:US1TXFR0001	0	5	5	28.9700	-99.2326	22-Apr-2007	31-Dec-2011
PEARSALL 5.6 WNW	GHCND:US1TXFR0006	0	3	3	28.9327	-99.1699	2-Apr-2009	15-Nov-2011
PEARSALL 7.9 NNW	GHCND:US1TXFR0002	1	4	5	28.9831	-99.1647	8-May-2007	31-Dec-2011
PEARSALL 9 WNW	GHCND:USC00416880	3	1	4	28.9667	-99.2167	1-Jan-1980	31-Jan-1983
SABINAL	GHCND:USC00417873	92	16	108	29.3622	-99.4864	1-Sep-1903	31-Dec-2011
UVALDE	GHCND:USC00419265	72	9	81	29.2167	-99.7667	1-Mar-1905	31-May-1985
UVALDE 0.1 WSW	GHCND:US1TXUV0023	0	2	2	29.2151	-99.7865	2-Jun-2010	31-Dec-2011
UVALDE 0.8 N	GHCND:US1TXUV0018	2	3	5	29.2271	-99.7837	13-Oct-2007	31-Oct-2011
UVALDE 3 SW	GHCND:USC00419268	12	9	21	29.2192	-99.7522	1-Jan-1982	31-Mar-2005
UVALDE 6.7 W	GHCND:US1TXUV0015	0	3	3	29.2020	-99.8950	11-May-2007	4-Jan-2009
UVALDE 9 SW	GHCND:USC00419264	0	3	3	29.1333	-99.9000	1-Aug-1996	31-Aug-1998
UVALDE	GHCND:USC00419267	21	6	27	29.2333	-99.8000	1-Mar-1920	20-Dec-1946

a. Complete years were considered those with less than 10 days of missing data.

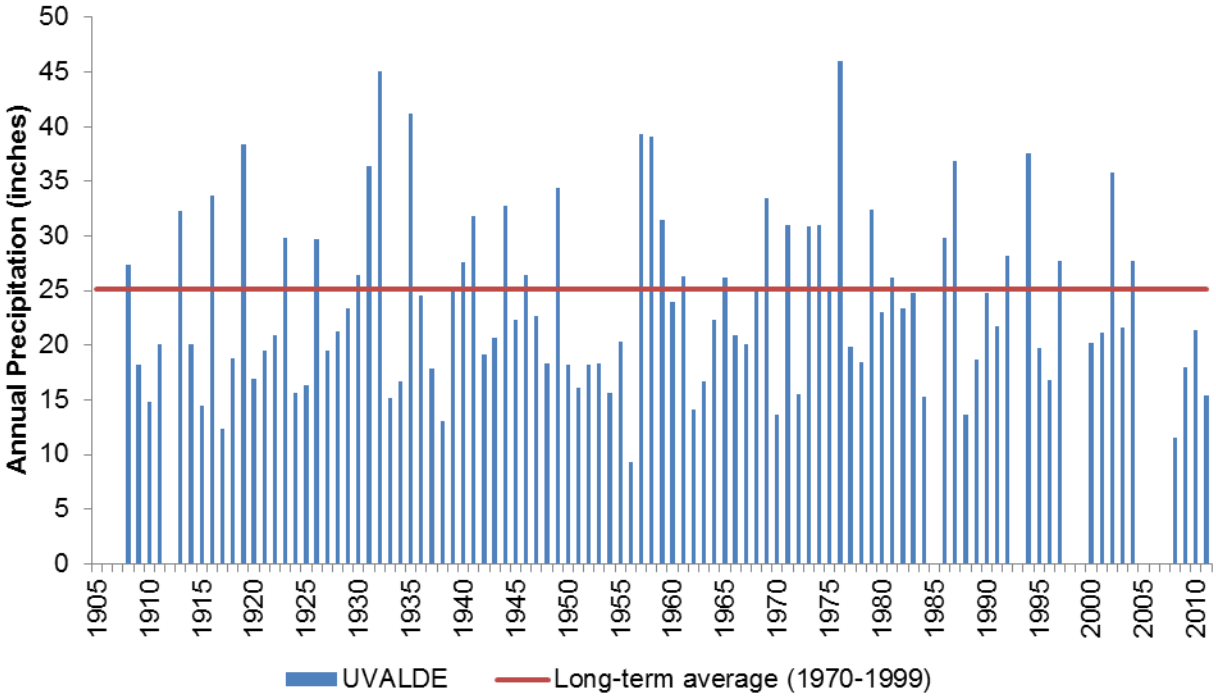


Figure 11 **A**nnual precipitation for Uvalde, Texas through 2011. Gaps indicate years with over 90 percent missing data for daily values. Source: NCDC (2012).

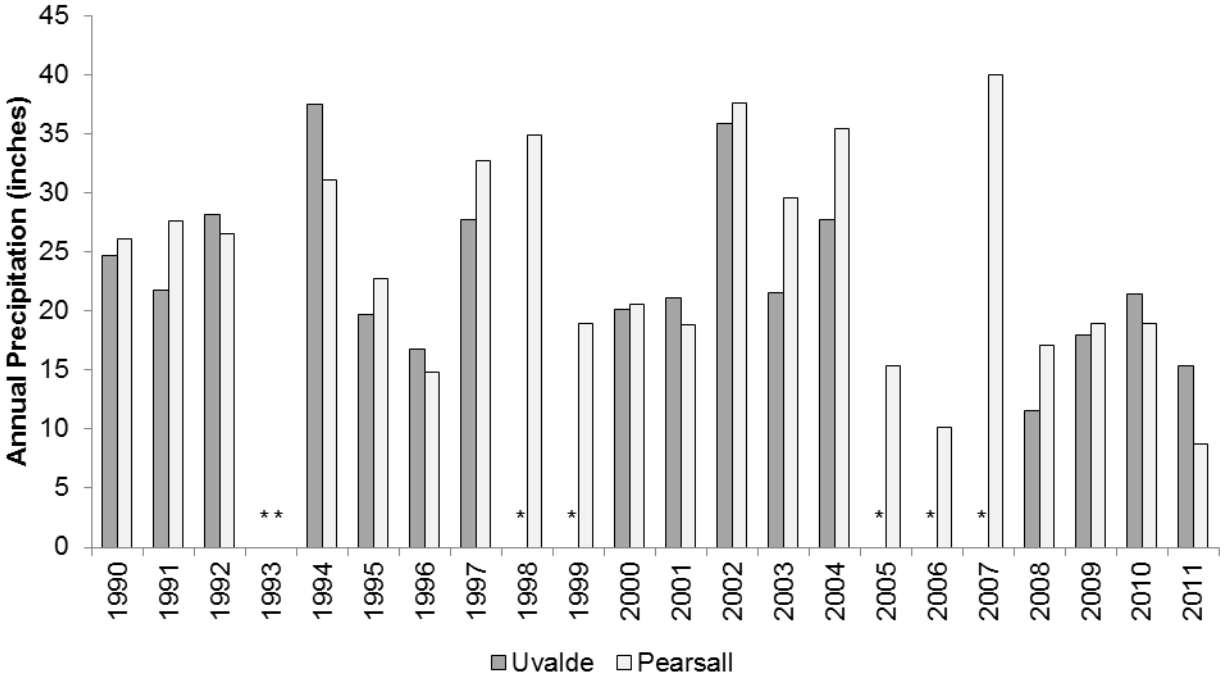


Figure 12 Comparison of annual precipitation for Uvalde and Pearsall NWS stations. Asterisks indicate years with over 90 percent missing data for daily values. Source: NCDC (2012).

