Assessment of Water Quality Trends for the North Bosque River through 2019

Jimmy Millican and Todd Adams

Green Creek Station 13486 (BO083) near Clairette, TX (April 8, 2019)

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

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

This report presents an update of water quality trends in the North Bosque River watershed, assessing effectiveness of nonpoint source (NPS) and point source control measures associated with the North Bosque River Total Maximum Daily Loads (TMDLs) Implementation Plan (I-Plan). This report largely follows the format of previous trend reports for the North Bosque River (e.g., McFarland and Millican, 2011 and 2012; McFarland and Adams, 2013; 2014a; 2015; 2016; 2017; 2018; and Millican, Adams, and McFarland 2019). Trend analyses focus on seven monitoring stations, five of which are index stations (17226 [BO020], 11963 [BO040], 18003 [BO083], 11956 [BO090], and 11954 [BO095])¹ for the phosphorus TMDLs along the North Bosque River (Figure 1). Other stations include station 11961 (BO070), a long-term monitoring station located along the North Bosque River between index stations 11963 (BO040) and 18003 (BO083), and station 13486 (GC100), located on a major tributary to the North Bosque River. Spatial information on regulated concentrated animal feeding operations (CAFOs), unregulated animal feeding operations (AFOs), and the land area associated with waste application fields (WAFs) is also updated within this report to aid in evaluating implementation practices within the watershed.

The TCEQ adopted two TMDLs for soluble reactive phosphorus² (SRP) for North Bosque River Segments 1226 and 1255 in February 2001, which USEPA approved in December 2001 (TNRCC, 2001). Jointly, these two segments represent the full length of the North Bosque River from its headwaters just north of Stephenville, where the North Fork and South Fork of the Upper North Bosque River merge, to its confluence with Lake Waco in McLennan County. The goal of these TMDLs is an overall reduction of about 50 percent in SRP loadings and concentrations within the North Bosque River, with specific reduction goals varying by the river reach. The I-Plan for these TMDLs was approved by TCEQ in late 2002 and by the Texas State Soil and Water Conservation Board (TSSWCB) in early 2003 (TCEQ and TSSWCB, 2002).

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

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

¹ Throughout this report, stations are identified with both the TCEQ station identification number and the TIAER identification to allow easy referencing to earlier reports where only one or the other may have been used to identify stream sampling locations.
² Soluble reactive phosphorus is commonly referred to as orthophosphate phosphorus (PO₄-P).
Figure 1  North Bosque River watershed trend analysis monitoring stations and USGS gauge locations. Sample station identifier – TCEQ (TIAER).
To address phosphorus application rates on dairy WAFs, the TSSWCB initiated the Comprehensive Nutrient Management Plan (CNMP) Program. The TSSWCB supports the voluntary implementation of CNMPs by dairy producers as part of their water quality management plans (WQMPs) for AFOs. In addition to voluntary compliance, the TCEQ amended rules for CAFOs in 2004 to require regulated dairies in the North Bosque to implement Nutrient Management Plans (NMPs). On July 2, 2014, the TCEQ adopted a revised CAFO rule to incorporate changes to federal regulations. These rule changes imposed additional requirements regarding NMPs for CAFOs in the watershed.

An NMP addresses nutrient management guidance for cropping systems as part of a conservation plan for producers and landowners. A CNMP encompasses most aspects of an NMP, but additionally may include specifications for feed management, manure and wastewater handling and storage, nutrient management, land treatment practices, and other manure and wastewater utilization options addressing the overall agronomic and environmental aspects of an animal feeding operation (TCEQ and TSSWCB, 2002). The development and adoption of CNMPs and NMPs has occurred over several years. In FY2006, 8 CNMPs were certified, 34 were certified in FY2007, and another 7 certified in FY2008 (TCEQ, 2009). In FY2009, TSSWCB indicated that two more CNMPs were certified. By the end of 2010, all 55 dairy CAFOs that were operating in the watershed in 2004 had certified CNMPs, adding substantive nutrient management practices to their operations (TCEQ, 2012a). The TSSWCB continues to review and certify, as appropriate, new or amended plans.

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 1990s, a survey of dairy diet formulations including dairies in the North Bosque River watershed indicated that cow diets averaged 0.52 percent phosphorus (Sansinena et al., 1999). Revised recommendations by the National Research Council (NRC) indicate optimal levels of about 0.38 percent phosphorus for high producing dairy cattle (NRC, 2001), which has been supported in studies focused on reducing excess phosphorus in manure (e.g., Powell and Satter, 2005; Miller et al., 2010; Kebreab, et al., 2013).

In dealing with the export of manure from the watershed, the two most visible projects associated with the I-Plan were the Dairy Manure Export Support (DMES) project and the Composted Manure Incentive Project (CMIP). The TSSWCB sponsored the DMES project to provide incentives to haulers to transport manure from dairies to composting facilities. Through the CMIP, TCEQ provided oversight of composting facilities and rebates to Texas state agencies that used manure compost associated with the DMES project. The TCEQ and TSSWCB initiated these manure composting projects in September 2000 as a way to export dairy manure from the North Bosque River watershed, while providing a beneficial soil amendment. The Texas Department of Transportation (TxDOT) was the major user of dairy manure compost for roadside revegetation. Through August 2006, over 650,000 tons of dairy manure were hauled to

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3 Subchapter B Concentrated Animal Feeding Operations, Chapter 321, Texas Administrative Code Title 30, §321.31 – §321.27.
composting facilities and about 329,000 cubic yards of compost were exported from the watershed (TCEQ, 2009).

Funding for the 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 these two incentive programs ended. Seven composting facilities were active during these projects, and as of March 2008, six were still active and receiving manure from dairy operations within the watershed. A follow up review in May and June 2009 indicated that five of these six composting facilities were still active, but as of early 2012, TCEQ reported that only two composting facilities were still operational, and one other only sporadically received manure (TCEQ, 2012a). As of 2019, there are still two active commercial composting facilities, Erath Earth and Green Cow Compost, both located in Dublin, Texas, just on the western edge of the watershed. There are also dairy operations within the watershed that compost their own manure, but the number is not readily available. CAFOs in the North Bosque watershed are currently required under their permits to either export manure outside the watershed, send it to an approved composting facility, or apply it to either their own or third-party WAFs within the watershed at specific rates. Soil must be tested for phosphorus levels at a WAF annually and before the first time waste is applied; waste cannot be applied if phosphorus levels in soil exceed certain criteria.

Another measure that has had a notable impact on water quality, particularly under low flow conditions, is the implementation of phosphorus-removal treatments by municipal WWTFs. There are seven municipal WWTFs that discharge within the North Bosque River watershed (Stephenville, Hico, Meridian, Iredell, Cranfills Gap, Clifton, and Valley Mills). An initial waste load allocation (WLA) was set for all seven municipal WWTFs and phosphorus reporting implemented in as part of Phase I in the I-Plan. The two largest facilities, in Clifton and Stephenville, had their permits amended in 2003 to require phosphorus limits that necessitate advanced treatment processes. In the fall of 2005, Stephenville began using biological treatment in conjunction with alum and polymers for phosphorus removal, with the goal of meeting a daily average discharge limit of 1 mg/L. The Clifton WWTF started using alum as a chemical treatment to remove phosphorus in the spring of 2005.

As Phase II of the wastewater treatment facilities measures, existing municipal permittees and other wastewater dischargers have had their permits amended to require phosphorus load limits in pounds per day and/or a 1 mg/L total-P effluent concentration limit. As of August 31, 2010, TCEQ reported that all seven municipal WWTFs within the North Bosque River watershed have compliance schedules consistent with the WLAs in the TMDL and I-Plan (TCEQ, 2011). Besides the seven municipal WWTFs, there are three other dischargers within the watershed that also have phosphorus limits (Table 1 and Figure 1).

With implementation of all these activities, it is important to monitor and statistically evaluate improvements in water quality. Changes in water quality may be gradual and lag actual implementation on the land, particularly with regard to reducing nonpoint
source pollutants (e.g., Meals, et al., 2010). There has also been temporal and spatial variability in the implementation of I-Plan activities, so it may take several years after implementation occurs before instream improvements become apparent throughout the watershed.
## Table 1
Phosphorus WLA for wastewater discharges within the North Bosque River watershed.

<table>
<thead>
<tr>
<th>Permitted Discharge</th>
<th>Permit ID TCEQ (EPA)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Total Phosphorus Daily Avg. (mg/L)</th>
<th>Total Phosphorus Daily Avg. (lbs/day)</th>
<th>Permitted Monthly Discharge (MGD)(^a)</th>
<th>Discharge Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Stephenville</td>
<td>WQ0010290001 (TX0024228)</td>
<td>32.197850</td>
<td>-98.18762</td>
<td>1</td>
<td>29.2(^b)</td>
<td>3.5(^b)</td>
<td>North Bosque River</td>
</tr>
<tr>
<td>City of Clifton</td>
<td>WQ0010043001 (TX0033936)</td>
<td>31.785277</td>
<td>-97.568333</td>
<td>Report</td>
<td>7.0</td>
<td>0.65</td>
<td>North Bosque River</td>
</tr>
<tr>
<td>City of Meridian</td>
<td>WQ0010113002 (TX0053678)</td>
<td>31.920139</td>
<td>-97.65444</td>
<td>Report</td>
<td>5.9</td>
<td>0.45</td>
<td>North Bosque River</td>
</tr>
<tr>
<td>City of Valley Mills</td>
<td>WQ0010307001 (TX0075647)</td>
<td>31.663333</td>
<td>-97.463611</td>
<td>Report</td>
<td>3.0(^c)</td>
<td>0.36</td>
<td>North Bosque River</td>
</tr>
<tr>
<td>City of Hico</td>
<td>WQ0010188001 (TX0026590)</td>
<td>31.978333</td>
<td>-98.026944</td>
<td>1</td>
<td>2.1</td>
<td>0.25</td>
<td>Jacks Hollow Branch of the North Bosque River</td>
</tr>
<tr>
<td>City of Iredell (Town Plant WWTF)</td>
<td>WQ0011565001 (TX0024848)</td>
<td>31.987103</td>
<td>-97.86455</td>
<td>Report</td>
<td>1.7</td>
<td>0.049</td>
<td>North Bosque River</td>
</tr>
<tr>
<td>City of Cranfills Gap</td>
<td>WQ0014169001 (TX0122360)</td>
<td>31.773655</td>
<td>-97.823223</td>
<td>Report</td>
<td>0.4</td>
<td>0.04</td>
<td>Austin Branch of Meridian Creek, which flows into the North Bosque River</td>
</tr>
<tr>
<td>Northside Subdivision Water Corporation</td>
<td>WQ0014735001 (TX0128996)</td>
<td>32.254444</td>
<td>-98.221944</td>
<td>Report</td>
<td>0.28</td>
<td>0.033</td>
<td>Unnamed tributary of the North Fork of the North Bosque River</td>
</tr>
<tr>
<td>Stephenville Mobile Home Park (Shady Oaks WWTF)</td>
<td>WQ0013966001 (TX0132039)</td>
<td>32.238353</td>
<td>-98.164966</td>
<td>Report</td>
<td>0.20</td>
<td>0.024</td>
<td>Unnamed tributary of Pole Hollow Branch</td>
</tr>
<tr>
<td>Western Dairies Transport</td>
<td>WQ0004314000 (Not Applicable)</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>No discharge</td>
</tr>
</tbody>
</table>

\(^a\) Source: Permit files obtained online through TCEQ Central Registry Query ([https://www15.tceq.texas.gov/crpub/](https://www15.tceq.texas.gov/crpub/)).

\(^b\) Total phosphorus and permitted discharge include both outfalls for Stephenville. Outfall 001 discharges below Stephenville, while outfall 002 discharges within the Stephenville City Park.

\(^c\) Source: North Bosque River I-Plan (TCEQ and TSSWCB, 2002). Also, noted in permit for the City of Valley Mills under Other Requirements.
Direct point source discharges occur to the North Bosque River from each community’s WWTF, with the exception of Cranfills Gap and Hico (Table 1). The Cranfills Gap WWTF discharges into the Austin Branch of Meridian Creek, a major tributary to the North Bosque River, and the Hico WWTF discharges into Jacks Hollow Branch a few hundred feet before its confluence with the North Bosque River. Three additional wastewater dischargers are as follows:

- Northside Subdivision WWTF for the Northside Subdivision Water Plant and Distribution Corporation located about 0.75 miles east of North State Highway (Hwy) 108 and 0.75 miles south of County Road 433, north of Stephenville,

- The Shady Oaks WWTF owned by the Stephenville Mobile Home Park located at the intersection of US Hwy 377 and Business US Hwy 377 northeast of Stephenville, and

- Western Dairy Transport, which has a no-discharge permit, is located at 771 County Road 176 (Smith Spring Road) north of Stephenville. Western Dairy Transport irrigates treated process wastewaters from tank and vehicle cleaning from a milk transport fleet to fields within the Indian Camp Creek drainage basin. Recycled wash water is routed through a sand trap and settling basin prior to discharge into a lined irrigation pond.

