Load Duration Curves for Three Locations along the Leona River

Prepared for:

Texas State Soil and Water Conservation Board
Project 11-50

Prepared by:

Anne McFarland

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

TR1303

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Cover photograph is the Leona River at Station 12985, taken by TIAER on October 11, 2011.

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SECTION 1

Introduction

Problem Statement

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, 2011a; 2011b). 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 contact recreation due to elevated bacteria concentrations (TCEQ, 2007). The 2012 Texas Water Quality Inventory continues to indicate these same impairments and concerns (TCEQ, 2013).

The purpose of this report is to develop and present load duration curves (LDCs) for three locations along the Leona River to aid in the evaluation of sources and potential load reductions related to elevated bacteria and nitrate concentrations.

Load Duration Curves

An LDC illustrates the variation in loadings for a given constituent in relation to duration in time that load condition occurs based on long-term flow conditions. Flow duration curves (FDCs) indicate the amount of time various flow conditions are exceeded by sorting long-term flow data from highest to lowest and relating a percentage from highest flows (0%) to lowest flow (100%) with each flow value. The FDC identifies general hydrologic conditions (i.e., wet versus dry) and generally how long each condition occurs (Cleland, 2003). A LDC is then developed by associating a concentration, generally the water quality criterion or screening level, with each flow value to develop a series of allowable loadings. Monitoring data representing the concentration of the constituent of interest collected at a given flow when overlaid with the allowable LDC aids in identifying flow conditions under which allowable or desired loads are exceeded and under what flow conditions these exceedances occur. If there is a clear picture that load exceedances occur primarily during high or low flow conditions, this information can be used in watershed planning in defining the transport mechanisms and source controls needed to decrease excessive loadings. Several publications have promoted use of a LDC approach in evaluating water quality problems, particularly in watersheds with limited stream data, and provide detailed guidance on LDC development and interpretation (e.g., Morrison and Bonta, 2008; EPA, 2007; Bonta and Cleland, 2003; Cleland, 2002; 2003; Bonta, 2002).

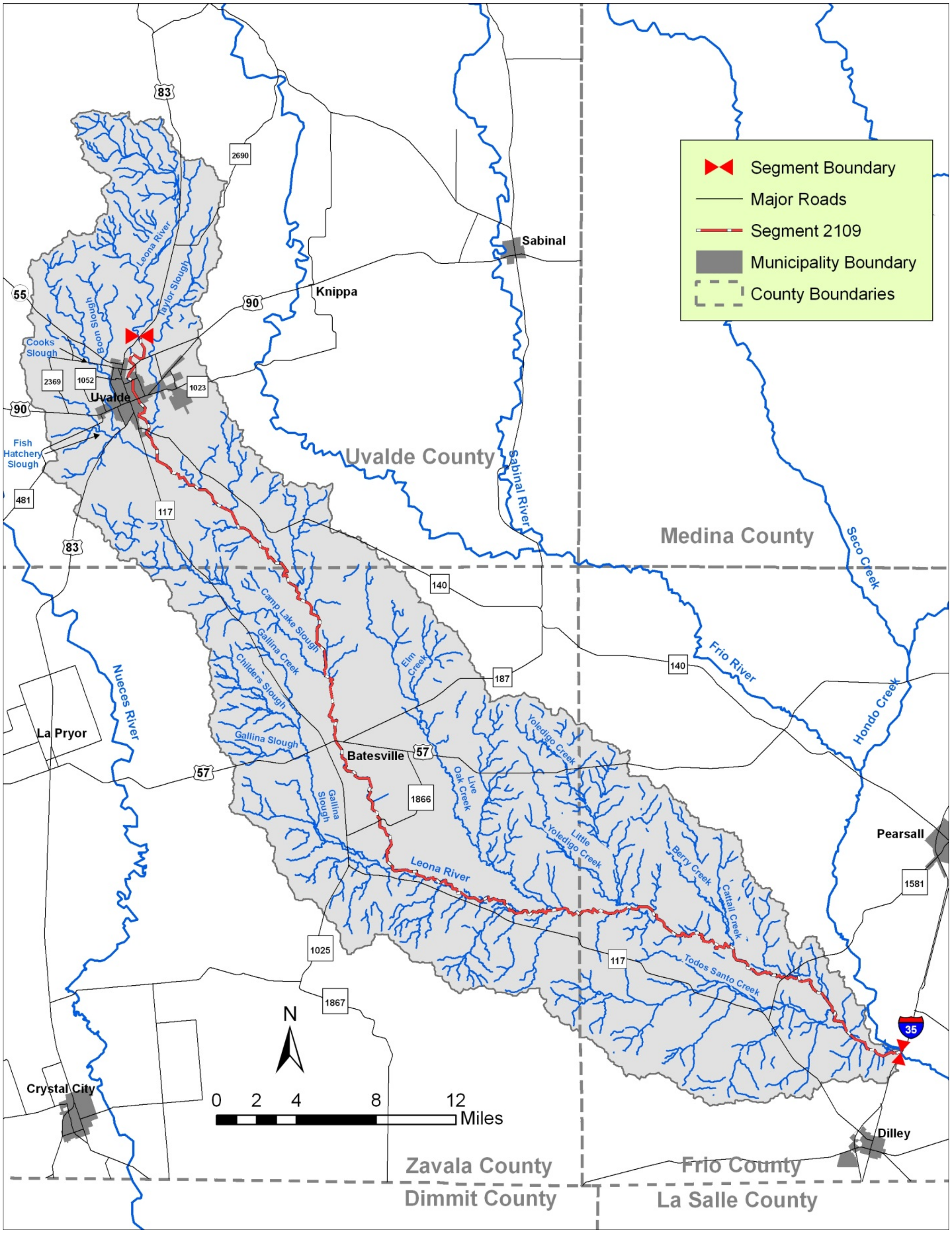

Figure 1 Map of Leona River watershed, Segment 2109.

Study Area

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 channel of the Leona River is fairly well delineated in its upper portion, although some tributary channels are difficult to define as water often flows underground while crossing limestone 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 (George et al., 2011). 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 stream flow. 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 declining 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 inter-bedded 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 Eco-Region (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 (Figure 2 and Table 1). Wheat (*Triticum sp.*), sorghum (*Sorghum bicolor*), cotton (*Gossypium sp*.), vegetables, and corn (*Zea mays*) are among the leading crops in all three counties (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, which raises imperiled fishes, such as the fountain darter (*Etheostoma fonticola*), Comanche Springs pupfish (*Cyprinodon elegans*), and Devils River minnow (*Cryprindodon elegans*).

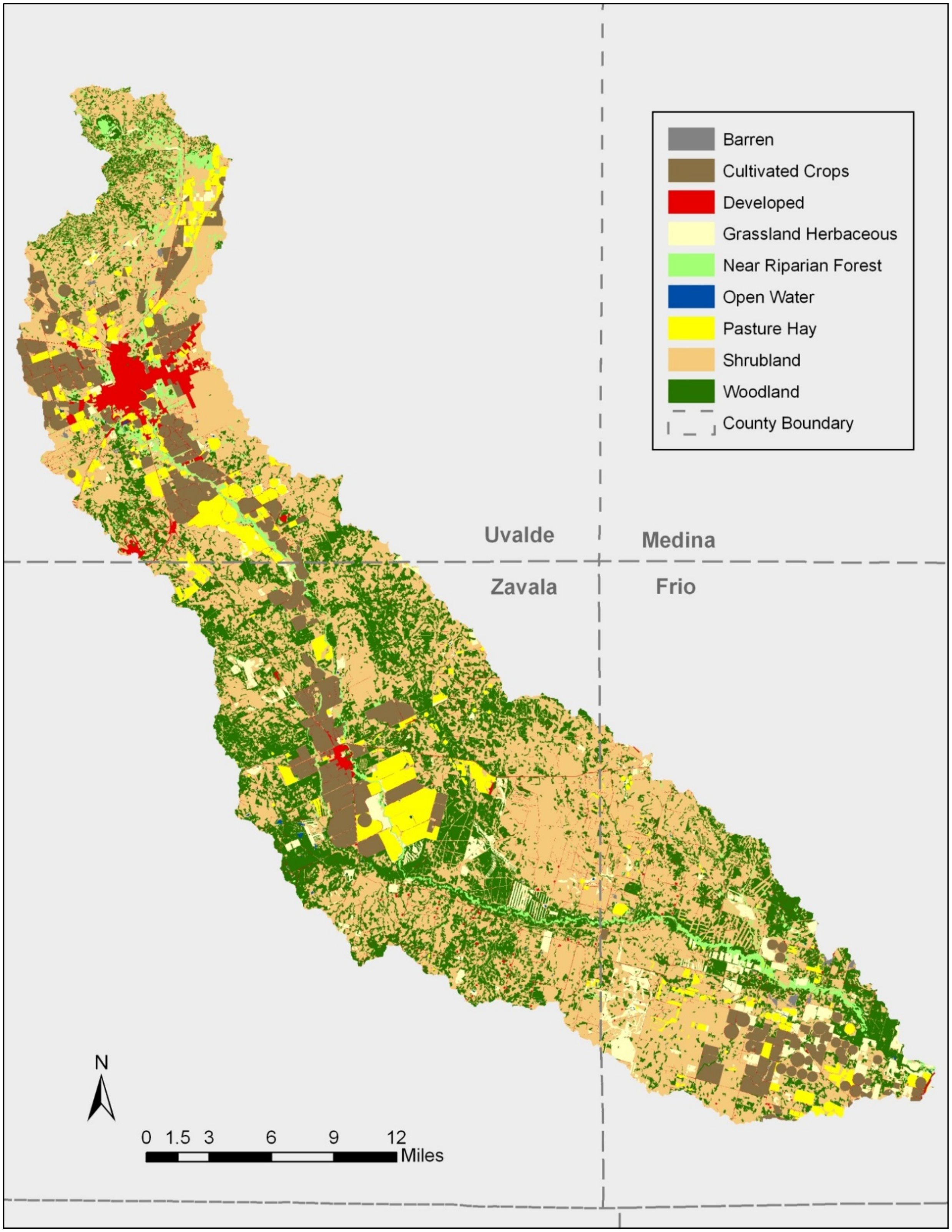

Figure 2 Land use/land cover within the Leona River watershed. Land use/land cover layer developed by the Spatial Science Laboratory at Texas A&M University, College Station, Texas.

Table 1 Summary of land use/land cover classifications for the Leona River watershed.

