

# Assessment of Water Quality Trends for the North Bosque River through 2013

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TR1405

July 2014



# **Assessment of Water Quality Trends for the North Bosque River through 2013**

**Interim Project Report to:  
CWA §319(h) Nonpoint Source Grant Program  
Texas Commission on Environmental Quality  
Austin, Texas  
Contract No. 582-12-10079**

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**July 2014  
TR1405**

## Acknowledgements

Financial support for preparation of this report was provided through the Texas Commission on Environmental Quality (TCEQ) Nonpoint Source Program Clean Water Act §319(h) project, Evaluating Effectiveness of Implementation Plan Activities within the North Bosque River Watershed (Contract No. 582-12-10079). All historical water quality monitoring data presented herein were collected and analyzed by TIAER under various projects. Major projects include Livestock and the Environment: A National Pilot Project sponsored by United States Environmental Protection Agency (USEPA), the Bosque River Watershed Pilot Project funded through the TCEQ Clean Rivers Program in cooperation with the Brazos River Authority, the United States Department of Agriculture Lake Waco-Bosque River Initiative, and the North Bosque River Watershed Water Quality Assessment Clean Water Act 319(h) project sponsored by the TCEQ in cooperation with USEPA Region 6. Historical information regarding the spatial distribution of animal waste application fields in the watershed was largely developed under a previous TCEQ project, Monitoring to Support North Bosque River Model Refinement, with the Total Maximum Daily Load Program.

The United States Geological Survey provided flow and rating curve information for the three gauging stations they maintain along the North Bosque River.

The authors would also like to acknowledge the dedicated work of the many field personnel and laboratory chemists who aided in the collection and analysis of samples, particularly since nonpoint source, water quality monitoring often requires personnel to be on-call seven days a week.

Mention of trade names or commercial products does not constitute their endorsement.

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## Table of Contents

<b>Introduction</b> .....	1
<b>Background and Station Descriptions</b> .....	5
<b>North Bosque River Watershed</b> .....	5
<b>Sampling Stations</b> .....	8
<b>Sample Collection and Laboratory Analysis Methods</b> .....	10
<b>Quality Assurance Procedures</b> .....	10
<b>Collection Methods for Routine Grab Samples</b> .....	11
<b>Collection Methods for Storm Samples</b> .....	12
<b>Laboratory Analysis Methods</b> .....	15
<b>Data Set Construction and Statistical Methods for Trend Analysis</b> .....	16
<b>Censored Data</b> .....	17
<b>Monitoring History</b> .....	18
<b>Exploratory Data Analysis (EDA)</b> .....	18
<b>Adjustment for Stream Flow</b> .....	19
<b>Trend Testing</b> .....	20
<b>Trend Analysis Results</b> .....	21
<b>Routine Grab Data</b> .....	21
<b>Volume-Weighted Data</b> .....	24
<b>Evaluation of Stream Water Quality Goal Attainment</b> .....	29
<b>Summary and Discussion</b> .....	40
<b>References</b> .....	51

## List of Tables

<b>Table 1</b>	Estimated city populations and municipal wastewater discharge information for the North Bosque River watershed .....	5
<b>Table 2</b>	Sampling station characteristics .....	9
<b>Table 3</b>	Parameter and methods of analysis for water quality samples used in trend analysis .....	15
<b>Table 4</b>	Years of available sampling data for trend analysis by station and parameter type .....	18
<b>Table 5</b>	Trend results for routine grab data for stations with flow data along the mainstem of the North Bosque River .....	22
<b>Table 6</b>	Trend results for routine grab data for station 18003 (BO083) along the mainstem of the North Bosque River .....	25
<b>Table 7</b>	Trend results for routine grab data for major tributary stations to the North Bosque River .....	26
<b>Table 8</b>	Trend results for monthly volume-weighted data for mainstem stations along the North Bosque River .....	27
<b>Table 9</b>	Trend results for monthly volume-weighted data for major tributary stations to the North Bosque River .....	28
<b>Table 10</b>	Stream conditions in 2013 at North Bosque River mainstem sampling stations during biweekly monitoring events .....	30
<b>Table 11</b>	Summary of active and historical WAF information for CAFOs and AFOs in the North Bosque River watershed as of fall 2013 .....	46
<b>Table 12</b>	Comparison of acres and number of fields categorized as active and historical WAFs in the North Bosque River watershed as 2000, 2005, and 2013 .....	46
<b>Table 13</b>	Estimated land use and drainage area above sampling stations along the North Bosque River watershed .....	47

## List of Figures

<b>Figure 1</b>	North Bosque River watershed trend analysis monitoring stations.....	2
<b>Figure 2</b>	Annual variation in the number of dairy producers and milk production for Erath County.....	7
<b>Figure 3</b>	Monthly normal precipitation for Stephenville, Texas (1981-2010).....	7
<b>Figure 4</b>	Relationship of the natural log of flow to annual average PO <sub>4</sub> -P concentration of routine grab samples for station 17226 (BO020).....	31
<b>Figure 5</b>	Relationship of the natural log of flow to annual average PO <sub>4</sub> -P concentration of routine grab samples for station 11963 (BO040).....	33
<b>Figure 6</b>	Relationship of the natural log of flow to annual average PO <sub>4</sub> -P concentration of routine grab samples for station 11961 (BO070).....	34
<b>Figure 7</b>	Relationship of the natural log of flow to annual average PO <sub>4</sub> -P concentration of routine grab samples for station 11958/18003 (BO085/BO083).....	35
<b>Figure 8</b>	Relationship of the natural log of flow to annual average PO <sub>4</sub> -P concentration of routine grab samples for station 11956 (BO090).....	36
<b>Figure 9</b>	Relationship of the natural log of flow to annual average PO <sub>4</sub> -P concentration of routine grab samples for station 17605/11954 (BO100/BO095).....	37
<b>Figure 10</b>	Annual average PO <sub>4</sub> -P from routine grab data for stations 17226 (BO020) and 11963 (BO040) compared to the long-term predicted concentration without TMDL implementation and the TMDL goal.....	38
<b>Figure 11</b>	Annual average PO <sub>4</sub> -P from routine grab data for stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095) compared to the long-term predicted concentration without TMDL implementation and the TMDL goal.....	39
<b>Figure 12</b>	Annual box and whisker plots of monthly volume-weighted PO <sub>4</sub> -P grab data for station 11963 (BO040).....	41
<b>Figure 13</b>	Annual box and whisker plots of monthly volume-weighted PO <sub>4</sub> -P grab data for station 11961 (BO070).....	41
<b>Figure 14</b>	Annual box and whisker plots of monthly volume-weighted PO <sub>4</sub> -P data for station 11956 (BO090).....	42
<b>Figure 15</b>	Annual box and whisker plots of monthly volume-weighted PO <sub>4</sub> -P data for station 11954 (BO095).....	42

**Figure 16** Annual box and whisker plots of monthly volume-weighted PO<sub>4</sub>-P data for station 11826 (NC060) ..... 43

**Figure 17** Map of CAFOs, AFOs, and associated WAFs (active and historical) within the North Bosque River watershed representing conditions as of fall 2013... 44

**Figure 18** Temporal variability in annual precipitation at Stephenville and Waco, Texas. .... 48

**Figure 19** Monthly difference from normal precipitation from January 2010 through December 2013 for Stephenville, Texas..... 48

**Figure 20** Temporal variability 2010 through 2013 in cumulative difference of measured to normal monthly precipitation for Stephenville, Texas ..... 49

**Figure 21** Annual runoff in millimeters for gauged stations along the North Bosque River ..... 49

## Introduction

This report is an interim update of water quality trends in the North Bosque River watershed assessing the effectiveness of nonpoint source (NPS) and point source control measures associated with the North Bosque Total Maximum Daily Load (TMDL) Implementation Plan (I-Plan). This report largely follows the format of the previous annual reports for this project (McFarland and Millican, 2012; McFarland and Adams, 2013) and similar reports produced for other projects (e.g., McFarland and Millican, 2011) with information updated as appropriate. Trend analyses focus on eight monitoring stations, five of which are index stations (17226 [BO020], 11963 [BO040], 18003 [BO083], 11956 [BO090], and 11954 [BO095]) for the phosphorus TMDLs along the North Bosque River (Figure 1). Station 11926 (BO070) is a long-term monitoring station located along the North Bosque River between index stations 11963 [BO040] and 18003 [BO083]. Stations 13486 (GC100) and 11961 (NC060) are on two major tributaries to the North Bosque River. This report also updates spatial information on permitted concentrated animal feeding operations (CAFOs) and nonpermitted animal feeding operations (AFOs) as well as the land area associated with waste application fields (WAFs) within the watershed.

The TCEQ adopted two TMDLs for soluble reactive phosphorus<sup>1</sup> (SRP) for North Bosque River Segments 1226 and 1255 in February 2001 that USEPA approved in December 2001 (TNRCC, 2001). The goal of these TMDLs is an overall reduction of about 50 percent in SRP loadings and concentrations within the North Bosque River, although actual reduction goals vary along the river reach. The I-Plan for these TMDLs was approved by TCEQ in late 2002 and by the Texas State Soil and Water Conservation Board (TSSWCB) in early 2003 (TCEQ and TSSWCB, 2002).

The I-Plan outlines a number of programs to reduce SRP in the North Bosque River. These programs include four basic elements for phosphorus control:

1. Use of phosphorus application rates for land application of dairy manure,
2. Use of reduced phosphorus in diets of dairy cows to decrease manure phosphorus,
3. Removal of about half the dairy-generated manure from the watershed, and
4. Implementation of phosphorus effluent limits on municipal wastewater treatment facilities (WWTFs).

To address phosphorus application rates on dairy WAFs, the TSSWCB initiated the Comprehensive Nutrient Management Plan (CNMP) Program. The TSSWCB supports the voluntary implementation of CNMPs by dairy producers as part of their water quality management plans (WQMPs) for animal feeding operations (AFOs). In addition to voluntary compliance, the TCEQ amended rules<sup>2</sup> for concentrated animal feeding

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<sup>1</sup> Soluble reactive phosphorus is commonly referred to as orthophosphate phosphorus (PO<sub>4</sub>-P).

<sup>2</sup> Subchapter B Concentrated Animal Feeding Operations, Chapter 321, Texas Administrative Code Title 30, §321.31 – §321.27.

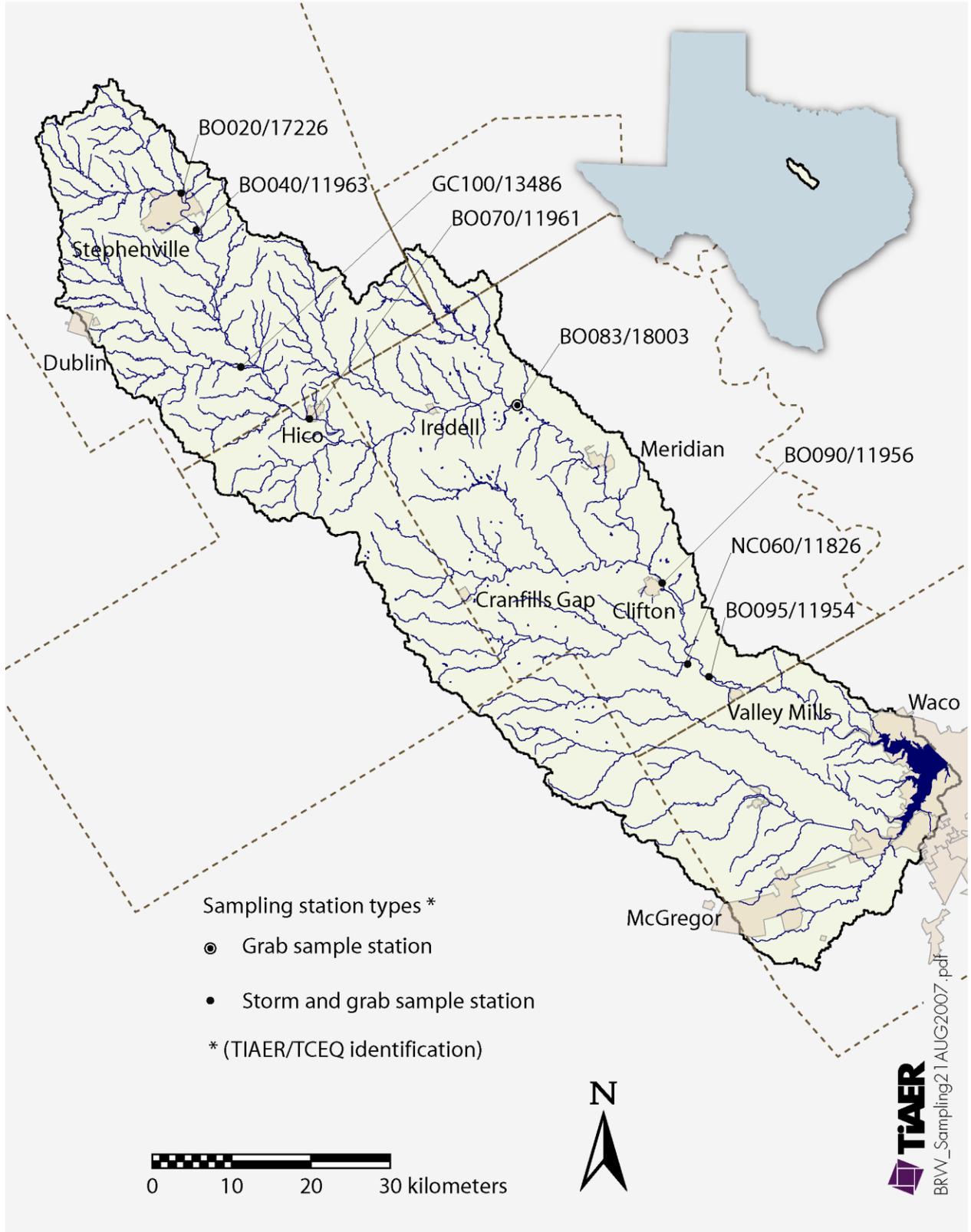


Figure 1 North Bosque River watershed trend analysis monitoring stations.

operations (CAFOs) in 2004 to require permitted dairies in the North Bosque to implement Nutrient Management Plans (NMPs).

A NMP addresses nutrient management guidance for cropping systems as part of a conservation plan for producers and landowners. A CNMP encompasses most aspects of a nutrient management plan (NMP), but additionally may include specifications for feed management, manure and wastewater handling and storage, nutrient management, land treatment practices, and other manure and wastewater utilization options addressing the overall agronomic and environmental aspects of an animal feeding operation (TCEQ and TSSWCB, 2002). The development and adoption of CNMPs, and, thus, NMPs, has occurred over several years. In FY2006, 8 CNMPs were certified, 34 were certified in FY2007, and another 7 certified in FY2008 (TCEQ, 2009). Communications with the TSSWCB indicate that two CNMPs were certified in FY2009 for CAFOs, and by the end of 2010, the TSSWCB had certified CNMPs for all 50 permitted CAFOs active in the watershed (TCEQ, 2012).

While there is not a specific program that addresses phosphorus in the diet of dairy cattle, anecdotal evidence from dairy producers supported by local feed specialists and Texas AgriLife Extension Service (formerly Texas Cooperative Extension) indicates that lower phosphorus diets are being fed. In the mid to late 90s, a survey of dairy diet formulations including dairies in the North Bosque River watershed indicated that cow diets averaged 0.52 percent phosphorus (Sansinena et al., 1999). Revised recommendations by the National Research Council (NRC) indicate that about 0.38 percent phosphorus is optimal for high producing dairy cattle (NRC, 2001), which has been supported in various studies to reduce excess phosphorus in manure (e.g., Powel and Satter, 2005; Miller et al., 2010).

Two of the most visible projects associated with the I-Plan were the Dairy Manure Export Support (DMES) project and the Composted Manure Incentive Project (CMIP). The TSSWCB sponsored DMES project provided incentives to haulers to transport manure from dairies to composting facilities. Through CMIP, TCEQ provided oversight of composting facilities and rebates to Texas State agencies that use manure compost associated with the DMES project. The TCEQ and TSSWCB initiated these manure composting projects in September 2000 as a way to export dairy manure from the North Bosque River watershed. In turn, the dairy manure compost may be used in other watersheds as a beneficial soil amendment. The Texas Department of Transportation (TxDOT) has been the major user of dairy manure compost for roadside revegetation. Through August 2006, over 650,000 tons of dairy manure had been hauled to composting facilities and about 329,000 cubic yards of compost were exported from the watershed (TCEQ, 2009).

Funding for CMIP continued through August 2006, while the DMES project continued to pay incentives to haulers through February 2007. The idea behind these two projects was to establish a manure composting industry that would be self-sufficient after the ending of these two incentive programs. Seven composting facilities were active during these projects, and as of March 2008, six were still active and receiving manure from dairy operations within the watershed. A follow up review in May and June 2009 indicated that five of these six composting facilities were still active, but as of early 2012, TCEQ

reported that only two composting facilities are still fully operational and one other only sporadically receives manure (TCEQ, 2012).

Another program that should have a notable impact on water quality, particularly under low flow conditions, is the implementation of phosphorus removal treatments by municipal WWTFs. There are seven municipal wastewater discharge facilities within the North Bosque River watershed (Stephenville, Hico, Meridian, Iredell, Cranfills Gap, Clifton, and Valley Mills). All municipal WWTFs are required as part of the I-Plan to monitor total phosphorus in their effluent, and the two larger facilities in Clifton and Stephenville, have had their permits amended in 2003 to require phosphorus limits that necessitate advanced treatment processes. In the fall of 2005, Stephenville began using biological treatment in conjunction with alum and polymers for phosphorus removal with the goal of meeting a daily average discharge limit of 1 mg/L. The Clifton WWTF started using alum as a chemical treatment to remove phosphorus in the spring of 2005.

A waste load allocation (WLA) has been set for all seven municipal WWTFs as well as three other facilities not associated with municipalities (Northside Subdivision Water Corporation, Stephenville Mobile Home Park, and Western Dairy Transport). If the WLA cannot be met, each WWTF shall have its permit amended to 1 mg/L total phosphorus as a daily average effluent limit. As of August 31, 2010, TCEQ reported that all seven municipal WWTFs within the North Bosque River watershed have compliance schedules consistent with the WLAs in the TMDL and I-Plan (TCEQ, 2011).

With implementation active, it is important to monitor and statistically evaluate water quality on a recurring basis to determine if these activities are improving water quality. The I-Plan activities are occurring over varying timeframes, but it is also anticipated that changes in water quality will be gradual and lag actual implementation on the land, particularly with regard to reducing nonpoint source pollutants. It may take several years after implementation occurs before instream improvements become apparent. To evaluate for improvements in water quality along the North Bosque River, the Texas Institute for Applied Environmental Research (TIAER) has sampled stream stations since late 1995. Prior to 1995, TIAER's monitoring focused primarily on stream stations and tributaries within the upper third of the watershed providing a sampling history at some stations dating back to 1991.

While soluble phosphorus is the focus of the North Bosque River TMDLs, excessive nutrients based on a variety of nitrogen and phosphorus constituents, elevated chlorophyll- $\alpha$  (CHLA) concentrations, and elevated bacteria levels have been a concern in the North Bosque River watershed for over a decade. To more fully assess overall water quality improvements in the North Bosque River, trends are presented for nitrogen, phosphorus, CHLA, total suspended solids (TSS), specific conductance (conductivity), and bacteria concentrations. Field parameters, (e.g., dissolved oxygen and pH) while routinely monitored as instantaneous measurements, were not included in this trends analysis due to the difficulty in correcting for diurnal fluctuations. Results are discussed in the context of I-Plan activities.

## Background and Station Descriptions

### North Bosque River Watershed

The North Bosque River is located in central Texas and extends about 180 river kilometers (110 river miles) from Stephenville, Texas to Lake Waco near Waco, Texas (Figure 1). The headwaters of the North Bosque River originate in Erath County just north of Stephenville. Lake Waco, a man-made reservoir, supplies drinking water to over 150,000 people. The North Bosque River watershed comprises about 74 percent of the land area draining into Lake Waco. Other major tributaries to Lake Waco include Hog Creek, the Middle Bosque River, and the South Bosque River. Stephenville is the watershed’s largest city with an estimated population of about 17,000 (Table 1).

**Table 1** Estimated city populations and municipal wastewater discharge information for the North Bosque River watershed.