To evaluate improvements in water quality, TIAER has sampled stream stations all along the North Bosque River since late 1995. Prior to 1995, TIAER's monitoring focused 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 quite some time. To more fully assess overall water quality improvements in the North Bosque River, trends are presented for nitrogen, phosphorus, CHLA, total suspended solids (TSS), specific conductance (conductivity), and bacteria concentrations. Field parameters (e.g., dissolved oxygen and pH), while routinely monitored as instantaneous measurements, were not included in this trends analysis due to the difficulty in correcting for diurnal fluctuations. Besides trends analysis, data were also evaluated in comparison to water quality goal attainment for the TMDLs, and results are discussed in the context of I-Plan activities.

**Background and Station Descriptions**

**North Bosque River Watershed**

The North Bosque River is located in central Texas and extends about 180 river kilometers (110 river miles) from Stephenville, Texas to Lake Waco near Waco, Texas (Figure 1). The headwaters of the North Bosque River originate in Erath County just north of Stephenville. Lake Waco, a man-made reservoir, supplies drinking water to over 150,000 people. The North Bosque River watershed comprises about 74 percent of the
land area draining into Lake Waco. Other major tributaries to Lake Waco include Hog Creek, Middle Bosque River, and South Bosque River. The urban population in the North Bosque River watershed has increased about 32 percent over the past 25 years, with Stephenville, the watershed’s largest city, encompassing most of this growth (Table 2).

### Table 2
Estimated populations and growth for municipalities within the North Bosque River watershed.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Estimated 1990 Population(^a)</th>
<th>Estimated 2000 Population(^a)</th>
<th>Estimated 2010 Population(^b)</th>
<th>Estimated 2019 Population(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stephenville</td>
<td>13,502</td>
<td>14,921</td>
<td>17,123</td>
<td>22,065</td>
</tr>
<tr>
<td>Hico</td>
<td>1,342</td>
<td>1,341</td>
<td>1,379</td>
<td>1,462</td>
</tr>
<tr>
<td>Iredell</td>
<td>339</td>
<td>360</td>
<td>339</td>
<td>340</td>
</tr>
<tr>
<td>Meridian</td>
<td>1,390</td>
<td>1,491</td>
<td>1,493</td>
<td>1,511</td>
</tr>
<tr>
<td>Cranfills Gap</td>
<td>269</td>
<td>335</td>
<td>281</td>
<td>289</td>
</tr>
<tr>
<td>Clifton</td>
<td>3,195</td>
<td>3,542</td>
<td>3,442</td>
<td>3,562</td>
</tr>
<tr>
<td>Valley Mills</td>
<td>1,085</td>
<td>1,123</td>
<td>1,203</td>
<td>1,292</td>
</tr>
</tbody>
</table>

\(^a\) Population estimates based on values presented by the Texas State Data Center based on U.S. Census data for 1990 and 2000 (Texas State Data Center, 2015).

\(^b\) Revised 2010 Census Count and estimated 2019 population estimates (Texas Demographic Center, 2019).

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

The headwaters of the North Bosque River are located in Erath County, which was consistently the number one milk-producing county in Texas between 1990 and 2010. Since 2011, Erath County has remained one of the top six milk-producing counties. The number of dairy producers in Erath County peaked in 1994 and since has decreased markedly (Figure 2). Milk production peaked in 2000 and has also decreased, but the decrease in milk production has not been proportional to the decline in producers. Milk production has also notably increased between 2014 and 2019. Part of this increase in milk production can be related to increased milk production per cow. Throughout the United States, milk production has increased about 12 percent over the last 10 years according to USDA-NASS statistics (USDA-NASS, 2019). Between 2014 and 2019 in Erath County, milk production has increased over 22 percent, indicating an increase in cow numbers as well. While Erath County expands beyond the range of the North Bosque watershed, about two-thirds of the dairy operations in Erath County are located within the North Bosque River watershed, so county level statistics likely reflect dairy
production within the watershed. Based on TCEQ inspection records for the North Bosque River watershed, the estimated number of dairy cows was about 45,000 in 2001 and about 40,300 in 2019\(^4\). In 2019, an estimated 11,200 animals were associated with beef and calf raising operations, bringing the total number associated with CAFOs or AFOs to about 51,500.

![Graph showing annual variation in the number of dairy producers and milk production for Erath County.](image)

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

Annual rainfall in the North Bosque River watershed averages 84.6 cm (33.3 in) per year. Rainfall typically follows a slightly bimodal pattern, with peaks in the spring and fall (Figure 3). On average, the wettest month is May and the driest month is January. Most tributaries of the North Bosque River are highly intermittent and frequently become dry soon after each rainfall-runoff event. In some years, winter rains corresponding with low evapotranspiration rates can establish a base flow that persists well into spring. Groundwater contributions in the upper portion of the watershed are generally insignificant, though groundwater seepage has been noted in the lower portion of the watershed.

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\(^4\) Because TCEQ no longer annually inspects all CAFOs within the watershed, estimated animal numbers for 2019 are based on inspected values from FY2010 through FY2019 using the most recent inspected value for active operations as the estimate for FY2019.
Figure 3  Average Monthly normal precipitation for Stephenville, Texas (1990-2019).
Source: National Oceanic and Atmospheric Administration, National Climatic Data Center.

Sampling Stations

Because TIAER has sampled at many of these stations under separate projects, all stations are listed by both their TCEQ and TIAER station identifications for easy reference to information or data in other reports. The TCEQ station identification is generally listed first, followed by the TIAER station identification in parentheses or brackets. Trend analyses focused on seven stream stations at which temporally intensive data collection has occurred for several years. Monitoring at most stations was initiated in the early to mid-1990s, while monitoring at station 18003 (BO083) was not initiated until 2003. These stations vary in drainage area, water quality, and hydrology (Table 3) and are grouped as follows:

- The five North Bosque River index stations (11954 [BO095], 11956 [BO090], 18003 [BO083], 11963 [BO040], and 17226 [BO020]) specified in the phosphorus TMDLs and I-Plan.

- North Bosque River at Hico, station 11961 (BO070), which is located in a long reach of the river between index stations.

- Green Creek, station 13486 (GC100), which has been collocated with one of TCEQ's Environmental Monitoring and Response System (EMRS) stations.
## Table 3  
Estimated land use and drainage area above sampling sites.

<table>
<thead>
<tr>
<th>Station Identification TCEQ (TIAER)</th>
<th>Location within the North Bosque River Watershed</th>
<th>Drainage Area (ha)</th>
<th>Dominant Land Use or Land Cover&lt;sup&gt;a&lt;/sup&gt;</th>
<th>General Water Quality and Hydrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>17226 (BO020)</td>
<td>North Bosque River above Stephenville, Texas</td>
<td>21,700</td>
<td>Woodland-range (34%), pasture and cropland (41%), waste application fields (19%), urban (6%)</td>
<td>Water quality moderately impacted by nonpoint sources; intermittent flow with perennial pools</td>
</tr>
<tr>
<td>11963 (BO040)</td>
<td>North Bosque River below Stephenville, Texas, about 0.6 km below the discharge from the Stephenville WWTF</td>
<td>25,700</td>
<td>Woodland-range (32%), pasture and cropland (41%), waste application fields (17%), urban (9%)</td>
<td>Water quality impacted by point and nonpoint sources; perennial flow</td>
</tr>
<tr>
<td>11961 (BO070)</td>
<td>North Bosque River at Hico, Texas, above the discharge from the Hico WWTF</td>
<td>93,100</td>
<td>Woodland-range (38%), pasture and cropland (45%), waste application fields (10%), urban (6%)</td>
<td>Water quality moderately impacted by point and nonpoint sources; nearly perennial flow</td>
</tr>
<tr>
<td>18003 (BO083)</td>
<td>North Bosque River between Iredell and Meridian, Texas</td>
<td>178,000</td>
<td>Woodland-range (57%), pasture and cropland (28%), waste application fields (8%), urban (5%)</td>
<td>Water quality moderately impacted by point and nonpoint sources; nearly perennial flow</td>
</tr>
<tr>
<td>11956 (BO090)</td>
<td>North Bosque River at Clifton, Texas, above the discharge from the Clifton WWTF</td>
<td>253,000</td>
<td>Woodland-range (57%), pasture and cropland (31%), waste application fields (5%), urban (6%)</td>
<td>Low impacts from point and nonpoint sources; perennial flow</td>
</tr>
<tr>
<td>11954 (BO095)</td>
<td>North Bosque River at Valley Mills, Texas above the discharge from the Valley Mills WWTF</td>
<td>297,000</td>
<td>Woodland-range (59%), pasture and cropland (32%), waste application fields (5%), urban (4%)</td>
<td>Low impacts from point and nonpoint sources; perennial flow</td>
</tr>
<tr>
<td>13486 (GC100)</td>
<td>Green Creek near the confluence with the North Bosque River</td>
<td>25,200</td>
<td>Woodland-range (38%), pasture and cropland (48%), waste application fields (9%), urban (5%)</td>
<td>Water quality moderately impacted by nonpoint sources; intermittent flow with perennial pools</td>
</tr>
</tbody>
</table>

<sup>a</sup> Waste application fields are land areas where animal waste is applied as organic fertilizer and considered separately from pasture and cropland areas that receive solely commercial fertilizer. Most WAFs are associated with CAFOs and AFOs, as noted in McFarland and Jones (2006) and Houser and Hauck (2010).

General land-use descriptions are based on National Land Cover Database (NLCD) 2016 (USGS, 2019), supplemented with information summarized by TIAER on animal waste.
application fields within the watershed (Table 3). A notable decrease in the percentage of urban land use cover as compared to percentages previously reported is due to a refinement in the 2016 NLCD layer that improved the accuracy in identifying roads. The Spatial Sciences Laboratory of the Texas Agricultural Experiment Station, now Texas AgriLife Research, conducted a land-use classification for the watershed based on satellite imagery from 2001 through 2003 (Narasimhan et al., 2005; Table 3). Information on animal waste application fields was compiled in 2000 from TCEQ records and modified in 2005 and again in the fall of 2007 by TIAER based on a review of TCEQ permit information to supplement this satellite imagery classification (McFarland and Jones, 2006; Houser and Hauck, 2010). The WAF information included milking and non-milking operations, with milking operations representing over 80 percent of the CAFOs and AFOs in the watershed. As a goal of the current project, updated WAF information for CAFOs and AFOs in the watershed is presented to aid in evaluating if changes in the amount and location of WAFs might be related to changes in water quality.

In addition to the stations listed in Table 3, data from station 17605 (BO100) were used in conjunction with data from station 11954 (BO095) for trends analysis. Station 17605 (BO100) was a TIAER sampling station located northeast of Valley Mills that was discontinued in July 2001 due to bank stability problems. Station 11954 (BO095) was installed about three river kilometers upstream of station 17605 (BO100). The discharge for the Valley Mills WWTF is located below station 17605 (BO100). Data from these two stations will be collectively 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 collected data from project stations under a variety of quality assurance project plans (QAPPs). Historical information used in this report includes water quality, rainfall, and streamflow data. 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.


5. Quality Assurance Project Plan for the North Bosque River Watershed Water Quality Assessment project funded through the TCEQ Surface Water Quality Monitoring Program (TIAER, 2010b). This QAPP covers data collected between September 2010 and August 2011.


8. Quality Assurance Project Plan for Evaluating Effectiveness of Total Maximum Daily Load (TMDL) Implementation Plan (I-Plan) Activities within the North Bosque River Watershed, funded through the TCEQ TMDL Program (TIAER, 2017, revised 2019). This QAPP is for the current project and covers data presented in this report collected between September 2017 and December 2019.

Water quality data associated with the projects above were collected and analyzed using similar assessment objectives, sampling techniques, laboratory protocols, and data validation procedures. The sampling design was changed in the spring of 2008 due to a decrease in funding. Prior to 2008, an effort was made to sample all storm events, but after 2008, only selected storms were monitored. This change has continued for storm monitoring through 2019. Information regarding storm monitoring is outlined by year from 2008 through 2018 in Appendix A and for 2019 under the section “Collection Methods for Storm Samples.”

A second known area of deviation was in the measurement of bacteria over time. Prior to 2000, fecal coliform (FC) rather than *Escherichia coli* were monitored. McFarland and Millican (2010) evaluated paired *E. coli* and fecal coliform data from November 2000 through March 2004 to compare these two types of bacteria data. This period of overlap was used to determine if fecal coliform could be adjusted to comparable *E. coli* values using accepted statistical methods for comparing different analytical methods (Bland and Altman, 1986). This comparison included 1,075 paired observations and produced the following regression relationship, which was used to adjust historical fecal coliform concentrations to *E. coli* concentrations prior to trend analysis.
\[
\ln(\text{E. coli}) = 0.946 \ln(\text{FC}) - 0.029 \quad R^2 = 0.93 \quad p = <0.0001
\]

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

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

Data external to TIAER from the United States Geological Survey (USGS) were used to determine flow at some sampling stations. The USGS maintains stage gauging stations along the North Bosque River near Hico (USGS station 08094800), Clifton (USGS station 08095000), and Valley Mills (USGS station 08095200). Associated USGS stream stage, discharge, and/or rating curve data were used in conjunction with data collected by TIAER to calculate discharge at stations 11961 (BO070), 11956 (BO090), and 11954 (BO095).