Category	Acres	Percent
Shrubland	206,517	48.1
Woodland	110,848	25.8
Cultivated Crops	41,416	9.7
Pasture Hay	25,699	6
Grassland Herbaceous	17,573	4.1
Developed	13,893	3.2
Near Riparian Forest	12,014	2.8
Barren	654	0.2
Open Water	630	0.1
Total	429,244	

SECTION 2

Methods

Development of FDCs

With regard to daily stream flow and water level data, four USGS gaging stations with historical data are located in the watershed (Figure 3; USGS, 2012), but only three have had routine data collected within the last few years (Table 2). 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-to-Market roads 1581 and 117 and is considered a ghost town, thus, no longer appearing on most maps (Ochoa, 2012).

Table 2 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	01-May-1924	30-Sep-1929	--	--
8204250	Leona River at FM 1866 near Batesville	28.905833	99.577222	22-May-2008	03-Jan-2011	23-May-2008	03-Jan-2011
8204005[a]	Leona River near Uvalde, TX	29.154167	99.743056	01-Mar-2003	Present	01-Mar-2003	Present
8203450	Leona River at CR 429A near Uvalde, TX	29.345278	99.748889	--	--	22-Jan-2010	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.

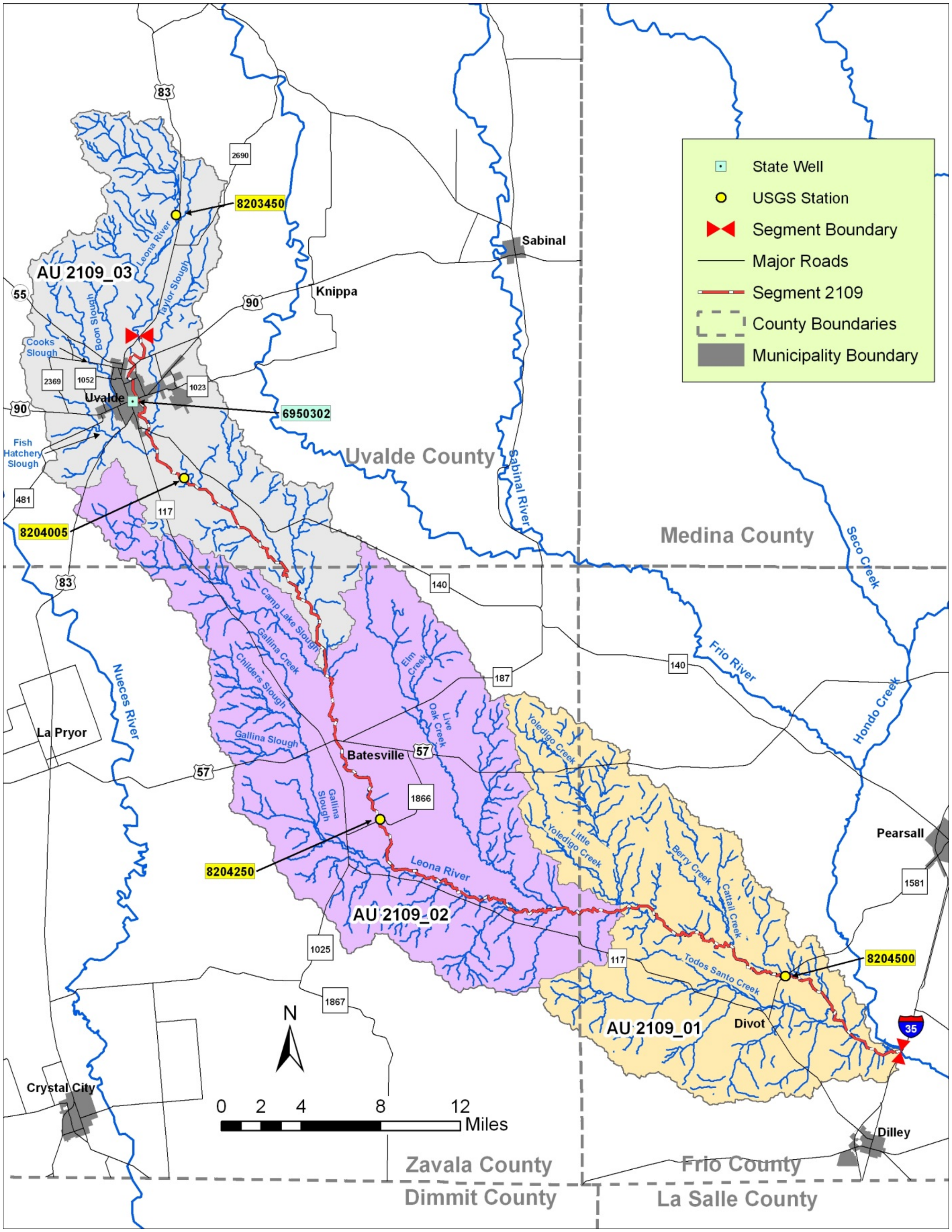

Figure 3 USGS daily stream gaging stations and State Well Index site within the Leona River watershed.

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 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.

Estimation of Long-Term Daily Flow History for Leona Station near Uvalde

Because FDCs are ideally based on 30 or more years of data, efforts focused on creating a daily discharge for station 8204005 would extend back to at least 1970 to correspond with available water quality data. This was done by comparing daily flows for USGS station 8204005 with water levels for the state well 695032, also known as well J-27, from the San Antonio Water System (2012). Instantaneous flow measurements for USGS station 8204000, Leona Springs, which is co-located with station 8204005 were considered as average daily values. Based on work conducted for the Uvalde County Underground Water Conservation District, a well water level of 865 ft or below has been associated with zero flow from springs to the Leona River and generally zero stream flow (Green and Bertetti, 2010). Within the headwaters of the Leona River (Uvalde County), base flow is largely spring discharge from the Edwards Aquifer when groundwater levels are high. Even though stream flow gauging station 8204005 is located below the Edwards Aquifer recharge zone (EAA, 2012; Green et al., 2008), when groundwater levels are low, most rainfall runoff in the headwaters of the Leona River quickly flows into the Edwards Aquifer recharge, limiting downstream flows. Previous work has shown a strong relationship of groundwater levels and stream flow throughout the Leona River (Livingston, 1947).

To estimate average daily flows for the Leona River near Uvalde, daily precipitation data for Uvalde along with well water levels for well J-27 were used as independent variables in developing a multiple regression model. The following model was developed considering well data only when the well level was above 865 ft:

$$\text{Avg. Daily Q (cfs)} = \text{well level (ft)}*3.65 - \text{precip. (inch)}*16.19 + \text{previous day precip. (inch)}*17.12 - 3161.13 \qquad R^2=0.72$$

One average daily discharge of 4,980 cfs for station 8204005 reported on July 29, 2007 was dropped from the regression analysis as an outlier. This equation underestimates high flows, but presents a very reasonable assessment of low to moderate flows along the Leona River near Uvalde, Texas (Figures 4 and 5). Because average daily flows along the Leona River near Uvalde are below 150 cfs over 95 percent of the time, the underestimation of high flows was considered acceptable for FDC development.

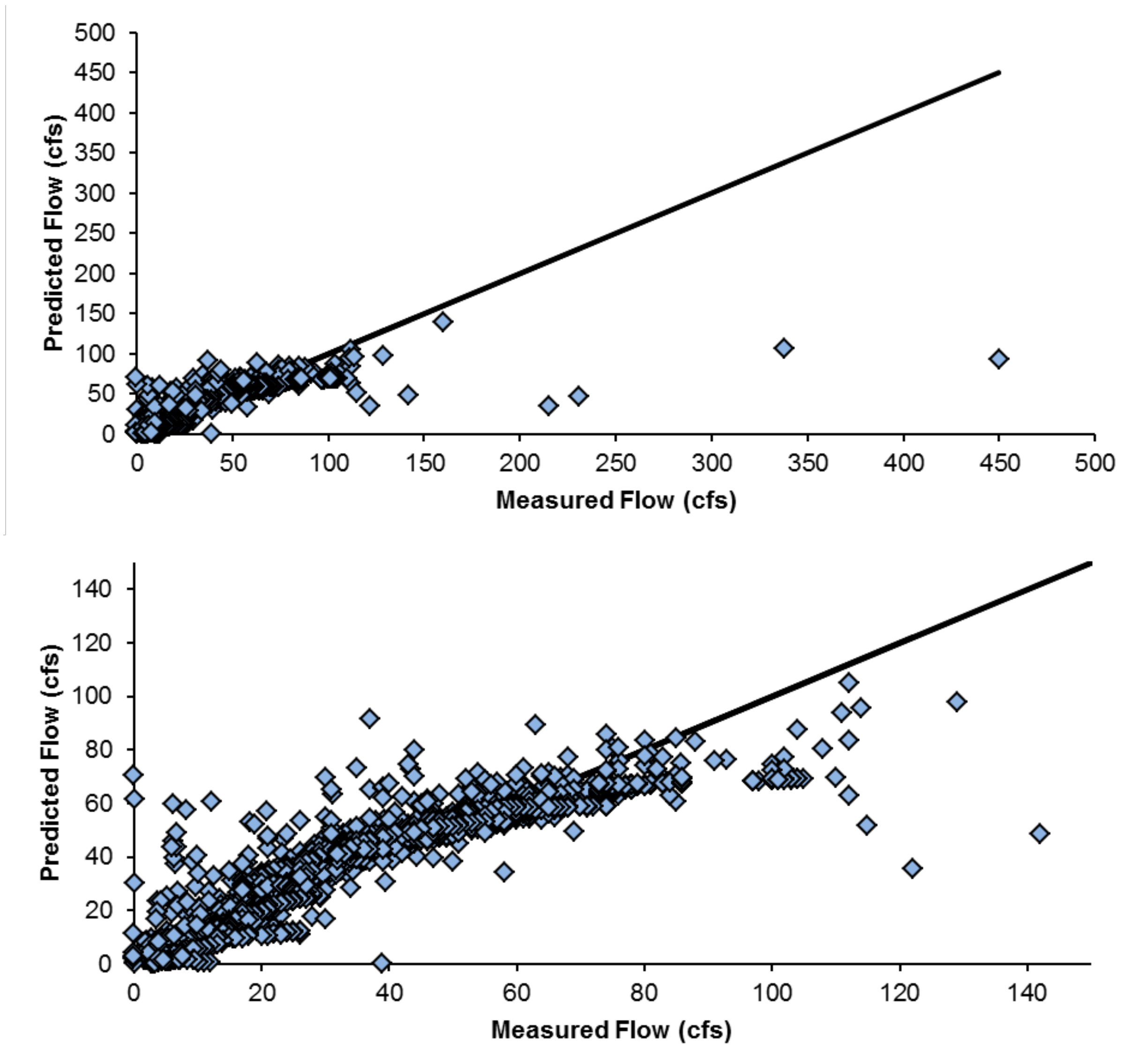

Figure 4 Relationship of predicted flows with measured flows for the Leona River near Uvalde. Top graph shows relationship for all flows modeled, while bottom graph focuses in on flows of 150 cfs or less. The solid line represents the one-to-one lines of measured versus measured values.