Municipality	Estimated 2010 Population <sup>a</sup>	Permitted Monthly Discharge (MGD) <sup>b</sup>	Discharge Location
Stephenville	17,293	3.0	North Bosque River
Hico	1,404	0.25	Jacks Hollow Branch of the North Bosque River
Iredell	386	0.05	North Bosque River
Meridian	1,585	0.45	North Bosque River
Cranfills Gap	377	0.04	Austin Branch of Meridian Creek, which flows into the North Bosque River
Clifton	3,821	0.65	North Bosque River
Valley Mills	1,179	0.36	North Bosque River

a. Population estimates based on values presented by the Texas State Data Center (2010) for January 1, 2010.  
 b. Source: USEPA (2013).

As mentioned previously, seven municipalities have WWTFs that discharge within the North Bosque River watershed. These are the cities of Stephenville, Hico, Iredell, Meridian, Cranfills Gap, Clifton, and Valley Mills (Table 1). Direct point source discharges occur to the North Bosque River from each community’s WWTF, with the exception of Cranfills Gap and Hico. The Cranfills Gap WWTF discharges into the Austin Branch of Meridian Creek, a major tributary to the North Bosque River, and the Hico WWTF discharges into Jacks Hollow Branch a few hundred feet before its confluence with the North Bosque River. Three additional WWTFs are as follows:

- Northside Subdivision Water WWTF north of Stephenville with a permitted monthly discharge of 0.033 MGD into an unnamed tributary of the North Fork of the North Bosque River,

- Stephenville Mobile Home Park with a permitted discharge of 0.024 MGD into an unnamed tributary of Pole Hollow Branch, and
- Western Dairy Transport, which has a no discharge permit, with irrigated effluent applied to fields within the Indian Camp Creek drainage basin.

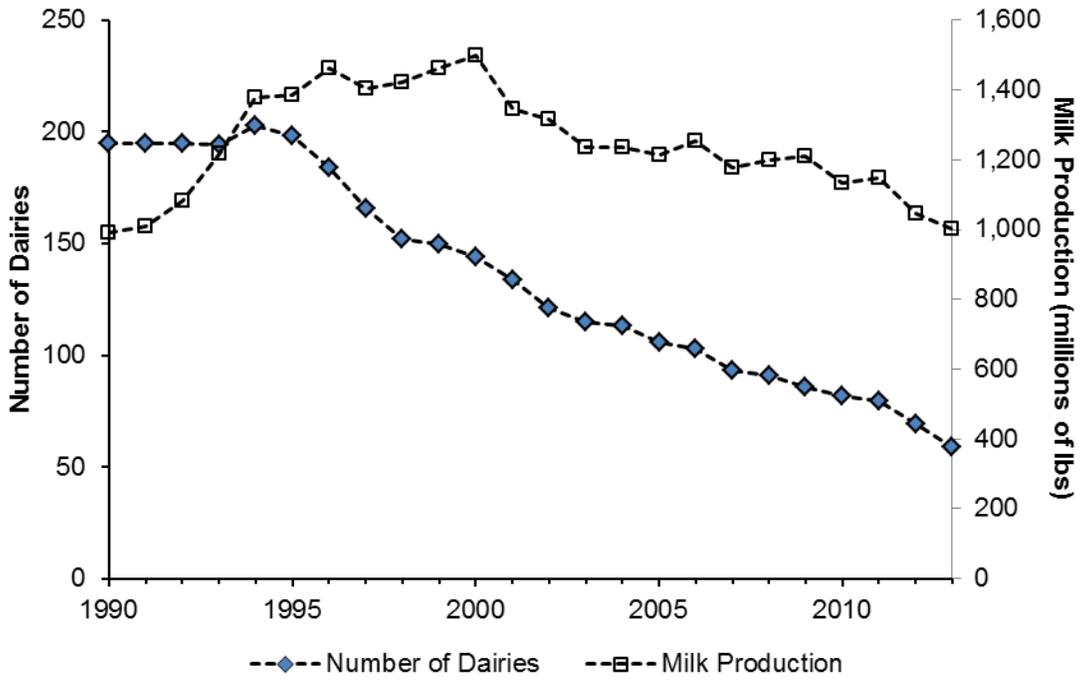
The North Bosque River watershed is typical of many watersheds in the region in that the dominant land covers are wood and range (Narasimhan et al., 2005). Improved pasture and some row crop farming occur throughout the watershed. Row crop farming is most common in the southern portions of the watershed, particularly in the floodplain of the North Bosque River close to the city of Clifton. Improved pasture is predominately fields of Coastal bermudagrass (*Cynodon dactylon*), while row crops of sorghum (*Sorghum bicolor*) and winter wheat (*Triticum* spp.) are often grown as a double-crop system. A large number of dairies are located within the upper third of the watershed where producers have generally applied dairy waste to improved pasture and row crops as an organic fertilizer.

The headwaters of the North Bosque River are located in Erath County, which has been the number one milk-producing county in Texas for a number of years according to records maintained by the USDA Agricultural Marketing Service. While Erath County has been the top milk producing county in Texas during most recent years, Castro County and on occasion Palmer County, both in the Pan Handle, have edged out Erath County in milk production (e.g., USDA-AMS, 2013). Within Erath County, the number of dairy producers has decreased substantially over the last several years (Figure 2), and while milk production has also decreased, it has not been proportional to the decline in producers. For reference, only about two-thirds of the dairy operations in Erath County are located within the North Bosque River watershed. Based on TCEQ inspection records for the North Bosque River watershed, the estimated number of dairy cows was about 45,000 in 2001 and about 32,000 in 2013<sup>3</sup>. For 2013, it was also estimated that another 6,400 animals were in the watershed in association with beef or calf raising CAFOs or AFOs bringing the total number of cattle in confinement to about 38,400.

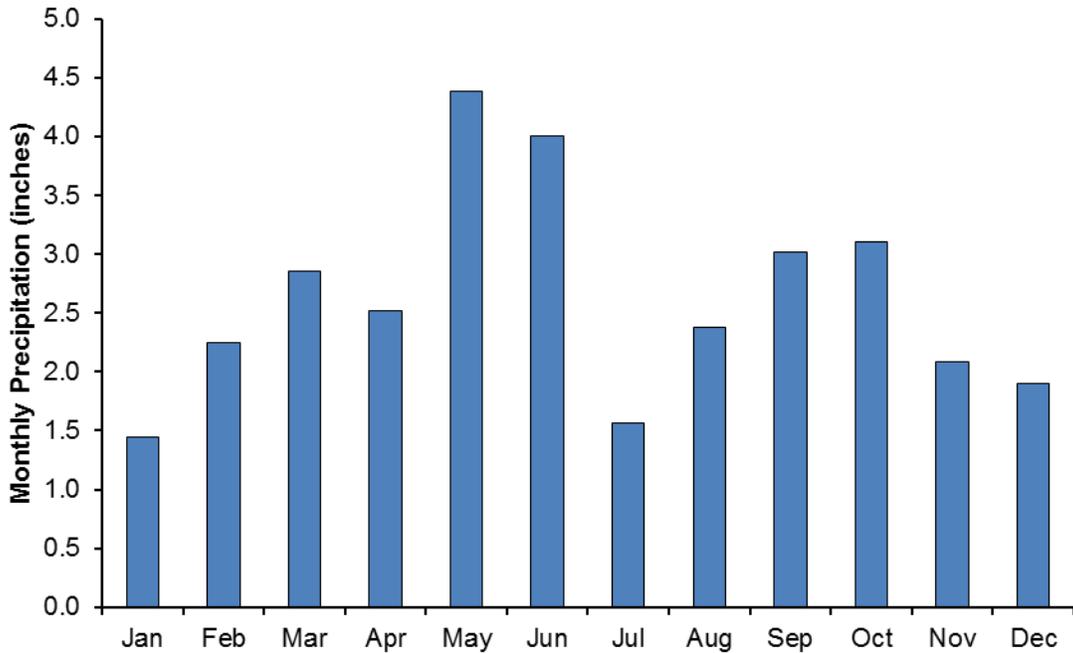
Annual rainfall in the North Bosque River watershed averages a little over 76 cm (30 in) per year. Rainfall typically follows a slightly bimodal pattern with peaks in the spring and fall (Figure 3). On average the wettest month is May and the driest month is January. Most tributaries of the North Bosque River are highly intermittent and frequently become dry soon after each rainfall-runoff event. In some years winter rains corresponding with low evapotranspiration rates can, however, establish a base flow that persists well into spring. Groundwater contributions in the upper portion of the watershed are fairly insignificant, though groundwater seepage has been noted in the lower portion of the watershed, particularly along Neils Creek. Neils Creek is a major tributary to the North Bosque River that joins the North Bosque River between Clifton and Valley Mills (Figure 1).

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<sup>3</sup> Because TCEQ no longer inspects each operation within the watershed annually, estimated animal numbers for 2013 are based on inspected values from FY2010, FY2011, FY2012, and FY2013 using the most recent inspected value for active operations in FY2013.



**Figure 2** Annual variation in the number of dairy producers and milk production for Erath County. Source: United States Department of Agriculture Agricultural Marketing Service milk marketing production records.



**Figure 3** Monthly normal precipitation for Stephenville, Texas (1981-2010). Source: National Oceanic and Atmospheric Administration, National Climatic Data Center.

## Sampling Stations

Because TIAER has sampled at many of these stations under separate projects, all stations are listed by their TCEQ and TIAER station identification for easy reference to information or data in other reports. The TCEQ station identification is generally listed first followed by the TIAER station identification in parentheses or brackets. Trend analysis activities focused on eight stream stations at which temporally intensive data collection has occurred for 10 years or more. Of note, monitoring at most stations was initiated in the early to mid-1990s, while monitoring at station 18003 (BO083) was not initiated until 2003. These stations vary in drainage area, water quality, and hydrology (Table 2) and are grouped as follows:

- The five North Bosque River index stations (11954 [BO095], 11956 [BO090], 18003 [BO083], 11963 [BO040], and 17226 [BO020]) specified in the phosphorus TMDLs and I-Plan.
- North Bosque River at Hico, station 11961 (BO070), which is located in a long reach of the river where index stations are absent.
- Green Creek, station 13486 (GC100), which has been collocated with one of TCEQ's Environmental Monitoring and Response System (EMRS) stations.
- Neils Creek, station 11826 (NC060), which is a reference or least disturbed stream for the Central Oklahoma-Texas Plains ecoregion.

The land-use information in Table 2 is based on classification of satellite imagery from 2001 through 2003 conducted by the Spatial Sciences Laboratory of the Texas Agricultural Experiment Station, now Texas AgriLife Research (Narasimhan et al., 2005). Information on animal waste application fields was compiled in 2000 from TCEQ records and modified in 2005 and again in the fall of 2007 by TIAER based on a review of TCEQ permit information to supplement the satellite imagery classification (McFarland and Jones, 2006; Houser and Hauck, 2010). The WAFs information includes milking and non-milking operations, although milking operations represent over 80 percent of the CAFOs and AFOs in the watershed. A goal of the current project is to update the WAF information for CAFOs and AFOs in the watershed, so it can be used to evaluate if changes have occurred in the amount and location of WAFs that might be related to changes in water quality. The task of updating the WAF information has been initiated and preliminary results are presented later in this report.

In addition to the stations listed Table 2, data from station 17605 (BO100) were used in conjunction with data from station 11954 (BO095). Station 17605 (BO100) was a TIAER sampling station located below Valley Mills that was discontinued in July 2001 due to bank stability problems. Station 11954 (BO095) was installed about three river kilometers upstream to replace station 17605 (BO100). Collectively data from these two stations will be referred to as station 11954 (BO095) throughout the rest of this report.

**Table 2** Sampling station characteristics. Land-use/land-cover information based on information from Narasimhan et al. (2005).

Station Identification TCEQ (TIAER)	Location within the North Bosque River Watershed	Drainage Area (ha)	Dominant Land Use or Land Cover <sup>a</sup>	General Water Quality and Hydrology
<b>Stations along the Mainstem of the North Bosque River</b>				
17226 (BO020)	North Bosque River above Stephenville, Texas	21,700	Wood-range (26%), pasture and cropland (51%), waste application fields (18%), urban (4%)	Water quality moderately impacted by nonpoint sources; intermittent flow with perennial pools
11963 (BO040)	North Bosque River below Stephenville, Texas about 0.6 km below the discharge from the Stephenville WWTF <sup>b</sup>	25,700	Wood-range (26%), pasture and cropland (50%), waste application fields (17%), urban (6%)	Water quality impacted by point and nonpoint sources; perennial flow
11961 (BO070)	North Bosque River at Hico, Texas above the discharge from the Hico WWTF	93,100	Wood-range (41%), pasture and cropland (45%), waste application fields (10%), urban (3%)	Water quality moderately impacted by point and nonpoint sources; nearly perennial flow
18003 (BO083)	North Bosque River between Iredell and Meridian, Texas	178,000	Wood-range (53%), pasture and cropland (36%), waste application fields (7%), urban (2%)	Water quality moderately impacted by point and nonpoint sources; nearly perennial flow
11956 (BO090)	North Bosque River at Clifton, Texas above the discharge from the Clifton WWTF	253,000	Wood-range (59%), pasture and cropland (32%), waste application fields (5%), urban (2%)	Low impacts from point and nonpoint sources; perennial flow
11954 (BO095)	North Bosque River at Valley Mills, Texas above the discharge from the Valley Mills WWTF	297,000	Wood-range (62%), pasture and cropland (31%), waste application fields (4%), urban (2%)	Low impacts from point and nonpoint sources; perennial flow
<b>Stations on Major Tributaries to the North Bosque River</b>				
13486 (GC100)	Green Creek near the confluence with the North Bosque River	25,200	Wood-range (39%), pasture and cropland (50%), waste application fields (8%), urban (2%)	Water quality moderately impacted by nonpoint sources; intermittent flow with perennial pools
11826 (NC060)	Neils Creek near the confluence with the North Bosque River	35,200	Wood-range (74%), pasture and cropland (24%), urban (1%)	Ecoregion reference site; intermittent flow with perennial pools

<sup>a</sup> Waste application fields are considered a distinct land use from pasture and cropland, although waste is generally applied to pasture and cropland. Most WAFs are associated with CAFOs and AFOs as noted in McFarland and Jones (2006) and Houser and Hauck (2010).

<sup>b</sup> WWTF, wastewater treatment facility.

## Sample Collection and Laboratory Analysis Methods

### Quality Assurance Procedures

Beginning as early as 1992, TIAER has collected data from project stations under a variety of quality assurance project plans. Historical information used in this report includes water quality, rainfall, and streamflow. Historical project QAPPs include the following:

1. Quality Assurance Project Plan for the National Pilot Project (TIAER, 1993) funded by USEPA. This QAPP covers data collected between June 1, 1992 and August 31, 1995 for stations in the upper portion of the North Bosque River watershed.
2. Quality Assurance Project Plan for the Bosque River Watershed Pilot Project (BRA, 1995) funded by the TCEQ Clean Rivers Program via the Brazos River Authority with TIAER as a subcontractor. This QAPP covers data collected between October 1, 1995 and May 31, 1996.
3. Quality Assurance Project Plan for the Lake Waco-Bosque River Initiative (e.g., TIAER, 2005) funded by the United States Department of Agriculture. This QAPP covers data collected between September 1, 1996 and August 31, 2006.
4. Quality Assurance Project Plan for the North Bosque River Watershed Water Quality Assessment Clean Water Act 319(h) project funded by the TCEQ and EPA Region 6 (e.g., TIAER, 2010a). This QAPP covers data collected between February 2006 and August 2010.
5. Quality Assurance Project Plan for the North Bosque River Watershed Water Quality Assessment project funded through the TCEQ Surface Water Quality Monitoring Program (TIAER, 2010b). This QAPP covers data collected between September 2010 and August 2011.
6. Quality Assurance Project Plan for Evaluating Effectiveness of I-Plan Activities within the North Bosque River Watershed, a Clean Water Act 319(h) project funded through the TCEQ Nonpoint Source Program (e.g., TIAER, 2013). This QAPP is for the current project and covers data presented in this report collected between September 2011 and December 2013.

Water quality data associated with projects above were collected and analyzed using similar assessment objectives, sampling techniques, laboratory protocols, and data validation procedures. One known area of deviation was in the measurement of bacteria. Prior to 2000 fecal coliform (FC) rather than *Escherichia coli* was monitored. McFarland and Millican (2010) evaluated paired *E. coli* and fecal coliform data from November 2000 through March 2004 to compare these two types of bacteria data. This period of overlap was used to determine if fecal coliform could be adjusted to comparable *E. coli*

values using accepted statistical methods for comparing different analytical methods (Bland and Altman, 1986). This comparison included 1075-paired observations and produced the following regression relationship, which was used to adjust historical fecal coliform concentrations to *E. coli* concentrations prior to trend analysis:

$$\ln(E. coli) = 0.946 \cdot \ln(FC) - 0.029 \quad R^2 = 0.93$$

Of note, McFarland and Millican (2010) indicate that this regression relationship did not meet all the assumptions associated with use of regression analysis in that the distribution of residuals was peaked and, thus, not normally distributed even after data were log normally transformed. We assumed that the regression relationship between fecal coliform and *E. coli* was robust enough that the violation of this statistical assumption would have only a minor impact on the outcome of the trend analysis.

Another known deviation was in the use of reporting limits for left-censored data. Prior to September 2003, TIAER used laboratory method detection limits (MDLs) as reporting limits for constituents. After September 2003, TIAER used TCEQ ambient water reporting limits (AWRLs) or limits of quantitation (LOQs) as reporting limits. Data for each constituent were standardized prior to trend analysis to make sure that differences in the reporting limit did not cause an indication of false trends.

Data external to TIAER from the United States Geological Survey (USGS) were used to determine flow at some sampling stations. The USGS maintains stage gauging stations along the North Bosque River near Hico (USGS station 08094800), Clifton (USGS station 0809500), and Valley Mills (USGS station 08095200). Associated USGS stream discharge and/or rating curve data in conjunction with stage data measured by TIAER were used to calculate discharge for stations 11961 (BO070), 11956 (BO090), and 11954 (BO095).

The overall project objective was to use direct data in conjunction with non-direct data from previous projects to evaluate changes in water quality over time. Because most historical data were collected and analyzed in a comparable manner, no limitations were placed on their use, except where known deviations occurred, such as changes in bacteria parameters and differences in reporting limits.

### **Collection Methods for Routine Grab Samples**

Routine grab sampling at stream stations occurred at least monthly and generally on a biweekly schedule throughout the period of available data. Grab samples were collected only when water was flowing at a station and not when the stream was dry or pooled. Grab samples were taken at a depth of 0.3 m or less below the surface depending on total water depth, as recommended in TCEQ surface water monitoring procedures (TCEQ, 2003; 2008). When grab samples were collected, water temperature, dissolved oxygen (DO), pH, and conductivity were measured in situ with a Hydrolab or YSI (multiprobe) field sampling instrument. Because stream stations within the North Bosque River watershed are generally shallow and unlikely to stratify, multiprobe readings were taken only at a surface depth corresponding to the depth of the routine grab sample.

In this report, surface samples are presented and evaluated for trends in nutrients, TSS, CHLA, bacteria (as *E. coli*), and conductivity. Trends in water temperature, DO, and pH were not evaluated, because many physical parameters, particularly water temperature and DO, follow a diurnal pattern that causes values to vary depending on the time of day when measurements are taken.

### Collection Methods for Storm Samples

Storm samples were collected at seven of the eight North Bosque River stream stations. Only routine grab samples were collected at station 18003 (BO083) due to issues with accessibility for installation of a storm sampling station. Storm samples were collected at automated sampling stations using an ISCO 3700 sampler in combination with an ISCO 4230 or 3230 bubbler-type flow meter. The ISCO flow meter operates by measuring the pressure required to force an air bubble through a 3 mm (0.125 in) polypropylene tube, or bubbler line, and represents the water level. The ISCO flow meters were programmed to record water level or stage continuously at five-minute intervals and to initiate sample retrieval by the ISCO 3700 samplers. Samplers typically were actuated based on a stream rise of about 4 cm (1.5 in) above the bubbler datum. Once activated, samplers were programmed to retrieve one-liter sequential samples. Historically, the typical sampling sequence at major tributary and mainstem stream stations was:

- An initial sample
- One sample taken at a one-hour interval
- One sample taken at a two-hour interval
- One sample taken at a three-hour interval
- One sample taken at a four-hour interval
- One sample taken at a six-hour interval
- All remaining samples taken at eight-hour intervals

Since the fall of 2006, the sampling sequence has been modified so that once the four-hour interval was encountered; all remaining bottles for an event were then taken at the four-hour interval.