The overall project objective was to use data collected specifically for evaluation of the North Bosque River TMDL I-Plan in conjunction with historical 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 collected at a depth of 0.3 m or less below the surface depending on total water depth, as indicated in TCEQ surface water monitoring procedures (TCEQ, 2003; 2008; 2012b). When grab samples were collected, water temperature, dissolved oxygen (DO), pH, and conductivity were measured in situ with a Hydrolab or YSI (multiprobe) field-sampling instrument. Because stream stations within the North Bosque River watershed are generally shallow and the water column unlikely to stratify at these locations, multiprobe readings were taken only at a surface depth corresponding to the depth of the routine grab sample. Flow measurements were also collected (or estimated if flow was too high or too low for direct measurements) at most sites. When necessary, flow estimates were performed by either using data from a nearby USGS
gauging station, stream level data from automated sampling locations and associated
erating curves, or float test estimation. Due to access issues, flow data generally could not
be collected for station 18003 (BO083), so flow data were quite limited for this location.

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

Collection Methods for Storm Samples

Storm samples were collected at six of the seven 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, which also hindered direct
measurement of flow at this location.

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

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

Since the fall of 2006, the sampling sequence has been modified so that once the four-
hour interval was encountered, all remaining bottles for an event were then taken at four-
hour intervals. If an automated sampler could not activate or became inoperable during a
storm event, daily storm grabs were generally collected to represent the event.

Until June 1997, most sequential storm samples within an event collected by an
automated sampler were analyzed individually by TIAER’s laboratory. To decrease
sample load to the laboratory, a flow-weighting strategy was initiated that composit
samples on about a daily basis. This flow-weighting strategy was initiated at stations 17226 (BO020), 11963 (BO040), 11961 (BO070), and 13486 (GC100) in May or June 1997 and at stations 11956 (BO090) and 11954 (BO095) in May 2000.

At each storm sampling station, stream stage was continuously monitored at five-minute intervals (or 15-minute intervals, if USGS stage or flow recordings were used). To convert stage readings to flow, stage-discharge relationships were developed. For stations 17226 (BO020), 11963 (BO040), and 13486 (GC100), 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 without available discharge measurements were extrapolated using the cross-sectional area and a least-squares relationship of the average stream velocity to the log of water level or expansion of a fitted polynomial regression line.

Stations 11961 (BO070), 11956 (BO090), and 11954 (BO095) are located near USGS stream gauging stations (Figure 1). Station 11961 (BO070) is located near USGS station 08094800, 11956 (BO090) is located near USGS station 08095000, 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 a flood-hydrograph partial record station. In mid-January 2016, USGS reinitiated reporting all flows for station 08094800 near Hico. TIAER relied primarily on stage and flow data measured at station 11961 (BO070) in 2016 through 2019, but has used flow and stage data at USGS station 08094800 to aid in filling in gaps.

For flows at station 11956 (BO090), instantaneous USGS data from station 08095000 are used in this report. For station 11954 (BO095), a combination of USGS data from station 08095200 and TIAER data are used for flows, because this USGS station has not continuously reported instantaneous flow. In October 2005, the USGS station 08095200 near Valley Mills was 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 11954 (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. Since 2007, TIAER has relied primarily on instantaneous flow data from the USGS station 08095200 for flows at station 11954 (BO095).

Monitoring Conditions

As noted earlier in this report, prior to the spring of 2008, an effort was made to sample all storm events. With decreased funding in the spring of 2008, the monitoring design
changed so that only selected storm events were monitored. This change has continued for storm monitoring through 2019. To include storms not directly sampled in estimates of annual loadings, event mean concentrations (EMCs) of previous storm events at a station or grab samples that coincided with the elevated flow events were used. Within Appendix A, general monitoring conditions between 2008 and 2018 are presented, along with how missing storm loadings were estimated for each year. Following is a summary of conditions in 2019 outlining storms monitored and missed. Within Appendix B, more details are presented on how loadings for storm events not monitored were estimated in calculating monthly loadings within 2019 for trends analysis.

2019
In 2019, only one storm event was monitored. The storm event was sampled for five days starting on April 24 through April 28, 2019 at all six storm monitoring locations. Storm sampling that occurred during September and October of 2018 resulted in budget limitations for storm sampling to occur during the May through August FY19 period. Compounding the issue, relatively dry conditions were present for much of the period of September through December of 2019.

Based on relationships developed for 2010 events (McFarland and Millican, 2011), a log-linear relationship between average storm flow and the EMC of events monitored in 2017 through 2019 was used to estimate the concentration of water quality parameters at stations not monitored during storm events; these estimated concentrations were used to estimate loadings associated with storm events not monitored in 2019 (see Appendix B). Combining storms for these three years seemed appropriate, as there were only a few events monitored in each year, and changes in water quality are anticipated to be gradual. Precipitation in Stephenville within the headwaters of the North Bosque River totaled 33.8 inches for 2019, slightly above the long-term average of 33.3 inches. The heaviest rainfall occurred in May, with a total of 8.4 inches. Low flow conditions affected the watershed for most of the last half of 2019 (Figure 4).
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-phosphorus (total-P), and TSS were evaluated for both routine grab and storm samples (Table 4). In addition, CHLA and *E. coli* were evaluated for routine grab samples. Total nitrogen (total-N) was derived as the sum of NO$_2$-N+NO$_3$-N plus TKN.

Prior to 2000, fecal coliform rather than *E. coli* were monitored as an indicator of bacteria concentrations. From November 2000 through March 2004, both fecal coliform and *E. coli* were analyzed to determine a relationship between these two measures of bacteria.
Table 4  Parameters and methods of analysis for water quality samples used in trend analysis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abbreviation</th>
<th>Units</th>
<th>Methoda</th>
<th>Parameter Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia-nitrogen</td>
<td>NH$_3$-N</td>
<td>mg/L</td>
<td>EPA 350.1 or SM 4500-NH3G</td>
<td>00608</td>
</tr>
<tr>
<td>Nitrite-nitrogen + nitrate-nitrogen</td>
<td>NO$_2$-N+NO$_3$-N</td>
<td>mg/L</td>
<td>EPA 353.2 or SM 4500-NO3-F</td>
<td>00631</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen</td>
<td>TKN</td>
<td>mg/L</td>
<td>EPA 351.2 or SM 4500-NH3Gb</td>
<td>00625</td>
</tr>
<tr>
<td>Orthophosphate-phosphorus</td>
<td>PO$_4$-P</td>
<td>mg/L</td>
<td>EPA 365.2 or SM 4500P-E</td>
<td>70507 or 00671c</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>Total-P</td>
<td>mg/L</td>
<td>EPA 365.4b</td>
<td>00665</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>TSS</td>
<td>mg/L</td>
<td>EPA 160.2 or SM 2540 D</td>
<td>00530</td>
</tr>
<tr>
<td>Chlorophyll-α</td>
<td>CHLA</td>
<td>µg/L</td>
<td>SM10200-H</td>
<td>32211</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>E. coli</td>
<td>cfu/100 mL or MPN/100mL</td>
<td>SM9222G or SM9223-B (IDEXX Coliert®)d</td>
<td>31699</td>
</tr>
</tbody>
</table>

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.  TKN and total-P methods modified to use copper sulfate as the catalyst instead of mercuric oxide.

c.  Field-filtering for PO$_4$-P began in October 2003 for routine grab samples (code 00671). All routine samples prior to October 2003 and all storm samples were lab filtered (code 70507).

d.  Most probable number (MPN) or IDEXX method for E. coli (SM9223-B) was implemented in April 2004.

Data Set Construction and Statistical Methods for Trend Analysis

Two data sets representing monthly estimates of average constituent concentrations for each station were developed for trend analysis. The first data set came from routine grab data, while the second data set combined routine grab and storm data. Trends associated with these two data sets address TMDL objectives regarding reductions in concentrations and loadings. Routine grab samples should reflect any decrease in concentrations associated with routine monitoring, while the volume-weighted data set including storm samples should reflect any decreases in stream loadings. Stream concentrations are often related to flow, so for all stream stations, except 18003 (BO083) where only very limited flow data were available, data sets were limited to timeframes with flow data for evaluation of trends.

Most routine grab samples for nutrients and TSS were collected biweekly, while samples for analysis of CHLA and bacteria were often collected only monthly. Measurements or
estimates of instantaneous discharge were paired with each biweekly or monthly grab sample as an indicator of flow conditions. Because variation in sampling frequency over time can cause unintended impacts on the analysis of trends (Gilbert, 1987), concentrations and flows were averaged on a monthly basis. Except at station 18003 (BO083), which did not have flow data, concentrations for trend analysis represented monthly flow-weighted averages to account for differences in instantaneous flow between individual grab samples within a month. At station 13486 (GC100), insufficient samples occurred in 2011 (only one), 2013 (only one), and in 2014 (none) for evaluating trends of routine grabs for these end years. Trends for station 13486 (GC100) were updated in this report for data through 2019, noting these gaps.

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 (generally 5 minutes for TIAER stations and 15 minutes for USGS gauging stations) was the minimum measurement interval. The flow associated with each interval was multiplied by the associated average monthly 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 volume of flow.

As noted in the section Monitoring Conditions, and within Appendix A, the volume-weighted data set often included estimates of EMCs for periods when storms were not directly monitored. Generally, EMCs for similarly sized events were used, or the concentration of grab samples coinciding with a given storm event were used in other years. Several studies have shown strong relationships between constituent concentrations and discharge (e.g., Agouridis and Edwards, 2003; Sharpley et al., 2008), and calculation of loadings is often based on non-direct measurements (e.g., Cohn et al., 1992; Robertson and Roerish, 1999). In 2010, several events were not directly monitored, and details are provided in McFarland and Millican (2011) describing how EMCs were estimated for 2010.

Appendix B provides details on how loadings for events not monitored in 2019 were estimated.

As noted earlier for routine grab samples, trends of loading data were not analyzed for station 13486 (GC100) in 2011, 2013, and 2014 due to a lack of monitoring data associated largely with dry weather conditions, although bridge work also made this station inaccessible during much of 2014. Trends through 2019 were evaluated for station 13486 (GC100), as the method used is robust enough to handle these missing data.

Censored Data

Analytical laboratories generally present data based on a reporting limit, where the reporting limit is the lowest concentration at which the laboratory quantitatively reports
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 would not exist 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 MDLs as the reporting limit. These MDLs were updated about once every six months. After September 2003, most TIAER projects used TCEQ-defined AWRLs or 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. Since variations in reporting limits have occurred, the highest minimum reporting limit was determined for each constituent. In preparing data sets for trend analysis, the highest minimum reporting limit for each station by constituent was set equal to one-half the maximum reporting limit.

Monitoring History

Because monitoring was conducted under a number of different projects, different lengths of record were available for each station that varied some by parameter (Tables 5 and 6). Stations 11961 (BO070) and 13486 (GC100) had the longest periods of record, with data starting in 1993. 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. Loading estimates at 11961 (BO070) in 1993 and 13486 (GC100) in 1993 and 1994 for TKN, total-P, and TSS were, thus, based on only storm data. Also, at 13486 (GC100), CHLA was not a routine parameter until 1996. Consistent data sets for all constituents were indicated at station 17226 (BO020) starting in 1997; at station 11963 (BO040) as of 1994; and at stations 11956 (BO090) and 11954 (BO095) of 1996.
Table 5  Years of available sampling data for trend analysis by station and parameter type for routine grab samples.

<table>
<thead>
<tr>
<th>Station</th>
<th>Conductivity</th>
<th>Soluble Nutrients</th>
<th>TKN, Total-P, and TSS</th>
<th>CHLA</th>
<th>Bacteria</th>
</tr>
</thead>
</table>

a. Sample data for station 13486 (GC100) were extremely limited in 2011, 2013, and 2014.

Table 6  Years of available sampling data for trend analysis by station and parameter type for storm samples.

<table>
<thead>
<tr>
<th>Station</th>
<th>Soluble Nutrients</th>
<th>TKN, Total-P, and TSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>18003 (BO083)</td>
<td>not applicable</td>
<td>not applicable</td>
</tr>
<tr>
<td>13486 (GC100)a</td>
<td>1993 – 2019</td>
<td>1993 – 2019</td>
</tr>
</tbody>
</table>

a. Sample data for station 13486 (GC100) were extremely limited in 2011, 2013, and 2014.

Exploratory Data Analysis

Exploratory data analysis (EDA) was used to initially evaluate each data set. The EDA graphical technique is used to characterize distributional properties, identify outliers and patterns, and select appropriate statistical tests using primarily histograms and box plots (Tukey, 1977). 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, 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 identify patterns and describe variability in the data. In addition, time series and box plots provide insight regarding the presence of trends and seasonality. Seasonality is a systematic variation that, if present, confounds the true trend. Removing seasonality prior to trend analysis is important, because a significant positive trend in one season and a significant negative trend in another season can result in a finding of no trend when evaluated together. The presence of seasonality was statistically evaluated using correlograms of monthly data as described by Reckhow et al. (1993). A correlogram expresses how the correlation of pairs of water quality data changes with time. A significant correlation at lags representing 6 and 12 months generally indicates seasonality (Reckhow et al., 1993). A significant correlation at shorter lags (lags representing 1 or 2 months) indicates autocorrelation. For the parameters and sites evaluated, seasonality was not significant.

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 (2002). The two most commonly used methods are simple linear regression and locally weighted scatterplot smoothing (LOWESS) (Helsel and Hirsch, 2002; 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, 2002; Bekele and McFarland, 2004).