An effort was also made to look at correlation of average daily flow for Leona River station 8204005 with nearby gaging stations having longer historical records on the Frio (820550, 8197500, and 8195000) and Nueces (8192000) Rivers, particularly with regard to estimating higher flows. None of these other gauging stations correlated well with flows on the Leona River, in part due to varying precipitation amounts and events between the various watersheds, as well as differences in groundwater influences.

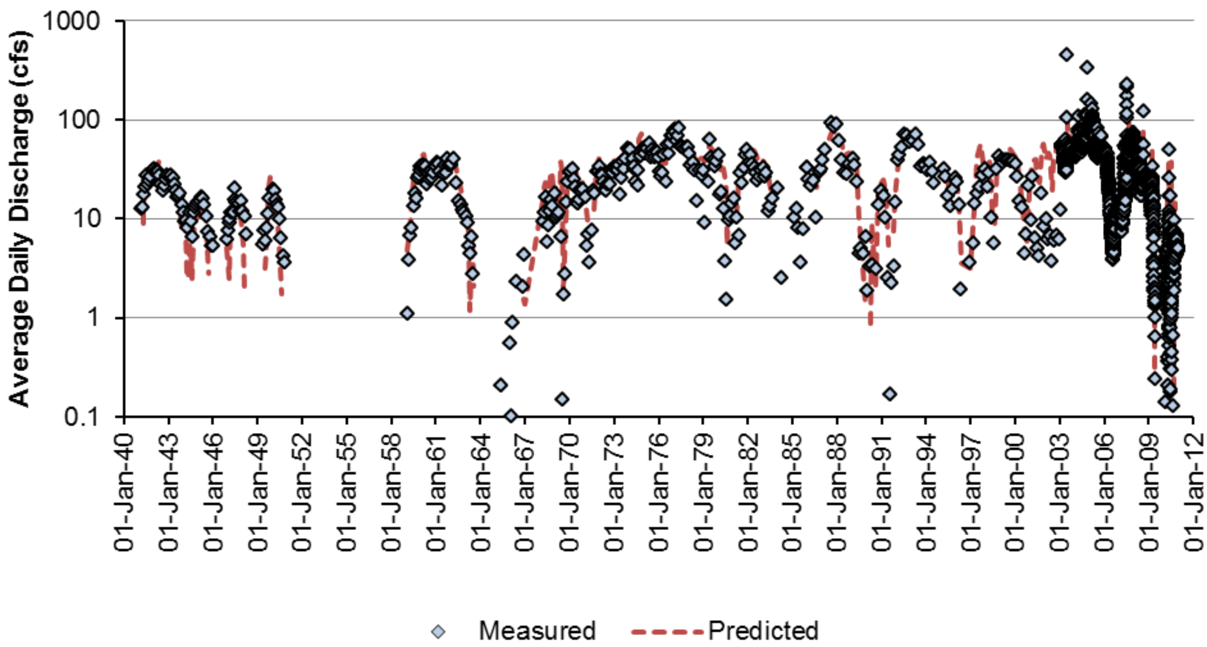

Figure 5 Measured and predicted flows over time for the Leona River near Uvalde.

When daily flow values were not available, estimates were derived using the equation above to represent 40 years of flow between 1971 and 2010 for the Leona River near Uvalde. This 40-year record was used to develop a FDC representing the percent of time various flow conditions were exceeded (Figure 6). For comparison, the short-term actual daily data from March 2003 through December 2010 were also developed into a FDC and showed a fairly good fit to the estimated long-term FDC (Figure 6).

Because season can be a factor in considering flow conditions and loadings, flow conditions were evaluated by plotting the percent flow exceeded by month (Figure 7). Only a slight seasonal pattern was indicated with lower flow conditions (a higher percent flow duration interval) associated with months May through August. Given that seasonality in flow was not strongly pronounced over the 40-year period, the FDC developed from the full 40-yr flow record was used in the development of LDCs. The FDC, as shown in Figure 7, was separated into five categories (high, moist, mid-range, low, and no flow)[1] based largely on break points defined by EPA (2007). The long-term FDC for the Leona River near Uvalde indicated zero or no flow about 12 percent of the time. Of note, current drought conditions based on data from 2011 through May 2013 indicate zero flow conditions about 93 percent of the time, as a strong contrast to the historical long-term average flows.

[1] The flow categories in this report vary slightly from those presented at the June 4, 2013 public meeting held in Uvalde, Texas. The "Dry Conditions" category in that presentation was relabeled "Low Flows" and the "Low Flows" category modified to represent zero or no flow to aid in clarifying the various flow conditions based on stakeholder feedback.

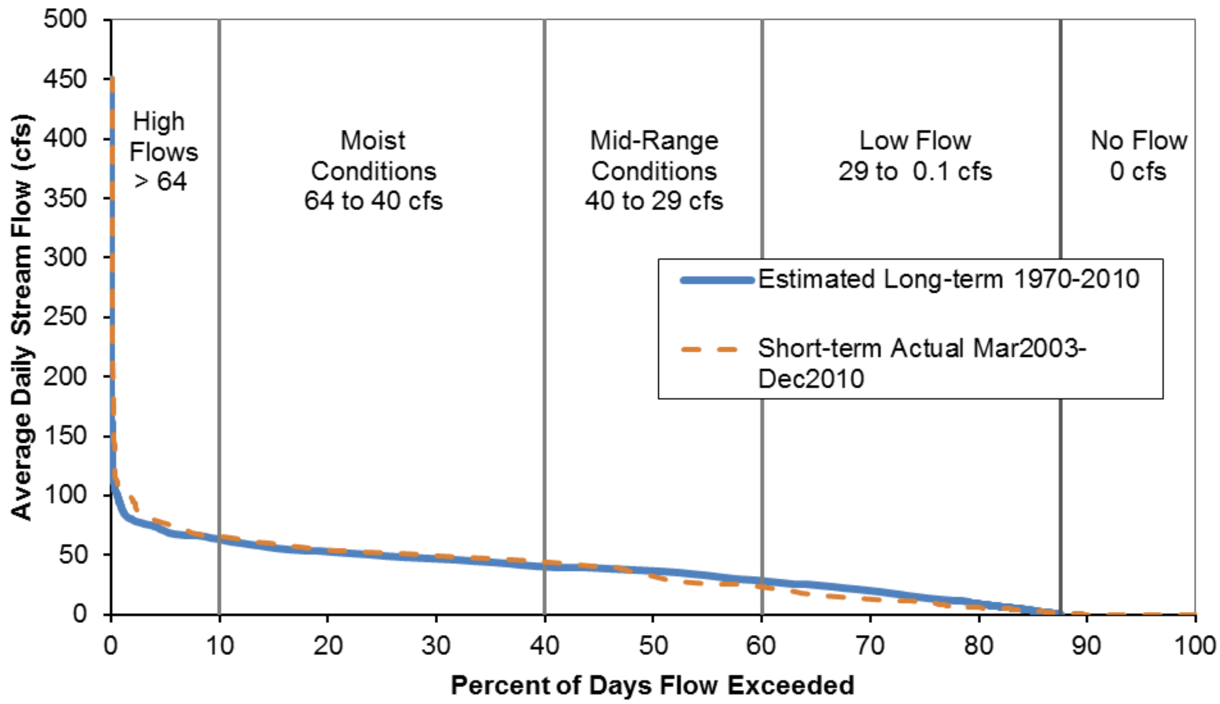

Figure 6 Estimated flow duration curve for the Leona River near Uvalde, Texas. Flow duration curve based on measured and estimated daily flow data for a 40-year period from 1971 through 2010.

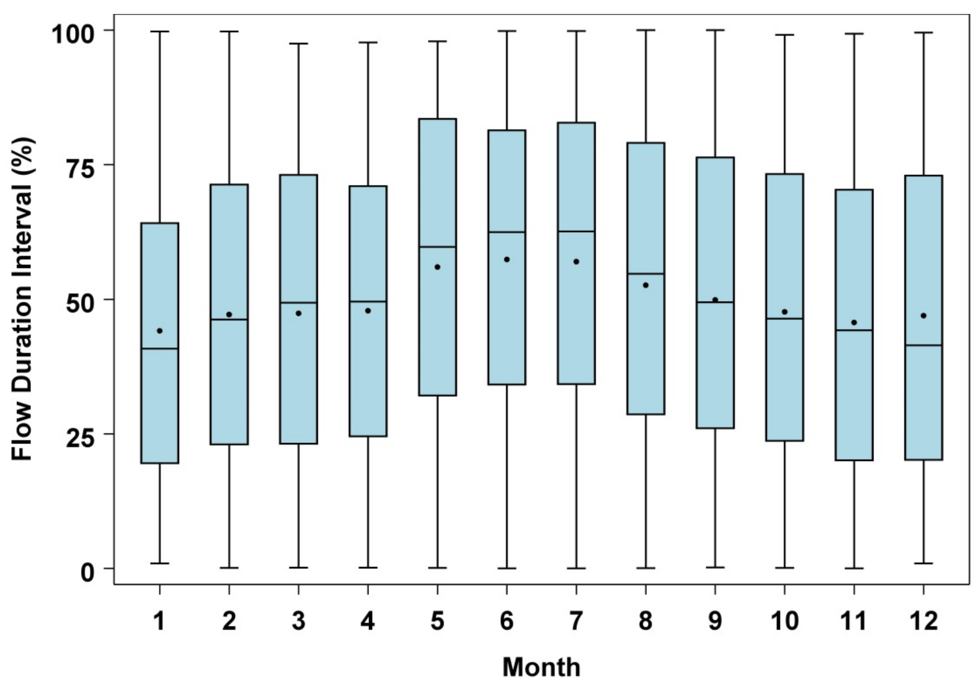

Figure 7 Monthly evaluation of flow duration for the Leona River near Uvalde, Texas. Flow duration interval based on measured and estimated daily flow data for a 40-year period from 1971 through 2010.