Until June 1997, most storm samples were analyzed individually by TIAER's laboratory. To decrease sample load to the laboratory, a flow-weighting strategy was initiated that composited samples on about a daily basis. This flow-weighting strategy was initiated in May or June 1997 at stations 17226 (BO020), 11963 (BO040), 13486 (GC100), and 11826 (NC060). In May 2000, the flow-weighting strategy for storm samples was initiated at stations 11956 (BO090) and 11954 (BO095).

At each storm sampling station, stream stage was continuously monitored at five-minute intervals. To convert stage readings to flow, stage-discharge relationships were developed. For stations 17226 (BO020), 11963 (BO040), 13486 (GC100), and 11826 (NC060), stage-discharge relationships were based on manual flow measurements by TIAER staff taken at various stage conditions that were then related to the cross-sectional area of the stream following USGS methods as outlined in Buchanan and Somers (1969).

Stage-discharge relationships for stages above available measurements were extrapolated using the cross-sectional area and a least-squares relationship of the average stream velocity to the log of water level.

Stations 11961 (BO070), 11956 (BO090), and 11954 (BO095) are located near USGS stream gauging stations. Station 11961 (BO070) is located near USGS station 08094800, 11956 (BO090) is located near USGS station 0809500, and 11954 (BO095) is located near USGS station 08095200. Very early in TIAER's monitoring program, stage recordings at station 11961 (BO070) were tied into the USGS rating curve for station 08094800. The daily average discharge values at station 08094800 were used as a check on the TIAER estimates of discharge at station 11961 (BO070) until October 1999, when the USGS station 08094800 near Hico was converted to flood-hydrograph partial record station. For stations 11956 (BO090) and 11954 (BO095), continuous 15-minute discharge data were obtained for USGS stations 0809500 and 08095200. Of note in October 2005 the USGS station 08095200 near Valley Mills was also converted to a flood-hydrograph partial record station. To obtain continuous discharge measurements after October 1, 2005, a period with USGS discharge measurements and TIAER stage recordings was used to develop a stage-discharge relationship for station 11954 (BO095) in conjunction with manual flow measurements collected by TIAER. This new rating curve for station 11964 (BO095) was used for discharge estimates after October 1, 2005 and USGS 15-minute discharge data were used prior to October 1, 2005. Starting in September 2007, the USGS station near Valley Mills (08095200) was converted back to recording all flows, but TIAER has continued to use stage and flow data from 11964 (BO095) with adjustments based on USGS data when data gaps occur.

Of note, heavy rains in late June 2007 led to flooding necessitating the temporary removal of automated sampling equipment from stations 11954 (BO095) at Valley Mills and 11956 (BO090) at Clifton. The automated sampler at station 11956 (BO090) was inoperable from June 27, 2007 through July 20, 2007. The automated sampler at station 11954 (BO095) was inoperable from June 27, 2007 through August 16, 2007. While automated samplers at 11956 (BO090) and 11954 (BO095) were inoperable, daily storm grabs were taken for laboratory analyses when water levels were elevated. The temporary removal of these two sampling stations corresponded with a period when the USGS was providing flow and stage data at nearby stations, so flow and stage from the corresponding USGS stations were used to estimate missing flow and stage data for 11956 (BO090) and 11954 (BO095).

Also of note in the spring of 2008, the monitoring design was changed due to changes in project funding so that only selected storm events rather than all events were to be monitored. Because of judicious efforts on the part of the field crew and favorable weather conditions, the project was able to monitor all storm events in 2008, while missing only a few relatively small events in 2009. In late November 2009, there was one event, which caused a small rise in water level at most stations, but led to a moderately sized runoff event at stations 11961 (BO070) and 13486 (GC100) during which storm samples were not collected. A routine grab sample was collected during this November 2009 event, which was used to represent the storm water quality for this event.

During most of 2010, storm sampling was restricted due to limited funding. From January through May 2010, storm samples were collected only at stations 11961 (BO070) and 11954 (BO095). From May through September 2010, storm samples were not collected at any of the seven stations. Starting in September 2010, renewed funding was obtained at which time storm sampling was reinitiated at all seven storm stations, so all events with a rise in water level of over 0.5 ft between September and December 2010 were monitored.

Although several storms during 2010 were not directly monitored, the contribution of these storms to nonpoint storms loadings was still important in evaluating annual trends. Because it is anticipated that changes in water quality will occur gradually, data from storms evaluated in 2009 and 2010 for most stations were used to estimate storm loadings. Of note for station 13486 (GC100), storm data from 2008 were included due to the paucity of storms that occurred at this station in 2009. Details on how previous storm concentrations were associated with 2010 storm events are presented in McFarland and Millican (2011).

In 2011, most months had relatively little rainfall and extreme drought conditions occurred across the watershed by late summer, enabling all events that occurred to be monitored. Routine grab sampling was limited, particularly during the summer and fall months at sites 17226 (BO020), 11961 (BO070), 18003 (BO083), 11826 (NC060), and 12486 (GC100) (see McFarland and Adams, 2012). The driest location was 12486 (GC100) where only one routine grab sample was collected in 2011. At 17226 (BO020), 11961 (BO070), 18003 (BO083), and 11826 (NC060), stream water was not flowing 31 to 53 percent of the time during biweekly sampling (McFarland and Adams, 2012).

In 2012, stream conditions were still often low, but routine grab samples were generally collected more frequently than in 2011. The only exception was station 17226 (BO020), which had fewer grab samples in 2012 (15 in 2011 and 12 in 2012). Routine grab samples were collected during all biweekly monitoring events at stations 11963 (BO040), 11961 (BO070), 11956 (BO090), and 11954 (BO095). At the other four stations, water was not flowing 42 to 54 percent of the time when visited for biweekly sampling. Most storm events in 2012 occurred between January and early June with a single fall event in late September. All notable elevated flows were monitored in 2012, except an event that occurred over the Christmas holidays (starting December 25) at stations 17226 (BO020), 11963 (BO040), and 11961 (BO070). For annual loading calculations, event mean concentrations (EMCs) from the September storm event were associated with this rise in water level.

In 2013, stream conditions were also quite low with moderate drought conditions noted for most of the year based on historical Palmer Drought Indices (NCDC, 2014). While pooled or no flow conditions are not unusual along portions of the North Bosque River, particularly in the summer months at stations 17226 (BO020), 11961 (BO070), and 18003 (BO083), they are unusual for the most downstream stations 11956 (BO090) and 11954 (BO095). In August and part of September 2013, pooled conditions were noted at

11956 (BO090) and 11954 (BO095) during biweekly routine monitoring (see McFarland and Adams, 2014). Pooled conditions were also noted at 11956 (BO090) in early July 2013. Compared to 2012, storm events were much smaller in volume but more frequent and more evenly spaced throughout the year in 2013. All storms with a notable rise in water level (generally 0.25 ft or greater) were monitored except two storm events in December 2013. On December 8-9, 2013, an ice storm led to a notable rise in water level at most stations, but also caused unsafe driving conditions for sample retrieval. Another notable rise in stream water level occurred in response to a rainfall-runoff on December 21, 2013. Due to a planned power outage associated with construction work on the Tarleton State University campus that affected the TIAER laboratory and, thus, the ability of the lab to process samples, samplers were not activated during the December 21, 2013, storm event. Loading for these December events were based on EMCs of similar size events collected at each station.

### Laboratory Analysis Methods

Ammonia-nitrogen (NH<sub>3</sub>-N), nitrite-nitrogen plus nitrate-nitrogen (NO<sub>2</sub>-N+NO<sub>3</sub>-N), total Kjeldahl nitrogen (TKN), orthophosphate-phosphorus (PO<sub>4</sub>-P) or SRP, total-P, and TSS were evaluated for both routine grab and storm samples (Table 3). In addition, CHLA and *E. coli* were evaluated for routine grab samples. Total nitrogen (TN) was calculated as the sum of NO<sub>2</sub>-N+NO<sub>3</sub>-N plus TKN for inclusion in the trend analysis.

Prior to 2000 fecal coliform rather than *E. coli* was monitored as an indicator of bacteria concentrations. From November 2000 through March 2004 both fecal coliform and *E. coli* were analyzed to determine a relationship between these two measures of bacteria.

**Table 3** Parameter and methods of analysis for water quality samples used in trend analysis.

Parameter	Abbreviation	Units	Method <sup>a</sup>	Parameter Code
Ammonia-nitrogen	NH <sub>3</sub> -N	mg/L	EPA 350.1 or SM 4500-NH3 G	00608
Nitrite-nitrogen + nitrate-nitrogen	NO <sub>2</sub> -N+NO <sub>3</sub> -N	mg/L	EPA 353.2 or SM 4500-NO3-F	00631
Total Kjeldahl nitrogen	TKN	mg/L	EPA 351.2 or SM 4500-NH3G <sup>b</sup>	00625
Orthophosphate-phosphorus	PO <sub>4</sub> -P	mg/L	EPA 365.2 or SM 4500P-E	70507 or 00671 <sup>c</sup>
Total phosphorus	Total-P	mg/L	EPA 365.4 <sup>b</sup>	00665
Total suspended solids	TSS	mg/L	EPA 160.2 or SM 2540 D	00530
Chlorophyll- $\alpha$	CHLA	$\mu$ g/L	SM <sup>d</sup> 10200-H	32211
<i>Escherichia coli</i>	<i>E. coli</i>	cfu/100 mL or MPN/100mL	SM9222G or SM9223-B (IDEXX Coliert®) <sup>d</sup>	31699

<sup>a</sup> EPA refers to *Methods for Chemical Analysis of Water and Wastes* (USEPA, 1983) and SM refers to *Standard Methods for the Examination of Water And Wastewater*, 18<sup>th</sup> Edition (APHA, 1992) for PO<sub>4</sub>-P and latest online edition for all other parameters.

<sup>b</sup> Modification of TKN and total-P methods involved using copper sulfate as the catalyst instead of mercuric oxide.

<sup>c</sup> Field-filtering for PO<sub>4</sub>-P began in October 2003 for routine grab samples as indicated by parameter code 00671. All routine samples prior to October 2003 and all storm samples were lab filtered as indicated by parameter code 70507.

<sup>d</sup> Most probably number (MPN) or IDEXX method for *E. coli* (SM9223-B) was implemented in April 2004.

## Data Set Construction and Statistical Methods for Trend Analysis

Two data sets representing monthly estimates of average constituent concentrations for each station were developed for trend analysis. The first data set was developed from routine grab data, while the second data set was developed from a combination of routine grab and storm data. Trends associated with these two data sets addresses TMDL objectives regarding reductions in concentrations and loadings. Routine grab samples should reflect any decrease in concentrations associated with routine monitoring, while the volume-weighted data set including storm samples should reflect any decrease in loadings at stream stations. Stream concentrations are often related to flow, so for all stream stations, except 18003 (BO083) where flow data were not available, data sets were limited to timeframes with flow data for evaluation of trends.

Most routine grab samples for nutrients and TSS were collected biweekly or monthly, while samples for analysis of CHLA and bacteria were collected only monthly. Estimates of instantaneous discharge at the time of routine grab sample collection were determined from stage recordings and paired with each biweekly or monthly grab sample as an indicator of flow. Because variation in sampling frequency over time can cause unintended impacts on the analysis of trends (Gilbert, 1987), concentrations and flows associated with biweekly samples were averaged to represent values on a monthly basis. Except at station 18003 (BO083), concentrations represented monthly flow-weighted averages to account for differences in instantaneous flow between individual grab samples within a month.

The second data set represented volume-weighted, average-monthly constituent concentrations based on calculations of total flow and loadings using routine grab and storm samples. Monthly masses and flows were calculated using a rectangular integration method applying a midpoint rule to associate water quality concentrations with streamflow (Stein, 1977). The interval for stage readings (5 minutes for TIAER stations and generally 15 minutes for USGS gauging stations) was the minimum measurement interval. The flow associated with each interval was multiplied by the associated water quality concentration and summed across the entire month to calculate total monthly constituent loadings. Monthly volume-weighted concentrations were calculated by dividing total monthly mass for a constituent by total monthly flow.

Of note for 2010, the volume-weighted data set includes estimated EMCs for events that were not monitored; because very few storm events were directly monitored between January and August 2010 (see McFarland and Millican, 2011). Some storm sampling occurred between January and May 2010 at stations 11961 (BO070) and 11954 (BO095), but at all other stations, only routine grab sample data were directly collected until September 2010, when storm sampling was reinitiated at all seven stations.

In the calculation of loadings for 2010, EMCs calculated for storms monitored in 2009 and 2010 (and 2008 for station 13486) were used to estimate storm loadings when direct measurements were missing. Because EMCs are expected to vary with the size of the

event, EMCs were compared to the average flow for each event generally using a log-linear relationship. Several studies have shown strong relationships between constituent concentrations and discharge (e.g., Agouridis and Edwards, 2003; Sharpley et al., 2008) and calculation of loadings is often based on non-direct measurements (e.g., Cohn et al., 1992; Robertson and Roerish, 1999). Stream level data for 2010 was then evaluated at each station to determine when storm events occurred that were not directly monitored and the average flow during each of these events was calculated. Based on the average flow of each event, EMCs were calculated using the parameter specific relationship developed for each station between flow and EMC (see Appendix A in McFarland and Millican, 2011). If there was not a clear relationship for a given parameter with average storm flow, the average EMC was used to estimate loadings for non-monitored events.

Almost all elevated flow events in 2012 were monitored, except an event that occurred over the Christmas holidays (starting December 25) at stations 17726 (BO020), 11963 (BO040), and 11961 (BO070). Event mean concentrations from a September event, which was of similar magnitude, were associated with the December rise in water level for these three stations in the calculation of annual loadings.

For 2013, two storm events in December were not sampled. Loadings for these two storm events were based on EMCs of similar size events at each station monitored in 2013.

### **Censored Data**

Analytical laboratories generally present data based on a reporting limit, where the reporting limit is the lowest concentration at which the laboratory will quantitatively report data as different from zero. Values below the reporting limit are generally indicated as less than the reporting limit or left censored. Left censored data can cause problems with trend analysis, especially when changes in the reporting limit occur over time. If differences due to variation in reporting limits are not accounted for prior to trend analysis, false trends may be observed. For example, if a relatively high reporting limit is used early and a lower reporting limit later in a project, a decreasing trend may be statistically shown that is not real if concentrations from the earlier data were actually lower than the later reporting limit. As part of the quality assurance of a project, reporting limits should be low enough that relevant changes in values can be observed.

For most projects prior to September 2003, TIAER used laboratory method detection limits (MDLs) as the reporting limit. These MDLs were updated about once every six months. After September 2003, most TIAER projects used TCEQ defined ambient water reporting limits (AWRLs) or limits of quantification (LOQs) as the reporting limit, although if not specified for a project, MDLs were still implemented. Following recommendations by Gilliom and Helsel (1986) and Ward et al. (1988), values measured below the laboratory reporting limit or left censored data were entered as one-half the reporting limit. In preparing data sets for trend analysis, the maximum reporting limit for each station by constituent was determined and all values below the maximum reporting limit were set equal to one-half the maximum reporting limit.

## Monitoring History

Because monitoring was conducted under a number of different projects, different lengths of record were available for each station (Table 4). The timeframe of available monitoring data also often differed by parameter. Stations 11961 (BO070) and 13486 (GC100) had the longest periods of record with data starting in 1993 for most routine grab and storm samples. With routine grab samples, TKN, total P, and TSS were not analyzed until 1994 at 11961 (BO070) and 1995 at 13486 (GC100), but these three constituents were analyzed with storm samples starting in 1993 at both stations. Loading estimates at 11961 (BO070) in 1993 and 13486 (GC100) in 1993 and 1994 for TKN, total P, and TSS were, thus, based only on storm data. Also, at 13486 (GC100), CHLA was not added to the analysis of routine grab samples until 1996. Consistent data sets for all constituents, whether routine or storm data, were indicated at station 17226 (BO020) starting in 1997; at station 11963 (BO040) starting in 1994; and at stations 11956 (BO090), 11954 (BO095), and 11826 (NC060) starting in 1996.

## Exploratory Data Analysis (EDA)

Exploratory data analysis (EDA) was used initially to evaluate each data set. The EDA graphical technique is used to characterize distributional properties, identify outliers and patterns, and select appropriate statistical tests (Tukey, 1977). Histograms, time series, and box and whisker plots, blocked by month and by year, were used. Histograms and the Shapiro-Wilk statistic were used to test for normality. The Shapiro-Wilk statistic showed that most water quality variables were not normally distributed. Natural log ( $\log_e$  abbreviated as ln) transformation improved the distribution and homogeneity of variance for routine grab and volume-weighted data sets.

**Table 4** Years of available sampling data for trend analysis by station and parameter type.

Station	Routine Grab Samples					Storm Samples	
	Conductivity	Soluble Nutrients	TKN, Total-P, and TSS	CHLA	Bacteria	Soluble Nutrients	TKN, Total-P, and TSS
17226 (BO020)	1997 – 2013	1997 – 2013	1997 – 2013	1997 – 2013	1997 – 2013	1997 – 2013	1997 – 2013
11963 (BO040)	1994 – 2013	1994 – 2013	1994 – 2013	1994 – 2013	1994 – 2013	1994 – 2013	1994 – 2013
11961 (BO070)	1993 – 2013	1993 – 2013	1994 – 2013	1993 – 2013	1994 – 2013	1993 – 2013	1993 – 2013
18003 (BO083)	2003 – 2013	2003 – 2013	2003 – 2013	2003 – 2013	2003 – 2013	not applicable	not applicable
11956 (BO090)	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013
11954 (BO095)	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013
13486 (GC100)	1993 – 2013	1993 – 2013	1995 – 2013	1996 – 2013	1995 – 2013	1993 – 2013	1993 – 2013
11826 (NC060)	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013	1996 – 2013

Time series and box and whisker plots identified patterns and described variability in the data. In addition, time series and box plots provided insight regarding the presence of trend and seasonality. Seasonality is a systematic variation that, if present, confounds the true trend. Removing seasonality prior to trend analysis is important, because a significant positive trend in one season and a significant negative trend in another season can result in a finding of no trend when evaluated together. The presence of seasonality in the data was statistically evaluated using a correlogram of monthly data as described by Reckhow et al. (1993). A correlogram expresses how the correlation of pairs of water quality data changes with time. A significant correlation at lags representing 6 and 12 months generally indicates seasonality (Reckhow et al., 1993). A significant correlation at shorter lags (lags representing 1 or 2 months) indicates autocorrelation. For the parameters and sites evaluated seasonality was not significant, so seasonality did not need to be separately accounted for in the trend analysis.

### **Adjustment for Stream Flow**

Another confounding factor in trend analysis of stream water quality data is variation in flow or volume and its influence on concentration. For example at stream stations where point source contributions dominate, increased flows associated with storm runoff may act to dilute concentrations, so concentrations decrease with increasing flows. In contrast at stream stations where nonpoint source contributions dominate, increasing concentrations may occur with increasing flow. Details on methods for removing ancillary effects associated with flow are discussed in Helsel and Hirsch (1992). The two most commonly used methods are simple linear regression and locally weighted scatterplot smoothing (LOWESS) (Helsel and Hirsch, 1992; Cleveland, 1979). The LOWESS method is preferred over simple linear regression as an adjustment method, because the relationship between most ancillary variables, such as flow or volume, and concentration is usually nonlinear (Helsel and Hirsch, 1992; Bekele and McFarland, 2004).

The LOWESS method is an extension of simple linear regression in that it fits simple regression models to localized subsets of the data to build up a function that describes the deterministic variation between two variables. The local regression is fit using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. A user-specified input called the “smoothing parameter” ( $f$ ) determines how much data are used to fit each localized regression. Values of  $f$  range from 0 to 1 with 1 using each individual data point as in simple linear regression. Large  $f$  values produce the smoothest functions that “wobble” the least in response to fluctuations in the data, while smaller  $f$  values fit functions that more closely conform to the data. Using too small an  $f$  value is not desirable, because the regression function will start to capture the random error in the data (SAS Institute, 1999).

An  $f$  value of 0.5 was used as recommended by USGS (Langland et al., 1998) and later confirmed to be optimum for data from the North Bosque River watershed (Bekele and

McFarland, 2004). The PROC LOESS procedure of SAS (SAS Institute, 1999) was used to develop the LOWESS regression relationships. Residuals associated with the LOWESS regression of flow with concentration were then used in trend testing as flow-adjusted concentrations. At stream stations, monthly average stream flow was calculated as the average of instantaneous measures with grab samples or as the total volume of flow divided by the number of seconds in a month with volume-weighted data. Flows and concentrations were transformed using a natural-log transformation prior to applying the LOWESS regression to decrease the variance in the regression residuals.