The LOWESS method is an extension of simple linear regression, in that it fits simple regression models to localized subsets of the data to build up a function that describes the deterministic variation between two variables. The local regression is fit using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. A user-specified input called the “smoothing parameter” \( f \) determines how much data are used to fit each localized regression. Values of \( f \) range from 0 to 1, with 1 using each individual data point as in simple linear regression. Large \( f \) values produce the smoothest functions that “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 start to capture random error in the data (SAS Institute, 2011).

An \( f \) value of 0.5 was used as recommended by USGS (Langland et al., 1998) and later confirmed to be optimum for data from the North Bosque River watershed (Bekele and McFarland, 2004). The PROC LOESS procedure of SAS (SAS Institute, 2011) was used
to develop the LOWESS regression relationships. Residuals associated with the LOWESS regression of flow with concentration were then used in trend testing as flow-adjusted concentrations. At stream stations, monthly average stream flow was calculated as the average of instantaneous measures with grab samples or as the total volume of flow divided by the number of seconds in a month with volume-weighted data. Flows and concentrations were transformed using a natural-log transformation prior to applying the LOWESS regression to decrease the variance in the regression residuals.

Trend Testing

The presence of a trend was tested using the nonparametric Kendall’s tau, using programs developed by Reckhow et al. (1993) and Helsel et al. (2006). The Kendall’s tau test is suitable for water quality data that show a non-normal distribution, contain missing data, and have censored 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.

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

Trend testing was done on flow-adjusted monthly data sets for all stream stations, except station 18003 (BO083), where flow data were generally not available. The null hypothesis tested was that there was no temporal trend in concentration of water quality constituents. The level of significance used to test the null hypothesis was 0.05. The slope calculated from the flow-adjusted concentrations (residuals) 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 on the natural log scale and calculated on an annual basis as follows (Helsel and Hirsch, 2002):

\[
\text{% change/year} = (e^{b1} - 1) \times 100
\]

Where “e” is the base of the natural logarithm and approximately equals 2.7183; and “b1” is the slope for the natural log transformed data on an annual basis.5

---

5 In several previous trend reports (i.e., McFarland and Millican, 2006; 2007; 2008; 2009; and 2010), the percent change was calculated as the percent change per month, although presented as the percent change per year and should be multiplied by 12 to obtain the percent change per year. In Tables 7 through 11 of this report, all slopes are provided as annual rates of change, including those obtained from previous reports.
Trend Analysis Results

Routine Grab Data

To account for variations over time, trend results are presented by end year for the past twelve years, with a focus on the most current end year, 2019. In comparing between end years, routine grab data usually indicated similar positive or negative trends, if significant, regardless of end year, although the slope representing the percent change per year often varied (Tables 7 through 11). Slopes representing the percent change per year frequently decreased with increasing end year. At stations 11963 (BO040) and 11961 (BO070), slopes associated with total-P generally became more negative with increasing end year for several years and then slightly less negative in more recent end years (Tables 8 and 9). In some instances, slopes representing the percent change per year have become less negative with increasing end year. Less negative slopes with end year are apparent at stations 11956 (BO090) and 11954 (BO095) for PO4-P. These patterns in slope over time may indicate step trends, in which reductions occurred at a given point in time; thus, the impact or slope decreases in magnitude with increasing time, or possibly reductions that occurred in the past that are now starting to increase.

For 2019, a significant decreasing trend was indicated at station 17226 (BO020), the most upstream site on the North Bosque River, for \textit{E. coli}, NH3-N, and total-P (Table 7). Significant decreasing trends for these three parameters were also indicated for 2017 and 2018.

Significant trends were indicated for all parameters but conductivity at station 11963 (BO040) located below Stephenville in 2019 (Table 8). Downward trends occurred with CHLA, \textit{E. coli}, NH3-N, PO4-P, TKN, total-P, and TSS. Significant increasing trends occurred with NO2-N+NO3-N and total-N. For NO2-N+NO3-N at 11963 (BO040), increasing trends have been apparent since 2011, but only since 2015 for total-N. At station 11963 (BO040), NO2-N+NO3-N often comprises over 85 percent of the total-N in routine samples, which likely reflects contributions from the Stephenville WWTF discharge located about a quarter mile above station 11963 (BO040). With regard to the TMDL, significant decreasing trends for PO4-P and total-P at station 11963 (BO040) were first detected with data through the end year 2007, which is a little over a year after the Stephenville WWTF started implementing phosphorus control practices as part of its treatment process.

Downward trends in PO4-P and total-P also are reflected at station 11961 (BO070) on a similar timeframe to station 11963 (BO040). These downward trends were first noted with analysis of data through 2008 for PO4-P and through 2007 for total-P (Table 9). At station 11961 (BO070), downward trends occurred for all parameters but TSS for data through 2019. Similar downward trends in nutrients have occurred since 2008 at 11961 (BO070), but only NH3-N has consistently indicated downward trends for all end years evaluated.
Table 7  
Trend results for routine grab data for station 17226 (BO020).
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period Evaluated</th>
<th>Kendall Test Statistica</th>
<th>p-valuea</th>
<th>End Year 2019</th>
<th>End Year 2018b</th>
<th>End Year 2017b</th>
<th>End Year 2016b</th>
<th>End Year 2015b</th>
<th>End Year 2014b</th>
<th>End Year 2013b</th>
<th>End Year 2012b</th>
<th>End Year 2011b</th>
<th>End Year 2010b</th>
<th>End Year 2009b</th>
<th>End Year 2008b</th>
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</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>1997-2019</td>
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<td>0.1339</td>
<td>-2.2</td>
<td>-3.1</td>
<td>-2.5</td>
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<td>nec</td>
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<tr>
<td>E. coli</td>
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<td>-4.9</td>
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<td>NO2-N+NO3-N</td>
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<td>3.3</td>
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<td>PO4-P</td>
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<td>TSS</td>
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</tr>
</tbody>
</table>

a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.

Table 8  
Trend results for routine grab data for station 11963 (BO040).
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period Evaluated</th>
<th>Kendall Test Statistica</th>
<th>p-valuea</th>
<th>End Year 2019</th>
<th>End Year 2018b</th>
<th>End Year 2017b</th>
<th>End Year 2016b</th>
<th>End Year 2015b</th>
<th>End Year 2014b</th>
<th>End Year 2013b</th>
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<th>End Year 2010b</th>
<th>End Year 2009b</th>
<th>End Year 2008b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>1997-2019</td>
<td>0.005</td>
<td>0.8946</td>
<td>-0.5</td>
<td>-0.6</td>
<td></td>
<td>-2.9</td>
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<td></td>
<td></td>
<td>nec</td>
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<tr>
<td>CHLA</td>
<td>1997-2019</td>
<td>-0.087</td>
<td>0.0241</td>
<td>-1.6</td>
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<tr>
<td>E. coli</td>
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<tr>
<td>NH3-N</td>
<td>1997-2019</td>
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<td>-4.3</td>
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<td>NO2-N+NO3-N</td>
<td>1997-2019</td>
<td>0.202</td>
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<td>2.9</td>
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<td>PO4-P</td>
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<td>Total-P</td>
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</table>

a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.
Table 9  
Trend results for routine grab data for station 11961 (BO070).

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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period Evaluated</th>
<th>Kendall Test Statistic&lt;sup&gt;a&lt;/sup&gt;</th>
<th>p-value&lt;sup&gt;a&lt;/sup&gt;</th>
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<th>End Year 2018&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2017&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2016&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2015&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2014&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2013&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2012&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2011&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2010&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2009&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2008&lt;sup&gt;b&lt;/sup&gt;</th>
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<td>-0.8</td>
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<td>-1.1</td>
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<td>-1.2</td>
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<td>-1.4</td>
<td>ne&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>TSS</td>
<td>1994-2019</td>
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<tr>
<td>Total-N</td>
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</tr>
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</table>

a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.

Table 10  
Trend results for routine grab data for station 11956 (BO090).

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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period Evaluated</th>
<th>Kendall Test Statistic&lt;sup&gt;a&lt;/sup&gt;</th>
<th>p-value&lt;sup&gt;a&lt;/sup&gt;</th>
<th>End Year 2019</th>
<th>End Year 2018&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2017&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2016&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2015&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2014&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2013&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2012&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2011&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2010&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2009&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2008&lt;sup&gt;b&lt;/sup&gt;</th>
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<tbody>
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<td>Conductivity</td>
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<td>CHLA</td>
<td>1996-2019</td>
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<td>0.4065</td>
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<tr>
<td>E. coli</td>
<td>1996-2019</td>
<td>-0.138</td>
<td>0.0007</td>
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<td>NO&lt;sub&gt;2&lt;/sub&gt;-N + NO&lt;sub&gt;3&lt;/sub&gt;-N</td>
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<td>0.0186</td>
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<td>0.0037</td>
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<tr>
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<td>0.0001</td>
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a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.
Table 11  Trend results for routine grab data for station 11954 (BO095).

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.

<table>
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<th>Parameter</th>
<th>Period Evaluated</th>
<th>Kendall Test Statistica</th>
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<th>End Year 2018b</th>
<th>End Year 2017b</th>
<th>End Year 2016b</th>
<th>End Year 2015b</th>
<th>End Year 2014b</th>
<th>End Year 2013b</th>
<th>End Year 2012b</th>
<th>End Year 2011b</th>
<th>End Year 2010b</th>
<th>End Year 2009b</th>
<th>End Year 2008b</th>
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<td>Conductivity</td>
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<tr>
<td>CHLA</td>
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<td>0.9740</td>
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<td></td>
<td>ne</td>
</tr>
<tr>
<td>E. coli</td>
<td>1996-2019</td>
<td>-0.080</td>
<td>0.0455</td>
<td>-1.8</td>
<td>-3.4</td>
<td>-3.7</td>
<td>-4.9</td>
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<td>NH₃-N</td>
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<td>0.6485</td>
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<tr>
<td>NO₂⁻-N+NO₃⁻-N</td>
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<td>-0.058</td>
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<td>-2.4</td>
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<tr>
<td>PO₄-P</td>
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<td>0.0011</td>
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<tr>
<td>Total-P</td>
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<td>TSS</td>
<td>1996-2019</td>
<td>-0.058</td>
<td>0.1453</td>
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<tr>
<td>Total-N</td>
<td>1996-2019</td>
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<td>-2.4</td>
<td>-2.8</td>
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</tr>
</tbody>
</table>

a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.
At station 11956 (BO090), similar to the previous three years, significant downward trends were indicated for all parameters but conductivity, CHLA, and total-P for data through 2019 (Table 10). In contrast, at station 11954 (BO095), decreasing trends for data through 2019 were reported only for PO4-P and \textit{E. coli} (Table 11). Significant decreasing trends have been indicated for other parameters at station 11954 (BO095) for data sets based on earlier end years, but slopes associated with these trends generally became less negative over time.

Results for 18003 (BO083) are presented separately from the other mainstem stations, because data for 18003 (BO083) were not flow adjusted (Table 12). Monitoring at station 18003 (BO083) also did not begin until 2003, representing a much shorter period of record than at any of the other stations. While in most previous end years, a downward trend has been indicated at station 18003 (BO083) for NH3-N, no significant trend was noted for data through 2017-2019. Of note, downward trends for NH3-N for data through 2010-2016 were significant but had a zero-slope value. A zero-slope estimate that is significant can occur using the Kendall’s tau method when values have multiple ties, particularly if many values are at the reporting limit (McBride, 2000), which was the case for NH3-N at station 18003 (BO083). For data through 2019, significant increasing trends were noted for CHLA, TKN, TSS, and total-N (Table 12). These increasing trends were also present in the previous three years.

At station 13486 (GC100) located on Green Creek, trends were not analyzed for end years 2011, 2013, or 2014 (Table 13). In 2011 and 2013, only one month (October 2011 and April 2013) had a routine grab sample, providing insufficient data for a meaningful annual trends update. In 2014, no routine water quality samples were collected at station 13486 (GC100), as conditions were dry or pooled when visited. Allowing for these gaps in the data set, trends evaluated through 2019 indicated significant decreases in conductivity, CHLA, \textit{E. coli}, NH3-N, PO4-P, TSS and total-N (Table 13).
Assessment of Water Quality Trends for the North Bosque River through 2019

Table 12  Trend results for routine grab data for station 18003 (BO083).

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.

<table>
<thead>
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</tr>
</thead>
<tbody>
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<td>Conductivity</td>
<td>2003-2019</td>
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<td>0.0978</td>
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<td>4.4</td>
<td>5.9</td>
<td>7.3</td>
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<td>11.4</td>
<td>10.9</td>
<td>12.1</td>
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<td>17.4</td>
<td>19.6</td>
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</tr>
<tr>
<td>CHLA</td>
<td>2003-2019</td>
<td>0.119</td>
<td>0.0195</td>
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<td>4.8</td>
<td>5.7</td>
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<tr>
<td>E. coli</td>
<td>2003-2019</td>
<td>0.064</td>
<td>0.2317</td>
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<tr>
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<td>0.3354</td>
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<td>-1.8</td>
<td>-7.7</td>
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<td>NO$_2$-N+NO$_3$-N</td>
<td>2003-2019</td>
<td>0.061</td>
<td>0.1856</td>
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<td>PO$_4$-P</td>
<td>2003-2019</td>
<td>-0.071</td>
<td>0.1536</td>
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<td>5.5</td>
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<tr>
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<td>8.9</td>
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<td>5.1</td>
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</table>

a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.
d. The percent slope change for NH$_3$-N is significant and decreasing, but estimated as 0.00 percent change per year due to multiple ties or readings at the reporting limit.

