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Assessment of Water Quality Trends for the North Bosque River through 2009

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The authors would 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 on weekends and holidays.

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Errata

In the original version of this report dated August 2010, the magnitude of the slope for trends was presented in units of percent change per month rather than percent change per year as indicated in the equation presented on p. 17 of the methods and in Tables 5-10 on pages 19-24 of the results. To obtain the percent change on an annual basis using the equation on p. 17, the percent change per month should be multiplied by 12. Also, the slope for conductivity for stations 17226 and 11961 in Table 5 on p. 19 was misreported as a positive rather than negative value. These changes impact TR1002 dated August 2010 and were reported on July 21, 2011. These errata are corrected in the most recent online version TR1002v2 dated September 2011 available on TIAER’s website at http://tiaer.tarleton.edu/ under publications.

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Introduction

This is the final report for the Clean Water Act §319(h) project, North Bosque River Effectiveness Monitoring, funded through the Texas Commission on Environmental Quality (TCEQ) and Region 6 of the United States Environmental Protection Agency (USEPA). Much of the introduction, background material, and report format are repeated from interim annual reports for consistency (McFarland and Millican, 2006; 2007; 2008; 2009) with information updated as appropriate. The goal of this report is to provide an assessment of water quality trends in the North Bosque River watershed to evaluate the effectiveness of nonpoint source (NPS) and point source control measures. Trend analysis focused on nine monitoring stations (Figure 1). These nine stations include index stations (17226, 11963, 18003, 11956, and 11954) associated with total maximum daily loads (TMDLs) for the North Bosque River and other stations that are important as either reference stations or stations to assess the impact of phosphorus control practices. Of note, the work plan for this project was revised in early 2008 and monitoring at the Public-Law 566 reservoir 17224 (NF030) ceased in April 2008. Due to the limited amount of data collected in 2008 at station 17224 (NF030), trends for this station are presented only through 2007.

The TCEQ adopted two TMDLs for soluble reactive phosphorus[1] (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. An Implementation 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 Implementation 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 plants.

To address phosphorus application rates on dairy waste application fields, 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[2] for concentrated animal feeding operations (CAFOs) in 2004 to require permitted dairies in the North Bosque to implement Nutrient Management Plans (NMPs).

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[1] Soluble reactive phosphorus is commonly referred to as orthophosphate phosphorus (PO_4-P).

[2] Subchapter B Concentrated Animal Feeding Operations, Chapter 321, Texas Administrative Code Title 30, §321.31 – §321.27.

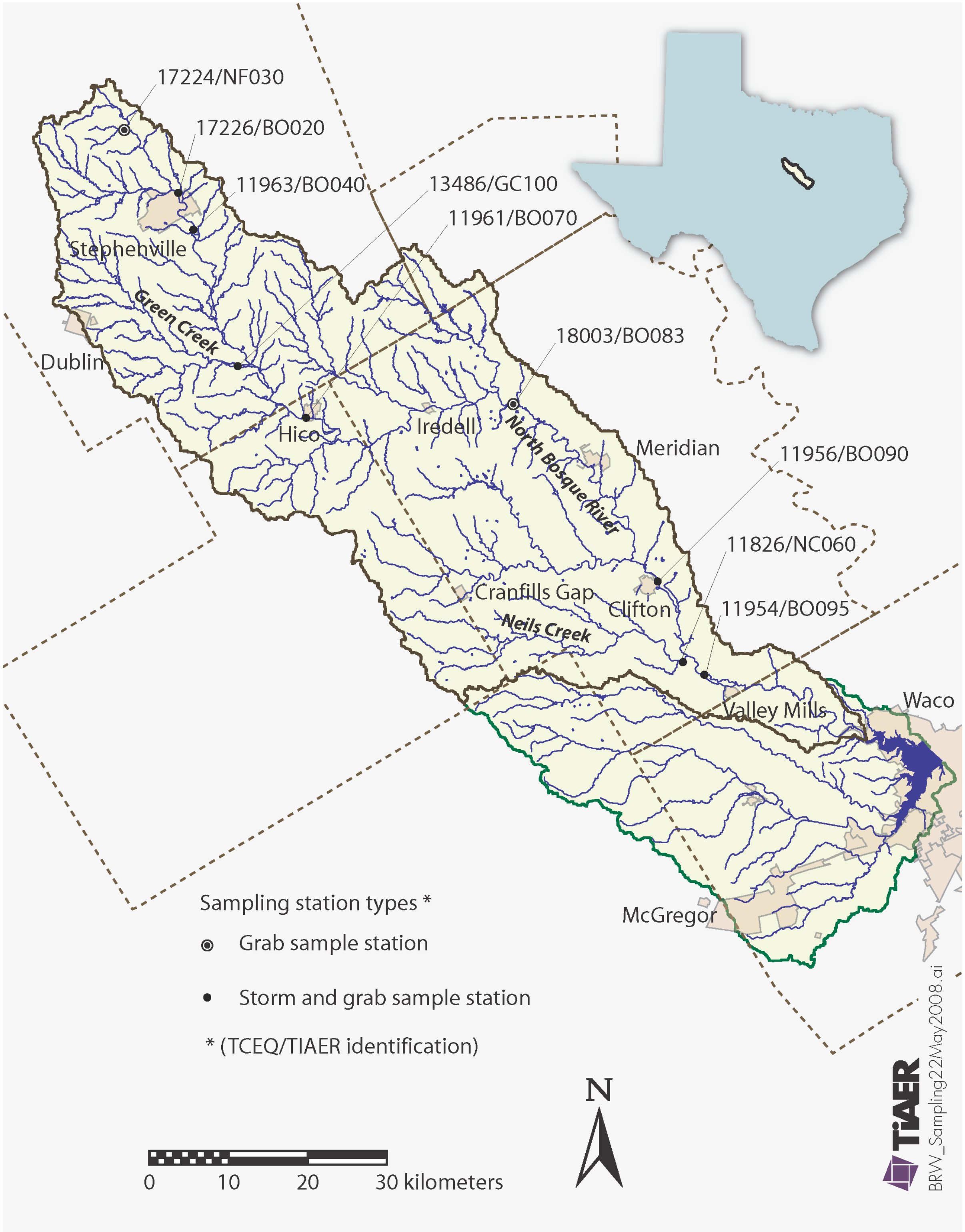

Figure 1 North Bosque River watershed trend analysis monitoring stations

A NMP generally 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 adoption of CNMPs, and, thus, NMPs, has been slow for various reasons, but in recent years a number of CNMPs associated with CAFOs have been certified. In F2006, 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 that in FY2007 and FY2008, 34 CNMPs were developed as part of WQMPs for AFOs.

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). About 0.38 percent phosphorus is a more recent recommendation for high producing dairy cattle (NRC, 2001).

One of the most visible programs associated with the Implementation Plan was the Dairy Manure Export Support (DMES) project in conjunction with 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 the manure composting program in September 2000 as a way to export dairy manure from the North Bosque River watershed. In turn, the dairy manure compost can 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 incentive programs. Seven composting facilities had been active in the program, and as of March 2008, six were still active and receiving manure from dairy operations within the watershed. A follow up in May and June 2009 indicated that five of these six composting facilities were still active. The sixth facility did not respond to repeated contact efforts and is suspected to now be out of business. The five composting facilities contacted indicated a decrease in manure handled in recent years, but an interest in moving more material through a variety of marketing ideas.

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 wastewater treatment plants (WWTPs). All municipal WWTPs are required as part of the Implementation Plan to monitor total phosphorus in their effluent, and at the two larger facilities in Clifton and Stephenville, phosphorus limits have been imposed that necessitate advanced treatment processes. Load allocations will be phased in at the smaller facilities, but have not yet occurred. In fall 2005, Stephenville began using biological treatment in conjunction with alum and polymers for phosphorus removal. Under the Implementation Plan, the Stephenville WWTP had until July 2006 to implement measures to meet a daily average discharge limit of 1 mg/L. Clifton has been operating since early 2005 using alum as a chemical treatment to remove phosphorus.

Although Implementation Plan activities are occurring over varying timeframes, it is important to monitor and statistically evaluate water quality on an interim basis to determine if improvements are occurring. It is anticipated that changes in water quality will be gradual and lag actual implementation on the land, particularly with regard to reducing nonpoint source pollutants, so it will require several years after implementation before instream improvements become apparent. To evaluate 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-α (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. The analysis of conductivity for trends was not included in interim reports but was added to this final report as an additional parameter. Other field parameters, (e.g., dissolved oxygen (DO) and pH), while routinely monitored, were not included in trends analysis due to the difficulty in correcting for variations associated with diurnal fluctuations.

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 almost 17,000 (Table 1).

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

Municipality	Estimated 2008 Population[a]	Permitted Monthly Discharge (MGD)	Average of Monthly Reported Discharge for April 2008 - March 2009 (MGD)[b]	Average of Monthly Reported Total Phosphorus for April 2008 - March 2009 (mg/L)[b]	Discharge Location
Stephenville	16,921	3.0	1.40 ± 0.24	0.45 ± 0.27	North Bosque River
Hico	1,403	0.20	0.099 ± 0.011	5.07 ± 0.99	Jacks Hollow Branch of the North Bosque River
Iredell	383	0.05	0.017 ± 0.009	1.87 ± 0.71	North Bosque River
Meridian	1,562	0.45	0.162 ± 0.025	2.87 ± 0.98	North Bosque River
Cranfills Gap	378	0.04	0.016 ± 0.009	2.76 ± 0.63	Austin Branch of Meridian Creek, which flows into the North Bosque River
Clifton	3,776	0.65	0.302 + 0.020	0.40 + 0.19	North Bosque River
Valley Mills	1,169	0.36	0.098 ± 0.019	2.87 ± 0.77	North Bosque River

[a] Population estimates based on values presented by the Texas State Data Center (2010) for January 1, 2009.

[b] Reported discharge in million gallons per day (MGD) and total phosphorus concentrations represent the average and standard deviation of monthly self-reported data for April 2008 through March 2009 as the most recently available 12 months of data for all seven municipalities (USEPA, 2010).

Seven municipalities have WWTPs 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 WWTP, with the exception of Cranfills Gap and Hico. Cranfills Gap discharges into the Austin Branch of Meridian Creek, a major tributary to the North Bosque River, and Hico discharges into Jacks Hollow Branch a few hundred feet before its confluence with the North Bosque River.

The North Bosque River watershed is typical of many watersheds in the region in that the dominant land covers are wood and range. Improved pasture and some row crop farming are found 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 is still the top milk producing county in Texas (USDA-AMS, 2010), the number of dairy producers in the watershed has decreased substantially since adoption of the TMDL from over 100 in 2001 to about 70 in 2009.[3] Although dairy cow numbers have also decreased, the decrease in cow numbers has not been proportional to the decline in dairy producers. Based on TCEQ inspection records for the North Bosque River watershed, the estimated number of dairy cows was about 45,000 in 2001 and only about 36,000 in 2009. Based on inspection records and other information for 2009, about another 8,000 animals in the watershed are associated with beef or calf raising CAFOs or AFOs bringing the total number of cattle in confinement to about 44,000.

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. 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).

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 listed first followed by the TIAER station identification in parentheses or brackets. Trend analysis activities focused on nine stations at which temporally intensive data collection has occurred for about 10 years or more. Of note, monitoring at station 18003 (BO083) was not initiated until 2003, so only seven years of data were available. 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 Implementation 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 is 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.
- Public Law–566 (PL-566) reservoir, station 11826 (NF030), which represents a subwatershed with a relatively high level of dairying activity.

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[3] The number of producers was based on a review of inspection records maintained by the Texas Department of Health and TCEQ. For reference, only about two-thirds of the dairy operations in Erath County are located within the watershed.

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

Station Identification TCEQ (TIAER)	Location within the North Bosque River Watershed	Drainage Area (ha)	Dominate Land Use or Land Cover[a]	General Water Quality and Hydrology
Stations along the Mainstem of the North Bosque River				
17226 (BO020)	North Bosque River above Stephenville, Texas	21,700	Wood-range (26%), pasture and cropland (53%), waste application fields (17%), 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 WWTP[b]	25,700	Wood-range (26%), pasture and cropland (51%), waste application fields (16%), urban (7%)	Water quality impacted by point and nonpoint sources; perennial flow
11961 (BO070)	North Bosque River at Hico, Texas above the discharge from the Hico WWTP	93,100	Wood-range (41%), pasture and cropland (46%), waste application fields (9%), urban (4%)	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 (54%), pasture and cropland (36%), waste application fields (6%), 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 WWTP	253,000	Wood-range (60%), pasture and cropland (33%), waste application fields (4%), 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 WWTP	297,000	Wood-range (62%), pasture and cropland (31%), waste application fields (4%), urban (2%)	Low impacts from point and nonpoint sources; perennial flow
Stations on Major Tributaries to the North Bosque River				
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
Station on a PL-566 Reservoir				
17224 (NF030)	Scarborough Creek, a tributary of the North Fork of the North Bosque River	1,580	Wood-range (22%), pasture and cropland (49%), waste application fields (26%), other (2%)	Water quality highly impacted by nonpoint sources

[a] Animal waste application fields are considered a distinct land use from pasture and cropland, although waste is generally applied to pasture and cropland.

[b] WWTP, wastewater treatment plant.