### Trend Testing

The presence of trend was tested using the nonparametric Kendall's tau using programs developed by Reckhow et al. (1993) and Helsel et al. (2006). The Kendall's tau test is suitable for water quality data that show a non-normal distribution, contain missing data, and have censored with values below method detection or reporting limits (Gilbert, 1987; Hirsch and Slack, 1984). The Kendall's tau statistic can also be modified to address seasonality, if present.

The Kendall's tau test is based on a rank order statistic. That is, it compares ranks rather than actual data values. Observations are ordered by date (assuming seasonality is not present) and the difference between successive pairs of observations is calculated. The Kendall's tau statistic is based on the number of positive versus negative differences from successive pairs to determine if the data set is increasing or decreasing over time. When seasonality exists, data are grouped by season for comparisons often with each month representing a separate season. An increasing trend exists when significantly more data pairs increase than decrease; a decreasing trend exists when significantly more data pairs decrease than increase; and if pairs decrease and increase at the same frequency, no trend exists (Newell et al., 1993).

Trend testing was done on flow-adjusted monthly data sets for all stream stations, except station 18003 (BO083), where flow data were not available. The null hypothesis tested was that there was no temporal trend in concentration of water quality constituents. The level of significance used to test the null hypothesis was 0.05. The slope calculated gives the magnitude of the trend and is interpreted as the change in concentration per month on a natural log scale. The slope in original units was computed on the natural log scale and calculated on an annual basis as follows (Helsel and Hirsch, 1992):

$$\% \text{ change/year} = (e^{b1} - 1) * 100$$

Where "e" is the base of the natural logarithm and approximately equals 2.7183; and "b1" is the slope for the natural log transformed data on an annual basis.<sup>4</sup>

<sup>4</sup> In several previous trend reports (i.e., McFarland and Millican, 2006, 2007, 2008, 2009, and 2010), the percent change was calculated as the percent change per month, although presented as the percent change per year and should be multiplied by 12 to obtain the percent change per year. In Tables 5-9 of this report, all slopes are provided as annual rates of change including those obtained from previous reports.

## Trend Analysis Results

### Routine Grab Data

To account for variations in trends over time, trend results are presented by end year for the past nine years with a focus on the most current end year, 2013. In comparing from year to year, grab samples generally indicated similar positive or negative trends, if significant, regardless of end year, although the percent change per year often varied (Table 5). Slopes representing the percent change per year frequently decreased with increasing end year, most notably for parameters at stations 11956 (BO090) and 11954 (BO095). These decreasing slopes over time may indicate a step trend, in which decreases occurred at a given point in time and then stayed at a lower value, or possibly decreases that occurred in the past that are now starting to increase. In contrast at station 11963 (BO040), slopes associated with both phosphorus parameters have generally become more negative with increasing end year, except when comparing the most recent end years, 2012 and 2013, with data from 2011.

At station 17226 (BO020), a significant decreasing trend was indicated for conductivity and an increasing trend for TSS. Most parameters at station 17226 (BO020) have indicated no significant trends. *E. coli* and NO<sub>2</sub>-N+NO<sub>3</sub>-N have indicated decreasing trends in discrete end years, but this has only occurred in a only one or two years and not when the most current end year (2013) of data are considered.

At station 11963 (BO040), significant downward trends were indicated for NH<sub>3</sub>-N, PO<sub>4</sub>-P, TKN, and total-P. Previous reports have also indicated a negative trend for NO<sub>2</sub>-N+NO<sub>3</sub>-N at 11963 (BO040) for data evaluated through 2007, but in contrast, data through 2011, 2012, and 2013 indicated a slight increasing trend for NO<sub>2</sub>-N+NO<sub>3</sub>-N. Of note, significant decreasing trends for PO<sub>4</sub>-P and total-P at station 11963 (BO040) were first detected with data through the end year 2007.

Downward trends in PO<sub>4</sub>-P and TP also occurred at station 11961 (BO070). These downward trends were first noted with analysis of data through 2008 for PO<sub>4</sub>-P and through 2007 for TP. At station 11961 (BO070), downward trends also were found for conductivity, CHLA, *E. coli*, NH<sub>3</sub>-N, NO<sub>2</sub>-N+NO<sub>3</sub>-N, and total-N for data through 2013. Similar downward trends in nutrients have been indicated since 2008 at 11961 (BO070), but only NH<sub>3</sub>-N consistently indicated downward trends for all nine end years.

At stations 11956 (BO090) and 11954 (BO095), significant downward trends were indicated for several parameters when data through 2013 were evaluated (Table 5). At 11956 (BO090), no trends were noted for conductivity, CHLA, or total-P. At 11954 (BO095), decreasing trends for data through 2013 were noted for only NO<sub>2</sub>-N+NO<sub>3</sub>-N and PO<sub>4</sub>-P. Of note in earlier trend analyses (data evaluated through end year 2005 and 2006), decreasing trends for total-P and CHLA were noted at both 11956 (BO090) and 11954 (BO095). No significant trends for total-P at 11954 (BO095) occurred for data representing end years 2007-2010, but a small significant downward trend emerged for total P with data representing end years 2010-2012.

**Table 5** Trend results for routine grab data for stations with flow data along the mainstem of the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)								
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>
17226 (BO020)	Conductivity	1997-2013	-0.116	0.0364	-2.5			-2.9	-5.0	ne <sup>b</sup>	ne	ne	ne
	CHLA	1997-2013	-0.059	0.2982									
	<i>E. coli</i>	1997-2013	-0.103	0.0947		-6.5							
	NH <sub>3</sub> -N	1997-2013	-0.073	0.1858									
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1997-2013	-0.068	0.2195							-7.8		-13.3
	PO <sub>4</sub> -P	1997-2013	0.002	0.9751									
	TKN	1997-2013	0.002	0.9660									
	Total-P	1997-2013	-0.026	0.6389									
	TSS	1997-2013	0.118	0.0329	2.5					5.3	6.8	9.6	10.2
Total-N	1997-2013	-0.040	0.4692							ne	ne	ne	
11963 (BO040)	Conductivity	1994-2013	-0.057	0.1885					-2.9	ne	ne	ne	ne
	CHLA	1994-2013	-0.079	0.0732									
	<i>E. coli</i>	1994-2013	-0.078	0.0777									
	NH <sub>3</sub> -N	1994-2013	-0.178	0.0000	-4.4	-5.6	-6.2	-7.6	-8.4	-8.9	-6.1	-5.2	
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1994-2013	0.145	0.0008	2.6	2.5	2.0				-3.1	-3.8	-5.6
	PO <sub>4</sub> -P	1994-2013	-0.352	0.0000	-7.2	-7.7	-7.9	-7.4	-5.8	-4.7	-3.6		
	TKN	1994-2013	-0.220	0.0000	-2.7	-3.0	-3.0	-4.0	-4.6	-4.9	-3.4	-2.8	-2.2
	Total-P	1994-2013	-0.368	0.0000	-6.7	-7.1	-7.1	-6.7	-5.0	-4.2	-3.1		
	TSS	1994-2013	-0.034	0.4328									
Total-N	1994-2013	0.081	0.0628							ne	ne	ne	
11961 (BO070)	Conductivity	1993-2013	-0.183	0.0000	-1.1	-1.2	-1.2	-1.2	-1.4	ne	ne	ne	ne
	CHLA	1993-2013	-0.150	0.0009	-3.4	-3.2	-2.4				-3.8		
	<i>E. coli</i>	1994-2013	-0.092	0.0456	-3.1	-4.2					-7.0		
	NH <sub>3</sub> -N	1993-2013	-0.243	0.0000	-2.5	-2.9	-3.6	-4.0	-4.3	-4.4	-6.1	-5.3	-8.9
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1993-2013	-0.166	0.0002	-4.3	-4.6	-4.4	-4.3	-4.0	-4.4			-6.2
	PO <sub>4</sub> -P	1993-2013	-0.295	0.0000	-7.4	-7.2	-5.5	-5.0	-4.3	-4.0			
	TKN	1994-2013	-0.076	0.0898				-1.4	-2.2	-2.3	-2.5		
	Total-P	1994-2013	-0.321	0.0000	-5.3	-5.5	-4.5	-4.4	-4.2	-4.3	-3.4		-4.2
	TSS	1994-2013	-0.014	0.7481									
Total-N	1994-2013	-0.159	0.0004	-1.8	-1.8	-1.6	-2.3	-2.8	-3.0	ne	ne	ne	

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)								
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>
11956 (BO090)	Conductivity	1996-2013	-0.025	0.5901				-0.7		ne	ne	ne	ne
	CHLA	1996-2013	-0.004	0.9412								-5.5	-9.7
	<i>E. coli</i>	1996-2013	-0.096	0.0425	-2.8	-3.8	-4.1	-5.0	-4.7	-5.0	-6.7	-7.9	-10.8
	NH <sub>3</sub> -N	1996-2013	-0.296	0.0000	-2.5	-2.8	-3.6	-4.1	-4.1	-4.8	-8.5	-5.3	-5.0
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1996-2013	-0.100	0.0302	-2.7			-5.8	-5.0	-4.4		-5.9	-8.8
	PO <sub>4</sub> -P	1996-2013	-0.102	0.0261	-1.9	-2.7	-3.6	-4.0	-4.7	-5.6	-12.2	-8.8	-20.4
	TKN	1996-2013	-0.105	0.0218	-1.6	-1.7	-2.5	-4.1	-5.9	-5.5	-4.8	-3.8	-5.9
	Total-P	1996-2013	-0.020	0.6674								-2.0	-4.6
	TSS	1996-2013	-0.094	0.0401	-1.7	-2.2	-2.7	-3.7	-3.1	-3.0	-4.9	-5.6	-10.4
Total-N	1996-2013	-0.179	0.0001	-2.3	-2.2	-3.0	-4.9	-5.5	-5.3	ne	ne	ne	
11954 (BO095)	Conductivity	1996-2013	-0.008	0.8658					-4.7	ne	ne	ne	ne
	CHLA	1996-2013	0.043	0.3599								-6.2	-10.8
	<i>E. coli</i>	1996-2013	-0.076	0.1015		-3.4		-3.7		-4.9	-8.8	-7.2	-7.8
	NH <sub>3</sub> -N	1996-2013	-0.068	0.1408		-1.5	-2.3	-3.4	-4.0	-4.2	-6.2	-4.8	-6.1
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1996-2013	-0.099	0.0313	-2.4	-2.4		-1.2					
	PO <sub>4</sub> -P	1996-2013	-0.177	0.0001	-2.4	-3.4	-4.4	-5.2	-5.3	-5.9	-7.1	-8.8	-17.3
	TKN	1996-2013	-0.015	0.7454			-1.8	-3.4	-4.4	-5.5	-5.3	-4.4	-5.3
	Total-P	1996-2013	-0.058	0.2068		-0.7	-1.0	-1.7				-2.0	-5.6
	TSS	1996-2013	-0.049	0.2831			-2.9	-4.1	-3.7	-5.3	-6.4	-7.1	-11.6
Total-N	1996-2013	-0.052	0.2562				-1.7	-2.4	-2.8	ne	ne	ne	

<sup>a</sup> Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, 2011, and 2012) and McFarland and Adams (2013).

<sup>b</sup> ne indicates parameter was not evaluated for noted end year.

Results for 18003 (BO083) are presented separately from the other mainstem stations, because data for 18003 (BO083) were not flow adjusted (Table 6). Monitoring at station 18003 (BO083) also did not begin until 2003, representing a much shorter period of record than at any of the other stations.

Similar to previous trend reports, a downward trend was indicated at station 18003 (BO083) for  $\text{NH}_3\text{-N}$ . A significant but small decreasing trend in  $\text{PO}_4\text{-P}$  was also noted in 2013 for the first time. Of note, the downward trend for  $\text{NH}_3\text{-N}$  for data through 2010-2103 was significant but indicated a zero slope value (Table 6). A zero slope estimate that is significant can occur when values have multiple ties, particularly if many values are at the reporting limit (McBride, 2000). An increasing trend in CHLA was indicated for data through 2013, but with a decreasing magnitude in the slope compared to annual results since 2007. The only other parameter with a significant trend at station 18003 (BO083) was TSS. The trend in TSS was increasing, but also with a general decline in the magnitude of the slope since 2009.

At station 13486 (GC100) located on Green Creek, trends were not analyzed for 2013 (Table 7). Only one month (April) had routine grab samples in 2013 and this provided insufficient data for a meaningful annual trends update for end year 2013.

At station 11826 (NC060) on Neils Creek downward trends continued to be indicated for CHLA,  $\text{NH}_3\text{-N}$ , and  $\text{PO}_4\text{-P}$  for data through 2013. At 11826 (NC060),  $\text{PO}_4\text{-P}$  was the only parameter that consistently showed a downward trend regardless of end year evaluated, although the slope of this decreasing trend generally diminished over time. Of note, 11826 (NC060) showed a significant increasing trend in *E. coli*, but this was apparent only with the three most recent end years evaluated.

### **Volume-Weighted Data**

Except for TSS at station 11963 (BO040), no increasing trends were indicated at any of mainstem stations for the volume-weighted data analyzed through 2013, but several decreasing trends occurred (Table 8). At station 17226 (BO020), decreasing trends were indicated  $\text{NH}_3\text{-N}$ ,  $\text{NO}_2\text{-N}+\text{NO}_3\text{-N}$ , and total-N. Decreasing trends were indicated at 11963 (BO040) for  $\text{NH}_3\text{-N}$ ,  $\text{PO}_4\text{-P}$ , TKN, and total-P. For data through 2013, station 11961 (BO070) indicated decreasing trends for all constituents but TSS. At station 11956 (BO090), decreasing trends were noted only for  $\text{NH}_3\text{-N}$ ,  $\text{NO}_2\text{-N}+\text{NO}_3\text{-N}$ , and TKN, while at station 11954 (BO095), decreasing trends were indicated for all constituents but TKN, TSS, and total-N.

For data through 2013 for station 13486 (GC100) on Greens Creek were not analyzed for trends, because Greens Creek was flowing only in the month of April in 2012. Station 11826 (NC060) on Neils Creek showed decreasing trends in  $\text{NH}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  for data through 2013 with similar trends also indicated for  $\text{NH}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  in all previous years evaluated, although with a decrease in the percent change per year occurred with increasing end year (Table 9). Several previous years also had indicated a decreasing trend in TKN that was not apparent when more recent years of data were evaluated.

**Table 6** Trend results for routine grab data for station 18003 (BO083) along the mainstem of the North Bosque River. Data were transformed using a natural log transformation prior to trend analysis. Flow data were not available for this station, so water quality data were not flow-adjusted prior to trend evaluation. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)								
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>
18003 (BO083)	Conductivity	2003-2013	-0.027	0.6771						ne <sup>b</sup>	ne	ne	ne
	CHLA	2003-2013	0.254	0.0001	10.9	12.1	14.4	17.4	19.6	21.5	23.4		
	<i>E. coli</i>	2003-2013	-0.104	0.1313									
	NH <sub>3</sub> -N	2003-2013	-0.243	0.0000	-0.0	-0.0	-0.0	-0.0	-1.8	-7.7	-22.7	-44.8	-45.5
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	2003-2013	-0.058	0.3047									
	PO <sub>4</sub> -P	2003-2013	-0.133	0.0370	-1.8								
	TKN	2003-2013	0.114	0.0788		5.4	5.5						
	Total-P	2003-2013	0.058	0.3730			4.4	6.1	8.9				-22.1
	TSS	2003-2013	0.152	0.0191	5.7	6.8	8.1	7.4	12.0				
Total-N	2003-2013	0.087	0.1799			5.1				ne	ne	ne	

<sup>a</sup> Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, 2011, and 2012) and McFarland and Adams (2013).

<sup>b</sup> ne indicates parameter was not evaluated for noted end year.

<sup>c</sup> The percent slope change for NH<sub>3</sub>-N is significant and decreasing but estimated as 0.00 percent change per year due to multiple ties or readings at the reporting limit.

**Table 7** Trend results for routine grab data for major tributary stations to the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)								
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>
13486 (GC100)	Conductivity	1993-2013	NA <sup>c</sup>	NA	NA	-1.9	-2.0	-1.9		ne <sup>b</sup>	ne	ne	ne
	CHLA	1996-2013	NA	NA	NA	-5.8	-5.3	-5.0					
	<i>E. coli</i>	1995-2013	NA	NA	NA						-10.9		
	NH <sub>3</sub> -N	1993-2013	NA	NA	NA	-2.6	-2.9	-3.1	-3.0	-3.0	-5.6	-4.3	-6.8
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1993-2013	NA	NA	NA				4.6	4.8			9.7
	PO <sub>4</sub> -P	1993-2013	NA	NA	NA	-5.3	-5.5	-6.1	-5.3	-7.0	-9.6	-10.4	-18.0
	TKN	1995-2013	NA	NA	NA								
	Total-P	1995-2013	NA	NA	NA								
	TSS	1995-2013	NA	NA	NA						-4.2		
Total-N	1993-2013	NA	NA	NA						ne	ne	ne	
11826 (NC060)	Conductivity	1996-2013	-0.052	0.3203									
	CHLA	1996-2013	-0.132	0.0166	-0.1	-0.2							
	<i>E. coli</i>	1996-2013	0.129	0.0219	3.9	4.1	4.0						
	NH <sub>3</sub> -N	1996-2013	-0.299	0.0000	-1.2	-1.3	-1.5	-1.8	-1.8	-2.3	-5.2	-3.6	
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1996-2013	-0.002	0.9675									
	PO <sub>4</sub> -P	1996-2013	-0.228	0.0000	-1.2	-1.2	-1.6	-1.7	-2.5	-4.4	-5.5	-6.2	-9.7
	TKN	1996-2013	-0.041	0.4296					-3.4	-4.3	-3.7		
	Total-P	1996-2013	0.086	0.0985									
	TSS	1996-2013	0.015	0.7667									
Total-N	1996-2013	0.011	0.8257							ne	ne	ne	

<sup>a</sup> Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, 2011, and 2012) and McFarland and Adams (2013).

<sup>b</sup> ne indicates parameter was not evaluated for noted end year.

<sup>c</sup> NA indicates not applicable. Trend analysis was not conducted for station 13486 (GC100), because only one month (April) of 2013 had routine grab data.