Correlation of Flow at Uvalde with Flow at Batesville

To estimate flow for the Leona River at Batesville, daily data from USGS station 8204005 were compared with data from station 820425 (Figure 8). While only a relatively short time period was monitored at station 8204005 near Batesville (Table 3), a fairly strong polynomial relationship was indicated for moderate to low flows below about 35 cfs (Figure 8). Above 35 cfs at Uvalde, only five paired observations were available. To extrapolate higher flows at the Batesville location, a modified drainage area ratio (DAR) approach was used. For flows at Uvalde above 35 cfs, the flow for the Uvalde station was multiplied by 1.83 (the ratio of the drainage area for the Batesville station divided by the Uvalde station based on drainage area estimates from the USGS) and then 35 cfs subtracted (see upper graph in Figure 8). A value of 35 cfs was subtracted from the DAR calculation to allow merging the DAR estimates of flow with the polynomial calculations used for lower flow values. The estimated FDC based on the 40-year period, 1971 through 2010, for the Leona at Batesville was then developed from this estimated dataset (Figure 9). For the Batesville location, no flow was indicated about 14 percent of the time for the long-term estimated data.

Table 3 Basic statistics for data used in correlating average daily flows on the Leona River near Uvalde and Batesville. Based on daily values from June 1, 2008 through January 3, 2011.

Basic Statistics	Uvalde (8204005), Daily Avg. Flow (cfs)	Batesville (8204250), Daily Avg. Flow (cfs)
Mean	22.3	11.0
Median	25.0	11.0
Standard Deviation	8.4	6.5
Minimum	0.2	0.01
Maximum	122	81.0
Number of Obs.	358	358

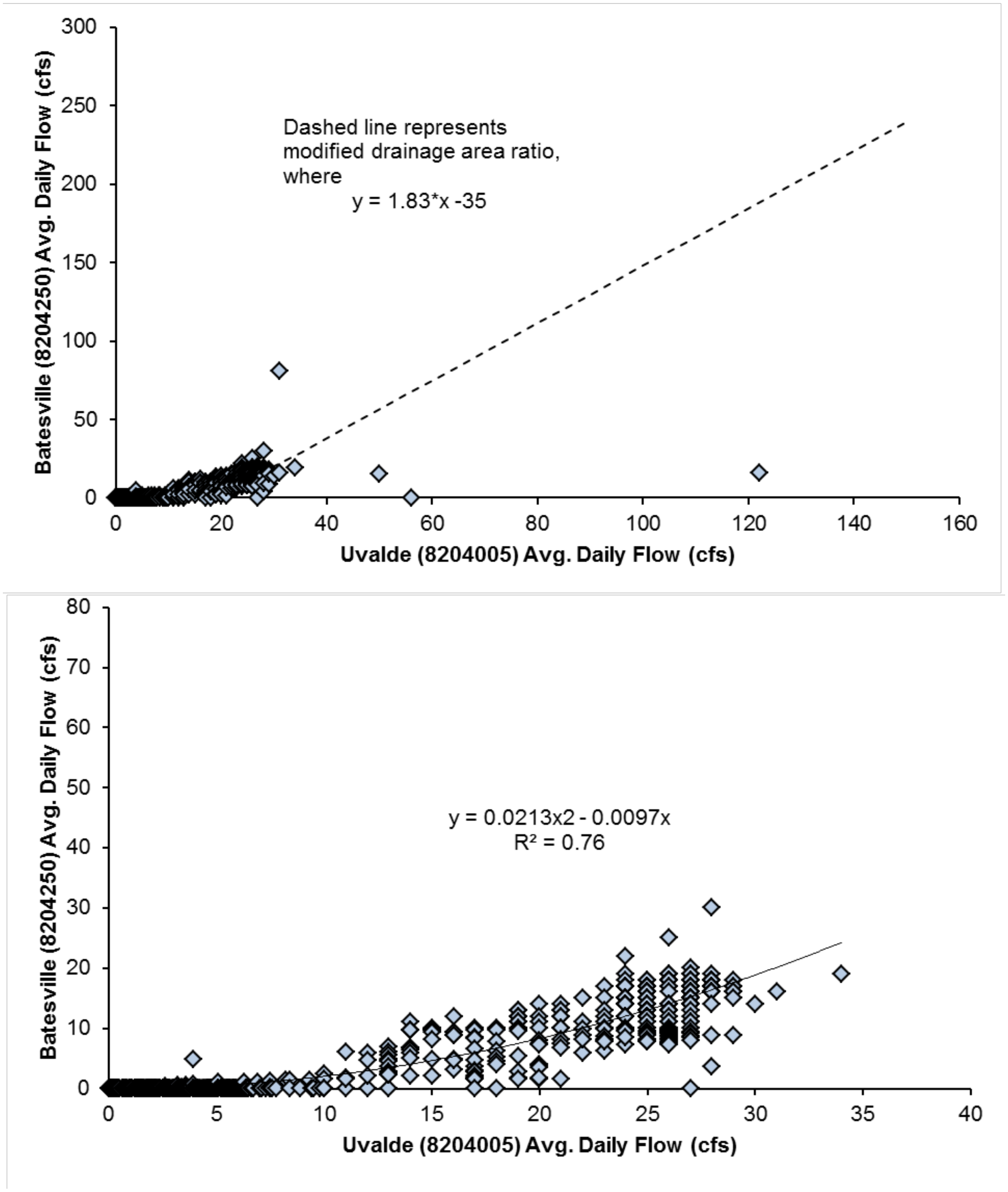

Figure 8 Relationship of average daily flow between stations 8204005 near Uvalde and 820425 near Batesville, Texas. Based on daily values from June 1, 2008 through January 3, 2011.

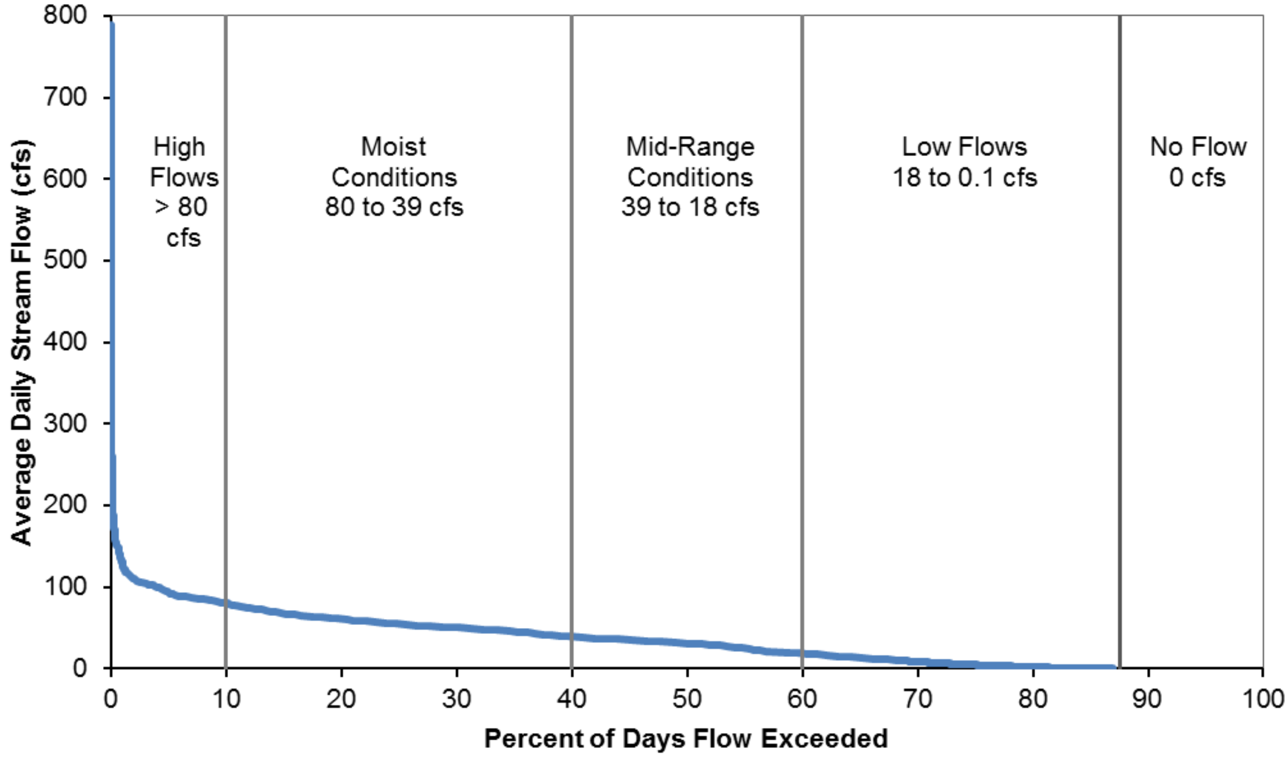

Figure 9 Estimated flow duration curve for the Leona River near Batesville, Texas. Flow duration curve based on measured and estimated daily flow data for a 40-year period from 1971 through 2010.

<u>Flow Estimation for the Leona River near Divot</u>

For the Leona River near Divot, only a very limited amount of daily flow data were available from USGS station 820455 that were collected in the 1920s. To estimate flows at this most downstream location, a modified DAR approach was used similar to that used for estimating flows for the Leona River near Batesville. Flows for the Divot area were based on flows for the Batesville location on the Leona River. For flows below 35 cfs at Batesville, the same polynomial equation was applied at Divot, assuming that springs in the headwaters were the major source of flow and that base flow contributions would decrease as the river proceeds further downstream. For flows above 35 cfs, the DAR of 2.34 was multiplied by the flow at Batesville with 35 cfs subtracted to allow the flow estimation to merge in with the estimations below 35 cfs. The FDC for the Leona at Divot was then based on estimated daily flows for 1971 through 2010 (Figure 10). This FDC for the Leona at Divot assumes that base flow is generated from the headwater springs near Uvalde and that base flow decreases from upstream to downstream along the river. High flows are most likely underestimated, but overall this estimated FDC should be representative of the general picture of flow conditions at this location.