Table 13  Trend results for routine grab data for major tributary station 13486 (GC100).

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.

<table>
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<td>0.0030</td>
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<td>0.0056</td>
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<td>0.0924</td>
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</table>

a. Results for year 2019.
c. ne indicates parameter was not evaluated for noted end year.
Volume-Weighted Data

Except for NO$_2$-N+NO$_3$-N at station 11963 (BO040), no increasing trends were indicated at any of mainstem stations for the volume-weighted data analyzed through 2019, but several decreasing trends occurred (Tables 14-19). At station 17226 (BO020), significant decreasing trends were indicated for all constituents except for NO$_2$-N+NO$_3$-N (Table 14). Decreasing trends were indicated at 11963 (BO040) for NH$_3$-N, PO$_4$-P, TKN, total-P, and TSS (Table 15). Stations 11961 (BO070) and 11956 (BO090) indicated significant decreasing trends for all constituents (Tables 16 and 17). At station 11954 (BO095), significant decreasing trends were indicated for PO$_4$-P, total-P, TSS, and total-N (Table 18). At station 13486 (GC100) on Green Creek, significant decreasing trends for data through 2019 were noted for all constituents (Table 19).

Evaluation of Stream Water Quality Goal Attainment

Three approaches were used to evaluate attainment of the TMDL water quality goals as presented in the I-Plan (TCEQ and TSSWCB, 2002). The first approach plotted annual average flow versus annual average PO$_4$-P concentrations of routine samples for more recent years compared to pre-TMDL regression relationships. The second approach compared annual average PO$_4$-P concentrations of routine grab to target concentrations or goals set for index stations in the TMDLs. The third approach compared data acquired post-implementation of the TMDL to a set of probability distribution curves constructed from TMDL model predictions.

Regression Relationships

To evaluate if the relationship between PO$_4$-P and flow has changed over time, a set of regression equations was derived from historical data for 1996 through 2000 representing each of the five index stations for pre-TMDL conditions (TCEQ and TSSWCB, 2002). 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) and were developed in the I-Plan 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 11954 (BO095) for the index station at Valley Mills
Table 14
Trend results for monthly volume-weighted data for station 17226 (BO020).
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.

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<td>NH₃-N</td>
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<td>0.0000</td>
<td>-3.6</td>
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<td>-5.9</td>
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<td>NO₂-N+NO₃-N</td>
<td>1997-2019</td>
<td>-0.013</td>
<td>0.7519</td>
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<tr>
<td>PO₄-P</td>
<td>1997-2019</td>
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<td>0.0090</td>
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<tr>
<td>Total-P</td>
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<td>0.0000</td>
<td>-2.1</td>
<td>-2.0</td>
<td>-1.8</td>
<td>-1.7</td>
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<td>TSS</td>
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<td>Total-N</td>
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<td>0.0016</td>
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</tbody>
</table>

a. Results for year 2019.

Table 15
Trend results for monthly volume-weighted data for station 11963 (BO040).
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.

<table>
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</table>

a. Results for year 2019.
Assessment of Water Quality Trends for the North Bosque River through 2019

Table 16  Trend results for monthly volume-weighted data for station 11961 (BO070).
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period Evaluated</th>
<th>Kendall Test Statistic&lt;sup&gt;a&lt;/sup&gt;</th>
<th>p-value&lt;sup&gt;a&lt;/sup&gt;</th>
<th>End Year 2019</th>
<th>End Year 2018&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2017&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2016&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2015&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2014&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2013&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2012&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2010&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2009&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2008&lt;sup&gt;b&lt;/sup&gt;</th>
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<sup>a</sup> Results for year 2019.

Table 17  Trend results for monthly volume-weighted data for station 11956 (BO090).
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.

<table>
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<th>Kendall Test Statistic&lt;sup&gt;a&lt;/sup&gt;</th>
<th>p-value&lt;sup&gt;a&lt;/sup&gt;</th>
<th>End Year 2019</th>
<th>End Year 2018&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2017&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2016&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2015&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2014&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2013&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2012&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2010&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2009&lt;sup&gt;b&lt;/sup&gt;</th>
<th>End Year 2008&lt;sup&gt;b&lt;/sup&gt;</th>
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<td>Total-P</td>
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<sup>a</sup> Results for year 2019.
Assessment of Water Quality Trends for the North Bosque River through 2019

**Table 18**  
Trend results for monthly volume-weighted data for station 11954 (BO095).  
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.

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- a. Results for year 2019.  

**Table 19**  
Trend results for monthly volume-weighted data for major tributary station 13486 (GC100).  
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.

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- a. Results for year 2019.  
- c. NA indicates not applicable. Trend analysis was not conducted for station 13486 (GC100) due to a lack of loading data in 2011, 2013, and 2014.
Due to changes in monitoring locations, some additional data were used in development of these regression relationships. Monitoring at station 11958 (BO085) was discontinued in April 2005, and data from station 18003 (BO083) were used in combination with data from station 11958 (BO085). While station 18003 (BO083) is located about 11.6 river miles upstream of station 11958 (BO085), it is considered more representative of the index station defined in the I-Plan as above Meridian. Flow was not measured at either 11958 (BO085) or 18003 (BO083) on a continuous basis, so annual average flows from station 11956 (BO090) were used in the equations presented in the I-Plan and in the current evaluation. As previously noted for trend analysis, data for stations 17605/11954 (BO100/BO095) were also combined. Station 11961 (BO070), while not an index station, had long-term data that were evaluated in a similar manner for comparison.

Of note, the regression equations comparing PO4-P concentrations versus annual average flow differ somewhat from those presented in the I-Plan and early annual reports for a couple of reasons. First, annual average flows were revised based on the most updated rating curve and stage data information. For this report, regression equations were also included using data from the post-TMDL period of 2001-2019. In addition, grab samples used in the analysis were scrutinized to ensure samples were representative of routine monitoring, with relatively equal time intervals between samples throughout the year as suggested in the I-Plan (TCEQ and TSSWCB, 2002). By including only samples representative of relatively equal time intervals, several samples associated with special studies were dropped that had been included in previous analyses. Previously, all available PO4-P data for grab samples had been included regardless of the time interval between samples. Using samples separated by relatively equal time intervals decreases the bias that may occur if sampling were more frequent during a particular time of year. Extended periods of pooling or no flow in association with the relatively dry summer months still caused unequal sampling intervals in some years, particularly at station 17226 (BO020), which more often has pooled conditions.

In comparing data in this manner to evaluate goal attainment, annual average PO4-P concentrations below the pre-TMDL regression line were considered indicative of potential improvements in water quality, while annual average PO4-P concentrations plotted above the pre-TMDL regression line were considered indicative of potentially worsening conditions (Figures 5 – 10). There is some variability expected, as these regression relationships are not perfect, but they provide a tool for general assessment of changes in water quality, taking variability in flow conditions into consideration.

At the most upstream index station, 17226 (BO020) located above Stephenville, only 8 out of 19 years clearly indicated annual average concentrations of PO4-P below the pre-TMDL regression line (Figure 5). The most recent years, 2018 and 2019, had PO4-P concentrations below the pre-TMDL regression line. To note the impact of flow, drought or low flow conditions represented in 2014 indicated the highest annual average concentrations of PO4-P reported. In contrast, the high annual average flows in 2015 and 2016 had PO4-P concentrations below the Pre-TMDL regression line. The influence of these drought or low flow years and wet or high flow years is also apparent in the post-TMDL regression line, which shows a decrease in concentration as annual average flows increase.
Figure 5  Relationship of the natural log of flow to annual average PO$_4$-P concentration of routine grab samples for station 17226 (BO020).
Figure 6  Relationship of the natural log of flow to annual average PO₄-P concentration of routine grab samples for station 11963 (BO040).
**Figure 7**  Relationship of the natural log of flow to annual average PO₄-P concentration of routine grab samples for station 11961 (BO070).
Figure 8  Relationship of the natural log of flow to annual average PO₄-P concentration of routine grab samples for station 11958/18003 (BO085/BO083).
Figure 9  Relationship of the natural log of flow to annual average PO₄-P concentration of routine grab samples for station 11956 (BO090).
Assessment of Water Quality Trends for the North Bosque River through 2019

Figure 10  Relationship of the natural log of flow to annual average PO₄-P concentration of routine grab samples for station 17605/11954 (BO100/BO095).
The station below Stephenville, 11963 (BO040), indicated annual average PO$_4$-P concentrations below the pre-TMDL line in all but two post-TMDL years (Figure 6). Only in 2004 and 2005 were concentrations slightly above the pre-TMDL regression line. Station 11963 (BO040) is located just below Stephenville about a quarter mile downstream of the major outfall for the Stephenville WWTF. The decreasing relationship of PO$_4$-P concentrations with increasing flows is indicative of dilution of a point source or constant contribution in both the pre-TMDL and post-TMDL regression lines. In the fall of 2005, the Stephenville WWTF started implementing phosphorus control practices, which correlates with a large decrease in the PO$_4$-P concentration of routine grab samples post 2005 for this location. Similar to station 17226 (BO020), the highest annual average flows occurred in 2015 and 2016, but extrapolation of the pre-TMDL regression line still indicated annual average PO$_4$-P concentrations below this line. For 2019, PO$_4$-P concentrations were well below the pre-TMDL regression line at station 11963 (BO040).

While station 11961 (BO070) near Hico is not an index station, it is shown as representative of conditions between index stations 11963 (BO040) and 11958/18003 (BO085/BO083). Station 11961 (BO070) is located near Hico, Texas, and is about 22.5 river miles downstream of station 11963 (BO040) and about 27.8 miles above station 18003 (BO083). In comparing annual average PO$_4$-P concentrations to the pre-TMDL line with annual average flow, only 2004 indicated annual average PO$_4$-P concentrations above the pre-TMDL regression line (Figure 7). While the slope is not as steep, station 11961 (BO070) also has a pre-TMDL regression line similar to station 11963 (BO040), with PO$_4$-P concentrations decreasing with increasing flows. This likely reflects the point source influence of contributions from the Stephenville WWTF at this downstream location. The post-TMDL regression line is essentially flat, which may indicate a significant reduction in point source contributions. For 2019, PO$_4$-P concentrations were well below the pre-TMDL regression line at station 11961 (BO070).

Moving downstream, the combined stations 11958/18003 (BO085/BO083) have annual average PO$_4$-P concentrations below the pre-TMDL regression line most years, including 2019 (Figure 8). Exceptions with concentrations above the pre-TMDL regression line occurred in 2006, 2009, 2011, and 2013. The post-TMDL regression line indicates a similar relationship to flow and PO$_4$-P concentrations as compared to the pre-TMDL regression.

At stations 11956 (BO090) and 17605/11954 (BO100/BO095), along the lower portion of the North Bosque River, very similar responses occurred, likely due to the close proximity of these two general locations (Figures 9 and 10). Station 11956 (BO090) is only about 10 river miles upstream of station 11954 (BO095), with one major tributary, Neils Creek, flowing in between these two stations. At these downstream locations, values above the pre-TMDL regression line generally occurred in years representing either very low or very high flows.

Annual average PO$_4$-P concentrations at stations 11956 (BO090) and 17605/11954 (BO100/BO095) were above the pre-TMDL regression lines in the low flow years of
2011 and 2013 and the high flow year of 2015 (Figures 9 and 10). In 2014, which was another very low flow year, annual average PO$_4$-P concentrations at station 11956 (BO090) were above the pre-TMDL regression line, but just along the line at station 17605/11954 (BO100/BO095) when extrapolated. In 2016, which was another high flow year similar to 2015, PO$_4$-P concentrations were well below the pre-TMDL regression lines for both locations. This shift in the relationship between PO$_4$-P concentrations for 2015 and 2016 likely reflects a flushing effect of two very wet years occurring back-to-back. Similar to station BO083, the post-TMDL regression lines for BO090 and BO095 indicate similar relationships to flow and PO$_4$-P concentrations, with concentrations increasing with flow. The PO$_4$-P concentrations for 2019 at both locations were well below pre-TMDL regression lines.

**Annual Average TMDL Goal**

The second approach used to evaluate goal attainment was to compare the annual average concentration to the long-term predicted concentration from the TMDL modeling effort and the target concentration for each index station (TNRCC, 2001). Comparing the annual average of routine grab samples shows the TMDL goal has been reached on occasion at all five stations (Figures 11 and 12), but not consistently at all locations. Of note, the comparisons shown in Figures 11 and 12 are similar to graphs shown in the annual status report provided by TCEQ (e.g., TCEQ, 2020), but the timeframe represented differs. In the graphs presented in the TCEQ status report, the annual timeframe represents a water year (October through September) rather than a calendar year (January through December). The calendar year is presented herein for consistency with charts comparing annual average PO$_4$-P concentrations with annual average flow (Figures 5-10) and the presentation of data in previous trend reports by TIAER (e.g., McFarland and Millican, 2012). Despite these time differences, annual PO$_4$-P concentrations follow a similar pattern to those in TCEQ status reports (TCEQ, 2020).