**Table 8** Trend results for monthly volume-weighted data for mainstem stations along the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)									
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>	
17226 (BO020)	NH <sub>3</sub> -N	1997-2013	-0.227	0.0000	-5.0	-4.9	-4.9	-5.2	-5.9	-5.2				
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1997-2013	-0.114	0.0210	-2.7	-4.8	-4.8	-4.2	-5.3	-5.9	-5.4			
	PO <sub>4</sub> -P	1997-2013	-0.003	0.9568										
	TKN	1997-2013	-0.084	0.0872				-1.4						
	Total-P	1997-2013	-0.027	0.5855										
	TSS	1997-2013	0.042	0.3990										
	Total-N	1997-2013	-0.108	0.0291	-1.3	-1.6	-1.6	-1.9	-2.4	-2.5	ne <sup>b</sup>	ne	ne	
11963 (BO040)	NH <sub>3</sub> -N	1994-2013	-0.264	0.0000	-5.3	-6.7	-6.5	-7.8	-8.2	-8.0	-6.7	-5.6	-4.2	
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1994-2013	-0.002	0.9583					-2.2	-2.5	-4.4	-4.8	-6.6	
	PO <sub>4</sub> -P	1994-2013	-0.388	0.0000	-7.2	-7.9	-7.6	-7.0	-5.9	-4.3	-3.5	-2.6		
	TKN	1994-2013	-0.114	0.0084	-1.1			-1.8	-2.3	-2.5	-2.2			
	Total-P	1994-2013	-0.341	0.0000	-5.3	-5.4	-5.2	-4.6	-3.8	-2.9	-2.3	-1.9		
	TSS	1994-2013	0.117	0.0072	3.2	4.0	3.9	4.4	4.0		4.1	5.4		
	Total-N	1994-2013	-0.020	0.6478				-1.3	-1.6	-1.7	ne	ne	ne	
11961 (BO070)	NH <sub>3</sub> -N	1993-2013	-0.296	0.0000	-3.9	-4.7	-4.5	-4.9	-5.0	-5.3	-6.7	-4.4	-5.9	
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1993-2013	-0.185	0.0000	-3.8	-3.3	-3.3	-3.6	-3.1	-3.7				
	PO <sub>4</sub> -P	1993-2013	-0.293	0.0000	-5.9	-4.7	-4.6	-4.6	-4.4	-3.6				
	TKN	1993-2013	-0.096	0.0248	-1.4	-1.6	-1.5	-2.3	-3.1	-4.0	-4.1	-2.3	-2.6	
	Total-P	1993-2013	-0.248	0.0000	-4.0	-3.2	-3.1	-3.0	-3.1	-3.4	-2.8		-2.5	
	TSS	1993-2013	-0.003	0.9372										
	Total-N	1993-2013	-0.144	0.0008	-1.8	-1.9	-1.9	-2.6	-3.0	-3.6	ne	ne	ne	
11956 (BO090)	NH <sub>3</sub> -N	1996-2013	-0.356	0.0000	-4.1	-5.3	-5.1	-5.5	-6.0	-6.2	-5.9	-4.2	-5.1	
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1996-2013	-0.119	0.0085	-2.4	-2.5	-2.5	-4.3	-4.2	-3.5	-4.9	-5.8	-7.2	
	PO <sub>4</sub> -P	1996-2013	-0.068	0.1346		-2.5	-2.4	-3.2	-4.2	-4.4	-5.3	-5.2	-9.0	
	TKN	1996-2013	-0.046	0.3102			-1.8	-3.6	-5.3	-5.4	-5.4	-3.6	-3.7	
	Total-P	1996-2013	0.020	0.6666									-4.1	
	TSS	1996-2013	0.015	0.7384										
	Total-N	1996-2013	-0.127	0.0054	-1.7	-2.8	-2.8	-4.4	-5.3	-5.4	ne	ne	ne	

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)								
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>
11954 (BO095)	NH <sub>3</sub> -N	1996-2013	-0.170	0.0002	-2.4	-4.1	-4.2	-5.2	-5.8	-6.0	-8.0	-6.5	-8.2
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1996-2013	-0.093	0.0416	-1.8						-4.3	-5.4	
	PO <sub>4</sub> -P	1996-2013	-0.187	0.0000	-3.3	-5.6	-5.5	-6.5	-6.7	-7.6	-7.9	-8.6	-11.4
	TKN	1996-2013	-0.061	0.1792		-2.8	-3.0	-4.3	-5.5	-6.7	-6.6	-4.1	-7.2
	Total-P	1996-2013	-0.095	0.0361	-1.5	-2.6	-2.6	-3.2	-3.4	-4.0	-4.1	-4.9	-7.4
	TSS	1996-2013	-0.057	0.2116		-5.5	-5.5	-6.5	-6.7	-8.6	-9.0	-7.4	-11.4
	Total-N	1996-2013	-0.072	0.1147		-1.4	-1.5	-2.2	-3.0	-3.2	ne	ne	ne

<sup>a</sup> Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, 2011, and 2012) and McFarland and Adams (2013).

<sup>b</sup> ne indicates parameter was not evaluated for noted end year.

**Table 9** Trend results for monthly volume-weighted data for major tributary stations to the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates probability of significance. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2013 Results			Slope (% change/yr)								
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2013	End Year 2012	End Year 2011	End Year 2010 <sup>a</sup>	End Year 2009 <sup>a</sup>	End Year 2008 <sup>a</sup>	End Year 2007 <sup>a</sup>	End Year 2006 <sup>a</sup>	End Year 2005 <sup>a</sup>
13486 (GC100)	NH <sub>3</sub> -N	1993-2013	NA <sup>c</sup>	NA	NA	-2.1	-2.1	-2.3	-2.9	-2.9	-7.4		-6.4
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1993-2013	NA	NA	NA	4.5	4.5	4.2	5.5	5.9			
	PO <sub>4</sub> -P	1993-2013	NA	NA	NA					-4.2	-9.2	-9.2	-12.0
	TKN	1993-2013	NA	NA	NA						-2.9		
	Total-P	1993-2013	NA	NA	NA						-4.4		-6.5
	TSS	1993-2013	NA	NA	NA								
	Total-N	1993-2013	NA	NA	NA	4.1	4.1	3.8	3.5	3.1	ne <sup>b</sup>	ne	ne
11826 (NC060)	NH <sub>3</sub> -N	1996-2013	-0.354	0.0000	-2.5	-3.1	-3.0	-3.1	-3.5	-3.7	-6.6	-5.2	-5.2
	NO <sub>2</sub> -N+NO <sub>3</sub> -N	1996-2013	-0.028	0.5884									
	PO <sub>4</sub> -P	1996-2013	-0.185	0.0003	-2.0	-3.1	-3.1	-3.8	-5.4	-6.8	-7.7	-8.6	-10.7
	TKN	1996-2013	0.020	0.6907					-3.1	-4.4	-3.8		
	Total-P	1996-2013	0.042	0.4042									-2.9
	TSS	1996-2013	0.043	0.3949									
	Total-N	1996-2013	0.053	0.2982							ne	ne	ne

<sup>a</sup> Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, 2011, and 2012) and McFarland and Adams (2013).

<sup>b</sup> ne indicates parameter was not evaluated for noted end year.

<sup>c</sup> NA indicates not applicable. Trend analysis was not conducted for station 13486 (GC100), because only one month (April) of 2013 had loading data.

## Evaluation of Stream Water Quality Goal Attainment

To measure success in improvements in water quality, one of the methods outlined in the I-Plan involves comparing average annual SRP concentrations at each of the five index stations to regression analyses of historical nutrient concentration and flow data (TCEQ and TSSWCB, 2002). A set of regression equations was derived from historical data for 1996 through 2000 representing each of the five index stations. These regression equations relate annual average concentrations of SRP from routine grab samples (y-axis values) to the base-10 logarithm of annual average stream flow (x-axis values). The index stations were not specifically defined as sampling stations in the I-Plan, but represent locations associated with the TMDL modeling effort. The regression equations in the I-Plan were developed using data from the following stations:

- Station 17226 (BO020) for the index station above Stephenville
- Station 11963 (BO040) for the index station below Stephenville
- Station 11958 (BO085) for the index station above Meridian
- Station 11956 (BO090) for the index station at Clifton
- Station 17605 (BO100) combined with data from station BO095 for the index station at Valley Mills

Station 11961 (BO070) is also included below for comparison as a station located between 11963 (BO040) and 11958 (BO085).

Monitoring at station 11958 (BO085) was discontinued in February 2005, and data from station 18003 (BO083) were used in its place. Station 18003 (BO083) is considered more representative of the index station defined in the I-Plan as above Meridian. Flow was not measured at either 11958 (BO085) or 18003 (BO083) on a continuous basis, so annual average flows from station 11956 (BO090) were used in the equations presented in the I-Plan and in the current evaluation.

The regression equations used for the most recent comparisons of  $\text{PO}_4\text{-P}$  concentrations versus annual average flow differ somewhat from those presented in the I-Plan and early annual reports for a couple of reasons. First, annual average flows were revised based on the most updated rating curve and stage data information. Also, grab samples used in the analysis were scrutinized to make sure samples were representative of routine monitoring with relatively equal time intervals between samples throughout the year as suggested in the I-Plan (TCEQ and TSSWCB, 2002).

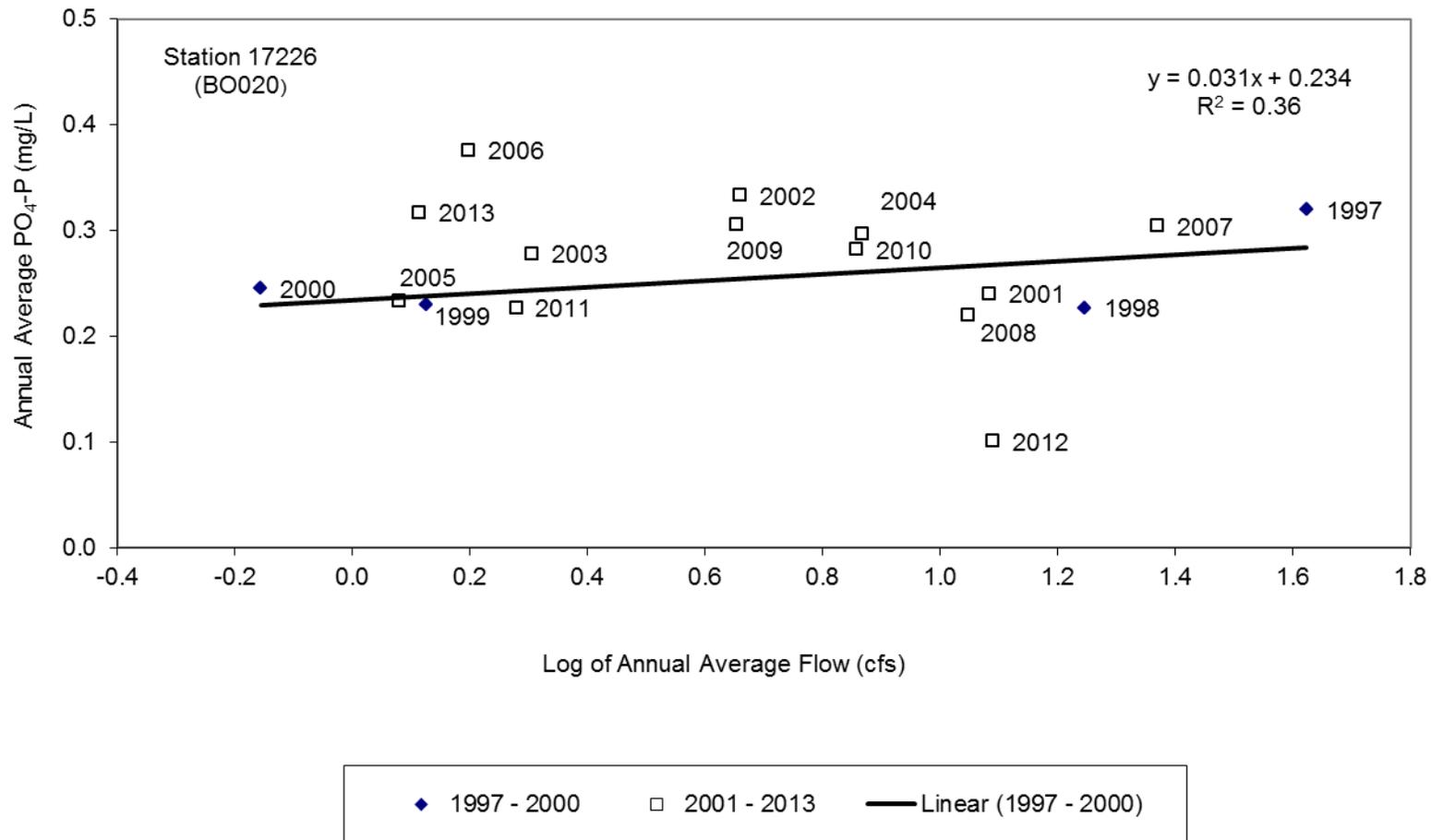
By including only samples representative of relatively equal time intervals, several samples associated with special studies were dropped that had been included in previous analyses. Previously all available  $\text{PO}_4\text{-P}$  data for grab samples had been included regardless of the time interval between samples. Using samples separated by relatively equal time intervals decreases the bias that may occur if sampling were more frequent during a particular time of year. Extended periods of pooling or no flow in association

with the relatively dry summer months still caused unequal sampling intervals in some years that could not be avoided. This was most apparent at 17226 (BO020), the most upstream station, which often becomes pooled or on rare occasion goes dry during the summer (see McFarland and Adams, 2014). For 2013, station 17226 (BO020) was pooled during 17 of the 26 biweekly monitoring events (Table 10). Pooled or dry conditions in 2013 were also noted at all index stations but 11963 (BO040). Station 11963 (BO040) is only about a quarter mile below the primary discharge for the City of Stephenville WWTF, so a low level of continuous flow is expected at this location even during extremely dry conditions.

**Table 10** Stream conditions in 2013 at North Bosque River mainstem sampling stations during biweekly monitoring events. (X = flowing and O = pooled, pooled sampling events shaded gray)

Month	Sampling Date	17226 (BO020)	11963 (BO040)	11961 (BO070)	18003 (BO083)	11956 (BO090)	11954 (BO095)
Jan	7	O	X	X	X	X	X
	22	O	X	X	X	X	X
Feb	5	O	X	X	X	X	X
	18	O	X	X	X	X	X
Mar	5	O	X	X	X	X	X
	19	O	X	X	X	X	X
Apr	2	X	X	X	X	X	X
	16	X	X	X	X	X	X
	30	O	X	X	X	X	X
May	14	X	X	X	X	X	X
	29	X	X	X	X	X	X
Jun	11	O	X	X	O	X	X
	24	O	X	O	O	X	X
Jul	8	O	X	O	O	O	X
	22	X	X	X	X	X	X
Aug	5	O	X	O	O	X	X
	19	O	X	O	O	O	O
Sep	3	O	X	O	O	O	O
	16	O	X	O	O	O	O
Oct	1	O	X	X	O	X	X
	14	X	X	X	O	X	X
	29	O	X	X	X	X	X
Nov	11	O	X	X	O	X	X
	25	X	X	X	O	X	X
Dec	11	X	X	X	O	X	X
	18	X	X	X	X	X	X

For 2013, station 17226 (BO020) indicated a PO<sub>4</sub>-P concentration above the pre-TMDL regression line (Figure 4). For station 17226 (BO020), most post-TMDL (2001-2011) concentrations of PO<sub>4</sub>-P in comparison with flow were near or above the pre-TMDL period (1997-2000) regression line with only four years (2001, 2008, 2011, and 2012) with data below (Figure 4). Of note in 2013, only nine out of a possible 26 biweekly samples were collected. Samples were not collected for this project when stream conditions are pooled and not flowing.



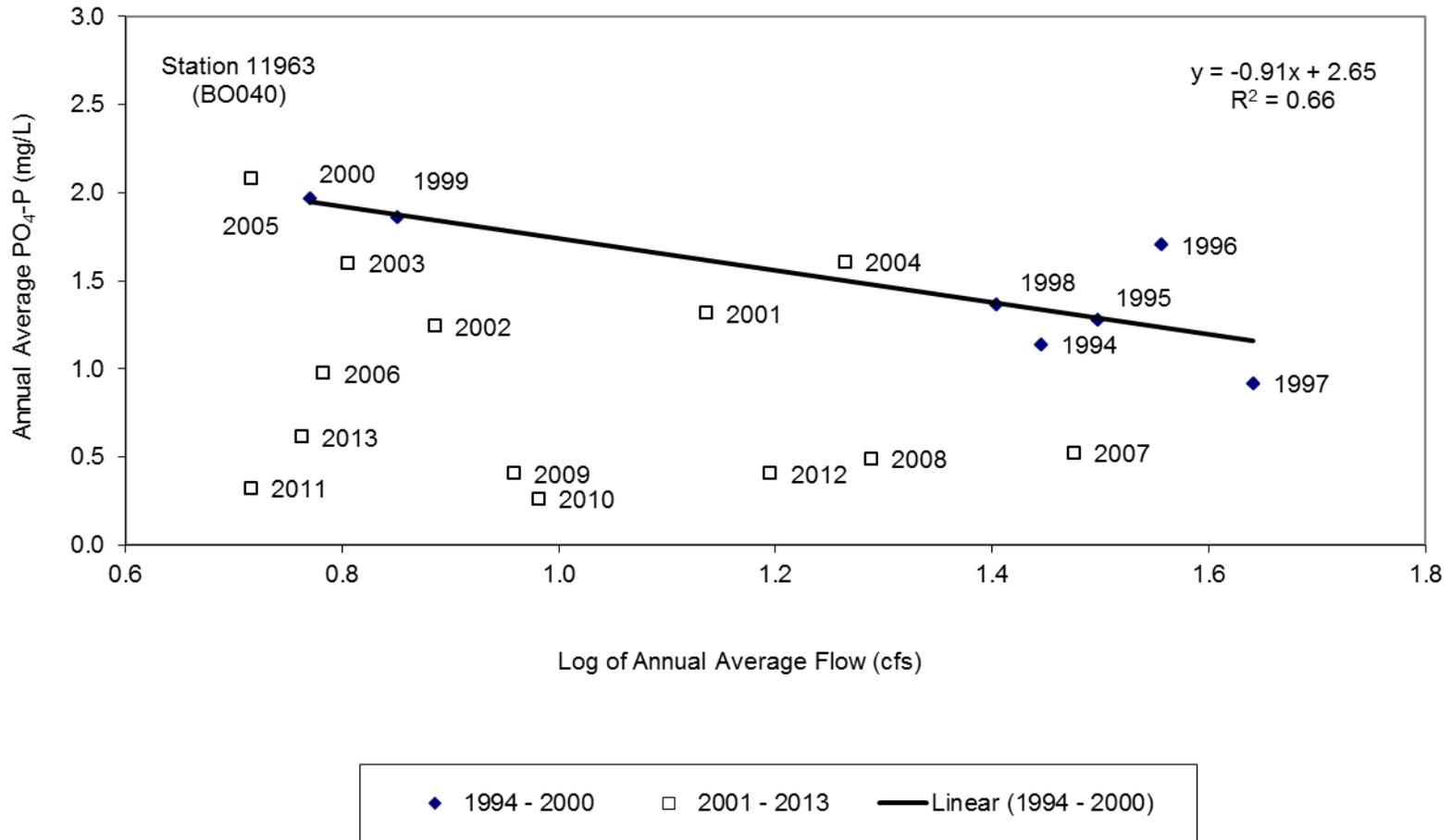
**Figure 4** Relationship of the natural log of flow to annual average PO<sub>4</sub>-P concentration of routine grab samples for station 17226 (BO020). Linear regression line fits annual average values for 2000 and before.

At stations 11963 (BO040) and 11961 (BO070) within the upper portion of the North Bosque River, PO<sub>4</sub>-P concentrations were well below the pre-TMDL regression lines (Figures 5 and 6). At 11963 (BO040), average PO<sub>4</sub>-P concentrations for 2004 and 2005 were on or above the pre-TMDL regression line (Figure 5), while values for 2001 through 2003 and 2006 through 2012 fell clearly below the regression line. Although not an index station, a comparison is shown for station 11961 (BO070) located near Hico, Texas for which all years but 2004 indicated PO<sub>4</sub>-P values below the pre-TMDL regression line (Figure 6). Of note station 11961 (BO070) was the only other station besides 11963 (BO040) to show average PO<sub>4</sub>-P concentrations in 2006 well below the pre-TMDL regression.