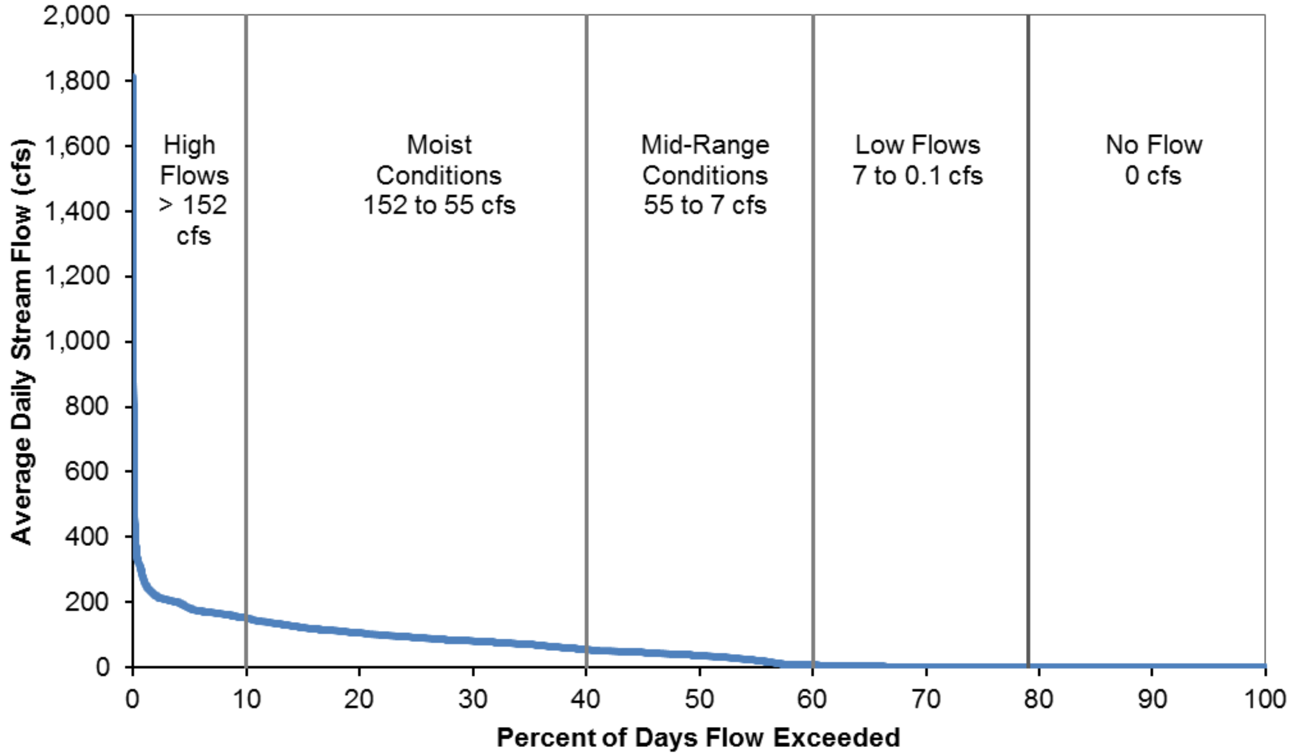

Figure 10 Estimated flow duration curve for the Leona River near Divot, Texas. Flow duration curve based on measured and estimated daily flow data for a 40-year period from 1971 through 2010.

Development of LDCs

Load duration curves representing allowable loads for bacteria were based on the geometric mean criterion associated with primary contact recreation for *E. coli* of 126 cfu/100 mL using the FDCs developed for the Uvalde, Batesville and Divot locations (TCEQ, 2010). Allowable loads for nitrate were based on the screening level for freshwater streams of 1.95 mg/L (TCEQ, 2010).

To determine available water quality data for comparison, the SWQMIS database was queried for nitrate and bacteria data at stations within the Leona River watershed available prior to July 2011. While historical water quality monitoring was noted for 14 stations within the Leona River watershed (Figure 11), only 5 stations indicated sufficient water quality data (> 10 observations) for bacteria and nitrate for LDC evaluation (Table 4). Of these five stations, only station 12988 was associated with a current USGS gaging station (8204005) with available daily discharge data. Based on available data, LDCs were developed using data from stations 12985, 12987 and 12988 combined with station 12989. Station 12989 replaced station 12988 as a routine monitoring location in 1990. Stations 12985, 12987 and 12989 represent routine monitoring stations under the Clean River Program maintained by TCEQ.

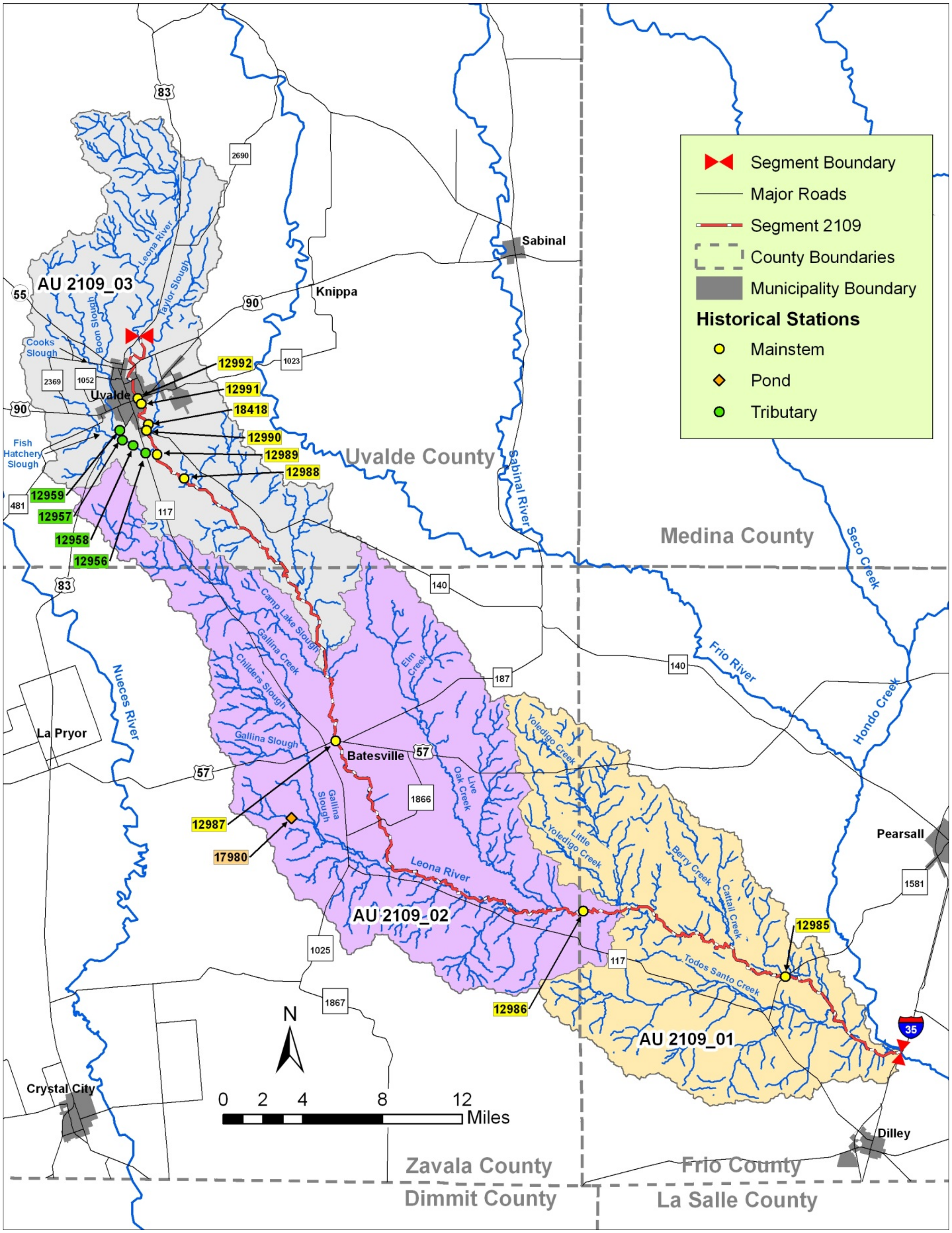

Figure 11 Location of historical TCEQ stations within the Leona River watershed. AU indicates assessment unit.

Table 4 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.

The allowable LDC was then overlaid with water quality data from stations 12988 and 12989 for the location near Uvalde, Texas; from station 12987 for the Leona River at Batesville, Texas; and from station 12985 for the Leona River near Divot, Texas (Table 5). Stations 12989, 12987, and 12985 were also included in monitoring under the current project, although due to drought conditions only a very limited number of additional samples were collected between July 2011 and May 2013 (Table 6). No additional samples were reported as collected in 2011, 2012, or 2013 by TCEQ during quarterly monitoring for these three stations. Bacteria or nitrate data were evaluated for seasonality, but no clear pattern emerged for either constituent.

Table 5 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

Table 6 Bacteria and nitrate samples collected for Leona River stations 12989, 12987, and 12985 between July 2011 and May 2013 under flowing conditions.

Station	Date	Flow (cfs)	E. coli (cfu/100 mL)	NO_3-N (mg/L)	Comments
12985	11Oct2011	1.3	6,100	0.94	After large rainfall event
12987	11Oct2011	1.3	1,000	0.37	After large rainfall event
12989	Not Applicable	No samples with flow	Not Applicable	Not Applicable	Four samples collected but under pooled conditions

Of note, prior to 2001 fecal coliform rather than *Escherichia coli* was measured as the bacteria indicator. Between 2001 and 2004 some overlap occurred during which both fecal coliform and *E. coli* were measured, as TCEQ migrated from a fecal coliform to an *E. coli* criterion for bacteria. For the Leona River watershed, nine observations had paired fecal coliform and *E. coli* data, but this was too limited a dataset to establish a reliable relationship between these two measures of bacteria. To relate fecal coliform to *E. coli* values, the following relationship based on 1075-paired observations collected in the North Bosque River watershed was used (McFarland and Millican, 2010):

$$\ln(E.\ coli) = 0.946*\ln(\text{fecal coliform}) - 0.029 \qquad R^2 = 0.93$$

To compare measured with allowable loads, a LDC of estimated measured loads for range of flow conditions was developed. This estimated measured LDC was calculated from a log-linear regression relationship of measured concentrations and flow for each location. The log-linear regression relationship was used to provide an estimated concentration for each daily flow used in the FDCs. Estimated flows were then multiplied by an appropriate conversion factor, to estimate measured loadings across all potential flow conditions. For bacteria, a concentration for *E. coli* of 1 cfu/100 mL at 1 cfs/day calculated a daily load of 24,465,715 cfu/day and was used as the conversion factor for estimating loadings for specific concentrations and flows (Table 7). For nitrate, a concentration of 1 mg/L at 1 cfs/day calculated daily load of 5.3938 lbs/day (Table 8).