The land-use information in Table 2 represents information available 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 by TIAER from a review of TCEQ permit information to supplement the satellite imagery classification. The location of animal waste application fields (WAFs) was based on detailed information obtained in 2000 from TCEQ records that was updated in the fall of 2007. The updated information on WAFs includes milking and non-milking operations, although milking operations represent over 80 percent of the CAFOs and AFOs in the watershed.

In two interim reports (i.e., McFarland and Millican, 2006; 2007), general land-use/land-cover descriptions were based on Landsat Thematic Mapper imagery classification provided by the USDA-NRCS, Temple State Office. This older land-use information was developed from a 1992 overflight of Erath County and a 1996 overflight of Erath, Bosque, Coryell, Hamilton, and McLennan Counties supplemented by extensive ground verification in January through April 1998 to update land use changes. Information on dairy waste application fields was obtained from dairy permits and dairy waste management plans on record with the TCEQ as of May 2000. A comparison between these two land-use estimates indicates a general shift of wood/range to improved pasture throughout the watershed (McFarland and Jones, 2006).

In addition to the stations listed above, 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 (B0100). Collectively data from these two stations will be referred to as station 11954 (BO095) throughout the rest of this report.

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 Stated Department of Agriculture. This QAPP covers data collected between September 1, 1996 and August 31, 2007.

The water quality data associated with projects above were collected and analyzed using similar assessment objectives, sampling techniques, laboratory protocols, and data validation procedures as the current project (TIAER, 2010), which was initiated in February 2006. One known area of deviation was in the measurement of bacteria. Prior to 2000 fecal coliform (FC) rather than *Escherichia coli* was monitored. From November 2000 through March 2004 both *E. coli* and fecal coliform were evaluated to allow comparison of 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). Appendix A, also presented in the first interim report (McFarland and Millican, 2006), evaluates the agreement between these two methods and the regression relationship for adjusting historical fecal coliform to *E. coli* concentrations for trend analysis. This comparison included 1075-paired observations and produced the following regression relationship:

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

Of note, this regression relationship did not meet all the assumptions associated with use of regression analysis. That is 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. Including fecal coliform data extended trend analysis for bacteria to include pre- and post-TMDL implementation periods.

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 stream 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 generally taken at a depth below the surface of about 0.08 to 0.15 meters (0.25 to 0.5 ft), as recommended in TCEQ surface water monitoring procedures (TCEQ, 2003; 2008).

Surface samples were taken within the PL-566 reservoir near the principle spillway at the deepest part of the reservoir at a depth of 0.3 meters (1.0 ft) for all laboratory analyses, except CHLA. For the PL-566 reservoir, the depth of a CHLA sample was dependent on the Secchi depth. If the Secchi depth was less than 30 centimeters (12 inches), then the CHLA sample was collected at a depth of 0.3 meters (1.0 ft). If the Secchi depth was greater than 30 centimeters (12 inches), the CHLA sample consisted of a composite of subsamples from the top, middle, and bottom depths of the Secchi reading with the top subsample occurring with the sampler submerged just below the surface of the water.

When grab samples were collected, water temperature, 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 of about 0.3 meters (1.0 ft). On the PL-566 reservoir, multiprobe readings were taken at 0.3 meter (1.0 ft) intervals throughout the profile.

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 may cause fluctuation or false trends to be detected depending on the time of day when measurements were 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

For this project, the sampling sequence was modified so that once the four-hour interval was encountered, all remaining bottles for an event were 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.[4] 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 stream flow and stage data for 11956 (BO090) and 11954 (BO095).

Also of note in the spring of 2008, the work plan for this project was changed 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 sites, but led to a moderately sized runoff event at sites 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.

Laboratory Analysis Methods

Ammonia-nitrogen (NH_3-N), nitrite-nitrogen plus nitrate-nitrogen (NO_2-N+NO_3-N), total Kjeldahl nitrogen (TKN), orthophosphate-phosphorus (PO_4-P) or SRP, total-P (TP), 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_2-N+NO_3-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. As previously discussed, from November 2000 through March 2004 both fecal coliform and *E. coli* were analyzed to determine a relationship between these two measures of bacteria.

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[4] Reinstallation of station 11954 (BO095) took a much longer than at 11956 (BO090), because water transfer pumps as well as sampling equipment had to be retrieved after water levels receded before they could be inspected and repaired. Also, due to bank erosion, a concrete platform and metal cover was installed at 11954 (BO095) to help protect transfer pumps under future high water conditions.

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

Parameter	Abbreviation	Units	Method[a]	Parameter Code
Ammonia-nitrogen	NH_3-N	mg/L	EPA 350.1 or SM 4500-NH3 G	00608
Nitrite-nitrogen + nitrate-nitrogen	NO_2-N+NO_3-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[b]	00625
Orthophosphate-phosphorus	PO_4-P	mg/L	EPA 365.2 or SM 4500P-E	70507 or 00671[c]
Total phosphorus	TP	mg/L	EPA 365.4[b]	00665
Total suspended solids	TSS	mg/L	EPA 160.2 or SM 2540 D	00530
Chlorophyll-α	CHLA	µg/L	SM[d] 10200-H	32211
Escherichia coli	*E. coli*	cfu/100 mL or MPN/100mL	SM9222G or SM9223-B (IDEXX Coliert®)[d]	31699

[a] 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*, 18th Edition (APHA, 1992) for PO_4-P and latest online edition for all other parameters.

[b] Modification of TKN and TP methods involved using copper sulfate as the catalyst instead of mercuric oxide.

[c] Field-filtering for PO_4-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.

[d] 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 site 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. Evaluation of these two data sets allows trends with regard to the TMDL objectives to address 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), data sets were limited to timeframes with flow data for evaluation of trends. At 18003 (BO083), flow measurements were generally not available.

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

In a similar fashion, surface grab samples from within the PL-566 reservoir were volume-weighted using depth of the bottom sample as an indicator of reservoir depth in the reservoir. A volume adjustment was implemented, because there appeared to be a clear increase in concentrations as the reservoir volume decreased. This relationship was most apparent in the months prior to April 2000 when sampling was temporarily suspended due to extremely low water levels (see Adams and McFarland, 2002). The volume within the reservoir was estimated using the following equation developed from design information obtained from the Natural Resources Conservation Service:

$$y = 2361.96 * x^{3.10}$$

where y equals water volume in cubic meters and x equals depth of the water in meters.

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.

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 site 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 site (Table 4). The timeframe of available monitoring data also often differed by parameter. The PL-566 reservoir, station 17224 (NF030), had the longest period of record with data for soluble nutrients starting back in 1991. Stations 11961 (BO070) and 13486 (GC100) had the longest periods of record for stream locations 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. For this report, data for all stations and constituents, except those for station 17225 (NF030), were analyzed through December 2009.

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

	Routine Grab Samples				**Storm Samples**	
Station	**Soluble Nutrients**	**TKN, TP, and TSS**	**CHLA**	**Bacteria**	**Soluble Nutrients**	**TKN, TP, and TSS**
17226 (BO020)	1997 – 2009	1997 – 2009	1997 – 2009	1997 – 2009	1997 – 2009	1997 – 2009
11963 (BO040)	1994 – 2009	1994 – 2009	1994 – 2009	1994 – 2009	1994 – 2009	1994 – 2009
11961 (BO070)	1993 – 2009	1994 – 2009	1993 – 2009	1994 – 2009	1993 – 2009	1993 – 2009
18003 (BO083)	2003 – 2009	2003 – 2009	2003 – 2009	2003 – 2009	not applicable	not applicable
11956 (BO090)	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009
11954 (BO095)	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009
13486 (GC100)	1993 – 2009	1995 – 2009	1996 – 2009	1995 – 2009	1993 – 2009	1993 – 2009
11826 (NC060)	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009	1996 – 2009
17224 (NF030)	1991 – 2007	1992 – 2007	1992 – 2007	not applicable	not applicable	not applicable

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.

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 on an annual basis. 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 eight stream stations evaluated, parameters did not show any statistically significant seasonal variation or autocorrelation, so seasonality did not need to be separately accounted for in the trend analysis. At station 17224 (NF030) on the PL-566 reservoir, seasonality was indicated for PO_4-P and total-P and trends were appropriately evaluated taking seasonality into account for these constituents.

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 scatter-plot 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 in the data. 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. This local weighting makes LOWESS less sensitive to outliers. 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 "wiggle" 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 eventually start to capture the random error in the data (SAS Institute, 1999; Helsel and Hirsch, 1992). Useful values of *f* typically are in the range 0.3 and 0.7. We used an *f* value of 0.5 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 representing the flow-adjusted concentrations.

At stream sites, 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 as described in Reckhow et al. (1993). The Kendall's tau test is suitable for water quality data that show a non-normal distribution, contain missing data, and are 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. Data are ordered according to year (assuming seasonality is not present) and comparisons are made between data-pair concentrations at year = t and year = t+1. When seasonality exists, data are paired by season and year for comparisons generally assuming each month represents 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. This test assumes that trend is monotonic as an increase or decrease (Newell et al., 1993).

Trend testing was done on flow-adjusted data sets for all stream stations, except station 18003 (BO083) where flow data were not available. As noted previously, data from the PL-566 reservoir (17224 [NF030]) were volume rather than flow adjusted. The null hypothesis tested was that there was no temporal trend in concentration of water quality constituents. The slope calculated gives the magnitude of the trend and is interpreted as the change in concentration per year on a natural log scale. The slope in original units was computed from the slope on the natural log scale as follows (Helsel and Hirsch, 1992):

$$\% \text{ change/yr} = (e^{b1} - 1)*100*12$$

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. The level of significance used to test the null hypothesis was 0.05.

Trend Analysis Results

Routine Grab Data

Compared to past interim reports (McFarland and Millican, 2006; 2007; 2008; 2009), grab samples generally indicated similar positive or negative trends, if significant, regardless of end year (Table 5). Slopes representing the percent change per year often decreased with increasing end year, particularly 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 have occurred in the past that are now starting to increase. In contrast, station 11963 (BO040) showed slopes that increased with increasing end year for phosphorus parameters. Patterns in the change in the slope over time will be further investigated in the discussion section of this report. These patterns in slope are important in considering what might be causing specific changes and in defining if changes (decreases or increases) are continuing.

At station 17226 (BO020), the only significant trend for data through 2009 was an increasing trend for conductivity. This increasing trend for conductivity was one of the few positive trends indicated at any of the stations. An increasing trend in conductivity was also noted at station 11961 (BO070). In past years, an increasing trend for TSS has been noted at 17226 (BO020), but that trend was not significant with data through 2009.

At station 11963 (BO040), significant downward trends were indicated for conductivity, NH_3-N, PO_4-P, TKN, and total-P. Previous reports have also indicated a negative trend for NO_2-N+NO_3-N at 11963 (BO040), but a significant trend for NO_2-N+NO_3-N was not indicated when analyzing data through 2008 and 2009. Of note, only the three most recent years of trends analysis indicated significant downwards trends for PO_4-P and total-P at station 11963 (BO040).

Downward trends in PO_4-P were also noted at station 11961 (BO070) for the first time with analysis of data through 2008 and continued with data through 2009. At station 11961 (BO070), downward trends were noted for all five nutrient constituents for data through 2009. Similar downward trends in nutrients were indicated for data through 2008 and 2007 at 11961 (BO070) for NH_3-N, TKN and total-P, but only NH_3-N consistently indicated a significant downward trend for all five years of analysis.

At stations 11956 (BO090) and 11954 (BO095), significant downward trends were indicated most parameters in evaluating data through 2009 (Table 5). At 11956 (BO090), no trends were noted for conductivity, CHLA, or total-P. At 11954 (BO095) no trends for data through 2009 were noted for CHLA, *E. coli*, NO_2-N+NO_3-N, or total-P. Of note

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.