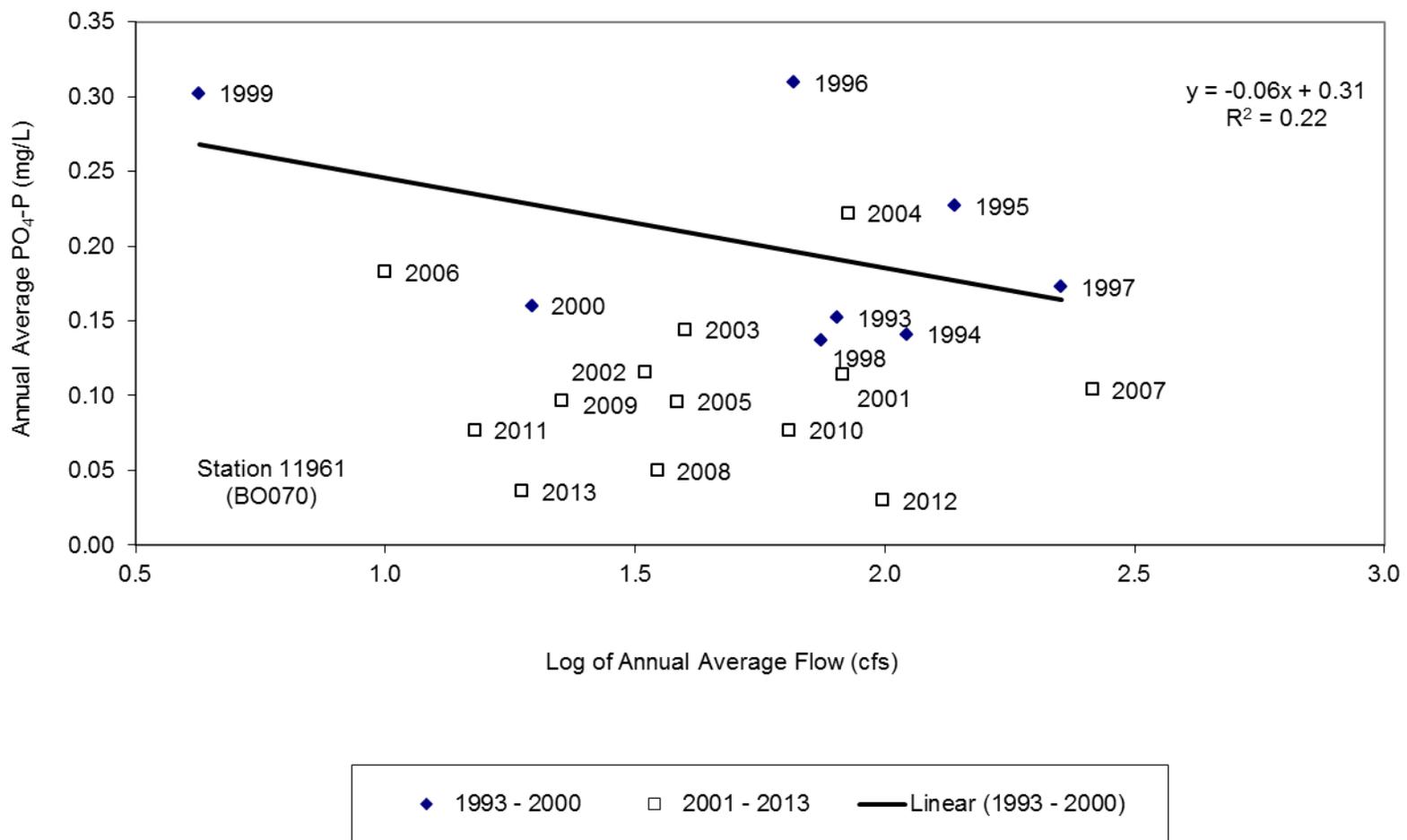
For 2013, stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095) along the lower portion of the North Bosque River all indicated concentrations above the pre-TMDL regression lines (Figures 7 – 9). This was in contrast to 2012, when all three stations had PO<sub>4</sub>-P concentrations below the pre-TMDL regression line. While most years have indicated PO<sub>4</sub>-P concentrations below the pre-TMDL regression lines at stations along the lower portion of the North Bosque River, exceptions have occurred in 2006 and 2009 at station 11958/18003 (BO085/BO083) and in 2011 at all three stations. In 2013, annual average flow conditions were at the lowest measured for these three stations.

Another way to evaluate goal attainment is to compare the annual average concentration to the long-term predicted concentration from the TMDL modeling effort and the target concentration for each index station (TNRCC, 2001). Comparing the annual average of routine grab samples shows the TMDL goal has been reached at most locations in recent years (Figures 10 and 11), although not consistently at all locations. At station 11963 (BO040), from 2009 through 2012 PO<sub>4</sub>-P concentrations were below the goal, but in 2013, concentrations were above. Due to low stream flow conditions in 2013, drought conditions are suspected to have led to these increased concentrations with a decrease in mixing water with effluent from the Stephenville WWTF. Of note, no violations have been reported with regard to phosphorus in the discharge effluent from the Stephenville WWTF.

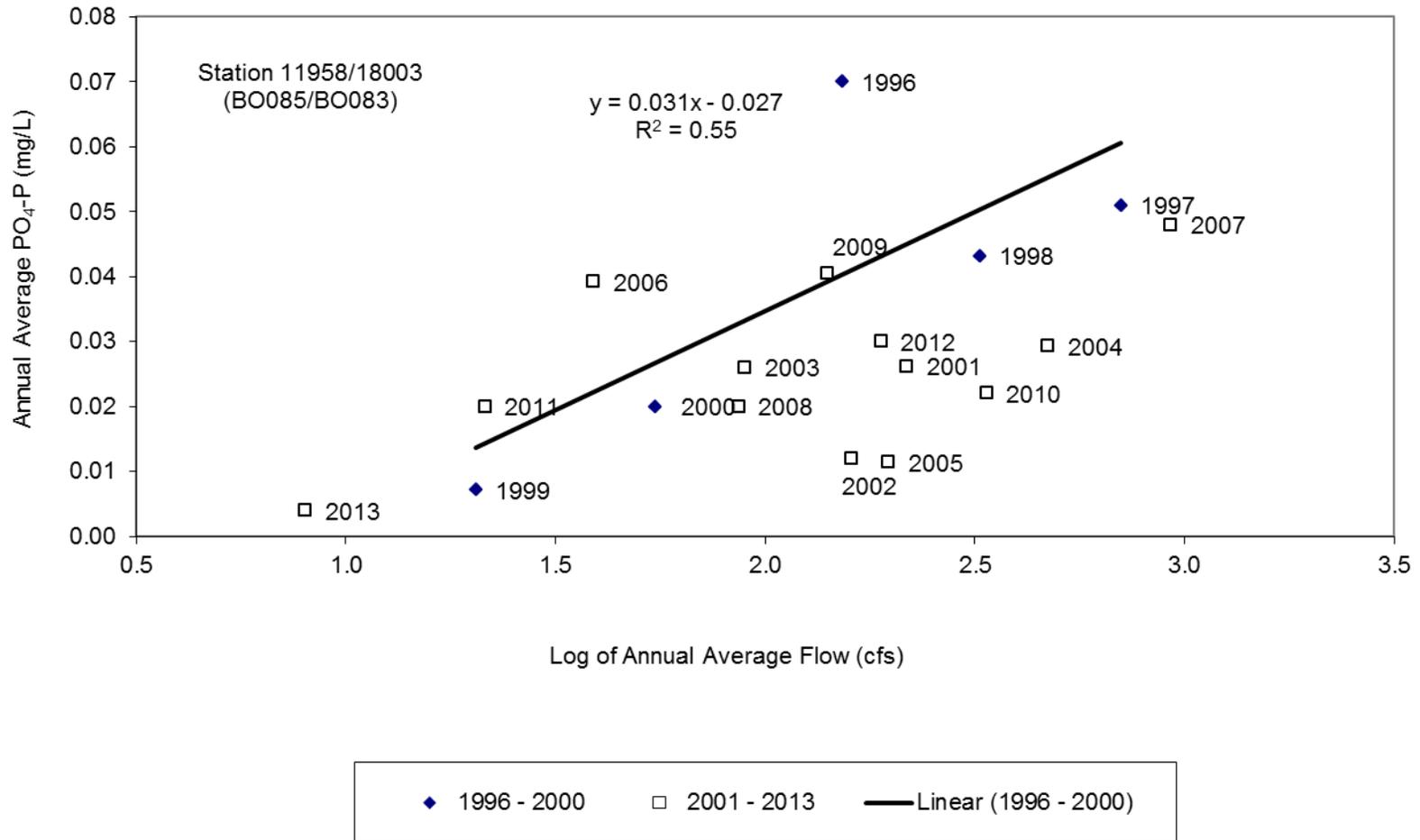
Station 17726 (BO020) is the other location where PO<sub>4</sub>-P concentrations were often above the TMDL goal. Only in 2012 have annual average PO<sub>4</sub>-P concentrations been below the TMDL goal. For 2013, the annual average PO<sub>4</sub>-P concentration were well above the goal. One potential factor that may be influencing the lower concentrations noted in 2013 is the timing of rainfall and, thus, streamflow. In 2012, flowing conditions occurred during the first half of the year at station 17226 (BO020) with relatively wet conditions from January into June allowing a baseflow at times to establish. In 2013, much of the year was dry with storm events causing pulses of flow to occur, but no extended periods of baseflow.



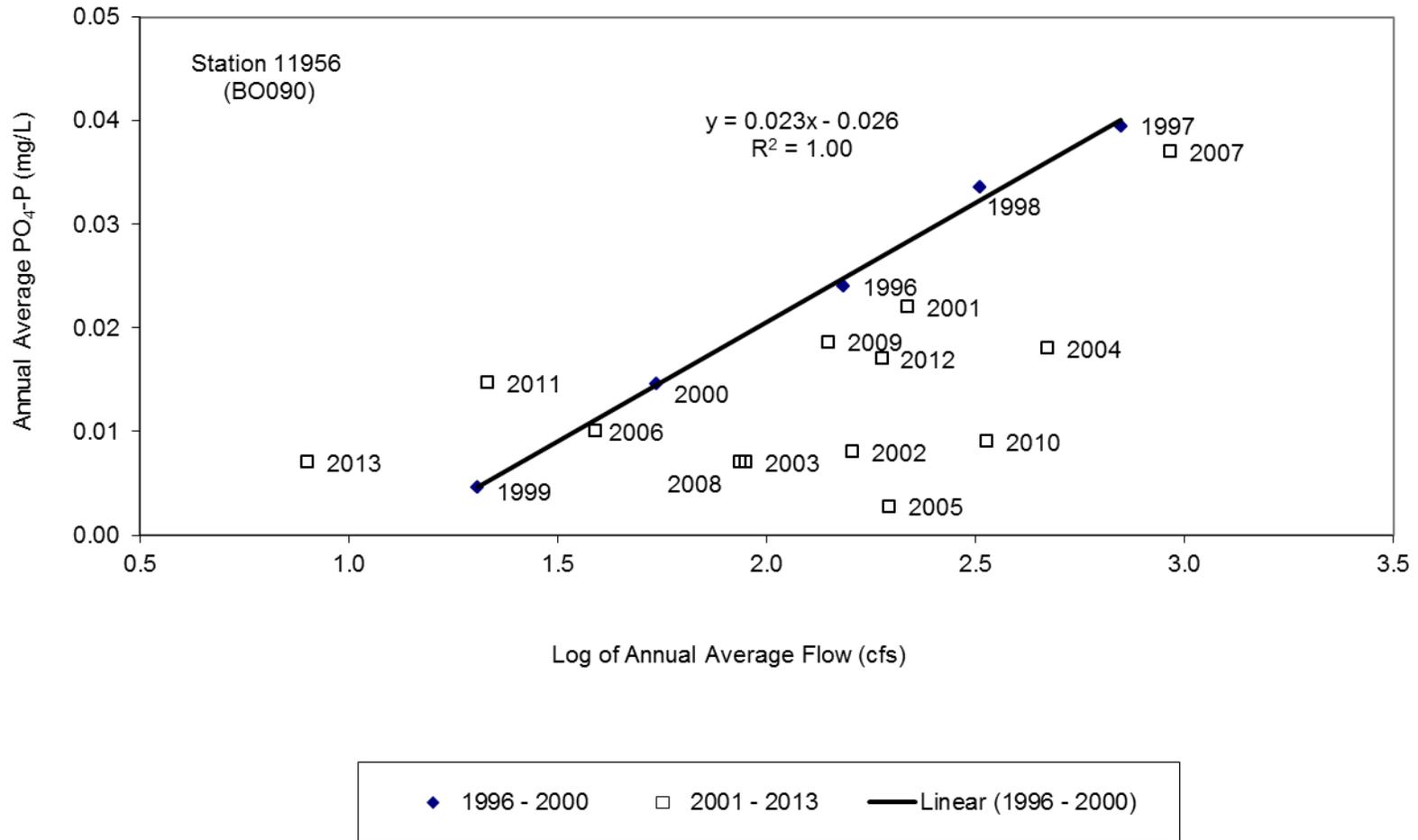
**Figure 5** Relationship of the natural log of flow to annual average PO<sub>4</sub>-P concentration of routine grab samples for station 11963 (BO040). Linear regression line fits annual average values for 2000 and before.



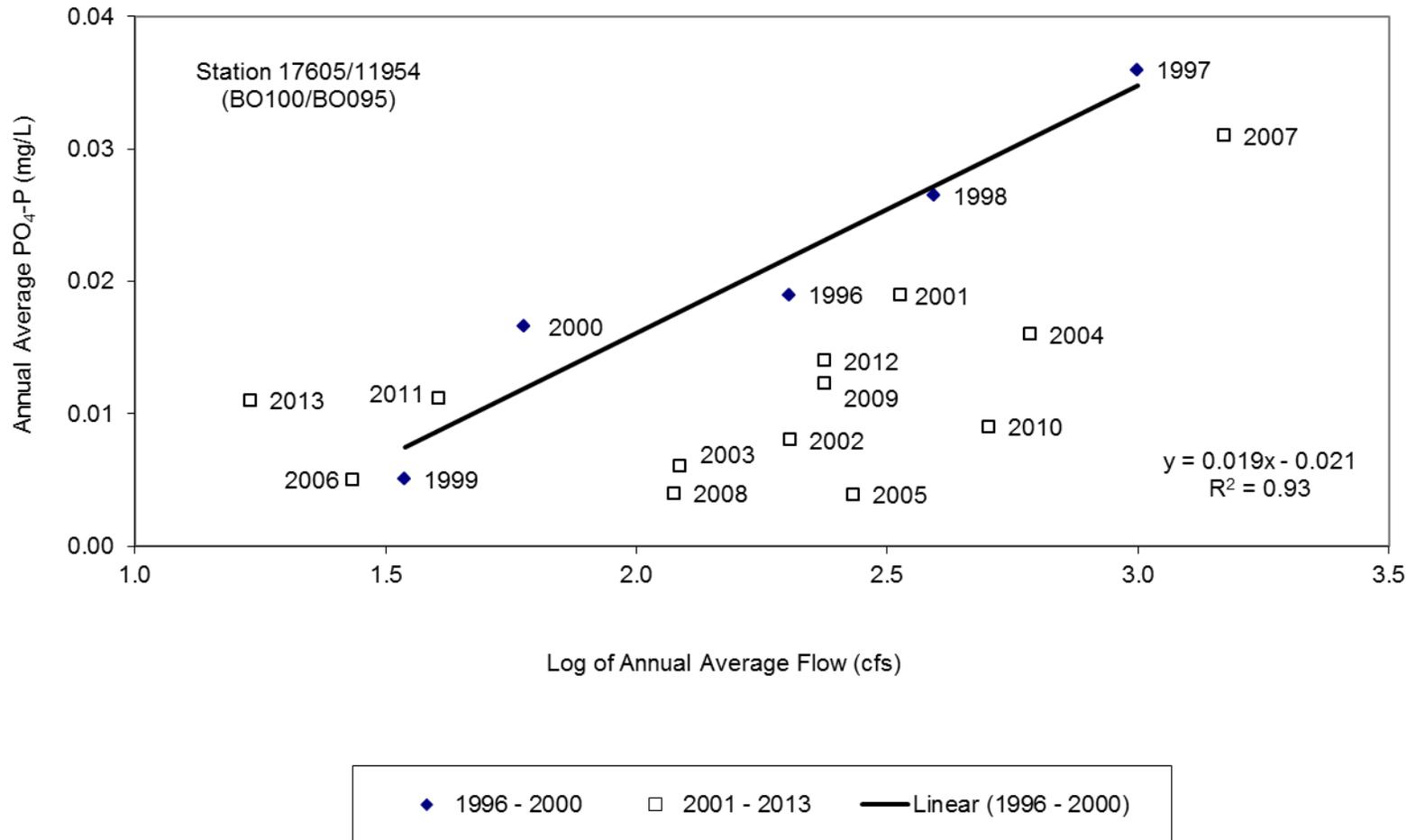
**Figure 6** Relationship of the natural log of flow to annual average PO<sub>4</sub>-P concentration of routine grab samples for station 11961 (BO070). Linear regression line fits annual average values for 2000 and before.



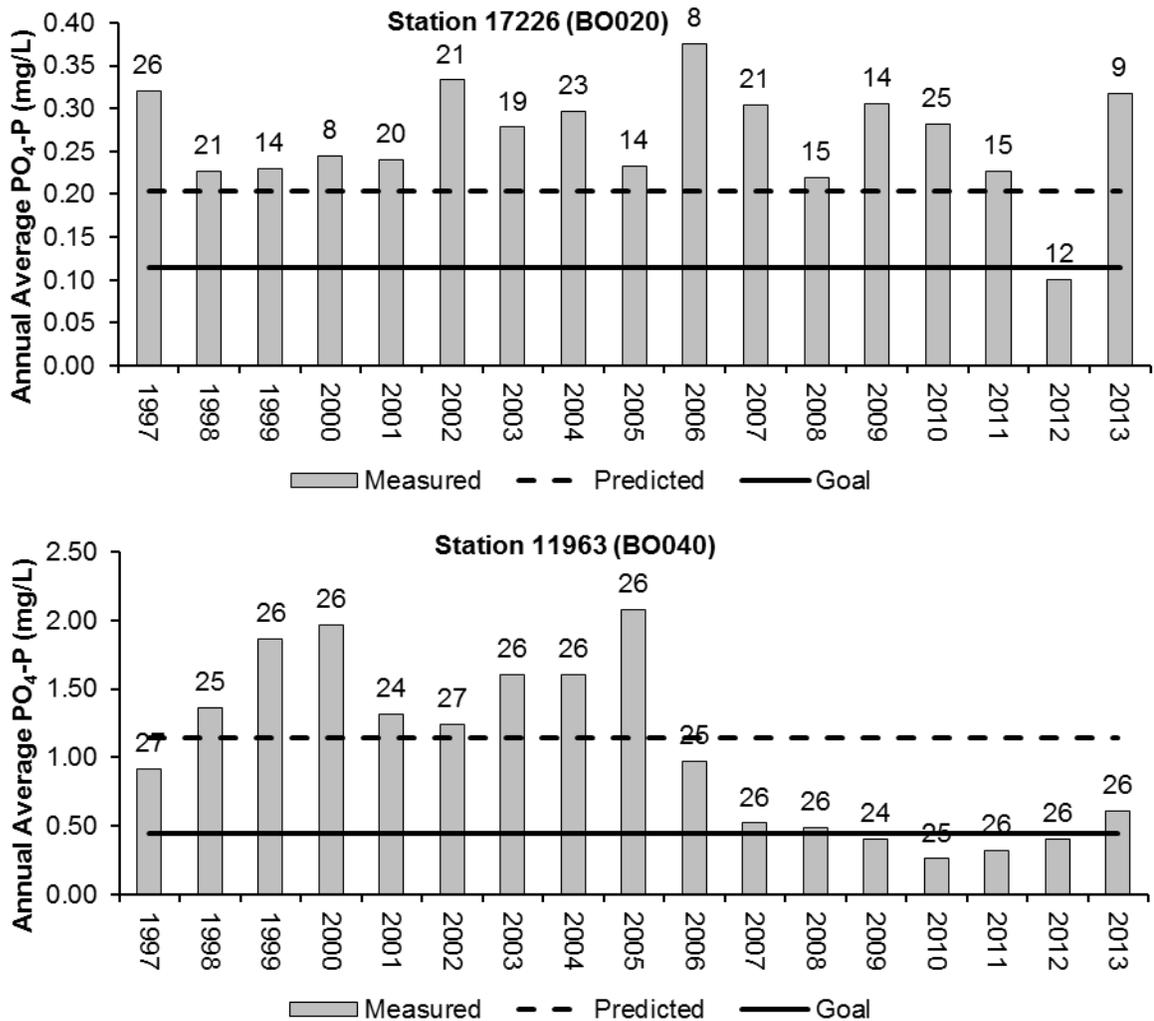
**Figure 7** Relationship of the natural log of flow to annual average PO<sub>4</sub>-P concentration of routine grab samples for station 11958/18003 (BO085/BO083). Linear regression line fits annual average values for 2000 and before.



**Figure 8** Relationship of the natural log of flow to annual average PO<sub>4</sub>-P concentration of routine grab samples for station 11956 (BO090). Linear regression line fits annual average values for 2000 and before.