Annual PO$_4$-P concentrations at station 17726 (BO020) were often above the TMDL goal, with concentrations dipping below the goal only in 2012 (Figure 11). In 2019, the annual average PO$_4$-P concentration was above the goal. In most years, the flow at station 17726 (BO020) is highly intermittent, with fewer than the potential 26 biweekly samples collected (Figure 11).

A very notable drop in PO$_4$-P concentrations occurred at station 11963 (BO040) from 2005 to 2006, coinciding with implementing of phosphorus control practices at the Stephenville WWTF in the fall of 2005 (Figure 11). Annual average concentrations at station 11963 (BO040) have remained below or only slightly above the target level since 2007. Drought conditions, as occurred in 2013 and 2014, are suspected to have caused increased concentrations in these years as decreased ambient stream flow was mixing with effluent from the Stephenville WWTF. In 2019, the annual average concentration was below the target concentration of 0.448 mg/L.

At station 11958/18003 (BO085/BO083), concentrations have been below the TMDL goal in all years but 2015 (Figure 12). The relatively high annual average concentration
of PO₄-P in 2015 followed two years of drought (2013 and 2014), when very low flows and low PO₄-P concentrations occurred (see Figure 8). In contrast to 2013 and 2014, 2015 was a year with very high flows. Flows in 2016 were comparable to 2015, but the lower concentrations in 2016 than 2015 are likely due to a flushing of the system in having two very wet years back-to-back. In 2019, PO₄-P concentrations were well below target levels.

In the post-TMDL period, evaluating data from 2000 through 2019, annual average concentration exceeded the goal at stations 11956 (BO090) and 17605/11954 (BO100/BO095) in 2007 and 2015 (Figure 12). Both 2007 and 2015 were years with unusually high annual average flows that followed years with low flows (see Figures 9 and 10). In 2016, annual average concentrations of PO₄-P were much lower than would be predicted based on flow alone (Figures 9 and 10), again likely due to two very wet years occurring one after the other. In 2019, PO₄-P concentrations continued to be below target levels.
Figure 11  Annual average PO$_4$-P from routine grab data for stations 17226 (BO020) and 11963 (BO040) compared to the long-term predicted concentration without TMDL implementation and the TMDL goal. Values above bars represent the number of samples in each year.
Figure 12  Annual average PO₄-P from routine grab data for stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095) compared to the long-term predicted concentration without TMDL implementation and the TMDL goal. Values above bars represent the number of samples in each year.
Probability Distribution Curves

The third approach used a set of probability distribution curves constructed from the TMDL modeling and within the I-Plan (TCEQ and TSSWCB, 2002). Comparison of these TMDL modeling curves (“TMDL-e” curves) to post-TMDL developed probability curves of annual average PO₄-P should indicate if water quality goals are being met. The post-TMDL probability curves presented are based on data from 2001 through 2019 (Figures 13- through 17). The I-Plan indicates the following for determining success based on these probability curves (TCEQ and TSSWCB, 2002):

- If the monitored data curve is entirely below the model-predicted TMDL-e curve, then the water quality goal is being attained.
- If the monitored data curve is entirely above the model-predicted TMDL-e curve, then the water quality goal is definitely not being attained.
- Partial attainment occurs if the monitored data curve crosses the model-predicted TMDL-e curve.

![Figure 13](image.png)

**Figure 13**  TMDL goal probability curve for index site above Stephenville (17226 [BO020]) compared to monitored data curve.
Figure 14  TMDL goal probability curve for index site below Stephenville (11963 [BO040]) compared to monitored data curve.

Figure 15  TMDL goal probability curve for index site above Meridian (18003 [BO083]) compared to monitored data curve.
Figure 16  TMDL goal probability curve for index site at Clifton (11956 [BO090]) compared to monitored data curve.

Figure 17  TMDL goal probability curve for index site at Valley Mills (11954 [BO095]) compared to monitored data curve.
• For station 17226 (BO020) above Stephenville (Figure 13), the TMDL goal is not being met as the monitoring probability curve is entirely above the model-predicted curve.
• For station 11963 (BO040) below Stephenville (Figure 14), the monitoring curve comes very close to the model-predicted curve, but does not cross the model-predicted curve. At station 11963 (BO040), it is anticipated that with additional years, crossing of the model-predicted curve will occur, particularly as the monitoring curve picks up more years associated with implementation of phosphorus control practices by the Stephenville WWTF.
• For station 18003 (BO083) above Meridian, attainment of water quality goals is indicated, with the all of the monitored data curve falling below the model-predicted curve (Figure 15).
• For station 11956 (BO090) at Clifton, adequate attainment is indicated, with only one point above and 95 percent of the monitored data below the model-predicted curve (Figure 16).
• For station 11954 (BO095) at Valley Mills, full attainment of water quality goals is indicated, with all points of the monitored data curve falling below the model-predicted curve (Figure 17).

Summary and Discussion

Results based on data through 2019 indicated several statistically significant decreasing trends in nutrients at stations within the North Bosque River watershed, although also a few increasing trends for some parameters. For PO4-P and total-P, only significant decreasing trends were indicated. To help illustrate these trends focusing on PO4-P, box-and-whisker plots are presented of the flow-adjusted, volume-weighted results by year (see Figures 18-23). Within these plots, “3σ Limits” refers to data within three standard deviations of the mean, with “UCL” denoting the Upper Control Limit and “LCL” denoting the Lower Control Limit. “M” equals the average of annual medians, and “n” represents the number of months with data represented for each year. The solid lines shown connect the median values of each year. The length of the box represents the distance between the 25th and 75th percentiles and the vertical lines or “whiskers” extending from the box represent the annual minimum and maximum values of the flow-adjusted, volume-weighted PO4-P concentration. The circles located within the box-and-whisker plots represent the annual mean value of the flow-adjusted, volume-weighted PO4-P concentration. Small boxes plotted outside of the box-and-whisker plots are outlier values. Similar box-and-whisker plots are shown in Appendix C for bacteria results. For bacteria, significant decreases were indicated for most stations based on routine monthly grab data, supporting the assertion within the I-Plan that practices implemented to decrease SRP should have some corollary effect in reducing bacteria loadings (TCEQ and TSSWCB, 2002).

With regard to TMDLs for the North Bosque River for SRP, decreasing trends in PO4-P were indicated at three of the five index stations for routine grab data (Tables 7-8 and 10-12) and at all four index stations evaluated for volume-weighted data (Tables 14-15 and
Assessment of Water Quality Trends for the North Bosque River through 2019

For routine grab data, this included index stations 11963 (BO040) below Stephenville, 11956 (BO090) near Clifton, and 11954 (BO095) near Valley Mills. Decreasing trends in PO₄-P were also indicated for routine grab and volume-weighted data at major tributary stations 13486 (GC100) on Green Creek, as well as at station 11961 (BO070) on the mainstem of the North Bosque River near Hico.

These decreasing trends in PO₄-P were similar to findings in previous reports (e.g., McFarland and Adams, 2018 and Millican, Adams, and McFarland, 2019). The decreasing trend at 17226 (BO020) is very subtle (Figure 18), representing a decrease of only about one percent per year (Table 14).

At station 11963 (BO040), significant decreases in PO₄-P appear to be directly related to implementation of phosphorus control at the Stephenville WWTF in late 2005 (Figure 19). Phosphorus control at the Stephenville WWTF is probably also influencing the decreasing trends noted at station 11961 (BO070) further downstream (Figure 20). Box and whisker plots of monthly average concentrations by year at station 11963 (BO040) showed a notable decrease in median PO₄-P for 2006 through 2019 (Figure 19), with a somewhat similar decrease shown at station 11961 (BO070) in Figure 20.

Figure 18  Annual box and whisker plots of monthly volume-weighted PO₄-P grab data for station 17226 (BO020). Data natural log transformed and flow adjusted.
Figure 19  Annual box and whisker plots of monthly volume-weighted PO$_4$-P grab data for station 11963 (BO040).
Data natural log transformed and flow adjusted.

Figure 20  Annual box and whisker plots of monthly volume-weighted PO$_4$-P grab data for station 11961 (BO070).
Data natural log transformed and flow adjusted.

Along Greens Creek station 13486 (GC100), decreasing trends were also observed. Greens Creek flows into the North Bosque River about 8 river miles upstream of station 11961 (BO070). The years 2000, 2006, and 2009 had only three months with water quality data and flow (Figure 21); thus, if these three years were removed, an even stronger downward trend may be observed. Greens Creek does not have any WWTFs above it, so the downward trend at station 11961 (GC100) reflects changes in nonpoint source contributions.
A decrease in PO$_4$-P concentrations also occurred at more downstream stations (11956 [BO090] and 11954 [BO095]), but the timing of the initial decrease occurred in 1999 (Figures 22 and 23), prior to implementation of phosphorus control practices at either the

**Figure 21**  Annual box and whisker plots of monthly volume-weighted PO$_4$-P grab data for station 13486 (GC100).
Data natural log transformed and flow adjusted.

**Figure 22**  Annual box and whisker plots of monthly volume-weighted PO$_4$-P data for station 11956 (BO090).
Data natural log transformed and flow adjusted.
Stephenville or Clifton WWTFs. Station 11954 (BO095) near Valley Mills is located below and station 11956 (BO090) above the Clifton WWTF discharge. These trends may be related to the handling of poultry litter from operations in the Neils Creek watershed and other drainages in the lower portion of the North Bosque watershed. As of 2006, 12 poultry facilities were operating in the lower portion of the North Bosque River watershed, primarily within the Meridian and Neils Creek watersheds (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 (McFarland and Jones, 2006). A recent follow up found that Dr. Gobbler (parent company Mida-Bio), based in Clifton, Texas, still hauls turkey litter from area operations, creating and distributing Dr. Gobbler Soil R/X Organic Compost (Dr. Gobbler, 2020). This initial decrease in PO₄-P concentrations at stations in the lower portion of the watershed appears to correspond in part with this change in handling of poultry litter.

In a similar fashion, changes in waste management associated with the I-Plan impacting CAFOs and AFOs are expected to impact water quality trends along the North Bosque River. Most CAFOs and AFOs are or have been located in the upper portion of the North Bosque River watershed (Figure 24). To evaluate land-use changes, information on regulated CAFOs was reviewed and used to develop a Geographic Information System (GIS) layer documenting the location of these facilities and associated WAFs as part of the TCEQ Nonpoint Source Program Clean Water Act §319(h) project, Evaluating Effectiveness of Implementation Plan Activities within the North Bosque River Watershed (McFarland and Adams, 2016). Metadata in the GIS layer for WAFs included crop type and dominant type of waste applied. This layer was updated under the current project to reflect new WAFs and those no longer in use (considered historical) based on permit changes effective through August 2019 (Figure 24).
The location of most AFOs, which are not regulated facilities, was determined from information from TCEQ or the Texas Department of State Health Services (DSHS), Division of Milk and Milk Products as part of a previous GIS effort focusing on

Figure 24  Map of CAFOs, AFOs, and associated WAFs (active and historical) within the North Bosque River watershed, representing conditions as of fall 2019. Map includes historical WAFs for the Microgy Biogas facility. Dots for CAFOs and AFOs, both active and inactive, are shown to give a general indication as to the type of operation (CAFO or AFO) associated with WAFs.
conditions representing active operations as of 2005 and historical operations since 1995 (see McFarland and Jones, 2006). The 2005 GIS layer of facilities and WAFs was also updated in 2007 for a modeling project for the North Bosque River watershed to include WAFs associated with the Microgy biogas facility (Houser and Hauck, 2010). Only one new AFO was identified as active in 2012 that was not represented in the 2005 GIS layer. Information on the location and size of WAFs for this new AFO was not available, so the size of these fields was estimated based on maximum herd size of 199 head and located on fields contiguous with the location of this AFO. The designation of “historical” versus “active” WAFs for AFOs was based on the status of the operations in 2019, with fields associated with inactive operations designated as historical.

The information on active CAFO and AFO operations was reviewed in the fall of 2019 based on TCEQ inspection data and drive-by assessments. As noted earlier, about 45,000 dairy cows were estimated within the watershed in 2001 and about 40,300 in 2019. In 2019, an additional 11,200 animals were estimated in association with beef or calf raising, bringing the total number of cattle associated with CAFOs or AFOs to about 51,500. The watershed included 50 active operations in 2019, of which 41 were regulated CAFOs. As of the fall of 2019, regulated CAFOs included 30 dairies, 6 heifer or calf raising operations, 3 feedlots, and 2 sale or auction barns. Of the 9 AFOs in the watershed, 2 are dairies, 3 feedlots, and 4 heifer or calf raising facilities.

For facilities that went inactive but still had a valid permit, fields identified for waste application were considered active rather than historical. This distinction was made because as long as the permit is valid, the operation still has the potential to become operational, although possibly under a different operator. This has occurred with at least two operations that were inactive for a year or two and then became active again. Some facilities with an active permit have active and historical fields, since the status of fields can change with permit renewals. The information for 2019 represents only updates associated with approved permits as of August 2019 (Figure 24 and Tables 20 and 21). Fields associated with smaller operations or AFOs were categorized as historical if inactive based on TCEQ inspection or drive-by assessments.