		2009 Results			**Slope (% change/yr)**				
TCEQ (TIAER) Station	**Parameter**	**Period Evaluated**	**Kendall Test Statistic**	**p-value**	**End Year 2009**	**End Year 2008[a]**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
17226 (BO020)	Conductivity	1997-2009	-0.186	0.0030	-5.0	ne[b]	ne	ne	ne
	CHLA	1997-2009	-0.005	0.9391					
	E. coli	1997-2009	-0.006	0.9297					
	NH_3-N	1997-2009	-0.114	0.0696					
	NO_2-N+NO_3-N	1997-2009	-0.083	0.1847			-7.8		-13.3
	PO_4-P	1997-2009	0.036	0.5702					
	TKN	1997-2009	-0.067	0.2859					
	Total-P	1997-2009	0.042	0.5086					
	TSS	1997-2009	0.119	0.0567		5.3	6.8	9.6	10.2
	Total-N	1997-2009	-0.113	0.0712			ne	ne	ne
11963 (BO040)	Conductivity	1994-2009	-0.152	0.0157	-2.9	ne	ne	ne	ne
	CHLA	1994-2009	-0.017	0.7285					
	E. coli	1994-2009	-0..021	0.6700					
	NH_3-N	1994-2009	-0.252	0.0000	-8.4	-8.9	-6.1	-5.2	
	NO_2-N+NO_3-N	1994-2009	0.037	0.4421			-3.1	-3.8	-5.6
	PO_4-P	1994-2009	-0.246	0.0000	-5.8	-4.7	-3.6		
	TKN	1994-2009	-0.288	0.0000	-4.6	-4.9	-3.4	-2.8	-2.2
	Total-P	1994-2009	-0.244	0.0000	-5.0	-4.2	-3.1		
	TSS	1994-2009	-0.015	0.7513					
	Total-N	1994-2009	-0.039	0.4291			ne	ne	ne
11961 (BO070)	Conductivity	1993-2009	-0.186	0.0001	-1.4	ne	ne	ne	ne
	CHLA	1993-2009	-0.073	0.1475			-3.8		
	E. coli	1994-2009	-0.058	0.2617			-7.0		
	NH_3-N	1993-2009	-0.307	0.0000	-4.3	-4.4	-6.1	-5.3	-8.9
	NO_2-N+NO_3-N	1993-2009	-0.109	0.0244	-4.0	-4.4			-6.2
	PO_4-P	1993-2009	-0.150	0.0020	-4.3	-4.0			
	TKN	1994-2009	-0.145	0.0038	-2.2	-2.3	-2.5		
	Total-P	1994-2009	-0.206	0.0000	-4.2	-4.3	-3.4		-4.2
	TSS	1994-2009	0.041	0.4097					
	Total-N	1993-2009	-0.185	0.0002	-2.8	-3.0	ne	ne	ne
11956 (BO090)	Conductivity	1996-2009	0.077	0.1217		ne	ne	ne	ne
	CHLA	1996-2009	-0.072	0.1767				-5.5	-9.7
	E. coli	1996-2009	-0.114	0.0346	-4.7	-5.0	-6.7	-7.9	-10.8
	NH_3-N	1996-2009	-0.303	0.0000	-4.1	-4.8	-8.5	-5.3	-5.0
	NO_2-N+NO_3-N	1996-2009	-0.145	0.0055	-5.0	-4.4		-5.9	-8.8
	PO_4-P	1996-2009	-0.188	0.0003	-4.7	-5.6	-12.2	-8.8	-20.4
	TKN	1996-2009	-0.308	0.0000	-5.9	-5.5	-4.8	-3.8	-5.9
	Total-P	1996-2009	-0.022	0.6719				-2.0	-4.6
	TSS	1996-2009	-0.143	0.0062	-3.1	-3.0	-4.9	-5.6	-10.4
	Total-N	1996-2009	-0.366	0.0000	-5.5	-5.3	ne	ne	ne
11954 (BO095)	Conductivity	1996-2009	-0.208	0.0001	-4.7	ne	ne	ne	ne
	CHLA	1996-2009	-0.092	0.0871				-6.2	-10.8
	E. coli	1996-2009	-0.080	0.1302		-4.9	-8.8	-7.2	-7.8
	NH_3-N	1996-2009	-0.339	0.0000	-4.0	-4.2	-6.2	-4.8	-6.1
	NO_2-N+NO_3-N	1996-2009	-0.074	0.1548					
	PO_4-P	1996-2009	-0.267	0.0000	-5.3	-5.9	-7.1	-8.8	-17.3
	TKN	1996-2009	-0.240	0.0000	-4.4	-5.5	-5.3	-4.4	-5.3
	Total-P	1996-2009	-0.102	0.0515				-2.0	-5.6
	TSS	1996-2009	-0.157	0.0026	-3.7	-5.3	-6.4	-7.1	-11.6
	Total-N	1996-2009	-0.155	0.0030	-2.4	-2.8	ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, and 2009).

[b] ne indicates parameter was not evaluated for noted end year.

for data evaluated through 2005 and 2006, total-P and CHLA at both 11956 (BO090) and 11954 (BO095) indicated significant downward trends that were no longer apparent when including more recent years of data.

Results for 18003 (BO083) are presented separately from the other mainstem stations, because data for 18003 (BO083) were not flow adjusted and represent a much shorter period of record (Table 6). Monitoring at station 18003 (BO083) did not begin until 2003, and although these trends represent only seven years of data, the results give some insight into water quality changes along the North Bosque River. Similar to previous interim reports, a downward trend was indicated at station 18003 (BO083) for NH_3-N. As noted for data through 2007 and 2008, an increasing trend in CHLA was indicated for data through 2009. Station 18003 (BO083) is about midway between stations 11961 (BO070) and 11956 (BO090), where downward trends in NH_3-N were also noted but not the upward trends in CHLA (Table 5). Total-P and TSS also showed upward trends for data through 2009 at station 18003 (BO083).

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.

		2009 Results			**Slope (% change/yr)**				
TCEQ (TIAER) Station	**Parameter**	**Period Evaluated**	**Kendall Test Statistic**	**p-value**	**End Year 2009**	**End Year 2008[a]**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
18003 (BO083)	Conductivity	2003-2009	-0.040	0.6180		ne[b]	ne	ne	ne
	CHLA	2003-2009	0.277	0.0004	19.6	21.5	23.4		
	E. coli	2003-2009	0.153	0.0703					
	NH_3-N	2003-2009	-0.315	0.0000	-1.8	-7.7	-22.7	-44.8	-45.5
	NO_2-N+NO_3-N	2003-2009	0.036	0.6174					
	PO_4-P	2003-2009	-0.009	0.9152					
	TKN	2003-2009	-0.023	0.7696					
	Total-P	2003-2009	0.196	0.0127	8.9				-22.1
	TSS	2003-2009	0.192	0.0149	12.0				
	Total-N	2003-2009	-0.005	0.9526			ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, and 2009).
[b] ne indicates parameter was not evaluated for noted end year.

At station 13486 (GC100) located on Green Creek, downward trends were noted for NH_3-N and PO_4-P, while an upward trend occurred for NO_2-N+NO_3-N (Table 7). Downward trends in PO_4-P and NO_2-N+NO_3-N have been consistent for all five years of analysis at 13486 (GC100). At station 11826 (NC060) on Neils Creek downward trends were indicated for NH_3-N, PO_4-P, and TKN. Only PO_4-P consistently showed a downward trend at 11826 (NC060) for all five years analyzed.

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	2009 Results			Slope (% change/yr)				
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2009	End Year 2008	End Year 2007[a]	End Year 2006[a]	End Year 2005[a]
13486 (GC100)	Conductivity	1993-2009	-0.013	0.8043		ne[b]	ne	ne	ne
	CHLA	1996-2009	-0.146	0.0579					
	E. coli	1995-2009	-0.073	0.3325			-10.9		
	NH_3-N	1993-2009	-0.209	0.0008	-3.0	-3.0	-5.6	-4.3	-6.8
	NO_2-N+NO_3-N	1993-2009	0.133	0.0319	4.6	4.8			9.7
	PO4-P	1993-2009	-0.136	0.0289	-5.3	-7.0	-9.6	-10.4	-18.0
	TKN	1995-2009	-0.005	0.9447					
	Total-P	1995-2009	0.044	0.5135					
	TSS	1995-2009	-0.050	0.4574			-4.2		
	Total-N	1993-2009	0.113	0.0935			ne	ne	ne
11826 (NC060)	Conductivity	1996-2009	0.023	0.7351					
	CHLA	1996-2009	-0.105	0.0854					
	E. coli	1996-2009	0.096	0.1233					
	NH_3-N	1996-2009	0.286	0.0000	-1.8	-2.3	-5.2	-3.6	
	NO_2-N+NO_3-N	1996-2009	0.016	0.7819					
	PO4-P	1996-2009	-0.345	0.0000	-2.5	-4.4	-5.5	-6.2	-9.7
	TKN	1996-2009	-0.191	0.0007	-3.4	-4.3	-3.7		
	Total-P	1996-2009	0.055	0.3310					
	TSS	1996-2009	0.020	0.7227					
	Total-N	1996-2009	-0.047	0.4061			ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, and 2009).

[b] ne indicates parameter was not evaluated for noted end year.

At station 17224 (NF030), the PL-566 reservoir off Scarborough Creek on the North Fork of the North Bosque River, trends are presented only for data through 2007. Downward trends were indicated in CHLA, NH_3-N, NO_2-N+NO_3-N, and TSS for volume-adjusted concentrations (Table 8). An upward trend was indicated at 17224 (NF030) for total-P for the volume-adjusted data. Of note, a distinct seasonality was indicated for PO_4-P and total-P with higher concentrations occurring more often in the summer than in the winter (Figures 2 and 3). Trends results for PO_4-P and total-P represent the Seasonal Kendall's test to account for this variability.

Table 8 Trend results for routine grab data from PL-566 reservoir station 17224 (NF030) within the North Bosque River watershed. Data transformed using a natural log transformation and adjusted for reservoir volume prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

Station TCEQ/TIAER	Parameter	Period Evaluated	Kendall Test Statistic[a]	p-value	Slope (% change/yr)
17224 (NF030)	Conductivity	1991-2007	0.061	0.2829	
	CHLA	1991-2007	-0.189	0.0002	-4.2
	NH_3-N	1991-2007	-0.177	0.0003	-6.2
	NO_2-N+NO_3-N	1991-2007	-0.176	0.0006	-0.8
	PO_4-P	1992-2007	0.070	0.2008	
	TKN	1992-2007	-0.011	0.8218	
	Total-P	1992-2007	0.118	0.0357	1.9
	TSS	1992-2007	-0.104	0.0386	-1.7

[a] Seasonal Kendall's test results presented for PO_4-P and total-P.

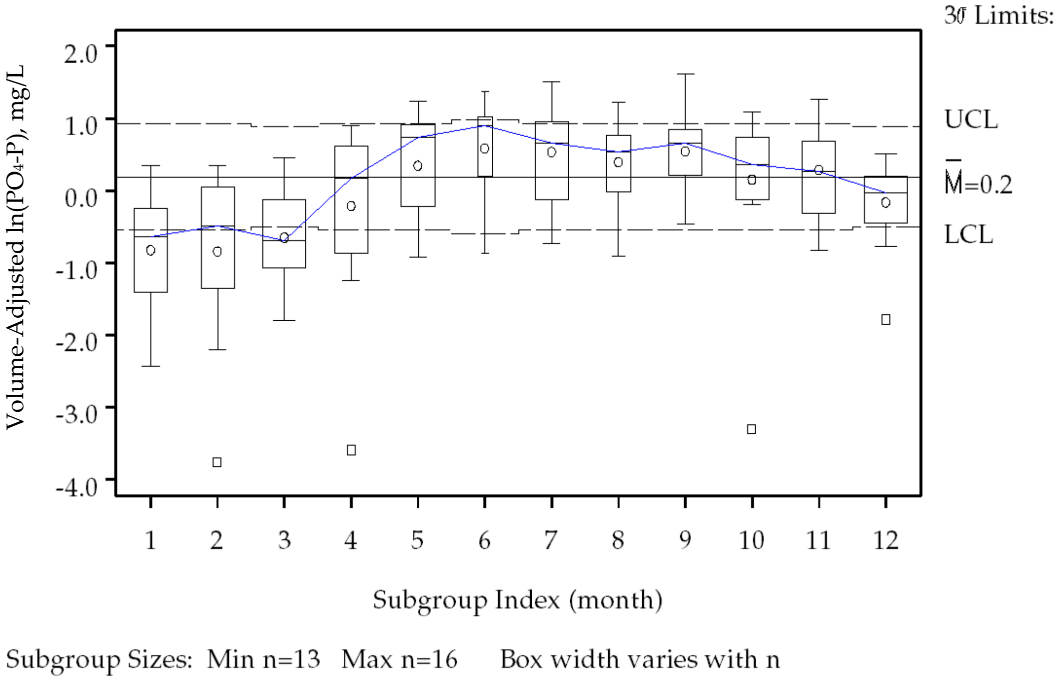

Figure 2 Seasonal variation at station 17224 (NF030) in the natural log transformed volume adjusted PO_4-P concentrations for data through 2007.

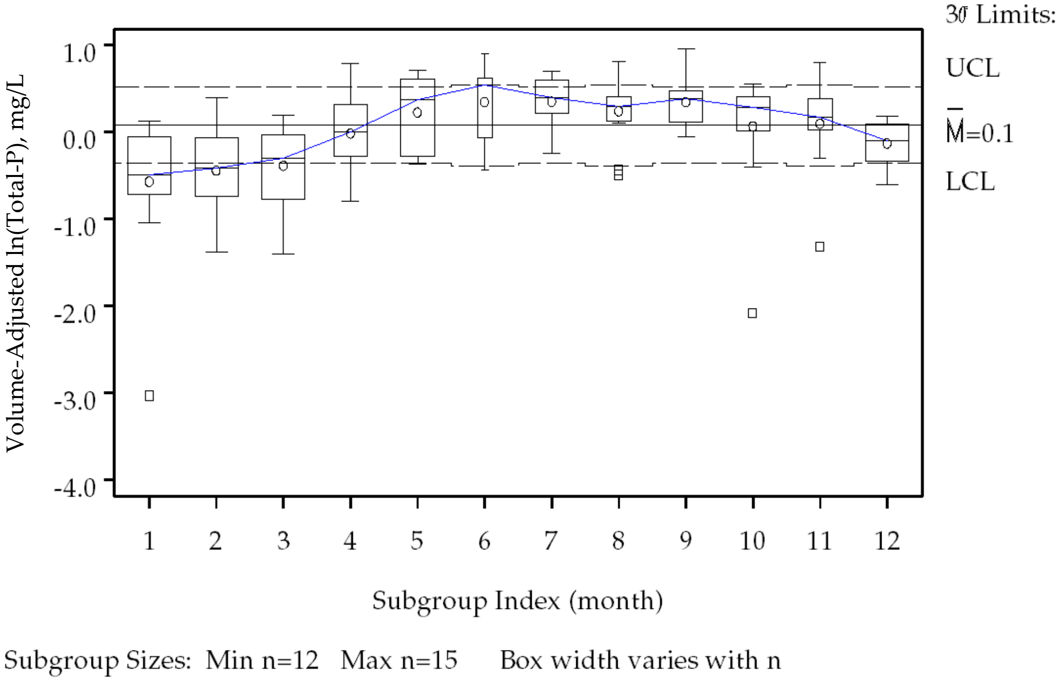

Figure 3 Seasonal variation at station 17224 (NF030) in the natural log transformed volume adjusted total-P concentrations for data through 2007.