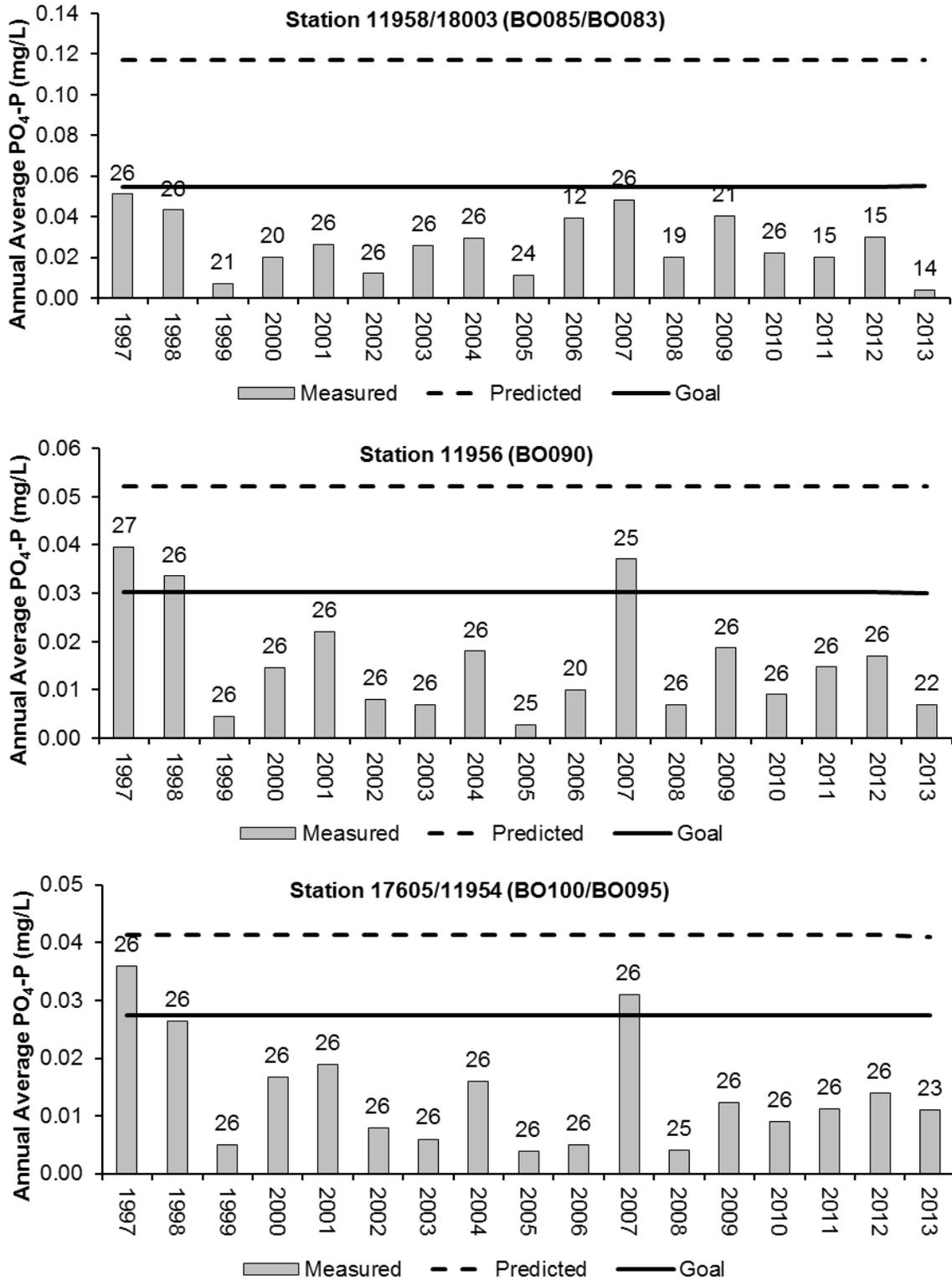


**Figure 9** Relationship of the natural log of flow to annual average PO<sub>4</sub>-P concentration of routine grab samples for station 17605/11954 (BO100/BO095). Linear regression line fits annual average values for 2000 and before.



**Figure 10** Annual average PO<sub>4</sub>-P from routine grab data for stations 17226 (BO020) and 11963 (BO040) compared to the long-term predicted concentration without TMDL implementation and the TMDL goal. Values above bars represent the number of samples in each year.

Of note, the comparisons shown in Figures 10 and 11 are similar to graphs shown in the annual status report provided by TCEQ (e.g., TCEQ, 2013), but the timeframe represented differs. In the graphs presented in the TCEQ status report, the annual timeframe represents the water year (October through September) rather than the calendar year (January through December) presented herein. The calendar year is presented herein for consistency with charts comparing annual average PO<sub>4</sub>-P concentrations with annual average flow (Figures 4 – 9) and the presentation of data in previous trend reports by TIAER (e.g., McFarland and Millican, 2012). Despite these timeframe differences, the annual PO<sub>4</sub>-P concentrations follow a similar pattern over time to those shown in the TCEQ annual status reports for the North Bosque (TCEQ, 2013).



**Figure 11** Annual average PO<sub>4</sub>-P from routine grab data for stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095) compared to the long-term predicted concentration without TMDL implementation and the TMDL goal. Values above bars represent the number of samples in each year.

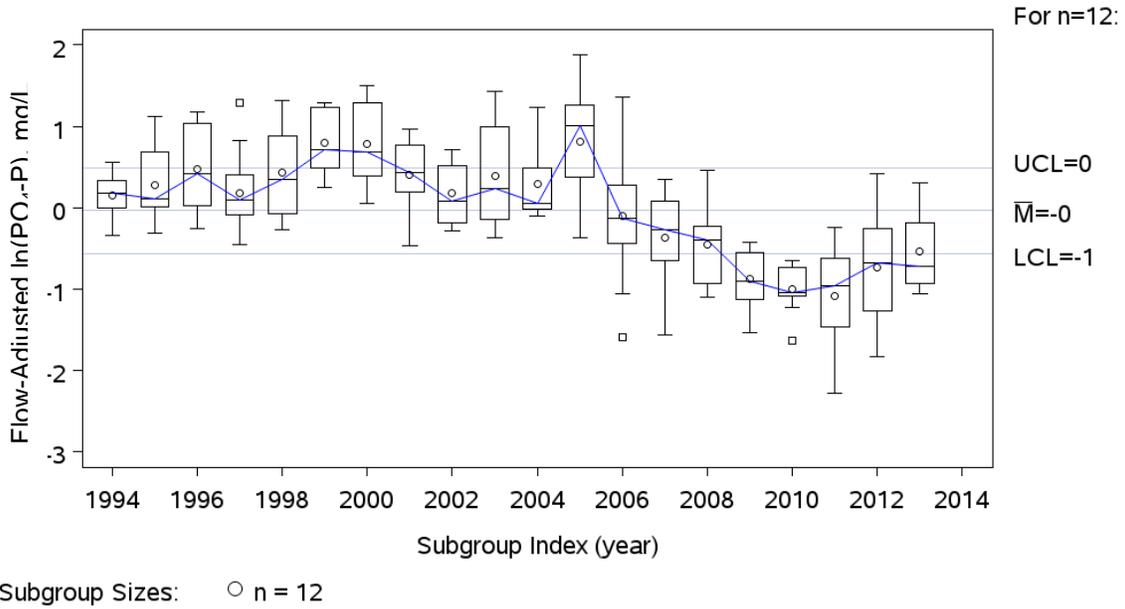
## Summary and Discussion

Results based on data through 2013 indicated several statistically significant decreasing trends in nutrients at stations within the North Bosque River watershed, although also a few increasing trends for some parameters. With regard to PO<sub>4</sub>-P and total-P, no increasing trends were found and only decreasing trends when significant.

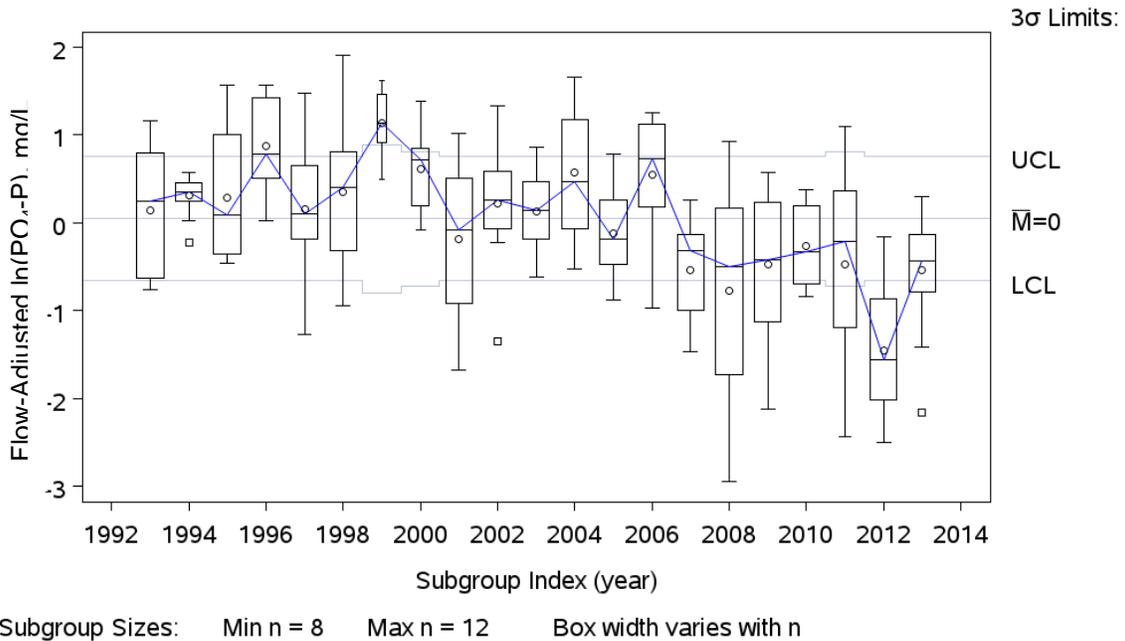
With regard to TMDLs for the North Bosque River for SRP, decreasing trends in PO<sub>4</sub>-P were indicated along the mainstem at stations 11963 (BO040) below Stephenville, 11961 (BO070) at Hico, and 11954 (BO095) near Valley Mills for routine grab and volume-weighted data. Station 11956 (BO090) near Clifton indicated decreasing trends only for routine grab samples. Decreasing trends in PO<sub>4</sub>-P were also indicated for both routine grab and volume-weighted data at major tributary stations 11826 (NC060) on Neils Creek. Neils Creek enters the North Bosque River between stations 11956 (BO090) and 11954 (BO095). Due to limited flows in 2013, updated trends for station 13468 (GC100) on Green Creek were not evaluated. For station 13468 (GC100), only one month in 2013 had flowing water during which samples were collected. Previously through 2012, station 13468 (GC100) has indicated decreasing trends in PO<sub>4</sub>-P for routine grab samples. Greens Creek enters the North Bosque River about 12 river kilometers (8 river miles) above station 11961 (BO070).

These decreasing trends in PO<sub>4</sub>-P were fairly consistent with findings in previous reports (e.g., McFarland and Adams, 2013). Of note, prior to the analysis of data through 2008, station 11961 (BO070) had not indicated significant decreasing trends in PO<sub>4</sub>-P. Also prior to analysis through 2007, station 11963 (BO040) had not indicated significant decreases in PO<sub>4</sub>-P for grab sample data. Implementation of phosphorus control at the Stephenville WWTF in late 2005 appears to be directly related to the decreasing trends in PO<sub>4</sub>-P noted at station 11963 (BO040) and is probably influencing the decreasing trends noted at station 11961 (BO070) further downstream (Tables 5 and 8). Box and whisker plots of monthly average concentrations by year at station 11963 (BO040) showed a notable decrease in median PO<sub>4</sub>-P for 2006 through 2012 (Figure 12) with a somewhat similar decrease shown at station 11961 (BO070) in Figure 13.

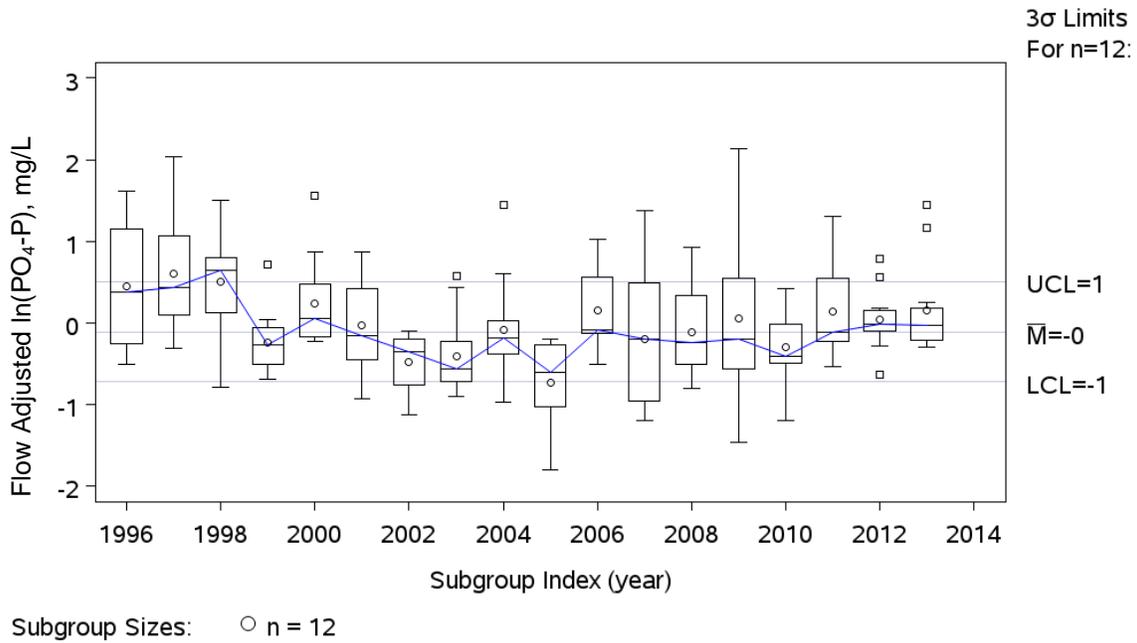
A decrease in PO<sub>4</sub>-P concentrations also occurred at more downstream stations (11956 [BO090] and 11954 [BO095]), but the timing of the initial decrease occurred in 1999 (Figures 14 and 15), prior to implementation of phosphorus control practices at either the Stephenville or Clifton WWTFs. Of note, station 11954 (BO095) near Valley Mills is located below the discharge for the Clifton WWTF and has shown lower PO<sub>4</sub>-P concentrations in recent years than station 11956 (BO090), which is located above the Clifton WWTF discharge.



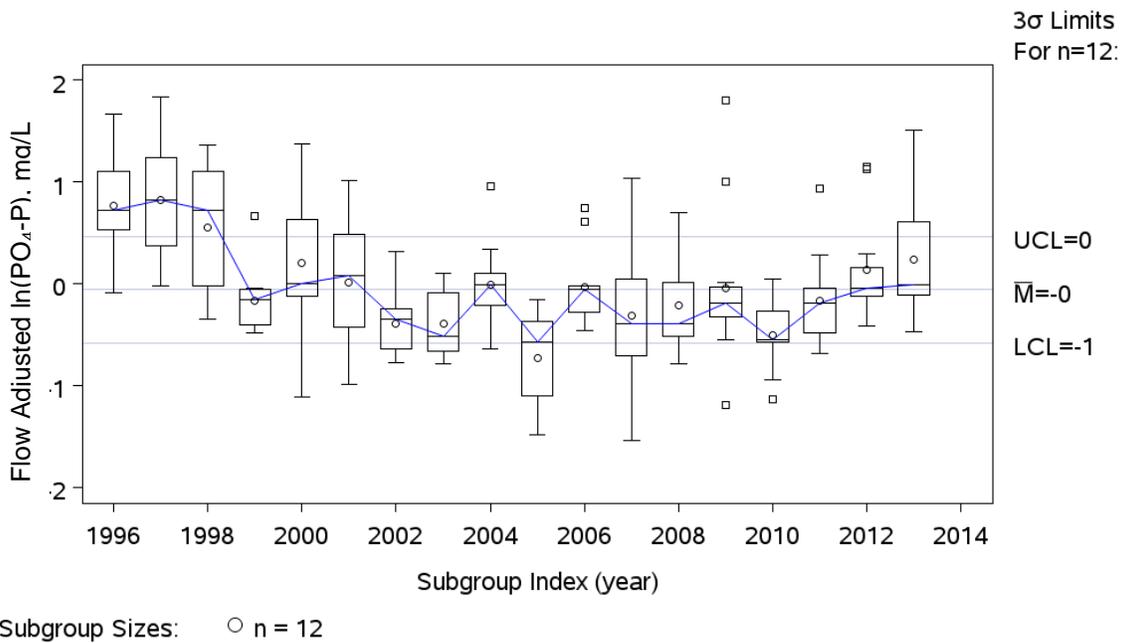
**Figure 12** Annual box and whisker plots of monthly volume-weighted PO<sub>4</sub>-P grab data for station 11963 (BO040). Data natural log transformed and flow-adjusted.



**Figure 13** Annual box and whisker plots of monthly volume-weighted PO<sub>4</sub>-P grab data for station 11961 (BO070). Data natural log transformed and flow-adjusted.

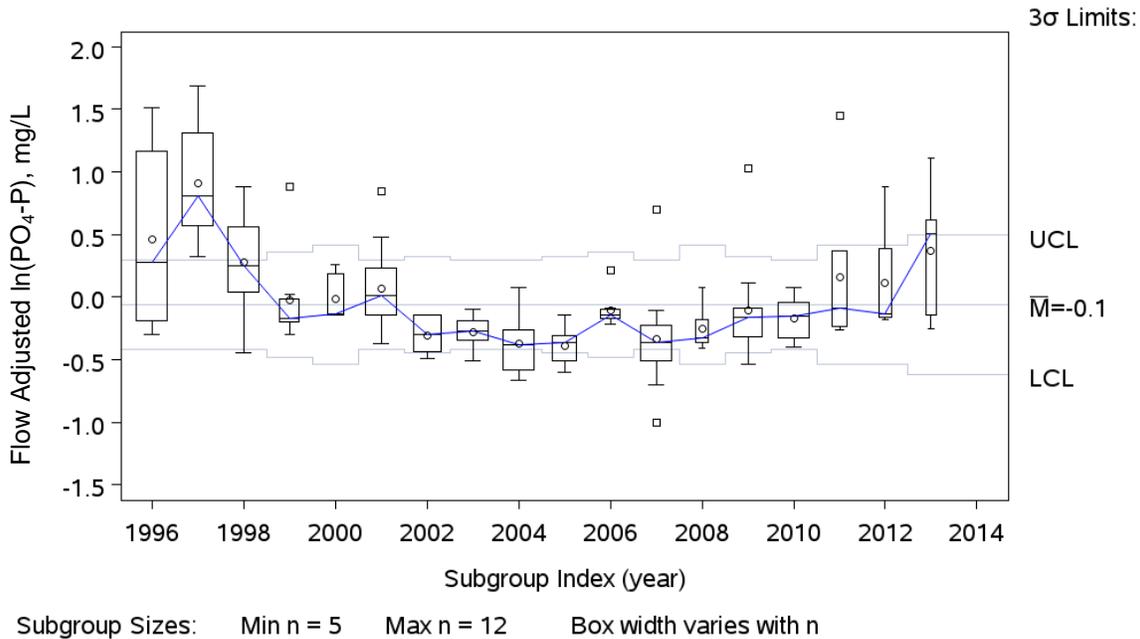


**Figure 14** Annual box and whisker plots of monthly volume-weighted PO<sub>4</sub>-P data for station 11956 (BO090). Data natural-log transformed and flow-adjusted.



**Figure 15** Annual box and whisker plots of monthly volume-weighted PO<sub>4</sub>-P data for station 11954 (BO095). Data natural-log transformed and flow-adjusted.