To evaluate the potential load reductions needed to change from measured to allowable conditions, as based on the *E. coli* criterion or nitrate screening level, the percent reduction was calculated as the difference in the estimate measured load minus the allowable, divided by the estimated measured load, multiplied by 100. The average percent reduction was then calculated for each flow condition (high, moist, mid-range, and low) as defined for the FDCs.

Table 7 Conversion factors used in calculating bacteria loadings from concentration and flow data. Daily load conversion is multiplied by the estimated or measured concentration (cfu/100 mL) at a given flow (cfs) to obtain the daily bacteria loading in cfu/day.

Parameter	Value	Units
Bacteria Concentration	1	cfu/100 mL
	1000	mililiters/liter
	10	cfu/liter
Average Daily Flow	1	cfs
	3600	sec/hr
	24	hrs/day
	28.3168	liters/cubic ft
Total Daily Discharge	2,446,571.5	liters/day
Daily Load Conversion	24,465,715	cfu/day

Table 8 Conversion factors used in calculating nitrate loadings from concentration and flow data. Daily load conversion is multiplied by the estimated or measured concentration (mg/L) at a given flow (cfs) to obtain the daily loading in pounds.

Parameter	Value	Units
Nitrate Concentration	1	mg/L
	1000	mg/g
	1000	g/kg
	0.000001	kg/L
Average Daily Flow	1	cfs
	3600	sec/hr
	24	hrs/day
	28.3168	liters/cubic ft
Total Daily Discharge	2,446,572	liters/day
Load (kg/L * L/day)	2.44657	kg/day
	2.20462	lbs/kg
Daily Load Conversion	5.3938	lbs/day

SECTION 3

Results

The LDC results are presented by flow condition category as defined by the percent time conditions were exceeded. Mid-range to low flow conditions indicate a decrease in average flow from the most upstream location near Uvalde, to more downstream near Divot indicating the dominant base flow contributions in the headwaters (Table 9). In contrast, the average flow associated with moist and high flow conditions increases from upstream to downstream as the size of the drainage area impacted by rainfall-runoff increases (Table 9).

Table 9 Average flows associated with flow condition categories for locations along the Leona River.

Flow Condition	Percent of Days Flow Exceeded	Average Flow (cfs) at Station 12988/12989 near Uvalde	Average Flow (cfs) at Station 12987 near Batesville	Average Flow (cfs) at Station 12985 near Divot
High flows	0 to 10%	116	161	297
Moist Conditions	10 to 40%	52	60	104
Mid-Range Conditions	40 to 60%	35	29	18
Low Flows	60 to <88%[a]	6	4	3

a. Zero or no flow conditions were indicate 12% of the time for the Uvalde location, 14% of the time for the Batesville location, and 21% of the time for the Divot location based on estimated long-term data.

For all LDCs, measured values above the allowable LDC indicate values above the criterion for bacteria or screening level for nitrate. Values below the allowable LDC indicate measured loads that are in compliance with current water quality standards.

Bacteria LDCs

For bacteria, location in the watershed greatly impacted the load reduction estimated, particularly for mid-range to low conditions (Table 10 and Figures 12-14). Only the location near Batesville indicated the need for load reductions under low conditions (average flow 4 cfs). The location near Batesville also indicated for mid-range and moist conditions the highest percent reductions of the three locations evaluated. For the location near Uvalde, reductions greater than 10 percent were noted for moist and high flows, which would be largely associated with rainfall-runoff. For the most downstream location near Divot, notable reductions greater than 10 percent were only indicated during high flow conditions.

Table 10 Summary of estimated *E. coli* load reductions for the Leona River.

Flow Condition	Percent Exceedence	Average Percent Reduction at Station 12988/12989 near Uvalde	Average Percent Reduction at Station 12987 near Batesville	Average Percent Reduction at Station 12985 near Divot
High flows	0-10%	39	33	24
Moist Conditions	10-40%	22	31	8
Mid-Range Conditions	40-60%	10	30	0
Low Flows	60 to <88%[a]	0	25	0

a. Zero or no flow conditions were indicate 12% of the time for the Uvalde location, 14% of the time for the Batesville location, and 21% of the time for the Divot location based on estimated long-term data.

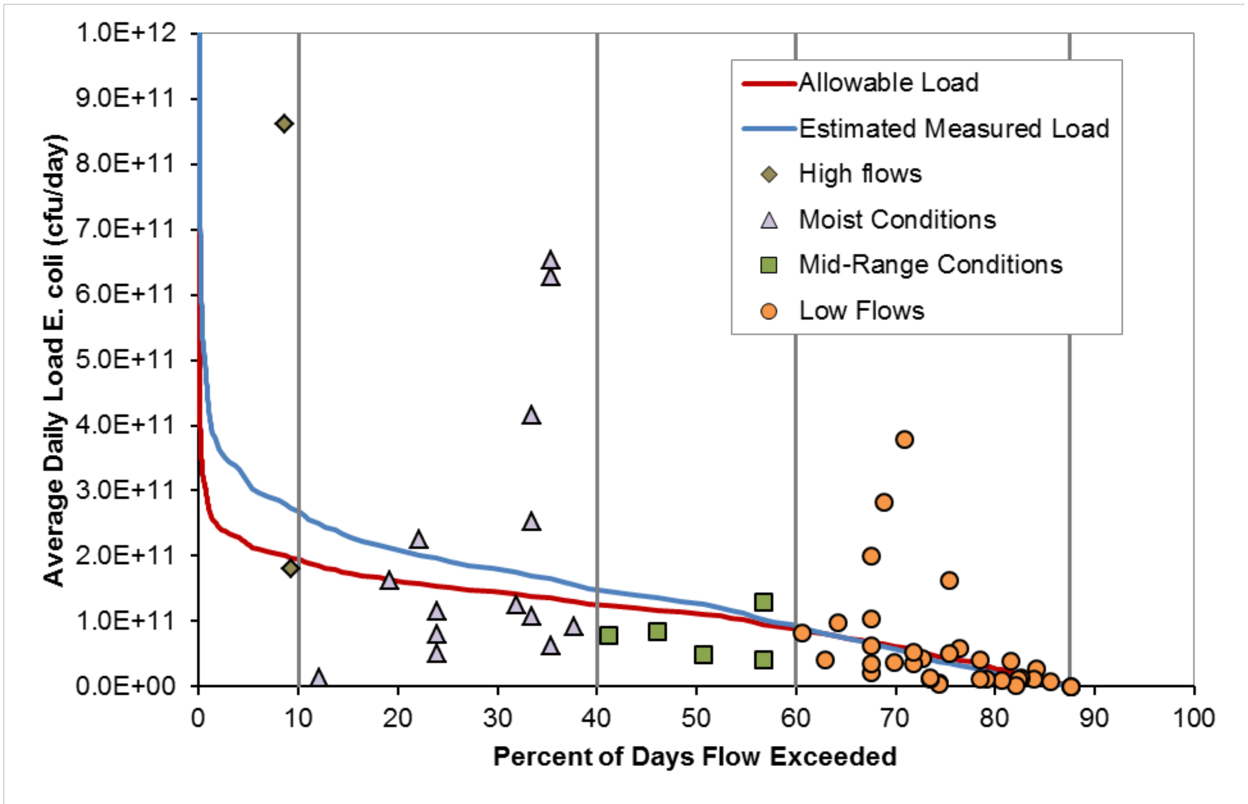

Figure 12 LDCs for *E. coli* for the Leona River at station 12988/12989 near Uvalde.

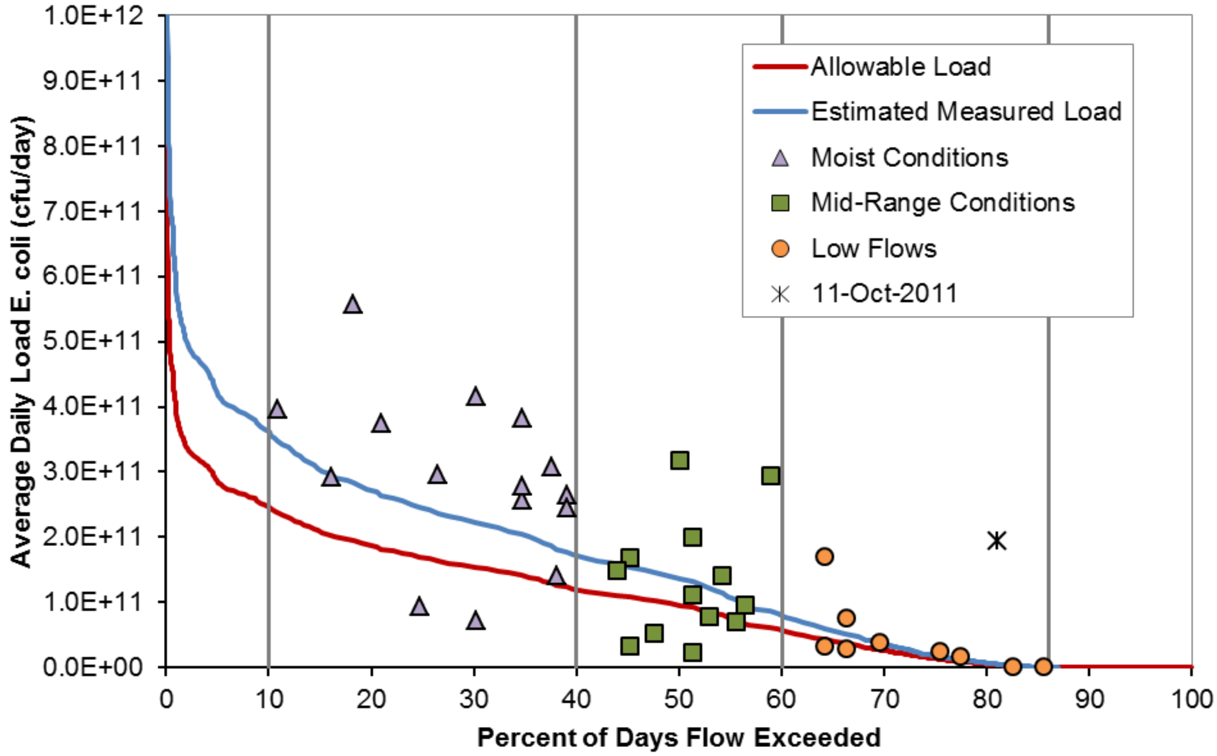

Figure 13 LDCs for *E. coli* for the Leona River at station 12987 near Batesville.