Other sources of precipitation data near or within the Leona River watershed include the AgriLife Extension TexasET Network and the EAA rainfall network. The AgriLife TexasET Network focuses on current and average evapotranspiration data and other weather information to provide farmers with irrigation watering recommendations. Texas ET Network weather stations online within or near the Leona River watershed include one in Uvalde and another near La Pryor that can be accessed http://texaset.tamu.edu/index.php. The EAA operates "real-time" precipitation gages that record data on six-minute intervals and transmit these data via a radio-telemetry system. While most of the EAA gages are outside the Leona River watershed, rainfall within the upper portion of the Leona River watershed near Uvalde is represented. The EAA network of rain gages can be accessed via the EAA website at http://www.edwardsaquifer.org/raingauge_network.php.

SECTION 3

Permitted Facilities and Effluent Discharges

Permitted Sources

Wastewater Treatment Facilities and Other Permitted Discharges

There are two permitted WWTF located within Segment 2109, the City of Uvalde and the City of Batesville (Figure 13). The City of Uvalde WWTF has three outfalls permitted for a total average daily flow of 0.97 million gallon per day (MGD). Outfall 001 is located at the facility south of the City and discharges into a series of ponds developed as a wetlands area and then into Cooks Slough, a tributary of the Leona River (Figure 14). A portion of the effluent is often diverted and piped to Outfall 002, which discharges directly into the Leona at a point within the Uvalde City Park (Figure 15). Of the effluent diverted to the Uvalde City Park, a small portion on occasion is pumped into a holding pond for use as irrigation water on the Municipal Golf Course. Outfall 3 for the City of Uvalde is seldom used but is located near the facility and directly discharges into Cooks Slough bypassing the wetland ponds. Discharge records for 2007-2011 indicate an average discharge of 0.39 MGD for all three outfalls combined with 28% of discharge going through Outfall 1, 66% through Outfall 2, and 6% through Outfall 3 (USEPA, 2012).

The effluent from the City of Batesville WWTF evaporates in holding ponds (Figure 16) and no discharges have occurred, but if a discharge were to occur, it would flow into Galliana Slough, a major tributary of the Leona River located in AU 2109_02. The permitted discharge for the Batesville WWTF is 0.184 MDG.

The only other discharge facility with an active permit is the U.S. Fish and Wildlife Service National Fish Hatchery in Uvalde, which discharges flush water intermittently into Fish Hatchery Slough, a tributary of the Leona River west of Uvalde in AU 2109_03. Records accessed through EPA for 2008-2011 indicate an average discharge of 0.84 MGD (USEPA, 2012).

A vegetable processing plant operated by TAFMI, Inc (previously Agrilink Foods) located north of Uvalde used to have a permit to discharge processing wastewater via land irrigation, but according to TCEQ records queried on February 7, 2012, this operation no longer has an active permit, thus, it is not included in Figure 13.

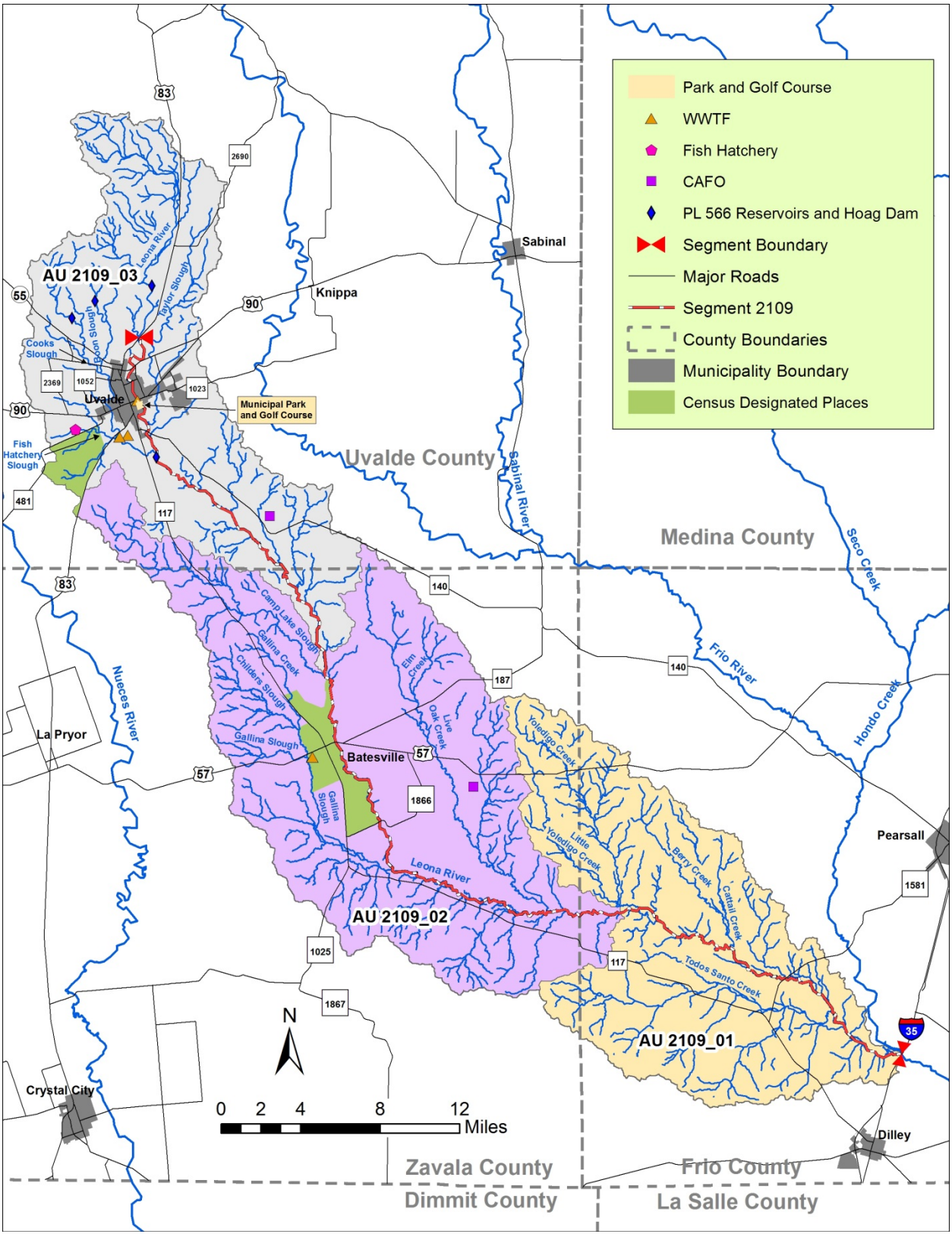


Figure 13 Location of permitted sources and populated areas within the Leona River watershed.