Volume-Weighted Data

Generally, trends observed in previous years at mainstem stations continued to be observed with the analysis of volume-weighted data through 2009 (Table 9). Except for TSS at station 11963 (BO040), no increasing trends were indicated at any of mainstem stations for the volume-weighted data analyzed through 2009, but several decreasing trends occurred. For data through 2009, stations 11963 (BO040) and 11961 (BO070) indicated decreasing trends for all constituents but TSS at 11963 (BO040). At station 11956 (BO090), decreasing trends were found for all constituents but total-P and TSS through 2009, while at station 11954 (BO095), decreasing trends were indicated for all constituents but NO_2-N+NO_3-N.

Table 9 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.

		2009			**Slope (% change/yr)**				
TCEQ (TIAER) Station	**Parameter**	**Period Evaluated**	**Kendall Test Statistic**	**p-value**	**End Year 2009**	**End Year 2008**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
17226 (BO020)	NH_3-N	1997-2009	-0.191	0.0007	-5.9	-5.2			
	NO_2-N+NO_3-N	1997-2009	-0.178	0.0016	-5.3	-5.9	-5.4		
	PO_4-P	1997-2009	0.052	0.3568					
	TKN	1997-2009	-0.092	0.1034					
	Total-P	1997-2009	0.055	0.3292					
	TSS	1997-2009	0.065	0.2479					
	Total-N	1997-2009	-0.146	0.0097	-2.4	-2.5	ne[b]	ne	ne
11963 (BO040)	NH_3-N	1994-2009	-0.302	0.0000	-8.2	-8.0	-6.7	-5.6	-4.2
	NO_2-N+NO_3-N	1994-2009	-0.105	0.0299	-2.2	-2.5	-4.4	-4.8	-6.6
	PO_4-P	1994-2009	-0.291	0.0000	-5.9	-4.3	-3.5	-2.6	
	TKN	1994-2009	-0.170	0.0005	-2.3	-2.5	-2.2		
	Total-P	1994-2009	-0.232	0.0000	-3.8	-2.9	-2.3	-1.9	
	TSS	1994-2009	0.116	0.0173	4.0		4.1	5.4	
	Total-N	1994-2009	-0.133	0.0061	-1.6	-1.7	ne	ne	ne
11961 (BO070)	NH_3-N	1993-2009	-0.300	0.0000	-5.0	-5.3	-6.7	-4.4	-5.9
	NO_2-N+NO_3-N	1993-2009	-0.147	0.0022	-3.1	-3.7			
	PO_4-P	1993-2009	-0.189	0.0001	-4.4	-3.6			
	TKN	1993-2009	-0.166	0.0006	-3.1	-4.0	-4.1	-2.3	-2.6
	Total-P	1993-2009	-0.169	0.0004	-3.1	-3.4	-2.8		-2.5
	TSS	1993-2009	-0.022	0.6498					
	Total-N	1993-2009	-0.191	0.0001	-3.0	-3.6	ne	ne	ne
11956 (BO090)	NH_3-N	1996-2009	-0.358	0.0000	-6.0	-6.2	-5.9	-4.2	-5.1
	NO_2-N+NO_3-N	1996-2009	-0.164	0.0016	-4.2	-3.5	-4.9	-5.8	-7.2
	PO_4-P	1996-2009	-0.172	0.0009	-4.2	-4.4	-5.3	-5.2	-9.0
	TKN	1996-2009	-0.231	0.0000	-5.3	-5.4	-5.4	-3.6	-3.7
	Total-P	1996-2009	-0.078	0.1317					-4.1
	TSS	1996-2009	-0.088	0.0897					
	Total-N	1996-2009	-0.303	0.0000	-5.3	-5.4	ne	ne	ne
11954 (BO095)	NH_3-N	1996-2009	-0.401	0.0000	-5.8	-6.0	-8.0	-6.5	-8.2
	NO_2-N+NO_3-N	1996-2009	-0.078	0.1356			-4.3	-5.4	
	PO_4-P	1996-2009	-0.284	0.0000	-6.7	-7.6	-7.9	-8.6	-11.4
	TKN	1996-2009	-0.247	0.0000	-5.5	-6.7	-6.6	-4.1	-7.2
	Total-P	1996-2009	-0.173	0.0009	-3.4	-4.0	-4.1	-4.9	-7.4
	TSS	1996-2009	-0.148	0.0045	-6.7	-8.6	-9.0	-7.4	-11.4
	Total-N	1996-2009	-0.176	0.0007	-3.0	-0.27	ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, and 2009).

[b] ne indicates parameter was not evaluated for noted end year.

For data through 2009, station 13486 (GC100) on Greens Creek showed decreasing trends in NH_3N, but increasing trends in NO_2-N+NO_3-N and, thus, total-N (Table 10). Of note, decreasing trends had previously been indicated for PO_4-P at station 13486 (GC100), but were not apparent with the most current data set. Prior to the 2009 analysis, all end years for 13486 (GC100) had shown decreasing trends in PO_4-P, although with a decrease in the slope value, particularly in end year 2008. Station 11826 (NC060) on Neils Creek showed decreasing trends in NH_3-N, PO_4-P, and TKN for data through 2009 with similar trends also indicated for NH_3-N and PO_4-P in all previous years evaluated (Table 10).

Table 10 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.

		2009			**Slope (% change/yr)**				
TCEQ (TIAER) Station	**Parameter**	**Period Evaluated**	**Kendall Test Statistic**	**p-value**	**End Year 2009**	**End Year 2008**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
13486 (GC100)	NH_3-N	1993-2009	-0.152	0.0080	-2.9	-2.9	-7.4		-6.4
	NO_2-N+NO_3-N	1993-2009	0.169	0.0031	5.5	5.9			
	PO_4-P	1993-2009	-0.087	0.1312		-4.2	-9.2	-9.2	-12.0
	TKN	1993-2009	0.003	0.9651			-2.9		
	Total-P	1993-2009	0.015	0.7944			-4.4		-6.5
	TSS	1993-2009	0.053	0.3622					
	Total-N	1993-2009	0.186	0.0014	3.5	3.1	na[b]	na	na
11826 (NC060)	NH_3-N	1996-2009	-0.355	0.0000	-3.5	-3.7	-6.6	-5.2	-5.2
	NO_2-N+NO_3-N	1996-2009	0.003	0.9656					
	PO_4-P	1996-2009	-0.369	0.0000	-5.4	-6.8	-7.7	-8.6	-10.7
	TKN	1996-2009	-0.127	0.0244	-3.1	-4.4	-3.8		
	Total-P	1996-2009	-0.044	0.4370					-2.9
	TSS	1996-2009	-0.015	0.7956					
	Total-N	1996-2009	-0.044	0.4380			na	na	na

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, and 2009).
[b] na indicates not applicable. Analysis for TN conducted only for data through 2008.

Evaluation of Stream Water Quality Goal Attainment

To measure success in improvements in water quality, the Implementation Plan outlines comparing average annual SRP concentrations at each of the five index sites 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 sites were not specifically defined as sampling stations in the Implementation Plan, but represent general locations defined from the TMDL modeling effort. The regression equations in the Implementation 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) are used in its place. Station 18003 (BO083) is considered more representative of the index station defined in the Implementation Plan as above Meridian. Monitoring at station 18003 (BO083) will continue as part of the current CWA §319 project. Flow was not measured at either 11958 (BO085) or 18003 (BO083) on a continuous basis, so annual average flow from station 11956 (BO090) was used in the equations presented in the Implementation Plan and in the current evaluation.

The regression equations used for the most recent comparisons of PO_4-P concentrations versus annual average flow differ somewhat from those presented in the Implementation Plan and previous interim 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 Implementation Plan (TCEQ and TSSWCB, 2002). By including only samples representative of relatively equal time intervals, several samples were dropped that had been included in previous analyses. Previously all available PO_4-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 was 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 station 17226 (BO020), the most upstream mainstem site.

For 2009, all stations indicated PO_4-P concentrations below the pre-TMDL regression line, except 17226 (BO020) and 11958/18003 (BO085/BO083) (Figures 4 and 5). For station 17226 (BO020), most post-TMDL (2001-2009) concentrations of PO_4-P in comparison with flow were near or above the pre-TMDL period (1997-2000) regression line (Figure 4a). Only PO_4-P concentrations for 2001 and 2008 were below the pre-TMDL regression, while the result for 2005 was directly on the line. At 11963 (BO040), PO_4-P concentrations for 2004 and 2005 fell on or above the pre-TMDL regression line (Figure 4b), while values for 2001 through 2003 and 2006 through 2009 fell clearly below the regression line. Although not an index site, a comparison is shown for station 11961 (BO070) located near Hico, Texas for which all years but 2004 indicated PO_4-P values below the pre-TMDL regression line (Figure 4c). Of note station 11961 (BO070) was the only other station besides 11963 (BO040) to show PO_4-P concentrations in 2006 below the pre-TMDL regression.

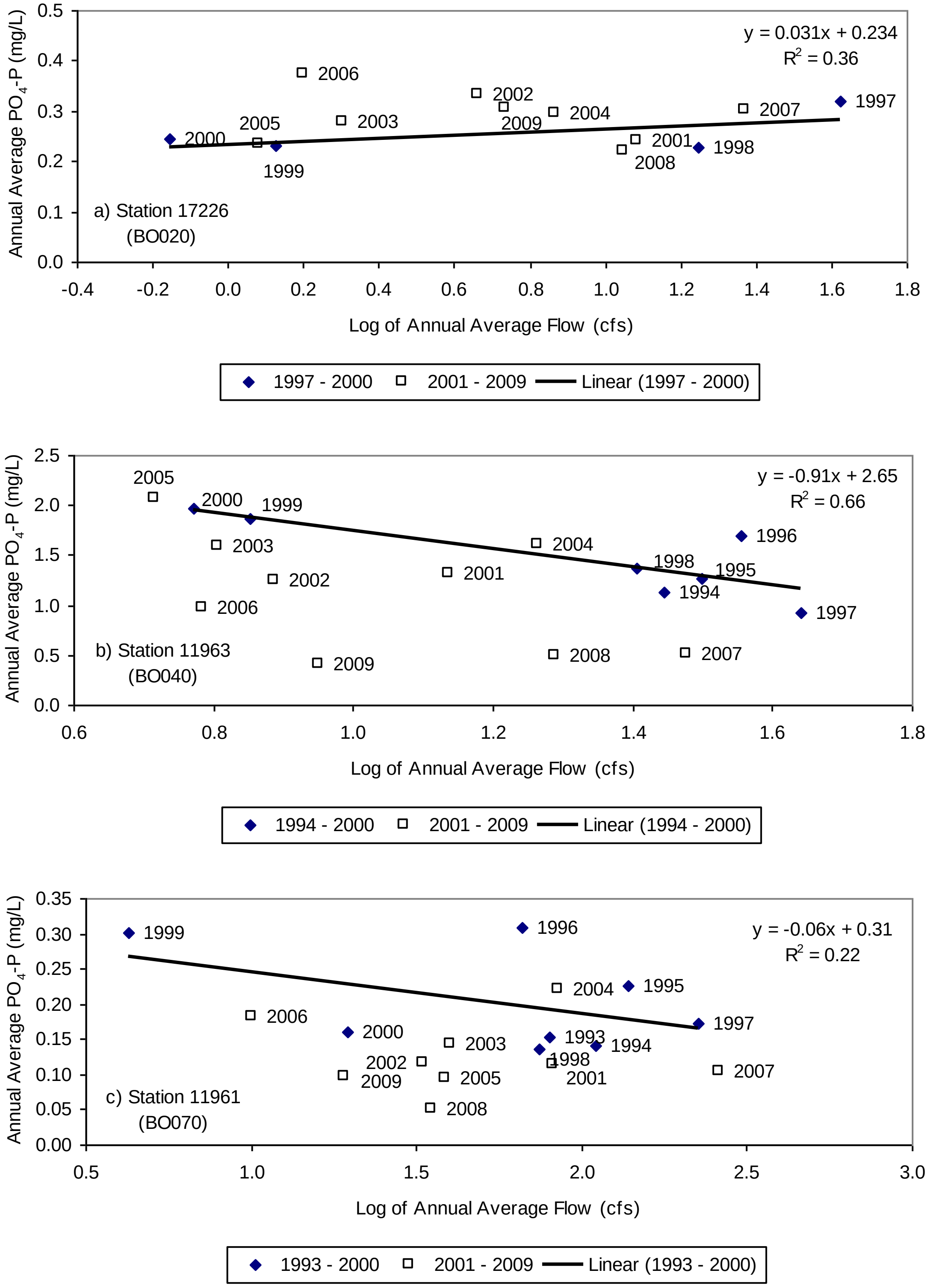

Figure 4 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for sampling a) station 17226 (BO020), b) station 11963 (BO040), and c) station 11961 (BO070). Linear regression line fits annual average values for 2000 and before.