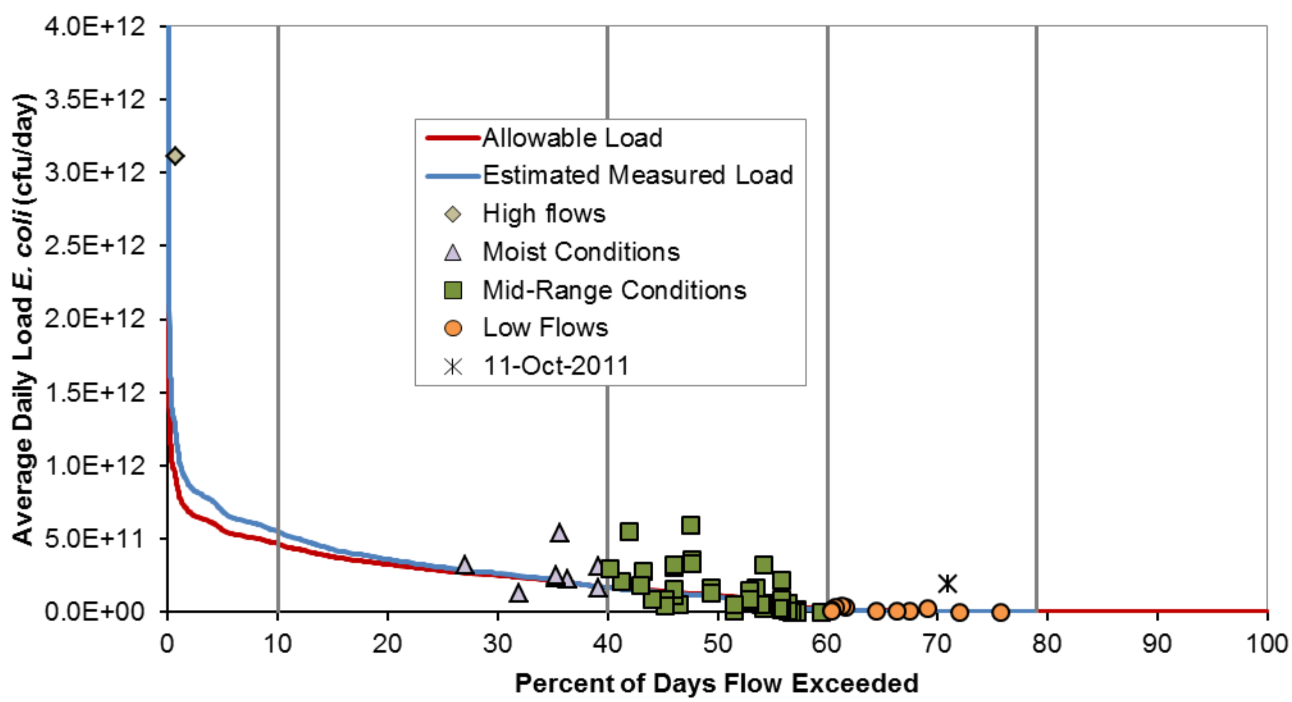

Figure 14 LDCs for *E. coli* for the Leona River at station 12985 near Divot.

Nitrate LDCs

For nitrates, most reductions were associated with moist and high flow conditions associated with rainfall-runoff (Table 11 and Figures 15-18). Only at the most downstream location near Divot were reductions indicated for the average of low conditions, which are emphasized by showing the LDC on a log scale (Figure 18). For the location near Uvalde, if only flows between 5 to 29 cfs were evaluated within the low category (percent flow exceeded from 60 to 84 percent), a percent reduction of 9 percent was indicated (see Figure 15).

Table 11 Summary of estimated nitrate load reductions for the Leona River.

Flow Condition	Percent Exceedance	Average Percent Reduction at Station 12988/12989 near Uvalde	Average Percent Reduction at Station 12987 near Batesville	Average Percent Reduction at Station 12985 near Divot
High flows	0-10%	44	79	76
Moist Conditions	10-40%	35	63	71
Mid-Range Conditions	40-60%	30	42	58
Low Flows	60 to <88%[a]	0	0	38

a. Zero or no flow conditions were indicate 12% of the time for the Uvalde location, 14% of the time for the Batesville location, and 21% of the time for the Divot location based on estimated long-term data.

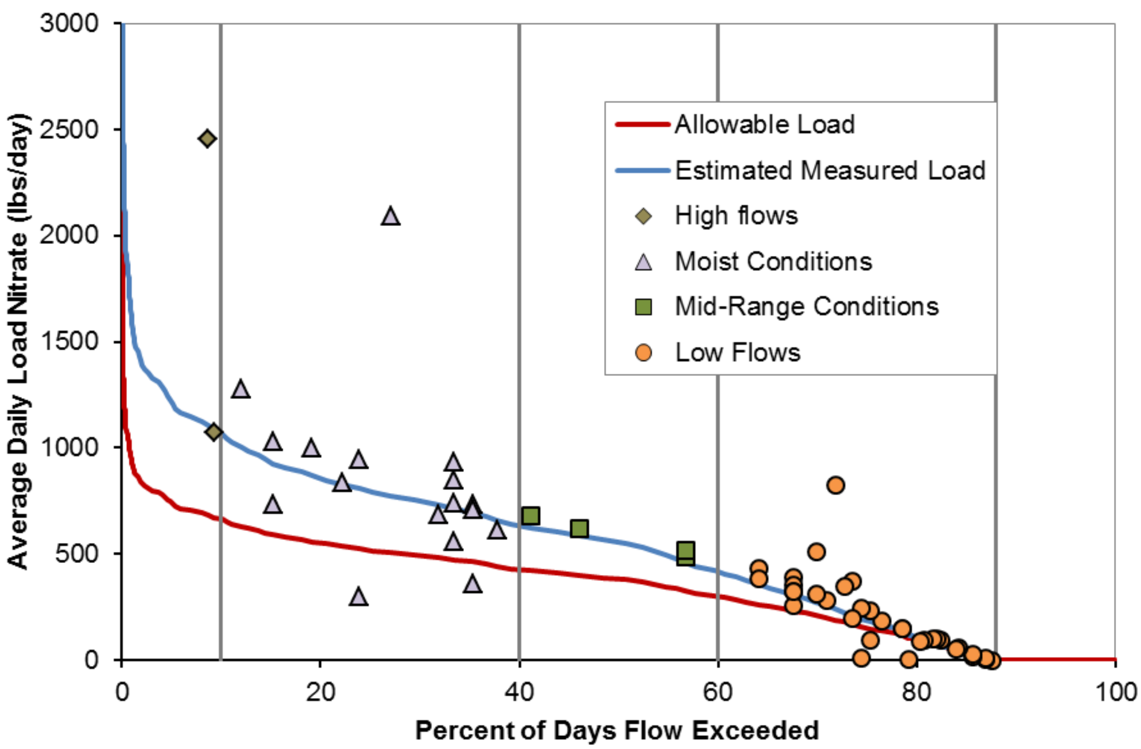

Figure 15 LDCs for nitrate for the Leona River at station 12988/12989 near Uvalde.

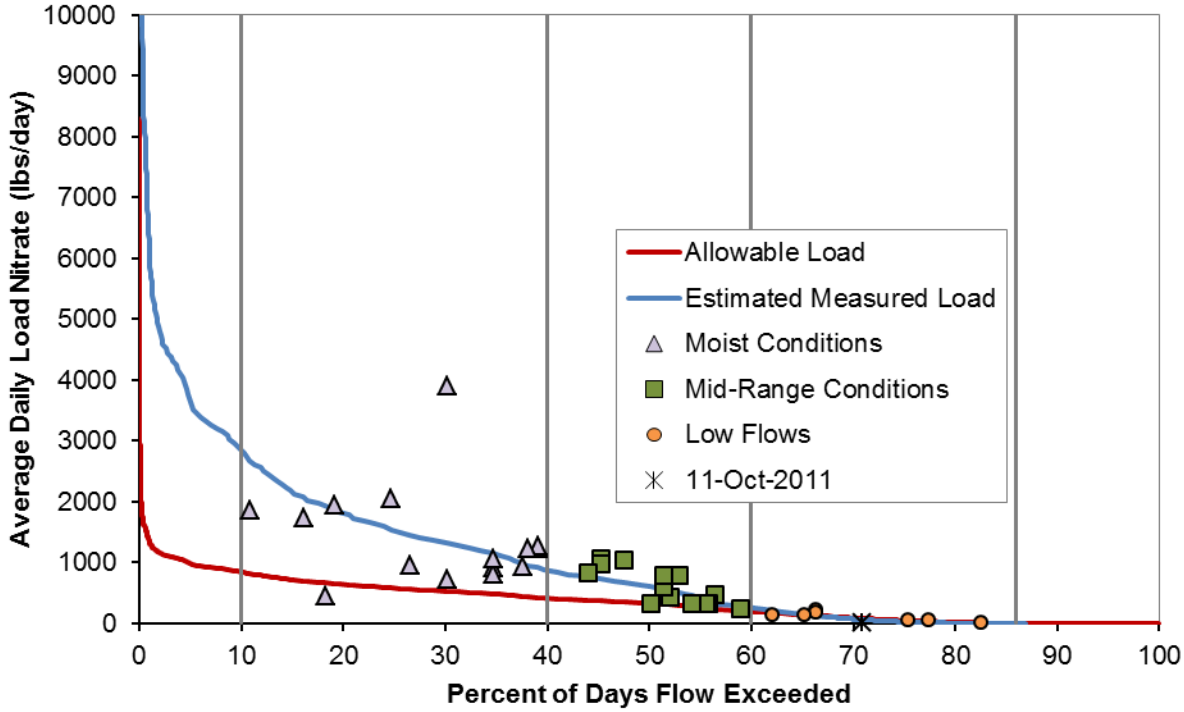

Figure 16 LDCs for nitrate for the Leona River at station 12987 near Batesville.