Figure 14 Uvalde WWTF discharge location within the Uvalde City Park. Photo taken September 28, 2011.

In a review of available discharge data for these permitted facilities, bacteria and nitrate were not reported nor required monitoring under current permits (USEPA, 2012). Ammonia nitrogen data have been reported by the Uvalde WWTF and the National Fish Hatchery. Both facilities have a daily average ammonia limit of 2 mg/L, and the Uvalde WWTF did receive an enforcement action for elevated ammonia concentrations for samples in March and April 2010 that were not in compliance based on concentrations of 4.0 and 9.0 mg/L. Excluding the March and April 2010 results, on average the ammonia from the Uvalde WWTF averages 0.5 mg/L. All ammonia values reported by the National Fish Hatchery were indicated to be below 1 mg/L. The only other permit violation noted was for the Uvalde WWTF for elevated concentrations of total suspended solids (TSS) in March, May and June of 2006. The TSS permit limit is 15 mg/L and concentrations leading to the 2006 enforcement action ranged from 17 to 29 mg/L TSS.

Figure 15 Uvalde WWTF wetland ponds that feed into Cooks Slough. Photo taken November 22, 2011.

Figure 16 Batesville WWTF effluent holding ponds 1 and 2. Photos taken March 9, 2011.

Regulated Stormwater

The Texas Pollutant Discharge Elimination System (TPDES) and the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer (MS4) Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Phase I permits are individual permits for large and medium sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities that are located within an "Urbanized Area". An "Urbanized Area" is defined by the U.S. Census Bureau as an area with populations greater than 50,000 and with an overall population density of at least 1,000 people per square mile. The City of Uvalde has a total population of 15,751 based on 2010 population estimates from US Census Bureau (Texas State Data Center, 2011) and is not considered to be located in an urbanized area based on population density, thus, Uvalde is not required to obtain a permit for their stormwater system. A separate population estimate of 2,171 is provided for the subdivision area, Uvalde Estates (Figure 13), which is located southwest of the City of Uvalde and is considered a census-designated place (CDP). A CDP is a statistical geographic entity representing closely settled, unincorporated communities that are locally recognized and identified by name. These CDPs are the statistical equivalents of incorporated places, with the primary differences being the lack of both a legally-defined boundary and an active, functioning governmental structure, chartered by the state and administered by elected officials (Federal Register, 2008). The City of Batesville is unincorporated and has a population estimate of 1,068 based on the 2010 Census data.

Concentrated Animal Feeding Operations

There are currently two permitted concentrated animal feeding operation (CAFO) located within Segment 2109 (Figure 13). The Chaparral Cattle Feedlot is located south of Uvalde in AU 2109_03 and the Live Oak Feedlot located southeast of Batesville within the watershed of Live Oak Creek in AU 2109_02. The Live Oak Feedlot is permitted for 8,000 head of beef cattle, while the Chaparral Cattle Feedlot is permitted for 10,000 head of beef cattle. A query of the TCEQ water quality permit site conducted on February 7, 2012 indicated no violations for either facility. These CAFOs have no discharge permits for wastewaters and manure.

SECTION 4

Water Quality Analysis

Assessment Review

Historical water quality data as noted in Table 2 for fecal coliform, *E. coli*, and nitrate were obtained from TCEQ's publicly available online SWQMIS database. These data were evaluated using TCEQ assessment guidance for the same periods of record used by TCEQ (see Tables 4 and 5). Assessment of these historical data was performed following TCEQ's "Guidance for Assessing and Reporting Surface Water Quality in Texas" as indicated for each assessment period beginning with the 2006 assessment (TCEQ, 2007b; 2008; 2010b). The results of TIAER's assessment matched those performed by TCEQ and confirm the bacteria impairment for Segment 2109 noted on the Texas 303(d) list and the concern indicated for nitrates.

Of the 14 TCEQ sampling stations indicated in the SWQMIS database (Table 1), only 4 are currently included in the routine monitoring conducted by the TCEQ and NRA. Stations 12985, 12987, and 12989 are monitored quarterly by TCEQ, while the NRA quarterly monitors station 18418 (Figure 4). Of note, station 12989 is in fairly close proximity to station 12988 and replaced station 12988 as a routine monitoring location in 1990; thus, data for stations 12988 and 12989 were combined for evaluation in this report. Data from 1974 through 1989 are from station 12988, while data from 1990 through 2010 are from station 12989.

Variability and Trends

The time history of bacteria and nitrate concentrations varied by station with data at stations 12988 and 12985 having records starting in the early to mid-1970s (Table 9). The shortest time history occurred at station 18418 with data starting in 2004. For bacteria data, the shift from fecal coliform to E. coli is shown with a slight overlap in the analysis of these two parameters between 2001 and 2004 at stations 12987 and 12985.

Table 9 Date range of historical bacteria and nitrate water quality data evaluated. Station presented in order of most upstream to most downstream.

Station	Fecal Coliform		*E. coli*		Nitrate	
	Start Date	End Date	Start Date	End Date	Start Date	End Date
18418	NA	NA	09Nov2004	30Nov2010	09Nov2004	30Nov2010
12988/12989	10Jun1974	22Jan1990	05May2005	29Nov2010	10Jun1974	19Apr2010
12987	10Aug1988	25Aug2004	18Jul2001	27Oct2009	10Aug1988	27Oct2009
12985	25Nov1974	22Jun2004	27Nov2001	31Mar2009	09Feb1972	31Mar2009

In plotting bacteria data over time, there was not a clear increasing or decreasing pattern at any of the four long-term stations, although a larger percentage of observations were above the geometric mean criteria for *E. coli* than for fecal coliform (Figures 17 and 18). For all four stations, 38 percent of fecal coliform observations were above the geometric mean criterion of 200 colonies/100 mL, while for *E. coli*, 72 percent of observations were above the geometric mean criterion of 126 colonies/100 mL. This shift in the number of observations above the geometric mean assessment criteria, at least in part, reflects a change in the assessment parameter, but may also reflect a change in water quality. Evaluating if there was a true increase in bacteria concentrations over time may be impossible to determine. There was a bit of overlap at station 12987 and 12985 (Figure 19) when both *E. coli* and fecal coliform were measured between 2001 and 2004, but this overlap involved only eight samples, so not enough data are available to indicate a potential relationship between *E. coli* and fecal coliform measurements for the watershed.