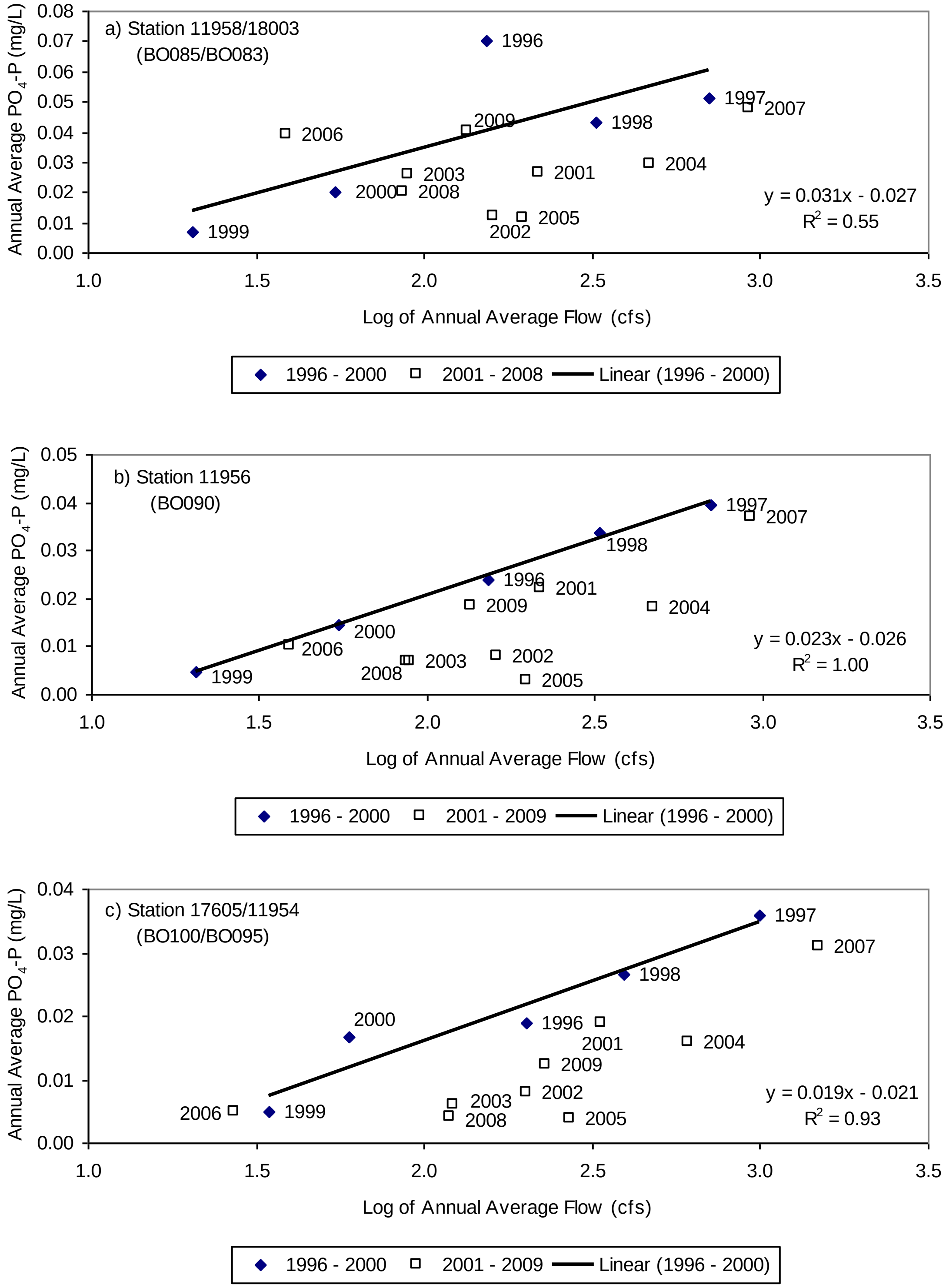

Figure 5 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for sampling a) station 11958/18003 (BO085/BO083), b) station 11956 (BO090), and c) station 17605/11954 (BO100/BO095). Linear regression line fits annual average values for 2000 and before.

At stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095), the annual average PO_4-P concentrations for 2001-2005 consistently fell below the pre-TMDL regression line (Figure 5). In 2006, the annual average PO_4-P concentration at these three stations was above or on the pre-TMDL regression line. While in 2007 and 2008, concentrations were again below the pre-TMDL regression line. For 2009, station 11958/18003 (BO085/BO083) indicated concentrations for PO_4-P above the pre-TMDL regression line.

Summary and Discussion

Trend results based on data through 2009 indicated several statistically significant, but relatively small (commonly < 5% per year) decreasing trends in nutrients at stations within the North Bosque River watershed. In contrast to the general finding of decreasing trends, increasing trends were noted in conductivity at station 17226 (BO020) and 11961 (BO070) and in CHLA, total-P and TSS at station 18003 (BO083) for grab samples and for NO_2-N+NO_3-N at station 13468 (GC100) for grab and volume-weighted data.

The increasing trend in CHLA at station 18003 (BO083) was based on data that were not flow-adjusted and that represent a relatively short time period of only seven years (2003-2009). Of note, significant decreasing trends in CHLA had been indicated at stations 11956 (BO090) and 11954 (BO095) for data through 2006, but no trends were indicated when data sets were updated for the last three years. At all three stations (18003, 11956, and 11954), there was a general increase in CHLA concentrations in 2006 through 2009 compared to sample values for 2001 through 2005.

The highest NO_2-N+NO_3-N concentrations at station 13468 (GC100) were generally associated with drier or decreased flow conditions. There were often extended periods at 13468 (GC100) during which low flow or pooled conditions occurred, which may be favoring the conversion of NH_3-N or organic-N to NO_2-N+NO_3-N at this station.

With regard to TMDLs for the North Bosque River for SRP, decreasing trends in PO_4-P were indicated along the mainstem at stations 11963 (BO040) below Stephenville, 11961 (BO070) at Hico, 11956 (BO090) near Clifton, and 11954 (BO095) near Valley Mills for routine grab and volume-weighted data. Decreasing trends in PO_4-P were also indicated for both routine grab and volume-weighted data at major tributary stations 11826 (NC060) on Neils Creek and for routine grabs at 13468 (GC100) on Green Creek. Station 11826 (NC060) is located near the confluence of Neils Creek with the North Bosque River. Neils Creek enters the North Bosque River between stations 11956 (BO090) and 11954 (BO095). Major tributary station 13486 (GC100) is located on Green Creek in the upper third of the watershed near the confluence of Green Creek with the North Bosque River. Greens Creek enters the North Bosque River about 12 river kilometers (8 river miles) above station 11961 (BO070).

Comparisons of average PO_4-P concentrations for grab samples to the log of annual average flow generally supported trend analysis findings (Figures 4 and 5). Most post-

TMDL years for stations showing significant downward trends had PO_4-P concentrations below the pre-TMDL regression relationship. Data for 2009 indicated PO_4-P concentrations below the pre-TMDL regression at four of the six mainstem stations evaluated.

These decreasing trends in PO_4-P were fairly consistent with findings in previous interim reports (McFarland and Millican, 2006; 2007; 2008; 2009). Of note, prior to the analysis of data through 2008, station 11961 (BO070) had not indicated significant decreasing trends in PO_4-P. Also prior to analysis through 2007, station 11963 (BO040) had not indicated significant decreases in PO_4-P for grab sample data. Implementation of phosphorus control at the Stephenville WWTP in late 2005 appears to be directly related to the decreasing trends in PO_4-P noted at station 11963 (BO040) and is probably influencing the decreasing trends now noted at station 11961 (BO070) further downstream (Tables 5 and 9). Box and whisker plots of monthly average concentrations by year at station 11963 (BO040) showed a notable decrease in median PO_4-P both routine grab and volume-weighted data sets for 2006 through 2009 (Figures 6 and 7).

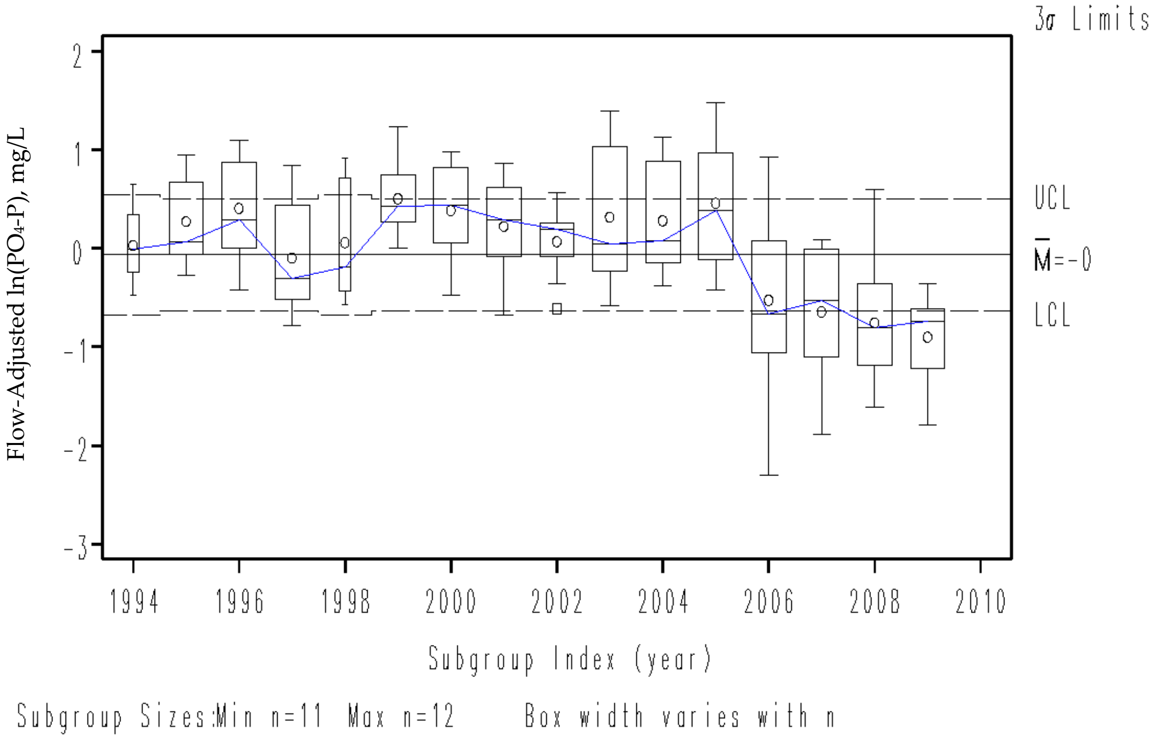

Figure 6 Annual box and whisker plots of monthly routine PO_4-P grab data for station 11963 (BO040). Data natural log transformed and flow-adjusted.

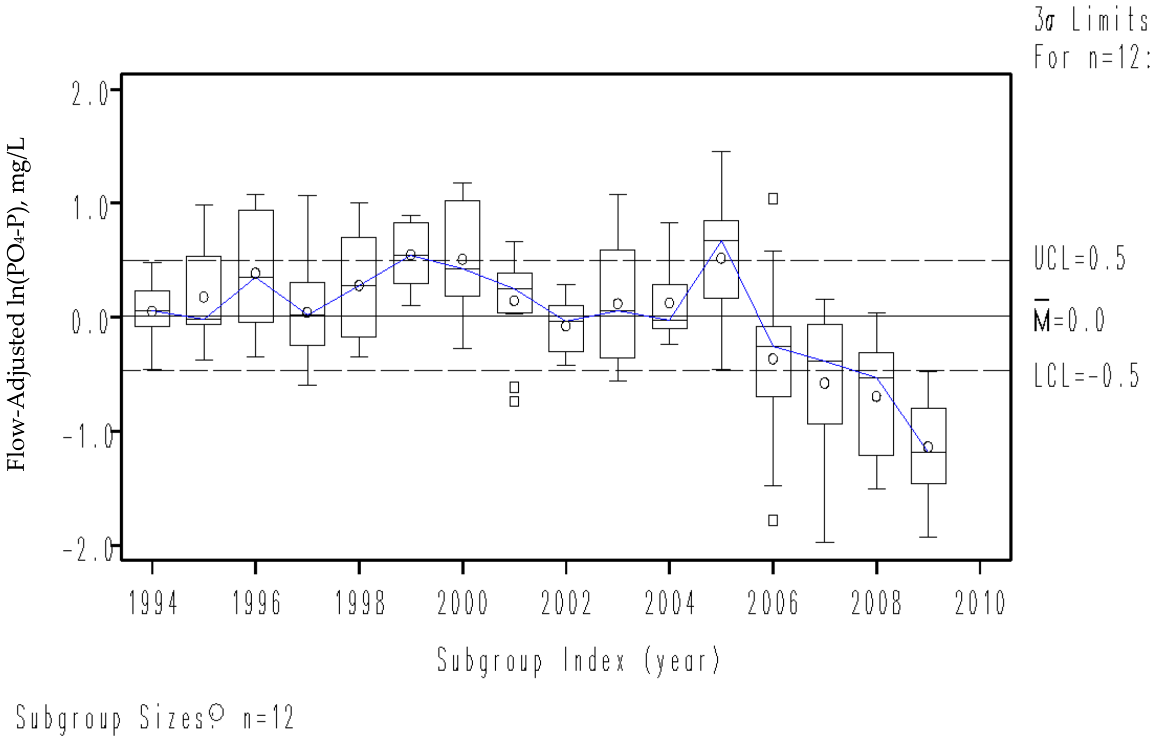

Figure 7 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11963 (BO040). Data natural-log transformed and flow-adjusted.