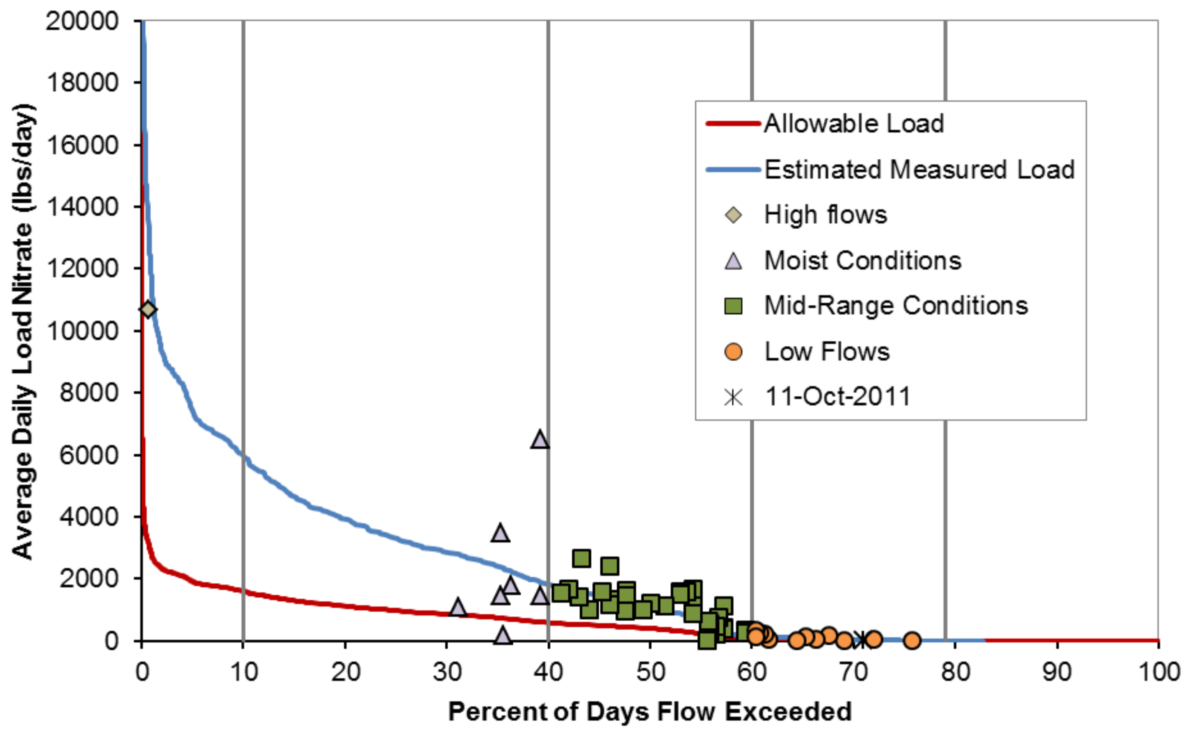

Figure 17 LDCs for nitrate for the Leona River at station 12985 near Divot.

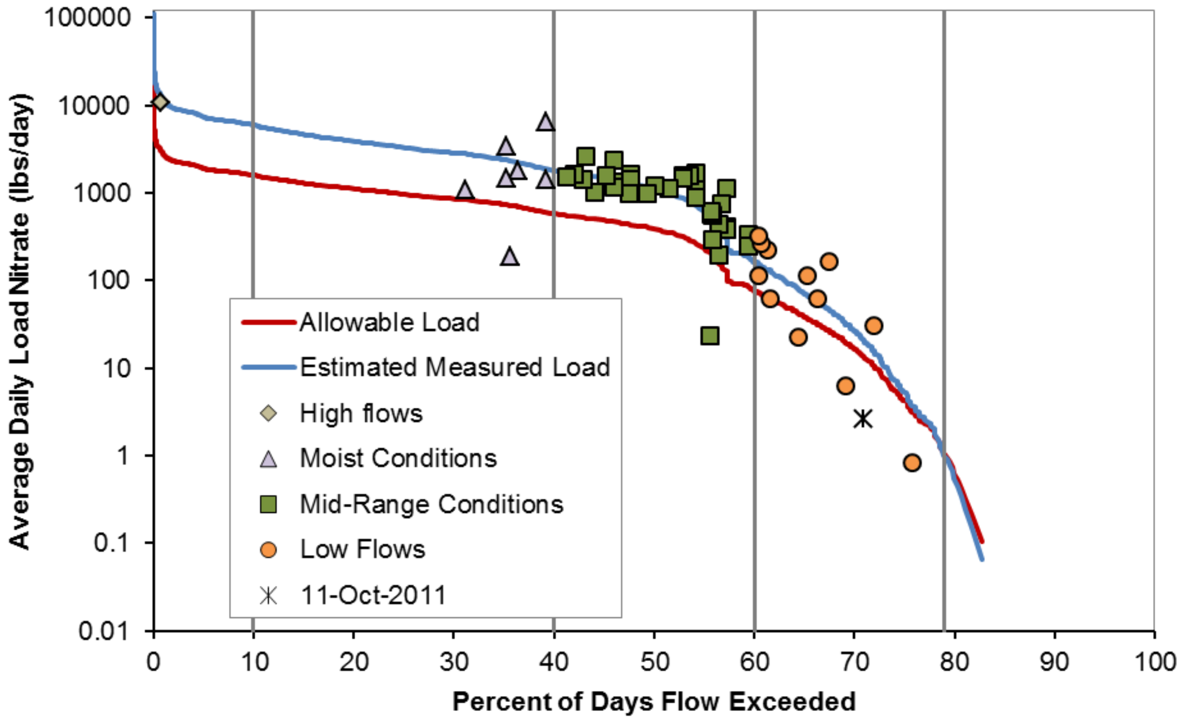

Figure 18 LDCs for nitrate for the Leona River at station 12985 near Divot, log scale.

SECTION 4

Summary and Discussion

Because base flow in the headwaters of the Leona River is largely spring fed, mid-range to low flow conditions indicate a decrease in average flow from the most upstream location near Uvalde to more downstream near Divot. Effluent discharges also in part feed base flow conditions, but is fairly limited. The Uvalde Wastewater Treatment Facility (WWTF) with a permitted discharge of 0.93 MGD (1.7 cfs), discharges into Cooks Slough (a tributary of the Leona River) or directly into the Leona River within the Uvalde City Park. The average discharge for the Uvalde WWTF is generally much less than the permitted value with measured discharges from 2007-2011 averaging 0.39 MGD (0.72 cfs). The United States Fish and Wildlife Service National Fish Hatchery in Uvalde also discharges wastewater intermittently into Fish Hatchery Slough with a permitted discharge of 0.8 MGD (1.5 cfs). Effluent from the City of Batesville, WWTF is permitted to discharge into Gallina Slough, a tributary of the Leona River that merges with the Leona River well below Batesville, but no discharges have occurred because this effluent is allowed to evaporate from holding ponds.

Based on findings from the LDCs, load reductions appear to be primarily associated with rainfall-runoff or nonpoint source pollution loadings for both bacteria and nitrate. Spatially, the largest load reductions for bacteria under all flow conditions were at the Batesville location (station 129987). Potential sources indicated in this area for bacteria may be related to deer, exotics, and beef cattle, but also feral hogs (see McFarland and Adams, 2013a). For nitrates, the largest load reductions were associated with the most downstream location (station 12985) near Divot. The land use/land cover indicates a notable amount of cultivated cropland near the Divot location that is largely irrigated using what appears to be center pivots based on the circle patterns shown in the land use/land cover (see Figure 2). Most irrigation uses groundwater, and groundwater nitrate levels from well data within the watershed indicate elevated concentrations primarily in Uvalde and Zavala Counties (see McFarland and Adams, 2013b). Stakeholders in the watershed have indicated irrigation return flows as a potential source of nitrates.

References

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

Bonta, J.V., and B. R. Cleland. 2003. Incorporating natural variability, uncertainty and risk into water quality evaluations using duration curves. Journal of the American Water Resources Association 39:1481-1496.

Bonta, J.V. 2002. Framework for Estimating TMDLs with Minimal Data, pp. 6-12. In: Proceedings American Society of Agricultural Engineers Conference, Watershed Management to Meet Emerging TMDL Regulations. Fort Worth, TX.

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

Cleland, B.R. 2003. TMDL Development From the "Bottom Up" -- Part III: Duration Curves and Wet-Weather Assessments. National TMDL Science and Policy 2003 Water Environment Federation Specialty Conference. Chicago, IL.

Cleland, B.R. 2002. TMDL Development From the "Bottom Up" – Part II: Using Duration Curves to Connect the Pieces. National TMDL Science and Policy 2002 Water Environment Federation Specialty Conference. Phoenix, AZ.

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. 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA Watershed Branch, Office of Wetlands, Oceans and Watersheds, Washington, D.C. EPA 841-B-07-006, August 2007.

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., and F. P. Bertietti. 2010. Development of a Candidate Drought Contingency Plan for Uvalde County, Texas. Final Report prepared by the Geosciences and Engineering Division , Southwest Research Institute, San Antonio, Texas for the Uvalde County Underground Water Conservation District.

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).

Livingston, P. 1947. Relationship of Ground Water to the Discharge of the Leona River in Uvalde and Zavala Counties, Texas. Prepared by the Texas Board of Water Engineers in cooperation with the United States Geological Survey.

McFarland, A., and T. Adams. 2013a. Leona River Watershed Geographic Information System Inventory and Bacteria Source Survey. Prepared for the Texas State Soil and Water Conservation Board by the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX (in review).

McFarland, A., and T. Adams. 2013b. Historical Review of Hydrology and Water Quality Data for Leona River Segment 2109. Prepared for the Texas State Soil and Water Conservation Board by the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX (in review).

McFarland, A., and J. Millican. 2010. Assessment of Water Quality Trends for the North Bosque River through 2009. Final project report prepared for the Texas Commission on Environmental Quality. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX (TR1002).

Morrison, M.A., and J.V. Bonta. 2008. Development of Duration-Curve Based Methods for Quantifying Variability and Change in Watershed Hydrology and Water Quality. U.S. EPA Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, OH, EPA/600/R-08/065, May 2008.

NASS, National Agricultural Statistics Service. 2011. United States Department of Agriculture, NASS. Available at http://www.nass.usda.gov/Statistics_by_State/Texas/Publications/County_Estimates/index.asp (accessed September 6, 2011).

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).

TCEQ, Texas Commission on Environmental Quality. 2013. 2012 Texas Water Quality Inventory: Assessment Results for Basin 21 - Nueces River (May 9, 2013). Available at http://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/12twqi/2012_basin21.pdf (link verified May 30, 2013).

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. 2010. 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. 2007. 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).

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