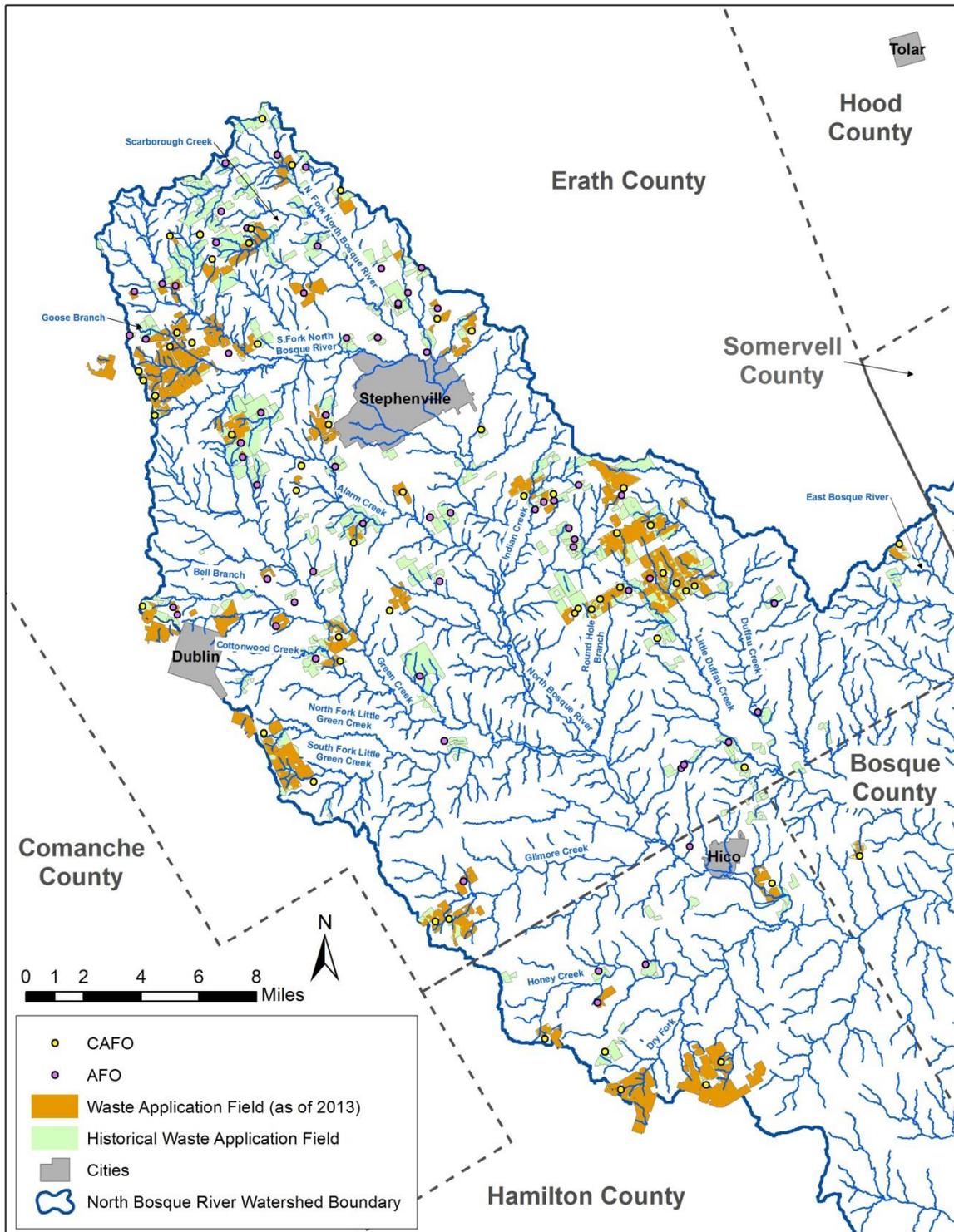
A pattern of decreasing PO<sub>4</sub>-P concentrations somewhat similar to those at 11956 (BO090) and 11954 (BO095) was found at station 11826 (NC060) on Neils Creek (Figure 16), which flows into the North Bosque River between 11956 (BO090) and 11954 (BO095). There are indications that changes in the handling of poultry litter from operations found in the Neils Creek watershed and other drainages in the lower portion of the North Bosque watershed may have influenced these decreases in PO<sub>4</sub>-P and other nutrient constituents.



**Figure 16** Annual box and whisker plots of monthly volume-weighted PO<sub>4</sub>-P data for station 11826 (NC060). Data natural-log transformed and flow-adjusted.

As of 2006, 12 poultry facilities were known to be operating in the lower portion of the North Bosque River watershed primarily within the Meridian and Neils Creek watersheds, and these poultry operations have likely been in business since at least the early 1990s (McFarland and Jones, 2006). Based on information reported by McFarland and Jones (2006), these poultry operations have had their litter collected by a composting company (Mida-Bio) and have not conducted onsite disposal since about 2000. This initial decrease in PO<sub>4</sub>-P concentrations at stations in the lower portion of the watershed appears to correspond in part with this change in handling of poultry litter.

In a similar fashion, changes in waste management associated with the I-Plan impacting CAFOs and AFOs are expected to impact water quality trends along the North Bosque River. Most CAFOs and AFOs are or have been located in the upper portion of the North Bosque River watershed, and based on information from TCEQ, as of September 2011, 50 CAFOs had permits in the North Bosque River watershed (Figure 17). Information from these 50 CAFO permits along with the technical packet were reviewed and used to develop a Geographic Information System (GIS) layer documenting the location of these facilities and associated WAFs (Figure 17). Metadata in the GIS layer for WAFs included crop type and dominant type of waste applied.



**Figure 17** Map of CAFOs, AFOs, and associated WAFs (active and historical) within the North Bosque River watershed representing conditions as of fall 2013. The dots for CAFOs and AFOs indicate the location of active and inactive facilities.

The location of most AFOs as nonpermitted facilities was determined from information from TCEQ or the Texas Department of Health, Division of Milk and Milk Products as part of a previous GIS efforts focusing on conditions representing active operations as of 2005 and historical operations since 1995 (see McFarland and Jones, 2006). The 2005 GIS layer of facilities and WAF was also updated in 2007 for a modeling project for the North Bosque River watershed to include WAFs associated with the Microgy biogas facility (Houser and Hauck, 2010). Only one new AFO was identified as active in 2012 that was not represented in the 2005 GIS layer. Information on the location and size of WAFs for this new AFO were not available, so the size of these fields was estimated based on maximum herd size of 199 head and located on fields contiguous with the location of this AFO.

The information on active CAFO and AFO operations was reviewed in the fall of 2012 and 2013 based on TCEQ inspection data and Texas Department of Health (TDH), Division of Milk and Milk Products reports. As of late 2012, 3 of the 50 permitted facilities noted in September 2011 were no longer operating. As of late 2013, eight additional permitted facilities were inactive. Although “inactive”, the fields for these operations were considered “active” rather than “historical” as long as the permit was still considered valid. This distinction was made, because as long as the permit is valid, the operation still has the potential to become operational, although possibly under a different operator. Also of note, some facilities with an active permit have “active” and “historical” fields as the status of fields can change with permit renewals. For smaller operations or AFOs, if the operation were inactive based on TCEQ inspection or TDH reports, the associated fields were categorized as “historical”. This updated information obtained for FY12 and FY13 was used to define the location and area associated with active and historical WAFs (Figure 17 and Table 11). Of note, while no additional “active” fields were noted as “historical” between the previous interim report and the current one, the numbers in Tables 11 and 12 differ some from McFarland and Adams (2013) due to corrections made in how some fields were designated.

In comparing the acres associated with WAFs over time, a notable decrease has occurred in the land area categorized as active based on data representing conditions as of 2000, 2005, and 2013 (Table 12). An increase, thus, has occurred in acres of historical WAFs with the split between active and historical WAFs for stations along the mainstem of the North Bosque River shown in Table 13. Of note, while only one “new” operation was noted in the update conducted in 2012, many of the dairy operations have expanded or identified new fields for waste application with permit renewals and associated updates in CAFO regulations. In addition, the fields identified as “active” WAFs do not include areas where animal waste has been transferred to a third party for potential land application, although those who accept animal waste are expected to apply it at appropriate agronomic rates. Because contributions from WAFs were considered a major nonpoint source of SRP to the North Bosque River, decreases in the land area used for waste application can be considered in part responsible for the decreases noted in stream PO<sub>4</sub>-P concentrations and loadings.

**Table 11** Summary of active and historical WAF information for CAFOs and AFOs in the North Bosque River watershed as of fall 2013.

Primary Type of Waste Applied	Primary Crop	FY12 & FY13 Estimated Active (acres)	FY12 & FY13 Estimated Number of Active Fields	FY12 & FY13 Estimated Historical (acres)	FY12 & FY13 Estimated Number of Historical Fields
Liquid	Coastal/Small Grain	3,527	89	1,853	91
Liquid	Coastal	2,914	84	1,793	68
Liquid	Sorghum/Small Grain	290	5	415	17
Liquid	Small Grain	120	3	165	8
Liquid	Rangeland	105	2		
Liquid	Other	17	1	24	1
	Subtotal	6,972	184	4,250	185
Solid	Coastal/Small Grain	3,655	93	2,720	74
Solid	Coastal	3,129	73	5,799	174
Solid	Rangeland	1,106	16	390	12
Solid	Sorghum/Small Grain	691	8	2,325	75
Solid	Sorghum	42	2	720	24
Solid	Small Grain	70	3	171	10
Solid	Other	0	0	94	4
	Subtotal	8,692	195	12,220	373
Microgy	Microgy	0	0	1,772	54
	Total	15,665	379	18,243	612

**Table 12** Comparison of acres and number of fields categorized as active and historical WAFs in the North Bosque River watershed as 2000, 2005, and 2013. Information on WAFs for 2000 and 2005 from McFarland and Jones (2006).

Categorization	2000 WAF Layer		2005 WAF Layer		2013 WAF Layer <sup>a</sup>	
	Acres	Number of Fields	Acres	Number of Fields	Acres	Number of Fields
Active	24,554	623	19,122	473	15,693	380
Historical	2,142	93	7,574	243	18,215	611
Total	26,696	716	26,696	716	32,136	937

a. (Note: The acres and number of fields from the 2013 WAF layer excludes fields associated with Microgy for comparison. The Microgy biogas plant began operation in late 2007 and ceased operation in 2010.)

**Table 13** Estimated land use and drainage area above sampling stations along the North Bosque River watershed. General land use based on Narasimhan, et al. (2005) with WAFs updated and split between active and historical as of FY2013.

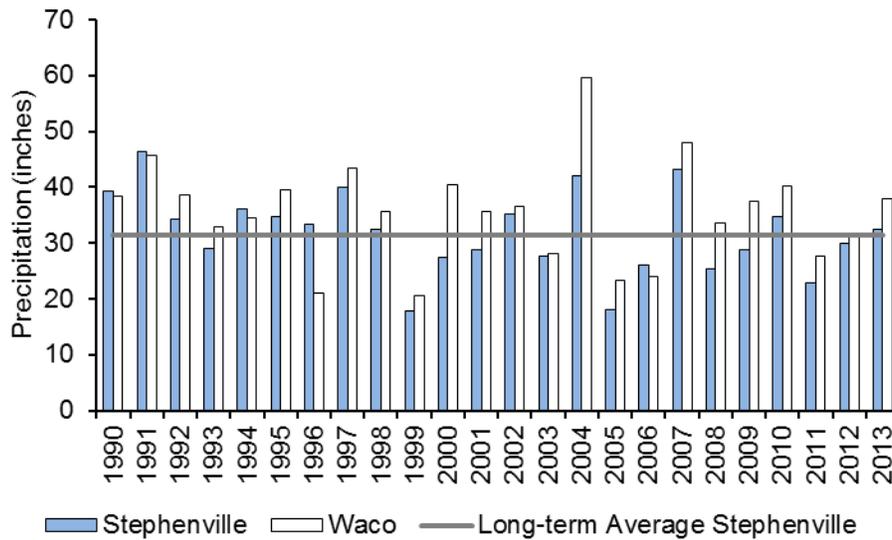
TCEQ Station ID	TIAER Station ID	Wood & Range (%)	Pasture (%)	Cropland (%)	Waste App. Fields <sup>a</sup> (%)	Historical Waste Appl. Fields <sup>b</sup> (%)	Urban (%)	Other (%)	Total Area (Hectares)
17226	BO020	26.0%	41.1%	9.6%	7.3%	11.0%	3.9%	1.0%	21,700
11963	BO040	25.8%	40.0%	9.5%	6.8%	10.4%	6.5%	1.1%	25,700
11961	BO070	41.0%	38.6%	6.2%	3.8%	6.0%	3.5%	0.8%	93,100
18003	BO083	53.4%	31.3%	4.6%	3.2%	4.1%	2.4%	1.0%	178,000
11956	BO090	59.4%	27.5%	4.6%	2.2%	2.9%	2.4%	0.9%	253,000
11954	BO095	61.5%	25.9%	5.0%	1.9%	2.5%	2.3%	0.9%	297,000

- a. Waste application fields represent estimates from milking operations and non-milking operations as well as fields associated with Microgy.
- b. Historical fields are previously permitted fields that are no longer permitted for animal waste application.

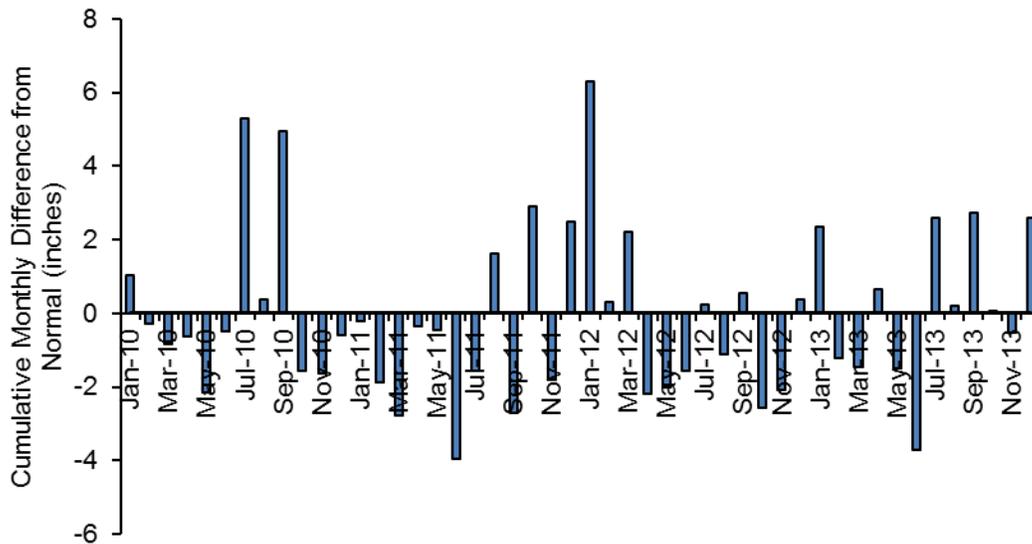
Besides changes in land management, long-term weather patterns, particularly with regard to precipitation, are expected to have a notable impact on the water quality trends observed. Precipitation has been variable over the analysis period for the watershed as indicated by annual precipitation values for Stephenville and Waco<sup>5</sup> (Figure 18). Based on precipitation data at Stephenville, most years prior to 1999 had precipitation levels near or above the 30-year average, while most years between 1999 and 2013 were below the 30-year average. Annual precipitation at Waco followed the same general pattern between years as at Stephenville, but annual precipitation was generally greater at Waco than Stephenville and indicated a larger number of years with above average precipitation using the Stephenville long-term average as a benchmark.

An important consideration in interpreting the annual rainfall data is to consider the pattern of rainfall within each year. Although total annual precipitation for 2012 and 2013 indicate near normal amounts, drought conditions have persisted in the watershed area for the last few years. By comparing month precipitation amount in comparison to monthly normals for Stephenville for the years 2010 through 2013, most months show well below normal precipitation with only a few months within each year having above normal amounts (Figure 19). The cumulative difference in monthly precipitation from normal for January 2010 through December 2013 indicated a continuing rainfall deficit throughout 2013 (Figure 20). These changes in precipitation are reflected in streamflow with very low runoff conditions occurring in 2011 and 2013 (Figure 21).

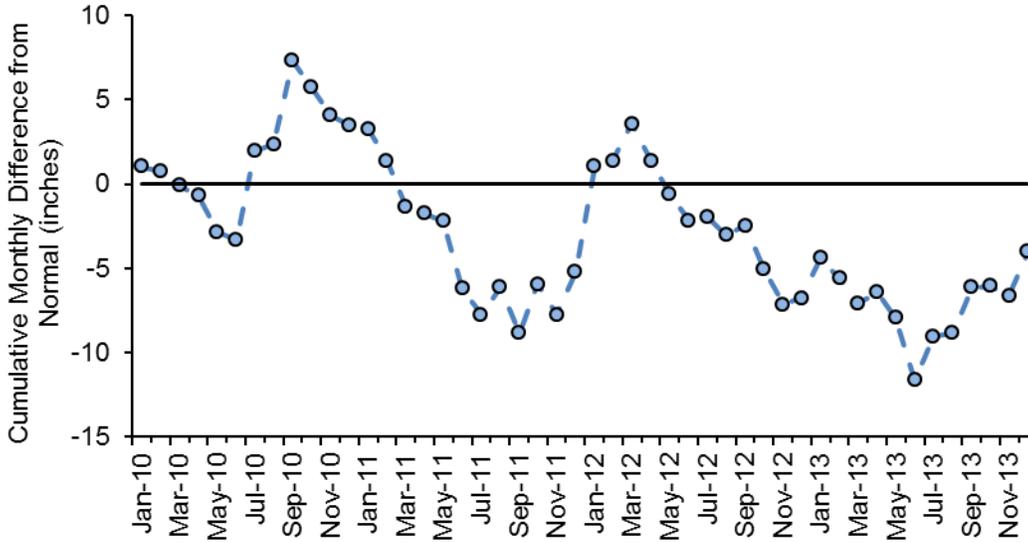
<sup>5</sup> In previous interim reports, precipitation data for Valley Mills has been reported. The precipitation data for Valley Mills has been inconsistently reported in the National Weather Service database, so data from the Waco Regional Airport is now being presented instead. While outside the watershed boundary, the precipitation data from the Waco is representative of conditions in the more southern portion of the watershed.



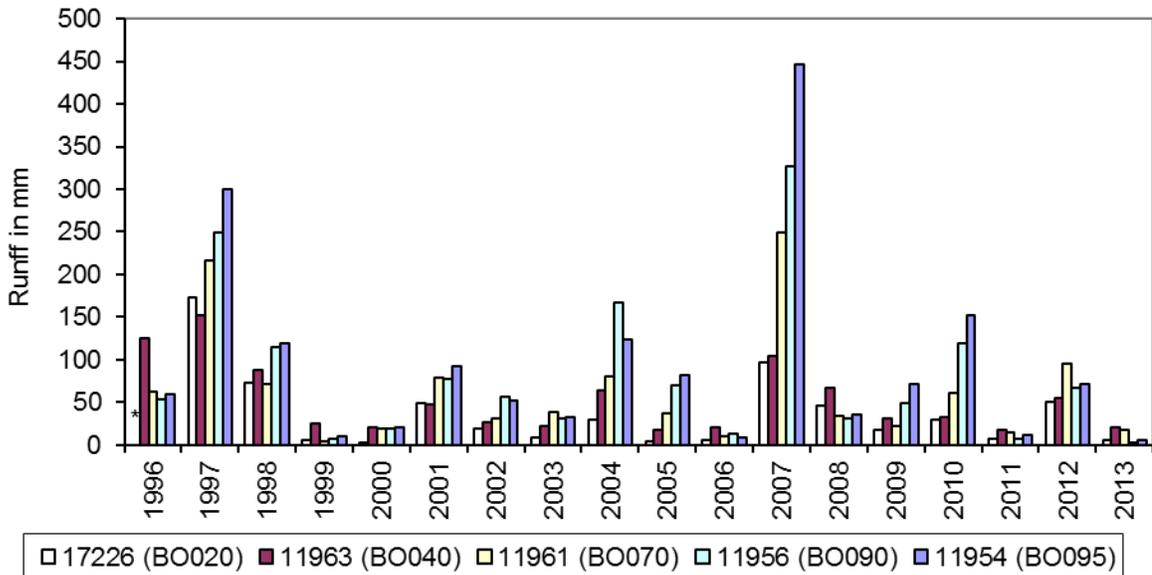
**Figure 18** Temporal variability in annual precipitation at Stephenville and Waco, Texas. Data source: National Weather Service (NWS).



**Figure 19** Monthly difference from normal precipitation from January 2010 through December 2013 for Stephenville, Texas. Data source: National Weather Service (NWS).



**Figure 20** Temporal variability 2010 through 2013 in cumulative difference of measured to normal monthly precipitation for Stephenville, Texas. Data source: National Weather Service (NWS).



**Figure 21** Annual runoff in millimeters for gauged stations along the North Bosque River. Asterisk indicates no data for 17226 (BO020) in 1996. Stations are listed in order of most upstream to most downstream.

Comparisons of average  $\text{PO}_4\text{-P}$  concentrations for grab samples to the log of annual average flow generally supported trend analysis findings (Figures 4 – 9). Most post-TMDL years for stations showing significant downward trends had average  $\text{PO}_4\text{-P}$  concentrations below the pre-TMDL regression relationship. Data for 2013 indicated average  $\text{PO}_4\text{-P}$  concentrations below the pre-TMDL regression at index stations 17226 (BO020) and 11963 (BO040) as well as station 11961 (BO070). Annual average  $\text{PO}_4\text{-P}$  from grab data indicated concentration below TMDL target goals for 2013 at three index stations: 18003 (BO083), 11956 (BO090), and 11954 (BO095) (Figures 10 and 11).

This report presents an annual update of trends in routine grab samples and loadings for stations within the North Bosque River watershed through the calendar year 2013. Monitoring through August 2015 is sponsored under a TCEQ Nonpoint Source Program Clean Water Act 319 project in cooperation with EPA Region 6 as well as upcoming trends report for data through 2014.

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