In evaluating just *E. coli* data for the most recent seven years available (2004-2010), all four stations had values above the geometric mean criterion of 126 colonies/100 mL for PCR (Figure 19). The highest geometric mean concentrations occurred at station 12987 (308 colonies/100 mL) and the lowest at station 12989 (161 colonies/100 mL), although geometric means for all four stations were not statistically different from one another. All four stations had geometric mean concentrations well below the criterion of 630 colonies/100 mL associated with SCR1.

For nitrates, most concentrations were above the screening level of 1.95 mg/L for all four long-term stations (Figures 20 and 21). Over time, there did not appear to be a clear increasing or decreasing trend, except at station 12985, the most downstream station, where concentrations increased from around 5 mg/L in the 1970s into the 1990s to around 8 mg/L.

In comparing average concentrations from the most recent seven years of data (2004-2010), concentrations were highest at the most downstream station 12985 with an average of 7.92 mg/L (Figure 22). Average concentrations increased slightly for the other three stations from upstream to downstream, but only from 2.24 mg/L at station 18418 to 2.86 mg/L at station 12987. In comparing average nitrate concentrations between stations, only station 12985 had significantly higher concentrations than the other three stations.

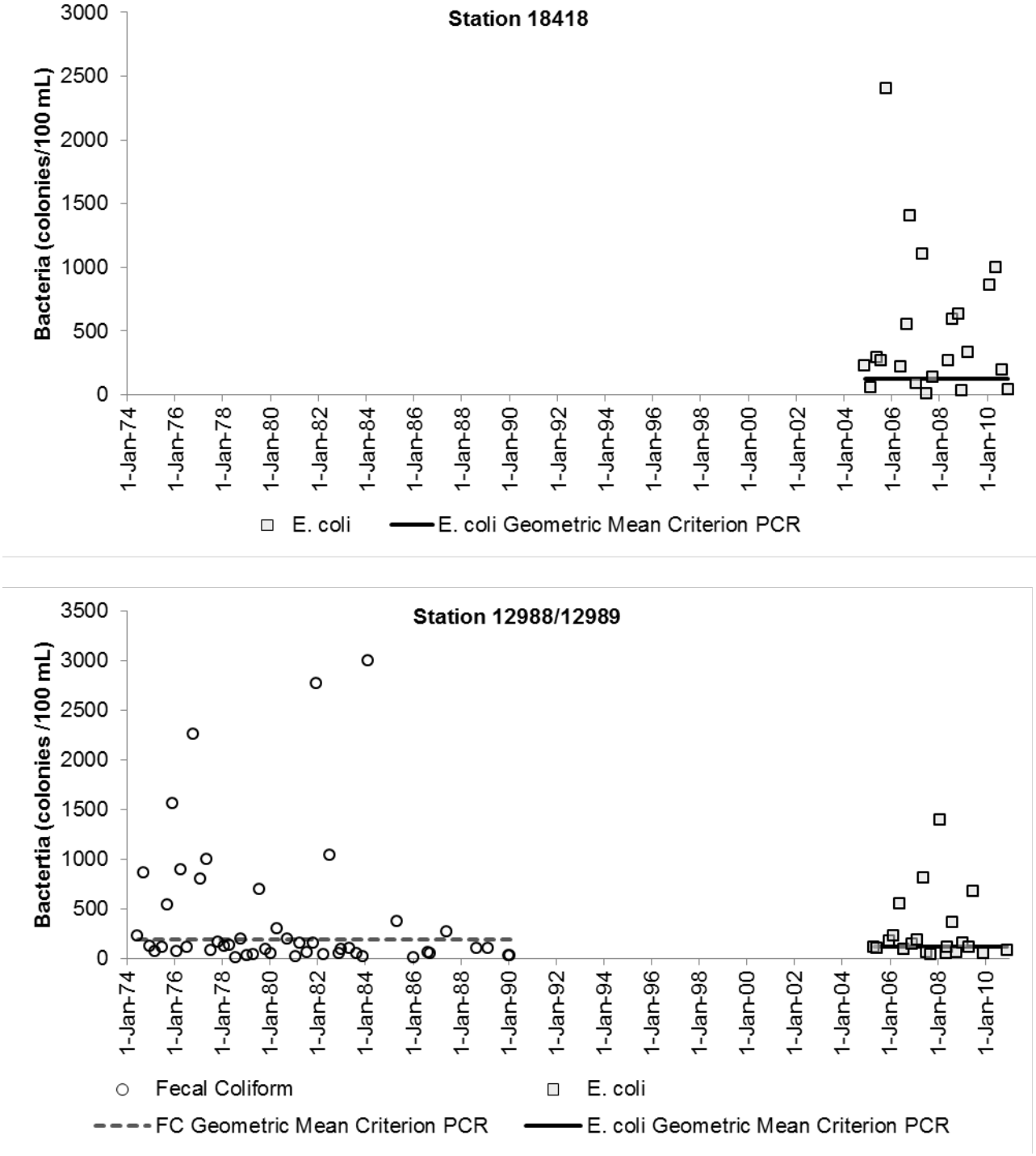
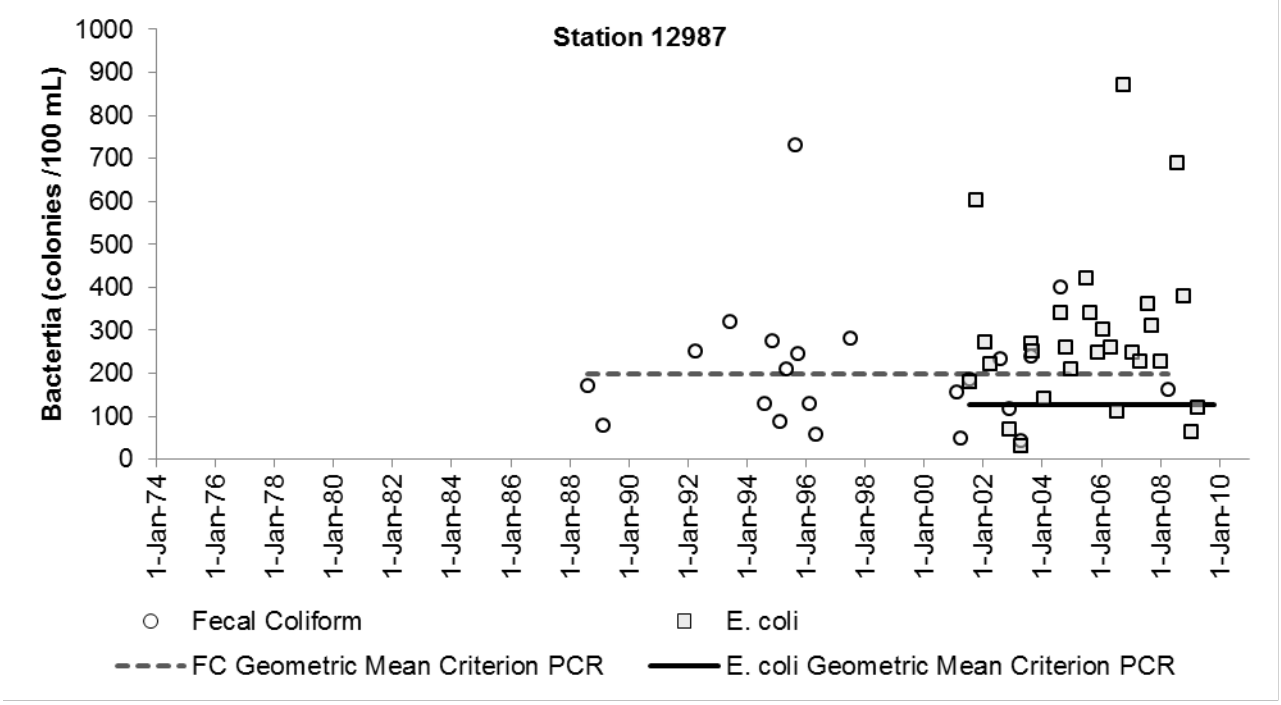