This decrease in PO_4-P at station 11963 (BO040) indicates a step trend with a known change in PO_4-P loading occurring at a set point in time. A step decrease in PO_4-P concentrations also appeared to occur at more downstream stations (11956 [BO090] and 11954 [BO095]), but the timing of the initial decrease occurred in 1999 (Figures 8 and 9), prior to implementation of phosphorus control practices at either the Stephenville or Clifton WWTPs. Of note, station 11954 (BO095) near Valley Mills is located below the discharge for the Clifton WWTP and showed lower PO_4-P concentrations between 2006 and 2008 than station 11956 (BO090), which is located above the Clifton WWTP discharge. The more recent decreases in PO_4-P at station 11954 (BO095) are likely related to implementation of phosphorus control practices at the Clifton WWTP.

A somewhat similar pattern in decreasing PO_4-P concentrations was found at station 11826 (NC060) on Neils Creek (Figure 10), which flows into the North Bosque River between 11956 (BO090) and11954 (BO095). There are indications that changes in the handling of poultry litter from operations found in the lower part of the watershed may have influenced these decreases in PO_4-P and other nutrient constituents. As of 2006, 12 poultry facilities were known to be operating in the lower portion of the North Bosque River watershed, 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_4-P concentrations at stations in the lower portion of the watershed appears to correspond in part with this change in handling of poultry litter.

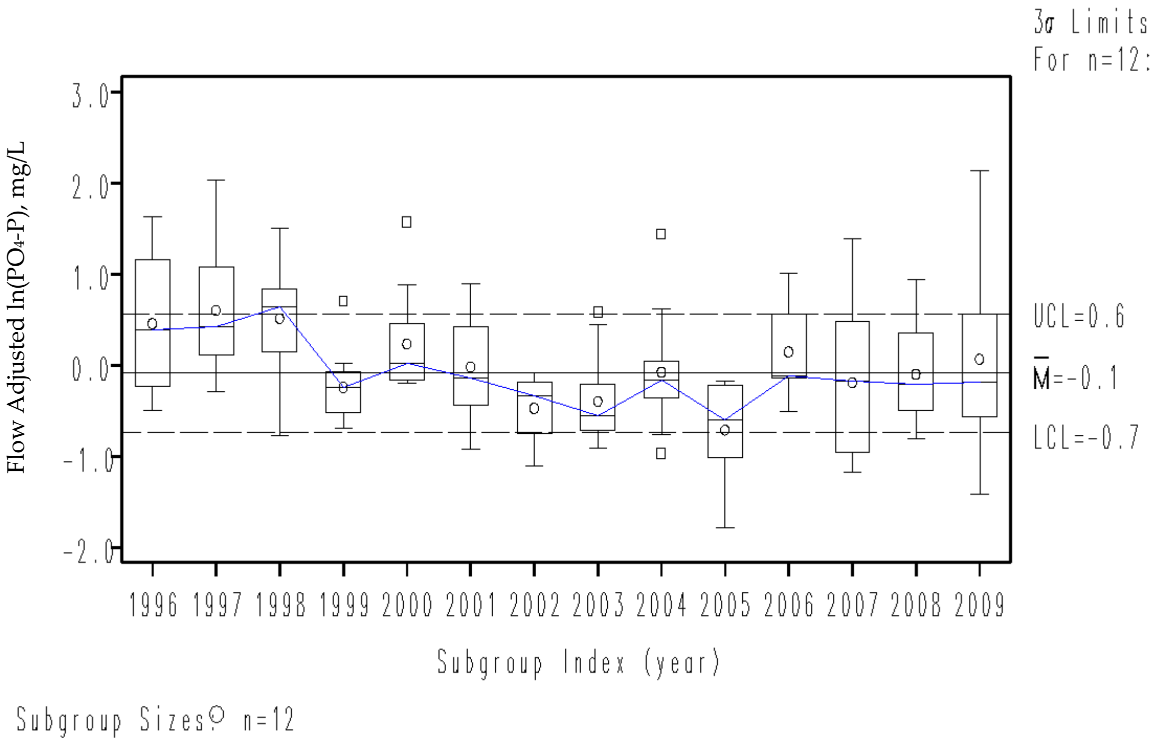

Figure 8 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11956 (BO090). Data natural-log transformed and flow-adjusted.

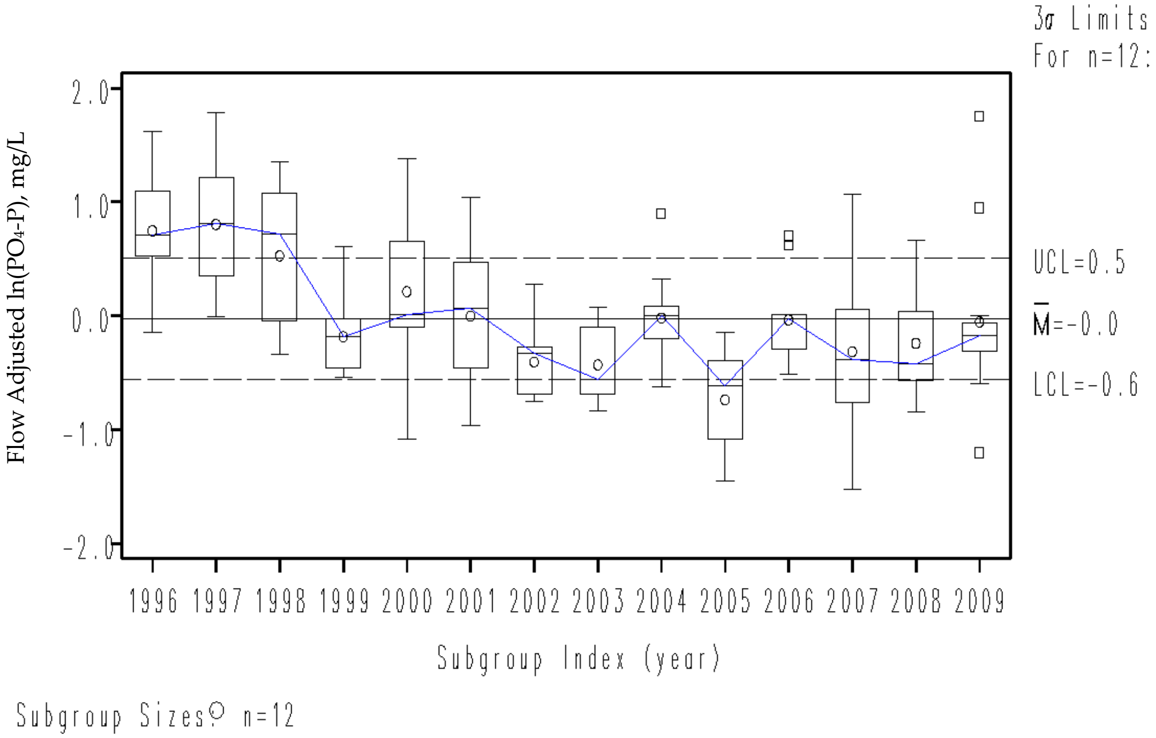

Figure 9 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11954 (BO095). Data natural-log transformed and flow-adjusted.

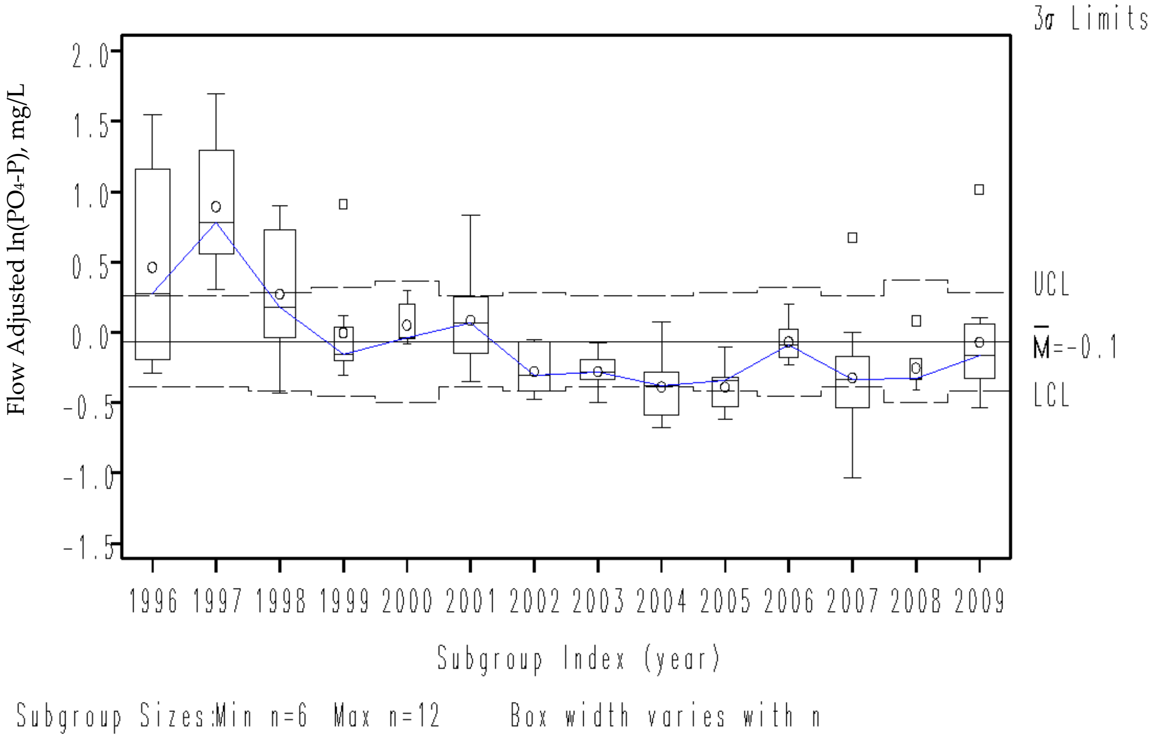

Figure 10 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11826 (NC060). Data natural-log transformed and flow-adjusted.

Step decreases in concentrations relate back to changes in slope (% change/year) based on end year for trend analysis noted in Tables 5-10. For several constituents, the negative slope as a percent change per year became less negative with each additional year of analysis. This decrease in percent change per year in some cases indicates a leveling off of concentrations after an initial or step decrease as shown in Figures 8-10. In other cases, the decrease in percent change per year is associated with concentrations that have decreased over time but in more recent years have increased (e.g., Figure 11). When the percent change per year between end years increases over time or stays relatively constant, this indicate that further decreases in the parameter are occurring over time (e.g., Figure 12). These patterns in concentration between years as well as the impact of end year (and begin year) are important considerations in interpreting trends.

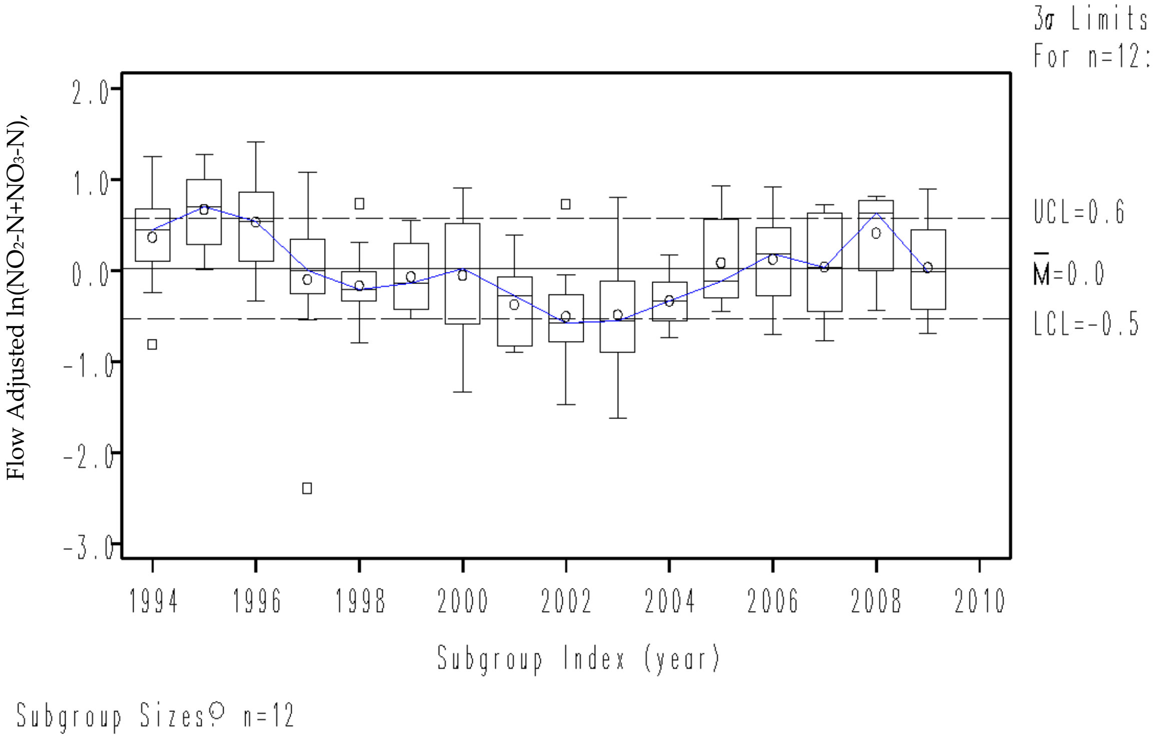

Figure 11 Annual box and whisker plots of monthly volume-weighted NO_2-N+NO_3-N data for station 11963 (BO040). Data natural-log transformed and flow-adjusted.