From 2000 to 2019, a notable decrease in the land area categorized as active WAFs has occurred, largely offset by an increase in historical fields (Table 20). From 2015 to 2019, the land area associated with active WAFs has slightly increased but is still much less than in 2000 (Table 20). This shift in land use indicates less land area in the watershed is being used for manure waste application and likely is having an impact on reductions indicated in stream phosphorus concentrations. The implementation of CNMPs plays an important role in facilitating this shift in land use, as fields high in soil phosphorus are no longer used for waste application.

Crop uptake of phosphorus is important to limiting runoff of phosphorus into streams, and Coastal bermudagrass is the dominant crop associated with WAFs (Table 21). These Coastal fields are often over-seeded with a winter grain crop. While soils, particularly in the headwaters, are often shallow, thus, not allowing the production of cropland, in some areas, a dual cropping system of sorghum and winter wheat is maintained. Rangeland or
native grasses are also used for waste application, although not as prominently as in the past.

**Table 20** Comparison over time of active and historical WAFs in the North Bosque River watershed.

<table>
<thead>
<tr>
<th>WAF Layer&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Year</th>
<th>Active&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Historical</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acres</td>
<td>2000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24,554</td>
<td>2,142</td>
<td>26,696</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>623</td>
<td>93</td>
<td>716</td>
</tr>
<tr>
<td>Acres</td>
<td>2005&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19,122</td>
<td>7,574</td>
<td>26,696</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2005&lt;sup&gt;b&lt;/sup&gt;</td>
<td>473</td>
<td>243</td>
<td>716</td>
</tr>
<tr>
<td>Acres</td>
<td>2012 &amp; 2013&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15,693</td>
<td>18,215</td>
<td>32,136</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2012 &amp; 2013&lt;sup&gt;c&lt;/sup&gt;</td>
<td>380</td>
<td>557</td>
<td>937</td>
</tr>
<tr>
<td>Acres</td>
<td>2014&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13,533</td>
<td>18,603</td>
<td>32,136</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2014&lt;sup&gt;c&lt;/sup&gt;</td>
<td>326</td>
<td>611</td>
<td>937</td>
</tr>
<tr>
<td>Acres</td>
<td>2015&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13,337</td>
<td>19,014</td>
<td>32,350</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2015&lt;sup&gt;c&lt;/sup&gt;</td>
<td>344</td>
<td>629</td>
<td>973</td>
</tr>
<tr>
<td>Acres</td>
<td>2016&lt;sup&gt;d&lt;/sup&gt;</td>
<td>13,451</td>
<td>19,191</td>
<td>32,642</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2016&lt;sup&gt;d&lt;/sup&gt;</td>
<td>351</td>
<td>637</td>
<td>988</td>
</tr>
<tr>
<td>Acres</td>
<td>2017&lt;sup&gt;e&lt;/sup&gt;</td>
<td>13,741</td>
<td>18,812</td>
<td>32,553</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2017&lt;sup&gt;e&lt;/sup&gt;</td>
<td>349</td>
<td>672</td>
<td>1,074</td>
</tr>
<tr>
<td>Acres</td>
<td>2018&lt;sup&gt;f&lt;/sup&gt;</td>
<td>13,753</td>
<td>18,850</td>
<td>32,603</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2018&lt;sup&gt;f&lt;/sup&gt;</td>
<td>357</td>
<td>685</td>
<td>1,042</td>
</tr>
<tr>
<td>Acres</td>
<td>2019&lt;sup&gt;g&lt;/sup&gt;</td>
<td>14,485</td>
<td>18,659</td>
<td>33,144</td>
</tr>
<tr>
<td>No. Fields</td>
<td>2019&lt;sup&gt;g&lt;/sup&gt;</td>
<td>359</td>
<td>709</td>
<td>1,068</td>
</tr>
</tbody>
</table>

a. The acres and number of fields excludes 54 fields representing about 1,772 acres associated with the Microgy biogas plant. The Microgy biogas plant began operation in late 2007 and ceased operation in 2010. Microgy fields were excluded to allow representation of just the fields associated with CAFOs and AFOs.
d. Represents updated review of WAF information based on permit changes effective between August 2015 and September 2016.
e. Represents updated review of WAF information based on permit changes effective between August 2016 and September 2017.
f. Represents updated review of WAF information based on permit changes effective between August 2017 and September 2018.
g. Represents updated review of WAF information based on permit changes effective between August 2018 and September 2019.
While only one “new” operation has been noted since 2012, many of the CAFOs have expanded or identified new fields for waste application with their permit renewals in association with amendments to the CAFO rules adopted by TCEQ in 2014 (TCEQ, 2014). In addition, fields identified as active WAFs do not include areas where animal waste has been transferred to a third party for potential land application, although those who accept animal waste are expected to apply it at appropriate agronomic rates. Because contributions from WAFs were considered a major nonpoint source of SRP to the North Bosque River, decreases in the land area used for active WAFs can be considered partially responsible for the decreases noted in stream PO4-P concentrations and loadings.

Besides changes in land management, long-term weather patterns, particularly with regard to precipitation, can have a notable impact on the water quality trends. Precipitation has been variable over the analysis period for the watershed, as indicated by annual precipitation values for Stephenville and Waco (Figure 25). The long-term annual average precipitation for Stephenville is 31.5 inches and 34.7 inches for Waco. For Stephenville, most years between 1990 and 1998 had precipitation amounts near or above

<table>
<thead>
<tr>
<th>Primary Type of Waste Applied</th>
<th>Primary Crop</th>
<th>FY19 Estimated Active (acres)</th>
<th>FY19 Estimated Number of Active Fields</th>
<th>FY19 Estimated Historical (acres)</th>
<th>FY19 Estimated Number of Historical Fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid</td>
<td>Coastal/Small Grain</td>
<td>4,216</td>
<td>127</td>
<td>2,068</td>
<td>123</td>
</tr>
<tr>
<td>Liquid</td>
<td>Coastal</td>
<td>1,141</td>
<td>38</td>
<td>2,139</td>
<td>82</td>
</tr>
<tr>
<td>Liquid</td>
<td>Sorghum/Small Grain</td>
<td>520</td>
<td>11</td>
<td>195</td>
<td>24</td>
</tr>
<tr>
<td>Liquid</td>
<td>Sorghum</td>
<td>0</td>
<td>0</td>
<td>165</td>
<td>8</td>
</tr>
<tr>
<td>Liquid</td>
<td>Small Grain</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Liquid</td>
<td>Rangeland</td>
<td>91</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Liquid</td>
<td>Other</td>
<td>21</td>
<td>1</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>Liquid</td>
<td>Subtotal</td>
<td>5,989</td>
<td>149</td>
<td>4,588</td>
<td>238</td>
</tr>
<tr>
<td>Solid</td>
<td>Coastal/Small Grain</td>
<td>5,028</td>
<td>127</td>
<td>3,694</td>
<td>142</td>
</tr>
<tr>
<td>Solid</td>
<td>Coastal</td>
<td>1,634</td>
<td>47</td>
<td>6,357</td>
<td>199</td>
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<tr>
<td>Solid</td>
<td>Rangeland</td>
<td>782</td>
<td>7</td>
<td>666</td>
<td>19</td>
</tr>
<tr>
<td>Solid</td>
<td>Sorghum/Small Grain</td>
<td>661</td>
<td>15</td>
<td>2,035</td>
<td>70</td>
</tr>
<tr>
<td>Solid</td>
<td>Sorghum</td>
<td>361</td>
<td>13</td>
<td>1,043</td>
<td>27</td>
</tr>
<tr>
<td>Solid</td>
<td>Small Grain</td>
<td>30</td>
<td>1</td>
<td>193</td>
<td>11</td>
</tr>
<tr>
<td>Solid</td>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>79</td>
<td>3</td>
</tr>
<tr>
<td>Solid</td>
<td>Subtotal</td>
<td>8,496</td>
<td>210</td>
<td>14,067</td>
<td>471</td>
</tr>
<tr>
<td>Microgy</td>
<td>Microgy</td>
<td>0</td>
<td>0</td>
<td>1,772</td>
<td>54</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>13,753</td>
<td>357</td>
<td>20,622</td>
<td>739</td>
</tr>
</tbody>
</table>
the 30-year average, while 11 out of 20 years between 1999 and 2019 were below the 30-
year average. Very wet years often followed very dry years, with well above normal
precipitation occurring in 2004, 2007, and 2015. In contrast, 2016 represents a
moderately wet year following a very wet year, 2015. Annual precipitation at Waco
followed the same general pattern as at Stephenville, but with more annual precipitation
generally reported for Waco.

An important consideration in interpreting the annual rainfall data is the pattern of
rainfall within each year. For example, although total annual precipitation for 2012 and
2013 indicate near normal amounts, drought conditions occurred that reflect a cumulative
precipitation deficit during this period (NCDC, 2014). By comparing monthly
precipitation totals to monthly normals for Stephenville for the years 2010 through 2016,
64 out of 96 months indicated below normal precipitation (Figure 26). May 2015 was an
extremely wet month, with 20.5 inches of rain reported, about 4.6 times the normal
monthly precipitation of 4.4 inches. In 2019, annual rainfall was slightly above normal,
with April and May being the wettest months, with a combined total of over 15.5 inches
of rain in Stephenville. For 2019, several months had below average precipitation,
particularly in the early and late part of the year (Figure 26). The variability month to
month within a given year has a larger impact on streamflow than total rainfall. These
temporal changes in precipitation within years are reflected in the stream flow, with very
low flow conditions in 2013 and 2014 and the very high stream flows occurring in 2015
and 2016 at all monitoring stations throughout the watershed (Figure 27). For 2019,
slightly higher flows were indicated than in 2018, even though total precipitation for
2019 was slightly less than that recorded in 2018.

![Figure 25](image_url)

**Figure 25** Temporal variability in measured annual precipitation for Stephenville and
Waco, Texas.
Source: National Oceanic and Atmospheric Administration, National Climatic
Data Center.
Assessment of Water Quality Trends for the North Bosque River through 2019

Figure 26  Monthly difference from normal precipitation from January 2010 through December 2019 for Stephenville, Texas.  
Source: National Oceanic and Atmospheric Administration, National Climatic Data Center.

Figure 27  Annual runoff in millimeters for gauged stations along the North Bosque River. Asterisk indicates no data for 17226 (BO020) in 1996. Stations are listed in order of most upstream to most downstream.

Comparisons of average PO₄-P concentrations for grab samples to the log of annual average flow generally supported trend analysis findings (Figures 5-10). Most post-TMDL years for stations showing significant downward trends had average PO₄-P concentrations below the pre-TMDL regression relationship. Weather extremes do appear to have an influence on meeting the TMDL goal and the evaluation of success,
depending on how the goal is evaluated. While all five index stations indicated exceedances to the TMDL goal in 2015, comparing solely routine grab concentrations to target levels (Figures 11 and 12), the more upstream stations indicated concentrations within target levels when annual average flows were taken into consideration (Figures 5, 6, and 8). In 2016, annual average flows were comparable to 2015, but much lower PO4-P concentrations occurred in 2016 at all stations. While 2015 was a wet year preceded by two very dry years, 2013 and 2014, 2016 was a moderately wet year preceded by a wet year, 2015. In 2019, eight months experienced lower than normal precipitation; however, the months of April through June had precipitation amounts that were well above normal. The above average precipitation amounts from those three months resulted in a total annual precipitation amount that was slightly higher than the normal. These extreme swings in weather conditions within a given year and in preceding years need to be considered in assessing the success of efforts within the watershed.

This report presents an annual update of trends in routine grab samples and loadings for stations within the North Bosque River watershed through the calendar year 2019. It is anticipated that monitoring starting September 2020 through August 2021 will be sponsored under the TCEQ TMDL program, as well as an upcoming trends report for data through 2020.
References


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


Houser, J.B., and L.M. Hauck. 2010. Refinement and application of the North Bosque River TMDL modeling system. Prepared for the Texas Commission on Environmental Quality TMDL Team by the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, PR1001.


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).


TIAER, Texas Institute for Applied Environmental Research. 2016. Evaluating Effectiveness of Total Maximum Daily Load (TMDL) Implementation Plan (I-Plan) Activities within the North Bosque River Watershed Quality Assurance Project Plan, Rev. 0. Prepared in cooperation with the TCEQ and USEPA Nonpoint Source Program CWA 319(h) by TIAER, Tarleton State University, Stephenville, Texas.

TIAER, Texas Institute for Applied Environmental Research. 2013. Evaluating Effectiveness of Implementation Activities within the North Bosque River Watershed Quality Assurance Project Plan, Rev. 2. Prepared in cooperation with the TCEQ and USEPA Nonpoint Source Program CWA 319(h) by 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.

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


Appendix A. Storm Conditions 2008-2018
2008 and 2009

In 2008 and 2009, because of judicious efforts on the part of the field crew and favorable weather conditions, TIAER was able to monitor most storm events, while missing only a few relatively small events in 2009. In late November 2009, there was one event that caused a small rise in water level at most stations, but led to a moderately sized runoff event at stations 11961 (BO070) and 13486 (GC100), during which storm samples were not collected. A routine grab sample collected during this November 2009 event was used to represent the storm water quality for this event.