Figure 17 Historical bacterial data for Leona River stations 18418 and 12988/12989. Station 18418 is located on the Leona River upstream of FM 140 and stations 12988 and 12989 are located on the Leona River southeast of Uvalde near Hoags Dam.



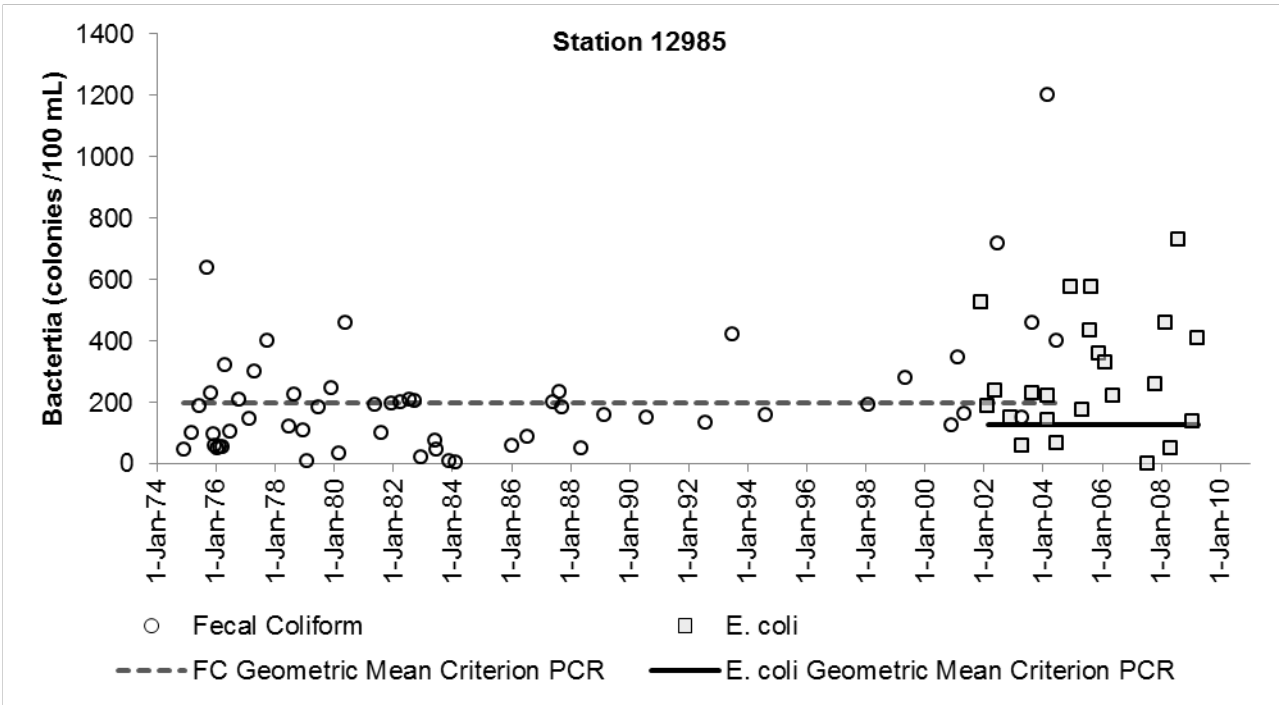


Figure 18 Historical bacterial data for Leona River stations 12987 and 12985. Station 12987 is located on the Leona River at US 57 near Batesville, and station 12985 is located on the Leona River at FM 1581. Note: One E. coli value at station 12987 of 10,000 colonies/100 mL collected on October 27, 2009 removed from graph for viewing purposes.

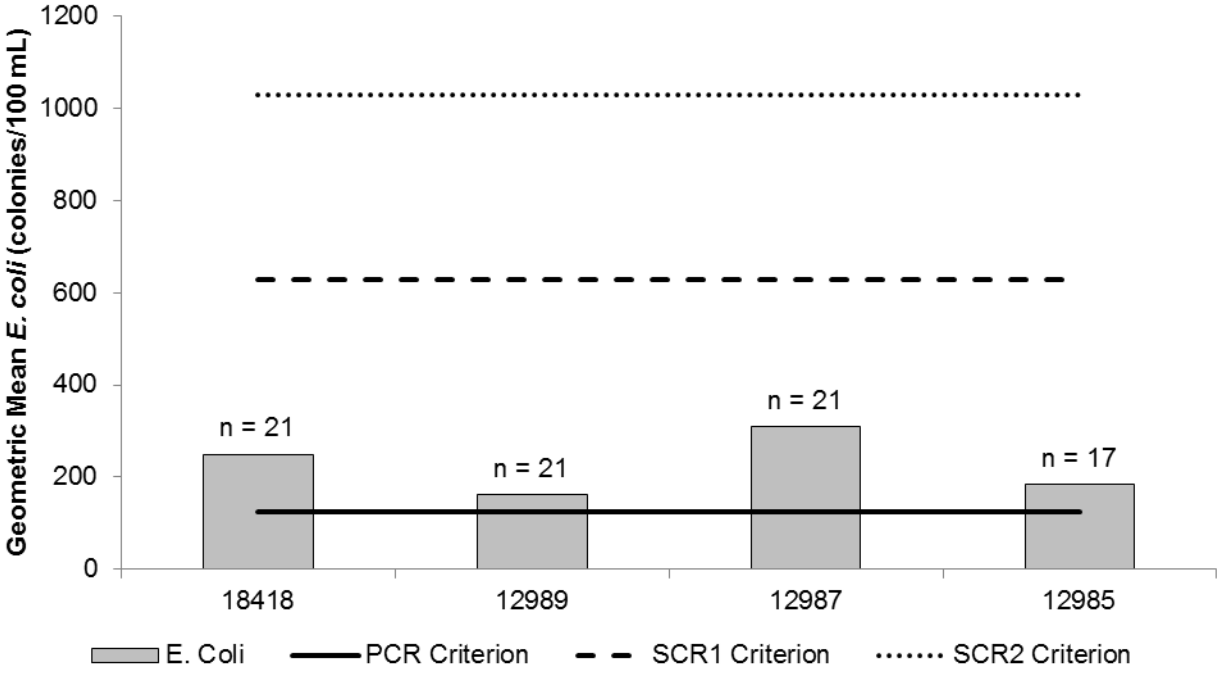


Figure 19 Geometric mean *E. coli* data from 2004-2010 for Leona River stations compared to criteria for expanded recreational use categories. Sites shown in most upstream to downstream order and "n" indicates the number of observations.