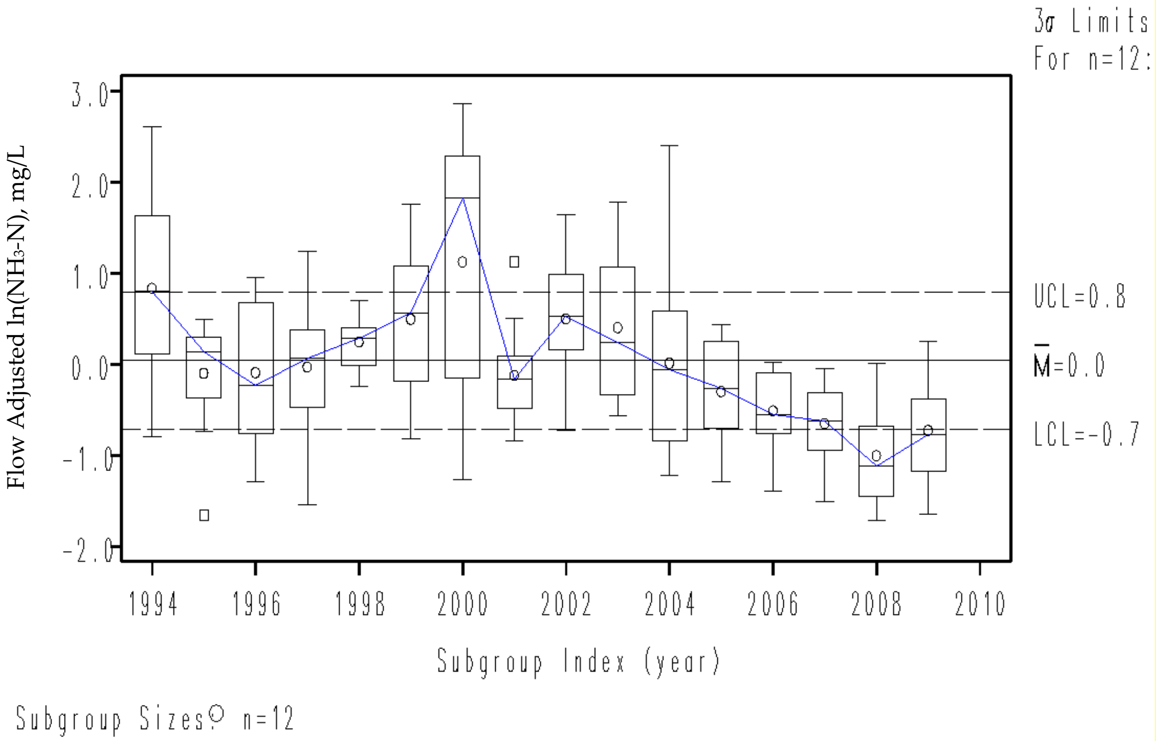

Figure 12 Annual box and whisker plots of monthly volume-weighted NH_3-N data for station 11963 (BO040). Data natural-log transformed and flow-adjusted.

Besides end year of trend analysis, long-term weather patterns can also impact trends. Long-term weather patterns, particularly with regard to precipitation, have been quite variable over the analysis period for the watershed as indicated by annual precipitation values for Stephenville and Valley Mills (Figure 13). Based on precipitation data at Stephenville, most years prior to 1999 had precipitation levels near or above the 30-year average, while all but three years between 1999 and 2009 were below the 30-year average. Of note, the time history for precipitation data at Valley Mills was not long enough to establish a 30-year average. Annual precipitation at Valley Mills followed the same general pattern between years as at Stephenville, but annual precipitation was generally greater at Valley Mills than Stephenville and indicated a larger number of years with above average precipitation using the Stephenville long-term average as a benchmark.

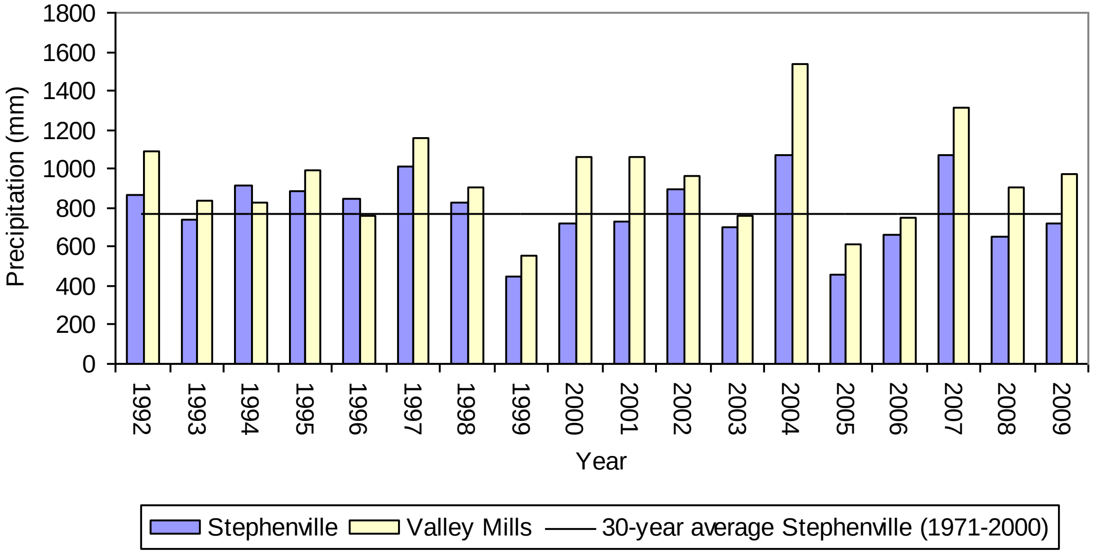

Figure 13 Temporal variability in annual precipitation at Stephenville and Valley Mills, Texas. Data source: National Weather Service (NWS) with missing values estimated from nearby rain gages maintained by TIAER or NWS.

Of note 2005 and 2006 were below average years for precipitation, and although slightly higher precipitation levels were indicated in 2006 than 2005 (Figure 13), annual runoff was generally less in 2006 than 2005 throughout the watershed (Figure 14). It is also interesting to note that in 2004 very similar or greater amounts of total precipitation occurred in comparison to 2007 (Figure 13), but that annual runoff was much higher in 2007 than in 2004 (Figure 14). In 2007, over 55 percent of the annual precipitation fell in March, May, and June, while in 2004, rainfall was not as high in any one month as in 2007 and more spread out with the greatest rainfall occurring in April, June, and November. More concentrated periods of rainfall, thus, resulted in more runoff in 2007 than in 2004.

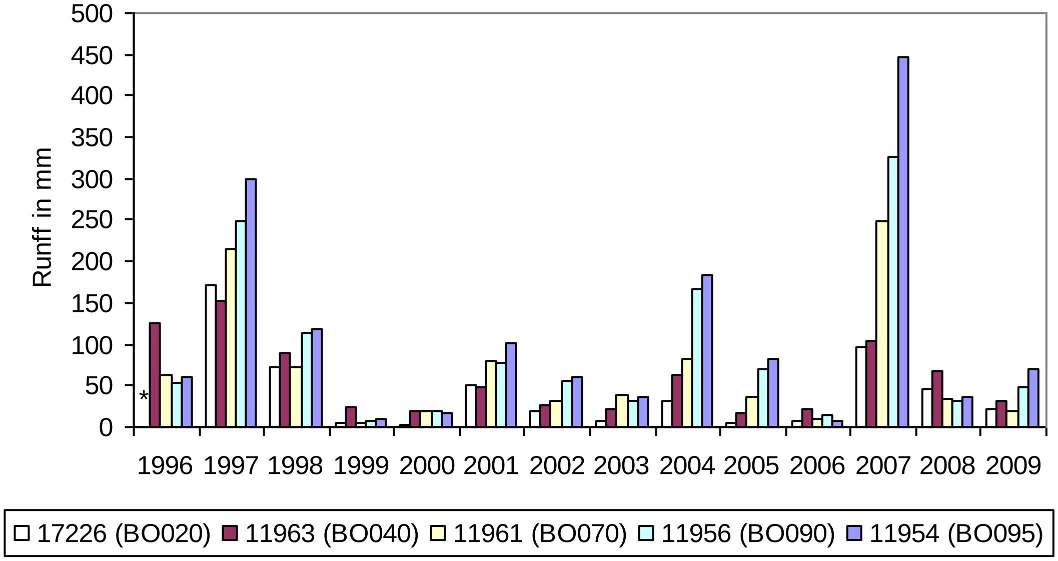

Figure 14 Annual runoff in millimeters for gauged stations along the North Bosque River. Asterisk indicates no data for 17226 (BO020) in 1996. Stations are listed in order of most upstream to most downstream.

These patterns of wet and dry conditions differ within as well as between years and influence the runoff patterns that drive nonpoint source pollution and, thus, the success of many land management practices. For example, although 2007 was a very wet year, almost all runoff events occurred in the first half of the year with the second half being quite dry. More rainfall and runoff was noted in the southern part of the watershed for 2004 indicating a spatial as well as temporal variability in hydrologic conditions (Figures 13 and 14).

While decreasing trends in nutrients and particularly PO_4-P are being observed within the North Bosque River watershed, it is still unclear whether long-term weather patterns or changes in land management are the primary driving factors causing these trends with regard to nonpoint source contributions. In support of changing land management practices, decreases in nitrogen and phosphorus concentrations were observed at several stations. These decreases in nutrients are likely related to decreases in the use of fertilizer (both commercial and manure). The manure haul-off program has led to less land application of manure (TCEQ, 2009). In addition, a decreasing trend in nitrogen and phosphorus fertilizer sales between 1990 and 2007 for Erath County indicates that farmers are not applying as much commercial fertilizer (AAPFCO, 2009).

With regard to point sources, the most apparent impact on stream PO_4-P concentrations occurred at 11963 (BO040) in association with phosphorus control practices implemented at the Stephenville WWTP in late 2005. While not as readily apparent, phosphorus control practices at the Clifton WWTP implemented in early 2005 are an influence on decreasing PO_4-P concentrations observed at 11954 (BO095).

References

AAPFCO, Association of American Plant Food Control Officials. 2009. National fertilizer database for 1985-2007. AAPFCO, Regulatory Services Building, University of Kentucky, Lexington, Kentucky.

Adams, T., and A. McFarland. 2002. Semiannual water quality report for the Bosque River watershed and Lake Waco (Monitoring Period: January 1, 1997 - December 31, 2001).Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0216.

APHA, American Public Health Association, American Water Works Association, and Water Environment Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.

Bekele, A. and A. McFarland. 2004. Regression based flow adjustment procedures for trend analysis of water quality data. Transactions of the American Society of Agricultural Engineers 47(4):1093-1104.

Bland, J.M., and D.G. Altman. 1986. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet i:307-310.

BRA, Brazos River Authority. 1995. Quality assurance project plan for the Bosque River watershed pilot project. Brazos River Authority, Waco, Texas.

Buchanan, T.J., and W.P. Somers. 1969. Chapter A8: Discharge measurements at gaging stations. In Techniques of Water-Resources Investigations, Reports Book 3. United States Geological Survey, Arlington, Virginia.

Cleveland, W. S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of American Statistical Association. 74:829--836.

Gilbert, R.O., 1987. Statistical methods for environmental pollution monitoring. Van Nostrand. Reinhold, New York.

Gilliom, R.J. and D.R. Helsel. 1986. Estimation of distributional parameters for censored trace level water quality data. 1. Estimation techniques. Water Resources Research 22:135-126.

Helsel, D.R. and R.M. Hirsch, 1992. Statistical methods in water resources. Elsevier Science B.V., Amsterdam, The Netherlands.

Hirsch, R.M. and J.R, Slack, 1984. A nonparametric trend test for seasonal data with serial dependence. Water Resources Research 20: 727-732.

Langland, M. J., R. E. Edwards, and L. C. Darell. 1998. Status yields and trends of nutrients and sediment and methods of analysis for the nontidal data collection programs, Chesapeake Bay Basin, 1985-96. U.S. Department of the Interior, U.S. Geological Survey. Open-File Report 98-17.

McFarland, A. and H. Jones. 2006. Chapter 2: Geographic information system layers and associated metadata. In: Sampling history report – Final project report for monitoring to support North Bosque River model refinement. Report to TMDL Team, Texas Commission on Environmental Quality prepared by the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0613.

McFarland, A. and J. Millican. 2009. Interim annual assessment of water quality trends for the North Bosque River through 2008. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0902.

McFarland, A. and J. Millican. 2008. Interim annual assessment of water quality trends for the North Bosque River through 2007. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0803.

McFarland, A. and J. Millican. 2007. Interim annual assessment of water quality trends for the North Bosque River through 2006. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0703.

McFarland, A. and J. Millican. 2006. Interim annual assessment of water quality trends for the North Bosque River through 2005. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0612.