2010

During most of 2010, storm sampling was restricted due to funding limits. Flow meters were kept operational and routine biweekly grab sampling continued, but only limited storm monitoring occurred. From January through May 2010, storm samples were collected only at stations 11961 (BO070) and 11954 (BO095). From May through September 2010, no storm monitoring occurred at any of the seven stations. Starting in September 2010, new funding was obtained allowing storm sampling to be reinitiated at all seven storm stations. Between September and December 2010, all events with a rise in water level of over 0.5 ft were monitored.

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

2011

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

2012

In 2012, stream conditions were still often low, but routine grab samples were generally collected more frequently than in 2011. The only exception was station 17226 (BO020), which had fewer grab samples in 2012 (15 in 2011 and 12 in 2012). Routine grab samples were collected during all biweekly monitoring events at stations 11963 (BO040),
11961 (BO070), 11956 (BO090), and 11954 (BO095). At the other four stations, water was not flowing 42 to 54 percent of the time when visited for biweekly sampling. Most storm events in 2012 occurred between January and early June, with a single fall event in late September. All notable elevated flows were monitored in 2012, except an event that occurred over the Christmas holidays (starting December 25) at stations 17726 (BO020), 11963 (BO040), and 11961 (BO070). For annual loading calculations, event mean concentrations (EMCs) from the September storm event were associated with this December rise in water level.

2013

In 2013, stream conditions were also quite low, with moderate drought conditions noted for most of the year based on historical Palmer Drought Indices (NCDC, 2014). While pooled or no-flow conditions are not unusual along portions of the North Bosque River, particularly in the summer months at stations 17726 (BO020), 11961 (BO070), and 18003 (BO083), they are unusual for the most downstream stations 11956 (BO090) and 11954 (BO095). At station 13486 (GC100) on Green Creek, flowing waters occurred only in the month of April in 2013. In August and part of September 2013, pooled conditions were noted at 11956 (BO090) and 11954 (BO095) during biweekly routine monitoring (see McFarland and Adams, 2014b). Pooled conditions were also noted at 11956 (BO090) in early July 2013. Some storm events did occur in the fall, and in October 2013, the auxiliary pump at station 11956 (BO090) had to be pulled and sent in for repairs. The auxiliary pump aids in pulling storm samples up the steep bank at this location, which has a height of over 20 feet. Only one relatively small storm occurred in November 2013 while the auxiliary pump was out, during which a storm grab was collected at station 11956 (BO090).

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

2014

In 2014, moderate drought conditions were indicated for much of the year (NCDC, 2014), with no storm events occurring in January, February, or March. In April 2014, storm samples were collected only at station 17226 (BO020) in association with a small isolated thunderstorm just north of Stephenville. In May and June 2014, there were rainfall events leading to storm samples throughout the watershed, while rains were such during the rest of the year that elevated flows were monitored almost exclusively in the upper third of the watershed. Because there were so few events in 2014, all elevated flow
Assessment of Water Quality Trends for the North Bosque River through 2019

events, except a relatively small event occurring between December 23-25, were monitored, except at station 13486 (GC100) due to bridge work at this location.

Between January and March 2014, Green Creek was dry, and on March 12, 2014, the storm sampler and flow meter at station 13486 (GC100) were removed for renovation of the county road bridge. Work on the bridge was completed in late September 2014, and the sampler and flow meter were re-installed. While sampling equipment was removed, station 13486 (GC100) was still visited biweekly, and during all 26 biweekly monitoring events in 2014, station 13486 was pooled with no flow or dry, so no grab samples were collected. One storm event in May and one in June 2014 likely led to elevated flows at Green Creek station, but because the flow meter as well as the sampler were removed, these storm events were not monitored. The bridge renovation work caused substantial changes in the cross-section of the creek at station 13486 (GC100). A new rating curve was developed based on stage-discharge measurements collected post-September 2014. While this new stage-discharge was being developed, a provisional rating curve was used based on standard hydraulic relationships of stage to the cross-sectional area for flow-weighting of storm samples.

During most of 2014, storms grabs continued to be collected at station 11956 (BO090), with elevated flows. The auxiliary pump that was found to be inoperable in October 2013 was finally repaired, returned to TIAER, and reinstalled on August 7, 2014.

2015

In 2015, only a few storm events occurred between January and March 2015, but a series of rain events starting in mid-April and continuing through May led to elevated flows and flooding throughout the watershed. In April 2015, 7.3 inches of precipitation fell in Stephenville and in May 2015, 20.5 inches. Normal monthly precipitation is 2.5 for April inches and 4.4 inches for May (NCDC, 2016). These elevated flows in April and May were largely monitored, though large debris carried by these storms damaged sampling equipment at 11954 (BO095) in late April and 11956 (BO090) and 11961 (BO070) in late May. Flow meters and samplers were removed from shelters at 11954 (BO095) and 11956 (BO090) due to concerns with anticipated flooding on May 29, 2015. These three sampling stations are collocated with USGS stations, so USGS data were paired with daily storm grabs data until repairs could be made.

The large number of repairs needed from the May events and limited project funding precluded storm monitoring of an event in mid-June. Loadings for this June event were estimated based on water quality measured during a similar sized event in late July. Storm grabs were collected at an event in early July at all stations, as it was unanticipated and equipment repairs had not yet occurred. In late July, all three sampling stations (11961 [BO070], 11956 [BO090], and 11954 [BO095]) damaged during the April and May events were repaired and operational.

Unfortunately, heavy rains in the lower two-thirds of the watershed in late October 2015 again caused damage at station 11954 (BO095), at which repairs could not be safely conducted until February 2016. Storm events for October through December 2015 at station 11954 (BO095) were represented by daily storm grabs. Also, in November 2015,
an unanticipated rainfall of about 4 inches occurring November 27-28, 2016, led to a relatively large event over the Thanksgiving weekend. Due to the unavailability of staff over the holiday weekend, this storm was not monitored in its entirety, but because stream levels were still elevated on November 30 when staff returned to work, storm grabs were collected as representative of this event.

2016

In 2016, storm monitoring was quite limited due to funding limitations. Storm sampling occurred January through March and then was limited to an event in November. Storms occurring April through October were not monitored, as well as a small event in December.

Between January and March 2016, there were some issues with storm monitoring. At station 11954 (BO095), daily storm grabs were collected with elevated flows through January 2016, because large debris associated with elevated flows in October 2015 damaged the sampler line. On February 11, 2016, stream levels dropped sufficiently that the field crew was able to fix the intake lines at station 11954 for the automated sampler. While storm monitoring station 11954 (BO095) had been fixed and operational for storm monitoring in late February, in March 2016, elevated flows once again led to debris (a large tree) wiping out much of the intake line, leading again to the collection of daily storm grabs until repaired in July.

Highly elevated flows occurred at most stations in mid-April in response to about 6 to 10 inches of rain over several days, and again the later part of May in response to 4 to 10 inches of rain occurring on very saturated ground. Between mid-April and late May, smaller rain events led to smaller pulses of flow. This kept the ground very moist, causing flooding in the upper third of the watershed in late May.

Flooding in late May into early June submerged storm monitoring stations 17226 (BO020) and 11963 (BO040), causing severe damage. With receding high water levels, the disconnection of sampler and flow meter lines was apparent at station 11956 (BO090). Repairs to stations 17226 (BO020) and 11963 (BO040) were completed on June 30, 2016, and flows during the period when these stations were inoperable were estimated using stage data from station 11961 (BO070) and 13486 (GC100). As of July 28, 2016, stations 11954 (BO095) and 11956 (BO090) were again operational.

Unfortunately, debris once again took out intake lines at station 11954 (BO095), with elevated flows in mid-August. The North Bosque rose about 15 feet overnight at 11954 (BO095) on August 18 in response to about 6 inches of rain occurring largely in the lower half of the watershed. The tubing was reinstalled at station 11954 on August 31, with assistance provided by one of the Bosque County Commissioners in removing a large tree that was lodged between the bridge and the sampling station. For stations 11954 (BO095) and 11956 (BO090), the USGS gaging stations were still operational during these periods when the TIAER automated stations were inoperable.

While heavy rains led to flood waters throughout the watershed in late May and early June, relatively little rain occurred in June or July. In mid-August, about 2 to 6 inches of
rain occurred August 17-20, 2016, with the heaviest rainfall in the most southern portion of the watershed. While some small events occurred in September and October, the next large event occurred in November 2016, with storm samples collected at all stations. Again, in December 2016, only small rises in streamflow occurred, which were not directly monitored as storm events.

To calculate monthly loading for 2016, concentrations of time-related, biweekly grab samples were used to represent elevated flow periods not monitored, as they often corresponded by happenstance with periods of elevated flow.

2017

In 2017, storm monitoring was limited to three or four events at each station. Based on relationships developed for 2010 events (McFarland and Millican, 2011), a log-linear relationship between average storm flow and the EMC of the few events monitored in 2017 was used to estimate the concentration; thus, loadings associated with storm events that were not monitored in 2017. This approach seemed appropriate given the storms that were monitored represented small to large events for the year. Events monitored were in January, April, June, and November 2017, although in November 2017, insufficient runoff occurred at stations 11954 (BO095) and 11826 (NC060) to enable storm monitoring. Precipitation in Stephenville within the headwaters of the North Bosque River totaled 36.8 inches for 2017, well above the long-term average of 31.5 inches. The heaviest rainfall occurred in June, with a total of 12 inches or about one-third of the total rainfall for the year. Flow conditions for each of the 7 stations for 2017 indicated a pulsing of storm events throughout the year, but a general decline in flow from July through December.

2018

In 2018, five storms were monitored at BO090 and BO095 and six were monitored at BO020, BO040, and BO070 along the mainstem of the North Bosque River. Only two storm events were monitored at tributary station 13486 (GC100) due to low or no flow conditions that persisted through much of the year at this location. Sampling was discontinued at tributary station 11826 (NC060) at the end of August 2018, which resulted in only two storm events being monitored in 2018 at this location. Precipitation in Stephenville within the headwaters of the North Bosque River totaled 38.8 inches for 2018, well above the long-term average of 31.5 inches. The heaviest rainfall occurred in October, with a total of 13.4 inches. Low flow or drought conditions affected the watershed for most of 2018, with some small storm events occurring. In October 2018, heavy rainfall events led to elevated flows throughout the watershed.
Appendix B. Estimated Loading Relationships for Storms in 2019
For storms not directly monitored in 2019, regression relationships were developed between EMCs and average storm flow assuming a natural log relationship. Due to the limited number of events monitored in 2019, storms from 2019 were combined with events from 2018 and 2017 to develop these relationships. The use of the natural log relationship was based on best-fit relationships previously developed based on storm and flow data from 2009 and 2010 (see McFarland and Millican, 2011).

Figure B-1  Average storm flow compared to parameter EMCs for station 17226 (BO020) for storm events monitored in 2017 through 2019.
Figure B-2  Average storm flow compared to parameter EMCs for station 11963 (BO040) for storm events monitored in 2017 through 2019.
Figure B-3  Average storm flow compared to parameter EMCs for station 11961 (BO070) for storm events monitored in 2017 through 2019.
Figure B-4  Average storm flow compared to parameter EMCs for station 11956 (BO090) for storm events monitored in 2017 through 2019.
Figure B-5  Average storm flow compared to parameter EMCs for station 11954 (BO095) for storm events monitored in 2017 through 2019.
Figure B-6  Average storm flow compared to parameter EMCs for station 13486 (GC100) for storm events monitored in 2017 through 2019.
Appendix C. Annual Box-and-Whisker Plots for Bacteria
The following box-and-whisker plots are of flow-adjusted bacteria concentrations from routine grab data collected at stations within the North Bosque River watershed. The timeframe of these plots varies by station depending on available flow and bacteria data, but generally represents the mid-1990s through 2019. These plots correlate with trend results presented in Tables 7- through 11 and 13 within the body of this report. General findings are that bacteria concentrations are significantly decreasing at most routine monitoring locations within the North Bosque River watershed.

Figure C-1  Annual box and whisker plots of residuals from monthly flow-weighted and flow-adjusted \(E. \text{coli}\) data for station 17226 (BO020). Station 17726 (BO020) is located on the North Bosque River at Farm-to-Market 8 immediately northeast of Stephenville.
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Figure C-2  Annual box and whisker plots of monthly flow-weighted and flow-adjusted *E. coli* data for station 11963 (BO040). Station 11963 (BO040) is located at Erath County Road 454 in Stephenville.

Figure C-3  Annual box and whisker plots of monthly flow-weighted and flow-adjusted *E. coli* data for station 11961 (BO070). Station 11961 is located at Walnut Street/US 281 near Hico.
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Figure C-4  Annual box and whisker plots of monthly flow-weighted and flow-adjusted E. coli data for station 11956 (BO090). Station 11956 (BO090) is located at Farm-to-Market 219 northeast of Clifton.

Figure C-5  Annual box and whisker plots of monthly flow-weighted and flow-adjusted E. coli data for station 11954 (BO095). Station 11954 (BO095) is located immediately upstream of River Road near SH 6 west of Valley Mills.
Figure C-6  Annual box and whisker plots of monthly flow-weighted and flow-adjusted E. coli data for station 13486 (GC100). Station 13486 (GC100) is located at Erath County Road 268 in Clairette.