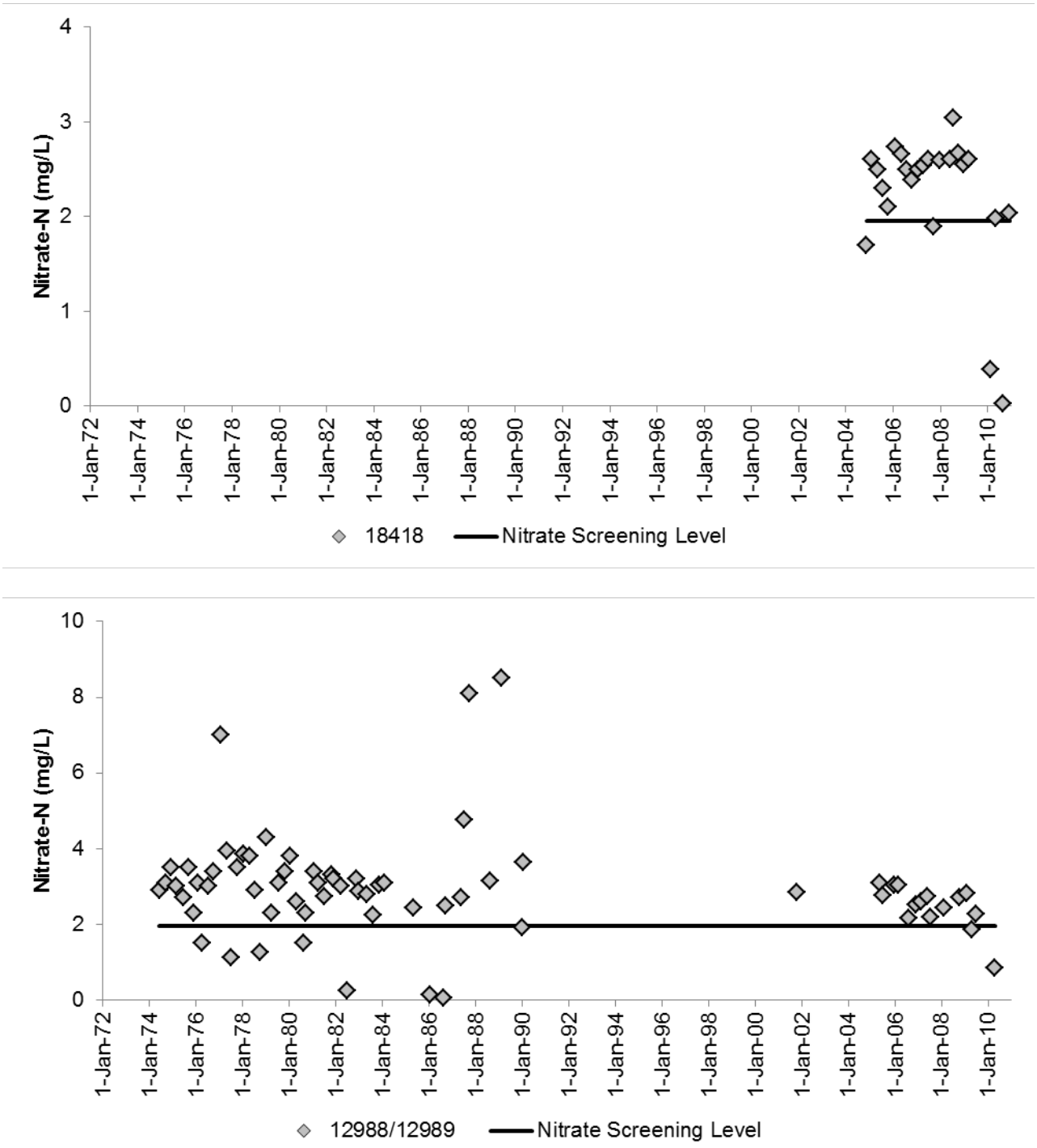


Figure 20 Historical nitrate-nitrogen data for Leona River stations 18418 and 12988/12989. Station 18418 is located on the Leona River upstream of FM 140 and stations 12988 and 12989 are located on the Leona River southeast of Uvalde near Hoags Dam.