Newell, A. D., D. J. Blick, R. C. Hjort. 1993. Testing for trends when there are changes in methods. Water, Air, and Soil Pollution 67:457-468.

Narasimhan, B., X. Zhang, and R. Srinivasan. 2005. Land use/land cover classification of Bosque River watershed using LANDSAT-7 enhanced thematic mapper (ETM+) imagery. Final Report submitted to TIAER by the Spatial Science Laboratory, Texas Agricultural Experiment Station, College Station.

NRC, National Research Council. 2001. Nutrient requirements of dairy cattle, 7th revised edition. National Academy Press, Washington, D.C.

Reckhow, K. H., K. Kepford, and W. W. Hicks. 1993. Methods for the analysis of lake water quality trends. United States Environmental Protection Agency, Office of water, Washington, D.C., EPA 841-R-93-003.

SAS Institute. 1999. The SAS system for windows. Version 8. SAS Inst., Cary, NC.

Stein, S.K. 1977. Calculus and analytic geometry. 2nd ed. McGraw-Hill Book Company, New York, N.Y.

Sansinena, M., L.D. Bunting, S.R. Stokes, and E.R. Jordan. 1999. A survey of trends and rationales for P recommendations among Mid-South nutritionists. p. 51–54. In Proc. Mid-South Ruminant Nutr. Conf., Dallas, TX. Also available online at www.txanc.org/proceedings/1999/surveyoftrends.pdf (verified 30 April 2008).

TCEQ, Texas Commission on Environmental Quality. 2009. Water quality in the North and Upper North Bosque Rivers February 2009: Status report of activities to address elevated nutrient concentrations. TCEQ, Austin, Texas (March 3, 2009). [Online] http://www.tceq.state.tx.us/assets/public/implementation/water/tmdl/06bosque/bosquereport_feb2009.pdf (verified 11 May 2010).

TCEQ, Texas Commission on Environmental Quality. 2008. Surface water quality monitoring procedures, Volume 1. TCEQ, Monitoring Operations Division, Austin, Texas (RG-415).

TCEQ, Texas Commission on Environmental Quality. 2003. Surface water quality monitoring procedures, Volume 1. TCEQ, Monitoring Operations Division, Austin, Texas (RG-415).

TCEQ, Texas Commission on Environmental Quality, and TSSWCB, Texas State Soil and Water Conservation Board. 2002. An implementation plan for soluble reactive phosphorus in the North Bosque River watershed for segments 1226 and 1255. TCEQ Strategic Assessment Division and Texas State Soil and Water Conservation Board TMDL Team Leaders, Austin, Texas (approved by TCEQ December 13, 2002).

Texas State Data Center. 2010. 2008 Total population estimates for Texas places, Estimates of the total populations of counties and places in Texas for July 1, 2008 and January 1, 2009. Office of the State Demographer, Institute for Demographic and Socioeconomic Research, The University of Texas at San Antonio, San Antonio, Texas. [Online] http://txsdc.utsa.edu/tpepp/2008_txpopest_place.php (verified 11 May 2010).

TIAER, Texas Institute for Applied Environmental Research. 2010. North Bosque River watershed water quality assessment Clean Water Act Section 319(h) quality assurance project plan, rev. 4. TIAER, Tarleton State University, Stephenville, Texas.

TIAER, Texas Institute for Applied Environmental Research. 2005. United States Department of Agriculture Bosque River initiative quality assurance project plan, rev. 5. TIAER, Tarleton State University, Stephenville, Texas.

TIAER, Texas Institute for Applied Environmental Research. 1993. Quality assurance project plan for the National Pilot Project. TIAER, Tarleton State University, Stephenville, Texas.

TNRCC, Texas Natural Resource Conservation Commission. 2001. Two total maximum daily loads for phosphorus in the North Bosque River for Segments 1226 and 1255.

Strategic Assessment Division, TMDL Team, TNRCC, Austin, Texas (adopted February 2001; approved by EPA December 2001).

Tukey, J. W., 1977. Exploratory data analysis. Addison-Wesley Publishing.

USDA-AMS, United States Department of Agriculture Agricultural Marketing Service. 2010. The market administrator's report: Southwest marketing area; Vol. XXXVI, No. 4 (April 2010).

USEPA, United States Environmental Protection Agency. 2010. Enforcement & compliance history online (ECHO). Compliance and Enforcement Division, USEPA [Online] http://www.epa.gov/echo/compliance_report_water.html (data downloaded 07 April 2010).

USEPA, United States Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory, Office of Research and Development, USEPA, Cincinnati, Ohio. EPA-600/4-79-020, Revised March 1983.

Ward, R.C., J.C. Loftis, H.P. DeLong, and H.F. Bell. 1988. Groundwater quality: A data analysis protocol. Journal of the Water Pollution Control Federation 60:1938-1945.

Appendix A
Comparison of Fecal Coliform with *Escherichia coli* Results

To evaluate the relationship between fecal coliform (FC) and *E. coli* results, 1075 paired samples analyzed by TIAER's laboratory between November 2000 and March 2004 were first evaluated using a paired t-test of the difference and graphical techniques to assess agreement between the two methods as outlined by Bland and Altman (1986). The paired t-test of the difference between bacteria methods indicated highly significant differences at an alpha of 0.01, which are graphically shown in Figure A1. The mean difference of $\log_e$ transformed data was 0.306 with a standard deviation of 0.55. The lack of agreement between these two methods of bacteria analysis indicates that *E. coli* values should not be used to replace FC values without some type of data adjustment.

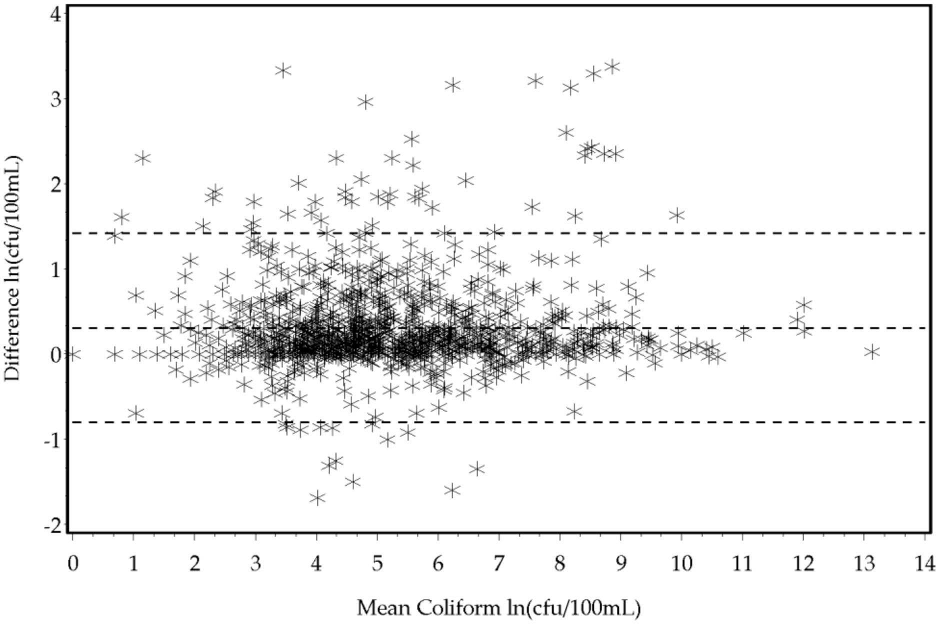

Figure A-1 Difference between fecal coliform to *E. coli* concentrations plotted against the mean of paired results. The dashed line in the middle represents the mean difference with the dashed lines on either side indicating the mean plus and minus two standard deviations.

Regression analysis was then used to determine a relationship between FC and *E. coli* that could be used to adjust historical FC concentrations to represent *E. coli* concentrations for trend analysis. The bacteria data were transformed using a natural log ($\log_e$) transformation prior to regression analysis to aid in normalizing the residuals from the regression. Of note, even with data transformed, the residuals still did not meet the assumption of normality when analyzed using the Shapiro-Wilk statistic. It was assumed that the regression relationship developed 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 data analysis.

The linear regression relationship developed was as follows and is graphically shown in Figure A2:

$$\ln(E.\ coli) = 0.946*\ln(\mathrm{FC}) - 0.029 \quad R^2 = 0.93$$

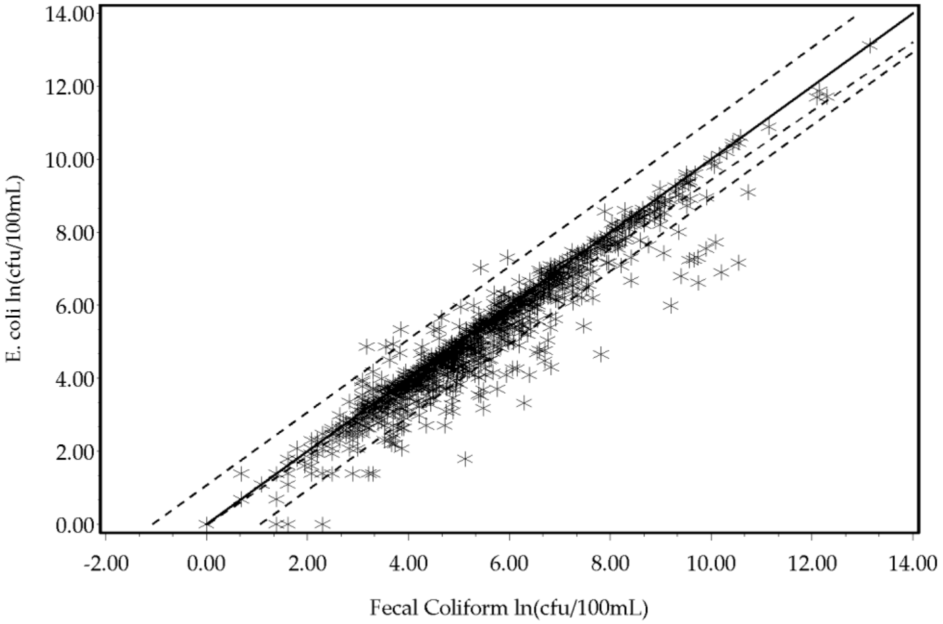

Figure A-2 Linear relationship of fecal coliform to *E. coli*. The solid line indicates the one-to-one relationship, while the dashed line in the middle represents the linear regression relationship with dashed lines on either side indicating the 95 percent upper and lower confidence intervals.

Because the bacteria data analyzed by TIAER's laboratory represented a wide range of sampling stations and watersheds, a check was done to make sure the regression relationship developed was applicable to conditions in the North Bosque River. The regression analysis was reevaluated using just paired data from the nine stream stations being used for trend analysis (Figure A3). This included only 239 paired observations and produced the following regression relationship:

$$\ln(E.\ coli) = 0.982*\ln(\mathrm{FC}) - 0.201 \quad R^2 = 0.93$$

The regression relationship developed for this reduced data set was not statistically different from the full data set of all 1075 paired observations, so the regression relationship based on the full data set was used to adjust FC concentrations to represent *E. coli* concentrations for bacteria data in the trend analyses presented in the body of this report.

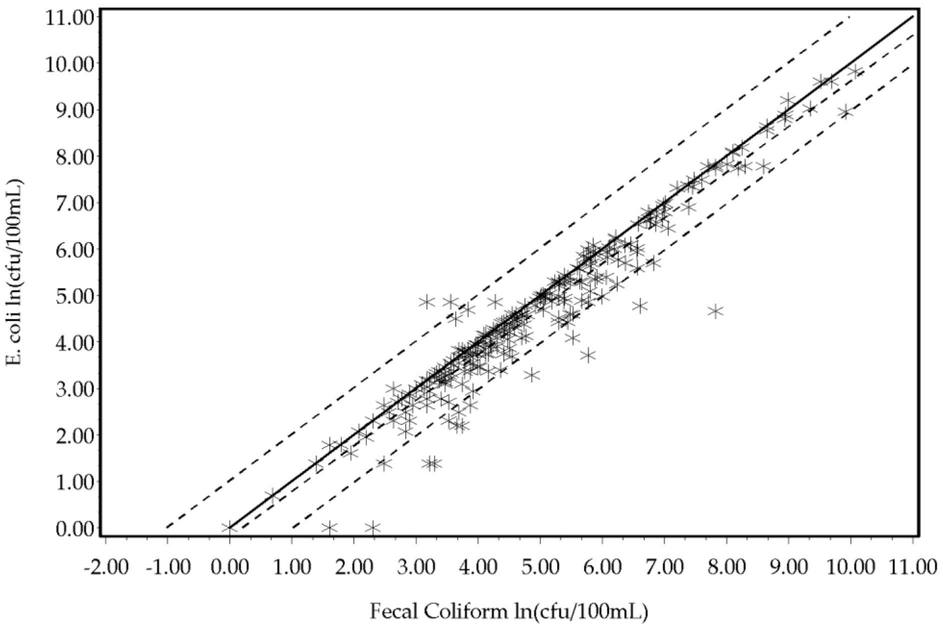

Figure A-3 Linear relationship of fecal coliform to *E. coli* for the reduced data set of nine North Bosque River stations. The solid line indicates the one-to-one relationship, while the dashed line in the middle represents the linear regression relationship with dashed lines on either side indicating the 95 percent upper and lower confidence intervals.

Reference:

Bland, J.M., and D.G. Altman. 1986. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet i:307-310.