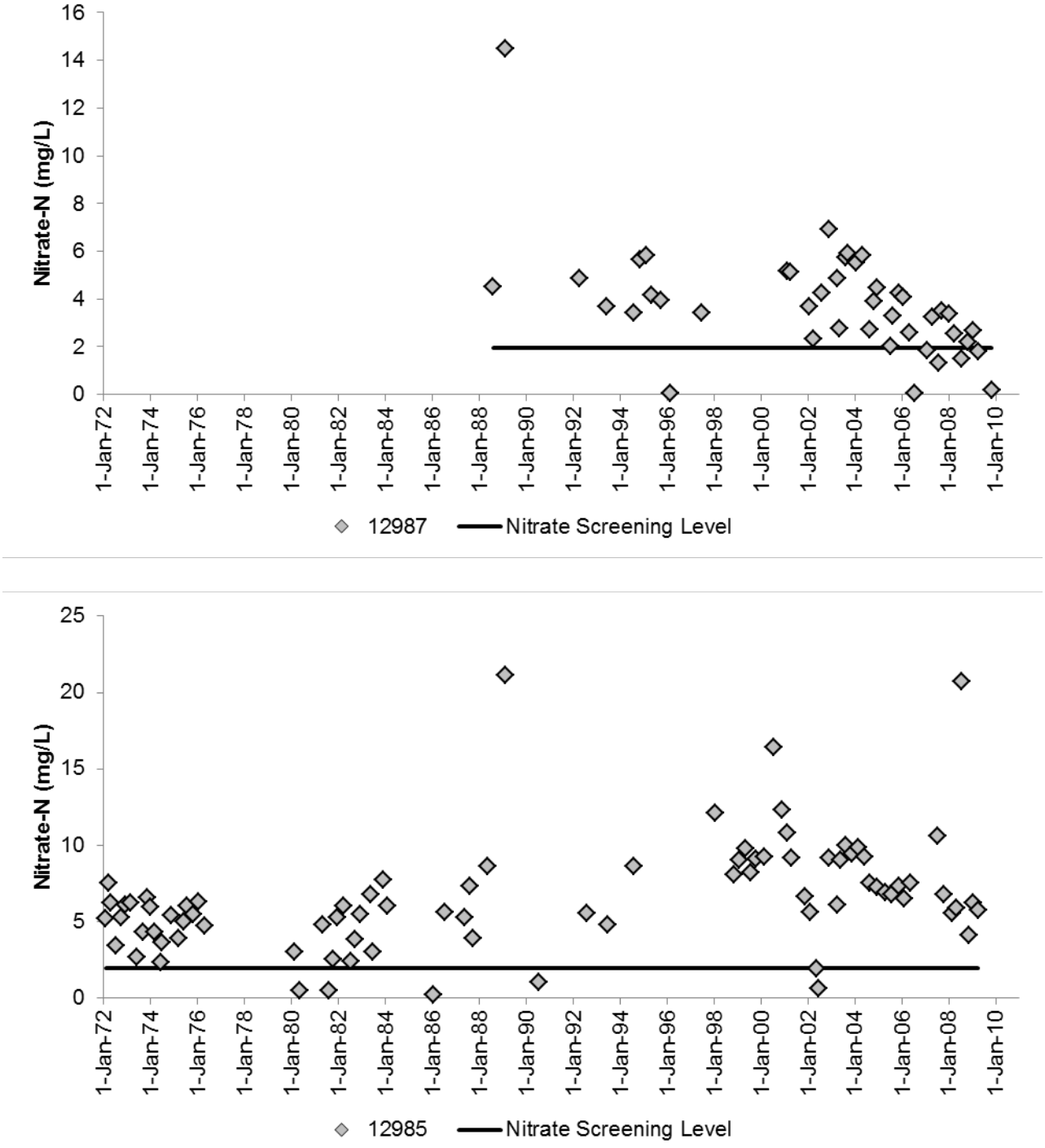


Figure 21 Historical nitrate-nitrogen data for Leona River stations 12987 and 12985. Station 12987 is located on the Leona River at US 57 near Batesville, and station 12985 is located on the Leona River at FM 1581.

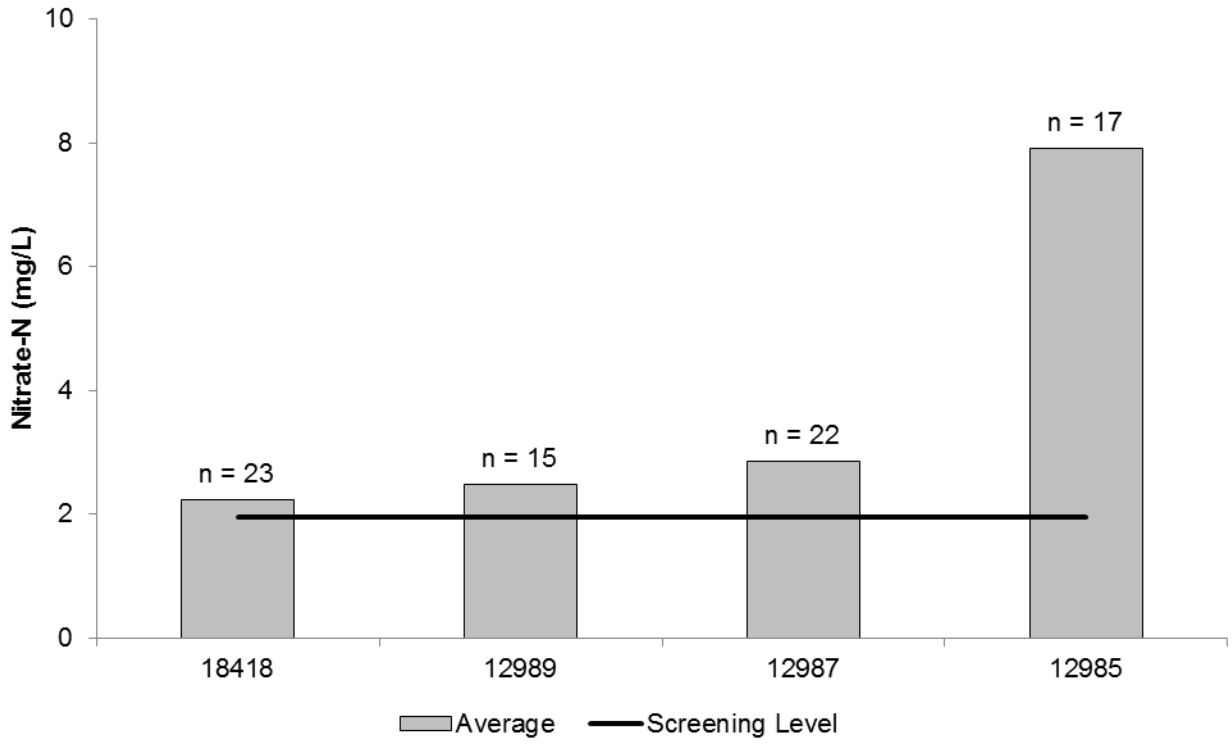


Figure 22 Average nitrate nitrogen from 2004-2010 for Leona River stations compared to screening level. Sites shown in most upstream to downstream order and "n" indicates the number of observations.

SECTION 5

Summary

This report presents an overview of hydrologic data for surface and groundwater for the Leona River watershed summarizing streamflow, well water level, precipitation, and effluent discharges as well as water quality data focusing on bacteria and nitrate concentrations. The Leona River (Segment 2109) is included in the 2010 Texas 303d List as impaired for primary contact recreation based on elevated *E. coli* concentrations. The 2010 Texas Water Quality Inventory also indicates concerns due to elevated nitrate concentrations.

The headwaters of the Leona River overlay the Edwards Aquifer recharge zone. Surface flows of the Leona River can be greatly influenced by spring flows when groundwater levels are elevated, but recent drought conditions have eliminated spring flows as a source of river flow. In evaluating water quality data, groundwater data indicated nitrate concentrations at several well sites within Uvalde and Zavala Counties greater than 10 mg/L with the highest concentration of 121 mg/l nitrate occurring for a well in Zavala County. Within Frio County, most wells indicated nitrate concentrations below 1 mg/L with the highest value reported of 4.5 mg/L nitrate.

Routine monitoring data for four stations were used to assess trends in water quality. The four stations were 12985, Leona River at FM 1581; 12987, Leona River at US 57; 12988/12989, Leona River SE of Uvalde/Leona River at Hoags Dam; and 18418, Leona River upstream of FM 140. Bacteria data included an evaluation of fecal coliform as well as *E. coli*, because most water quality samples prior to 2004 were evaluated for fecal coliform rather than *E. coli*. For data collected between 2004 and 2010, geometric mean concentrations of *E. coli* were elevated at all four routine monitoring stations along the river above the criterion of 126 colonies/100 mL with no statistical difference indicated between the four stations. While bacteria data at stations 12988/12989 and 12985 had been collected since 1974, no increasing or decreasing pattern in bacteria concentrations was apparent over time. Average nitrate concentrations at all four sites for data collected between 2004 and 2010 were elevated above the screening level of 1.95 mg/L, but the highest average concentrations were indicated at the most downstream monitoring station, 12985. As with the bacteria data, there did not appear to be a strong increasing or decreasing trend over time in nitrate concentrations.

References

Ashworth, J.B., and J. Hopkins. 1995. Aquifers of Texas. Report 345, Texas Water Development Board, Austin, TX.

Brune, G. 1975. Major and Historical Springs of Texas. Report 189, Texas Water Development Board, Austin, TX.

EAA, Edwards Aquifer Authority. 2012. Critical Period Trigger Levels. Available at: http://www.edwardsaquifer.org/display_conservation_portal_m.php?pg=conservation_critical_period (link verified April 11, 2012).

EPA, Environmental Protection Agency. 2012. Enforcement & Compliance History Online (ECHO). Available at: http://www.epa-echo.gov/echo/ (data downloaded April 13, 2012).

Federal Register, 2008. Census Designated Place (CDP) Program for the 2010 Census--Final Criteria, February 13, 2008 (Volume 73, Number 30, pp. 8269-8273. Available at: http://www.census.gov/geo/www/psap2010/cdp_criteria.html (link verified July 2, 2012).

Fipps, G. 2001. Managing Texas Groundwater Resources through Groundwater Conservation Districts. Texas Water Resources Institute and Texas AgriLife Publication B-1612, College Station, Texas.

George, P.G., R.E. Mace, R. Petrossian. 2011. Aquifers of Texas. Report 380 (July 2011) Texas Water Development Board, Austin, Texas.

Green, R.T., J.R. Winterle, and J.D. Prikryl. 2008. Discharge from the Edwards Aquifer through the Leona River floodplain, Uvalde, Texas. Journal of the American Water Resources Association 44(4):887-901.

Griffith, G., Bryce, S., Omernik, J., and Rogers, A. 2007. Ecoregions of Texas. Project Report to the Texas Commission on Environmental Quality, Austin, Texas, AS-199 (12/07).

NCDC, National Climatic Data Center. 2012. Online Climate Data Directory, Surface Daily Data. Available at: http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html (accessed April 17, 2012).

Ochoa, R. E. 2012. Divot, TX; Handbook of Texas Online published by the Texas State Historical Association. Available at: http://www.tshaonline.org/handbook/online/articles/hnd27 (accessed March 29, 2012).

Odintz, M. 2012. Winter Garden Region, Handbook of Texas. Texas State Historical Association. Available at: http://www.tshaonline.org/handbook/online/articles/ryw02 (accessed July 11, 2012).

San Antonio Water System. 2012. Aquifer Level & Stats, Advanced Statistics Search. Available at: http://www.saws.org/our_water/aquifer/Water_Stats/WaterStatsAdvanced.cfm (assessed April 10, 2012).

Talaro, K.P., and A. Talaro. 1999. Foundations in Microbiology, Third Edition. McGraw-Hill, New York, New York. 873 pp.

TCEQ, Texas Commission on Environmental Quality. 2011a. 2010 Texas Water Quality Inventory: Assessment Results for Basin 21 - Nueces River (November 18, 2011). Available at http://www.tceq.texas.gov/assets/public/compliance/monops/water/10twqi/2010_basin21.pdf (link verified July 11, 2012).

TCEQ, Texas Commission on Environmental Quality. 2011b. Texas 303(d) List (November 18, 2011). Texas Commission on Environmental Quality, Austin, Texas. Available at http://www.tceq.texas.gov/assets/public/compliance/monops/water/10twqi/2010_303d.pdf (link verified July 11, 2012).

TCEQ, Texas Commission on Environmental Quality. 2011c. Sampling Data Query, Surface Water Quality Monitoring. Available at http://www.tceq.texas.gov/waterquality/clean-rivers/data/samplequery.html/ (accessed November 16, 2011).

TCEQ, Texas Commission on Environmental Quality. 2010a. 2010 Texas Surface Water Quality Standards. Available at http://www.tceq.texas.gov/waterquality/standards/2010standards.html (link verified July 11, 2012).

TCEQ, Texas Commission on Environmental Quality. 2010b. 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas. TCEQ, Monitoring Operations, Surface Water Quality Monitoring Program, Austin, Texas (August 25, 2010). Available at http://www.tceq.texas.gov/assets/public/compliance/monops/water/10twqi/2010_guidance.pdf (link verified July 11, 2012).

TCEQ, Texas Commission on Environmental Quality. 2008. Guidance for Assessing and Reporting Surface Water Quality in Texas. TCEQ, Monitoring Operations, Surface Water Quality Monitoring Program, Austin, Texas (March 19, 2008). Available at http://www.tceq.texas.gov/assets/public/compliance/monops/water/08twqi/2008_guidance.pdf (link verified July 11, 2012).

TCEQ, Texas Commission on Environmental Quality. 2007a. 2006 Texas 303(d) List (June 27, 2007). Texas Commission on Environmental Quality, Austin, Texas. Available at http://www.tceq.texas.gov/assets/public/compliance/monops/water/06twqi/2006_303d.pdf (link verified July 11, 2012).

TCEQ, Texas Commission on Environmental Quality. 2007b. 2006 Guidance for Assessing and Reporting Surface Water Quality in Texas. TCEQ, Monitoring Operations, Surface Water Quality Monitoring Program, Austin, Texas (June 27, 2007). Available

at http://www.tceq.texas.gov/assets/public/compliance/monops/water/06twqi/2006_guidance.pdf (link verified July 11, 2012).

Texas State Data Center. 2010. 2010 Census Demographic Profile Summary File (DPSF), State of Texas and All Texas Places (AFF zipped CSV download). Available at http://txsdc.utsa.edu/Data/Decennial/2010/DPSF/Index.aspx (accessed April 5, 2012).

TWDB, Texas Water Development Board. 2012. Groundwater Database Reports. Available at: http://www.twdb.state.tx.us/groundwater/data/gwdbrpt.asp (Water Quality Reports for Uvalde, Zavala and Frio County downloaded June 20, 2012).

USDA, U.S. Department of Agriculture. 2011. National Agricultural Statistics Service. Available at http://www.nass.usda.gov/Statistics_by_State/Texas/Publications/County_Estimates/index.asp (accessed November 15, 2011).

USEPA, U.S. Environmental Protection Agency. 2010. Permit Compliance System (PCS) Database. Available at http://www.epa.gov/enviro/html/pcs/adhoc.html (accessed April 13, 2012).

USGS, U.S. Geological Survey. 2012. USGS Surface-Water Data for Texas. Available at: http://waterdata.usgs.gov/tx/nwis/sw (accessed January 4, 2012).